

Scenario Analysis of Indonesian Ferronickel Supply Chain Resilience with System Dynamics

I Anna Tul Munikhah^{1*}, Ade Yanyan Ramdhani¹,
Aiza Yudha Pratama¹, Ratih Windu Arini¹

Abstract: This study aims to determine the impact of Indonesian government policies on the supply chain resilience of the ferronickel industry in Indonesia. The existing problem is that the law prohibits nickel ore exports, and the policy of industrial downstream causes delays in the process of nickel processing. The problems happen because Indonesia's nickel industry is still incapable of downstream. As a result, the nickel supply chain faces dynamic and complex events that can disrupt operational activities. At the same time, supply chains need to withstand and recover from disruptions quickly. Therefore, Supply Chain Resilience, which is the ability to survive, adapt, and recover from disruptions to meet customer needs, is needed. This study uses system dynamics to analyze complex and dynamic systems to provide more practical policy advice. The system dynamics model starts by building a conceptual model through a system diagram. Inside the model is a causal loop diagram, then proceeds with developing a quantitative stock flow diagram (SFD) model. Finally, this SFD model operated with several scenarios used as policy suggestions for the Indonesian government.

Keywords: Supply chain, resilience, ferronickel, system dynamics.

Introduction

Nowadays, Nickel is a hot topic of conversation around the world. Nickel is pushing a change in energy use, one of which is an essential component in producing electric vehicle batteries. In 2019 it was estimated that there would be 3,269,671 electric vehicles in the global electric vehicle market, and the number will reach 26,951,318 units by 2030. The increased demand for electric vehicles will automatically make the industry one of the most popular. Therefore, as an essential component, Nickel will be the target of countries around the world. Indonesia has abundant nickel reserves. In 2021, Indonesia had 37% of the world's nickel reserves, which amounted to 21 million tons. Indonesia ranks first in the world's nickel contribution, followed by the Philippines at 13% and Russia at 9%. Nickel spread around in various areas in Indonesia, such as East Halmahera in North Maluku, Morowali in Central Sulawesi, Obi Island in North Maluku, and Gag Island in the Raja Ampat Islands [1].

Nickel is a valuable metal used in various industrial sectors such as automotive, electronics, construction, shipping, and aircraft components [1], [2]. Four nickel products are marketed by Indonesia: Nickel Ore,

Nickel Matte, Ferronickel, and Nickel Pig Iron [2]. Nickel ore is raw ore that does not go through further processing and refining. Those that go through processing and refining are Nickel Matte, Ferronickel, and Nickel Pig Iron. Of the three types of processing, Ferronickel is the product with the highest production in Indonesia, reaching 50.24%, compared to Nickel pig iron at 38.32% and Nickel matte at 11.45%. Ferronickel is the main product of processing high-grade nickel ore (sapolite) through pyrometallurgy. Generally, ferronickel is useful as a raw material for producing stainless steel.

Indonesia has imposed a ban on nickel ore exports since January 1, 2020, stipulated through the Minister of Energy and Mineral Resources Regulation Number 11 of 2019. Previously, Law number 4 of 2009 also stipulates that nickel ore must be processed first in Indonesia. The Ministerial Regulation seeks to increase awareness that Indonesia has mineral resources that must be appropriately managed and have added value [3]. The Ministry of Industry also mandates that industry development has to be balanced and integrated, one of which is by optimizing all available natural, human and financial resources. In other words, it is necessary for downstream industry [4], [5].

This government's policy disrupts the ferronickel supply chain because nickel ore is the raw material for its processing. In an increasingly dynamic and volatile global environment, supply chains face various events that threaten to disrupt supply chain operational activities and jeopardize their efficient and effective

¹ Faculty of Industrial Technology and Design, Department of Industrial Engineering, Institut Teknologi Telkom Purwokerto. Jl. DI Panjaitan No. 128, Karangrejo, Purwokerto Kidul, Kabupaten Banyumas, Indonesia 53147. Email: anna@ittelkom-pwt.ac.id, ade@ittelkom-pwt.ac.id, aiza@ittelkom-pwt.ac.id, ratih@ittelkom-pwt.ac.id.

