J. Eng. Technol. Sci., Vol. 54, No. 5, 2022, 220504

Analysis of the Copper Industry Chain in Indonesia Using a System Dynamics Approach to Optimize Its Added Value

Atika Rahmahwati[1,*], Arjo Prawoto Wibowo[1,2] & Fadhila Achmadi Rosyid[1,2]

[1]Master Program Department of Mining Engineering, Faculty of Mining and Petroleum Engineering, Institut Teknologi Bandung, Jalan Ganesa 10, Bandung 40132, Indonesia
[2]Centre of Research Excellence Policy and Economics of Minerals and Coal, Faculty of Mining and Petroleum Engineering, Institut Teknologi Bandung, Jalan Ganesa 10, Bandung 40132, Indonesia
*E-mail: atika.rahmahw@gmail.com

Highlights:

- This research addresses the interactions of variables using a causal loop diagram and quantitatively determined the added value using a stock and flow diagram.
- The developed Indonesian copper industry chain model has four subsystems: mining, smelting and refinery, intermediate industries, and consumption.
- The added value was calculated from the total profit obtained from mining, smelting, and intermediate industry subsystems.

Abstract. Indonesia is a leading producer of a wide range of minerals, including copper. Nonetheless, the copper-based industry in Indonesia is still not well developed, especially the limited number of products from the intermediate copper industry which will become raw materials for its downstream industry. The underdeveloped intermediate copper industry has forced Indonesia to import several types of copper-based semi-finished products to meet the needs of the downstream industry. On the other hand, the mining industry still exports copper concentrate and some copper cathodes produced by smelting. As a result, the added value obtained by Indonesia from copper is not optimal. Therefore, it is necessary to conduct research on the copper industry chain and to estimate the increase in added value that could be generated. In this study, a system dynamics (SD) model was developed. During the simulation period of 2020 to 2030, the total added value along the copper industry chain that can be obtained is USD 70,422,840,000 if the planned smelter and refinery is completed in 2023 to process all domestic concentrates and to increase intermediate industry capacity.

Keywords: *added value; copper industry chain; intermediate industry; system dynamics; value chain.*

Received March 9th, 2021, 1st Revision August 19th, 2021, 2nd Revision February 2nd, 2022, 3rd Revision March 29th, 2022, Accepted for publication May 12th, 2022.
 ISSN: 2337-5779,
DOI: 10.5614/j.eng.technol.sci.2022.54.5.4

.

1 Introduction

Copper, a transition metal element with atomic number of 29, is a metal that is essential to our daily lives. It has high electrical and thermal conductivity, malleability, ductility, and high endurance towards corrosion. According to the International Copper Study Group [1], the proportion of copper used for electrical cables reaches 60% of the world's total copper usage, 20% for pipes and roofing materials, 15% for industrial machinery, and 5% for alloys such as brass (Cu- Zn) and bronze (Cu-Sn). According to the United States Geological Survey [2], Indonesia has the world's seventh-largest copper reserve, contributing 3% of the total copper reserve in the world. However, as a non-renewable natural resource, the amount of copper is limited, so it needs to be well-managed in order to be beneficial for the nation.

Indonesia's copper ore reserves tend to decline. In 2019, Indonesia possessed 2,631.6 million tons of copper ore reserves, the lowest level in the past ten years [3]. Copper ore is domestically processed into copper concentrate. Then, the concentrate is smelted and refined to produce copper cathodes with a purity of 99.99% and by-products. At present, the capacity of domestic copper smelters is only capable of processing one-third out of the total national copper concentrate production, while the rest is exported [4]. Furthermore, the export of concentrate and anode slime is still permitted for a maximum period of three years after Law No. 3/2020 came into force.

Copper cathodes are further processed to produce semi-finished goods by the intermediate industry. Currently, the domestic intermediate copper industry only absorbs 40 to 50% of the total national copper cathode production [5]. The domestic demand for copper cathodes is related to producing copper wire for cables, while several types of copper-based semi-finished products, such as slabs, billets, and powder are still imported due to the underdevelopment of the intermediate copper industry [4]. With the current condition of the industrial chain, the goal of increasing the added value of minerals as stated in PP 23/2010, among others, in order to ensure the availability of domestic industrial raw materials cannot be achieved.

With respect to the added value of copper as a commodity, this study aimed to estimate the value added of the domestic copper metal industry chain. In order to achieve this aim, a system dynamics (SD) model of the copper industry chain was used to represent the supply and demand conditions for the commodity of copper in Indonesia. This approach was selected because it can explain the complex structures and behaviors in the copper industry chain. The model that was built produced an estimate of the economic value added for several scenarios.

2 Literature Review

2.1 Copper Industry Chain in Indonesia

The copper industry chain can be divided into three parts, namely upstream industry, intermediate industry, and downstream industry. The structure of the copper industry is summarized in Figure 1, based on the process flow.

