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Prediction of Growing Electric Vehicle and Battery Production to Nickel Supply Chain in Indonesia Using System Dynamics Approach

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Abstract. Currently, Asia Pacific region accounts for 80% of global Lithium-Ion Battery (LIB) manufacturing [1]. While in Association of Southeast Asian Nations (ASEAN) region, Indonesia is the most probable country to become a lithium battery manufacturing hub as Indonesia has the resources required to make LIB such as Nickel, Aluminum, Copper, Manganese, and Cobalt [2]. At the same time, the Government of Indonesia (GoI) has shown their support in battery manufacturing ecosystem by building Indonesia Battery Holding (IBH) [3]. GoI aims to prevent the losses made by Battery Electric Vehicle (BEV) disruption to the Internal Combustion Engine Vehicle (ICEV) supply chain that already exists in Indonesia, by enacted law regarding to BEV roadmap and battery local content regulation in 2020 [6].

INTRODUCTION

Currently, Asia Pacific region accounts for 80% of global Lithium-Ion Battery (LIB) manufacturing [1]. While in Association of Southeast Asian Nations (ASEAN) region, Indonesia is the most probable country to become a lithium battery manufacturing hub as Indonesia has the resources required to make LIB such as Nickel, Aluminum, Copper, Manganese, and Cobalt [2]. At the same time, the Government of Indonesia (GoI) has shown their support in battery manufacturing ecosystem by building Indonesia Battery Holding (IBH) [3]. GoI aims to prevent the losses made by Battery Electric Vehicle (BEV) disruption to the Internal Combustion Engine Vehicle (ICEV) supply chain that already exists in Indonesia, by enacted law regarding to BEV roadmap and battery local content regulation in 2020 [6].

Globally, BEV market share has been growing rapidly from less than 50,000 car sales in 2012 up to 3 million car sales in 2017 [7]. Moreover, BEV can also support the electrical grid by providing additional services as alternative energy storage system [9]. In Indonesia, the Minister of Industry targeted to produce 600 thousand four-wheeled BEV, and 2.45 million two and three wheeled BEV by 2030 [10]. These demands must be aligned with sufficient battery manufacturing capacity, as battery component accounts for around a third of overall BEV cost [11].

In addition to BEV, batteries are also required in electricity grid because renewable energy power plant like solar and wind are highly dependent on the hardly predictive mother nature condition. To overcome this intermittent characteristic of renewable energy, Battery Energy Storage System (BESS) integration in the grid is required due to its capability to store energy rapidly. GoI aims to produce more than 5 TWh of electricity from VRE sources in 2030, therefore, adequate capacity of BESS is required to ensure this high amount of intermittent energy source can be integrated into the electricity grid [13]. It is predicted that the main driver (80%) of the growth of LIB will come from

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BESS and BEV application [16]. The current LIB technology development is to use less cobalt and increase usage of nickel, which reflects to increasing nickel demand for battery.

Battery demand mentioned above should be met with the optimal policy and supportive ecosystem. Indonesia as the biggest nickel reserves owner in the world with 1.2 billion ton nickel ore or equivalent to 21 million ton nickel metal [19] should prepare end-to-end battery production ecosystem to ensure higher competitiveness than other potential country such as Australia or Brazil which also have decent nickel and cobalt resources [20]. To design the most effective policy and decision, stakeholders need to understand the mental model of nickel supply chain considering the potential increase of BESS and BEV. Therefore, study that formulates a model of impact of growing battery and electric vehicle to nickel supply chain using system dynamic is significantly needed.

According to aforementioned problem, this research has the objectives to: 1) Predict nickel supply-demand to understand and learn about its behaviour, 2) Forecast how long the security of nickel reserve over time, 3) Calculate the impact of electric vehicle and battery energy storage system to nickel's smelter capacity, and 4) Analyse the rise of electric vehicle and battery energy storage system according to government's policy and its impacts to nickel demand's composition.

METHODOLOGY

Model Overview

In general, nickel industry chain can be classified into three groups. First, upstream industry which contains exploration, mining, processing and refining. Exploration and mining generate products in the form of nickel ores. Once ores have been mined, they are crushed, screened, and cemented to produce an uniform fine-grained powder [21] that is used as raw materials in the processing and refining process. The end product of upstream industry can be Nickel Pig Iron (NPI), ferronickel, and nickel mattes, depending on the technology used [22]. Second, intermediate industry which process the products of upstream industry further. In this group, the primary nickel products are generally divided into three categories which are charge nickel products, melting nickel products, and plating nickel products [21]. The results of this group are in the forms of batteries, Ni Alloy, Ni Plating, etc. Third, downstream industry that uses the material containing nickel that is produced from the intermediate industry. This part produces end-users' products such as vehicles, electronic casing, home appliances, etc.