* Corresponding author

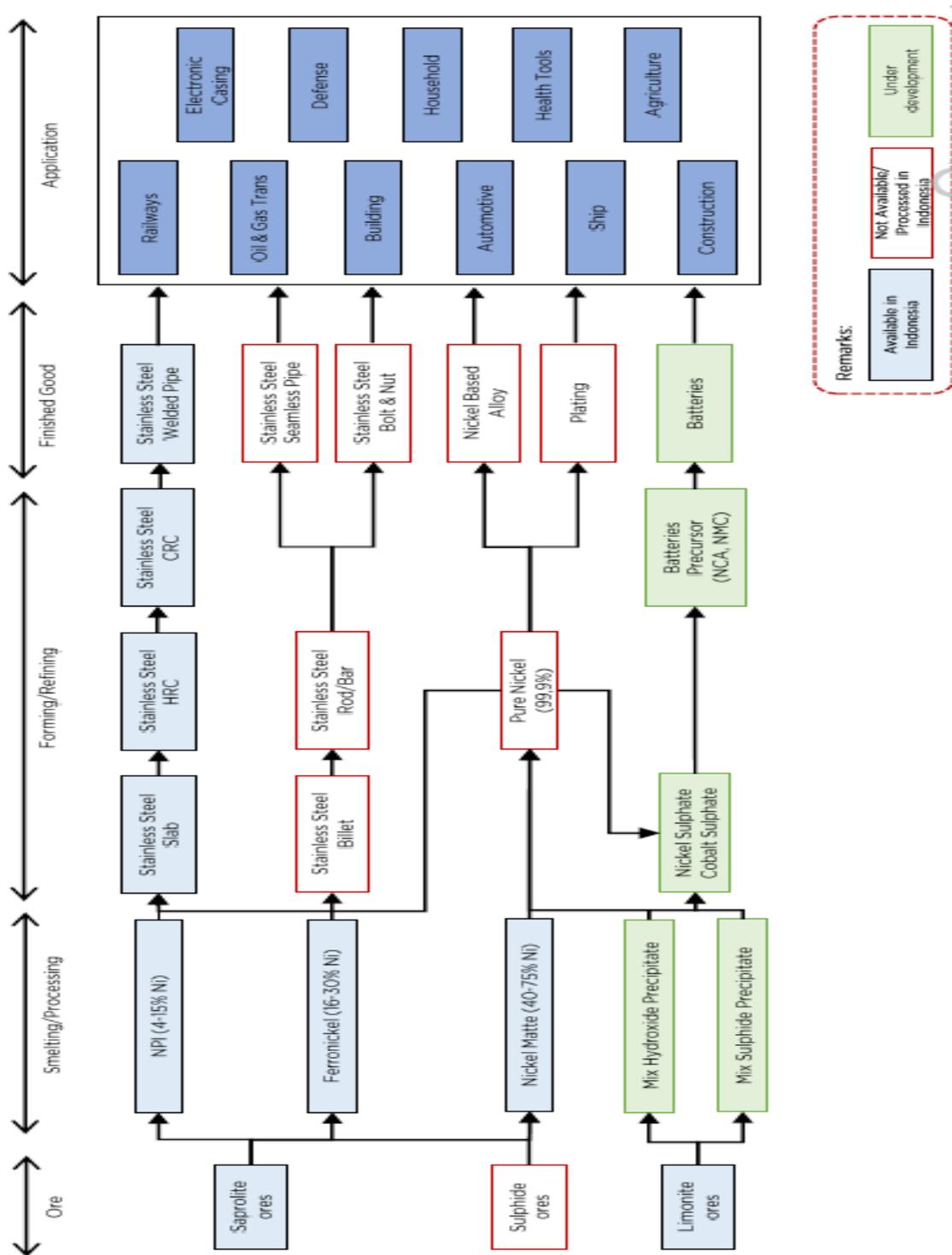


Figure 1. The Indonesia's nickel supply chain [14]

performance. Therefore, the designs of the supply chain system must be able to withstand disruptions and recover from them quickly, with minimal costs [6]. Therefore, law Number 4 of 2009, concerning the policy that prohibits the export of nickel ore and industrial downstream, is a disruption in the supply chain of the nickel industry. In other words, there is a need for research on Supply Chain Resilience, which is the ability of the supply chain to survive, adapt and

recover from disruptions to meet customer demands and ensure performance [7].

There are several studies conducted on supply chain resilience in various industrial sectors. Mancheri, et al. analyze the mechanisms of maintaining supply chains, such as supply diversity, material substitution, recycling, and stockpiling in the tantalum and rare earth element industries [6], [8]. Shao *et al.*[9]

assessed the lithium supply chain's resilience due to increasing demand and the risk of supply chain disruption to the lithium industry in China. These three studies used the dynamic system method. Research on supply chain resilience still needs to be completed because the term resilience has only emerged since 2016. Based on previous research, the methods used in supply chain resilience are the dynamic system method, discrete event simulation, and structural equation modeling.

The method used in this study is system dynamics. Therefore, it can study the supply chain problem of the nickel industry that operates based on feedback information [9], has various complex and dynamic factors, has a causal relationship, and produces circular and non-linear diagrams, which are characteristics of the system dynamics [10]. Furthermore, system dynamics are usable to identify a system's basic structure to gain insight into behavioral patterns, focusing on how the components of a system interact and understanding the role each component plays [11]. Therefore, system dynamics is the right method as a modeling and analysis tool for policy suggestions to maintain supply chains against future disturbances.

This study did not use discrete event simulation because the method is unsuitable for the nickel industry, where the status changes occur at the discrete time triggered by events. In contrast, the problems in this study are continuous [12]. Furthermore, the SEM method is not usable because this method cannot analyze policies. After all, the output is in the form of factor analysis (relationships between variables), and the ultimate goal is to make program recommendations by considering the model structure [13].

Methods

Literature Review

The supply chain structure of the nickel industry generally consists of the upstream industry chain, i.e., the mining chain and the mining products are in nickel ores. These nickel ores are used as raw materials in processing and refining. The result of processing and refining products are Nickel Pig Iron (NPI), ferronickel (FEND), and nickel mattes. Then, these products, i.e., NPI, ferronickel, and nickel mattes, are further processed into the intermediate/downstream products in the forms of batteries, Ni Alloy, Ni plating, and various stainless steel products. These products will serve as raw materials for their respective downstream industry. Finally, they will be distributed to their end users in household appliances, ships, construction, agriculture, electronic casing,

defense, oil and gas transport, vehicles, and trains [2]. In Figure 1, the Indonesia' nickel supply chain is shown.

The supply chain is all parties involved, either directly or indirectly, in meeting customer needs. The parties from upstream to downstream include suppliers, manufacturers, distributors, logistics service companies, warehouses, retailers, and customers [14], [15].

The ferronickel industry supply chain starts from the nickel ore mining process, and then the nickel ore is sold domestically and for exports. The nickel ore sold domestically is then processed into ferronickel, which they export abroad. In the mining and processing industry, Nickel impacts the environment because the process produces carbon emissions. In addition, the transportation process for distribution from the mining site to the ferronickel processing also generates carbon emissions. Nearly 93% of the waste from nickel ore that becomes the source for ferronickel processing becomes slag, which is unusable for a series of nickel industrial processes. Instead, the mining company uses the slag as raw material for paving the road around the mine area. It can also be distributed to recycling cement companies so it can be utilized [2].

In an increasingly dynamic global environment, supply chains are faced with disruptions that can disrupt operational activities. As a result, the supply chain becomes inefficient and ineffective. The risk of disruption usually occurs with low likelihood but has a high impact. Disruptions are unexpectedly varied in type, nature, scale, and intermittent. It is also irregular to identify and predict well so it can have short or long-term effects [16].

The supply chain system must be designed to withstand disruptions (vulnerabilities) and recover from a disruption quickly. Supply chain resilience (SCR) emerged when designing global networks. SCR is the supply chain's ability to survive, adapt and recover from disruption to meet customers and ensure performance. Supply chains need to be designed to be resilient, robust, and stable to maintain their basic properties and ensure performance. In addition, the supply chain needs the ability to adapt its behavior in the event of a disruption to achieve planned performance using recovery action [7].

