Evaluation of economic and environmental impacts and the social preference for alternative resource security strategies in Japan

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Abstract

There are concerns, globally and at the national level for many countries, about the potential for future imbalance between supply and demand of various mineral resources. It is anticipated that the expansion of renewable energy will increase the demand for mineral resources, but on the supply side, there is a possibility of supply restrictions due to factors such as ore grade decline and climate change. A strategy for maintaining a stable supply of mineral resources is required in order to achieve a low-carbon society.

Unconventional resource development can be considered as one option for ensuring supply of mineral resources. Therefore, in this research, domestic unconventional mineral production including recycling and deep ocean mining was examined. This study puts forward a methodology to evaluate the environmental, economic and social impacts of domestic mineral production as alternatives to the conventional resource supply, and demonstrates the methodology with an evaluation based on technological and macro-economic data.

For countries which are currently dependent on importing raw materials, like Japan, producing minerals by recycling or deep ocean mining (hereinafter referred to as “domestic mineral production”) requires the establishment of domestic facilities for the upstream processes in the supply chain. The impacts of these upstream processes is unknown for Japan, thus evaluation of the theoretical domestic supply chain was conducted. In addition, the mining industry is generally regarded as an industry with high environmental impacts, and since the development requires the agreement of the entire community including the local residents, it is also necessary to investigate the stakeholders’ attitudes toward domestic mineral production.

This paper takes copper resources as an example, and conducted research for the purpose of evaluating the environmental, economic, and social impacts of domestic production of resources in Japan.

Chapter 1 describes the research background and summarizes the results of a literature review on domestic and global resource supply, resource security, and alternative mineral production methods.

Chapter 2 discusses the methodology proposed in this study. It explains the copper production method in this study, and also explains the assumptions for evaluating the impacts on the environment, economy, and society.

In Chapter 3, the material flow analysis, which is the bottom-up analysis method explained in Chapter 2, was applied to recycling and deep ocean mining. By quantitatively estimating the material flow for the supply chain including the upstream processes that would need to be established in Japan to support domestic mineral production, energy consumption, CO_2 emissions and waste streams were compared with the current resource supply system. As a result, it was shown that domestic mineral production of copper utilizing deep ocean mining and recycling reduces energy consumption and CO_2 emissions. It was also quantitatively shown that a recycling-oriented domestic

production method contributes to mitigating environmental impacts.

In Chapter 4, the impacts of recycling and deep ocean mining on society and economy were evaluated by a top-down method using extended input-output analysis, in which upstream processes for domestic production in Japan were added to the input-output table. As a result, it was shown that the economic multiplier effect per unit production value is smaller than that of other general manufacturing industries in both deep ocean mining and recycling. Furthermore, by estimating the amount of employment required for recycling and evaluating the impact on labor through input-output analysis, it was highlighted that promoting recycling under the current labor-intensive structure would require a very large labor force.

Chapter 5 examines resource acquisition strategies that could facilitate social acceptance, by investigating knowledge about deep ocean mining and preferences for resource acquisition strategies based on the results of a survey of citizens. The results of the questionnaire showed that the respondents living in Okinawa Prefecture, which is considered to be a promising site for the deep ocean mining, tend to support the development of deep ocean mining in Okinawa Prefecture more than respondents living in other prefectures. It was also shown that citizens tended to prefer recycling and the development of alternative technologies or materials, as means of securing resource supply. From these results, it is suggested that the development of deep ocean mining should have a structure which benefits the residents near the mining site, and outreach activities related to domestic mineral production need to be expanded.

In Chapter 6, based on the results obtained from this study, the effect of domestic production on resource security was measured with consideration of country risk and climate risk. It was suggested that recycle-oriented domestic mineral production contributes to improving resource security, but if climate risks such as large typhoons or heat waves follow an increasing trend in Japan, conventional supply systems will lead to more stable supply.

Chapter 7 summarizes the results obtained from this study.

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1. Introduction

Japan is a country that has widely been considered as particularly vulnerable to resource restriction, due to its heavy reliance on imported raw materials for fabricating metals to support its manufacturing export industries, with most of its historic mines having closed. For example, 100% of iron ore, copper, lead and zinc concentrates are imported (JOGMEC., 2017). These materials are processed into metals, from which a variety of products, such as automobiles, electrical and electronic equipment are produced. A certain proportion of these products are exported outside Japan, which leads to these metals not being 100% recoverable in the domestic material cycle by recycling. Japan has traditionally developed a range of strategies to improve resource security—including upstream development in resource-producing countries, recycling, stockpiling and research and development of alternative (substitute) materials (Government of Japan., 2018a). However, these approaches still rely on a variety of uncontrollable factors, which leads to the conclusion that domestic mineral production would be attractive if the possibility arose.

Recent discussions regarding resource security, besides those focusing on commodity price, can be divided into four broad categories: supply stability, environmental impact, stockpiling and nationalism (Gunn and Bloodworth, 2012; Lusty and Gunn, 2015). Supply stability includes consideration of self-sufficiency, import intensity or substitutability of materials and supplies, including recycling (De Ridder, 2013). These discussions focus in part on the promotion of independence from external circumstances, with differentiation between short-term risk and long-term risk. One commonly cited example is China's rare earth element (REE) export restrictions that occurred around 2010 (Bradsher, 2010). At that time Japan was highly dependent on REE from China, and this restriction of supply from the dominant player in the market drove Japanese industries to reduce REE demand through a variety of measures. For example, Honda Motor Co. Ltd. started battery recycling to recover restricted metals, while Hitachi commercialized a rare metal-free motor (Hitachi., 2012; Honda Motor., 2012). This supply risk hit important minor metal components; however, if a similar restriction was to occur for base metals, the effects could be expected to be much broader and to last much longer. Stockpiling is a temporary alternative to help buffer the impact of supply restriction, but is only valid for addressing short-term risks.

Environmental impact refers to factors related to reserves, ore grades, energy consumption, emissions or wastes. These are factors potentially affecting the long-term sustainable development of resource exporting countries, which have been posited as potentially reducing cumulative production through direct restrictions on environmental damage or loss of social license (Prior *et al.*, 2012). In recent years, climate change has also been seen as having a potential effect on resource supply (Pearce *et al.*, 2011), with unpredictability due to climate change possibly threatening resource security.

The geopolitical risks associated with resource supply chains have been of increasing interest due to supply-demand pressures and a resurgence of nationalism in supply countries. Nationalism, in this study, refers to resource nationalism, which is the restriction of exports in order to ensure domestic supply, or increasing export tariffs or applying other measures in order to obtain higher domestic benefit from resources. Resource nationalism has been seen to occur in or among resource-rich countries, particularly developing countries. Resource nationalism factors indicate both risk and driving forces, affecting both short-term and long-term supply (Bremmer and Johnston, 2009). One recent example is the raw material export ban in Indonesia. Under this regulation, the export of unprocessed ores such as nickel or copper ores was prohibited, in order to improve their economy in 2014. Subsequently, nickel ore was not exported until 2017, while copper ore was exported under transition measures. This policy changed in 2017 and these materials could again be exported from 2017 (Warburton, 2017).

Examining resource security indicators from another perspective, they can be divided into factors that are focused on either the importer or the exporter. Importers are able to deal with the aspects of stable supply and stockpiling, but environmental impacts in producing countries and resource nationalism are largely out of the control of importers. These various factors need to be considered when mineral supply and risk reduction strategies are proposed.

1.1. Research Background

1.1.1. Minerals Overview

As nations undergo a low-carbon energy transition, including large-scale electrification and a shift toward a more efficient transportation system, the need for mineral raw materials (ore and concentrates), some of which are critical, are expected to increase. While it has been an ongoing concern from the early days of human history, in recent years there have been growing concerns that resource supply in the future will be vulnerable to supply restrictions. Supply restrictions can occur for various reasons such as strikes (Rosenau-Tornow *et al.*, 2009), price spikes, long-term ore grade decline or political issues. Japan is one of country that is almost completely dependent on imports of raw materials such as ferrous and non-ferrous metal ores and concentrates (e.g. iron, copper, lead and zinc), which makes it vulnerable to potential global supply disruptions. Such disruptions may occur for various political, economic and environmental reasons. Therefore, not only Japan but also many other countries have considered strategies for improving resource security in the face of perceived growth in uncertainty over supply, including approaches to alternative resource supply.

1.1.2. Demand side perspective

It has widely been forecast that mineral demand will continue to increase across most categories of minerals, with the exception of certain minerals that are deleterious to the environment or health such as mercury or asbestos (Virta, 2005; Halada, Shimada and Ijima, 2008; United Nations Environment Programme., 2017). Demand increases in the future will be likely to exacerbate resource competition because reserve decline may, in some cases, mean that producers are not able to supply sufficient material to meet the total demand. Ore grade decline, has widely been discussed as a potential future issue as well, with implications for increases in energy and environmental costs (Rankin, 2011; Prior *et al.*, 2013). Environmentally inefficient mining may be an operational limitation due to tougher regulations. From this point of view, ore grade may become a limiting factor in future. Demand increases will likely be caused by new technologies, especially in the sectors of renewable energy, electric vehicles or telecommunications, not only in the transition for developed countries but also in the rapid catch-up demand from developing nations. Renewable and clean energy technologies require a wide variety of metals, both rare and common (De Ridder, 2013; Elshkaki *et al.*, 2016), and it is important to consider the additional supply that low carbon technology might add to the conventional demand growth.

One example is global copper demand, which has been estimated elsewhere to increase by between 200% and 350% in 2050 compared to 2010 (Elshkaki *et al.*, 2016), or growth to 31,200 to 54,600 kt per annum based on the USGS (USGS., 2011). Another estimate indicates growth to 34,000 ktpa in 2050 (Matsuura, 2009), which shows agreement with an increase of copper consumption of nearly double in the next few decades. The International Copper Association estimates that in 10 years, copper demand for electric vehicles will increase 9 times compared to the demand of 2017 (International Copper Association, 2017), which is likely to exacerbate copper demand beyond historical trends.

1.1.3. Supply side perspective

The global situation of the mineral industry indicates that average ore grades are declining, mined ores are tending to be more refractory, ore bodies are being mined at greater depths, whilst associated waste problems and processing prices are increasing (Mudd, 2007; Norgate and Haque, 2010; Norgate and Jahanshahi, 2010; Kosugi, Unei and Nojiri, 2014; International Copper Association, 2017; Consejo Minero, 2018). There are a variety of social, geological and technical factors involved in these trends, but long-term ore grade has declined significantly (Mudd, 2007; Consejo Minero, 2018). Large-scale mines have in some cases been closed recently because of lower ore grade and the inability to economically mine and process it (Kosugi, Unei and Nojiri, 2014). Low-grade ore extraction typically requires higher energy and/or reagent consumption, and results in larger quantities of wastes. This is in part attributable to the additional amount of material that must be treated in these stages. When processing lower grade, particularly refractory ore, removing waste requires significant energy consumption (Norgate and Haque, 2010). On the other hand, lower ore grades will not significantly increase the energy consumption of the downstream metal extraction and refining stages of many metals (Norgate and Jahanshahi, 2010). Mining lower grade ore requires greater energy since more tonnes of ore must be mined per tonne of metal. On the other hand, once the ore has been processed to concentrate, the difference between ore grade is no longer relevant. These factors together indicate that it is most likely to be largely the resource extracting countries that are affected environmentally because of low-grade ore, whereas countries further down the supply chain are less affected (although this may not be the case with some impurities contained in the concentrate). It is perceivable that ore exporting countries might consider regulating low-grade ore extraction 0due to the associated increased environmental impacts. Additionally, it has been estimated that (for example) many copper producing countries will not be able to sustain their production until 2050 (Elshkaki *et al.*, 2016).

These gaps could lead to potential supply imbalance, and may become a severe risk for those countries who are highly dependent on imported mineral raw materials.

1.2. Concept of Resource Security

Although both energy and minerals can be categorized as resources, discussion of security in the context of each of these is different. Energy security has been discussed for a long period, particularly since the 1970’s oil crises (Ogawa, Noda and Yamashita, 2010), including reserves, choke points and geographical distribution. On the other hand, mineral resource security has not been discussed as thoroughly as energy security. There are many possible reasons that could be suggested for this, but primarily it may be that the variety of minerals is large, making such discussions complex—whereas for energy security the issues are relatively generalizable across countries for a limited number of commodities. Moreover, there has been little reason for concern over global mineral resource security until recently, leading to the issues being addressed largely on a country-by-country basis. The situation must be differentiated by mineral. For base metals, for example, supply distribution is geographically quite broad, and supplying countries are relatively politically stable compared to the centralized nature of certain energy resources, such as oil, making the potential for supply restriction theoretically lower. However, as non-renewable resources, minerals face the same resource limitations as fossil fuel-based energy. As a remedy to reliance on imports, energy security considers domestic production an important factor—with the key non-fossil fuel technologies of renewables and nuclear being the focus for countries with minimal conventional fuel reserves. Recycling can be considered as the closest mineral analogy to renewable energy. However, whereas renewable energy can be installed quickly and predictably so that there is minimum time lag between supply and demand (on a macro-scale), raw materials from recycling take time to come back into the supply chain after been consumed. (Copper produced at year t takes years or decades to reenter the supply chain as a secondary material depending on the lifetime of the product containing it). Likewise, while renewable energy may be focused on domestic supply to meet domestic demand (apart from certain interconnected regions such as Europe), materials are utilized to manufacture products, which may be exported—therefore creating a barrier to the recovery of those materials by recycling. Based on these characteristics, an alternative method for evaluation is required when it comes to discussion of mineral resource security.

Recent discourse around resource security has been focused on critical materials, essential for industry, civil life and military applications for which alternative materials are not available and which use minerals whose probability of supply restriction is elevated or, in some cases, whose environmental implications of supply are high (National Research Council of the US., 2008). “Critical materials” can be broadly defined as relating to materials that fulfil an important (or vital) role in society and for which there is a high possibility of supply restriction, which could lead to higher prices (economic scarcity) or physical unavailability (physical scarcity). A variety of factors are typically included in the evaluation of “criticality”, which includes factors of economic importance or reliance (vulnerability to supply restriction, including the number of people using, the importance to economic sectors and the potential for substitution) and supply risk (factors that affect this might include the level of monopolization of supply chains, environmental intensity of production and governance in producing countries). The National Research Council refers to the key components of criticality of mineral resources as “importance in use” and “availability” (National Research Council of the US., 2008). The European Commission evaluates criticality by considering economic importance, supply risk, economic stability of resource producing countries and substitution/recycling rate, and environmental country risk (European Commission., 2008).

Taking copper for example, it is vital to some applications such as electric wire but can be substituted with aluminium with some loss of performance; at the same time, the global production of copper ore is quite diversified, giving a potentially lower supply risk. However, due to increasing demand and potential for lagging supply, ore grade decline in terrestrial mines and potential subsequent cost increases per ton of metal, it may face both economic and physical scarcity risks in future.

The specific definition of a critical material differs from nation to nation, depending on the applied evaluation criteria although materials such as rare earth elements (REE) and Platinum group metals (PGM) are common among materials considered as critical in most nations. In Japan, as a country that is almost entirely dependent on imports of raw materials, apart from the concept of "criticality", other metals are considered "strategic" due to their economic importance (regardless of the likelihood of global supply disruptions which is included in criticality), including copper, lead, nickel and zinc (European Commission., 2008; U.S. Department of Energy., 2011; Prime Minister's Office of Japan, 2012).

Resource importing countries have severe limits on their ability to exert control over political, economic or environmental issues which are occurring in resource exporting countries. Cognizant of this limitation and, as metals play an important role in achieving a low-carbon society (La Porta *et al.*, 2017), many import-reliant countries have seen the need to develop a resource acquisition or resource security strategy. Applications of strategic metals (that would fit in such policies) to renewable energy includes, for example, photovoltaic panels requiring copper, indium, gallium and selenium and wind turbines requiring nickel, molybdenum, neodymium and boron as functional materials (La Porta *et al.*, 2017). As renewable energy installation increases, battery demand will also likely increase. Lithium-ion batteries are one key storage option in renewable energy societies, and these also include potentially critical minerals such as cobalt and lithium (La Porta *et al.*, 2017). In order to improve low levels of raw-material self-sufficiency, each country needs to decide their own approach. For example, the USA drew up the Critical Materials Strategy (European Commission., 2008) which has three key factors, namely: expanding global supply chains, developing substitute materials and efficient mineral use including recycling. The EU developed the list of Critical raw materials for the EU (Steiner and Geissler, 2018), and focuses on expanding global supply chains, developing substitute materials and efficient mineral use including recycling (U.S. Department of Energy., 2011). Overall resource policy in the EU relies on resource exporting countries for primary resources and intra-EU material flows for secondary resources. Japan's resource policy is quite similar to the EU and United States. The Japanese government outlined their strategy in the Strategic Energy Plan (Government of Japan., 2018a) (the inclusion of a materials strategy in the energy plan is highly indicative of the interconnectedness and interdependence of these two sectors). This plan includes a raft of measures, such as, supply diversification, recycling of end-of-life products and research and development for extraction from unestablished or alternative materials (U.S. Department of Commerce, 2019).

The circular economy is one tightly-linked concept to maximize resource efficiency and minimize waste production, within the context of sustainable economic and social development (Hislop and Hill, 2011). Promoting recycling is one of the key components of the circular economy, as well as a key strategy for critical material resource security.

Domestic or internal mineral production, which improves resource security such as unconventional resource or redevelopment of closed mines, is one of the potential strategies.

Importantly, in the EU and USA approaches to criticality, there is a growing consideration of the environmental implications of alternative mineral supplies. This has not yet been adequately addressed in the Japanese context.

Examining Japan's strategies, all are dependent on other nations, except for research and development and domestic recycling of end-of-life products. In order to ameliorate this issue, domestic mineral production needs to be considered alongside domestic recycling in order to achieve resource security, critical to the low-carbon energy transition.

1.2.1. Japan's idea of resource self-sufficiency rate

Self-sufficiency rate is one of the indicators that measures vulnerability level with relation to exogenous events such as supply restriction. Typically a self-sufficiency rate is defined as the amount of imported material in total domestic supply. However, Japan's self-sufficiency rate for of base metal raw materials is said to be 50%, despite the fact that there are no fully domestic produced raw materials—for example, all raw ores of copper, zinc, lead are all imported. This discrepancy happens because Japan`s definition of self-sufficiency rate reflects the acquisition of mining rights in resource exporting countries (so that the apparent self-sufficiency rate of base metals in Japan is about 50%) (Government of Japan., 2018a), while for most metals there is no domestic mining, and there is no policy promoting the extraction of minerals in Japan.

1.3. Japan's Alternative Material Supply

1.3.1. Raw Material Perspective

Recently, unconventional deposits of minerals have grown in commercial interest as alternative mineral supply options. On land, waste from mining and processing is considered for potential reprocessing with new technology to extract metal (Kamradt *et al.*, 2012; Falagán, Grail and Johnson, 2017). Offshore, such unconventional ores include those found on the deep seabed, which have been an exploration target for decades but only recently come close to extraction, led by Nautilus Minerals in Papua New Guinea (Nautilus Minerals, 2013). On a global scale, deep ocean resources including manganese nodules, and cobalt-rich ferromanganese crusts are estimated to be vast, but despite the smaller resource amount, seafloor massive sulfides (SMS) are likely to become the first mineral resources to be mined because of the shallower depth and presence of key target metals giving them commercial or domestic interest (James R. Hein *et al.*, 2013; Petersen *et al.*, 2016). In Japan, the Okinawa Trough and Izu Ogasawara areas have deposits of seafloor massive sulfides (Hannington *et al.*, 2010; JOGMEC., 2016) containing copper, lead, zinc, silver, gold and rarer elements, including REE in some cases (Masuda, 2011). It is expected that resources of such ores will be at least 7.4 million tonnes around the Okinawa area alone (JOGMEC., 2016). Deep-sea rare earth mud has also been a focus of attention—

particularly in the period of Chinese export restrictions—with deposits around Minamitori Island, located in the Ogasawara area, which contains heavy rare-earth elements (Kato *et al.*, 2011). Developing these resources has become a key focus of the Japanese government because of their potential to help reduce metal supply risk, as well as the possible technology developments that could be capitalized-on by Japanese industries (Government of Japan., 2018b).

1.3.1.1. Re-opening closed mines

In recent history, mineral resource security policy has tended to focus on upstream investment, such as acquisition of mining rights in resource exporting countries. However, in many places there is a possible alternative for resource importing countries that have an historical mining history, but whose mines have been shut down, like Japan. Due to ore grade decline, it is possible that ore grades of closed mines, or even the waste of certain mines, may be higher than cut-off grades today, since both mineral prices and extraction technology have improved. When countries whose resource policy previously changed from producing domestically to importing concentrate shift their policy again to restarting-mining, the issues of tailings, localized environmental impacts and energy consumption issues arise. It is also clear that in countries who no longer mine, there is often a lack of mining expertise as well as broader social recognition and acceptance, both of which need to be obtained before domestic mining can restart.

1.3.1.2. Seafloor Massive Sulfide Mining

Deep ocean resources around Japan's exclusive economic zone, such as seafloor massive sulfides, manganese nodules and rare earth rich deep sea muds, have been widely studied (Kato *et al.*, 2011). The key reason for this is Japan's lack of commercial domestic mineral production, which makes importing the only way for Japan to supply its mineral concentrates. Under this constraint, the current supply system is vulnerable to supply disruptions from external parties and this may engender significant economic damage to the manufacturing industry if key mineral inputs are affected. Although modern-day deep ocean mining technologies and the current deposit levels are not yet economically competitive with land-based mining, utilizing these resources in the future may ease the potential for untoward impacts should supply disruptions occur.

The strength of deep ocean mining is its lower waste footprint. Land-based mining requires land clearing and removal of overburden or waste rock before extraction of the valuable ore. On the other hand, deep ocean mining typically does not need to remove much overburden for extraction because the minerals are right on or near the surface of the seabed. When deep ocean resources are extracted, waste rock is expected to be significantly lower than terrestrial mining (James R. Hein *et al.*, 2013). Of course, there are many uncertainties around deep ocean mining, across all fronts—technical, environmental, economic and social. Notably, most studies consider the biodiversity and direct ecosystem impacts of deep ocean mining, which are difficult to compare adequately with land-based mining because of the lack of environmental baselines as well as the lack of commercial deep ocean mines as precedents. Thus, these aspects—which may be negative for deep ocean mining—are left out of the present examination. One of Japan's well-studied potential deep ocean ore bodies lies approximately 110 km offshore from Okinawa Island (Agency for Natural Resource and Energy of Japan., 2013). It is reported that this deposit has grades and tonnages of 0.4% copper (3000 kt), 1.4% lead (10,000 kt), 5.8% zinc (43,000 kt), 1.5g/t gold (11 t), and 95.6 g/t silver (1 kt) (Agency for Natural Resource and Energy of Japan. and JOGMEC., 2018). Although the total quantity of copper in this deposit is not large considering Japan's annual copper demand is approximately 1500 kt (JOGMEC., 2017), combined production with other metals such as zinc, lead, gold and silver could contribute positively toward overall national resource security.

Although there is a high degree of uncertainty about the potential environmental impacts of deep ocean mining, and there is inevitable local ecosystem damage, deep ocean mining may be environmentally and economically competitive with land-based conventional mining on certain indicators (Hoagland *et al.*, 2010). While not dismissing these localized environmental impacts, this study seeks to evaluate the quantifiable global environmental impacts of comparative mineral supply strategies.

1.4. Secondary Material Perspective

In a seeming paradox from the overall perspective of Japan's raw material demand and supply situation, Japan exports a significant amount of mineral scrap (Ministry of Finance of Japan.; JOGMEC., 2017). For example, the major importer of Japan's copper scrap up until 2017 was China, which accounted for around 95% of scrap exports over the 5 years to 2017 (Ministry of Finance of Japan.). The volume of Japan's exported scrap accounted for the equivalent of about 30% of its domestic demand (Ministry of Finance of Japan.; JOGMEC., 2017). While the export of a potentially valuable resource from a resource-poor country seems counter-intuitive, the reason for exporting copper scrap was purely economic—the availability of cheap labor costs in China. Scrap exported to China was too complex to recover copper with automated technology in Japan—power cables, motors, or other complex end-of-life products. This scrap was processed by hand in China. However, recently China placed restrictions on the import of waste from other countries, including copper, aluminium, and steel scrap including End-of-Life products (end of 2018) and magnesium (end of 2019) (Ministry of Ecology and Environment of the People's Republic of China., 2018; Rauters., 2018). Because of this regulation, Japan has had to find alternative ways to treat its large quantities of metal scrap.

The way scrap is typically recycled in Japan is a process of down-cycling. Down-cycling is defined in this study as “a way of recycling whereby the quality of recycled materials is lower than that of the original scrap”. In the case of Japan`s current recycling process, copper wire which requires an extremely high purity of copper uses only wire scrap, while brass, which can absorb a certain amount of other materials, uses various types of copper scrap (Ministry of Finance of Japan.). Brass recycling is categorized as down-cycling. Due to the increasing concentration of impurities, down-cycling reduces the quality of material over time (McDonough and Braungart, 2002). In order to move from down-cycling, impurities should be removed to prevent down grading of recycled material.

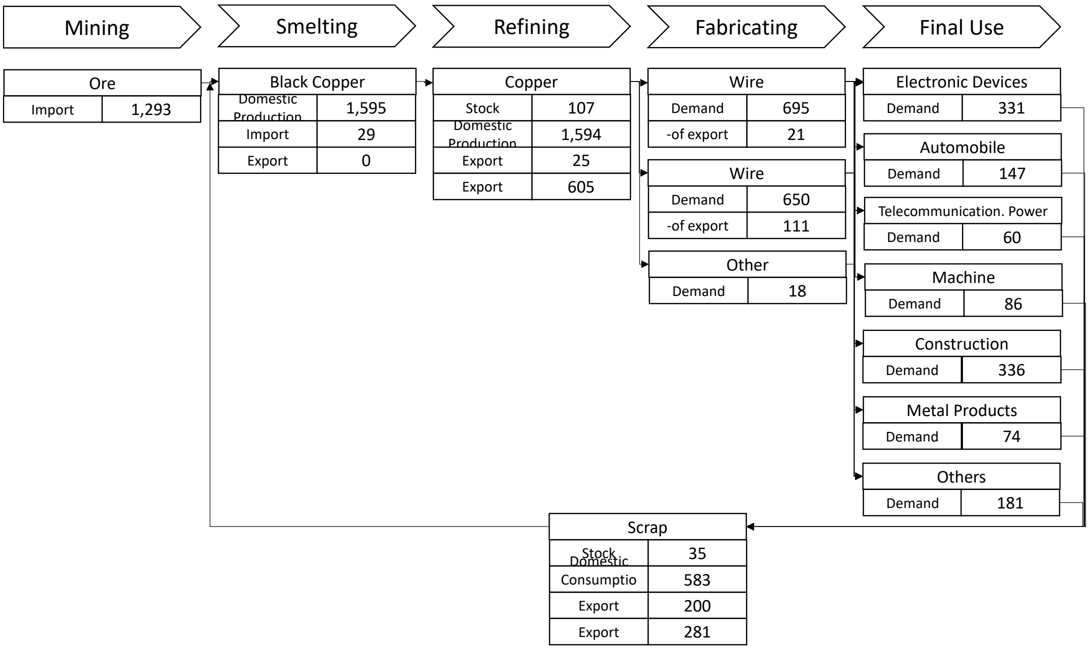
It is possible to apply appropriate smelting and refining processes to avoid downgrading recycled material. Japan has 15 nonferrous smelters (Japan Mining Industry Association., 2013) which separate various materials during processing, including copper, lead, zinc, gold, silver, nickel, platinum and palladium, although they largely input primary concentrates. To prevent downgrading, separating impurities is vital. Without smelting facilities it would be difficult to recover metals from end-of-life products.

Some of the difficulties facing end of life product recycling are the level of dispersion across society and the complexity of products. In the case of household appliances such as microwave ovens, once the product is sold to consumers, manufacturers of that product do not know where it is located. While there are certain regulations and provisions for recycling through extended producer responsibility, it consumes a lot of energy to collect enough end-of-life products to recover the metals inside them economically.

1.5. Copper Production and Application in Japan Overview

Copper is used as a case study example in this research, as it is a metal that is vital to many industries in Japan and globally. It has been examined as a potential critical mineral, and although the level of criticality is deemed to be low, it is an essential mineral to Japan’s economy, and potentially important material for expanded renewable energy deployment such as CIGS photovoltaic panel and CIS (copper (C), indium (I) and selenium (S)) photovoltaic panel (La Porta *et al.*, 2017) and the many kilometres of additional wiring required for electric vehicles, and large-scale distributed renewable systems.

According to JOGMEC, copper material flow of Japan is expressed as Figure 1(*‘Kobutsu Shigen Materiaru Furo 2019 Dou (Cu) [Minerals Material Flow 2019 Copper (Cu)’*, 2019).



Source: Minerals Material Flow, JOGMEC 2019

Figure 1 Copper Material Flow (CY 2018)

With regards to copper in Japan, 100% of mineral concentrate is imported, and the annual production of copper in Japan in 2017 was 1488 kt, split between the end uses of wire (64%), brass (35%), and casting (1%) (JOGMEC., 2017). The recycling rate for 2017 was reported as 32% (JOGMEC., 2017). The recycling rate reflects the percentage of copper produced utilizing copper scrap. In-process scrap, which is scrap generated during wire or brass production, is utilized at the rate of almost 100% and the wire and brass industry also utilizes end-of-life product scrap, which is generated from waste copper products, for production (MERIJ., 2015). Scrap produced in Japan was distributed to the wire, brass, copper smelting and export industries (MERIJ., 2015). Wire and brass industries use scrap so that they can reduce material input costs (MERIJ., 2015). The smelting industry uses scrap to productively utilize the excess heat created by the converting reaction in converter furnaces (Mark E. Schlesinger . [et al.], 2011). Copper smelting and export industries currently process lower grade scrap, whereas high grade scrap was recycled in the wire and brass sectors (MERIJ., 2015). China has consistently been a major importer of Japan’s scrap—particularly scrap which required labor inputs in order to be economically recycled (such as plastic-coated cables). However, scrap imports, including not only copper scrap but also various kinds of metal scrap, slag and plastic imports were banned by China in 2018, in order to protect the environment (Ministry of Ecology and Environment of the People’s Republic of China., 2018). Recyclable plastic is another example of the materials whose imports were banned by China. According to Morita and Hayashi’s analysis of the Trade

Statistics and survey of the experts, plastics that used to be imported changed their destination. Higher grade plastics are easily sold to other countries while lower grade plastics remain in Japan and are used for thermal recycling. Plastics which have much lower grade are dumped and landfilled as industrial wastes (Morita and Hayashi, 2018). Unlike plastics, metals are not able to be utilized as a fuel, but may have higher monetary value compared to plastics. Thus, this outcome means that Japan will need to process lower grade scrap domestically or find an alternative processing destinations.

1.6. Evaluation of deep sea mining for resource security

Deep sea mining is still not commercially undertaken anywhere in the world, though there is some extraction of seabed diamonds and gravel at shallow depths. So far, much of the evaluation of seabed mining has been from the environmental or technical perspectives.