The demand of LIB is driven by two major sectors, they are renewable energy power plant integration in the grid and electric vehicles sales [23]. This is also aligned with Indonesia's plan to achieve renewable energy penetration target in electricity grid and to boost electric vehicle usage. Historically, nickel demand has been driven by stainless steel production; up to 74% of global demand share in 2019; while nickel for battery only contributes 5% of total demand [24].

Nickel portion in LIB has grown in recent years due to instability of cobalt global supply chain. One major reason of this instability is due to market raising awareness to sustainable mining activity. The long process of nickel supply chain and the growing market demand for LIB makes nickel supply chain complex. The approach that is fit with complexity is system dynamics, a model-based approach to interpret non-linear behavior of complex systems over time using stocks, flows, internal feedback loops, table functions and time delay.

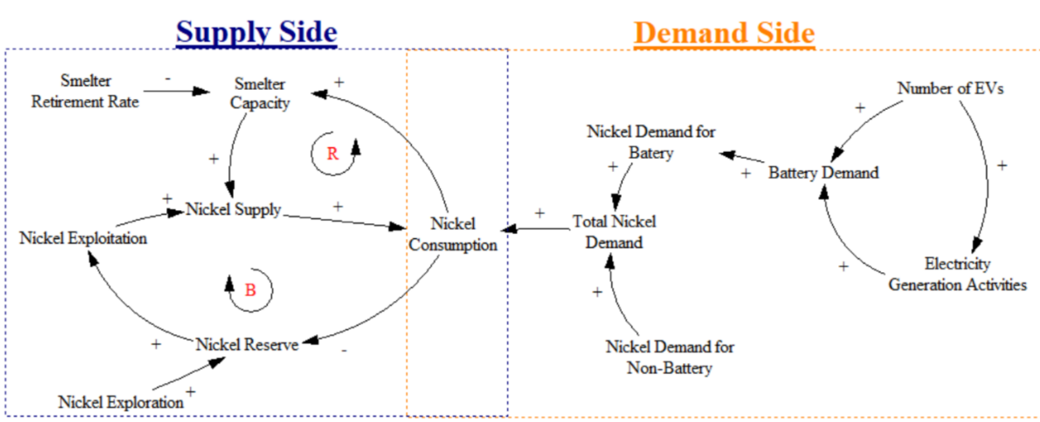

Figure 1. Causal Loop Diagram (CLD).

System dynamics enables nonlinear simulation because of correlation and feedback from one variable to other variable. As a result, it can provide more reliable forecasts of short-to mid-term trends than statistical models, and therefore, lead to better decisions. Finally, it will ease GoI and stakeholders in the nickel industry to have clear and reliable prediction about the future supply-demand of nickel and battery that will result in better decisions and effective policy.

In using system dynamics approach, defining causality relations between parameters are crucial. To do so, it is necessary to, first, build a general model named causal loop diagram (CLD) as a basis for developing the complex model. Figure 1 is the CLD for nickel supply-demand system in which it shows, either direct or indirect, effect of one variable to another. For instance, increasing "Number of EVs" and "Electricity Generation Activities" can increase "Total Nickel Demand". Then, "Total Nickel Demand" will affect the number of "Nickel Consumption" that decreases the "Nickel Reserve" in the upstream. The positive signs (+) in the arrows show a direct proportion between two connected variables, whereas the negative signs (-) show inverse proportion.

In the CLD, there are also closed-loop relations between several variables which can be categorized into 2 types of loop: Reinforcing Loop (R) and Balancing Loop (B). Reinforcing loop means an action on a variable will result in the same behavior (growing or declining) to other variable(s) in the loop [26]. In the model, this is reflected on how increasing "Nickel Consumption" will require the system to increase "Smelter Capacity" to meet required "Nickel Supply" to be consumed. On the other hand, balancing loop means that an action on a variable will result in inverse behavior to other variable(s) that finally creates an inverse feedback in the loop. The balancing loop can be seen in how "Nickel Exploitation" that meets "Nickel Consumption" will deplete "Nickel Reserve". The more massive the exploitation rate, the faster the reserve will deplete.

Detailed Model and Data Sources

Nickel Production

Indonesia approximately has 21 million tons of proven nickel metal reserve [19], mostly located in eastern part of Indonesia such as Southeast Sulawesi (32%), North Maluku (27%), and Central Sulawesi (26%) [27]. According to Pusat Sumber Daya Mineral, Batubara, dan Panas Bumi (2020), reserve of nickel has been gradually increased from 2016 to 2020. In this paper, this increase is used as approach to forecast the trend of exploration rate.