SCR has vulnerabilities and capabilities. Vulnerabilities are factors that make an enterprise susceptible to disruptions. It can be found in both the supply and demand sides of operations. A class of vulnerabilities, including turbulence, exists when a company operates in an environment characterized by frequent change—for example, geopolitical disruptions,

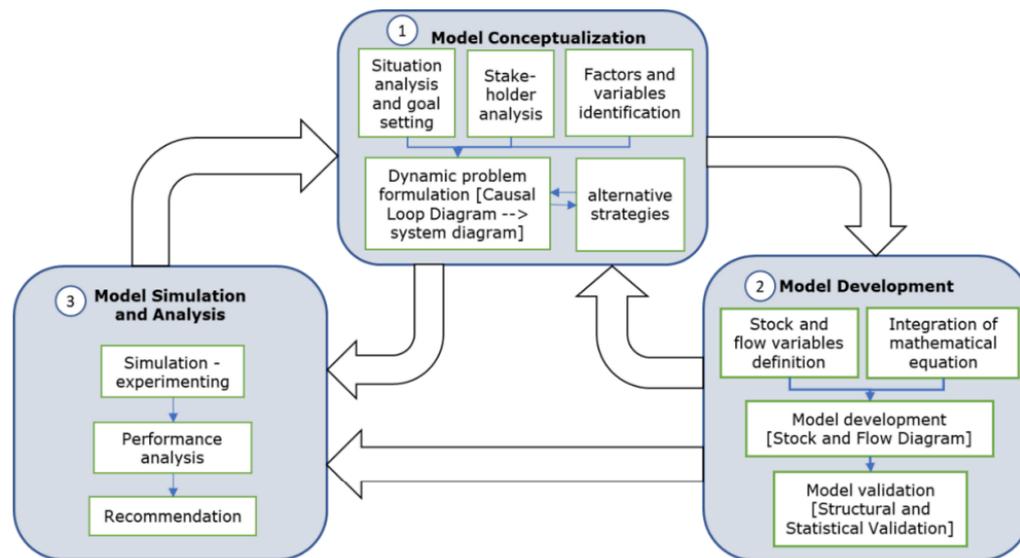


Figure 2. Development of a model based on the methodology developed by Sterman [22]

currency fluctuation, and unpredictable customer demand. *Capabilities* are attributes that enable an enterprise to anticipate and overcome disruptions. They can be either inherent or developed throughout the organization, including in finance, operations, logistics, transportation, and human resources [17].

Research Methodology

The system dynamics model describes the system's behavior, which has an interdependent relationship and changes with time [10]. The dynamic system is the most popular method in the modeling process because it can describe the environmental conditions modeled in the simulation with conditions such as the actual environment as closely as possible [10]. In practice, system dynamics can accept the complexity, nonlinearity, and feedback structure inherent in social and physical systems [11]. This system dynamics also reflects changes through simulation or based on real-time and calculates components constantly by including several alternative future actions.

The system dynamics model is developed by following four general stages of development: model conceptualization, model formulation, model verification, and policy recommendations [18]. First, the system diagram is illustrated using a causal loop diagram and proceeds with quantitative data processing using Stock Flow Diagrams (SFD). Next, the SFD describes a model structure that includes system information and feedback using system dynamics symbols, namely stock and flow [18].

The Causal Loop Diagram (CLD) is a critical tool to represent the feedback structure of the system. For a

long time, used in academic work, it is now increasingly common in business. CLDs are excellent for quickly capturing hypotheses about the causes of dynamics, acquiring and capturing individual or team mental models, and communicating important feedback for a problem [11]. However, CLDs suffer from several limitations and are easy to abuse. One of the most critical limitations of cause-and-effect diagrams is their inability to capture the stock and flow structure of the system. Stock and flow, along with feedback, are the two central concepts of systems dynamic theory [10].

Figure 2 shows the research methodology. The first step is to create a conceptual model. The conceptual model consists of a situation analysis and goal setting, stakeholders, factors, variable identification, and a causal loop diagram combined into a system diagram. After compiling the conceptual model, the next step is model development using stock-flow diagrams. Next, stock flow diagrams must be verified and validated so that the model built follows the original. After that, the next step is model simulation and analysis.

Five experts validated the causal loop diagram through interview sessions. The background of these experts is the ministry of energy and mineral resources, who has 17 years of experience in nickel mining, an Indonesian economist and politician, and several supply chain fields from a ferronickel company. The expert advises separating demand for nickel ore and ferronickel because there are companies that only carry out mining, and there is no smelting process. In addition, the model also needs to add export prohibition and downstream industry factors to the scenario so that supply and demand can be seen when an export ban occurs. The influence of interaction