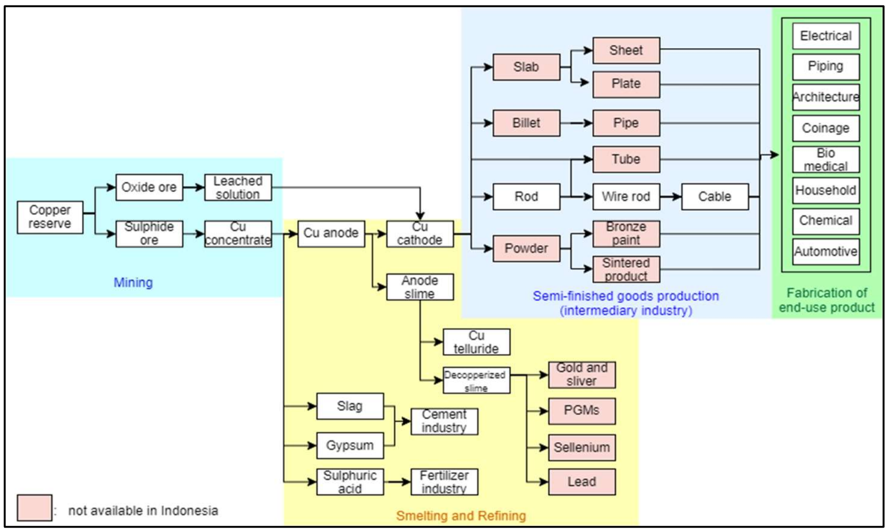

Figure 1 Copper industry chain in Indonesia [4,6].

2.1.1 Upstream Industry

Copper mining in Indonesia is closely related to the business activities of PT Freeport Indonesia (PT FI) in Papua and PT Amman Mineral Nusa Tenggara (PT AMNT) in West Nusa Tenggara as the largest copper mining companies in the country. Both companies mine and process copper sulphide ore to produce copper concentrate [7,8]. Concentrate products are marketed abroad and to one domestic copper smelter and refinery, namely PT Smelting. In the smelting and refining process, not only copper cathodes with a purity of 99.99% are produced but also some by-products. By-products such as sulfuric acid, copper slag, and gypsum, are sold on the domestic market while by-products in the form of copper telluride and decopperized slime are exported [5]. With the ban on selling certain unrefined metal mineral products abroad in 2023, as mandated in Law no. 3/2020 concerning the Amendments of Law No. 4/2009 concerning Mineral and Coal Mining, smelting and refinery industries are supported to continue developing, as well as precious metal refinery (PMR) industries.

.

2.2 Intermediate Industry

Half of the total domestic copper cathode production is processed by the domestic intermediate industry and the rest is exported. Ironically, even though Indonesia is able to process copper cathode products, the copper wire cable industry still imports copper cathodes. This happens because large quantities of imported copper cathodes have lower prices following trade liberalization and due to business ties between domestic producers of copper-containing goods and overseas suppliers [9]. Currently, in Indonesia there are only industries that process copper cathodes into copper wire, while industries that produce copper in the form of sheets, slabs, plates, foil, pipes, tubes, whether pure or alloyed, do not exist in the country. As a result, Indonesia imports these copper-based semi-finished goods. This indicates that there are still missing links in the copper industry chain [4].

2.3 Downstream Industry

Copper is a metal that is very useful in everyday life. This metal has the highest electrical conductivity when compared to other metals, except for pure silver. Copper is used in electrical cables rather than silver because it is cheaper. In addition, copper also has good heat conductivity properties and corrosion resistance. Therefore, copper is used for electronic applications, industrial machinery, and is also one of the materials of choice in the construction sector, especially for pipes and roofs.

2.4 System Dynamics

In the mid-1950s, Jay W. Forrester introduced system dynamics (SD), which is used to analyze complex behavior in the social sciences, particularly in management, using computer simulations. In the formation of an SD model, it is essential to arrange the factors that are considered influential within the system by way of a causal loop diagram (CLD). Every causal relation consists of causal links (arrows) that indicate the cause and effect between variables, polarities (+ and – signs), and delay signs (||).

Each loop inside the diagram is either positive feedback (strengthening) or negative feedback (balancing). The system conceptualization based on causal loop diagrams was further developed using a stock and flow diagram (SFD). Subsequently, the stock illustrates the system condition at a certain time, while the flow signifies how high the stock's rate of change is [10,11].

An SD model has been used by Sverdrup, *et al*. [12-14] to model the trading market for metal commodities such as global copper, zinc and nickel. Meanwhile Huang & Yin [15] used an SD model to analyze the supply and demand of water resources. In addition, several scenarios were simulated using the copper material flow model by Glöser, *et al*. [16] based on the SD approach to improve resource efficiency. In Indonesia, Hanafi, *et al*.[17] have conducted research to explore the complexity of the smelter industry in Indonesia by building a conceptualization of the system and revealing ways to increase competitiveness. Based on our literature review on SD and the copper industry chain, using SD for the supply chain and demand of copper in Indonesia is a novelty of this research.

3 Methodology

Secondary data were obtained from the Ministry of Energy and Mineral Resources and Industry, Statistics Indonesia, and company annual reports. The Vensim software was used to describe the CLD and SFD so that the model could be drawn and used for simulation. The model was used to represent the structure and behavior of the system's past (2001 to 2019) and to assess the model's performance with the Mean Absolute Percentage Error (MAPE) test. Lewis [18] stated that MAPE is the most useful measure for comparing the approximate accuracy of relative performance measures. When the model's performance is satisfactory (MAPE less than 10%), then the model can be used to simulate what may happen in the future (2020 to 2030).