Indonesia produces around 800.000 tons of nickel per year [20]. In this model, see Figure 2, the nickel reserve will deplete as equal as nickel production. Nickel mining production is affected by nickel demand for battery and for other purposes. Those demands create a directly proportional relationship since growth of nickel demand, either from battery or other industry, will increase the production of nickel in mining. Nickel demand for other purposes is obtained from historical data that is projected to 2070 through logarithmic equation, as this equation can better illustrate limited commodity exploration rate. Nickel demand for battery will be explained further in the Subsection 2.2.2 regarding BESS Demand.

Nickel ore that is produced from mine site will be processed further and refined in the smelter. According to *Asosiasi Penambang Nikel Indonesia (APNI)* or Indonesia Association of Nickel Mining Company, the production capacity of nickel smelter in 2019 is 1,036,562.4 ton annually. Nickel smelter has an optimal lifetime until 30 years. In this paper, the number of nickel feed rate to the smelter is assumed similar with nickel production. Also, smelter production rate is considered same as smelter capacity. Once nickel feed rate variable is more than smelter production variable, then, the capacity is inadequate to receive the raw material input. Therefore, additional capacity of smelter is needed.

Battery Energy Storage System (BESS) Demand

Battery Energy Storage System (BESS) demand is estimated based on portion of VRE in the grid. The assumption of current and future electricity generation up to year 2030 is based on *Rencana Usaha Penyediaan Tenaga Listrik (RUPTL)* PT Perusahaan Listrik Negara (Persero) or PT PLN Electric Power Generation Plant. After year 2030, the estimated electricity production growth is shown on the Figure 3. In addition to this, EV also pushes the demand of future electricity generation in the form of electricity used when charging the EV. VRE's share in the overall electricity generation is based on *Rencana Umum Energi Nasional* (RUEN) or *General National Energy Plan* document, which later will be modified depending on the model scenario.