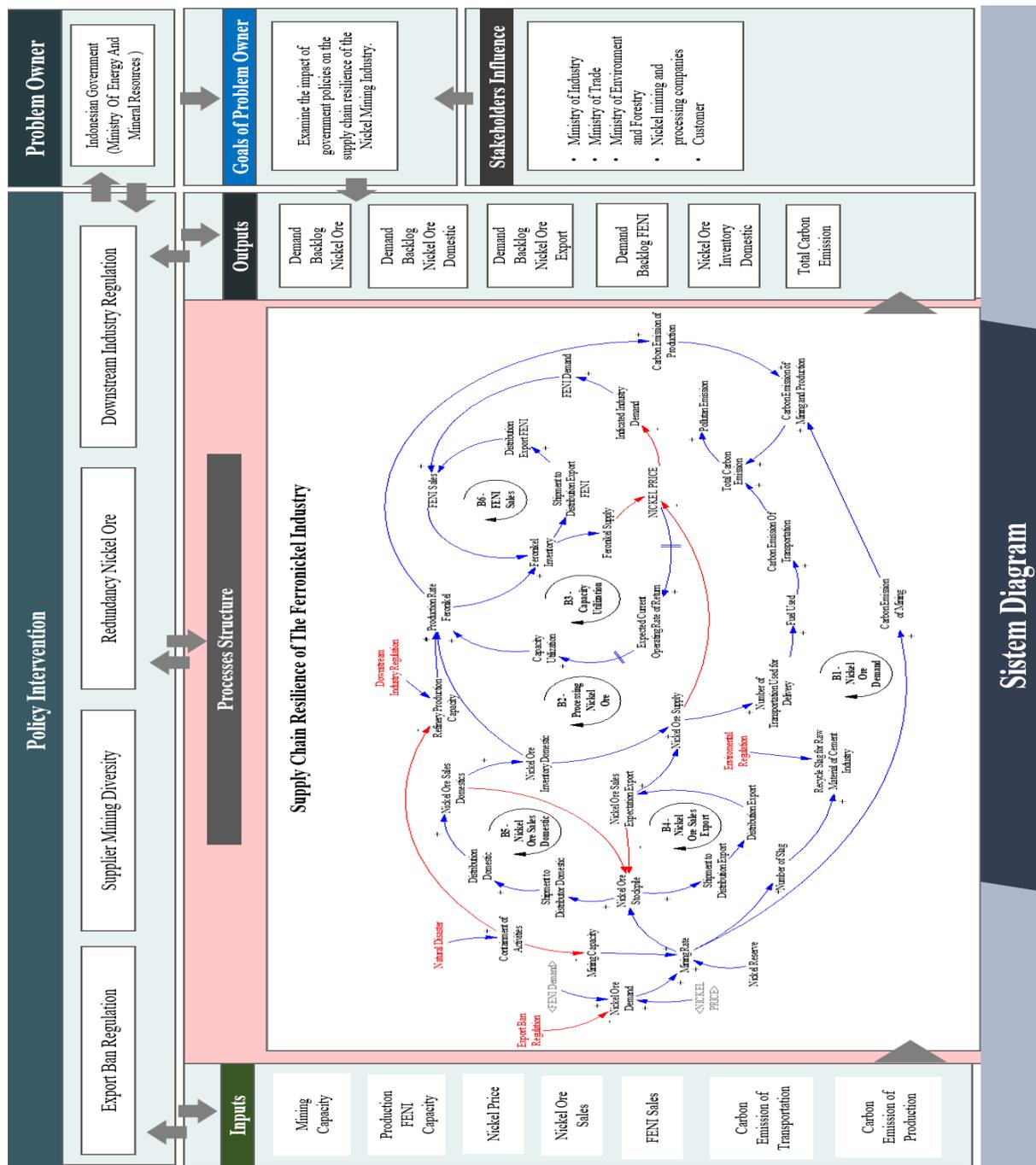


Figure 3. System diagram of supply chain resilience in the Ferronickel industry of Indonesia

between variables is indicated by causal connection and polarity. Causal connection is indicated by an arrow running from the "cause" to the "effect" and polarity indicated by a "+" or "-" [20], [21]

Results and Discussions

Conceptual Model of Supply Chain Resilience Ferronickel Industry

Modeling using system dynamics is a simulation method that focuses on the causal relationship of the interrelationships between variables that have a

complex and dynamic system. It can show a systemic picture of the complete structure of the system under study. A *system diagram* is a tool that can provide a complete understanding of the system. It consists of the problem owner in charge of the system from the topic to be studied, research objectives, policy interventions, inputs, process structures in the form of causal loop diagrams, outputs, and stakeholders' influences. In order to make it easier to understand how to create the next model, the following Figure 3 is a system diagram for the supply chain resilience of the Indonesian ferronickel industry to be developed based on the data processing results.

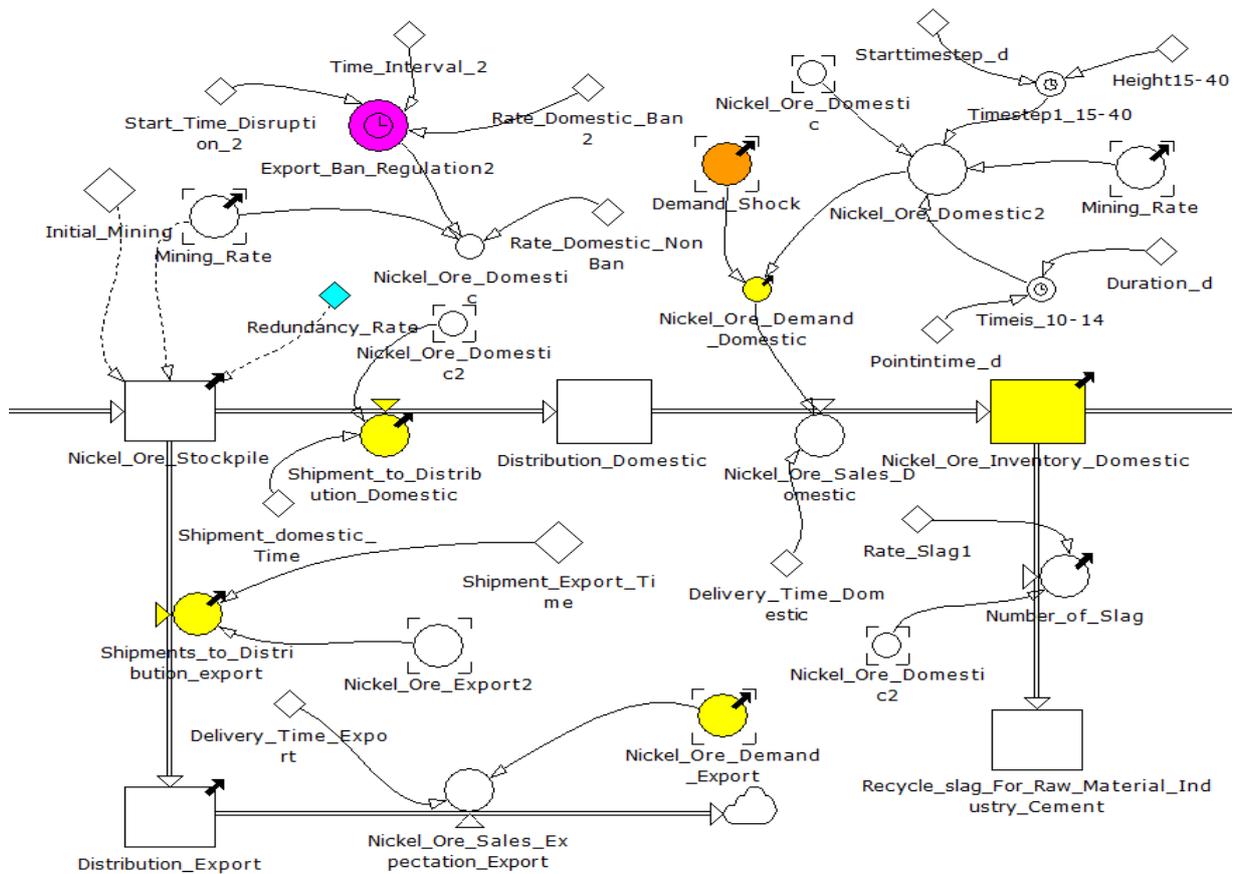


Figure 4. Stock flow diagram of supply chain resilience in the Ferronickel industry of Indonesia