Environmental impacts have been evaluated for various mining activities, largely from the local environmental perspective through Environmental Impact Assessment (EIA) or alternatively the full supply chain in the form of lifecycle assessment (LCA). For example, Norgate et al. investigated the environmental impacts of selected ferrous and non-ferrous metals, which were assessed by using LCA methodology from mining to refining. In the overwhelming majority of studies, the mining methodology for copper ore was land-based mining (Norgate and Haque, 2010).

As for the environmental impact assessment of deep ocean mining, the International Seabed Authority (ISA) has established 'Environmental Guidelines' which are recommendations for the guidance of contractors for the assessment of the possible environmental impacts arising from exploration for marine minerals in the area (*Recommendations for the guidance of contractors for the assessment of the possible environmental impacts arising from exploration for marine minerals in the Area*, 2013). It is recommended to assess items such as both physical and chemical oceanographical indicators as well as biological communities when mining the deep sea for ore acquisition. For example, impacts on animal diversity, water quality, and surface structure changes are often discussed as potential issues at Solwara 1 Project, which has been planned to be mined in Papua New Guinea (Boschen *et al.*, 2013). In the Japanese context, Narita gives the comprehensive results of EIA for mining of the Izena Cauldron, Okinawa Trough. This result was obtained by a long-term survey conducted at potential mining sites. The survey indicates, through test mining, that the impact of turbidity is highly localized (Teruyoshi Narita *et al.*, 2015). Batker made a comparison with the Solwara 1 project and on-land copper mining, and concluded that Solwara 1 has the potential for far fewer social and environmental impacts than the existing terrestrial mines examined (Batker and Schmidt, 2015). On the other hand, McLellan et al. conclude that the Solwara 1 project would consume more energy than average land-based mining on the basis of a tonne of ore due to the higher depth (McLellan, Motoori and Tezuka, 2015). Koschinsky and most other research focused only on the mining phase for evaluation (Koschinsky *et al.*, 2018). As for mineral importing countries such as Japan, assessing the whole value chain including transportation is crucial, since alternative mineral supply for improving resource security relies on the full-supply chains' existence domestically. Thus, this study evaluate the minerals full supply chain from mining to refining. In order to assess the environmental impacts process by process, a lifecycle evaluation of energy and some environmental impacts was combined with material flow analysis as the core methodology applied here.

It is also important to consider the community, business and economic perspectives in understanding the impact and priority of alternative resource security strategies. Prior research regarding the circular economy (CE), the field in which recycling is often discussed, showed that although CE relevant research has been and is an aggressive field of study, there has been a lack of business and economic perspectives (Lieder and Rashid, 2016). The ignorance of these issues leads to the risk of inhibiting CE implementation since advantages for industry are implicit. Hence, this study evaluates the impact to the economy and industry explicitly.

1.7. Research Objective and Structure of the Thesis

To summarise the literature review, (1) mineral resource dependence has an inherent potential vulnerability caused by possible supply and demand gaps, (2) compared to energy resources, the concept of resource security has yet to be developed sufficiently, (3) it has been reported and investigated that unconventional ore exists within Japan's territory (4) due to the strict regulation for exporting recyclable (but difficult to separate or lower grade material) materials, Japan may have to deal with the prospect of recycling these materials.

From this emerges the key research question that this study is trying to answer: "What are the impacts of alternative mineral production methodologies, and what is a sustainable resource acquisition strategy for Japan?"

This study aims to evaluate the alternative mineral supply methods in terms of techno-economic, environmental and social perspectives as well as understanding peoples' preferences for resource acquisition. Finally, a future policy is proposed to design a society with secured resource supply.

Alternative mineral supply methods in this study are represented by SMS mining from the deep ocean, (DOM), recycling end-of-life material (REC) and conventional on-land mining (CONV). Each methodology is explained in the next chapter. Chapter 3 investigates the environmental impact of domestic mineral production, chapter 4 presents a techno-economic analysis of domestic mineral production, and chapter 5 presents survey results of people's preference over deep ocean mining and other resource acquisition strategies. The effectiveness of domestic mineral production is estimated at chapter 6. And finally chapter 7 gives the conclusions of this study.

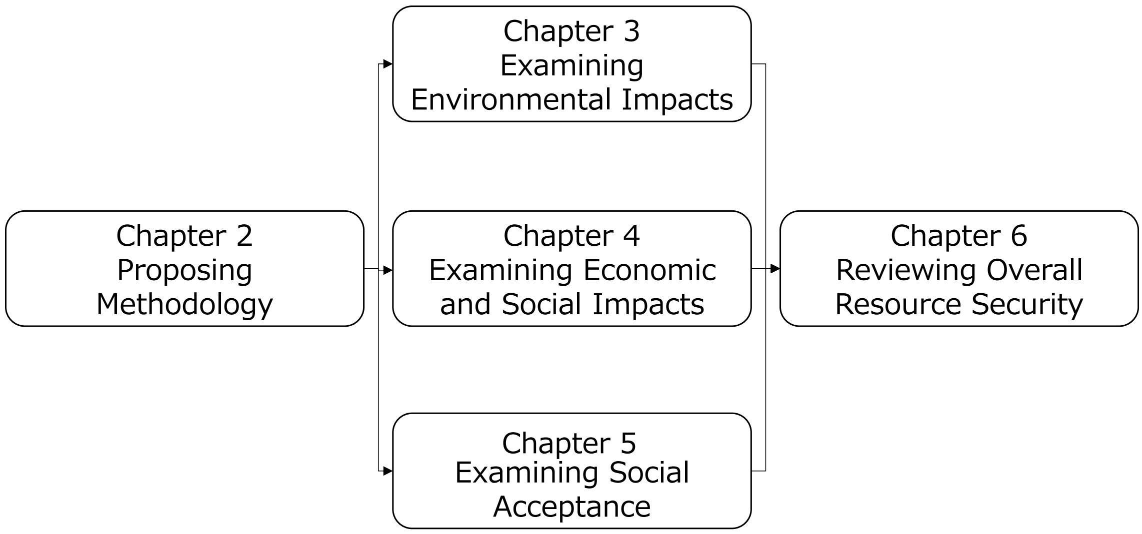


Figure 2 Thesis Structure

2. Methodology and Assumptions

2.1. Overall Methodology

Figure 3 shows the overall methodology corresponding to the research question. To answer the research question, this study employed three methodologies; material flow analysis (MFA), Input-Output Analysis (I-O), and a stakeholder survey. Each output contributes to the outcome of this study.

Material flow analysis is applied to answer the question “How much do alternative mineral production methods affect energy consumption, CO_2 emissions and waste?” Input-Output analysis is used to answer “What will be the reaction of industry when alternative mineral production methodologies are dominant in Japan?” A stakeholder survey will help to answer the question “Will stakeholders accept alternative methods?” Each of these component studies leads to the final outcome of this study, a policy proposal; designing optimal mineral supply management for Japan.

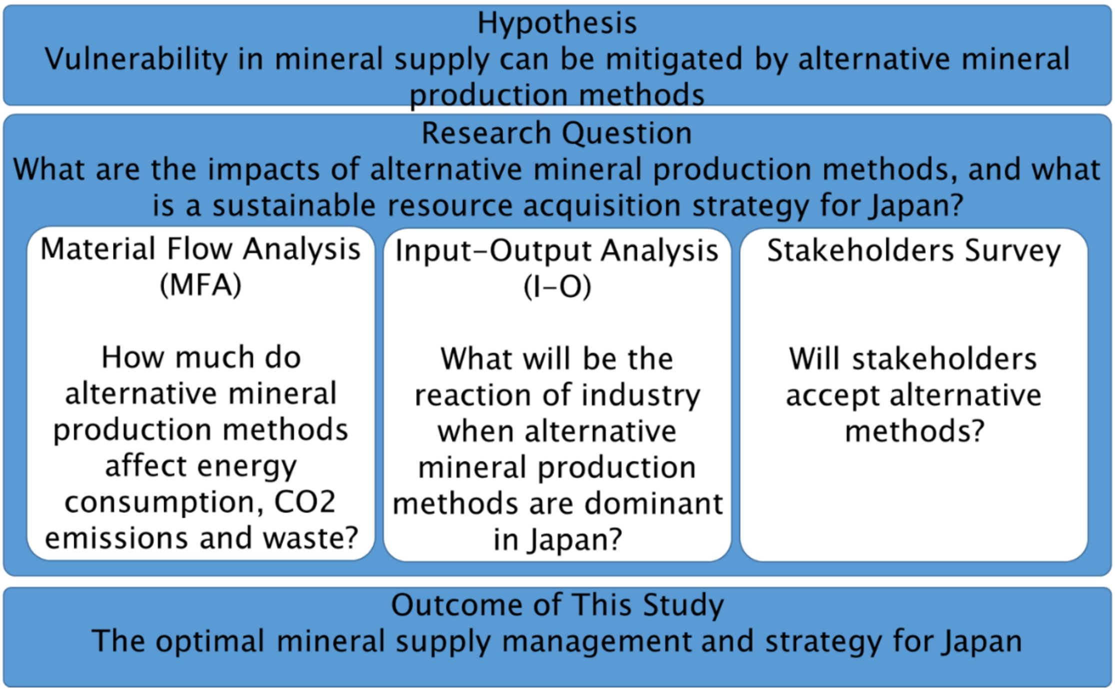


Figure 3 Research Question and Overall Methodology

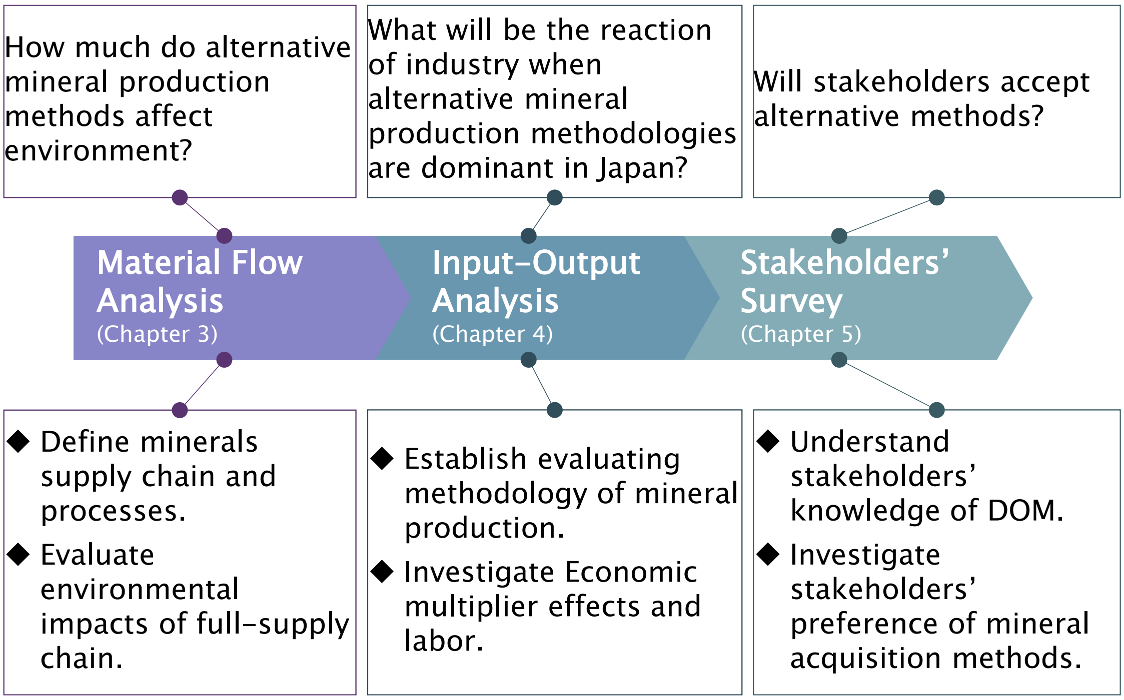


Figure 4 Methodology Overview

The novelty of this study is to evaluate environmental, economic and social impacts on resource-importing countries throughout the full-supply chain of copper, which is lacking from prior studies. To evaluate environmental impacts, upstream processes that are not yet present in these countries for deep ocean mining and sorting processes for recycling were defined. This enables the comparison of process-by-process impacts across each production method on a equivalent basis. The bottleneck evaluating economic impact by applying input-output analysis in this study is, copper production and recycling do not exist in the table. Thus, in this study, these industries are newly added to the input-output table. Input coefficients for upstream copper production (mining to concentration) are approximated by utilizing the Chilean input-output table. Because of the linearity of the I-O table, input coefficients can be considered to be applicable even though the size of the economies are different. Finally, to understand the peoples' acceptance, a consumer survey focused on the upstream stages of production. Smelting and refining phases already exist in Japan, and the impact to citizens are expected to be more limited or contained. However, because mining and concentrating phases do not exist in Japan currently and they may be conducted in the open environment and would be a new operation, it is assumed that people may have preferences at this stage.

In order to assess the environmental impacts of domestic mineral production from full-supply chain perspective, it requires process-by-process evaluation. As for economic impacts, this study focuses more on multiplier effects to see inter-industry impacts. Possible methodologies are listed in Table 1.

Table 1 Potential Methodologies

Perspective	Methodology	Description
Environment	Life Cycle Assessment	● Assess the environmental impacts at the entire life cycle of a certain product / service ● Gives better understandings of specific process
	Material Flow Analysis	● Assess the flow and stocks of a certain product / service ● Gives better understandings of overall process
	Input-Output Analysis	● Estimates the energy consumption from monetary base ● Process-by-process energy consumption will not be obtained
Economic	Computable General Equilibrium (CGE)	● Assess the reaction of economy when policy, technology or other external factors change ● In practical, it is applied when assessing the long-term impacts
	Dynamic Stochastic General Equilibrium (DSGE)	● Assess the reaction of economy when policy, technology or other external factors change ● In practical, it is applied when assessing the short-term impacts
	Input-Output Analysis	● Assess the inter-industry transactions and multiplier effects ● Obtained results show a snapshot of certain year
Social	Expert Survey	● Acquire a small number of experts' opinion ● Expected to acquire the preference based on the expertise
	Non-Experts Survey	● Acquire a large number of general opinion ● Expected to acquire personal preference

When investigating the environmental impacts, there are a number of methodologies that are commonly used such as life cycle assessment (LCA), material flow analysis (MFA), or Input-Output analysis. LCA is a 'cradle-to-grave' approach to investigate the environmental impacts. On the other hand, MFA is focused on a limited scope, such as materials or energy. While LCA and MFA are analytic methodologies that typically utilize a mass basis, Input-Output analysis utilizes monetary-base data, and can be used as a basis to estimate both socio-economic impacts and environmental impacts.

MFA in this study is applied using a bottom-up approach, while Input-Output analysis can be categorized as a top-down approach. By applying these methodologies together, the impacts from the alternative mineral production methods are estimated multilaterally from alternative perspectives and on multiple categories of impact.

Material flow analysis enables understanding of the amount of materials required, including energy, chemicals and materials discharged from mining to processing. This study considers a limited number of environmental impact, specifically: energy consumption, CO_2 emissions and wastes, and makes a comparison across alternative mineral acquisition methods. The scope of analysis, for both conventional and deep ocean mining is from mining to processing, while recycling starts from collecting end-of-life products and extends through to processing. In all cases, final goods production, transportation of final goods and in-use energy consumption are considered to be out of scope.

When estimating economic impacts, computable general equilibrium (CGE), dynamic stochastic general equilibrium (DSGE), and Input-Output analysis are common methodologies. Input-output (I-O) analysis is applied to estimate socio-economic impacts. Both CGE and DCGE can describe macroeconomic indicators are not suitable for assessing multiplier effects, input-output analysis investigates multiplier effects.

The I-O table, which is the primary data source for this methodology, is a statistical table showing inter-industry transactions of goods and services conducted in the domestic economy for a certain period (usually one year) in matrix form. This table has been prepared for the purpose of understanding the economic structure of a single region (country, prefecture or city level, although international and multi-regional I-O tables also exist). It is also possible to analyze the economic ripple (multiplier) effects by using this table. Economic ripple effect can be defined as new economic production which is triggered to meet new demand.

Finally, to determine the community`s understanding and preference of mineral supply, an internet survey for citizens was conducted. The survey was undertaken in Japan during the period 25-28 March, 2016. Respondents were asked a series of questions regarding the following themes: (1) familiarity with Okinawa where potential ore exists; and economic sectors important to Okinawa at present and in the future; (2) their familiarity with mining and the deep ocean environment; (3) acceptability and priority for deep sea mining in comparison to other industries and the environment; (4) how the benefits of deep sea mining should be distributed; (5) deep sea mining as a source of minerals for domestic industry as compared with importing, recycling and other strategies. Respondents are from both Okinawa and rest of Japan, seeking to gain an understanding of whether local residents were more or less in favor of DOM, and whether there were any main differences in concerns.

2.2. Mineral Acquisition Methodology

This study considers conventional mineral processing (A), Deep Ocean mining (B), and recycling the end-of-life products (C).

The overall system is shown in Figure 7 The blue dashed box delineates the domestic processes and flows within Japan. Streams marked (A) occur only or primarily in the conventional copper processing situation; (B) occur in the deep ocean mining situation and (C) is the recycling scenario. Combined copper processing scenarios (discussed in Section 3.2) for identifying the optimum mix of copper from each process consisted effectively of combinations of (A) + (B) + (C). As discussed later in more detail, the potential collectable copper material for recycling is limited as the amount used in domestic demand (domestic production and imports minus exports). Import of concentrate is considered to be used to fill the remainder of demand.

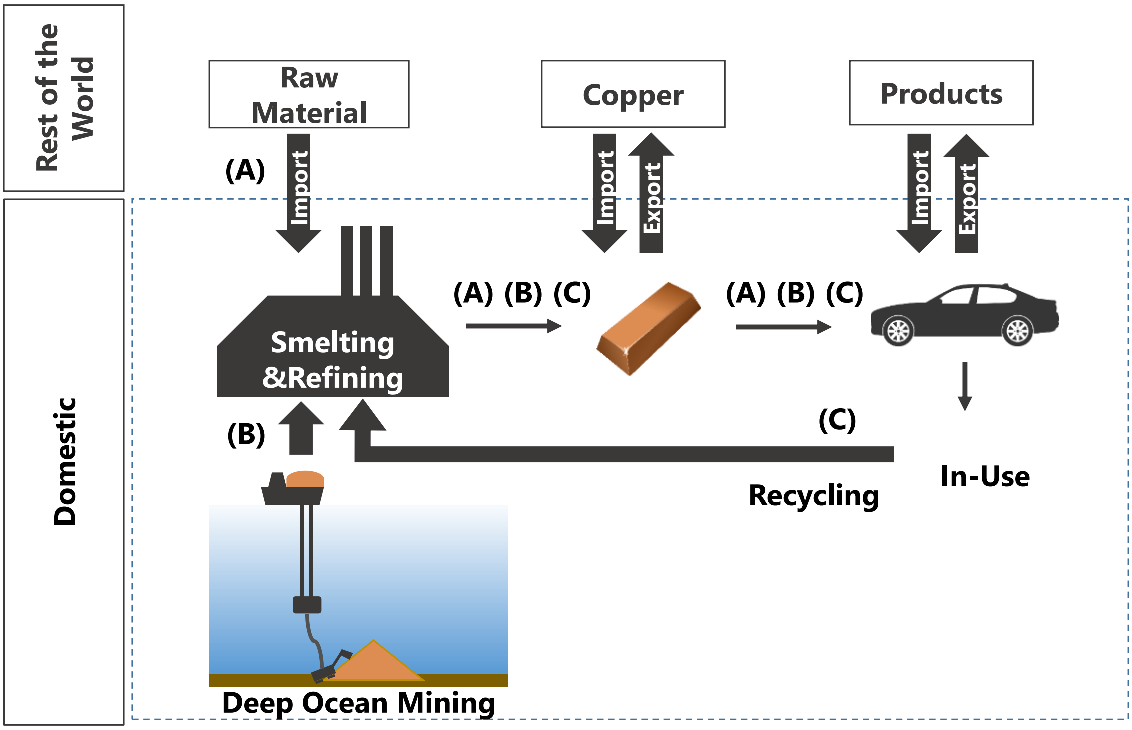


Figure 5 Domestic Mineral Production and Life Cycle Assessment System Boundary

Figure 2 shows the copper processes evaluated in this study. The conventional copper process uses concentrate that is mined from land-based mines in other countries (Japanese mines are no longer operating). Concentrate is typically produced at or close to the mine site by processing the ore. Concentrate is then shipped to Japan (in this case) and electrolytic copper is produced by flash smelting and electro refining. On the contrary, deep ocean mining copper processing uses ore from the ocean around Japan (within its Exclusive Economic Zone, EEZ). Ore from the deep ocean requires concentration facilities and dams to store tailings, both of which are expected to operate domestically. Deep ocean mining and land-based mining are assumed to use the same type of facilities for smelting and refining. The recycling process for copper requires end-of-life products as raw material. End-of-life product is defined as end-of-life households' electrical and electronic equipment in this study. Since the composition of raw materials for recycling is different from primary ore, an alternative type of smelting facility has typically been used (Forsén, Aromaa and Lundström, 2017). Conventional smelters cannot typically absorb massive amount of scrap because the feed material should be very dry and fine (Forsén, Aromaa and Lundström, 2017); therefore, recycling processes use bath smelting rather than flash smelting. The recycling process requires end-of-life product collection and sorting, and in this study estimates have been made for the latter using the energy for crushing and magnetic sorting processes, which were considered to have the largest impact. The impacts of land-based mining (mining and concentration stages) in resource exporting countries are included as well. The following sections provide more detailed descriptions of each of the copper supply alternatives.

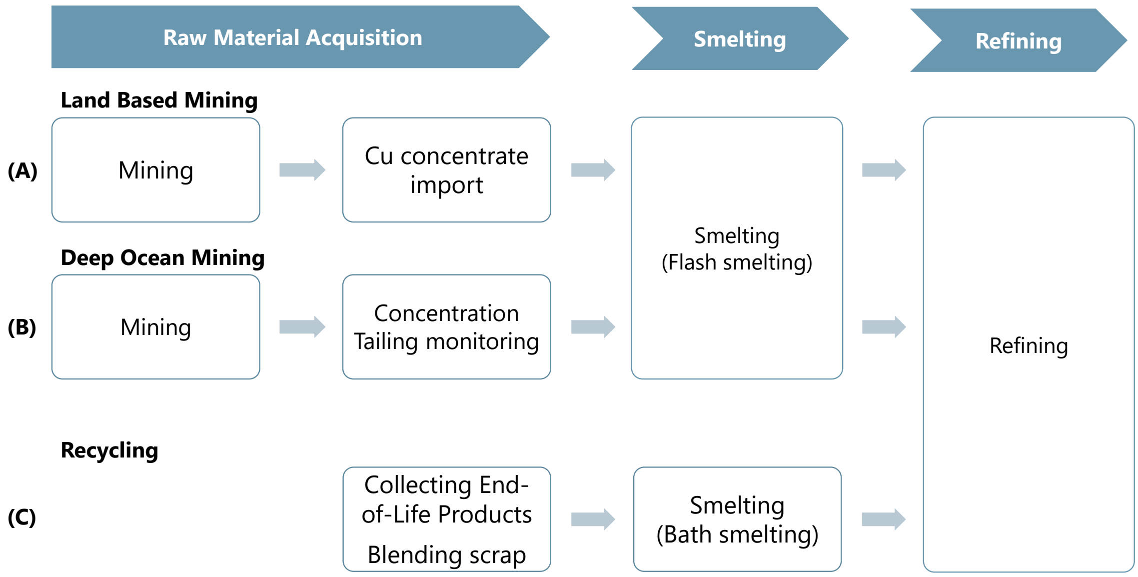


Figure 6 Domestic Copper Production Process

2.2.1. Conventional Mineral Processing

The conventional copper production process used for comparison here is from mining to electro-refining using a flash furnace and converting furnace. Although the energy and material consumed in Japan is only considered to be from transportation to refining, the impacts of mining and concentration processes are also evaluated for comparison with deep ocean mining.

2.2.2. Deep Ocean Mining (DOM)

Deep ocean mining will provide virgin material from seafloor massive sulfide (SMS) ore, with initial focus on deposits within Japan's EEZ. The ore produced by deep ocean mining will then be beneficiated and processed through to metal in Japan. Figure 7 shows the deep ocean mining process considered in this study, which is modelled on the basis of examples from the Agency for Natural Resources and Energy (Agency for Natural Resource and Energy of Japan. and JOGMEC., 2018). The SMS deposit lies at a depth of 1600 m of water (Agency for Natural Resource and Energy of Japan. and JOGMEC., 2018). Ore is mined by a mining unit, crushed and lifted to the surface through a riser pipe. On the mining vessel, ore is dewatered and transferred to a shuttle tanker. Dewatered ore is shipped to a concentration facility where copper concentrate is produced. Copper concentrate is then shipped to the smelting and refining facility and cathode copper is produced. Transportation between the concentration plant and smelting/refining plant is not considered in this study, as the locations are not certain. Water lifted up to the mining vessel with the ore is returned to the deep ocean as return water. Deep ocean mining may affect marine ecosystems in a variety of ways; mining activity may disturb benthos, and return water may be hazardous to marine animals due to the content of particulates, hazardous metals and dissolved oxygen and temperature differences that may affect deep water life (Hiscock and Tyler-Walters, 2006; Boschen *et al.*, 2013; Levin *et al.*, 2016). However, these impacts are extremely difficult to quantify, as well as being very location-specific, making comparison with onshore mining difficult. This study therefore focuses on quantifiable global environmental impacts.

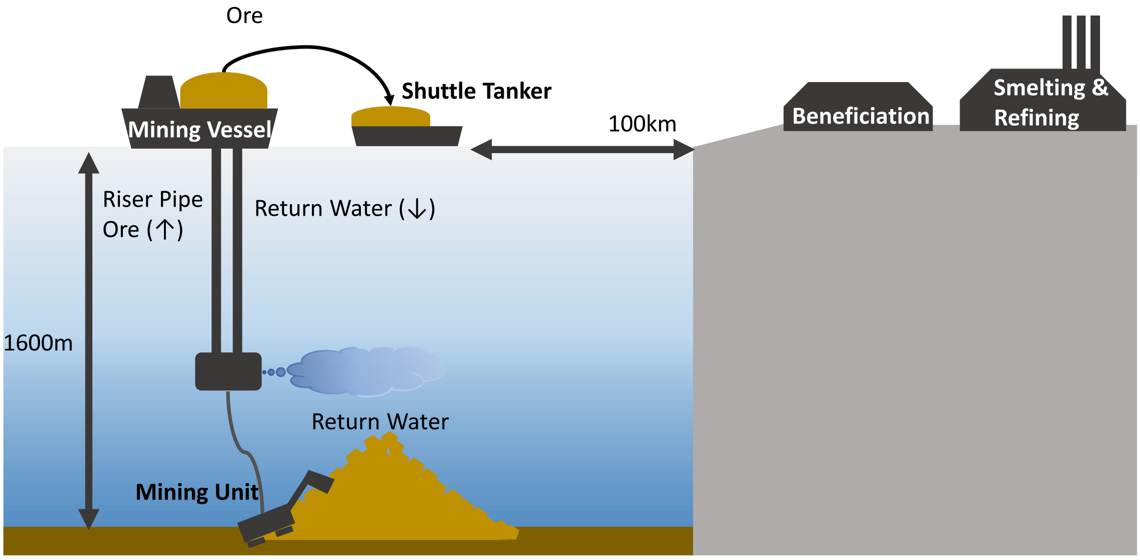


Figure 7 Deep Ocean Mining

Note that the 100 km indicates the estimated distance between the mining site and the main island of Okinawa. It is possible that ores are processed at the closest island and transported to the existing smelters in Japan.

2.2.3. Recycling from end-of-life products (REC)

Materials considered for recycling in this study are copper scrap obtained from end-of-life home appliances. In this study, in order to avoid degradation of the quality of copper produced, all materials are processed to make copper cathode. No brass or wire will be produced in this recycling process. Product-to-product type recycling, or component reuse, is also not considered. The process flow is shown in Figure 1. In order to give a fair comparison, collection of end-of-life products through to refining copper is included. Data for the industrial processing steps are obtained from references (Ministry of Environment of Japan., 2011; Coelho and De Brito, 2013; Valero Navazo, Villalba Méndez and Talens Peiró, 2014). Table 3 lists the materials and assumptions used to estimate the material flows in the recycling process. Figure 8 shows the recycling process modelled in this study. End-of-life products are assumed to be collected as follows: end-of-life products will be brought in by consumers to household appliance retail stores around Japan. Retailers will then transport these items to the closest smelter where they are recycled to produce electric copper. This process flow is similar to the practical recycling process that operates under extended producer responsibility regulations in Japan. The smelting facility information is acquired from corporate websites (DOWA Holdings.; Mitsubishi Materials.; Mitsui Mining & Smelting.; Onahama Smelting and Refining.; Pan Pacific Copper.; Sumitomo Metal Mining.; Toho Zinc.). The smelting facilities are not always copper smelters, but are treated as such for the initial estimation. In real recycling processes, separation is an important component in ensuring quality and in terms of the energy and labor costs associated with the recycling process. According to the Ministry of Environment, end-of-life products contain a large amount of steel (Ministry of Environment of Japan., 2011). To remove steel from scrap, a magnetic separation process is applied. Then non-ferrous metals and plastics are separated by air separation. Finally, light metals such as aluminum and heavy metals such as copper are separated by density separation (Coelho and De Brito, 2013). Although the data in this reference are for construction and demolition waste, it is assumed that separating ferrous and non-ferrous materials use the same operations, which have been observed at recycling facilities.

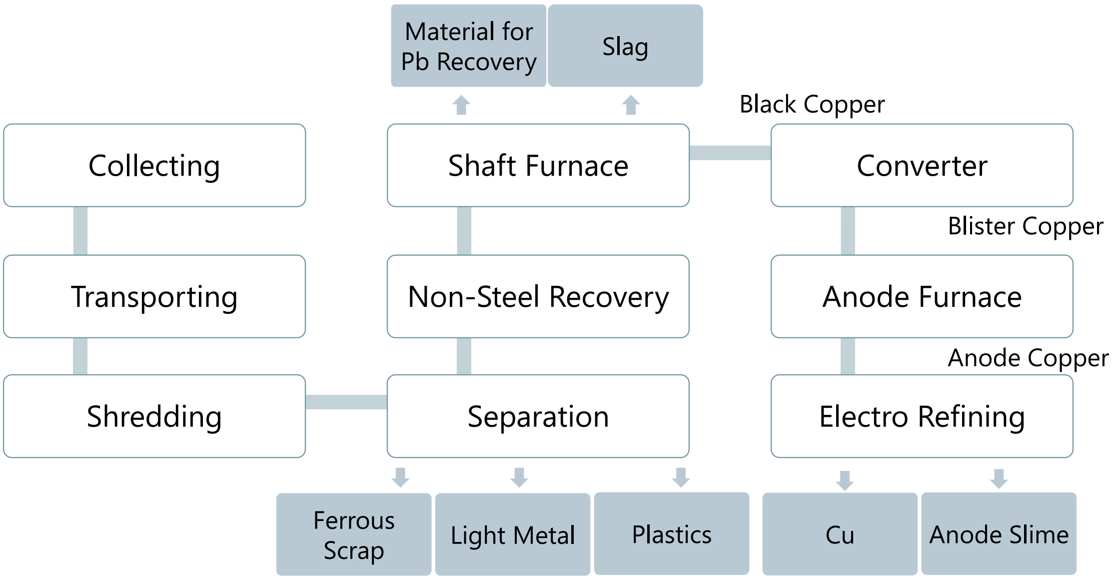


Figure 8 Recycling Process-All Material Recovery

2.3. Overall Assumptions

Although ore from deep ocean deposits is complex, polymetallic ore, this study estimates impacts on copper due to its wide application and importance for both clean energy technology and the economy. The mining site for deep ocean resources is considered to be the Izena Caldron, Okinawa, which is one of the target areas for DOM development. It is also assumed that end-of-life products, which are the source of scrap for recycling, are not exported and remain in Japan no matter what grade they are. It is not assumed that any importation of recyclable materials from other countries will occur.