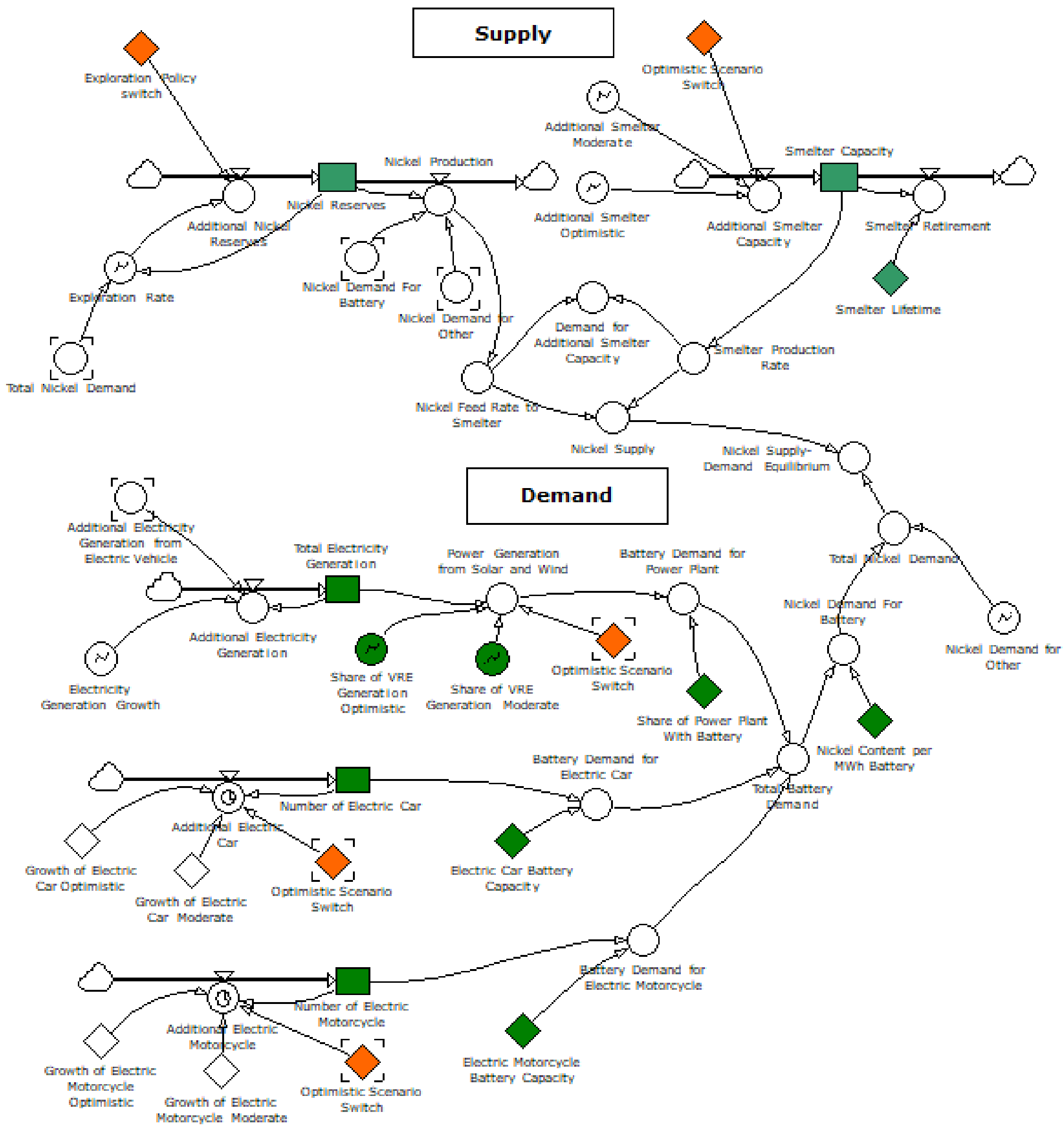

Figure 2. Stock & flow diagram.

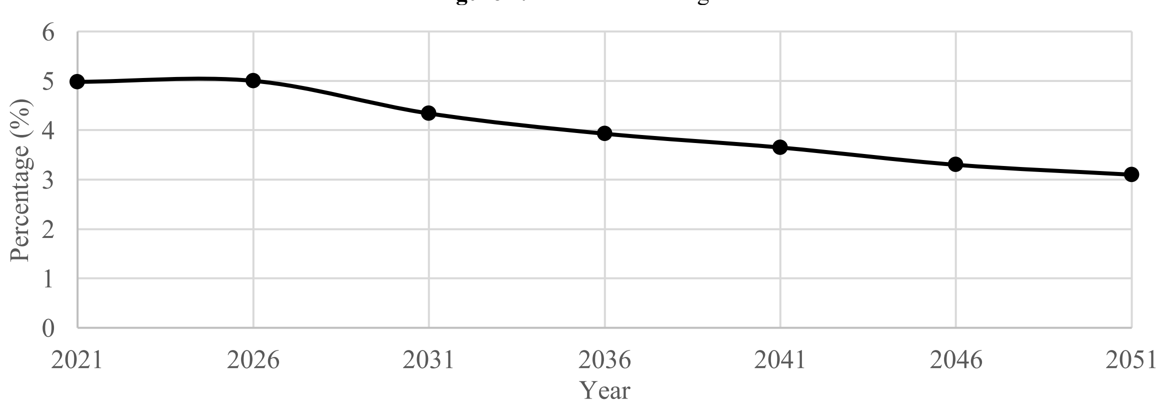

Figure 3. Annual electricity production growth (%).

Annual required battery capacity is calculated from the calculation of minimal battery capacity, by assuming that 100% electricity produced from VRE sources (solar and wind) are designed to supply all-day flat electricity demand. This is an extreme approach where the VRE power plant will be able to supply baseload, therefore VRE sources can be integrated in small or distributed grid, which can be found in eastern part of Indonesia. Thus, the battery calculation is simply the product of VRE production target in 1 day (MWh) and portion of time in which the VRE is not producing electricity (%). Solar PV generation is set at ~1500 production hour/year (kWh/kWp) to simulate Solar Power Plant (SPP) production level in Indonesia. While Wind Power Plant (WPP) generation is set at ~48% capacity factor or equivalent to 4240 production hour/year. Using these assumptions, the results showed that ~66% of VRE generation should be stored in BESS in year 2030. This calculation resulted in 10.5 GWh BESS demand in year 2030 as can be seen in Table 1. The calculation for year 2030 up to 2070 is done using the projected electricity generation growth and projected VRE shares in annual electricity generation.

$$Battery\ Demand\ (GWh) = \frac{VRE\ Production\ in\ 1\ year}{365\ day} * \frac{(8760\ hours - prod.hour\ of\ VRE\ in\ 1\ yr)}{8760\ hour} \ \ldots.(1)$$

Table 1 RUPTL Projection regarding VRE generation from year 2021 to 2030.