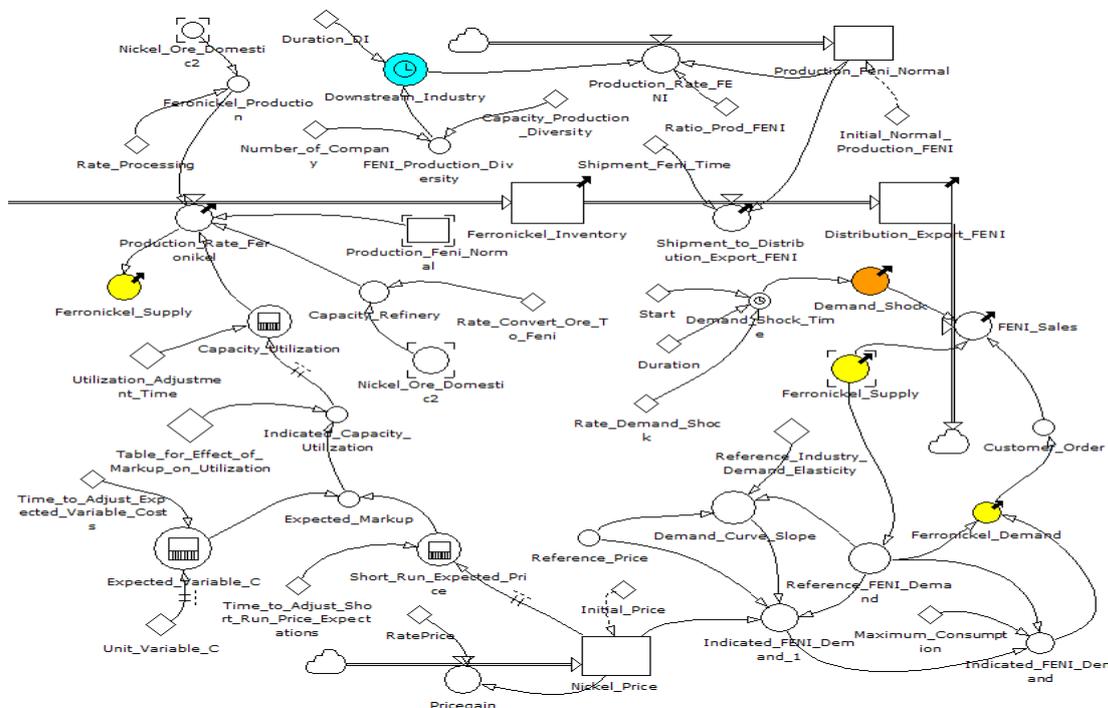


Figure 5. Stock and flow diagram of ferronickel sub-model

Based on the system diagram, the conceptualization of the developed model is divided into three parts. The first part is the dynamics of supply and demand from

nickel ore. The second one is supply and demand from ferronickel. Total carbon emissions from the production process of nickel ore into ferronickel is the

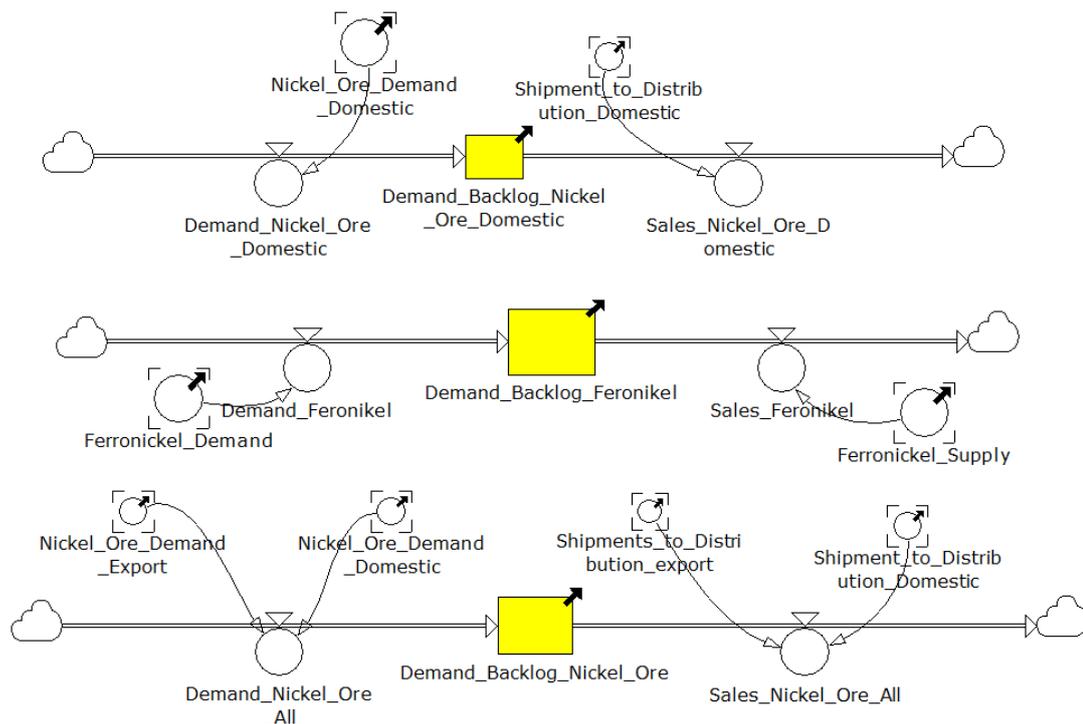


Figure 6. Stock and flow diagram of demand backlog of nickel industry

last part of the model development. The problem owner of this system is the Government of Indonesia, mainly the Ministry of Energy and Mineral Resources. This research aims to examine the impact of government policies on the resilience of the Nickel Industry supply chain. For example, the government's policy to ban nickel ore exports has led to the addition of nickel processing industries (downstream industry), diversity of mining supplies, and redundancy of nickel ore. However, the SCR system of the Indonesian nickel industry is also influenced by stakeholders, whether they are individuals or groups who have an interest and are directly or indirectly able to influence or be influenced by the existence of the organization's activities.