As for macroeconomic indicators, it is assumed that copper demand in Japan is stable at the level it was in 2017, and GDP is the same as 2011 where the Input-Output table is based.

3. Environmental Implications of Resource Security Strategies for Critical Minerals: A Case Study of Copper in Japan

3.1. Introduction

Japan is a country that has widely been considered as particularly vulnerable to resource restriction, due to its heavy reliance on imported raw materials for fabricating metals to support its manufacturing export industries, with most of its historic mines having closed. For example, 100% of iron ore, copper, lead and zinc concentrates are imported (JOGMEC., 2017). These materials are processed into metals, from which a variety of products, such as automobiles, electrical and electronic equipment are produced. A certain proportion of these products are exported outside Japan, which leads to these metals not being 100% recoverable in the domestic material cycle by recycling. Japan has traditionally developed a range of strategies to improve resource security—including upstream development in resource-producing countries, recycling, stockpiling and research and development of alternative (substitute) materials (Government of Japan., 2018a). However, these approaches still rely on a variety of uncontrollable factors, which leads to the conclusion that domestic mineral production would be attractive if the possibility arose.

Recent discussions regarding resource security, besides those focusing on commodity price, can be divided into four broad categories: supply stability, environmental impact, stockpiling and nationalism (Gunn and Bloodworth, 2012; Lusty and Gunn, 2015). Supply stability includes consideration of self-sufficiency, import intensity or substitutability of materials and supplies, including recycling (De Ridder, 2013). These discussions focus in part on the promotion of independence from external circumstances, with differentiation between short-term risk and long-term risk. One commonly cited example is China’s rare earth element (REE) export restrictions that occurred around 2010 (Bradsher, 2010). At that time Japan was highly dependent on REE from China, and this restriction of supply from the dominant player in the market drove Japanese industries to reduce REE demand through a variety of measures. For example, Honda Motor Co. Ltd. started battery recycling to recover restricted metals, while Hitachi commercialized a rare metal-free motor (Hitachi., 2012; Honda Motor., 2012). This supply risk hit important minor metal components; however, if a similar restriction was to occur for base metals, the effects could be expected to be much broader and to last much longer. Environmental impact refers to factors related to reserves, ore grades, energy consumption or wastes. These are factors potentially affecting the long-term sustainable development of resource exporting countries, which have been posited as potentially reducing cumulative production through direct restrictions on environmental damage or loss of social license (Prior *et al.*, 2013). In recent years, climate change has also been seen as having a potential effect on resource supply (Pearce *et al.*, 2011), with unpredictability due to climate change possibly threatening resource security. Stockpiling indicates a temporary alternative to help buffer the impact of supply restriction, but is only valid for addressing short-term risks. Nationalism, in this study, refers to resource nationalism, which is the restriction of exports in order to ensure domestic supply, or increasing export tariffs or applying other measures in order to obtain higher domestic benefit from resources. Resource nationalism has been seen to occur in or among resource-rich countries, particularly developing countries. Resource nationalism factors indicate both risk and driving forces, affecting both short-term and long-term supply (Bremmer and Johnston, 2009). One recent example is the raw material export ban in Indonesia. Under this regulation, the export of unprocessed ores such as nickel or copper ores was prohibited, in order to improve their economy in 2014. Subsequently, nickel ore was not exported until 2017, while copper ore was exported under transition measures. This policy changed in 2017 and these materials could again be exported from 2017 (Warburton, 2017).

Examining resource security indicators from another perspective, they can be divided into factors that are focused on either the importer or the exporter. Importers are able to deal with the aspects of stable supply and stockpiling, but environmental impacts in producing countries and resource nationalism are largely out of the control of importers. These various factors need to be considered when mineral supply and risk reduction strategies are proposed.

3.2. Research Objectives

This chapter aims to examine alternative resource supply strategies for Japan by assessing the primary domestic environmental implications, which are related to a potential risk factor for guaranteeing supply, but also have not placed sufficient attention on differentiated impacts of alternative production routes in Japan particularly. Alternative resource supply strategies aim to improve resource security. Copper is used as a case study to be discussed in this study, as it is a metal that is vital to many industries in Japan and globally. It has been examined as a potential critical mineral, and although the level of criticality is deemed to be low, it is an essential mineral to Japan’s economy. This assessment is part of on-going resource security framework development process.

3.3. Methodology

To evaluate the environmental impacts, material flow analysis is employed to this chapter. As explained in chapter 2, input materials and output products/waste will be investigated across the supply chain for alternative resource provision. Input data for each methodology is collected from various references.

3.3.1. Conventional processing

The process considered here is from mining to electro-refining using a flash furnace and converting furnace. Although the energy and material consumed in Japan is only considered to be from transportation to refining, the impacts of mining and concentration processes are also evaluated for comparison with deep ocean mining. The distance between resource exporting countries and Japan is the total copper content weighted average of distances from major ports in source countries and is based on Japan's imports from 2017 (Ministry of Finance of Japan.). Electricity usage in mining, CO_2 emissions intensity in mining and concentration processes are based on a Chilean case in this study, since Chile shares 44% on a mass basis, and 38% on a monetary basis of Japanese copper concentrate imports in 2017 (Ministry of Finance of Japan., 2019). Summary data for the conventional process route are shown in Table 2.

It should be noted that energy for crushing is generally included in the concentration process, but in deep ocean mining it is categorized as a mining process, as most crushing is done on the seafloor. This leads to some difference when comparing on a stage-by-stage basis but does not affect the overall values.

Waste from the conventional mining and concentration process, which is produced outside Japan, can be estimated by the following equations (Rankin, 2011). On the basis of 1 tonne of unmined ore;

$$Waste\ from\ mining\ process(tonne/tonne\ ore) = W + (1 - R_M) \tag{1}$$

$$Waste\ from\ concentration\ process(tonne/tonne\ ore) = R_M - \frac{G_O R_M R_C}{G_C} \tag{2}$$

where W is the stripping ratio, RM is the recovery rate for mining, GO is ore grade, RC is recovery rate for concentration, GC is the concentrate grade. These parameters are determined from reference (Rankin, 2011).

Table 2 Materials and Assumptions for the Conventional Copper Process

Factor	Data	Units	Reference
Mining			
Ore grade	0.5	%	(Koppelaar and Koppelaar)
Stripping ratio	3	-	(Rankin, 2011)
Recovery rate	90	%	(Rankin, 2011)
Energy			
Mining (51% electricity)	13,700	MJ/t	(Chilean Copper Comission, 2015; Koppelaar and Koppelaar, 2016)
Crushing (electricity)	1800	MJ/t	(Koppelaar and Koppelaar)
Concentration			
Concentrate grade	30	%	(Davenport, King and Biswas, 1996)
Recovery rate	85	%	(Rankin, 2011)
Energy (Electricity) (Cu-Only)			
Grinding	11,900	MJ/t	(Koppelaar and Koppelaar)
Flotation	4100	MJ/t	(Koppelaar and Koppelaar)
Transportation			
Distance	12,400	km	(Ministry of Finance of Japan.) *
Energy (Diesel)			
Energy consumption	0.00131	L/t-km	(Japan Environmental Management Association for Industry)
Smelting (Flash Furnace, Convert Furnace, Anode Furnace) and Refining			
Both energy and materials input data are obtained from **Gößling** (2001).			(Gößling, 2001)
CO_2 Emission Intensity	0.00019	t-CO_2/kWh	(International Energy Agency., 2017)

*: distance is the weighted average of Japan's copper concentrate trade partners.

3.3.2. Deep Ocean Mining

As SMS deposits are polymetallic, it is possible that mining can be specifically for copper recovery or for multiple mineral recovery—in fact, in many cases copper is more likely to be a coproduct. This study focuses on copper production, but we consider the allocation of mining and other processing activities that are shared across various potential mineral streams as per standard LCA procedures. In the 'DOM Cu-Only' case, all the impacts (energy consumed, etc.) are allocated to copper recovery, with no other metals assumed to be produced. This applies to the energy for mining, and transportation, as from concentration onwards, the energy for each metal is for dedicated processes so there is no need to consider allocation. In the smelting and refining stages, by-products produced from copper concentrate are produced (including other base metals as well as minor elements and slag). These are potentially of commercial interest, but are not considered as main product streams in this study, where the value of recovered metals is used, it is only for the purpose of allocation of shared processing stages. In the 'DOM Multiple' case, copper is produced in conjunction with zinc and lead as shown in Table 2. Energy for mining and transportation, and wastes are allocated according to mass balance. Energy for smelting and refining is also allocated considering by-products.

In both cases, energy for concentration is estimated as being composed of two parts: grinding and froth flotation. Energy for grinding can be estimated by using the Bond work index of 13.9 kwh/t-ore. This index is estimated as the average of the work index of grinding ores which contain pyrite, sphalerite and galena previously produced in Japan, and which have been considered to be similar to deep ocean sulfide ores (Fushimi *et al.*, 1965). Feed size and product size are 40 mm and 5 μm, respectively [64]. Froth flotation is assumed to consume 7.5 kwh/t-ore (Norgate and Haque, 2010).

Ore from the deep ocean will be processed in pyro-metallurgical process plants which already exist in Japan. On the other hand, mining and concentration processes require new facilities since base metal mining ended decades ago in Japan. Reference data were obtained from literature (Davenport, King and Biswas, 1996; Gößling, 2001; Norgate and Haque, 2010; Agency for Natural Resource and Energy of Japan., 2013; JOGMEC., 2016; Ministry of Land Infrastructure Transportation and Tourism of Japan., 2018). **Table 3** shows the energy requirement for concentration processes for deep ocean mining in this study. It should be noted that the literature on which this is based uses an initial copper ore grade of 0.5% although the actual surveyed DOM ore grade is closer to 0.4%. It is assumed that the energy requirement is not significantly different between 0.4% and 0.5%.

Table 3 Materials for Deep Ocean Mining

Factor	Data	Units	Reference
Mining			
Depth	1600	m	(Agency for Natural Resource and Energy of Japan., 2013)
Vessel			
Dynamic Positioning System	25,200	kW	(Agency for Natural Resource and Energy of Japan., 2013)
Mining Unit	1000	kW	(Agency for Natural Resource and Energy of Japan., 2013)
Water Pump	2770	kW	(Agency for Natural Resource and Energy of Japan., 2013)
Hourly Mined Ore	210	t	(Agency for Natural Resource and Energy of Japan., 2013)
Ore Grade			
Copper	0.4	%	(JOGMEC., 2016)
Lead	1.4	%	(JOGMEC., 2016)
Zinc	5.8	%	(JOGMEC., 2016)
Transportation			
Distance	100	km	*
Energy consumption	0.012	L/t-km	(Ministry of Land Infrastructure Transportation and Tourism of Japan., 2018)
Concentration			
Concentrate Grade	30	%	(Davenport, King and Biswas, 1996)
Energy			
Grinding	41,000	MJ/t	**
Flotation	7600	MJ/t	(Norgate and Haque, 2010)
Materials Input	Data of Bagdad Copper, Arizona State, USA		(Davenport, King and Biswas, 1996)
Smelting (Flash Furnace, Convert Smelting, Anode Smelting) and Refining			
Both energy and materials input data are obtained from Gößling (2001).			(Gößling, 2001)

*: distance indicates distance from the mining site to the closest island. **: based on the Bond work index.

3.3.3. Recycling

Materials considered for recycling in this study are copper scrap obtained from end-of-life home appliances. In this study, in order to avoid degradation of the quality of copper produced, all materials are considered to be processed to make copper cathode.

The average minimum distance (dmin) between retail shops and smelters across Japan. The distance between smelters and retailers was estimated using the Google Maps API Directions Matrix. This distance indicates actual road transportation. In total, 245 retail shops were sampled randomly (from over 4000 national shops) from the major cities in Japan. The closest smelters from each retailer were chosen and the average minimum distance calculated. These major cities are home to most of the population, thus the estimated distances are considered to be indicative (but not precise measures) of the actual weighted average of transportation. Non-ferrous metal processing smelters were chosen in this study. Smelters and retailers in Japan are shown in Figure A 1.

Energy for transportation is estimated by applying energy consumption factors on the basis of net ton-kilometers (ntk). All transportation is assumed to be conducted by road using 4 t diesel trucks, and specific instances where sea transport would be a practical requirement (such as Okinawa) are not considered. Energy consumption for transportation is estimated by Equation (3):

$$\mathrm{e} = w \times d_{min} \times f \times h \tag{3}$$

where e is energy consumption, w is weight of end-of-life products, d_{min} is distance from retailer to the closest smelter, f is fuel use per unit (L/t-km). In this study, 0.0686 (L/t-km) which is typical of a 4 ton diesel truck with 80% loading rate is applied, while the fuel heating value per unit, h, is 38.2 GJ/kL with these values being based on Japan's standard ton-kilometer method (Agency for Natural Resource and Energy of Japan.). Energy consumption for households bringing their end-of-life products to the retail shop is not considered, as the variability in potential transportation modes and distances is very diverse. Actual energy consumption is therefore likely to be greater than this estimation, making it an optimistic estimate. It is assumed that copper is contained in end-of-life product by 2.5%, thus 40 t of end-of-life products need to be collected to produce 1 t of recycled copper (at 100% recovery rate) (Ministry of Environment of Japan., 2011).

The recycling scenarios, like polymetallic ores, can be divided into two categories: copper recovery only (REC Cu Only) and all material recovery (REC All Materials). The two scenarios require different allocation of the environmental impacts, whereby in the former case all materials other than copper are categorized as waste, and thus have no energy or environmental impact allocated to them, with 100% of energy for transportation and concentration consumed for copper recovery. Energy for smelting and refining is used entirely for the production of copper since this study considered slag and anode slimes to be wastes. The REC All Materials scenario indicates the situation in which all materials will be recovered. Energy for all processes are therefore allocated according to the mass in the relevant feed stream. Recovered plastics are used as fuel and coke (Valero Navazo, Villalba Méndez and Talens Peiró, 2014), and no material will be counted as waste in raw material collection. The heat value shown in Table 3 is calculated based on Japan’s plastic production in 2017 (Plastic Waste Management Institute., 2016; The Japan Plastics Industry Federation., 2017). On the other hand, downstream energy for smelting and refining will not change due to allocation.

In both cases, the work referenced here assumed a copper content of 12.9%. In this case study, however, copper in the feed material is 7.8% after separating other materials (Ministry of Environment of Japan., 2011). This study assumes the material compositions of not only copper but also other materials are as per the referred work for input streams, thus some additional processes to concentrate copper content would practically be required, although these are not evaluated as it is assumed that they will not contribute significantly to overall energy consumption. The additional mass stream from this theoretical separation process is allocated as waste.

Table 4 Materials for Recycling

Factor	Data	Units	Reference
Transportation			
Collected E-O-L products	40	t	(Ministry of Environment of Japan., 2011)
Copper contained	1	%	(Ministry of Environment of Japan., 2011)
Energy (diesel)	14,600	MJ/t-Cu	*
Distance	170	km	**
Concentration			
Energy (electricity) (Cu-Only case)			
Shredding	1100	MJ/t-Cu	(Valero Navazo, Villalba Méndez and Talens Peiró, 2014)
Magnetic Separation			
Magnet	1.5	MJ/t-Cu	(Coelho and De Brito, 2013)
Air Separation	5.0	MJ/t-Cu	(Coelho and De Brito, 2013)
Metal Separation	3.8	MJ/t-Cu	(Coelho and De Brito, 2013)
Density Separation	54.4	MJ/t-Cu	(Coelho and De Brito, 2013)
Conveyor	1.5	MJ/t-Cu	(Coelho and De Brito, 2013)
Smelting(Reduction Furnace, Oxidation Furnace) and Refining			
Energy and materials input data obtained from Navazo et al. (2016).			(Valero Navazo, Villalba Méndez and Talens Peiró, 2014)
Heating value of plastics	44.4	MJ/kg	(Plastic Waste Management Institute., 2016; The Japan Plastics Industry Federation., 2017)

*: Calculated by Equation (3). **: Calculated by Google Maps API.

3.3.4. Resource Security

Based on previous research (discussed earlier), in this study, resource security for long-term sustainable supply is evaluated considering the following factors: substitutability, energy consumption, CO_2 emissions, and waste disposal. Substitutability in this context describes the ability to substitute the supply of raw material from imported material to domestic material. Environmental factors may become more significant in the future, especially considering low grade ore development, effecting energy use, waste and emissions. Waste disposal has not been a recent issue for metal production in Japan, but in the selection of alternative sources it may become a more prominent issue as the available land is scarce and the geological stability is uncertain.

3.3.5. Sensitivity Analysis

As a sensitivity analysis, various shares of deep ocean mining are considered. This analysis assumes that conventional copper processing and recycling fill any demand gap between the available production from deep ocean mining. "Demand" is estimated as the average copper demand in Japan from 2001 to 2016. Copper demand in Japan includes domestic demand and export demand. The potential collectable recycling material is assumed to be the same as average domestic demand in Japan from 2001 to 2016. The demand breakdown is shown in Table 5. Demand is provided for by DOM as a priority. For instance, when deep ocean mining produces 10% of demand, the remainder will be produced by conventional and recycling copper processes. Various mixes of supply, from 100% conventional to mixes containing primarily DOM are considered, and the range of energy consumption, CO_2 emissions and waste disposal is examined. While it is assumed that DOM can supply up to 100% of demand, there is a limit on the amount that can be supplied by recycling (up to 100% of the domestic component of demand), so in cases where recycling cannot fill the total remaining demand, conventional supply is used to fill the gap.

Table 5 Overall demand for materials—basis for analysis

Factor	**Data (ktpa)**	**Data Range**	**Reference**
Demand in Japan	1500	Average between 2001–2016	(METI.)
Domestic demand	1100	Average between 2001–2016	(METI.)
Export	400	Average between 2001–2016	(METI.)

3.4. Results

3.4.1. Process Energy and Mass Balances, CO_2 and Waste

Table 6 shows the major overall material and energy inputs for each process. Step-by-step energy consumption is shown in Table A 1 in the appendix. It can be seen that conventional copper processing consumes more energy than deep ocean mining, although more than half the energy of conventional processing is consumed in resource exporting countries in the mining stage. Although raw material inputs are small in the recycling process, a large amount of energy is consumed for transportation to acquire end-of-life products.

Table 6 Inputs to each process per ton of copper metal

Inputs			**CONV**	**DOM Cu-Only**	**DOM All Material**	**REC Cu Only**	**REC All Material**
Raw Material	Ore	(t)	-	283.8	283.8	-	
	Concentrate	(t)	3.8	-		-	
	Scrap	(t)	-	-		22.4	22.4
Energy	Oil	(MJ)	13,700	149,300	12,300	146,000	600
	Natural Gas	(MJ)	3,800	3,800	3,800	10,100	1,300
	Electricity	(MJ)	26,100	50,000	3,900	5,500	1,700
	Total	(MJ)	43,600	203,100	20,100	21,000	3,200

a potential drawback of DOM (Motoori, Mclellan and Tezuka, 2015)

Table 7 shows the waste output from the domestic stages of mineral production. In the conventional process, mill tailings including waste rock shown in red indicate waste produced outside Japan. Waste from end-of-life products in the recycling process is included as mill tailings here. The amount of waste which is produced in Japan is very high for deep ocean mining and quite high for recycling (if only Cu is recovered). Although where and how to store the tailings are not considered in this study, monitoring tailings that contain harmful materials is a major environmental issue for resource producing countries—and has been noted as a potential drawback of DOM (Motoori, Mclellan and Tezuka, 2015)

Table 7. Waste outputs of each process.

Outputs			**CONV**	**DOM Cu-Only**	**DOM All Material**	**REC Cu Only**	**REC All Material**
Metal	Cathode Copper	(t)	1	1	1	1	1
Solid Waste	Mill Tailings	(t)	(620)	280.1	11.1	40	5.2
	Slag	(t)	2.7	2.7	0.1	3.2	0.4

Note: Mill tailings (including overburden) in the conventional process are produced in the resource exporting countries. These are not brought to Japan, but are included for comparison.

Figure 9 shows the energy consumption of the alternative mineral production routes. Cu-Only recovery from deep ocean mining consumes a very large amount of energy in the mining process, due to the low ore grade. When multiple materials are recovered (and thus the shared stage impacts are allocated across all target metals), less energy is consumed in mining and transportation process than conventional and the Cu-Only recycling copper process. According to the Agency for Natural Resources and Energy, deep ocean mining does not include crushing in the concentration stage, but rather it is accounted for in the mining process (Agency for Natural Resource and Energy of Japan., 2013). Thus, there is some interpretation required when examining the individual stage energy consumption, although the overall energy can be considered to be consistent. Deep ocean ores are often noted for having finer particle sizes, as well as being more refractory than terrestrial ores, thus potentially requiring finer grinding and subsequently more energy usage (Norgate and Haque, 2010). Based on the results, it can be stated that multiple material recovery will make deep ocean mining more competitive than the Cu-Only case. Smelting consumes less fuel energy in recycling partly because of the utilization of co-mingled plastics as a fuel source, as well as the fact that the reduction process is not needed for the recycled material. Note that only a very small amount of plastic is fed to the furnace while generally end-of-life products contain a large amount of plastics, which leaves the problem of how to deal with the remaining waste plastic stream. When the multiple-material recycling case is considered with allocation to the copper content, the energy consumption is quite small.

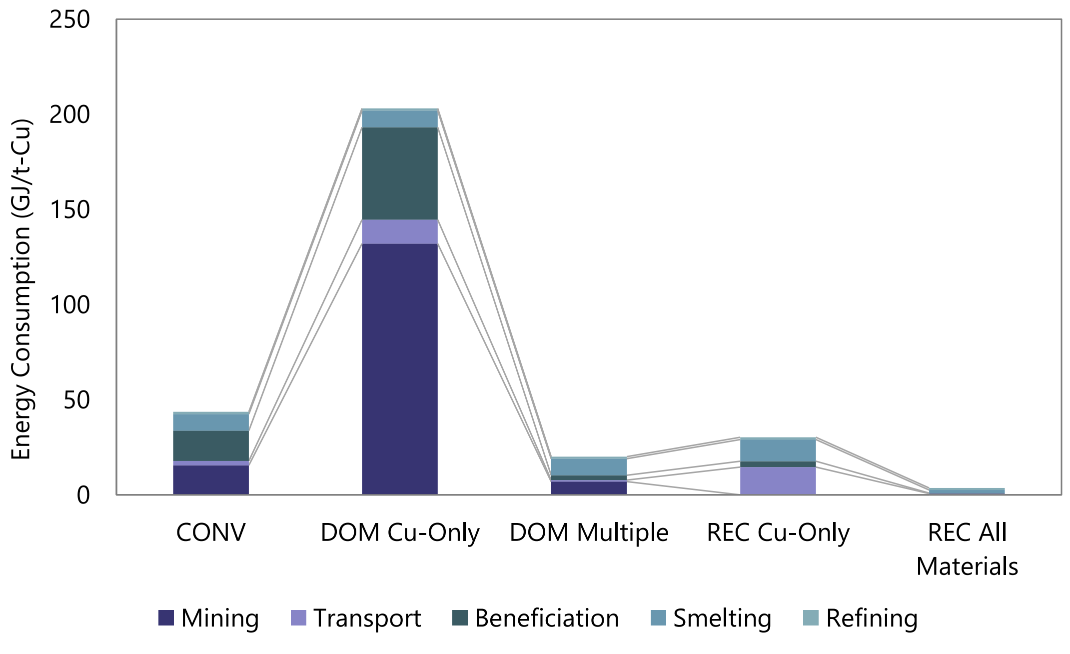


Figure 9. Energy Consumption of Domestic Mineral Production.

Figure 10 shows the CO_2 emissions for each option. The trend is similar to energy consumption shown in Figure 9 as the energy mixes for most stages are similar, while those stages relying on more CO_2-intensive energy sources are exacerbated. This has been noted as a weakness in the potential benefits of DOM (Mclellan, 2015).

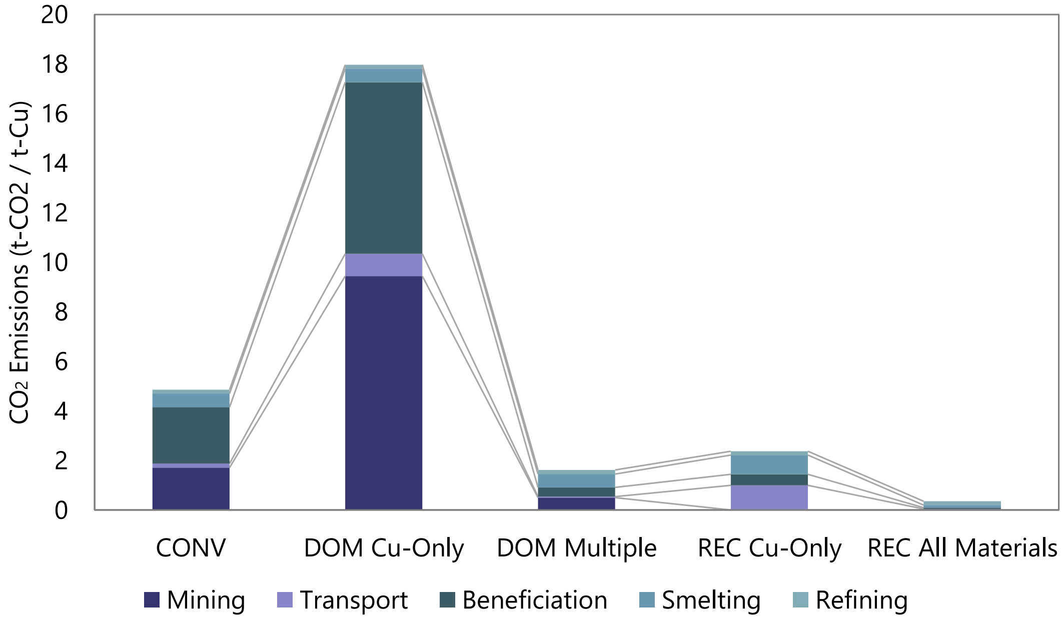


Figure 10. CO_2 Emissions of Domestic Mineral Production.

Figure 11 shows the waste from each option. Note that mill tailings or mine waste in resource exporting countries which is shown in the dotted line box does not count as waste in later analysis due to the focus on domestic environmental implications. In recycling, 'mill tailings' indicates non-copper materials as already mentioned. Waste from Cu-Only type deep ocean mining and recycling will be significant if materials excluding copper are dumped rather than valorised.

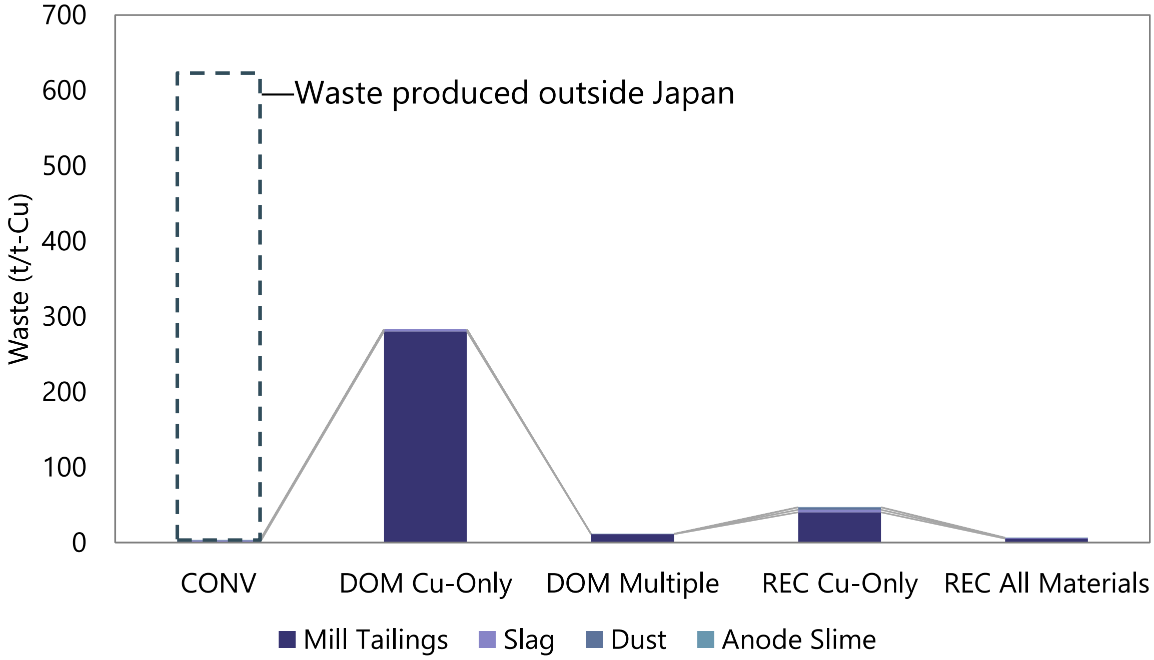


Figure 11. Waste from Domestic Mineral Production.

3.4.2. Optimal Solution of Resource Supply Strategy

The currently considered SMS deposits in Japan are very limited when compared with the annual material demand for copper. The overall size of SMS deposits is reported as inferred mineral resources of 7.4 million tons (JOGMEC., 2016). However, it is possible that known resources may expand with further exploration. How energy consumption would change if deep ocean mining were able to supply a greater component of the material requirement is shown in Figure 8. 'Conventional Oriented' in the figures indicates that conventional copper supply is used to fill the gap between the production of copper from deep ocean mining and total consumption, while 'Recycle Oriented' is the case in which recycling is utilized as a priority up to the limits imposed by the use of copper in exported products which may not be recovered, so conventional copper processing also supplies raw materials in this case where necessary. The minimum amount of energy consumption in this figure can be considered as the optimal solution for domestic mineral production.

The meshed area in each of the graphs indicates the potential zone of choice in which Japan can choose alternative low energy mixes under energy restrictions—where there is potential excess supply capacity from recycling (the lowest energy option) that can be utilized to fulfil demand. In the cases where only copper is recovered (in Figure 12 a,c), the minimum energy consumption point is at 0% of deep ocean mining. On the other hand, when multiple metals are recovered (in Figure 12 b,d) less energy consumption occurs when deep ocean mining is in the mix. Recycle-oriented supply cannot meet domestic demand due to supply capacity restrictions (some demand is exported). Due to this, conventional processing, which is a higher energy consuming method, is introduced to fill the supply gap. When recycling and deep ocean mining can meet the total demand, the conventional supply is no longer needed. This result is largely due to the LCA approach to allocation, but it is likely that real reductions are present at the overall system level.