SD models have controllable and uncontrollable inputs as well as desired and undesirable outputs. Inputs that can be controlled through government control, among others, are export and import permits for copper products. In this case, exports can be carried out only if domestic industrial needs have been met, while imports can be carried out if domestic production is smaller than national demand.

The desired outputs include increased absorption of concentrated domestic products, copper cathodes, lowered import of copper-containing semi-finished products, as well as increased economic added value obtained by Indonesia along with growth of the copper industries. Meanwhile, in the SD model of the national copper industry chain, some inputs are not controllable, such as the population growth rate and the level of consumption, and undesirable outputs, such as fluctuations in commodity prices.

The parameter used to evaluate the system's performance was added value. The added value of the copper industry chain was calculated from the total profit (gross profit) obtained from the mining, smelter, and intermediary copper industries, while deducting expenses for imports of semi-finished copper goods. Further, the copper grade in the concentrate has decreased from year to year. This is one of the factors that reduce the production of copper cathodes. In order to increase the production of copper cathodes along with a decrease in concentrate

.

production, smelting utilizes copper scrap. However, the recycling aspect was not considered in detail in this study.

3.1 Model Conceptualization

The structure of the copper industry chain in Indonesia is illustrated by a CLD in Figure 2. The copper ore reserve variable has a negative feedback relationship (B1 loop) with the Cu ore production variable from mining activities. The constructed model explains that the main booster mechanism of mining activities is driven by profit and the availability of reserves. Further, the revenue of the mining industry will increase when the commodity selling price and the amount of mining ore also increase, and it is balanced with the operating cost (B2 loop). The operating cost is decided by two factors, energy price and ore grade.

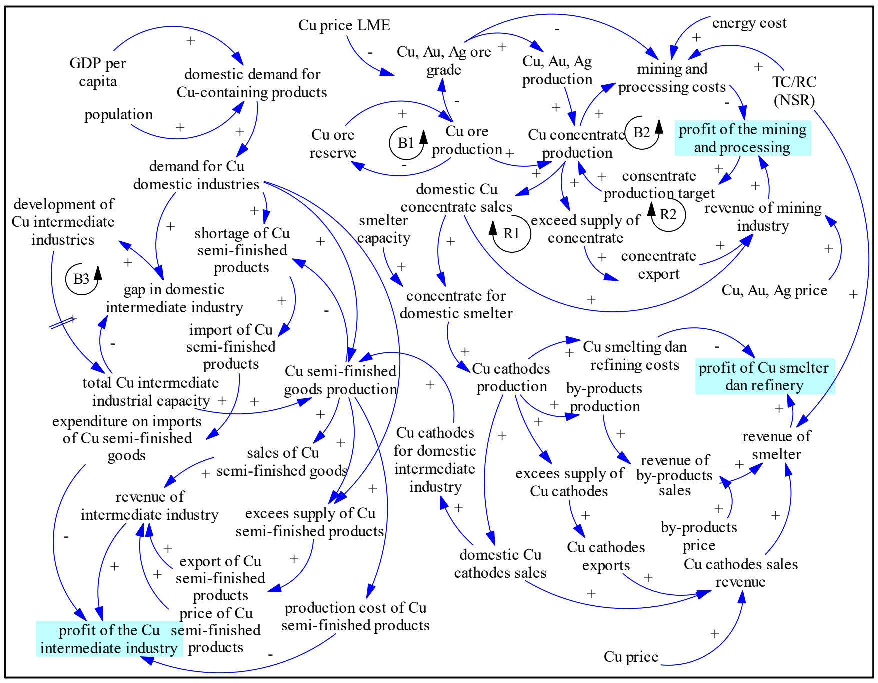

Figure 2 Causal loop diagram (CLD) of the copper industry chain.

The lower the grade, the more rocks need to be moved in order to gain metal minerals. The impact is that the commodity prices have to be higher than the production cost for the mining production level to be maintained. Furthermore, when the demand for copper-containing products in the country increases, the intermediate copper-industry capacity needs to be increased. Additional capacity is calculated from the production capacity gap, which is the difference between the estimated domestic demand for copper and the actual industrial capacity (B3 loop). The addition of intermediate industrial capacity depends on the rate of investment. However, the factors of investment attractiveness were not further considered in this study.

3.2 Model Formulation

Model formulation is the process of changing the system concept or model structure that has been compiled into equations or computer language using an SFD. The formulation of the model aims to allow the model to be simulated and determine the dynamic behavior caused by the assumptions of the model. These equations were developed based on the logical relation that occurs among the variables it contains related to the four subsystems of the national copper industry chain.

Mining activities can be carried out as long as ore reserves are still available. In the mining subsystem (Figure 3), copper ore reserves are assumed to have increased by an average of 4% per year from 2001 to 2008. After 2008, the reserves continued to decline due to mining activities, while no new reserves were discovered. The average amount of additional copper ore reserves in Indonesia is obtained from USGS and the Geology Agency [2,3].