Model Development (Stock and Flow Diagram) of Supply Chain Resilience Ferronickel Industry

In the next stage, a Stock and Flow Diagram (SFD) is developed after collecting the required data to translate mental data, filled with input from the numerical data obtained to produce the expected output. The ferronickel model describes the supply and demand relationship for ferronickel, which is affected by the supply of nickel ore from mining, ferronickel production capacity, capacity utilities, nickel prices, slag recycling management, and sales data exported abroad. The SFD is given numerical information from the Ministry of Energy and Mineral Resources and the company's annual report. Figure 4-6 shows the

development of the ferronickel sub-model SFD in this study that explains into 3 sub-models.

The SFD of nickel ore sub-model consists of nickel ore supply that affected by nickel export and government regulation, distribution domestics, nockel ore inventory domestics and its recile variabel. The nickel ore stockpile will be rising if government ban nickel export selling and distribution without well prepare for the downstream industry and makes nickel ore's price falling down.

The SFD of Ferronickel sub model represents the ferronickel production rate that will be increase if the downstream industry does. Increasing downstream industry will boost nickel ore demand and make competitive price of nickel ore along with ferronickel. The SFD of Demand backlog of Nickel industry consist of demand backlog of nickel ore industry, ferronickel and nickel ore itself. Nickel ore backlog is affected by demand and distribution from domestic that will be increase if the downstream industry has doing well then decreasing the demand and distribution from export and finally gives the best nickel price. The nickel ore industry and ferronickel industry of backlog will do the same. The key is the downstream industry improvement will absorb nickel ore stockpile without exporting.

Verification and validation of the model after developing the SFD model is to ensure that the designed simulation model can represent the actual structure

Table 1. Alternatives to disruption and capabilities

Disruption			
Disruption Alternative	Base Model	Low (L)	High (H)
Nickel Ore Export Ban (B)	Export ban tightened in 2014-2016 (100%)	Tightened (70%)	Tightened (100%)
Nickel Ore and Ferronickel Demand (D)	Fixed	Increase 50%	Increase 100%
Capability			
Capability Alternative	Base Model	Low (L)	High (H)
Diversity of Mine Supply (MD)	Fixed	Decrease 10%	Increase 20%
Processing Facility Capacity (PD)	Downstream 2013-2019	Increase 10%	Increase 30%
Nickel Ore Redundancy (R)	0	5%	10%

and dynamics of the system. The sub-chapter below will describe the verification and validation process. The supply chain resilience model for the Indonesian ferronickel industry was created and developed with the help of Powersim Studio 10 software.

Model verification is the process of determining whether there are errors in the structured model in the software. Powersim Studio 10 has a feature to automatically identify the presence of errors in the model and demands a consistency of dimensions in the model so that the model can run without any problems. As a result, the model can run well in this study, which means the model in this study has been tested and verified. Model validation assesses whether the created model can provide a correct picture of a system and the resulting output. Validation is done by testing the model with six validity tests. The validity test consists of the adequacy of limits shows that the constructed model fits its purpose to study the impact of government policies, natural disaster and supply chain resilience of nickel industry as explain in the system diagram (see Figure 3). The structural assessment test validation explain that the constructed model has valid because the SFD has represented CLD as its can be seen from its loop. The dimensional consistency test validation is valid along with Powersim figure that will give red hashtag if the SFD's dimension is inconsistency. The historical data test validation compares historical data with the simulation output that shows the same pattern. Extreme condition tested demand ore domestic variable behavior by modified into 4 times more, then the model is valid because it still shows the same behavior. The integration error tes of model is valid from the time steop used (15; 7,5 and 3,75 days). The model given nonsensitive to time step test. Based on some of these tests, the model's results can provide a correct picture of the system and the output results.

Scenario Analysis of Supply Chain Resilience Ferronickel Industry

In supply chain resilience, vulnerabilities or disruptions can disrupt an industry's supply chain, both definite and uncertain disruptions that will occur in the future. In the short term, disruption generally has a relatively low impact. However, a more in-depth analysis is necessary for the long term to make more effective strategies and policies for future implementation.

The planned supply chain resilience model for the Indonesian ferronickel industry is over a reasonably long period, from 2010 to 2040, or the equivalent of 30 years. Therefore, in addition to the need for a robust model, it is also necessary to consider the future problem. This model will help decision-makers to explore future possibilities to produce better policy and strategy formulations [21].

Scenario planning is one of the approaches used to examine what could happen in the future. Scenario planning has a focal point to study phenomena that occurred in the past and explore the present to understand what will happen in the future.

Scenario design identifies alternative disruptions and capabilities of the Indonesian ferronickel industry's supply chain resilience model. Table 1 shows the disruption alternatives and the capabilities of this research problem.

Based on Table 1, several disruptions occurred in the supply chain of the Indonesian ferronickel industry. The first disruption is the ban on nickel ore exports. The enactment of the mandate of Law Number 4 of 2009 concerning mineral and coal mining contains a policy prohibiting the export of nickel ore. It stipulates that the ore must be processed first in Indonesia. The ban on nickel ore exports has been in effect since 2014. However, in early 2017 the Minister of Energy and Mineral Resources Regulation No. 5 of 2017 was issued. The regulation allows the sale of nickel ore abroad if a smelter is being or has been built [2]. Thus, nickel ore exports are tightening between 2014 and 2016 to 100%. However, from 2017 to 2019, the tightening began to be relaxed and reduced to 70%. The latest regulation is the Minister of Energy and Mineral Resources Regulation Number 25 of 2018 concerning Mineral and Coal mining concessions, which limits nickel ore exports to only 30% until 2022 [2]. Based on this, the authors designed an alternative scenario for disrupting the export ban on nickel ore with a low-level tightening of 70% and a high level of 100%.