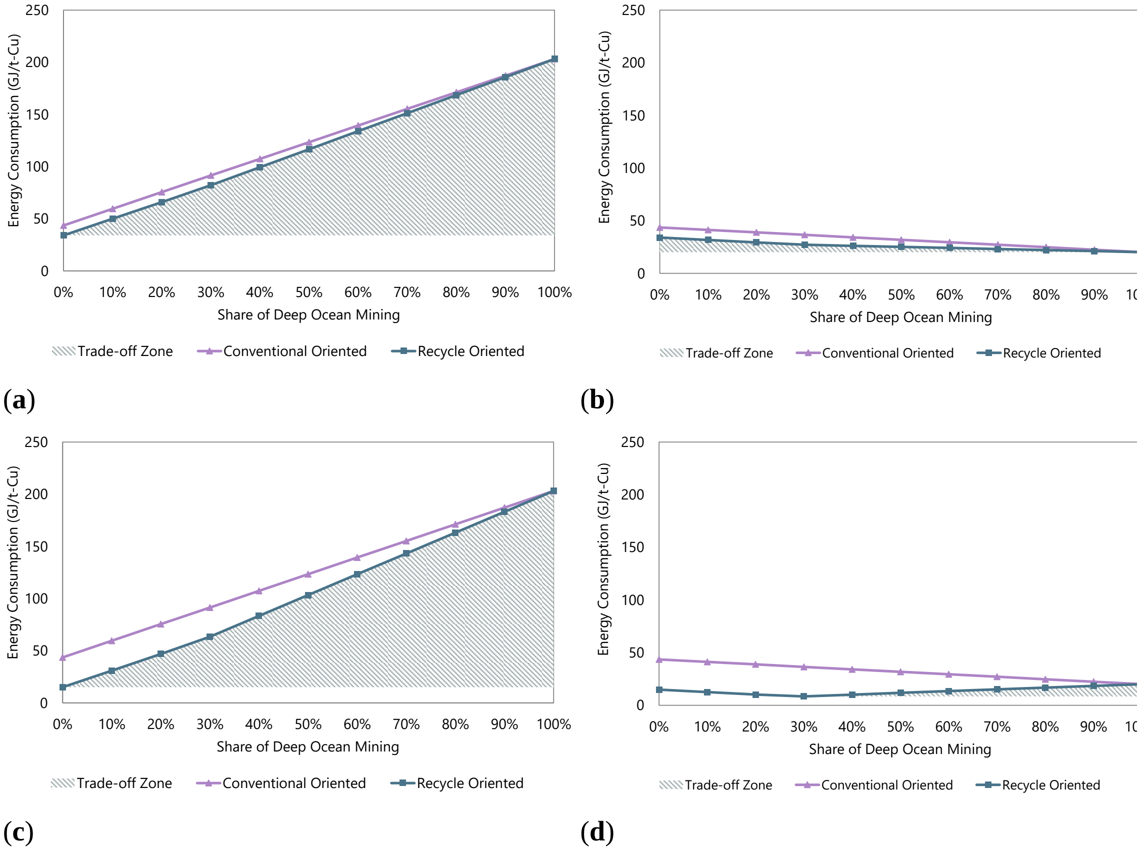


Figure 12. Deep Ocean Mining and Energy Consumption. (**a**) Cu-only recycling case; Cu-only recovery from DOM (**b**) Cu-only recycling case; Multiple recovery from DOM (**c**) All material recycling case; Cu-only recovery from DOM (**d**) All material recycling case; Multiple recovery from DOM.

The 30% deep ocean mining in case (d) consumes the least energy of the four options, and it can thus be said that this is the optimal solution for domestic mineral production in this study with regards to energy consumption. Due to the limits on the supply capacity from recycling, conventional copper processing which consumes more energy than REC All and DOM Multiple is introduced up until 30% production from deep ocean mining. From 30% of deep ocean mining onwards, conventional copper processing is not necessary to fill the demand and supply gap, so the lowest energy option of recycling can cover the remaining demand. For this reason, 30% deep ocean mining (in combination with 70% provision by recycling) can be considered as the optimal solution. The results for CO_2 emissions are shown in Figure 13, demonstrating, predictably, the same trends.

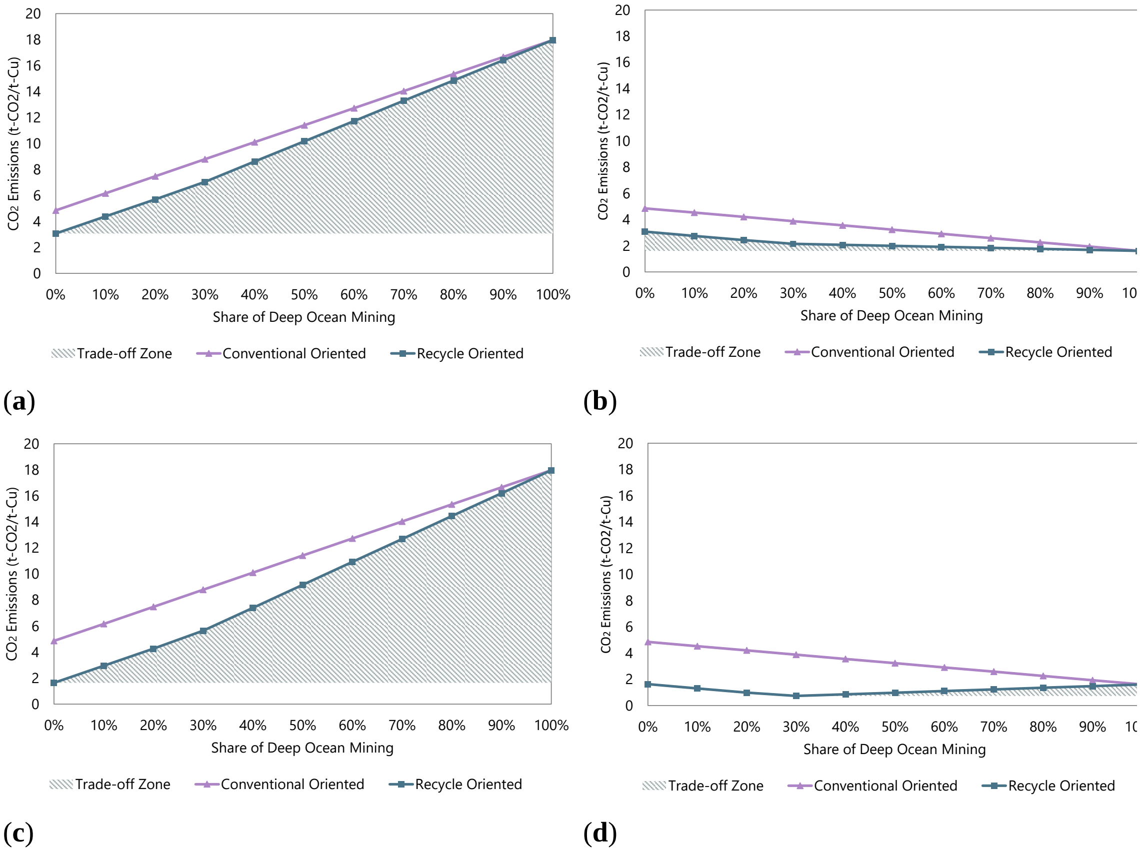


Figure 13. Deep Ocean Mining and CO_2 Emissions. (**a**) Cu-only recycling case; Cu-only recovery from DOM (**b**) Cu-only recycling case; Multiple recovery from DOM (**c**) All material recycling case; Cu-only recovery from DOM (**d**) All material recycling case; Multiple recovery from DOM.

The trend for waste disposal is also similar to energy consumption, as Figure 14 shows. The trends for the Cu-Only recovery from DOM cases are similar to the previous two indicators, although the conventional-oriented and recycle-oriented curves have switched places since, when it comes to waste, conventional copper processing produces less waste domestically in Japan. The multiple metal recovery cases show different trends—in (b) which represents Cu-only recovery from recycling and multiple-metal recovery from deep ocean mining a large amount of waste is produced up until 30% deep ocean mining, which is driven by the amount of tailings from Cu-Only recycling.

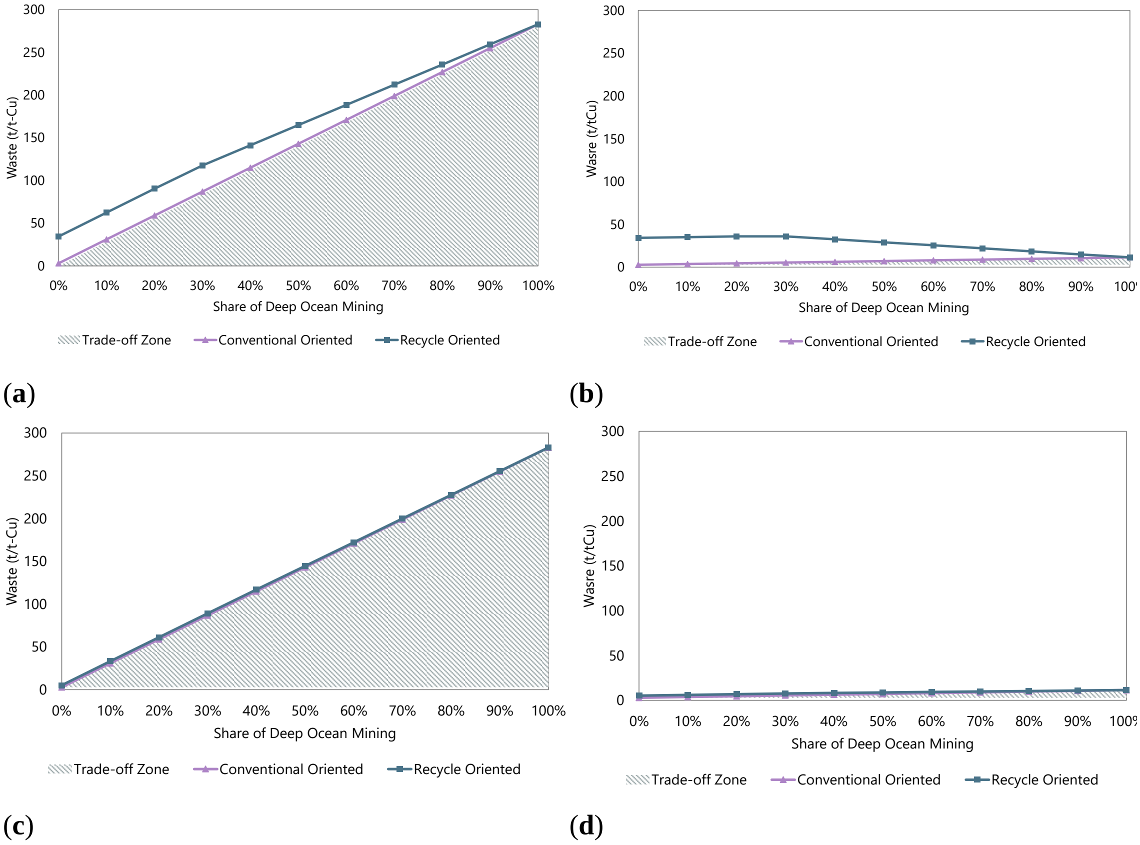


Figure 14. Deep Ocean Mining and Waste Disposal. (**a**) Cu-only recycling case; Cu-only recovery from DOM (**b**) Cu-only recycling case; Multiple recovery from DOM (**c**) All material recycling case; Cu-only recovery from DOM (**d**) All material recycling case; Multiple recovery from DOM.

3.4.3. Renewable Energy Installation

While considering the application of these technologies in the future, particularly in the context of national resource and energy security, the energy mix should also be discussed. Expanding the amount of renewable energy installed will affect the impacts from the mining sector - although there are limitations of renewable energy (denoted as RE from now on) usage. In this study, it is assumed that there are two steps to utilize renewable energy technology: the first is substituting conventionally produced electric energy to electric energy generated by renewables; the next is substituting fossil-fuel-based thermal energy to thermal energy generated by renewables. Table 8 shows which of the process stages are considered to have potential for conversion to renewables in the first step according to the utilized energy resources, with the substitution of thermal (T) and electrical (E) energy for the various processes in this study. Note that transportation in recycling originally uses oil products as a fuel but this is considered to be converted to electricity. This transition reflects recent expansion of electric vehicles, and their potential for greater utilization of RE (Iacobucci, McLellan and Tezuka, 2018; International Energy Agency., 2018). Importantly, in the first step, not all shipboard energy use can be substituted for renewables—notably the long distance transport for conventional import of concentrate and the mining energy for DOM. This reflects the current reality, in which it is highly non-feasible for large boats to use alternative fuels. Table 9 shows the possibility of energy conversion in the second step. This step focuses on substituting oil for other resources. Transport in conventional processing and mining in deep ocean mining are assumed to utilize biofuel; transport in deep ocean mining is assumed to use electric vessels, which have batteries charged using wind power, due to its greater proximity to the shore. Table 10 shows emission factors in each technology.

Table 8**.** Substituted Processes in Domestic Mineral Production Step 1 (* indicates solar-power-based electricity supplied for this operation, ** indicates wind power-based electricity supplied for this operation).

Transition	**Option**	**Process**
Electricity → Renewable Electricity	Conventional processing	Mining *
		Concentration **
		Smelting **
		Refining **
	Deep ocean mining	Concentration **
		Smelting **
		Refining **
	Recycling	Concentration **
		Smelting **
		Refining **
Oil → Renewable Electricity	Recycling	Transport **

Table 9. Substituted Processes in Domestic Mineral Production Step 2(** indicates wind power-based electricity supplied for this operation).

Transition	Option	Process
Oil → Biofuel	Conventional process	Mining Transport Smelting
	Deep ocean mining	Mining Smelting
Natural Gas → Biofuel	Conventional process	Smelting
	Deep ocean mining	Smelting
	Recycling	Smelting
Oil → Electricity	Deep ocean mining	Transport **

Table 10. Emission Factors by Technologies.

Technology	Emission Factor	Reference
Oil Fuel	69.3 kg-CO_2/MJ	(Ministry of Environment of Japan.)
Natural Gas	49.5 kg-CO_2/MJ	(Ministry of Environment of Japan.)
Electricity (Japan's grid mix)	0.512 kg-CO_2/kWh	(Ministry of Environment of Japan and Ministry of Economics and Trade of Japan, 2017)
Solar	0.038 kg-CO_2/kWh	(Imamura, Iuchi and Bando, 2016)
Wind	0.026 kg-CO_2/kWh	(Imamura, Iuchi and Bando, 2016)
Biofuel	0.0556 kg-CO_2/MJ	(IPCC, 2014)

RE is most readily utilized directly for electrical applications (McLellan *et al.*, 2012), while RE can also indirectly be converted to fuels (biofuel, hydrogen) which can be utilized in transportation or as thermal energy. This is relevant for understanding how much the results of emissions can be impacted by the energy mix. For example, the vessel for deep ocean mining does not have access to the electrical grid, and is likely to continue to use conventional fuels. Thus, it is assumed to be a non-RE process in the first step, with perhaps the only likely conversion being to the use of biofuel instead of oil. On the other hand, since conventional copper mines are land-based, it is easier for them to utilize RE. Based on this assumption, CO_2 emissions can change significantly with increased RE and thereby shift the order of results. Biomass fuel is chosen as an applied technology for thermal energy, which has been previously estimated as having potential to mitigate up to 65% of CO_2 emissions across the conventional minerals sectors (McLellan *et al.*, 2012). Hydrogen could be another technology for consideration for thermal processes, but is not evaluated here, while solar and wind are the assumed renewable electricity technologies for other processes. Note that the smelting process in both recycling options already utilises electrical furnaces, so biofuel is assumed not to be required in this process.

The obtained results are shown in Figure 15. CO_2 emissions from multiple metal recovery deep ocean mining are reduced by 54% while emissions from the conventional process are reduced by 28%.

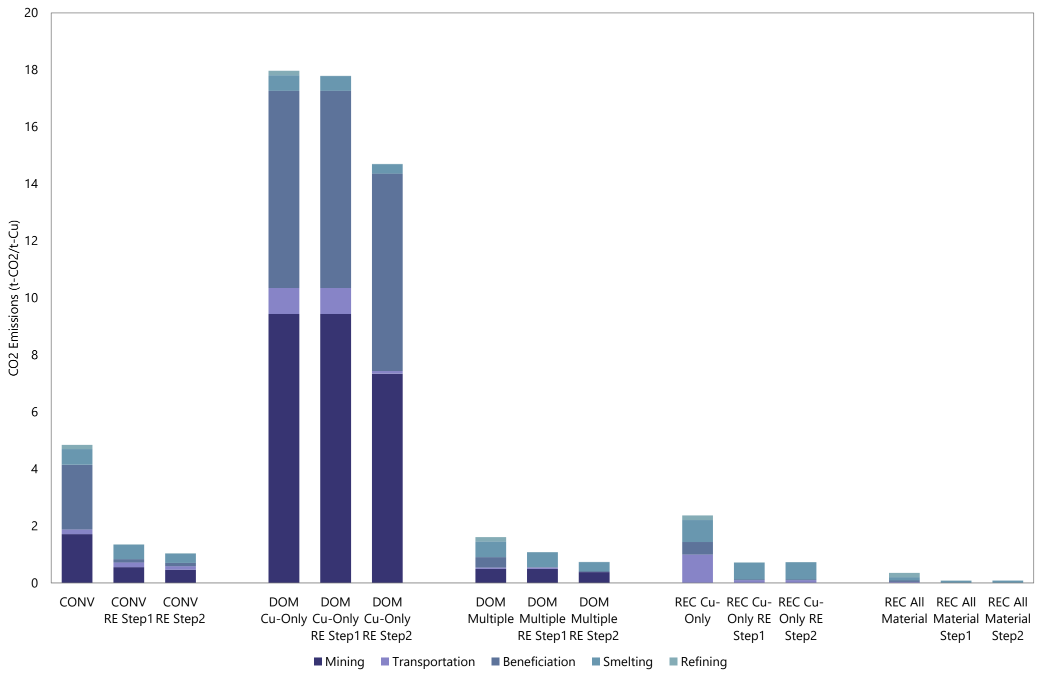


Figure 15. CO_2 Emissions Reduction Utilizing Renewable Energy.

3.4.4. Ore Grade Variation

Another element of the overall environmental impacts is the grade and complexity of mined ores. Generally, higher grade ore emits less waste during extraction and also affects energy consumption and CO_2 emissions significantly. In this study, energy consumption in different ore grades is examined as a sensitivity analysis. Currently it is reported that ore grade in deep ocean hydrothermal ore is 0.4% (Agency for Natural Resource and Energy of Japan., 2013). When higher grade ore is developed, the energy consumption of deep ocean mining will change as shown in Figure 16 and Figure 17. This study examined copper ore grades of 0.75%, 1% and 1.5%, and energy consumption data for concentration are obtained from Marsden (Marsden, 2008).

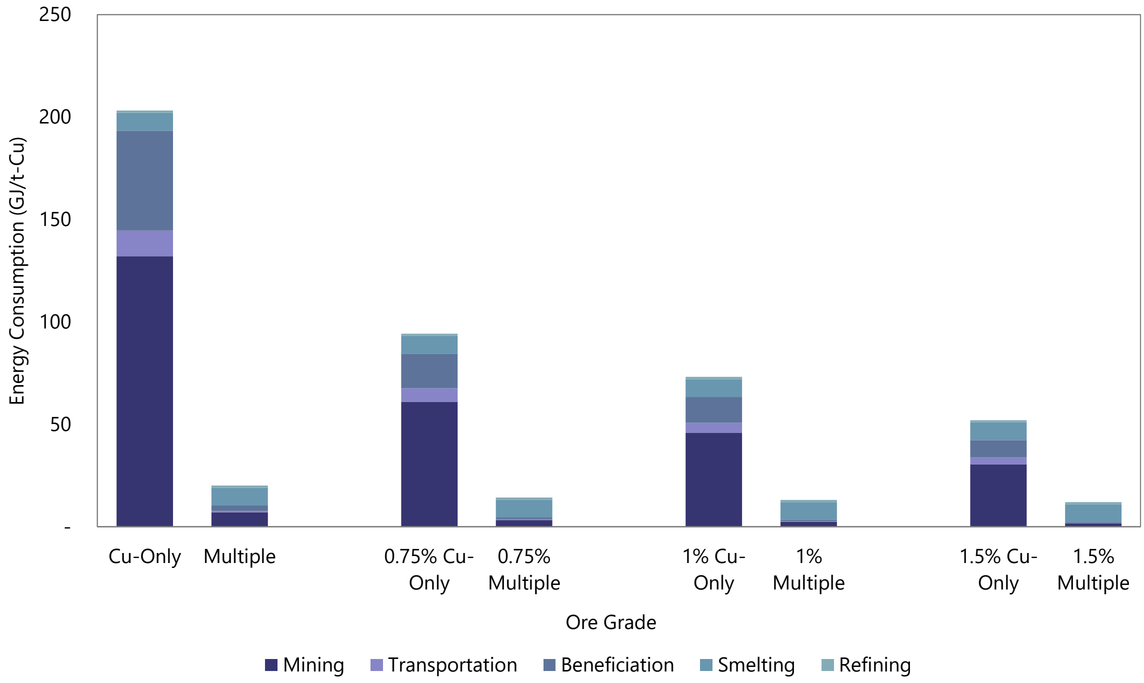


Figure 16. Energy Consumption in Higher Grade Ore.

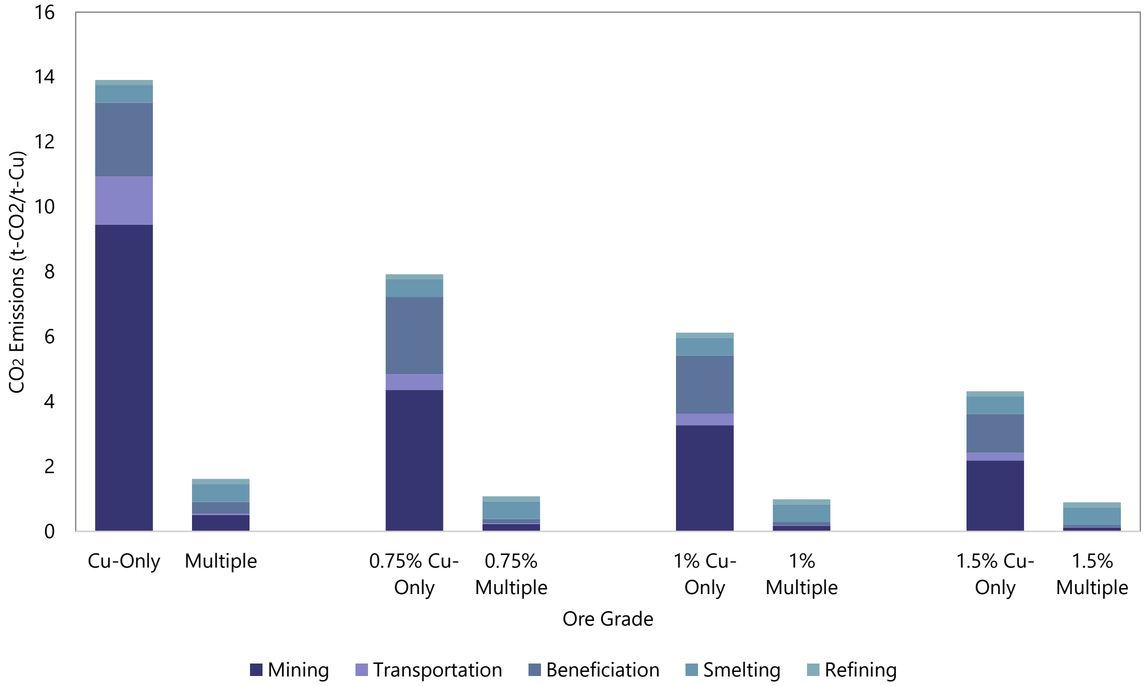


Figure 17. CO_2 Emissions in Higher Grade Ore.

Energy consumption in concentration is reduced by 50% when ore grade becomes 1.5% compared to the base case, showing slightly less than direct proportionality. Higher grade ore does not need as much transport and separation as those of waste material, thereby requiring less energy to produce the same amount of product. CO_2 emissions are also significantly reduced in higher grade ore extraction—especially in transportation.

Figure 18 shows the change in mill tailings in higher grade ore extraction. The actual amount of mill tailings domestically produced would be expected to be higher in deep ocean mining even if higher grade ore is extracted; however, it should also be considered that if only conventional copper processing is undertaken, this implies that waste disposal at resource producing countries still remains and end-of-life products will not be recycled, leading to an increase in waste. Thus, from the whole system perspective, conventional copper processing potentially disposes more waste than deep ocean mining. Additionally, utilizing deep ocean mining to supply 30% of demand, with recycling contributing the rest, which is the optimal point in Figure 8, can maintain disposal levels as conventional copper processing without potential unrecycled waste.

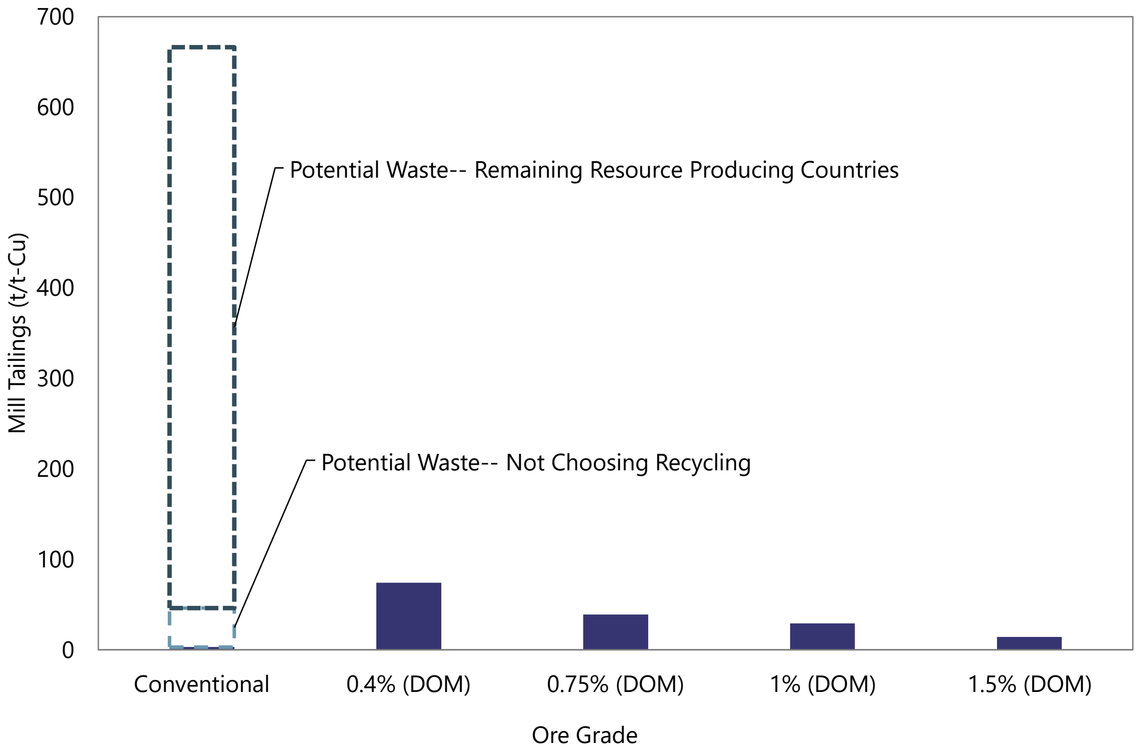


Figure 18. Waste Disposal from Higher Grade deep ocean Ore (Multiple Mineral Recovery).

3.4.5. Optimal Strategy Considering Resource Supply Capacity

Energy consumption, CO_2 emissions and waste disposal considering the practical supply capacity of raw materials in each strategy are shown in Figure 19. The results indicate the minimization of each impact by prioritizing the utilization of the minimum consumption/emission technology option based on production rate and limitation of raw material supply. Regarding waste, as discussed above, conventional copper processing disposes the smallest amount of waste and there is no practical limitation at this time. Thus, minimizing the waste results in 100% of raw material supply from conventional copper processing. However, examining the whole system, conventional copper processing includes approximately 40 t of waste due to not choosing end-of-life product recycling, which leads to recycling all material becoming the option producing the smallest amount of waste. The results indicate that prioritizing utilizing recycling material will result in the lowest energy consumption, CO_2 emissions, and waste disposal.

Overall, from the results obtained this study it can be concluded that the greatest fraction of copper being supplied by recycling will best improve resource security, while simultaneously improving the environmental impacts of waste and emissions, and reducing energy usage. Waste disposal in the case of conventional copper processing itself is small domestically, but in the total copper supply chain, the indirect impact of waste produced in resource exporting countries and waste produced by end-of-life products not being recycled will occur. This waste problem can be a driver to promote recycling, and runs counter to utilizing imported concentrate. Installing deep ocean mining requires the disposal of a significant amount of waste; however, utilizing it with recycling for material supply will maintain the total domestic disposal level in line with conventional copper processing.

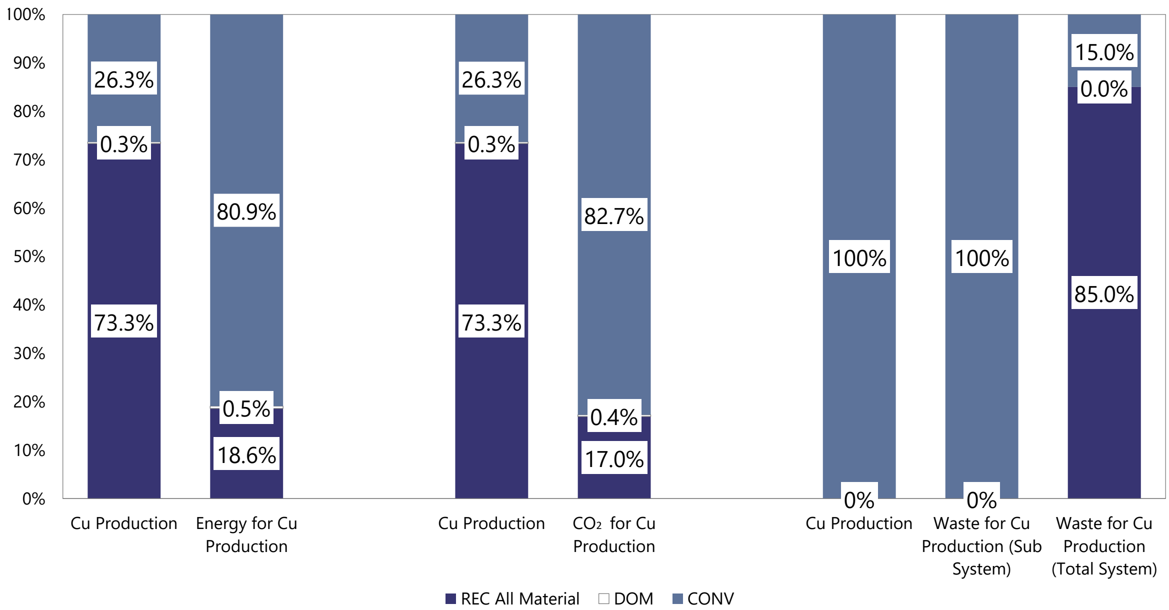


Figure 19. Optimized Energy Consumption, CO_2 Emissions and Waste Disposal.