Copper ore reserves in 2008 stood at 4,299 million tons. Using an average growth rate of 4%, the initial simulation value of the ore reserves in 2001 was 3,326.71 million tons. Apart from being affected by the availability of reserves, the level of copper ore production is also influenced by several other conditions, from strikes of workers to the destruction of factory facilities, which brought about decreased production in 2011 and 2012. The strike action variable was given a value of 0.8; when this is in normal condition, it is given a value of 1.

Furthermore, concentrate production for export has decreased as much as the sales of copper concentrate abroad with a grade of more than 15%, which are subject to progressive export duty rates in accordance with the Minister of Finance Regulation Nr. 6/PMK.011/2014. Additionally, the transition period from open-pit mining to underground mining as well as the development of a new phase resulted in the decrease of the copper production target in 2019 [7,8]. When copper concentrate is sold by the mining company to a smelter, the smelter pays the copper, gold, and silver contained in the concentrate, which is then reduced by processing and refining costs (TC/RC).

.

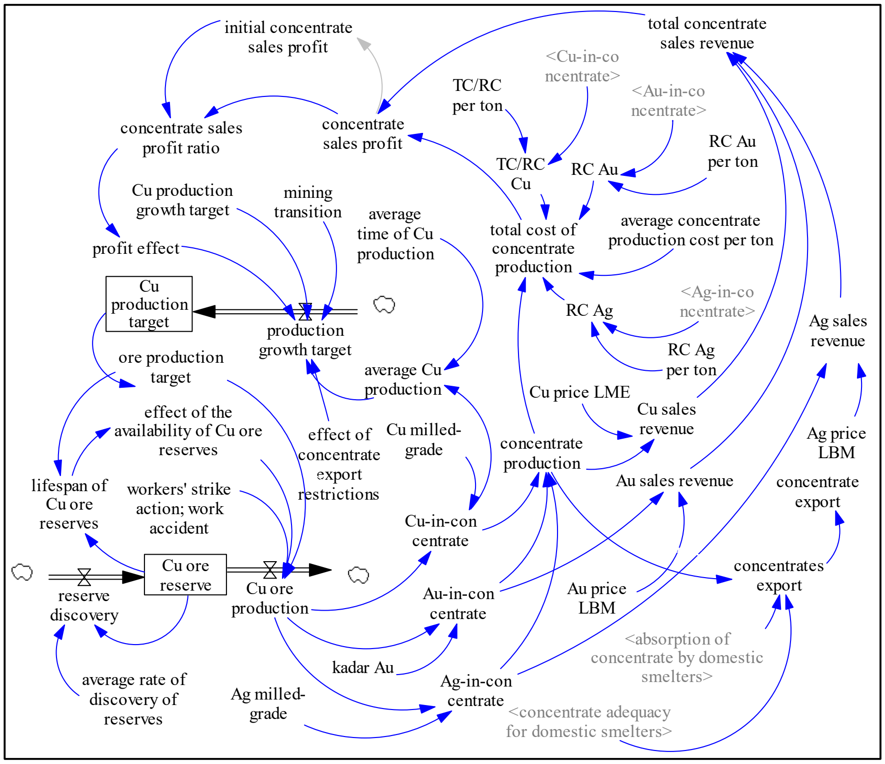

Figure 3 Stock and flow diagram (SFD) of the mining subsystem.

The smelting and refining subsystem (Figure 4) determines the level of copper cathode production for domestic and export purposes, along with the level of production of by-products. The amount of copper cathode produced is obtained by multiplying the copper content in the concentrate with the tonnage of the concentrate processed, where the dynamics are described by the level of smelter utility. Then the revenue from the smelter and refinery is obtained by the sale of copper cathodes and by-products. In addition, the construction of a new smelter and refinery with an input capacity of 3.3 million tons of concentrate is expected to reach completion in 2023.

In this research model, intermediate industries being developed are the sheet and bar copper industry and the wire rod industry. Later, from the intermediate industrial subsystem (Figure 5), the production level of semi-finished goods containing copper can be found; the sale of these goods is to satisfy domestic and export demand. Moreover, the expansion structure of the sheet and bar copper industry in this model was developed to meet domestic demand and does not consider demand from abroad. In addition, the copper bar and sheet industry will develop based on the increasing rate of capacity calculated from the production capacity gap divided by the estimated construction time of the industry. In the intermediate industry producing wire rod, there is no gap between the demand for cable wire raw materials and the industrial capacity [19]. Hence, the development of the wire rod industry in this model is influenced by the assumption of an increasing rate in wire rod industry capacity.