Table 2. Scenario design

Scenario	Disruption			Capability			
	Nickel Ore Export Ban (B)	Ore and Ferronickel Demand (D)	Disruption Year	Diversity of Mine Supply (MD)	Processing Facility Capacity (PD)	Nickel Ore Redundancy (R)	Capability Year
Base Model	Export ban tightened in 2014-2016 (100%)	Fixed	2010 - 2019	Fixed	Downstream Industry in 2013-2019	0	2010 - 2019
Scenario 1	High	-	2020-2040	Fixed	Fixed	0	2020-2040
Scenario 2	Low	-	2020-2040	Fixed	Fixed	0	2020-2040
Scenario 3	-	High	2025-2035	High	High	High	2020-2040
Scenario 4	-	Low	2025-2035	Low	Low	Low	2020-2040
Scenario 5	High	High	2020-2040	High	High	High	2020-2040
Scenario 6	High	Low	2020-2040	Low	High	Low	2020-2040
Scenario 7	Low	High	2020-2040	High	Low	Low	2020-2040
Scenario 8	Low	-	2020-2040	Fixed	High (10x)	0	2020-2040

The second disruption is the increasing demand for ore and ferronickel. As previously noted, Indonesia is ranked first in the world's nickel producer contribution of 37% [1]. In addition, one of the world's leading electric car brands estimates that the world's demand for electric cars will increase by 50% yearly. This 50% increase in demand for electric cars is likely to increase over time up to 100%, which causes the world demand for nickel ore to increase [2]. Based on this, the authors design an alternative scenario of disrupting world nickel ore demand with a low-grade increase by 50% and a high-grade increase by 100%. Several alternative capabilities occur in the supply chain of the Indonesian nickel industry. The first alternative is the diversity of the mine supply. For example, some mining companies have Mining Business Permits (IUPs) in Indonesia and apply a flexible system that all mining companies can supply to any processing company in Indonesia. This mining company's supply diversity strengthens the supply chain because it relies not on one supplier but on multiple suppliers. Based on this, the authors design alternative scenarios for the capability of mining supply diversity with a low-level decrease of 10% and a high-level increase of 30%.

The second capability is the processing facility's capacity. Since the banning of nickel ore exports policy, the government has implemented the obligation to process and refine raw minerals in the country. This obligation is to increase the mineral's added value to achieve economic independence and promote national downstream industries that can support the national economy in the future. From 2010 to 2015, the ferronickel processing capacity was still below 24,000 tons. However, due to the industrial downstream implementation, which impacts the capacity increase, ferronickel processing in 2016 reached around 27,000 tons of Nickel, an increase of 10% from 2015. Then downstream continued to be intensified until 2018, reaching around 100,000 tons and slowly increasing by 30% yearly. Based on this, this study design alternative scenarios on the capability of

processing facility capacity with a low level of 10% increase and a high level of 30% increase.

The third capability is the existence of redundancy. Redundancy is a form of a component or product backup to increase the actual system performance. In other words, redundancy is a kept reserve stock used to anticipate disruption.

The next step after determining the disruption and capability alternatives is to design a scenario. Finally, the scenario design is prepared based on the disruption alternatives and predetermined capabilities, as shown in Table 2.

Based on Table 2 regarding scenario design shows that there are eight designed scenarios. This scenario combines disruption, disruption year, capability, and capability year. Disruption consists of banning nickel ore exports and demand for ore and ferronickel, and the Capabilities include the diversity of mine supply, processing facility capacity, and nickel ore redundancy. The year of disruption and capability differ depending on the case experienced. In the basic model itself, the only disruption that occurred was the ban on nickel ore exports, which tightened 100% from 2014 to 2016, then downstream, which began to grow from 2013 to 2019.

The demand backlog is the supply's inability to meet demand. Based on Figure 7, regarding the demand for nickel ore backlog, shows that from 2010 to 2040, all scenarios have a demand for nickel ore backlog that continues to increase every year. In the basic model shown in blue, the authors assume the export ban was tightened by 100% from 2014 - 2016, decreased to 70% in 2017 - 2019, and increased to 98% from 2020-2040. Furthermore, the carried out downstream in 2013-2040 has experienced a constant increase since 2019. Therefore, in the basic model, it can be seen that the demand for nickel ore backlog has occurred but is insignificant; in 2040, it will reach around 20,000,000 tons of nickel ore.

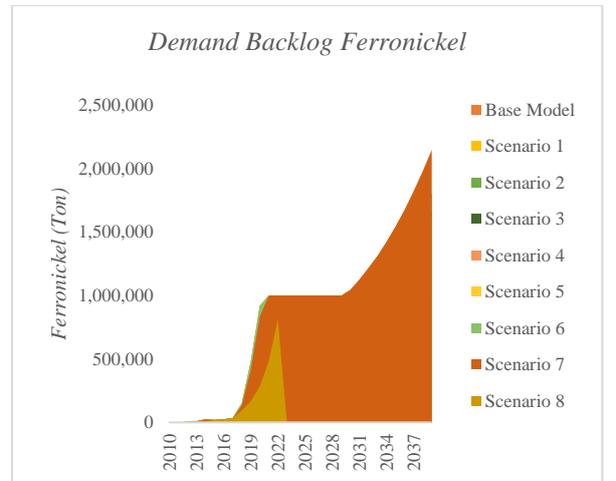
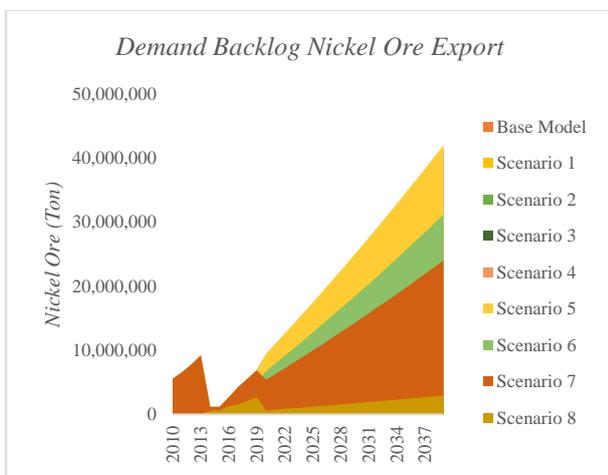
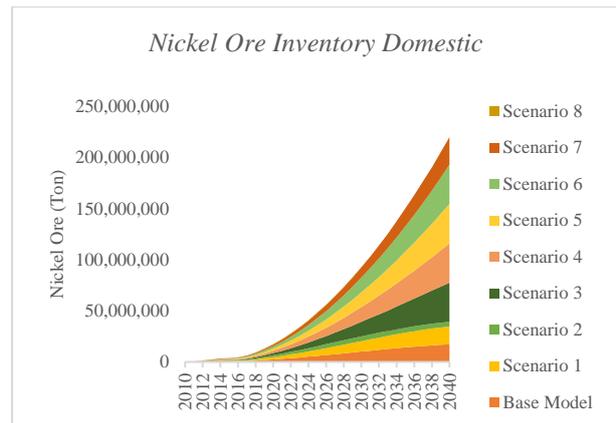
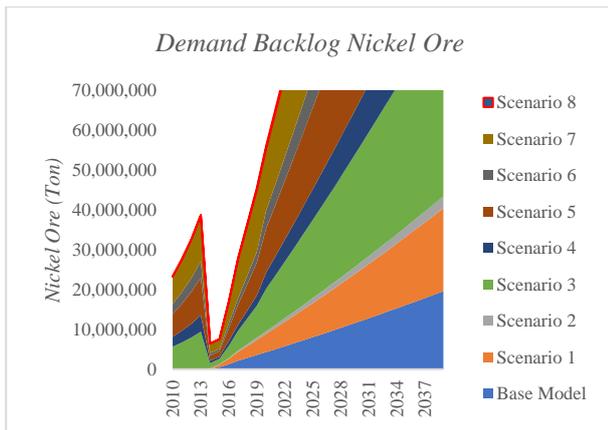