Year	**2021**	**2022**	**2023**	**2024**	**2025**
SPP Production (GWh)	125	808	1,223	1,523	2,269
WPP Production (GWh)	477	477	567	1,880	2,839
VRE Total Production (GWh)	602	1,285	1,790	3,403	5,108
Total Production (GWh)	289,448	304,624	319,720	336,331	357,445
BESS Required due to SPP (GWh)	0.28	1.83	2.78	3.46	5.15
BESS Required due to WPP (GWh)	0.67	0.67	0.80	2.66	4.01
Combined Production Hour (hour)	3671	2517	2368	3014	3023
Portion of VRE which should be stored	58%	71%	73%	66%	65%

Year	**2026**	**2027**	**2028**	**2029**	**2030**
SPP Production (GWh)	2,360	2,425	2,503	2,596	2,714
WPP Production (GWh)	2,898	3,088	3,087	3,088	3,087
VRE Total Production (GWh)	5,258	5,513	5,590	5,684	5,801
Total Production (GWh)	374,379	390,799	408,352	427,145	445,519
BESS Required due to SPP (GWh)	5.36	5.51	5.68	5.89	6.16
BESS Required due to WPP (GWh)	4.10	4.37	4.36	4.37	4.36
Combined Production Hour (hour)	3010	3035	3013	2989	2960
Portion of VRE which should be stored	66%	65%	66%	66%	66%

Demand of Battery for Electric Vehicles (EVs)

This study only includes four wheeled and two wheeled EV in the calculation, considering the major market share of those two in transportation sector. System dynamics model in this study calculates the demand of battery for EVs based on the amount of EVs that penetrated the transportation market. The number of EVs is projected through Ministry of Industry Roadmap for EVs and estimation of their annual growth in total vehicles number [6].

Battery capacity requirement for electric cars and electric motorcycles are different. This study benchmarks the battery capacity for existing electric car and motorcycle, resulted in setting the battery for electric car at 38.3 kWh/unit (Hyundai Ioniq Electric) [28], and battery for electric motorcycle at 4 kWh/unit. This study does not consider increasing efficiency for EVs, thus the battery capacity will remain constant throughout the modelling year.

Nickel Content in LIB

Nickel content in LIB is calculated on every nickel processing step. The first step is the production of NMC precursors. For every ton of NMC-811 precursors manufactured, 1.34 ton of $NiSO_4$ is required. After that, NMC active cathode material or NMC powder is produced via calcination process, which requires 0.949 ton of NMC precursors for every ton of product. Lastly, it is known that for every 23.5 kWh battery pack studied, 34.93 kg of active cathode material is required [29]. It is also assumed that the nickel content in $NiSO_4$ as the raw material can be calculated using molar weight equivalent. It is calculated that nickel accounts for 36.8% of $NiSO_4$ total weight. Thus, the nickel raw material calculation for every MWh battery can be seen on the Equation 1. The calculation is also confirmed by [7] where ~0.69 ton of nickel metal is required for every MWh battery.

$$Nickel\ required\ = 1000\frac{kWh}{MWh} * \frac{34.93\ kg\ Active\ Cathode\ Material}{23.5\ kWh} * \frac{0.949\ kg\ Precursor}{1\ kg\ Active\ Cathode\ Material} * \frac{1.34\ kg\ NiSO4}{1kgPrecursor} * \frac{36.8\ kg}{100\ kg\ NiSO4} * 0.001\frac{ton}{kg}$$

$$Nickel\ required\ = \ 0.696\frac{ton}{MWh}\ \ldots..(2)$$

RESULTS AND DISCUSSION

This study assesses the significance of battery demand to Indonesia's nickel reserve from 2020 to 2070. Year 2070 is chosen as the simulation's end-time because Indonesia is targeting to reach net zero carbon emission by 2070 [30]. The model is run in two scenarios, moderate and optimistic. By assessing through 2 scenarios, it is possible to carry out sensitivity analysis for battery demand's impact to nickel supply-demand system. Therefore, suitable policy measures can be drafted by using the results from the sensitivity analysis.

The model is also simulated in two conditions: without and with exploration activity. It is run so because this paper does not only aim to analyze how long nickel reserve in 2020 will last without exploration, but also to approach the real condition of nickel supply chain in which exploration takes significant role.

Projection of Battery and Nickel Demand

Moderate Scenario

Main assumptions for moderate scenario are:

1. Electricity generation from VRE power plant is around half of RUEN target

According to RUEN, renewable energy is expected to generate around 37% of electricity in 2050. Among them, VRE is expected to supply around 13% of power generation. Therefore, moderate scenario is set to increase the share of VRE to around half of RUEN target, which is 6% in 2050, and prolonged in linear behavior through 2070. This results a total battery capacity demand for VRE around 582 GWh in 2070.