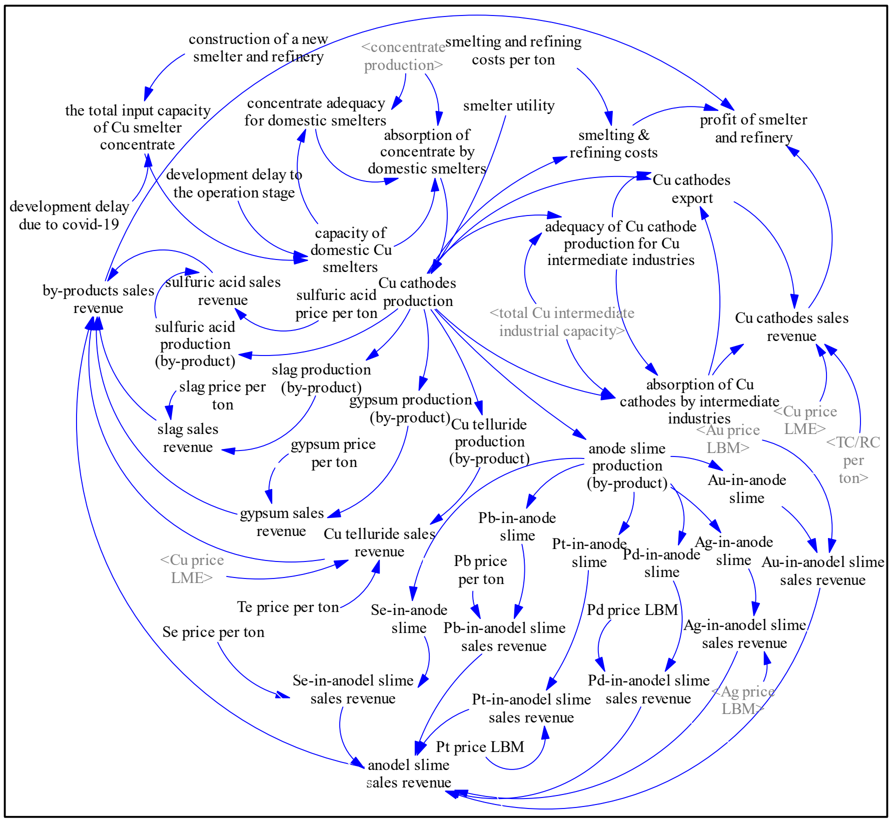

Figure 4 SFD of the smelter and refinery subsystem.

In the consumption subsystem (Figure 6), the level of copper consumption in this model is affected by population size and per-capita copper consumption. Two important factors influencing population dynamics are births and deaths. The birth and death rates of the population integrate the crude birth rate and the crude death rate obtained from the World Bank [20]. The average crude birth rate for the population in Indonesia is 20.6 per 1,000 population while the average crude death rate is 6.82 per 1,000 population.

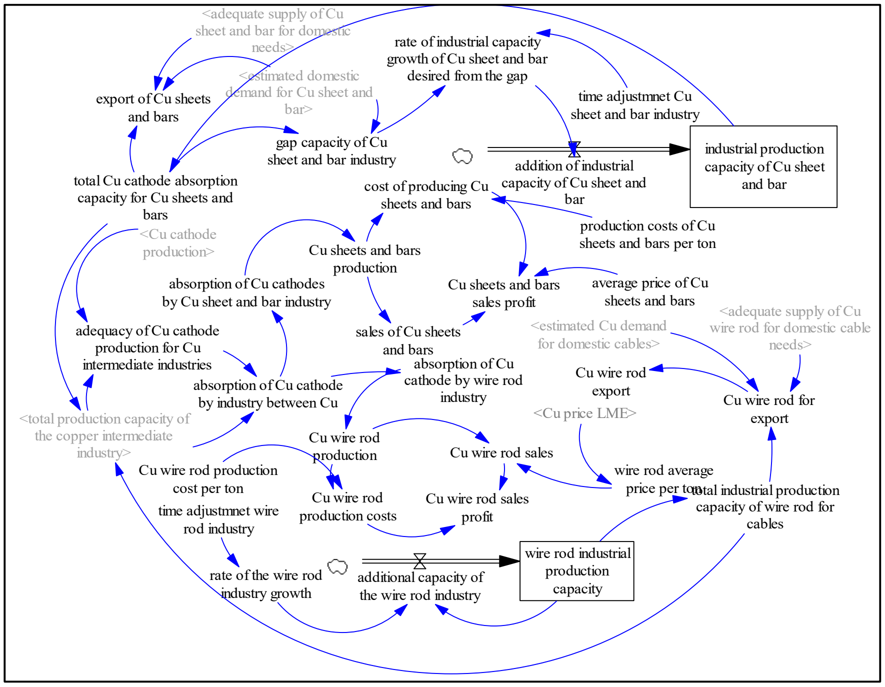

Figure 5 SFD of the intermediate industry subsystem.

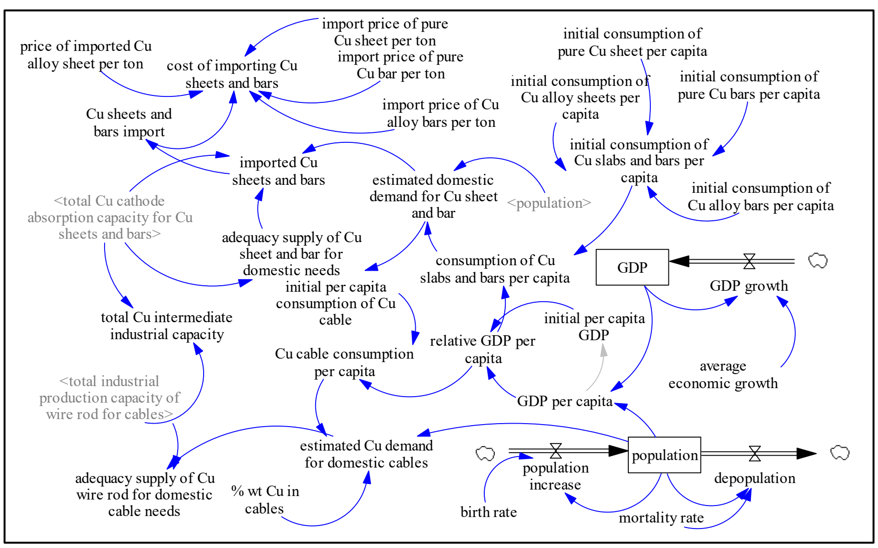

Figure 6 SFD of the consumption subsystem.