3.5. Discussion

Resource policy in resource importing countries has historically tended to focus on upstream development in resource producing countries and downstream improvements including research and development on substitute materials. Unconventional resources in the form of recycled materials have been focused on by some, but primary unconventional resources of deep ocean minerals remain beyond the practical scope of most resource security evaluation, due to the uncertainties in extractive economics. However, considering the uncertainty of resource supply in the future, relying on resource producing countries is not an optimal solution from the perspective of long-term resource security. In this context, domestic mineral production is an important alternative to consider for future supply.

Domestic mineral production in this study focused on deep ocean mining; however, there are other possible alternative resources for resource importing countries such as the reopening of mines that were previously closed due to ore grade decline, safety or economics under previous eras` technology. It is possible that ore grades of closed mines may be higher than cut-off grades today, due to both the increase in prices and the improvement in technology. When countries whose resource policy previously changed from producing domestically to importing concentrate shift their policy again to restarting-mining, the issues of tailings, localized environmental impacts and energy consumption issues arise.

Since tailings, which possibly include harmful materials such as cadmium, arsenic or mercury, need to be stored in safe and stable environments and require long-term monitoring, this could be a significant issue to be traded-off against resource security benefits of domestic mining. The volume of tailings dams should be considered as well. Generally speaking, the lower the ore grade becomes, the more tailings are produced. When unconventional mining or redevelopment of closed mines occurs, ore grades are unlikely to be very high. Environmental impacts related to tailings storage need to be understood and evaluated. It should be noted that in the whole mineral supply chain, conventional processing produces more waste since deep ocean mining does not have waste rock. Because Japan does not import and process ore, waste rock and mill tailings from conventional mining become hidden waste streams. Considered from a global perspective, deep ocean mining may contribute to reduce waste from the mining process. Other solid wastes such as plastics or other minerals are not explicitly discussed in this study; however, how to deal with this kind of waste should also be considered—particularly when polymetallic ores or mingled recycling streams are considered. It is estimated that recycling will practically produce less waste than shown here, since this study does not consider recovery from waste except copper.

Energy consumption is another issue to be discussed. The results show that the conventional copper process consumes more energy than recycling or multiple metal recovery from deep ocean mining, when considering the whole supply chain. A key factor for developing a competitive strategy in terms of energy consumption is multiple metal production from either deep ocean mining or recycling. As shown in Figure 9, from the environmental perspective, only producing copper from deep ocean mining will never be a competitive option for domestic mineral production, but co-production with other metals from the polymetallic ores (e.g., zinc, lead, gold and silver) will not only reduce energy consumption allocated to each metal in mining, but also improve resource security. Energy consumption in resource importing countries includes transportation, smelting and refining, though roughly as much energy is consumed in resource exporting countries. As for recycling, since China will stop importing copper scrap by the end of 2018 [40], the necessity for copper scrap recycling in domestic facilities will increase in Japan. Japan has long been struggling to secure its energy supply—especially after the nuclear power plant shut down in 2011. As recycling is further improved, Japan has to find alternative, secure energy resources to maintain its mineral production, along with the remainder of its economy. Japan has been trying to reduce energy demand for a long time, and while promoting mineral recycling may result in energy consumption decrease, and continue Japan's declining energy demand trend, deep ocean mining would impact adversely on energy consumption. On the other hand, even if recycling were to become a dominant raw material supply stream, it still consumes imported energy. Renewable energy technology installation is therefore one of the requirements to achieve a more resource-secure society.

By minimizing energy consumption, CO_2 emissions and waste disposal based on the capacity limitations of each supply source, it is indicated that installing processes that recover all materials from recycling on a priority basis will reduce these impacts significantly. If large-scale deep ocean mining extraction is conducted, it is obvious that this type of material supply can improve resource security significantly. However, as shown in the results, the optimal solution found in this study was utilizing deep ocean mining at a level of 30% of raw material supply if all metals are recovered from the ore, with the rest of demand filled by recycling. Even though there are some challenges, such as how to find more deep ocean hydrothermal ore (particularly higher grade ore), it can be said that realizing domestic mineral production could help to achieve stable resource supply for Japan.

It can be concluded that: (1) domestic mineral production is one option to obtain resources so as to avoid vulnerability of external affairs. Supply controllability of domestic mineral production should be a key factor in evaluating the sustainability of supply; and (2), based on supply capacity, enterprises, installing recycling will improve resource security while also enabling better performance in terms of energy consumption, CO_2 emissions and waste disposal. Considered within the framework of criticality, the combination of pressures from increasing demand globally with potential lags in primary supply could promote domestic mineral production. On the other hand, domestic production environmental implications could work to restrict their output or development, increasing the mineral criticality. For countries considering such options for reducing supply risk, the environmental considerations should also be factored in.

3.6. Conclusions

The main objective of this chapter is to examine alternative resource supply strategies for Japan and their environmental impacts, in order to consider the implications of resource security approaches for critical minerals. Evaluating the extraction of copper (a critical mineral for Japan), especially including shifts further upstream in the supply chain in order to provide resource security in a resource importing country like Japan, and the environmental implications of resource security strategies is considered to be a point of novelty of this study. The key result of this study is that expansion of recycling to the largest extent possible is indicated to be the optimal option to improve resource security, while also enabling better performance in terms of energy consumption, CO_2 emissions and waste disposal. The aspect of waste disposal may be a critical barrier for deep ocean mining in a country like Japan that is highly seismically active and has minimal available space for storing tailings.

Future supply of critical minerals is subject to various uncertainties, such as demand increase in developing countries or environmental regulations. This study focuses on domestic mineral production as a means of reducing vulnerability to import restrictions resulting from this kind of supply risk. The results show that deep ocean mining processes consume more energy than conventional copper processing, when only the production of copper is considered, and when only the domestic components of energy are taken into account. When recycling copper from end-of-life home appliances is conducted with the effective valorization of all materials, energy consumption and CO_2 emissions are significantly lower than the other options examined in this study.

The optimal mix of domestic production regarding energy consumption and CO_2 emissions will rely on 70% supply from recycling with deep ocean mining and co-production of all valuable metals making up as much as possible of the remainder, and conventional copper processing the remainder based on current production capacity. When recycling of all the materials is conducted, waste disposal from domestic mineral production is the same as introducing conventional copper processing if no waste is consequently recycled. Large-scale ore or higher grade ore extraction will change the priority of raw material supply of conventional copper processing but the optimum still remains at 30% deep ocean ore in terms of energy consumption and CO_2 emissions.

Application of renewable energy is one solution to realize domestic mineral production in a way that also promotes energy security and reduces CO_2 emissions. However, by maximizing deep ocean mining, there will be a consequent increase in solid waste unless conducting higher grade ore extraction.

4. Resource Security Strategies and Their Environmental and Economic Implications: A Case Study of Copper Production in Japan

4.1. Introduction

This chapter focuses on the effects of domestic copper production and recycling in Japan. Copper is selected from among the group of critical materials as it has many applications and demand is expected to increase due to expanded renewable energy deployment such as CIGS photovoltaic panel and CIS (copper (C), indium (I) and selenium (S)) photovoltaic panel(La Porta *et al.*, 2017). Recently, the United States published a federal strategy, which focuses on the improvement of critical mineral supply by: Identifying new sources of critical minerals, enhancing activity at all levels of the supply chain, seeking to stimulate private sector investment and growth of domestic downstream value-added processing and manufacturing, ensuring that miners, producers, and land managers have access to the most advanced mapping data; and outlining a path to streamline leasing and permitting processes in a safe and environmentally responsible manner (Government of Japan., 2018b). Resource acquisition options for an import-reliant country include (1) on-land mining, (2) imports of raw materials, (3) recycling, and (4) unconventional resource exploration. In the context of Japan, because of its lack of on-land mines, option (1) is unlikely. In terms of improving resource security, option (2) does not relieve the vulnerability to export restrictions by exporting countries. Lacking known deposits on land or near shore, development of domestic primary production is focused on ore production by means of deep ocean seafloor massive sulfide (SMS) mining. Thus, recycling and deep sea mining (which is a subset of option (4)) are the options to be discussed in this study.

This study aims to assess the constraints of energy, material, economic and labor under domestic mineral production.

4.2. Research Objectives

This study aims to contribute to the debate surrounding resource security for nations reliant on raw material imports, and to specifically investigate recycling approaches, deep ocean mining, and a combination of the two. This approach is applicable to not only copper but also other non-ferrous minerals. Copper has been chosen as a case study because of following reasons. Lead, which is used in applications such as automobile batteries or large-scale batteries, is already recycled effectively, giving only marginal potential for improvement. On the other hand, zinc is typically used in alloys, or for additives in galvanization or paints or as sacrificial anodes, which can be considered dissipative uses. Generally speaking, it is difficult to recover zinc metal by itself, but it is recovered in the steel recycling process. Unlike these metals, copper is used as the main material in products, in relatively pure form, and there is still room for improvement in recycling rates. Copper is therefore chosen as a case study, although this approach could be applied to these and other metals that are found in unconventional ore deposits.

4.3. Methodology

This study focuses on domestic mineral production in Japan as primary ore via deep ocean mining or as secondary material from recycling. In order to elucidate the energy, material, economic and labor flows, input-output analysis and material flow analysis will be employed in this study. The system boundary considered in this study is shown in Figure 5. Copper production is dependent on (A) the import of raw material, and domestic mineral production including: (B) Deep ocean mining and (C) end-of-life product recycling.

Detailed processes are shown in Figure 20. Due to the fact that both imported ores and domestic ores are sulfides, it is possible to utilize the same smelting facilities. As each production process will produce refined copper, the focus of this study, there are considered to be no quality issues that could prevent certain sectors from utilizing copper. The scope of this study is specific to the copper production process, while further processing for manufacturing electrical wire, brass or automobiles is not considered.

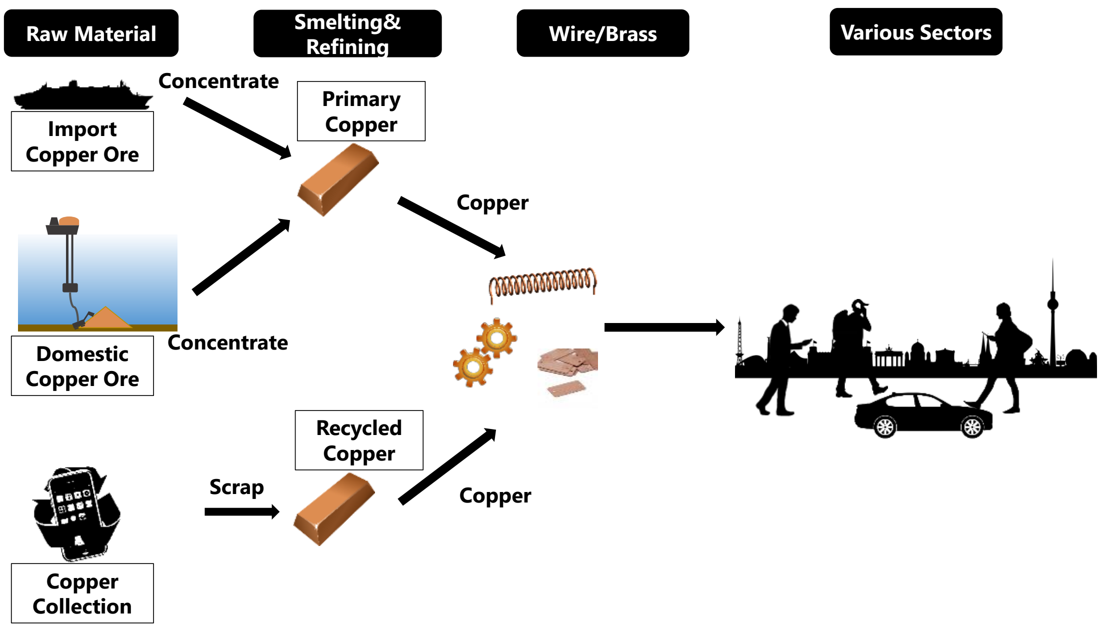


Figure 20 Material flows between sectors related to copper production in this study (boxes indicate sectors in the I-O table).

4.3.1. Input-Output Analysis

This study analyzes domestic mineral production in Japan utilizing the Japanese Input-

Output (I-O) Tables from 2011, the latest version available at the time of writing, in which copper is differentiated from other minerals (Ministry of Internal Affairs and Communications of Japan, 2015). The I-O table is a statistical table showing inter-industry transactions of goods and services conducted in the domestic economy for a certain period (usually one year) in matrix form. This table has been prepared for the purpose of understanding the economic structure of a single region (country, prefecture or city level, although international I-O tables also exist). It is also possible to analyze economic ripple (multiplier) effects by using this table. Economic ripple effect can be defined as new economic production which is triggered to meet new demand. Currently, there are no industries dedicated specifically to deep ocean mining, secondary copper smelting/refining and end-of-life product collection in Japan. Deep ocean resource exploration requires mining and concentration processes which do not currently exist in Japan. Within the I-O table, the recycling sector is reflected, however this is not specific to copper recycling. Should domestic mineral production become mainstream, such sectors would likely emerge in the I-O table. However, it is impossible to investigate these sectors when employing the I-O table in its current form, and for this reason the Japanese 2011 I-O table has been extended in order to add these emerging sectors.

Although I-O analysis is widely used, we will present a brief description of the methods here. Figure 21 shows a conceptualized I-O table. Each row of the I-O table indicates the output of inter-industry transactions, while the columns of the I-O table show the inputs to each industry on a monetary basis. Intermediate demand sectors, which are sectors producing each good or service, perform production activities through the purchase of raw materials, services or energy and applying capital and labor. The final demand sector, which covers consumption, exports and imports, is mainly a buyer of consumer and capital goods as finished products. The intermediate input sector is a supplier of goods and services as intermediate goods. Each supply industry supplies goods and services to demand industries. The gross value added sector consists of a factor cost for production (such as capital and labor). Essentially, the subtotal of final demand and the subtotal of gross added value are balanced. The I-O table is balanced by Equations (1) and (2).

Demand side / Supply site		Intermediate demand				Final demand			Domestic production
		Industry 1	Industry 2	…	Industry n	Domestic final demand	Export	Import	
Intermediate input	Industry 1	$x_{1,1}$	$x_{1,2}$	…	$x_{1,n}$	F_1	Ex_1	Im_1	Y_1
	Industry 2	$x_{2,1}$	$x_{2,2}$	…	$x_{2,n}$	F_2	Ex_2	Im_2	Y_2
	…	…	…	…	…	…	…	…	…
	Industry n	$x_{n,1}$	$x_{n,2}$	…	$x_{n,n}$	F_n	Ex_n	Im_n	Y_n
Gross value added		V_1	V_2	…	V_n				
Domestic production		Y_1	Y_2	…	Y_n				

Figure 21 General conceptualized input-output table

$$[x + F + Ex - Im = Y] \quad (4)$$

$$[x + V = Y] \quad (2)$$

x: Intermediate input, F: Domestic final demand, Ex: Export, Im: Import, Y: Domestic production, V: Value added

The input coefficient matrix, which is explained by Equation (3) and also known as the technology coefficient matrix, represents the raw material inputs required to produce 1 unit of the desired product. By utilizing the inverse matrix of the input coefficient matrix, the economic ripple effect can be estimated using Equation (4). The inverse matrix in equation (4), (I-A)^(-1), is known as the Leontief inverse matrix.

$$a_{ij} = x_{ij}/Y_j \quad (3)$$

$$\text{Economic ripple effect} = (I - A)^{-1}\Delta \quad (4)$$

$a_{i,j}$: input coefficient, $x_{i,j}$: intermediate input in sector ij, Y_j: Domestic production in sector j, A: Input coefficient matrix, I: Identity matrix

As noted above, since the Japanese I-O table combines various mineral ore industries into one sector, copper ore should be separated from this sector to consider domestic mineral production. Also, the recycling sector does not clearly delineate copper flows. Thus, this study modifies the conventional I-O table to suit to domestic mineral production by using the procedures detailed below.

4.3.2. Copper Ore

The copper ore sector, which was separated from the mineral sector, is then separated into two sectors; imported copper ore and domestic copper ore. Both sectors only produce ore for the primary copper sector. The input structure (which is the materials and services for producing copper expressed in the columns of the I-O table), of domestic copper ore is approximated using the Chilean copper production structure (OECD., 2018).

4.3.3. Copper Collection

The end-of-life copper collection sector was added to the extended I-O table. This sector collects end-of-life copper products such as electronic home appliances or metal containing products, disassembles and sorts them and produces materials to be recycled by copper smelters, the ferrous sector and plastic sector. Note that the I-O table only allows a single output from a single sector, so, it is assumed that this sector produces raw materials only for the secondary copper sector. The input structure of this sector is approximated using life cycle assessment (LCA) data from a previous study (Motoori, B. C. McLellan and Tezuka, 2018a).

4.3.4. Copper Recycling

When large amounts of scrap become the main raw material for copper production, primary copper smelters cannot be utilized due to technical limitations. This limitation necessitates the use of a furnace for recycling, which can process scrap materials (Mark E. Schlesinger . [et al.], 2011). To highlight the flow of recycled copper, this sector is newly added to the extended I-O table. The output structure of this sector is identical to primary copper smelting.

End-of-life products are collected and sorted into individual grades and provided to suitable sectors for modern day copper recycling. This means that copper scrap collected from end-users is not always recycled as copper and could be used for wire or brass production. This type of recycling, often called cascading may cause quality issues due to impurities. To prevent downgrading, the recycled copper sector and copper collection sectors are independent of each other, which means that collected copper scrap considered in this study is processed only to high-quality copper. Table 1 highlights the sectors and options considered in the extended I-O table.

Table 11 Sectors added to the extended I-O table

Added sector	Code	Notes
Import copper ore	CONV	Import copper concentrate; does not include concentrating processes in Japan.
Domestic copper ore	DOM	From mining to concentration. Does not include the distance from concentration site to smelter.
Recycled copper	REC	Separated from conventional primary copper processing. Does not use flash smelting.
Copper collection	REC	Collecting, disassembling and sorting of end-of-life products. Distance from collecting point to sorting point is included.

4.3.5. Assumptions

In addition to the augmentation of the I-O table, the following assumptions are made for this study.

4.3.5.1. Copper Production

This study assumes that copper production in any scenario is set at 1,500 kt, equal to copper production at 2017 in Japan (JOGMEC., 2017). The gross domestic product (GDP), which is the total of the value added by all sectors, is also set to the same value as the 2011 I-O table in order to highlight the difference in final demand distribution among sectors, rather than overall GDP change.

4.3.5.2. End-of-Life Product Recycling

We assume that the copper collecting sector recovers end-of-life products from consumers, dismantles, sorts and separates them, and provides secondary materials for secondary copper production, iron and steel and plastic sectors. Here, it is assumed that there is a collection point of end-of-life products in the city, requiring consumers to bring end-of-life products for collectors to gather them. The "recovery" of the end-of-life copper collecting sector is transported from these collecting points to the copper recycling smelters (Motoori, B. C. McLellan and Tezuka, 2018a).

As recycling progresses, the value of production in the recycled copper production sector and the copper recovery sector will increase and the intermediate input and import value of the imported copper ore sector will decrease. The copper recovery sector is assumed to be an industry that requires labor. Wages for this labor were substituted using values from the similarly structured waste treatment sector (Ministry of Internal Affairs and Communications, 2015).

4.3.5.3. Extended I-O Table

Imported copper ore, domestic copper ore, primary copper, recycled copper, and the copper collecting sector were newly added to the 2011 I-O table. Copper production and GDP are assumed to remain constant at 2011 levels. When estimating final demand and domestic production for the progressing recycle rate, the input factor and ratio of the final demand sector to domestic production for each industry are used.

It was also assumed that the wage rates for estimating the labor force costs are the same as in the 2011 I-O table. In addition, wages are set in accordance with the employment table of the I-O Table.

This study applies both a bottom-up and top-down approach to estimating the input coefficients for extended industries. Figure 22 details the methodology used to extend the I-O table for this study. For example, for deep ocean mining (a non-existent industry in Japan) the input coefficient is substituted for that of land-based mining in Chile (a top-down estimate). On the other hand, the input coefficients for industries related to recycling are estimated through a bottom-up estimate approach, using LCA data (Motoori, B. C. McLellan and Tezuka, 2018a). LCA data is mass-based, and for the purposes of this study, these data were converted to a monetary basis utilizing the value and quantity table attached to the I-O table.

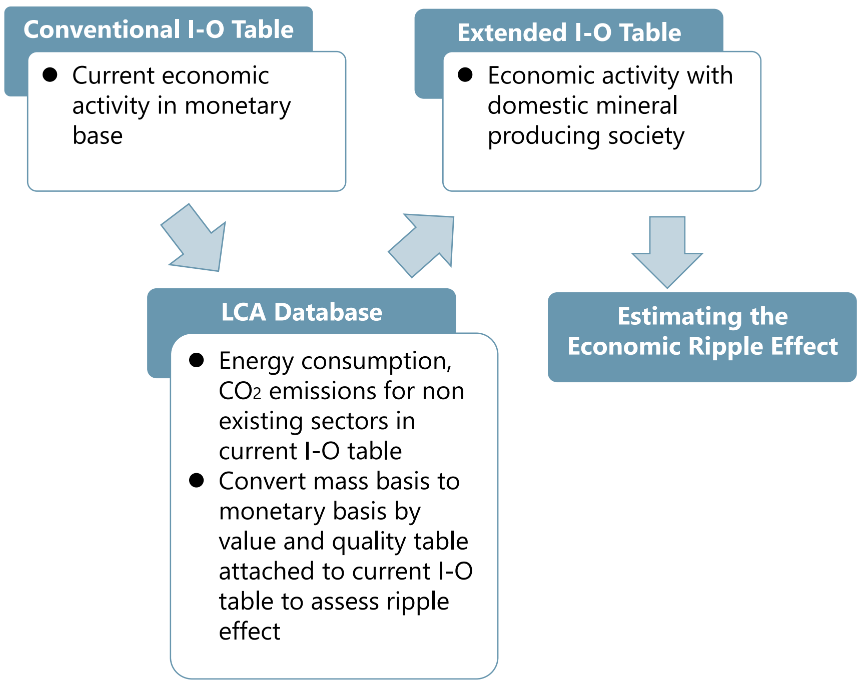


Figure 22 Methodology to extend the I-O table

4.3.5.4. SMS Ore Production

As SMS deposits are polymetallic, deep ocean mining is not specifically targeted toward copper recovery and will result in multiple minerals being recovered—in fact, in many cases copper is more likely to be a coproduct. For example, the ore body considered here consists of copper, lead, zinc, gold and silver. The ore grade has been estimated at 0.4% (copper), 1.4% (lead) and 5.8% (zinc) (Agency for Natural Resource and Energy of Japan., 2013). To estimate environmental impact factors of SMS ore production, allocation by weight is usually adopted. Previous research revealed that multiple mineral production from SMS ore reduces energy consumption, CO_2 emissions and waste disposal amounts (due to their allocations to each material extracted) when compared to the production of copper ore alone (Hislop and Hill, 2011)**.** This study applies the assumption that deep ocean mining will produce various minerals in addition to the target metal of copper for the estimation of environmental impacts.

According to current estimates, SMS reserves of ore are not sufficient to cover Japan's production (U.S. Department of Commerce, 2019), however there are large uncertainties as to the available resources, so this study assumes for the purpose of analysis that there is no limitation on this resource and that SMS ore can meet the demand.

4.3.5.5. Energy Consumption and CO_2 Emissions

The recycling of end-of-life products is considered to reduce energy consumption and CO_2 emissions when compared with processing ore, since recycling does not require an oxidization process. Additionally, since it is possible to utilize waste plastics as a reducing agent and energy source, we estimate that utilizing end-of-life products will assist in reducing CO_2.

Deep ocean mining is also able to reduce energy consumption and CO_2 emissions due to shorter material transportation distances. Mining, concentrating and transportation are invisible processes for resource importing countries since these processes are conducted only in resource exporting nations. Domestic mineral production by Japan may also have the flow on effect of reducing CO_2 emissions in resource exporting countries, although this is not considered in this study. To estimate Japanese CO_2 emission impacts, existing LCA data are used (Motoori, B. C. McLellan and Tezuka, 2018a) .

4.3.5.6. Labor

The I-O table contains supplemental information regarding labor and employment. An example portion of the employment table is shown in Figure 23. The inducement of employment by demand increase is estimated utilizing this data, focusing on all employed persons, including the employer as well as self-employed persons and family workers.

	Sector 1	Sector 2	Sector 3	⋯	Sector n
Employee	l_{11}	l_{12}	l_{13}	⋯	l_{1n}
Self-employed	l_{21}	l_{22}	l_{23}	⋯	l_{2n}
Family worker	l_{31}	l_{32}	l_{33}	⋯	l_{3n}
⋮	⋮	⋮	⋮		⋮
Domestic production	X_1	X_2	X_3	⋯	X_n

Employment Table

Figure 23 Employment table

The employment factor is estimated using equation (5). As shown in equation (6), by transforming employment factors to a diagonal matrix and by multiplying the domestic production of each sector, employment inducement due to 1 unit of demand increase is estimated. The scale of the inducement can be estimated by dividing the average of the sum of all industries.

$$p_j = L_j / X_j \tag{5}$$

p_j: employment coefficient L_j: employed person in sector j X_j: Domestic production in sector j.

$$Employment\ Inducement = \hat{L} * (I - A)^{-1} \tag{6}$$

$\hat{L}: diagonal\ matrix\ of\ p_j.$

Annual income per person can also be estimated by the employment table, as the table includes average incomes along with the number of employed persons. Since copper collection does not exist as an activity within the current I-O table, incomes from the similar waste collection industry are substituted here.

4.4. Results

The results are expressed in three parts beginning with I-O analysis, final energy consumption and CO_2 emissions, followed by labor impacts.

4.4.1. I-O Analysis

I-O analysis reveals industries that will be affected by domestic mineral production. This study considers two extremes; 100% SMS production and 100% recycling. I-O analysis reveals that in a recycling society, 1 unit increase of final demand of recycled copper engenders 1.43

overall units. Table 12 shows the top five industries that will be affected.

Table 12 Economic ripple effect in recycled copper sector

Industry	**Ripple Effect**
Recycled Copper	1.00
Copper Collection	0.26
Transportation	0.06
Service Industry	0.03
Electricity	0.02

On the other hand, an increase in deep ocean mining on final demand engenders a 1.75 unit increase, with the top 5 industries shown at Table 13.

Table 13 Economic ripple effect in domestic copper ore sector

Industry	**Ripple Effect**
Domestic Copper Ore (Deep Ocean Mining)	1.14
Service Industry	0.19
Electricity	0.09
Mining (minerals and quarrying except copper ore)	0.09
Transportation	0.06

The estimated ripple effect in either case is smaller than for other industries, since the average ripple effect of all industries is 2.40. However, observing these impacts, deep ocean mining will relatively increase the output (on a monetary basis) of other industries more than copper recycling alone, as demand for copper increases.

4.4.2. Final Energy Consumption and CO_2 Emissions

Final energy consumption is estimated based on I-O and material flow analysis. In each process, multiple minerals are produced and this study allocates energy consumption and CO_2 emissions by the ratio of mass of final products.

Figure 24 indicates domestic energy consumption for the copper recycling scenario. A recycling rate of up to 10% only requires conventional copper smelting due to the relatively low capacity. For rates of 20% and above both conventional and recycled copper processing are required. As the recycling rate increases, the amount of energy required for transportation (collecting end-of-life products) increases rapidly.

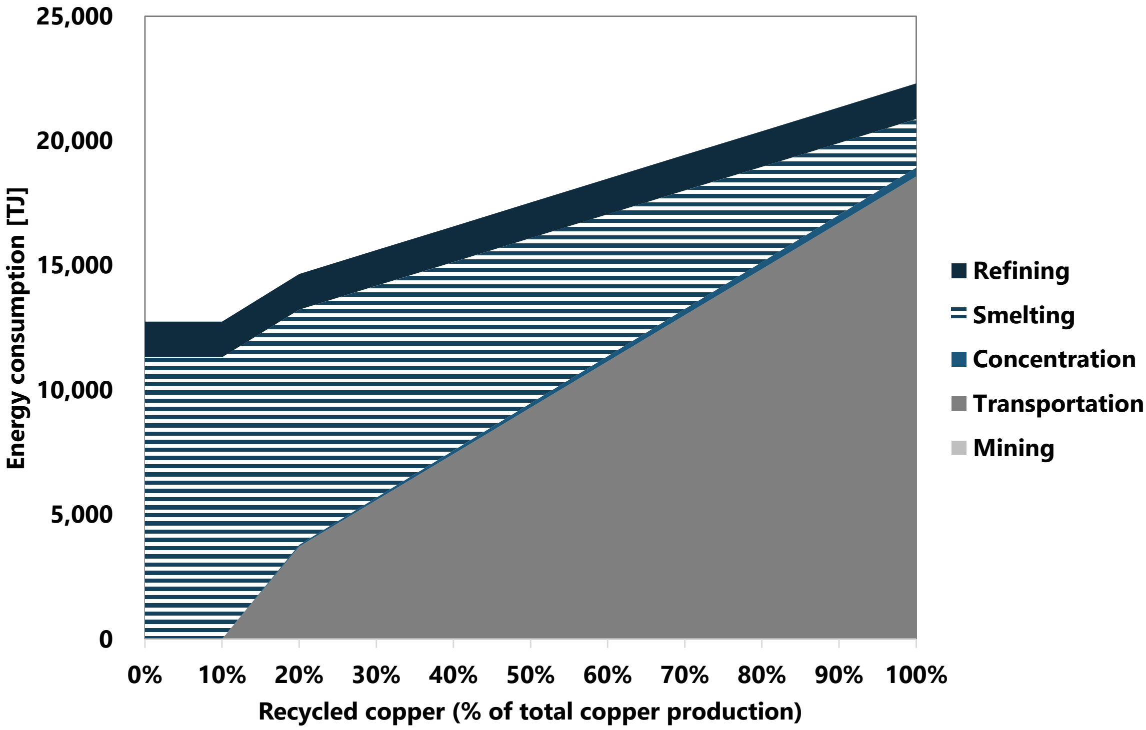


Figure 24 Final energy consumption in a recycling society

Figure 25 shows energy consumption required for deep ocean mining. Although the reserves of deep ocean ore are very small relative to the total copper demand in Japan, this limitation is deliberately ignored here. Basically, the deep ocean mining scenario can be considered to be using conventional smelting and refining processes with added domestic mining and ore concentration. Thus, the energy required for mining and concentration processes increases as the supply provided by deep ocean ores increases.