Table 2 Moderate Scenario BESS Demand Projection

Year	2021	2030	2040	2050	2060	2070
Total Power Generation (GWh)	270,647	419,565	626,261	878,093	1,176,471	1,519,095
Share of Power Generation from VRE (%)	0.2	1	4	6	9	12
Total Battery Capacity Demand for VRE (GWh)	1	10	40	101	198	332

2. EVs market share will account for up to 50% of all car and motorcycle market in 2070

Projection of total number of EVs for early year is cited from Ministry of Industry's EVs Roadmap. Then, for EVs to reach 50% of market share, electric car and motorcycle are set to have annual growth of 8% and 10.2% respectively up to year 2070.

After running the model in moderate scenario, cumulative nickel demand due to battery utilization will be around 14.6 million tons from year 2021 to 2070. The annual nickel demand for battery rises more than 700 times initial value, from 746 tons in 2020 to 553 thousand ton in 2070. With this number, nickel for battery contributes approximately 24%, (see Figure 4), from total nickel demand in 2070. This percentage grows from less than 1% in 2020. The trajectory shows that the LIB demand line and other demand line will ultimately cross at some point in the future, even though longer simulation is required to accurately determine when it will occur.

Table 3 Moderate Scenario EV Demand Projection

Year	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Total Number of Electric cars (thousand)	0.8	154	682	1,494	3,275	7,177
Total number of Electric Motorcycles (thousand)	3	878	2,376	6,427	17,380	47,002
Total Battery Capacity Demand for EVs (GWh)	0.04	9	36	83	195	463

Table 4 Moderate Scenario Nickel Demand Projection

Year	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Total Battery Capacity Demand (GWh)	1	19	76	184	393	795
Annual Nickel Demand for Battery (ton)	746	13,521	52,811	128,251	273,838	553,471
Cumulative Nickel Demand for Battery (ton)	746	135,659	802,234	2,551,812	6,536,437	14,648,233

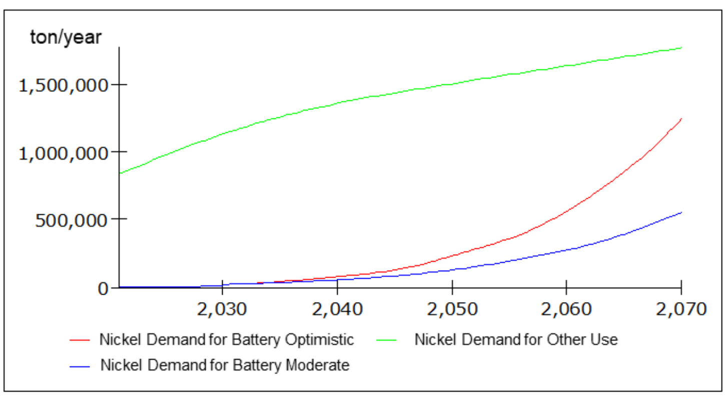

Figure 4. Nickel demand for battery material compared to other nickel demand for moderate scenario and optimistic scenario.

Optimistic Scenario

Main assumptions for optimistic scenario are:

1. Electricity generation from VRE power plant meets RUEN target in 2050

In optimistic scenario, power generation from VRE is expected to meet RUEN target. Thus, the share of VRE in power generation is set to reach 13% in 2050. This scenario results in higher increment of battery demand for VRE to 207 GWh in 2050, and 801 GWh in 2070.

Table 5 Optimistic Scenario BESS Demand Projection

Year	2021	2030	2040	2050	2060	2070
Total Power Generation (GWh)	270,647	418,136	624,959	877,023	1,177,780	1,523,995
Share of Power Generation from VRE (%)	0.2	1	6	13	22	29
Total Battery Capacity Demand for VRE (GWh)	1	9	67	207	460	801

2. All cars and motorcycles will be EV in 2050

In optimistic scenario, all cars and motorcycles are assumed to be EVs in year 2050. This scenario assumes the electric vehicle movement will success. Few of the success parameter are whether the ownership cost of EV will be cheaper compared to ICEV, and whether the charging infrastructure will be ready for massive EV penetration. Optimistic scenario has higher EVs growth rate compared to moderate scenario which are 10% and 11.8% for electric car and motorcycle respectively up to year 2070. Therefore, the projection of battery capacity demand will be higher as well.