Figure 7. Scenarios on demand backlog Nickel Ore and demand backlog Nickel Ore Export

Figure 8. Scenarios on Nickel Ore inventory domestic and demand backlog Ferronickel

Scenario 1 has results that are close to the basic model because scenario one only adds disruption in the form of a ban on nickel ore exports which is tightened to 100% in 2020 to 2040, which is pretty close to the created basic model. Scenario 1 shows that the demand for nickel ore backlog in 2040 will reach around 20,000,000 tons of nickel ore. Scenario 2 has a demand backlog for nickel ore which is relatively small, less than the basic model or scenario 1. Scenario 2 is where the designed scenario is export ban is reduced by 30% from scenario one or equivalent to a tightened 70% from 2020 to 2040. In scenario 2, the demand for nickel ore backlog has occurred but is insignificant; in 2040, it will reach around 3,000,000 tons of nickel ore. Scenario 8 has a minor demand backlog because there are two disruptions, namely a ban on nickel ore exports, with only tightened by 70%, and an increase in demand for ore and ferronickel by 50%. Ferronickel increased ten times to reduce the demand backlog significantly. In scenario 8, the demand for nickel ore backlog in 2040 will reach around 2,900,000 tons of nickel ore, which has a minor demand backlog among all scenarios and basic models. This result is because the domestically produced nickel ore is also exported. The demand

backlog also occurred in nickel ore exports due to the implementation of the policy to ban nickel ore exports. Due to the export ban policy that has not matched the domestic downstream capabilities, the domestic nickel ore inventory will increase, as shown in Figure 8.

The graph in Figure 6 about domestic nickel ore inventory shows that all scenarios have domestic nickel ore inventory, which continues to increase yearly. The basic model shows that domestic nickel ore inventory has occurred but is not significant; in 2040, it will reach around 17,000,000 tons of nickel ore.

Scenario 1 has results that are close to the basic model because scenario one only adds disruption in the form of a ban on nickel ore exports which is tightened to 100% in 2020 to 2040, which is not too far from the created basic model. As a result, scenario 1 shows that domestic nickel ore inventory in 2040 will reach around 17,200,000 tons of nickel ore. On the other hand, Scenario 2 shows that domestic nickel ore inventory has occurred but is not significant; in 2040, it will reach around 4,700,000 tons of nickel ore.

Scenario 8 has the smallest domestic nickel ore inventory, and this is because there are two disruptions, namely a ban on nickel ore exports, tightened only by 70%, and an increase in demand for ore and ferronickel by 50%. However, with capabilities supporting only specifics in scenario 8, the ferronickel processing capacity increases ten times to reduce demand backlog significantly. Therefore, Scenario 8 shows that domestic nickel ore inventory in 2040 will reach around 0 tons of nickel ore, which has the smallest demand backlog among all scenarios and basic models.

In the ferronickel demand backlog graph, all scenarios have a demand backlog that continues to increase yearly. The basic model shows that the demand for ferronickel backlog has occurred but is insignificant; in 2040, it will reach around 1,000,000 tons of ferronickel. Scenario 1 shows that the demand for the ferronickel backlog in 2040 will reach around 1,000,000 tons of ferronickel. Scenario 2 reaches around 1,800,000 tons of ferronickel. Finally, scenario 8 has the smallest demand backlog reaching 0 tons in 2040.

Conclusion

This study develops a system dynamics model in the ferronickel industry in Indonesia. The system dynamics model starts by building a conceptual model through a system diagram in which there is a Causal Loop Diagram, then proceeds with developing a quantitative stock flow diagram (SFD) model. Finally, this study carried out this SFD model with several scenarios usable as policy suggestions for the Indonesian government.

The designed supply chain resilience policy for the Indonesian nickel industry needs to be as effective to benefit all parties, including the government, mining companies, processing companies, domestic consumers, and export consumers. Moreover, Indonesia is the first nickel ore producer in the world, which is rich in nickel content, so an effective policy is needed.

The study aims to examine the impact of Indonesian government policies on the nickel industry supply chain's resilience with the indicator of minimizing the demand backlog. Based on the results of the carried out scenarios and analysis, Scenarios 1 to 7 produce a reasonably high demand backlog. However, in scenario 8, the demand backlog can be minimized. This happened due to the scenario by choosing an export ban policy that is only tightened by 70% and increasing the ferronickel processing capacity to 10x the base model. The chosen 10-fold increase is because scenarios 1 to 7, with an alternative capacity of ferronickel processing facilities that only reached 30%,

could not reduce the demand for the ferronickel backlog. In addition, with only 30% additional capacity, the domestic nickel ore inventory becomes High due to the processing facilities' inability to accommodate and process the nickel ore into ferronickel. Therefore, this increase will harm mining companies due to domestic oversupply.

Based on this, the study proposes a new policy for the Government of Indonesia, especially the Ministry of Energy and Mineral Resources, in the Nickel industry for 2020 to 2040. First, the government has to formulate a policy for the nickel ore export ban that only tightened by 70% and increased ferronickel processing capacity to 10 times. The Indonesian government also needs to loosen the export ban as long as Indonesia has yet to reach its maximum downstream capacity to overcome the demand backlog. Finally, the government needs to support and intensify the industry downstream to increase the ferronickel processing capacity to 10 times to resolve the oversupply problem.

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