3.3 Model Testing

In this study, the variables tested were copper ore production, concentrate production, copper cathode and wire rod production. The historical data pattern of these four variables could be captured well by the model (Figure 7 (a-d)) with MAPE smaller than 10%.

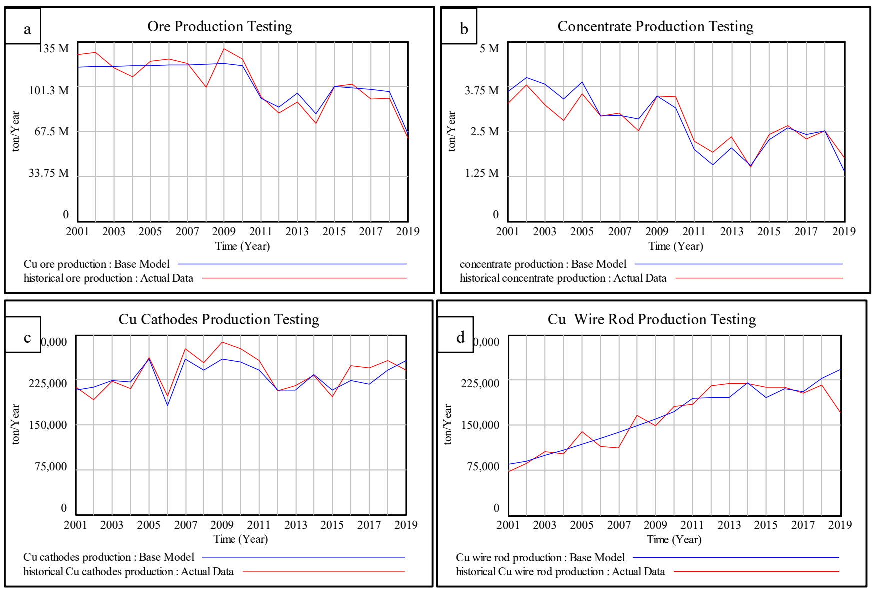

Figure 7 Comparison of historical data with simulation results: (a) ore production MAPE 5.86%, (b) concentrate production MAPE 8.12%, (c) copper cathode production MAPE 5.52%, and (d) wire rod production MAPE 9.92%

4 Result and Discussion

4.1 Mining Subsystem

The model was used to forecast future production levels from 2020 to 2030. In the ore production variable, after ore production decreased in 2019 due to the mining transition period, the national copper ore production will experience growth from 2020 to 2022, assuming a growth of 23% per year. In 2022, ore production will be at optimal capacity. The increase in ore production will have an effect on the level of copper concentrate production, as shown in Figure 8(a). An increased and optimal level of concentrate sales in 2022 will affect the profits derived by the mining subsystem (see Figure 8(b). The profit from selling concentrate is influenced by the total sales revenue and the concentrate production costs. In the period from 2001 to 2019, the highest profit was achieved in 2010 because the highest total revenue from sales of concentrate was in that year. The total sales revenue of concentrate is influenced by the price of copper on the London Metal Exchange (LME) and the price of gold and silver refers to the London Bullion Market (LBM), as well as prices in the forecast period in this study, using prices based on the World Bank [21].

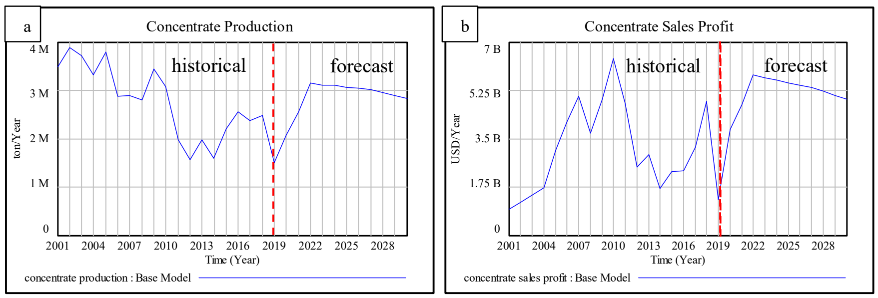

Figure 8 Simulation results for the period from 2001 to 2030: (a) copper concentrate production and (b) profit from concentrate sales.

4.2 Smelter and Refinery Subsystem

Figure 9(a) shows the profits of the smelter and refinery subsystems. If there is no additional smelting and refinery capacity, the absorption rate of domestic copper concentrate will not increase, thus there will be no increase in copper cathode production either. Moreover, the level of wire rod production also will not change, even though the capacity of the wire rod factory is still capable of processing copper cathodes. When the export of concentrate is still carried out, there will be no increase in added value along the copper industry chain.