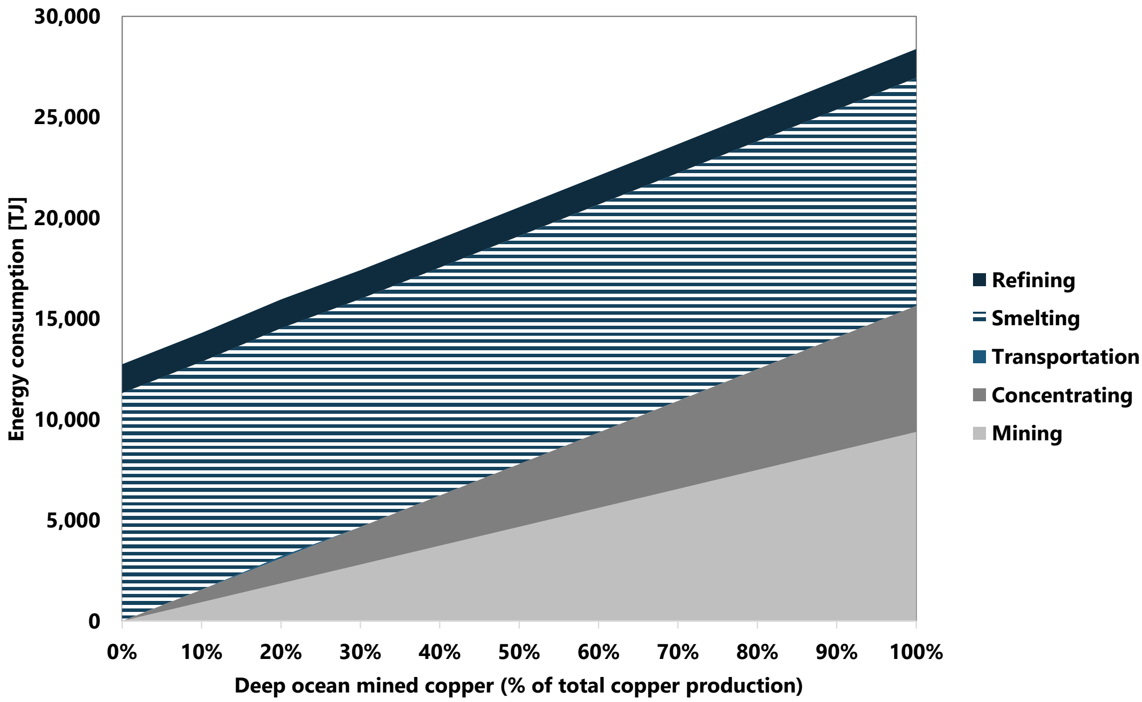


Figure 25 Final energy consumption for deep ocean mining

According to this result, domestic mineral production will increase overall energy consumption. In the case of recycling, energy for smelting succeeds in reducing energy consumption due to the utilization of waste plastics and the absence of an oxidization process. However, transportation of end-of-life products consumes the most energy across all processes. In the case of deep ocean mining, mining and concentration processes are added to the current copper production system. The mining processes require more energy than concentration processes. Note that the current import-based system estimate does not consider mining, transportation and concentration processes because these are all currently conducted abroad. As our estimates only encompass the domestic impacts, actual total energy consumption will be greater than our estimate due to international energy consumption.

Contrarily, CO_2 emissions in domestic mineral production may be less than for conventional copper processing. Figure 26 shows CO_2 emissions, incorporating those from overseas. It can be seen that deep ocean mining will contribute additional CO_2 emissions when compared with current copper production, however, considering the available reserves it is likely not a feasible method to supply Japan's copper ore needs solely from SMS deposits. It is more likely that domestic mineral production will utilize recycling, leading to a reduction in CO_2 emissions from copper production. Note that since environmental impact allocation is based on the mass balance,

CO_2 emissions in mining and concentration of deep ocean mining process are smaller than those in conventional processes. A value-based allocation may change these outcomes.

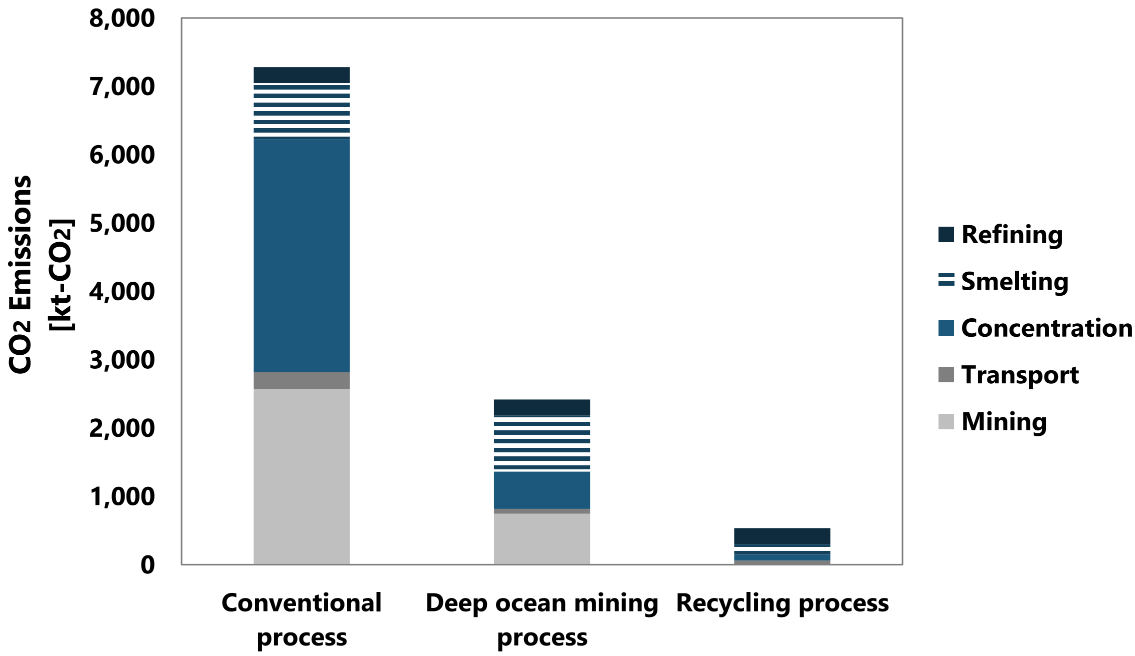


Figure 26 CO_2 emissions in copper production

In addition, Japan's population is forecast to continue to decrease into the future. According to the National Institute of Population and Social Security Research, by 2055, the population in Japan will reduce to roughly 100 million people, approximately 80% of the current population (National Institute of Population and Social Security Research Tokyo, 2017).

Table 14 shows the population change observed and forecasted in Japan (National Institute of Population and Social Security Research Tokyo, 2017; Statistics Breau of Japan, 2018). Following the assumption that copper consumption per person will remain constant, Japan's overall requirements for copper will decrease. Thus, by 2055 we anticipate that environmental impacts will be limited to those shown at an 80% DOM or recycling level in Figure 24 and Figure 25, although alternatively exports could increase to take-up additional copper production. This study assumed that copper consumption per capita and GDP is constant. It has been shown that copper consumption is strongly correlated to GDP per capita (Kishita *et al.*, 2013). Following the assumption that copper consumption per capita is stable, it is more important to maintain the GDP per capita when considering an aging society, which could lead to a decline in copper consumption commensurate with population decrease.

Table 14 Population change in Japan and copper consumption

	Age Group [Thousand People] (National Institute of Population and Social Security Research Tokyo, 2017)				Copper Consumption [kt] (Statistics Breau of Japan, 2018)
	0–14	**15–64**	**65–74**	**75 or over**	
1995	19,400	87,000	12,000	7,800	1,300
2015	15,900	77,300	17,500	16,300	1,300
2035	12,500	64,900	15,200	22,600	1,200
2055	10,100	50,300	12,600	24,500	1,000

4.4.3. Labor

Based on the I-O analysis, employment induced by recycling will make it the third largest sector next to textiles and construction. This indicates that the demand increase for recycled copper will lead to a larger labor demand.

When the final demand increased by 1 unit (1 million yen), 0.17 people are required as labor. Comparing to other industries under the same assumptions, recycling is the industry which requires labor force the most.

Average annual income per person in the recycling industry is estimated to be about three million yen, the second lowest income level in Japan. This industry may struggle to attract employees under these conditions

4.5. Discussion

In terms of economic ripple effect, it is estimated that copper ore production via deep ocean SMS mining will give a larger effect than that yielded by recycling alone. Demand increase for recycled copper leads to a commensurate demand increase for copper collection. It is also estimated that this demand increase for copper collection will also lead to a larger labor demand. It is unclear from the methodology applied in this study as to whether the recycling sector will increase the overall number of employees or simply extend the working hours of the current employee pool. This is one of the limitations of I-O analysis and an issue faced by Japan as a whole. Another limitation of the I-O table is the limitation of bottom-up estimation of input coefficients. As this study mainly employed bottom-up analysis based on LCA data, it does not consider industries which do not appear in the LCA for the given technologies (e.g. service industry). In that sense, energy consumption or CO_2 emissions can be considered as a conservative estimate. Regarding LCA, allocation in this study employed mass balance allocation assuming multiple mineral recovery the likelihood may be very low of its actual occurrence, but when only copper is recovered, the environmental impacts of deep ocean mining are much larger than the conventional process. Figure 27 shows the comparison of CO_2 emissions when only copper is recovered. CO_2 emissions from the recycling process are smaller than the conventional process though, unlike multiple mineral recovery, domestic emissions will become larger than what they are today. In the case of deep ocean mining, it will not be able to reduce CO_2 emissions across the entire copper supply chain.

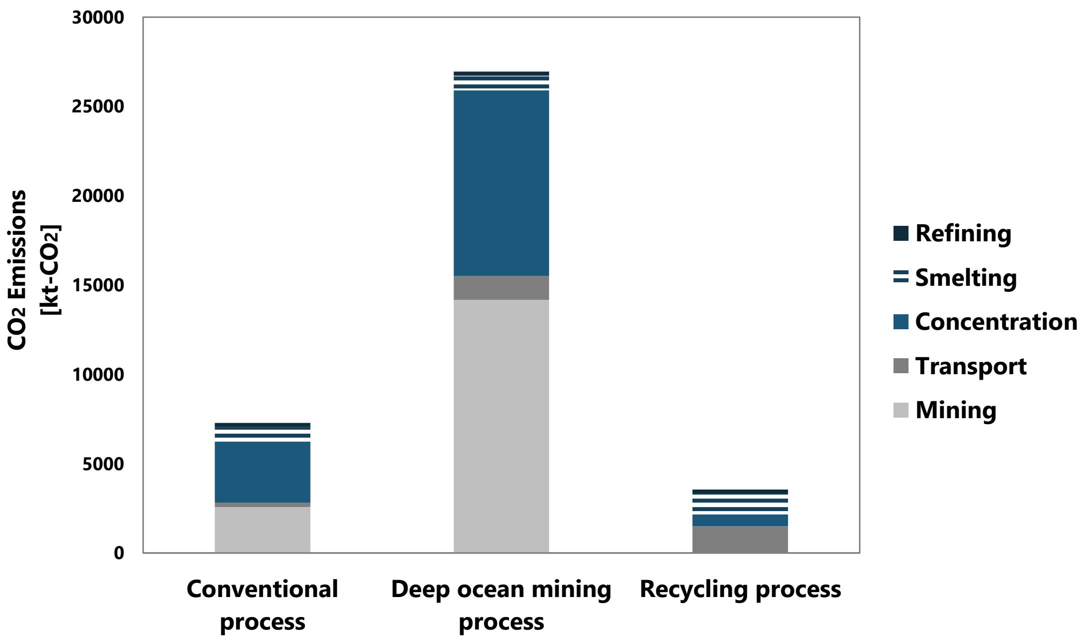


Figure 27 CO_2 emissions under the assumption that all emissions for deep ocean mining and recycling are allocated to copper

As mentioned in the introduction, up until the end of 2018, Japan had been exporting lower grade copper scrap to China (Ministry of Finance of Japan., 2019). In the context of Japanese resource security, processing scrap in Japan could contribute to building a more stable supply chain and build a measure of resilience against inopportune external events including political, economic or environmental restrictions. A measure of independence from importing raw materials will result in resource security improvements. Also, according to the results of this study, a national approach to recycling or deep ocean mining, or a combination of the two can also contribute toward decreasing CO_2 emissions across the entire copper supply chain. Although some positive aspects are identified, we also find that the available working population may be a limitation for Japan's copper recycling capacity. In order to address these issues, we assessed three mitigatory measures, as follows.

Sensitivity analysis

Process 1. Smelter process end-of-life products scraps

This study assumed that all scrap is dismantled and separated, and then processed in a smelting plant. Under this type of recycling regime, generally, high-quality separation is not required since impurities are treated at the smelting and refining process. Processed end-of-life copper scrap by smelters proposes that smelters disassemble end-of-life products and collect scrap by utilizing shredders and separation machinery. This type of recycling is expected to decrease energy requirements for concentration and labor when compared to the recycling option assessed in this study. The labor and energy needs of each facility is based on previous studies (Coelho and De Brito, 2013) and it is assumed that all pre-treatment processes such as crushing are conducted close to the smelting plant, so that energy for transportation is negligible.

Process 2. Producing sector processes collected waste

Since smelters play an important role in recycling in this study, it is assumed to be preferential to maintain smelters' profits under any future regime. One way to achieve this is to improve the recovery rate from scrap. Smelters' recycling process proposed that the smelter would be responsible for scrap collection, however, the mixture of materials will likely cause a lower recovery level of materials. Thus, in processed end-of-life products by producing sectors, producers of final products are made responsible for dismantling and sorting. This is achieved by producers installing mechanical dismantling facilities in their production factories. Metals and a certain amount of plastics will be provided to the recycled copper sector, with producers able to collect desirable materials. As the wire industry is able to reuse their end-of-life products, only scrap for brass production theoretically needs to be recycled. Generally, brass scrap contains about 60% copper. Copper demand for the brass industry was approximately 30% of total copper production in 2011 (JOGMEC., 2017). Thus, energy consumption for transportation is allocated at 60%, with smelting and refining at 30%. In this case zinc from brass scrap is also assumed to be recovered. Since this recycling process requires careful dismantling processes, the labor requirements are assumed to be the same as for the production stream. It is expected to improve the smelters' profit rate compared to the recycling process by smelters, but it may reduce overall profits due to a reduced quantity of available scrap. Moreover, this approach will increase system costs and energy for transportation. This approach also requires a large investment for producing industries, as it is assumed that the labor requirements for this process are the same amount as for the production process, i.e. securing the labor base is critical to its success. This type of recycling does not necessarily produce copper and may not increase the recycling rate according to the current Japanese definition (JOGMEC., 2017).

Process 3. Local recycling

The above two recycling process options both rely on hardware. However, this process encourages community level (including residential and commercial) recycling by consumers. This approach does not consider disassembling and sorting as full-time work. By consigning the disassembling and sorting process to consumers, the copper collection industry will not require large amounts of labor as is necessary for options (1) and (2). Finalizing scrap before the smelting process is a major function for the copper collection process within this process. According to the Ministry of Environment of Japan, copper accounts for 7% of end-of-life household electronic appliance materials after removing plastic and ferrous metals (Ministry of Environment of Japan., 2011). For this process, instead of hiring workers, the copper collection industry will provide incentives to consumers who separate their end-of-life products prior to recycling. Labor used for disassembling is not considered in the same way as options (1) and (2), but as a voluntary practice. Labor within this process only includes the workers in the copper finalizing processes. As we assume rapid aging in Japan, the retiring generations will likely play an important role in this proposed process. In addition, consumer driven recycling may provide non-traditional employment opportunities for those wishing to continue working past the retirement age. Table 15 illustrates a comparison among the three proposed mitigatory processes and the recycling of copper through traditional channels in Japan when 1 unit of final demand increase.

Table 15 Efficiency of processes proposed when compared with baseline copper recycling [corresponding to 1 unit change in copper recycling sector]

	Energy [GJ]	**CO_2 Emissions [t-CO_2]**	**Labor [No. of People]**
Process 1	+0.2	0	−0.02
Process 2	+0.5	0	+0.03
Process 3	−0.1	0	−0.02

Comparing these three process, we observe the existence of an energy-emissions-labor trade-off. Process 1 increase energy, however it is able to produce comparable amounts of copper with a relatively small labor force. Process 2 increase energy consumption and the estimated labor requirement the most, it may be impossible to realize under Japan’s current demographic restrictions, i.e. an aging, shrinking society. Process 3 seems to be the ideal process approach with a moderate energy and emissions contribution and the smallest labor (actually hired) requirements of the three proposed approaches. Process 3 is unlikely to be realized unless consumers are willing to cooperate, as separating and sorting processes are dependent on consumers under this process. Note that CO_2 emissions in each process is less than 1 kg.

4.6. Conclusions

Japan is facing a number of challenges, among them, an aging shrinking population, and over-dependence on raw material imports from foreign nations. This study seeks to provide policy implications and recommendations for improving resource security in Japan, incorporating both recycling and indigenous deep ocean mining operations. Findings show that although deep ocean mining may have strong flow-on economic impacts, the overall quantity of copper extracted may not contribute strongly to Japan's resource security. On the other hand, I-O analysis of domestic copper production scenarios provides a new finding, that labor may be a constraint of realizing a recycling-centric society. Although producing copper by recycling eases environmental impacts, it requires significant manpower.

In order to overcome these shortcomings of individual resource security policies, this study provides three processes, complemented by economic, environmental and social analyses—considering employment, demographics and societal norms.

The analysis undertaken in this study enables a deeper understanding of the effect of demand increase for new industries under constant technological coefficients. However, I-O table-based analysis has some limitations. Since the I-O table is a snapshot of a single year, the effect of investment over the long-term is not recognized. A model to analyze the effect of longer-term investments, such as recycling plant construction which takes longer than a single I-O period will allow for the further development of this research.

5. Resource Security Strategies and Preferences for Deep Ocean Mining from a Community Survey in Japan

5.1. Introduction

Deep ocean mining (DOM) or seabed mining is one of the most widely discussed options, with a large potential resource in international waters as well as in territorial waters of some nations (James R Hein *et al.*, 2013). Other alternative sources of metal include recycling, further exploration or the exploitation of deeper, lower grade or more complex terrestrial ores (Prior *et al.*, 2012). Each of these alternatives has implications for the environmental impacts of metal provision, as well as direct and indirect effects on local communities and the economy, and there is not necessarily a clear-cut ideal supply route across all facets of concern.

5.1.1. Japan and Deep Ocean Mining

The focus of this study is on Japan, due to its strong focus on DOM as well as its challenges with providing both energy and minerals needed in its economy (Motoori *et al.*, 2019). Japan has been involved in the research, exploration and development of deep ocean mining deposits and technology for more than 4 decades through the Deep Ocean Resources Development Corporation (DORD, 2019). As DOM has been seeing a resurgence of interest in recent years, due to a variety of converging factors including spiking prices of metals and costs of extraction (on land), concerns over potential scarcity (physical, economic or political), progress in technology and the potential commencement of mining by Nautilus Minerals in Papua New Guinea (PNG) (Nautilus Minerals, 2013), Japan has increased its investment in the sector and continues to test technology towards commercialization (Thompson *et al.*, 2018). At the same time, there is growing impetus and pressure on the International Seabed Authority and national governments to clarify the environmental and other requirements for companies who wish to undertake mining and exploration, both to give more certainty to industrial players, and to assure those opposed that adequate safeguards are in place.

The Japanese government has placed particular focus on seabed minerals, due largely to its scarcity of domestic economic terrestrial resources, and the consequent reliance on imported raw materials to support its industry (Motoori, B. C. McLellan and Tezuka, 2018b). It is notable that the government has emphasized ocean extraction of methane hydrate as well as metals (used in energy technologies) within its Strategic Energy Plan (GOJ, 2018), highlighting the importance of metals within clean energy technologies, and the similar considerations of resource and energy security for Japan. Within its exclusive economic zone (EEZ), Japan currently has a focus on Seafloor Massive Sulphides (SMS) deposits in the Okinawa Trough and the Izu-Bonin areas (JOGMEC, 2013), in addition to methane hydrate exploration around the country and exploration for manganese nodules in the international Area (GOJ, 2018). The Okinawa Trough is located relatively close (~100km) to the Okinawan islands which are well-known as a tourist destination within Japan, having picturesque coral reefs and beaches. It is also home to a number of United States military bases, which have been the cause of significant controversies over the years.

While the technological, geological and environmental aspects of deep ocean mining have received a large amount of attention, the social acceptance and community impacts have not been widely examined in the Japanese context. There are minimal examples of studies on social acceptance or perspectives from other countries, notably Australia (Boughen *et al.*, 2010)(Parr *et al.*, 2009; Mason *et al.*, 2010) and Pacific island states (Roche and Bice, 2013), and it has also been identified that public participation is a potential weakness in the law regarding international deep sea minerals exploitation (Lallier and Maes, 2016). Part of this lack of social engagement has likely been due to the lack of urgency for most countries, as the prospect for deep sea mining appears to be still quite distant in both time and space. The areas which have seen most engagement have been the focus of shorter-term mining prospects (e.g. PNG, pacific nations), particularly in the case of Nautilus Minerals` Solwara I project (Smith, 2010, 2011; Nautilus Minerals, 2013) which had been nearing actualization (before being stalled by ongoing financial issues), where the attainment of environmental and other permits requires some level of stakeholder engagement. A recent review of EIA processes for DSM in "The Area" has further emphasized the need for stakeholder consultation and the current underestimation of this in DSM application processes (Durden *et al.*, 2018) despite some argument that such consultation may be more optional than critical (Willaert, 2020).There is therefore a gap in knowledge relating to the perspectives of community stakeholders in Japan regarding this resource issue which has significant political support and may have environmental, social and economic implications for the nation if it is actualised. For countries such as Japan, the security of resource supplies is of vital importance for ongoing economic prosperity, but the negative sustainable development implications of the resource inputs are a potential vulnerability that could restrict new resource supplies such as DOM. If stakeholder opinion is against the exploitation of DOM, whether due to actual or perceived negative aspects, this can potentially eliminate this supply route, or present an ongoing risk.

5.2. Research Objectives

On the basis of the points described above, the aim of the present study was to understand the perspective of Japanese towards deep ocean mining, and the drivers behind these perspectives, and to analyse the implication of these results to current and future deep sea mining policy. The study was a first-pass examination, specifically exploring perspectives with regards to the Okinawa Trough, as it is one area that has been widely explored for minerals, and it is considered a potentially controversial site due to its environmental characteristics and relative proximity to land. At the same time, the study seeks to evaluate the preference for alternative resource security strategies to understand the priority that should be placed on DOM within the policy sphere.

5.3. Methodology

The study utilised an internet-based survey of 681 respondents, with approximately half of the respondents from Okinawa (329) prefecture and the other half from across Japan (352). The survey was undertaken in Japanese during the period 25-28 March, 2016. Respondents covered an age range from 17 to 84, with the largest group of respondents (over all prefectures) in their 30`s, distribution of respondents by age and gender is shown in Table 16. Median ages were 42 yrs in Okinawa and 45 yrs in the rest of Japan group, which were very similar to the population median ages (42.1 yrs and 46.4 yrs) in the 2015 census (Government of Japan, 2015).

Table 16 Distribution of respondents by age band, gender and area

Age band (yrs)	Okinawa		Rest of Japan	
	Female	Male	Female	Male
15-29	34	30	32	35
30-39	35	39	37	37
40-49	33	35	35	31
50-59	32	34	33	43
60-84	24	33	35	34

Respondents were asked a series of questions regarding the following themes: (1) familiarity with Okinawa; and economic sectors important to Okinawa at present and in the future; (2) their familiarity with mining and the deep ocean environment; (3) acceptability and priority for deep sea mining in comparison to other industries and the environment; (4) how the benefits of deep sea mining should be distributed; (5) deep sea mining as a source of minerals for domestic industry as compared with importing, recycling and other strategies. Themes 3, 4 and 5 are the key focus from the perspective of this research, and are discussed in detail in the results.

With regards to the research aim, theme 3 was expected to give insight into whether deep sea mining would be acceptable if it were to impact on the existing uses of the ocean, thus indicating if there was a latent concern that threats to these alternative uses could occur, which in turn may cause a barrier to community acceptance of DOM. Theme 4 was relevant to understand where the various stages of DOM and processing of the subsequent ore would be acceptable, and to whom the benefits should flow. Theme 5 was then a higher-level strategic consideration of whether DOM would be the rational preference for Japan to provide its required resources, based on immediate alternatives and on the anticipated environmental and cross-industry impacts.

Survey responses have been analysed as two parallel groups (Okinawa and non-Okinawa) for comparative purposes, as well as overall results being used for certain questions where the difference in the groups is not statistically significant or where the location of respondents is not considered to be an important research variable.

5.4. Results

The results of analysis of the responses are provided in the following sections for the key themes.

5.4.1. Background and future vision for Okinawa and its economy

By way of understanding the expressed familiarity with the specific case study region, respondents were asked how familiar they were with Okinawa in regards to a number of categories, and with mining and the deep ocean. In the categories of: environment, industry, culture and politics/history; more than 66% of local Okinawans expressed that they had a familiarity at least from reading about it in the news, through to studying it or being an expert in the field. On the other hand, at best 48% (politics/history) to at worst 71% (industry) of non-Okinawans reported that they have no knowledge or have only “heard about” the topics. The politics and history of Okinawa have often been in the news, due to various controversies around US military bases.

The respondents were further asked what sector of the economy they considered to be most important for Okinawa now and in the future (percentage of respondents shown in Table 17). The responses were compared with the Japanese government statistics for employment and gross prefectural domestic product (GPDP) (Table 18). Across both groups, the largest sector in terms of importance was considered to be the tourism sector, both now and in the future, though in both cases it was considered that the sector would decline in importance somewhat. It should be noted that Tourism is not reported as an official sector in the overall Japanese statistics, but would include elements of a number of official sectors including non-specified services and industries. In this case, the most important differences were that non-Okinawans thought that fishing was much more important than Okinawans, which reflects a potential better understanding of Okinawa by locals. Moreover, Okinawans considered that education, research and welfare sectors would be more important in the future, whereas non-Okinawans did not rate these as important. Perhaps most relevantly, it was well-known that the mining sector was not important currently in Okinawa, and it was not expected to play a large part in the economy in the future.

Table 17: The most important sector for Okinawa (now and future) according to respondents, broken down by residence

Sector	Okinawa		Rest of Japan	
	Now	Future	Now	Future
Fisheries	***2%***	***2%***	***12%***	***10%***
Agriculture ·Forestry	4%	5%	1%	1%
Construction industry	2%	0%	0%	0%
Manufacturing industry	2%	2%	1%	2%
Information and communication industry	2%	4%	1%	3%
Transportation industry ·Postal service	1%	1%	0%	1%
Wholesale / Retail	0%	0%	1%	0%
Academic research professional technical service	2%	5%	1%	3%
Mining	***0%***	***0%***	***0%***	***0%***
Accommodation ·Food service	***8%***	***8%***	***11%***	***10%***
Lifestyle related services / entertainment industry	***1%***	***1%***	***1%***	***2%***
Tourism	***64%***	***48%***	***65%***	***54%***
Education and learning support industry	5%	9%	1%	1%
Medical / welfare	4%	9%	1%	6%
Service industry (not classified elsewhere)	2%	2%	2%	3%
Public service	2%	2%	2%	3%

Table 18: Employment and Gross Prefectural Domestic Product (GPDP) for Okinawa (Statistics of Japan, 2020)

Sector	Employment (% of employed persons)			GPDP (sector as % of total)		
	2010	2015	Change	2010	2015	Change
Agriculture and forestry	4.5%	4.1%	-0.4%	1.6%	1.1%	-0.6%
Fisheries	***0.5%***	***0.4%***	***0.0%***	***0.2%***	***0.2%***	***0.1%***
Mining and quarrying of stone and gravel	***0.04%***	***0.0%***	***0.0%***	***0.1%***	***0.1%***	***0.0%***
Construction	9.2%	8.9%	-0.3%	8.3%	9.4%	1.1%
Manufacturing	4.8%	4.9%	0.1%	4.6%	5.0%	0.4%
Electricity, gas, heat supply and water	0.5%	0.5%	0.0%	3.4%	3.9%	0.5%
Information and communications	2.0%	2.2%	0.3%	4.9%	5.0%	0.1%
Transport and postal activities	4.9%	4.3%	-0.6%	5.7%	6.8%	1.1%
Wholesale and retail trade	14.9%	13.9%	-1.0%	10.1%	9.5%	-0.6%
Finance and insurance	1.9%	1.9%	-0.1%	4.2%	3.8%	-0.4%
Real estate and goods rental and leasing	1.9%	2.1%	0.2%	11.8%	10.8%	-1.0%
Scientific research, professional and technical services	2.8%	2.9%	0.1%	8.3%	9.3%	1.0%
Accommodations, eating and drinking services	***8.1%***	***7.8%***	***-0.3%***	***4.3%***	***4.4%***	***0.1%***
Living-related and personal services and amusement	***4.1%***	***3.8%***	***-0.2%***			
Education, learning support	5.2%	5.4%	0.2%	5.6%	5.5%	-0.1%
Medical, health care and welfare	12.1%	13.9%	1.8%	10.3%	10.3%	0.0%
Compound services	*0.7%*	*0.9%*	*0.3%*			
Services, n.e.c.	*7.9%*	*8.2%*	*0.3%*	*6.1%*	*5.7%*	*-0.3%*
Government, except elsewhere classified	5.4%	5.7%	0.3%	10.5%	9.4%	-1.2%
Industries unable to classify	8.7%	8.2%	-0.5%			

5.4.2. Understanding of mining

Regarding the basic level of understanding of mining (both on and off shore) some further questions were asked. As shown in Table 19, of the sample, most respondents expressed very little knowledge about mining on land, but more had some knowledge about deep ocean mining (although still minimal). There was slightly more familiarity with deep ocean mining from

Okinawans than for the rest of Japan, which is as expected given that Okinawa is an area of particular interest for DOM.

Table 19: Familiarity of the respondents with mining

	Terrestrial Mining		Deep Ocean Mining	
	Okinawa	Non-Okinawa	Okinawa	Non-Okinawa
I do not know at all	73%	82%	44%	57%
I have heard about it	15%	12%	29%	28%
I know what it is like from news reports	10%	5%	22%	14%
I have studied a bit, so I know it to a certain extent	2%	0%	5%	1%
I am familiar with it because I work in it or am an expert	0%	1%	0%	0%

5.4.2.1. Alternate uses of the ocean

One of the primary concerns expected to be expressed, in particular from Okinawan locals, was over the potential for impacts on existing or priority uses of the ocean. The opinion of respondents with respect to the impact of DOM on fishing and tourism in particular were sought in this case, as these were notable uses of the ocean, particularly tourism in the case of Okinawa. As shown in Table 18, the fisheries sector is not among the most significant sectors for employment or GPDP, whereas tourism-related sectors of accommodation and various service sectors are highly important. Around 10% of non-Okinawan participants though, thought the fisheries sector was the most important sector for Okinawa now and in the future (Table 17), while most Okinawans recognized this as less important.

The participants were later asked whether they believed that DOM would have any impact on the ocean environment or the tourism industry (Figure 28). While around 12-15% of respondents replied that they didn`t know or couldn`t select a response, and 16-23% of respondents believed the impact would be “neutral”, the majority of respondents considered that there would be somewhat of an impact or a definite impact. The expectation of a negative impact on the ocean environment was overall stronger than the expectation of an impact on tourism.