In the optimistic scenario, cumulative nickel demand due to battery utilization will be around 29.1 million ton from year 2021 to 2070. The annual nickel demand for battery rises 1665 times from 746 tons in 2020 to 1.2 million ton in 2070. Demand for nickel as raw material for LIB will increase to 41% from total nickel demand of around 3 million ton per year. This can happen because of the plateauing other nickel production rate as can be seen on Figures 4, while at the same time the growth of LIB is increased dramatically. By looking at the trajectory of the curve, we can assume that the LIB line and other nickel line will cross sometime in the future, in particular for the optimistic scenario where the line is much closer together and the LIB demand trajectory is soaring compared to moderate scenario. Longer simulation and more accurate baseline data are required to find out when this will happen for both scenarios.

Table 6 Optimistic Scenario EV Demand Projection

Year	2020	2030	2040	2050	2060	2070
Total Number of Electric cars (thousand)	0.83	157	827	2,194	5,822	15,446
Total number of Electric Motorcycles (thousand)	2,3	1,000	3,146	9,902	31,164	98,078
Total Battery Capacity Demand for EVs (GWh)	0.04	10	44	124	348	984

Table 7 Optimistic Scenario Nickel Demand Projection

Year	2020	2030	2040	2050	2060	2070
Total Battery Capacity Demand (GWh)	1	19	111	331	808	1,785
Annual Nickel Demand for Battery (ton)	746	13,235	77,250	230,354	562,100	1,242,455
Cumulative Nickel Demand for Battery (ton)	746	140,185	1,007,046	3,825,483	11,440,281	29,110,396

Nickel Reserve Security

In supply side, without any exploration activity, nickel reserve for both moderate and optimistic scenarios are expected to be fully depleted in 2040. To anticipate long run nickel demand until 2070, an aggressive exploration rate is necessary to prolong its nickel reserve security at least for another 30 years. Otherwise, Indonesia will become dependent on nickel imports or even battery imports to fulfil its long-term demand.

While nickel demand for moderate scenario grows annually at 2.1% growth rate, the optimistic scenario indicates that nickel demand is projected to grow 2.6% annually. Although the growth difference seems insignificant, absolute tonnage for annual nickel demand for optimistic scenario will be doubled compared to moderate scenario in 2070. Hence, the implication is the vast difference in required additional nickel reserve between the two scenarios. In moderate scenario, Indonesia is expected to increase its nickel reserve by 13 million ton cumulatively until 2070, while in optimistic scenario, 28 million of additional nickel reserve is expected until 2070.

Table 8 Additional Nickel Reserve Required from Year 2040 to 2070

Scenario	Ton
Moderate scenario	13,845,999
Optimistic scenario	28,103,350

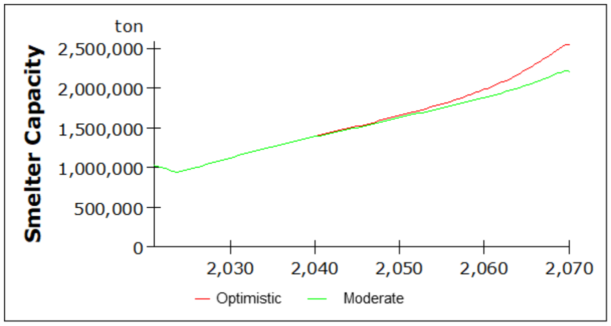

Figure 5. Illustrated graph of smelter capacity of both scenarios.

Following the rise of demand mentioned in Subsection 3.1.1 and Subsection 3.1.2, the supply side especially nickel ore production will be increased as well. It results on the deficiency of smelter capacity to accommodate nickel ore production. In either moderate or optimistic scenario, current Indonesia's smelter capacity can only accommodate nickel ore production until 2024. After that, additional smelters are needed. In moderate scenario, smelter capacity rises from 1 million tons in 2020 to 2.2 million tons 2070, while, in optimistic scenario the number will be 2.5 million tons in 2070.

Policy Implications

In 2055 for moderate scenario and 2054 for optimistic scenario, see Figure 5, there is a giant leap of exploration rate so the nickel reserve can still satisfy the demand until 2070. In real condition, extreme increase like this cannot be met since the exploration activity requires strong financial support, involves several parties including government and private companies, and impacts high risk of business which all should be assessed in proper method. Thus, GoI needs to stimulate the nickel exploration rate, so, nickel reserve will be maintained available as well as manage the time of execution to ensure national nickel reserve security and to keep reserve's rise more smoothly.