4.3 Intermediate Industry Subsystem

In 2019, the capacity of the copper wire rod producing industry was at 500,000 tons per year, and with the current production level, the domestic demand for copper wire could be achieved, and the rest was exported [19]. Based on the simulation results, the production of wire rods in 2019 was at 242,198 tons. With the number of copper cathodes as raw material for the wire rod industry not changing, the production of wire rods will not change significantly either. This will affect the profits obtained from the wire rod subsystem; a slight increase will occur due to an increase in wire rod prices by around 1% per year until 2030, as shown in Figure 9(b).

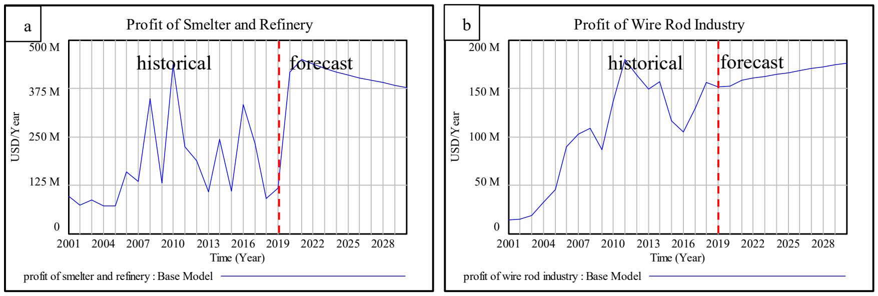

Figure 9 Simulation results for the period from 2001 to 2030: (a) the profits of smelters and refineries and (b) the profits of wire rod production.

4.4 Scenario Analysis

Referring to the objectives and model structure, there are variables that can be used to analyze the effects of controllable changes in the input. In this study, the variable is the rate of increasing smelting and intermediate industrial capacity. Three scenarios were developed to analyze the behavior of the copper industrial chain system until 2030. The Business as Usual (BaU) scenario is a basic model in which the state of the system is without intervention. In addition, the condition of the system was also developed with the scenario of adding smelting and refinery capacity in accordance with the plans of the Ministry of Energy and Mineral Resources and the Ministry of Industry (first scenario) and the scenario of increasing the capacity of the wire rod producing industry to process national copper cathodes in line with the development of the intermediate industry to produce sheet and bar copper (second scenario).

In the final year of the simulation (2030), the first scenario generates an added value of USD 6,370,210,000, an additional 16.32% compared to the added value obtained by the BaU scenario at USD 5,476,480,000. Further, from the simulation results for the second scenario, an added value of USD 6,592.7 million is obtained in 2030. This value is 3.49% greater than for the first scenario and 20.38% greater than the for the BaU scenario (see Figure 10).

During the period of forecasting (2020 to 2030), the total added value along the copper industry chain is USD 70,422,840,000, if smelters and refineries are built domestically to process all domestic concentrate. However, if no smelters and refineries are built domestically until 2030, concentrate will still be exported, which will result in a loss of added value from this chain of USD 6,861,520,000. If smelters and refineries as well as intermediate industries are not developed domestically, Indonesia will lose an added value of USD 8,707,930,000.

.

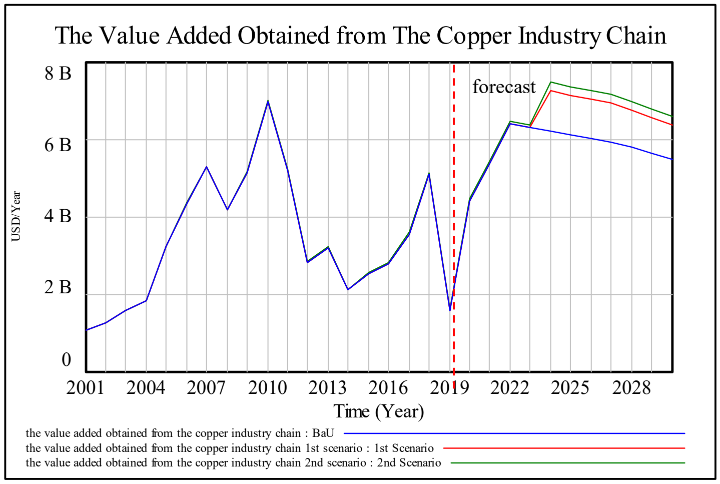

Figure 10 Added value obtained from the copper industry chain based on the three different scenario simulations.

Based on the simulation results, the increase in the capacity of the intermediate industry that produces sheet and bar copper and the capacity of the wire rod industry show an insignificant increase in added value. However, efforts to process copper metal minerals to produce finished products are essential and cannot be postponed, as copper ore is a non-renewable natural resource. The increase in added value will be even higher when this is followed by growth of copper-metal-based downstream industries for electricity, construction and transportation as well as other derivative industries. The downstream industry will be able to extend the domestic value chain so that will have a positive impact on the economy in the form of creating added value, creating more output, increasing employment, increasing state revenues, and mastering technology in mineral processing.