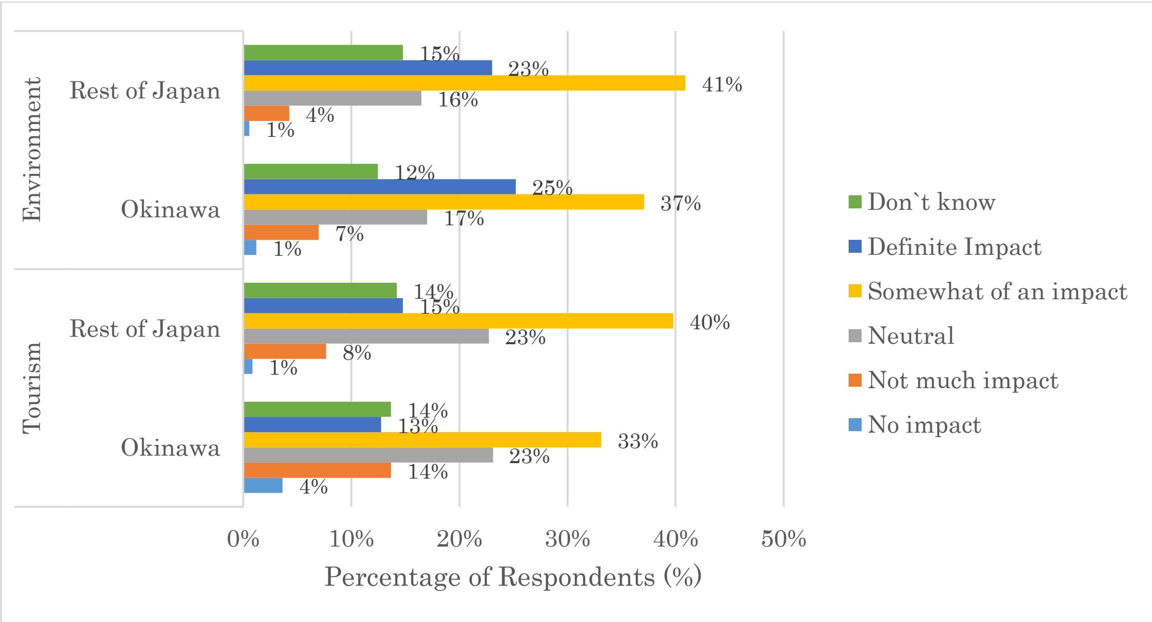


Figure 28: Responses to "Would deep ocean mining have an impact on tourism or the environment?"

Respondents were further asked whether they believed that the fisheries sector or DOM would have a higher impact on the environment. Figure 29 shows that most respondents expect DOM to have a higher impact.

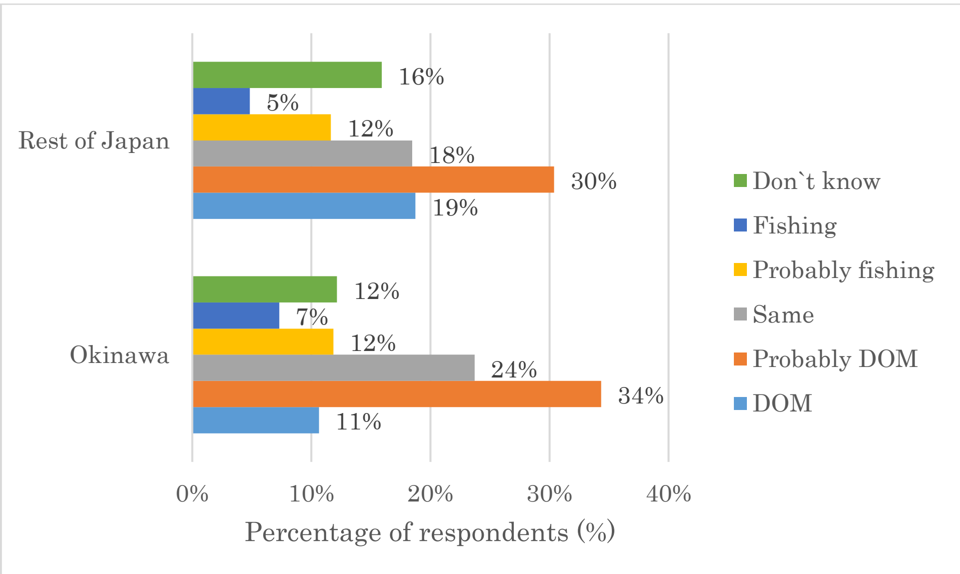


Figure 29: Responses to "Which industry would have the higher environmental impact?"

When asked whether DOM should be allowed under conditions that impact on the existing economic sectors, approximately two-thirds of respondents indicated that if DOM impacts on either fishing or tourism it should not be allowed. This was consistent across both groups. When cross-correlating these responses, it was shown that those who believed that fishing had the same or greater impact than DOM were typically more supportive of DOM being undertaken even if it has an impact on fishing (Figure 30). On the other hand, for those who expected DOM to have greater impacts than fishing, the majority said that DOM should not be undertaken if it impacts on fishing (Figure 31), as would be expected as confirmation of their expectations, but even those who expected fishing to be higher impact than DOM prioritized fishing in the case of a demonstrated impact on the sector from DOM (notably for the non-Okinawan group).

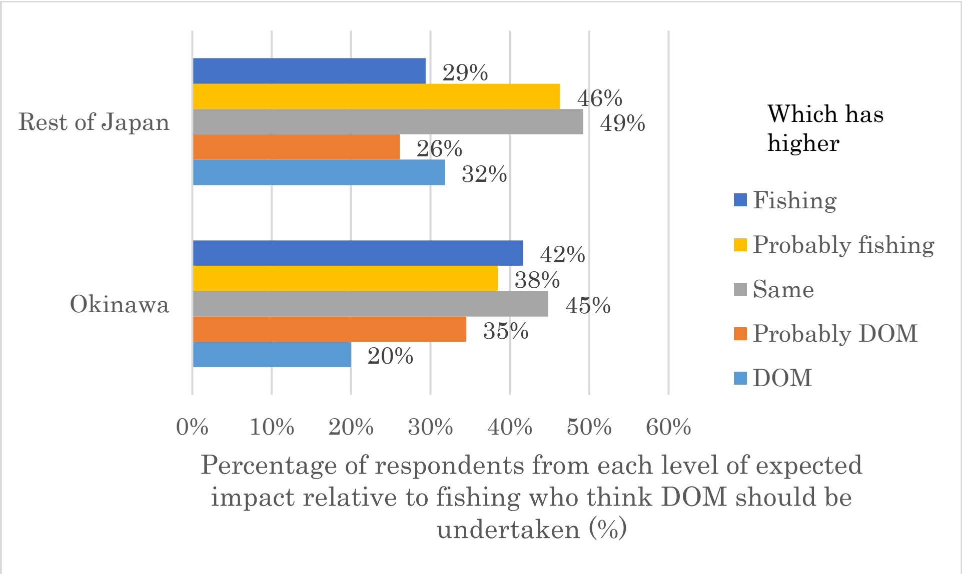


Figure 30: Percentage of respondents who believed that DOM <u>should</u> be undertaken even if it has an impact on fishing off those answering at each level of expected impact

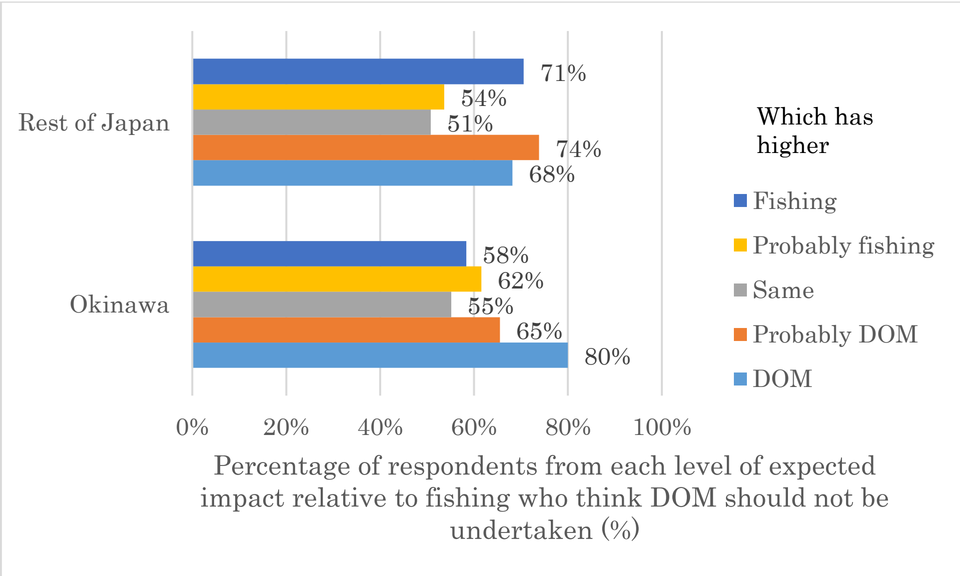


Figure 31: Percentage of respondents who believed that DOM should not be undertaken if it has an impact on fishing off those answering at each level of expected impact

With regards to tourism, which is seen as a much more important sector, the respondents generally anticipated at least some impact on the sector from DOM (Table 20). While there was no significant trend in the ratio of responses in the Okinawan group (there were generally more negative responses if an impact on tourism would occur), the non-Okinawan group responses were more against DOM with a stronger expected impact on tourism.

Table 20: Responses regarding the expected impact on tourism and the acceptability of DOM

	If DOM impacts on Tourism, should it be done?							
	Okinawa				Non-Okinawa			
Expected impact of DOM on Tourism	Yes	No	Row Total	Ratio Yes/No	Yes	No	Row Total	Ratio Yes/No
No impact	1%	2%	4%	0.5	1%	0%	1%	2.0
Not much impact	8%	5%	14%	1.5	4%	3%	7%	1.4
Neutral	9%	14%	23%	0.7	12%	11%	22%	1.1
Somewhat of an impact	11%	22%	33%	0.5	17%	23%	40%	0.7
Definite Impact	5%	8%	13%	0.6	2%	12%	15%	0.2
Don`t know	2%	11%	14%	0.2	4%	11%	15%	0.4
	36%	64%		0.6	40%	60%		0.7

5.4.2.2. Distribution of impacts and benefits

An ongoing concern with all extractive industries, the balance of local benefit and local impact for those most immediately affected by mining, compared with the regional or national benefit, is an important consideration. The location of impacts of DOM, notably with regards to the potential environmental impacts and cross-sectoral impacts on industries such as fishing and tourism, are highly relevant to stakeholder acceptance of an operation and its "social license to operate". The present study was also interested in examining whether Japanese would be happy to have the negative impacts located in Okinawa, or whether they considered that other parts of Japan or other parts of the world would be more appropriate. Also, the economic benefits from mining, which could potentially be undertaken by non-Japanese companies, was interesting to examine as a balance to these negative impacts.

Firstly, with regards to the potential for DOM in various areas outside of Okinawa, the respondents were largely neutral, but the Okinawan group was overall more supportive of DOM in Japan`s EEZ than in other parts of the world, and slightly more supportive than the non-Okinawan group (Figure 32).

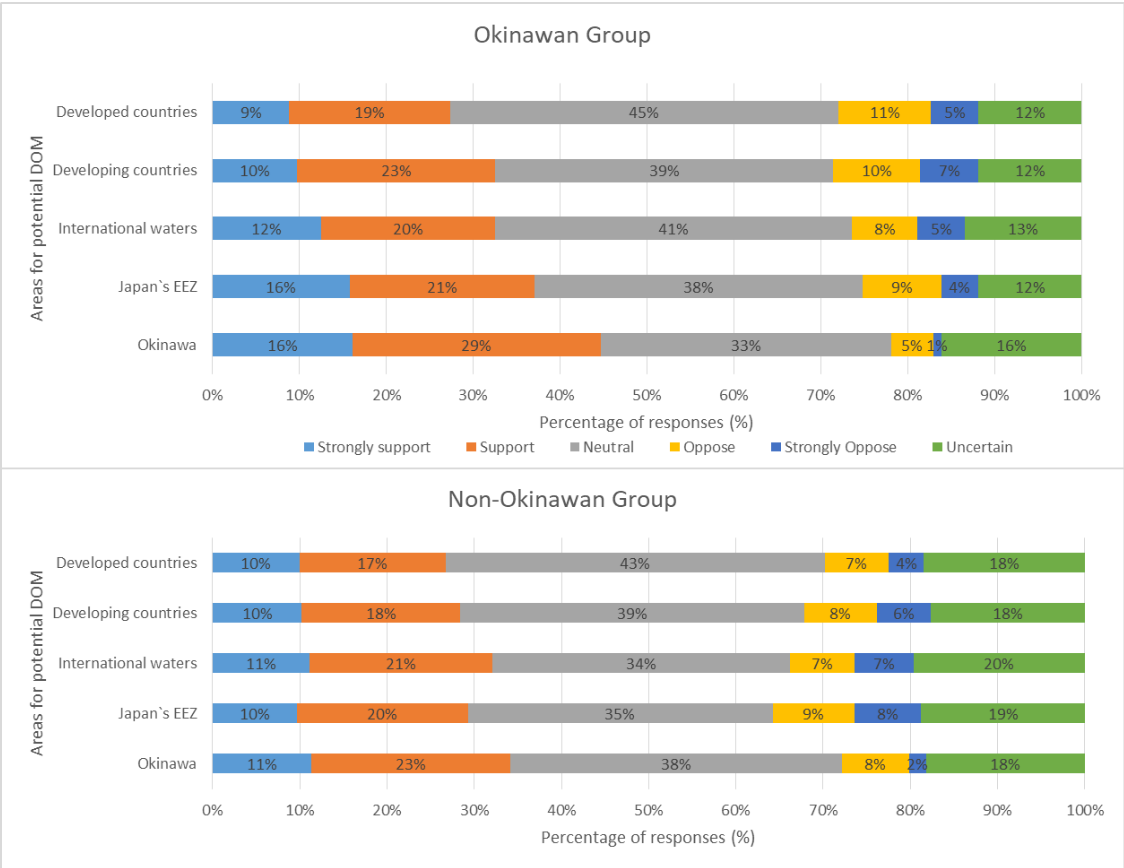


Figure 32: Responses regarding the preference for deep ocean mining in alternative locations

Table 21: Appropriate places for supply chain components for exploitation of DOM ore

Supply chain components	Would you support the following supply chain components for DOM in the following areas? (by groups – Okinawa or Rest-of-Japan, ROJ)							
	Okinawa		The area you live in		Other places in Japan		None of these places	
	Okinawa	ROJ	Okinawa	ROJ	Okinawa	ROJ	Okinawa	ROJ
Construction of a new mineral processing facilities	62%	49%	9%	10%	25%	25%	16%	31%
Expansion of existing mineral processing facilities	55%	46%	9%	10%	33%	29%	18%	32%
Construction of new accommodation facilities for mining workers	67%	58%	9%	10%	23%	22%	14%	26%
Construction of a new port for mining	64%	55%	8%	9%	25%	22%	16%	28%
Existing port expansion	65%	56%	9%	12%	26%	24%	16%	28%

Mining is not the only process needed to obtain useful metals from deep ocean ores. shows the responses with regards to where the various components required to support a DOM industry should be located. In general, there was more support for supply chain elements to be constructed in Okinawa from local Okinawans. Of the mentioned supply chain elements, there was less support for mineral processing facilities to be constructed or expanded in Okinawa, and more support for these to be elsewhere in Japan.

As shown in Table 22, both respondent groups considered that Okinawans should be the greatest recipients of the financial benefits of any DOM in Okinawa, with other Japanese citizens and the companies involved being the next-biggest recipients. Less than one third of respondents allocated any of the benefits to “anyone” and on average the percentage allocated was low.

Table 22: Who should obtain the financial benefit of DOM in Okinawa?

Recipients of financial benefit	Average percentage of financial benefits (%) **(by respondent group)**	
	Okinawans	Rest of Japan
Residents of Okinawa Prefecture	50.9	48.5
Japanese citizens other than Okinawans	20.4	21.0
Non-Okinawan and foreign companies and individuals who developed the mine	22.3	19.5
Anyone	6.5	11.0

Specifically, given that many foreign companies are involved globally in efforts to mine the deep ocean, the respondents were asked whether non-Japanese companies were acceptable to undertake DOM in Okinawa. The responses in Figure 33 indicate an overall preference for local, Japanese companies to undertake any DOM if it was to be undertaken in Okinawa. It was further identified (as shown in Figure 34), that the respondents would prefer that most of the benefits of any potential DOM should be kept within Japan. 39% of non-Okinawans and 30% of Okinawans believed that all of the benefits (physical and financial) should be kept within Japan, but 39% and 35% respectively were supportive of jobs and employment incentives being taken by foreigners. The Okinawan group was overall more willing to accept the benefits flowing to foreign countries.

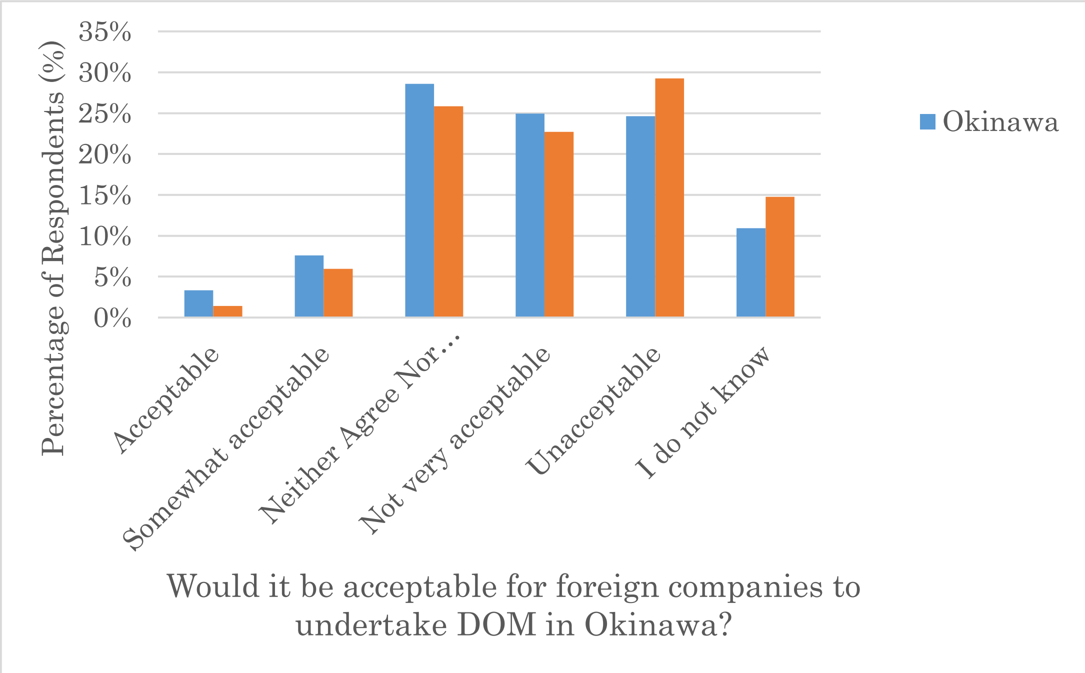


Figure 33: Responses on whether it would it be acceptable for foreign companies to undertake DOM in Okinawa

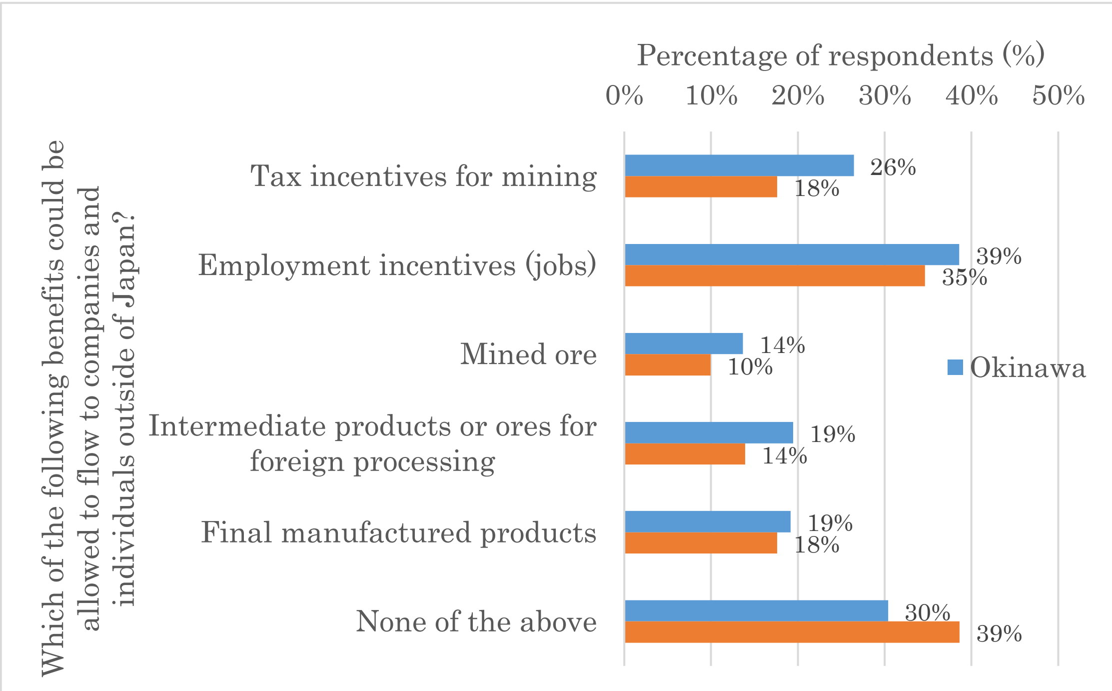


Figure 34: Responses to which products or benefits could be allowed to be exported or flow outside Japan

5.4.2.3. Deep ocean mining, terrestrial mining or other forms of resource security?

The relative importance of the environmental impact of terrestrial and deep-ocean mining as a factor in whether they would support DOM was tested using a series of questions. 32% of respondents maintained that DOM should not be undertaken regardless of whether it was more or less environmentally harmful than terrestrial mining. 19% of respondents believed the opposite - that DOM should be undertaken regardless of the comparative environmental impacts. 49% of respondents indicated that they would only support DOM if the impacts were lower than terrestrial mining. These results were mirrored in both groups (Okinawa and non-Okinawa). Due to the similarity of results, the two groups were combined for evaluation of this issue.

As shown in Figure 35, opinion was slightly skewed towards DOM being expected to have a higher impact than terrestrial mining, but most respondents considered the impact likely to be similar.

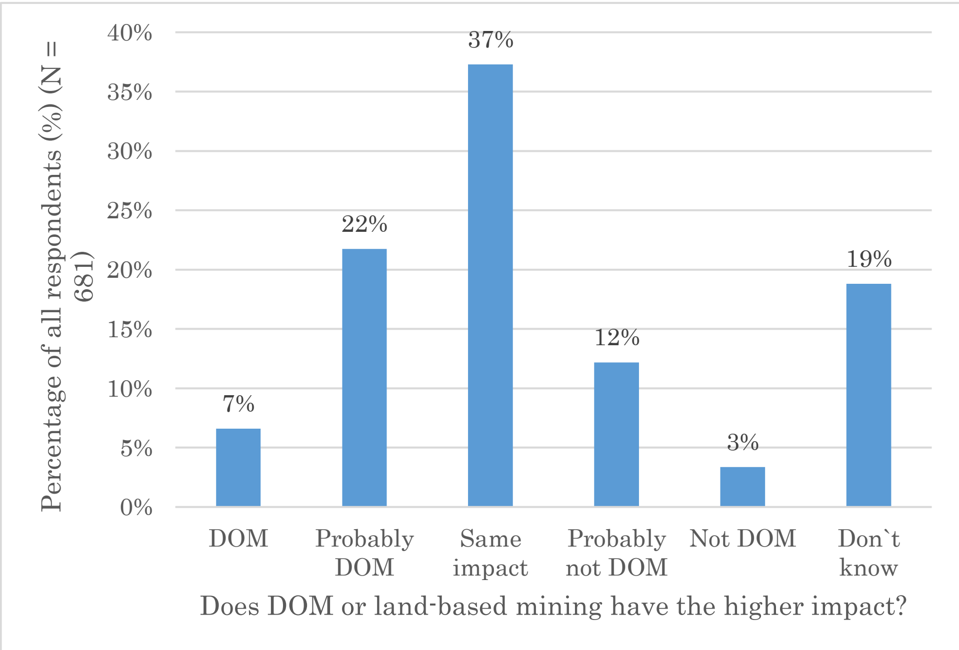


Figure 35: Responses to whether DOM or Land-based mining has the higher impact (total sample)

In cross-correlation of whether they expected DOM to have a higher or lower impact than terrestrial mining with their preference for whether DOM should go ahead given a proven higher or lower impact, the responses are shown in Table 23. Of those who gave a specific answer on the expected impact, it is clear that if the impact of DOM is proven to be higher, then it should not be undertaken (78.7% of responses), whereas if the impact is shown to be lower, the majority (70.7%) would accept DOM. In the group of respondents indicating that DOM should be undertaken regardless of impacts, the main reasons given were that there would be economic benefits and that Japan`s industry and economy required resources.

Table 23: Cross-correlation of preferences on terrestrial or DOM versus expected impact ("Don`t Know" responses removed)

Which has the higher impact, DOM or land-based mining?	**If DOM has a lower impact than land-based mining, should we do DOM?**				**If DOM has a higher impact than land-based mining, should we do DOM?**			
	Yes	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
DOM	29	16	5.2%	2.9%	8	37	1.4%	6.7%
Probably DOM	106	42	19.2%	7.6%	27	121	4.9%	21.9%
Same impact	177	77	32.0%	13.9%	56	198	10.1%	35.8%
Probably land-based mining	61	22	11.0%	4.0%	21	62	3.8%	11.2%
Land-based mining	18	5	3.3%	0.9%	6	17	1.1%	3.1%
(N=533)	**391**	**162**	**70.7%**	**29.3%**	**118**	**435**	**21.3%**	**78.7%**

As anticipated, respondents supportive of DOM regardless of the level of impact relative to land-based mining raised economic and resource security issues as important considerations outside of environmental concerns. These are real issues for a country like Japan that has minimal domestic resources of minerals (particularly). Therefore additional questions were used to evaluate the support for some of the main resource supply options – DOM, imports from overseas, recycling, reduction of the amount of material used, and R&D on alternative materials. The results of a multiple option question showed (Figure 36) that recycling was the most preferred option, followed by research to find substitute materials, then DOM, while importing was the least preferred. DOM was significantly more preferred in Okinawa than in the rest of Japan. The respondents were further asked to prioritise the alternatives (at least one selection was required), overall the trend shown in Figure 36 is repeated in Figure 37. On first preferences, recycling was slightly less preferred in Okinawa, while DOM (as the 3rd overall preference in Okinawa) was supported by a higher percentage of Okinawans than the second option (R&D) in areas other than Okinawa.

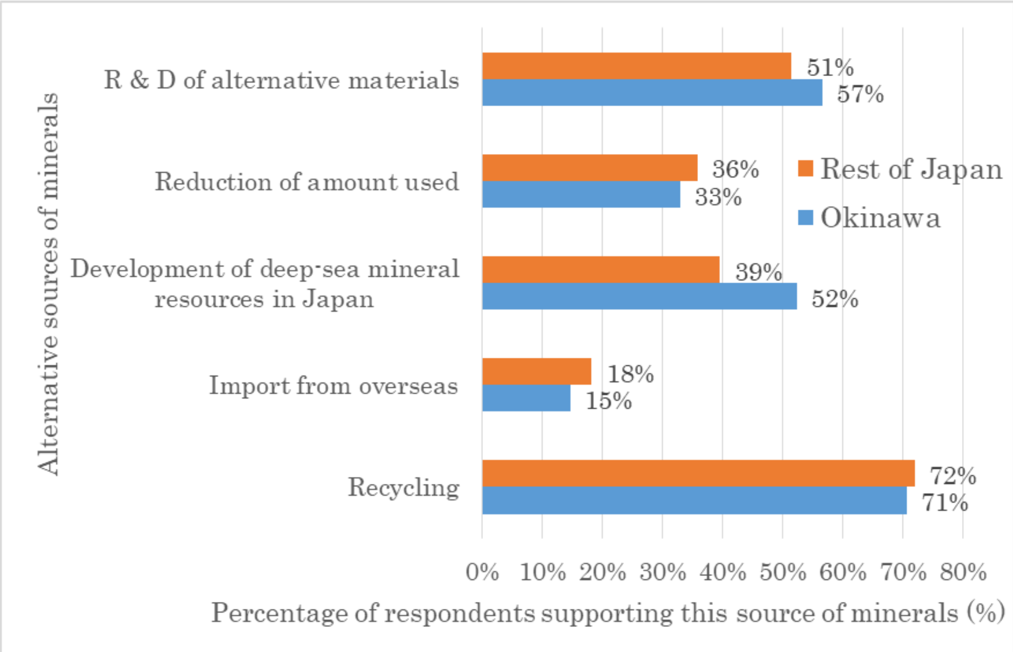


Figure 36: Responses regarding preferred sources of minerals for Japan

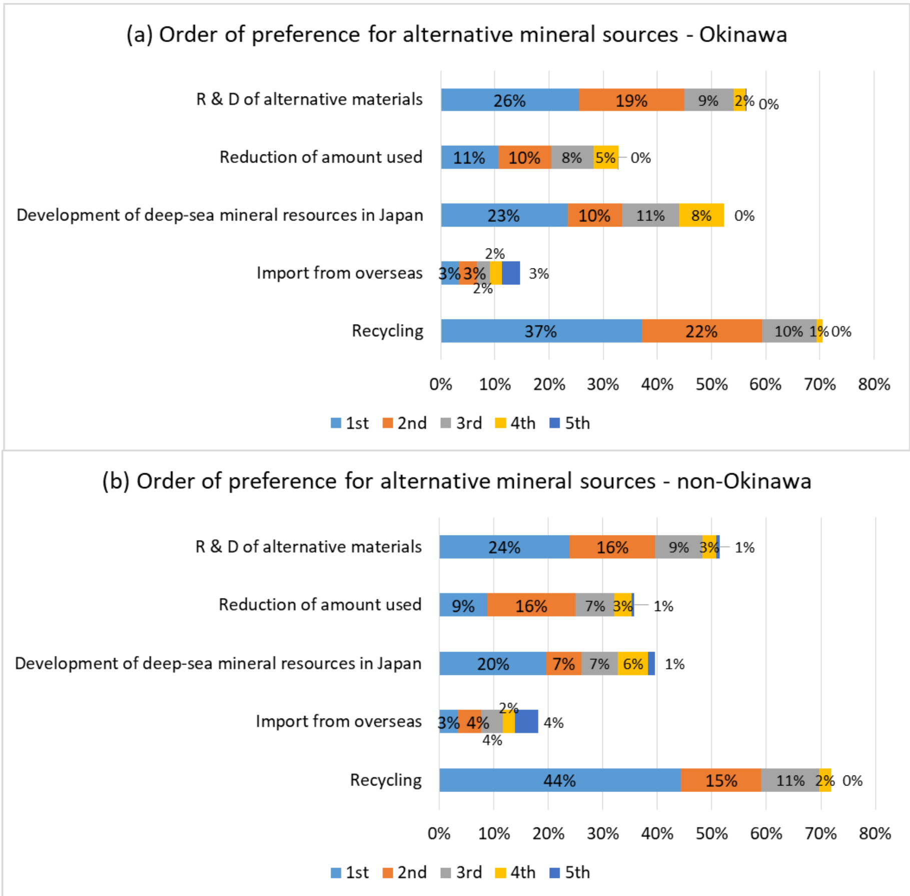


Figure 37: Preferences for alternative sources of mineral supply for Japan

5.5. Discussion

One important challenge in the context of stakeholder engagement in Japan on mining generally, as well as the specific case of DOM, is the lack of familiarity with the sector, due to the relative absence of the industry domestically. The most prominent mines were closed between the 1960`s and 1990`s due to accidents and declining economic competitiveness, and only a few mines remain in operation. There have been historic issues with mining, such as Ashio Copper Mine that caused an environmental disaster in the late 19th century whereby effluent from the mine polluted water and land, damaged agriculture, and killed fish. Other pollution such as Itai-itai disease (due to cadmium poisoning), affected local people and industry around mines and smelters. Such a legacy may influence stakeholders` opinions on mining generally. Deep ocean mining is an even more unfamiliar technology, dealing with and unfamiliar and hidden environment. This makes it difficult to draw out definitive preferences from general community stakeholders, particularly with only a small amount of background information provided. However, on the basis of the results presented above, it is possible to make some broad conclusions regarding the key themes that were the focus of this research:

1. acceptability and priority for deep sea mining in comparison to other industries and the environment;
2. how the benefits of deep sea mining should be distributed; and,
3. deep sea mining as a source of minerals for domestic industry as compared with importing, recycling and other strategies.