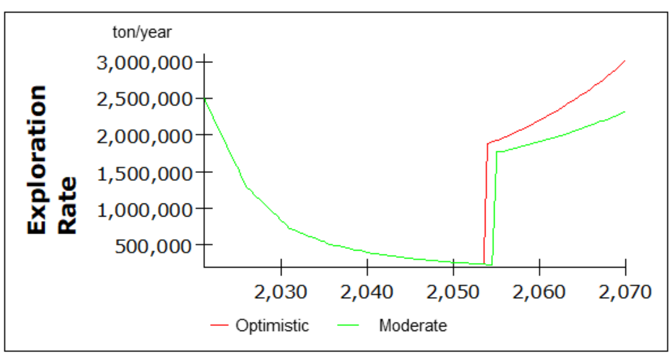

Figure 6. Exploration rate required for both scenarios.

This challenge may be solved with, for instance, financial scheme that can reduce exploration risk borne by one party and share it to more capable party. There are several financial schemes that can potentially be used in this case such as Public Private Partnership (PPP) or Cost Recovery scheme. As the risk decreases, corporations will be stimulated to do their exploration activities, therefore can support overall national nickel supply security. Other way that can be used is simplifying the bureaucracy of *Izin Usaha Pertambangan Eksplorasi (IUP-E)* or Exploration Permit. It will reduce the period of time required to secure the permit. As a result, the exploration can be started earlier. In overall, determining suitable steps to stimulate exploration activity should be done through careful study and assessment in order to ensure suitability from political, financial, and operational point of view.

Since exploration can potentially leads to raise of nickel ore production, such policies have to be followed by the increase of smelter capacity as well. In one hand, if the smelter capacity is way too much than the market needs, it will be inefficient and uneconomical. On the other hand, if the smelter capacity is insufficient to keep up with the nickel ore production, the export of nickel ore will rise. This condition will possibly be inconsistent with the spirit of Act No. 3 of 2020 concerning Mineral and Coal Mining that wants to create downstream industry of mining by building smelter and reducing export of nickel ore as raw materials.

After 2024, the smelter capacity will increase gradually, see Figure 6. Because of that, the GoI needs to maintain the rise of smelter capacity as well as the rise of nickel ore production. The GoI can create a long-term master plan that includes smelter capacity targets until 2070. This target will be divided into five years and be evaluated after each period over. Even though, the Act No. 3 of 2020 concerning Mineral and Coal Mining mandates the obligations of building smelters to the corporations which mine the nickel ore, the GoI still have role to create target that can be followed by the corporations. This target of smelter capacity can simultaneously be released with other policies that can stimulate corporation's willingness to build smelters such as incentivizing the corporations which plan to build smelters, linking and matching the several relatively small corporations to create consortium to fund their joint smelter, etc.

On the demand side, *Tingkat Kandungan Dalam Negeri (TKDN)* or Local Content Regulation implementation will also be influenced by national nickel supply security. Since market will always look for the most efficient system, Local Content Regulation will only inhibit the market efficiency if the supply side is not secured. This inefficiency could result in slower market growth, and potentially unlawful activity such as using material that is not comply with Local Content Regulation, or fraudulent business activity. These facts put another pressure to ensure sufficient reserve level by stimulating exploration activities.

CONCLUSION

This study provides a method for developing models to forecast nickel supply to meet the estimated future demand considering the emerging market of BEV and BESS. By implementing system dynamics model, it is known that increasing demand side will impact the nickel supply side. In this paper, optimistic scenario uses high EV penetration and fulfills the RUEN VRE share target, while moderate scenario only uses low EV penetration and only satisfies around a half of RUEN VRE share target.

From those scenarios, battery demand ratio from EV and BESS are comparatively similar, but the cumulative battery demand of those scenarios is far different. Nickel demand for LIB will significantly grow compared to nickel demand for other purposes. In moderate scenario the demand of nickel for LIB will increase from less than 1% of the nickel market in 2020 to 24% in 2070, while, in optimistic scenario the number will be 41% in 2070.

Even though, the increase of nickel's demand in the optimistic scenario will be higher than the moderate one, the year of full depletion is forecasted to be similar. The existing reserve of nickel in Indonesia will fulfill the demand until 2040 in both scenarios. To cover the need of nickel until 2070, Indonesia has to find new nickel reserve up to 13 million tons cumulatively in 2070 for moderate scenario and 28 million tons for optimistic scenario. Also, the smelter capacity has to be increased as well as from 1 million tons in 2020 to 2.2 million tons 2070 for moderate scenario and to 2.5 million tons in 2070 for optimistic scenario.

The GoI shall create policy that stimulates exploration activities such as incentivizing the corporate's exploration initiatives or any financial and risk mitigation schemes and reduce the bureaucracy of exploration permit. Also, the GoI can create master plan of smelter capacity target as well as policies that can stimulate the corporations to build smelters. With such policies, the nickel reserve and production can be maintained to fulfill the target of nickel demand in growing EV and BESS.

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