5 Conclusion

The copper industry chain model developed in this study consists of four subsystems, namely mining, smelting and refinery, intermediate industries, and consumption. During the simulation period from 2020 to 2030, a total added value along the copper industry chain of USD 70,422,840,000 will be obtained when the smelter and refinery are completed in 2023 to process all domestic concentrate. However, if no smelting and refinery industries are constructed domestically until 2030, concentrate exports will still be carried out. Hence, Indonesia will lose an added value of USD 6,861,520,000. In addition, Indonesia will lose an added value of USD 8,707,930,000, if smelters and refineries as well as intermediary industries are not developed domestically. Nevertheless, intermediate products are usually produced close to their customers, while mining and smelting operations are carried out near the source or in a supportive location. Therefore, the geographical presence of end users plays an important role. Moreover, copper recycling plays an essential role in the copper industry chain. The system dynamics model is limited to the aspect production from primary raw materials. Future research can consider aspects of copper recycling due to limited reserves and decreasing copper grade in the ore and/or concentrate.

References

[1] International Copper Study Group, *The World Copper Factbook*, Portugal, 2014.

[2] United States Geological Survey, *Copper Statistics and Information*, https://www.usgs.gov/centers/nmic/copper-statistics-and-information (9 Feb. 2020).

[3] Ministry of Energy and Mineral Resources – Geological Agency, *Executive Summary Update of Data and Mineral Resources Balance for 2019*, Jakarta, 2019.

[4] Ministry of Energy and Mineral Resources Indonesia, *Study of Minerals Supply and Demand*, 2012.

[5] PT Smelting, *PT Smelting: Copper Smelter and Refinery*, Gresik, 2019.

[6] Ministry of Industry, *Downstream of Mineral-Based Industry Development*, Jakarta, 2016.

[7] PT Freeport-McMoran, *Building on Strength*, Annual Report, 2019.

[8] PT Medco Energi Internasional, *40 Years Young, Annual Report*, 2019.

[9] Ministry of Industry, *Cost Benefit Analysis of the Export Prohibition of Minerba Raw Materials, and Its Impact on the Industrial Sector: Nickel and Copper Case Study*, 2012.

[10] Márquez, A.C., *Dynamic Modelling for Supply Chain Management: Dealing with Front-end, Back-end and Integration Issues*, Springer, London, 2010. DOI: 10.1007/978-1-84882-681-6.

[11] Sterman, J.D., *Business Dynamics-Systems Thinking and Modeling for a Complex World,* New York: Irwin McGraw-Hill, 2000.

[12] Sverdrup, H.U. & Ragnarsdottir, K.V., *On Modelling the Global Copper Mining Rates, Market Supply, Copper Price and the End of Copper reserves*, Resources, Conservation and Recycling, **87**, pp. 158-174, Jun. 2014. DOI: 10.1016/j.resconrec.2014.03.007.

[13] Sverdrup, H. U., Olafsdottir, A. H., & Ragnarsdottir, K. V., *On the Long-Term Sustainability of Copper, Zinc and Lead Supply, using a System Dynamics Model. Resources*, Conservation & Recycling, 4, May. 2019. DOI: 10.1016/j.rcrx.2019.100007.

[14] Olafsdottir, A. H. & Sverdrup, H. U., *Modelling Global Nickel Mining, Supply, Recycling, Stocks-in-Use and Price under Different Resources and*

.

Demand Assumptions for 1850–2200, Mining, Metallurgy & Exploration, **38**, pp. 819-840, Jan. 2021. DOI:10.1007/s42461-020-00370-y.

[15] Huang, L. & Yin, L., *Supply and Demand Analysis of Water Resources based on System Dynamics Model*, Journal of Engineering and Technological Science, **49**(6), pp. 705-720, Dec. 2017. DOI: 10.5614/j.eng.technol.sci.2017.49.6.1.

[16] Glöser, S., Soulier, M. & Tercero Espinoza, L.A., *Dynamic Analysis of Global Copper Flows. Global Stocks, Postconsumer Material Flows, Recycling Indicators, and Uncertainty Evaluation*, Environ. Sci. Technol., **47**(12), pp. 6564-6572, Jun. 2013. DOI: 10.1021/es400069b.

[17] Hanafi, M., Wibisono, D., Mangkusubroto, K., Siallagan, M. & Badriyah, M.J.K., *Designing Smelter Industry Investment Competitiveness Policy in Indonesia through System Dynamics Model*, Journal of Science and Technology Policy Management, 2019. DOI: 10.1108/JSTPM-06-2018-0064.

[18] Lewis, C.D., *Industrial and Business Forecasting Methods*, London: Butterworths, 1982.

[19] Association of Indonesian Cable Manufacturers, *Mapping of Supply and Demand for Copper Mineral Materials in the Cable Industry*, presented at the Webinar Downstream of Indonesian Copper, October 2020.

[20] World Bank, *Population, Total – Indonesia Data*, 2020. https://data.worldbank.org/indicator/SP.POP.TOTL?locations=ID, (8 Jun. 2020).

[21] World Bank, *World Bank Commodities Price Forecast*, 2020. https://www.worldbank.org/commodities (20 Nov. 2020)