With regards to the first point, deep sea mining was generally considered to be unacceptable if it would impact on the existing industries – tourism and fishing (Figure 31). This was strengthened in the case of fishing when respondents believed that DOM would indeed have more negative impact than fishing. However, there were still around 20-35% of the respondents who believed that DOM should be undertaken even though they believed that DOM had a greater impact than fishing and if it was proved that there would be an impact on fisheries (Figure 30). This sub-set of respondents may anticipate greater economic and resource security benefits from DOM than from fishing, or see resource supply risks as a greater threat than potential decline in fishing output. In the case of tourism, which is considered to be highly important for Okinawa (and is in reality a very important economic sector), the stronger the expected impact of DOM on the sector, the less likely for there to be support for undertaking DOM Table 20) although the trend was more pronounced for those outside of Okinawa. This again reflects the importance of tourism as a sector. In current plans the site of mining is expected to be quite distant from the main islands and beaches of Okinawa, and given the depth of the mining it would be expected that direct impacts on the aspects that attract tourists to the area would be minimal. However, from the perspective of the proponents of deep sea mining, it would be important to ensure the mitigation of impacts on this sector and to communicate this effectively to the community, as they see this as an important sector of the economy both now and in the future.

Regarding the benefits of DOM and their distribution, it was clear that most respondents would prefer that the economic and material benefits be retained locally in Japan, with the majority flowing to those most likely to be directly impacted (in Okinawa). This is fairly common in most extractive industries – for example, a study in Australia (Mason *et al.*, 2014), examining attitudes towards mining, indicated that the expectation of society was that the mining industry should:

"(1) Minimise environmental impacts, (2) support and look after local communities, (3) keep Australia's economy strong (4) provide employment for Australians and look after workers, (5) leave something for future generations of Australians, and (6) maintain Australia's international standing."

Points 2, 3 and 4 reflect a similar opinion to the respondents in Japan.

While Okinawa was the focus of this study due to recent pilot-scale mining and exploration projects, the non-Okinawan group was slightly more supportive of DOM in international waters than in the rest of Japan or other countries, but was most supportive of DOM in Okinawa (Figure 32). On the other hand, Okinawans were most supportive of DOM in Okinawa or another part of Japan. These two tendencies would seem to indicate a more positive view of local production from those most likely to be in the area of influence of the new activity "if we can do it in Okinawa that is best, but if we can`t, then we should do it somewhere else in Japan", versus a less positive view for those situated more remotely and less likely to be directly impacted "if they do it in Okinawa that`s acceptable, otherwise it is better to be outside Japan entirely". This not-in-my-backyard (NIMBY) attitude was somewhat reflected in the responses as to where the various parts of the supply chain could be built or expanded, though at a more local level (Table 21). While DOM is likely (at least in early stages) to provide only a small amount of ore for processing – and therefore require minimal expansion of existing facilities or construction of new processing facilities – this would be another challenge to ensuring stakeholder support for the supply chain elements needed to ensure domestic mineral supply. Such considerations would also need to be traded-off with the local and global environmental implications of DOM (Motoori, B. McLellan and Tezuka, 2018).

On the third issue, respondents had a clear preference for recycling over other forms of securing resources, while importing from other countries was the least preferable. There may be many background reasons for these responses, but it may be that recycling is a familiar environmental and resource-recovery practice in Japan (although most people would not be familiar with the process after collection of recyclables, it is common to have mandated municipal recycling) and there is a recognition that dependence on external sources of resources is a vulnerability to the economy. Notably in recent years there have been restrictions of rare earth exports by China, which have had relatively wide media exposure, thus potentially heightening awareness of the resource supply risk. In support of recycling may also be the well-known concept of "mottainai" – an expression meaning basically "what a waste" – that is also broadly known and socially-learned. The development of alternative substitute materials was considered the second most preferred option, again potentially reflective of a culture that promotes innovation in technology. DOM was a higher preference than reduction in use of materials, but this may also reflect an inadequate description and understanding by participants of material intensity.

It is important to note that the respondents were not given information on the current or likely potential of any of these techniques in providing or promoting resource security. It is apparent that recycling on its own cannot supply sufficient material in an economy that exports significant volumes of manufactured products and does not mine its own minerals (Motoori, B. McLellan and Tezuka, 2018). At the same time, the currently proposed Japan-based DOM mines are not able to provide more than a very small proportion of domestic mineral requirements. In either of these cases, either a dramatic reduction in material intensity over time, or a significant policy development to re-import end-of-life products potentially via some form of lease arrangement, would be required to increase mineral self-sufficiency over time. More likely, the large part of mineral requirements would continue to be imported as ore, concentrate and primary metal.

5.5.1. Challenges and limitations

The current survey has a number of obvious limitations with regards to getting a detailed picture of the specific concerns of the community. Primarily, the number of questions and the use of multiple choice style questions rather than open, qualitative questions made it impossible to extract the specific underlying drivers for each individual in each issue of concern. The intention of the survey was as a first step in understanding some high level preferences rather than as a detailed evaluation. To get a deeper understanding it would be necessary to engage in interviews or other deliberative processes. This is particularly notable given the lack of certainty about DOM. Even the scientific consensus on many of the issues examined is still unclear – for example, the local environmental impacts of DOM have been widely examined but the circumstances and planning of an individual mining operation would be needed to clarify the extent of those impacts.

Lifecycle assessments have been partially undertaken for DOM with respect to terrestrial mining (McLellan, 2015), but again the particular metal and the specific mining techniques need to be further investigated – particularly because there are no deep ocean mines in operation. Other aspects – particularly the importance of the environmental and health considerations – also need further investigation.

5.6. Conclusions

This study used a survey of Okinawans and residents of other parts of Japan to investigate the community preference for DOM. The major conclusions were that there was around 30-40% support for DOM under positive assumptions, whereas if there were expected impacts on fisheries or tourism sectors, then the support was lower. Respondents preferred that most of the benefits of mining flow to Okinawans and then to the remainder of the Japanese population, rather than flow offshore. With regards to minerals supply, they considered that recycling and innovation to find alternative technologies or materials were preferable options to DOM, but importing was highly undesirable. The conflicts and trade-offs between environmental, socio-economic and resource security issues were partially examined, but the survey indicates that more extensive examination of these issues is required. Further, more sophisticated survey techniques would be useful to further this investigation, as well as in-depth interviews supplemented with institutional stakeholder surveys.

6. Evaluating the Effects of Domestic Mineral Production Strategies on Resource Security

6.1. Introduction

This study has proposed a methodology to evaluate the impacts of domestic mineral production in chapter 2, and evaluated the environmental, economic and social impacts from chapters 3 to 5. Results obtained from the previous chapters are listed below.

1 Producing minerals domestically using alternative methods mitigates energy consumption and CO_2 emissions in the entire resource production system, but would raise a potential waste treatment and storage issue for a resource importing country such as Japan if it were to start domestic production.

2 When utilizing alternative resource supply mixes in Japan, a resource combination with 30% deep ocean mining and 70% of recycled material from end-of-life products would minimize the environmental impacts. However, in a practical sense, copper export accounts for about 30% to 40% of domestic production. Thus, 70 % of domestic production should be considered a theoretical limitation of copper scrap collection.

3 Supplying copper from recycling end-of-life products would require the 3rd largest labor contribution of all industries in Japan, since exporting lower grade scraps would no longer be acceptable, and these should be treated within the country due to stricter environmental regulations.

4 The preferred resource acquisition methods for Japanese citizens are: recycling, research and development for substitute materials, and deep ocean mining, in order of preference.

5 People have a “not-in-my-backyard” (NIMBY) attitude for resource production (mining) in general, thus large-scale development of raw materials may not be viable in terms of social acceptance.

From these results, it can be said that domestic mineral production in Japan could contribute to mitigating the environmental impacts from a whole-of-supply chain perspective, but there are challenges for transforming recycling to being economically beneficial and mitigating labor restrictions, and to acquiring social acceptance of deep ocean mining.

Then how could the domestic mineral production affect resource security, and which strategy or combination of strategies would be best? This chapter evaluates the domestic mineral production strategy impacts on the resource security of Japan.

6.2. Methodology

To evaluate resource security improvement, this study developed a method based on the indices which the Government of Japan uses for measuring energy security (Ministry of Economics and Trade of Japan, 2010). Table 24 shows the original indices.

Table 24 Evaluation indices **(Ministry of Economics and Trade of Japan, 2010).**

	Original indices	Indices of this study
A)	Development and utilization of domestic and semi-domestic energy resources	Self-Sufficiency Rate To assess the development and utilization of domestic mineral production, **self-sufficiency rate** is chosen as an index. Recycling and deep ocean mining are counted as domestic resources.
B)	Diversification of energy import origin	Herfindahl-Hirschman Index (HHI) Diversity level of resource supply is assessed by **Herfindahl-Hirschman Index by country by supply method**. Conventional, recycling, and DOM in Japan are considered as 3 methods, while it does not matter how other countries produced the ore, they are counted as 1 method per country. Supply method, climate risk and country risk as a demand constraint index are evaluated.
C)	Diversification of energy supply source structure	Herfindahl-Hirschman Index Diversity of supply methodology is evaluated in B).
D)	Resource transport risk management	Number of choke points Transport risk is assessed by **number of choke points**.
E)	Domestic risk management	Recycling rate To assess the risk management level, this study chose **recycling rate** as an index.
F)	Demand restraint	Recycling rate Demand restraint in this study is considered for raw materials (i.e. ore, concentrates). Thus, to see how much of raw materials are substituted, **recycling rate** is going to be assessed.
G)	Response to supply disruption	Recycling rate To assess the risk management level, this study chose **recycling rate** as an index.

6.2.1. Evaluating Scenarios

Several scenarios for resource supply have been provided in chapter 3:

1. Conventional processing
2. Recycling and deep ocean mining processing combined
3. Recycling, deep ocean mining and conventional processing combined (minimum exports)

Scenario 1 represents a business as usual scenario, in which no materials are mined within Japan. Scenario 2 represents the minimum energy consumption scenario, which is constructed with a supply mix of 70% recycling and 30% deep ocean mining. Scenario 3 also represents a minimum energy consumption scenario that takes into account the likely resource supply capacity for each option, constructed with 73.3% recycling, 0.3% deep ocean mining, and 26.3% conventional processing. Minimum exports means that more copper produced domestically remains in Japan. Extending from Chapter 3, another scenario is going to be analyzed here. This scenario considers the resource capacity for deep ocean mining, but also sets the resource capacity for recycling, and less copper produced domestically remains in Japan.

4. Recycling, deep ocean mining and conventional processing combined (maximum exports)

Table 25 summarizes the advantages and disadvantages of each of the individual supply methods from economic, environmental, social and resource security perspectives.

Table 25 Advantages and Disadvantages of Resource Supply Methods

	Deep Ocean Mining	Recycling	Conventional
Economic-Positive	✓ Multiplier effect is bigger than recycling	✓ Imports of copper ore should be minimized	✓ Positive economic impact is the biggest among the three methods
Economic-Negative	✓ Among overall industry, the economic impact is quite small	✓ Multiplier effect is quite limited	✓ Capital outflow to overseas
Environment-Positive	✓ No waste rock will be produced	✓ Achieves the lowest energy consumption, CO_2 emissions and waste	✓ Waste produced within Japan is quite small
Environment-Negative	✓ Waste produced within Japan will be the largest	✓ Transporting the end-of-life products requires significant energy	✓ Overall waste including waste rock is the largest
Social-Positive	✓ People in Okinawa tend to accept deep ocean mining operation in Okinawa	✓ People's acceptance is quite high	✓ -
Social-Negative	✓ People do not know about deep ocean mining	✓ Requires large labor force	✓ People do not prefer importing ore
Resource Security-Positive	✓ Achieves domestic primary copper supply chain	✓ Achieves large-scale domestic copper supply chain	✓ There are no clear resource capacity limits
Resource Security-Negative	✓ Contribution to improving resource security is limited due to the capacity	✓ May have vulnerability in scrap supply (mass and quality)	✓ Highly dependent on imports, resource security is quite low

6.2.2. Self-sufficiency rate

Japan has defined its self-sufficiency rate for minerals as equation 6-1:

$$self - sufficiency\ rate = \frac{ore\ or\ conxentrate\ that\ Japan\ mined}{Japan's\ demand} \tag{6-1}$$

As mentioned, Japan counts ore which was mined abroad by Japanese companies as domestic production. By following this theory, the Government of Japan declares that its self-sufficiency rate is 50%. However, actual domestic production of ore within Japan is almost zero. Despite recycling being promoted, the self-sufficiency rate is still low. When considering a resource security index, this study considers a more conventional self-sufficiency rate as a comparative index. The self-sufficiency rate can be estimated with the following equation (eq 6-2):

$$New\ self - sufficiency\ rate = \frac{ore\ mined\ within\ Japan\ and\ scrap\ collected\ in\ Japan}{Japan's\ demand} \tag{6-2}$$

Because ore and scrap cannot be directly summed, for instance, 1 tonne of copper ore and 1 tonne of copper scrap have different grade, they are converted to t-Cu equivalent.

Before calculating the self-sufficiency rate, reserves of alternative resource supply should be discussed. It has been reported that the SMS deposits in the Okinawa Trough are much smaller than Japan's demand. By calculating the potential copper production using the data JOGMEC provides, DOM can only produce about 1% of Japan's demand if the deposit in Okinawa Trough were to be developed over a period of 10 years. Recycling also has limitations on its ability to supply copper. According to the material flow diagram shown in chapter 1, approximately 35% of copper is exported. There is still old stock available in society as stored end-of-life products, but this limitation might affect supply more acutely when recycling becomes a major source of resources.

The self-sufficiency rate of the four scenarios are evaluated with the following equation (eq 6-3).

$$self - sufficiency\ rate = \frac{(ore\ produced\ in\ Japan) + (scrap\ processed\ in\ Japan)}{copper\ produced\ in\ Japan} \tag{6-3}$$

Note that ore produced overseas by Japanese capital is not included as domestic raw material for the purposes of this study.

6.2.3. Herfindahl-Hirschman Index (HHI)

HHI is a widely-used index that evaluates diversity in markets. It is based on the idea that the more diverse a market is with regards to supply, the more stable the supply becomes. It is calculated using the equation below.

$$HHI = \sum_{i=1}^{n} {C_i}^2 \tag{6-4}$$

Where C_i: production rate (decimal fraction of market) of i th country

n: number of countries

To investigate the level of resource supply stability with consideration of the supply risk, the HHI is evaluated using the following aspects:

- Diversity of import origin (countries)
- Diversity of supply methodologies

Also, to understand the supply risk, this evaluation is weighted using following risk indices.

- Climate risk
- Country risk

Climate risk and country risk by country are shown in Table 26 as well as share of imports.

Table 26 Share of Import, Climate Risk and Country Risk by Country

Country	Share of Copper Ore Imports	Climate risk	Country risk
Chile	44.8%	0.01	0.40
Peru	17.3%	0.01	0.58
Canada	8.6%	0.05	0.12
Australia	8.5%	0.02	0.12
Indonesia	8.4%	0.01	0.58
Papua New Guinea	4.5%	0.01	0.94
United States	3.0%	0.04	0.12
Philippine	2.3%	0.09	0.58
Mexico	1.4%	0.03	0.58
Saudi Arabia	0.9%	0.01	0.40
Mongolia	0.1%	0.04	0.98
Russia	0.1%	0.01	0.75

Table 27 shows the domestic production and recycling rate over 10 years (*'Kobutsu Shigen Materiaru Furo 2019 Dou (Cu) [Minerals Material Flow 2019 Copper (Cu)'*, 2019).

Table 27 Domestic Production and Recycling Rate over 10 years - data from (*'Kobutsu Shigen Materiaru Furo 2019 Dou (Cu) [Minerals Material Flow 2019 Copper (Cu)'*, 2019)

	Production [kt]	**Recycled copper [kt]**	**Recycling rate**
2009	1,440	98	7%
2010	1,549	123	8%
2011	1,328	115	9%
2012	1,516	158	10%
2013	1,467	171	12%
2014	1,555	156	10%
2015	1,483	149	10%
2016	1,553	173	11%
2017	1,488	209	14%
2018	1,594	192	12%

Thus, the original HHI equation is adapted as follows:

$$Weighted\_HHI = \sum_{n=1}^{n}({C_i}^2 \times {climate\_risk_i}^2 \times {country\_risk_i}^2) \tag{6-5}$$

Where C_i: production rate (decimal fraction of market) of i th country

$climate\_risk_i$: climate risk index of i th country

$country\_risk_i$: country risk index of i th country

n: number of countries

When the Weighted_HHI score is closer to 0, it shows more secure supply. When the Weighted_HHI score is closer to 1, its supply is more vulnerable.

Diversity of import origin is based on the Trade Statistics from 2018. Diversity of supply methodology is based on the scenario description given in previous section. Climate risk index is based on Germanwatch's 'Global Climate Risk Index 2018 (Eckstein *et al.*, 2019). Country risk classification is based on indices from the OECD (*Country risk classification - OECD*, 2021). Since the country risk is provided by classification (0 to 7: countries classified 0 have the lowest risk, while countries classified 7 have highest risk), this study applies a country risk score according to level. Countries classified as 0 are designated 1, while countries classified 7 are designated 8, and normalized to scale the index from 0 to 1.

6.2.4. Number of choke points

Choke points are narrow channels or straights where shipping is high, congesting traffic because of their strategic locations. As discussed, base metals including copper have relatively stable and safe supplying countries compared to energy resources. However, ore may need to pass some choke points according to the origin and destination. Table 28 summarizes the number of choke points estimated for the countries Japan imports ore from, as extracted from the Trade Statistics.

Table 28 List of Copper Ore Import Countries and Choke Points (Ministry of Finance of Japan., 2019)

Country	% of Share	Choke Points
Chile	44.8%	-
Peru	17.3%	-
Canada	8.6%	-
Australia	8.5%	-
Indonesia	8.4%	Strait of Malacca (possible)
Papua New Guinea	4.5%	-
United States	3.0%	-
Philippines	2.3%	-
Mexico	1.4%	-
Saudi Arabia	0.9%	Strait of Hormuz, Strait of Malacca
Mongolia	0.1%	
Russia	0.1%	

6.2.5. Recycling rate

Recycling rate in each scenario is given in Table 29. Note that in-process recycling, which returns scrap generated in the manufacturing process to the copper production process and use it as raw material, is not considered in this rate.

Table 29 Copper production and export (Ministry of Finance of Japan., 2019)

	% of Exports [kt]
Min	29.9%
Max	39.1%

6.2.6. Assumptions

In this evaluation, copper export rate, domestic production and recycling rate are considered. **Table 27**shows copper production and export rates averaged over a period of 10 years (*'Kobutsu Shigen Materiaru Furo 2019 Dou (Cu) [Minerals Material Flow 2019 Copper (Cu)'*, 2019). The Maximum % export scenario implies that resources remaining in Japan are reduced, while minimum % export case is the opposite. In both cases, recycling is maximized. Note that the recycling rate of scenario 2 and 3 are approximated to minimum export case.

6.3. Results

Table 30 shows the evaluation results. Comparing the BAU scenario (Scenario 1), other scenarios improve the self-sufficiency rate and recycling rate as well as the number of choke points. On the other hand, the HHI shows that Scenario 1, the business as usual case provides the most stable supply of the four scenarios. The reason for this is that Japan was ranked as the most severe climate risk country due to heavy rains, typhoons and heatwaves in 2018. In order to identify whether this result was an anomaly specific to one-year a sensitivity analysis was conducted. Results are shown in Table 31.

Table 30 Overall evaluation results

	Self-sufficiency rate	HHI	Choke points	Recycling rate
Scenario 1	7-14%	0.000010-0.000016	3	7-14%
Scenario 2	100%	0.00028	0	70%
Scenario 3	73.6%	0.00026	1	73.3%
Scenario 4	61.9%-71.1%	0.00018-0.00024	1	60.9%-70.1%

In the sensitivity analysis, the climate risk index scores for 1999 to 2018 were applied. Results of the sensitivity analysis show that the HHI scores of scenario 2 to 4 are below the BAU scenario. The most stable supply scenario was scenario 2. Scenario 3 and 4 were quite similar to each other. By applying climate risk over time, HHI becomes smaller than the 2018 score. It should be noted that if climate risk has an upwards trend, this would be expected to continue increasing.

Table 31 Sensitivity Analysis

	Self-sufficiency rate	HHI	Choke points	Recycling rate
Scenario 1	7-14%	0.0000064-0.000007	3	7-14%
Scenario 2	100%	0.000003	0	70%
Scenario 3	73.6%	0.000002	1	73.3%
Scenario 4	61.9%-71.1%	0.0000022-0.0000024	1	60.9%-70.1%

6.4. Drivers and Barriers of Domestic Mineral Production

Results of the domestic production strategies` effects on resource security imply that domestic mineral production improves resource security in terms of ability to produce raw materials within the country and maintain stable supply.

Also, as mentioned in chapter 1, this evaluation considers that climate change will continue to be a severe threat. As the climate risk index overtime and the 2018 snapshot show, this risk can suddenly change. This should be considered thoroughly when designing a domestic supply chain including raw material supply.

The results obtained above indicate that there are two drivers and two barriers for achieving greater mineral production within Japan. Drivers are: stricter environmental regulation and large-scale renewable energy technology.

As discussed, both raw material and secondary material supply have ongoing and/or potential environmental restrictions such as cut-off grade decline or recyclable material trade bans. When these restrictions becomes stricter, the end-of-life products tend to remain within the country, and raw materials tend not to be imported because of the promoted recycling of this scrap. Input from outside the country becomes less and output to outside the country may need to be reconsidered – particularly waste streams that become a valuable resource, meaning that there is a need to circulate resources domestically. Taking account of peoples' preference for domestic mineral production, recycling could be the primary option. Additionally, as already investigated above, collecting the end-of-life products requires large amounts of energy since these materials are not concentrated, but are spread across the country. However, as is also mentioned, renewable energy initiatives are ongoing in Japan, so more electricity will be produced from low-carbon technology. Electrification in the transportation sector is no exception. It is anticipated that before long much of the transportation sector will be electrified.

This could enable renewables such as wind and PV to cover the energy required to collect end-of-life products from citizens.

However, there are also barriers to domestic mineral production; lack of labor and complexity of materials, and climate risk. As discussed, if Japan transforms to produce 100% of its copper from end-of-life materials, the required labor force would expand to be the 3rd largest industry when scaling-up the modern-day recycling methods, since it is a labor intensive industry at present. Considering the population decline in Japan, it may be difficult to achieve large-scale recycling unless there are technological or systemic breakthroughs. Another barrier is the complexity of materials from both recycling and deep ocean mining. It is well-known that recyclable materials such as plastic coated wire were exported to China because they required extra treatment for recycling because of the cost (MERIJ., 2015). Recovering complex recycling resources traditionally requires disassembly by hand, and is typically not economically feasible for developed countries (MERIJ., 2015). Even wire requires laborious processes, and it goes without saying that end-of-life product recycling tends to require more complex processes as the complexity and diversity of products increases. Technology installation reducing labor intensive processes in recycling is an important action that industry could take, but there are also efforts involving the whole of society required to avoid this problem, for example reducing comingling. Additionally, ore from deep ocean mining often has a complex composition. Complex ores which contain harmful elements such as arsenic or mercury make processing harder or more costly than conventional processes. It was also revealed that continuous climate risk increase may affect stability of domestic mineral production. In some cases, it is possible that importing ore from overseas may achieve more secure supply than domestic production.

6.5. Conclusion

It was revealed that producing raw materials within the country does contribute to improving resource security. The domestic production considered in this study may require more labor and be less cost-effective, but improving independence from imported raw material will lead to improved national security. Since Japan’s population is shrinking, it may not be possible to conduct labor-intensive recycling, so policy to promote technology installation to enhance automate recycling may be necessary.

7. Conclusions

7.1. Summary of this study

Vulnerability in raw material supply is an ongoing global concern. Taking account of the expansion of renewable energy which requires metals for electrification, more effort for raw material acquisition will be required, especially for resource-importing countries such as Japan. There are a variety of options to mitigate the imbalance in demand and raw material supply. In the case of Japan, to-date the government has emphasized investing in upstream development, but this strategy is still highly dependent on unknown factors, and cannot be said to be sustainable. Other options are promoting recycling, or developing unconventional ore, but since these have not been applied yet, unknown impacts could be observed. Whatever policy is constructed, society will face a bold transition in various aspects. This study then is trying to answer the questions, 'what are the impacts of alternative mineral production methods, and what would a sustainable resource acquisition strategy for Japan be?' Breaking down this research question, the magnitude of environmental impacts is investigated by answering 'How much do alternative mineral production methods affect energy consumption, CO_2 emissions and waste?' in chapter 3. The impacts on socio-economic aspects are investigated in chapter 4 by answering the question 'What will be the reaction of industry when alternative mineral production methods are dominant in Japan?' Lastly, since resource supply methods may involve the whole social system, it is vital to gain a social license to operate. However, there is no ongoing project extracting unconventional mineral ore (i.e. deep ocean mining), and peoples' knowledge and acceptance levels are unknown. This study then seeks to answer the questions 'Will the stakeholders accept alternative methodologies?' and, 'What level of acceptance do the people have?' in chapter 5, in order to identify preferable resource acquisition strategies for Japan.

This study in its entirety aims to evaluate alternative mineral supply methods in terms of techno-economic, environmental and social perspectives. It also aims to support a policy to design a society with secured resource supply.

The literature review indicates that Japan should find a strategy to extract itself from high dependence on resource imports. Historically, Japan's resource acquisition strategies have been focusing on upstream investment. However, this strategy is still highly dependent on uncontrollable factors such as climate change or political issues, and it should seek to find other independence strategies. To achieve this, the current study focused on alternative mineral production entirely conducted domestically, to decrease the vulnerability of raw material supply. Domestic mineral production measures in this study are: deep ocean mining and recycling. To compare the impacts, conventional mineral production processes are also estimated.

Deep ocean mining, as an example of domestic mineral production, is estimated to be able to mitigate many environmental impacts across the whole system, with the exception of waste. It also has an economic impact, and can be considered as a prominent option from both energy and economic perspectives. However, in the context of Japan, deep ocean mining will bring waste issues such as tailings, wastewater or harmful materials including mercury or arsenic that will need to be suitably disposed of, stored or treated. Another challenging aspect that deep ocean mining faces is the scale of resources. It cannot cover all of Japan's demand based on current reported reserves, so there would need to be other resource supply methods to cover the remainder of demand.

Recycling, on the other hand, is another method to supply materials by mitigating environmental impacts as well. Its energy consumption, CO_2 emissions and waste discharge give quite small impacts from the resource production system. Survey results also show that people prefer recycling more than other types of mitigation measures. Due to these reasons, it can be said that putting efforts into recycling will be an acceptable resource supply strategy for Japan. The challenging thing in promoting recycling is that it requires a lot of low-skilled labor, which does not fit in Japan where the population is decreasing, as investigated in chapter 4. Now that Japan cannot export lower grade scrap to China, which was the major importer until the end of 2018, there is theoretically a large domestic scrap resource remaining in Japan. Since the current recycling system is quite labor-intensive in its structure as many people have pointed-out (MERIJ., 2015), the labor required to deal with scrap will increase linearly. This is not considered to be readily achievable in the Japanese context where the population is shrinking. Technology advances, notably in automation, to improve the recycling process is an urgent need to promote large-scale recycling. Smaller economic impacts compared to deep ocean mining may be another challenge. In other words, recycling needs to transform its industry structure to be more profitable.

7.2. Policy Implications

The OECD has categorized good practice obtained from policy instruments from OECD countries with regards to waste and materials management as follows: (1) regulatory instruments, (2) economic instruments, (3) extended producer responsibility (EPR), (4) green public purchasing, (5) public information, (6) monitoring and (7) reporting and enforcement (*Policy instruments for waste and materials management | Waste Management and the Circular Economy in Selected OECD Countries : Evidence from Environmental Performance Reviews | OECD iLibrary*, 2019). The concepts of these include:

(1) Regulatory instruments

Regulatory instruments include governance of hazardous waste, and requirements for waste handling and treatment to ensure safety and environmental protection.

(2) Economic instruments

Economic instruments would be effective to avoid, minimize or manage wastes as well as changing people's behavior.

(3) Extended producer responsibility (EPR)

EPR instruments can contribute to internalizing end-of-life products cost. EPR schemes can include recycling targets or treatment requirements for end-of-life products.

(4) Green public purchasing

Green public purchasing, which mainly implies government purchasing, can promote recycled products and move to a circular economy.

(5) Public information

Public awareness can be an important factor to change behavior, and thus for the success of many waste policies.

(6) Monitoring and reporting

To manage waste issues effectively, monitoring and reporting is recognized as a key tool.

(7) Enforcement and compliance promotion

Enforcement actions, such as on-site inspections and sanctions for violators, as well as the broader range of compliance promotion activities to ensure that operators and polluters are aware of their responsibilities and the penalties.

Considering these seven instruments as a basis, this study gives suggestions for resource security policy.

One of the findings and potential challenges of this study was the required labor for recycling. Generally, the current manufacturing system is optimized for production. However, when recycling becomes the producers' responsibility, product design should become more recycling-oriented. It is important to involve the concept of recycling into manufacturing (design for recycling).

It was revealed by the survey in this study, that Japanese citizens do not have knowledge about deep ocean mining nor on-land mining. It can be considered that there are few opportunities to get information about deep ocean mining, as it is still only a concept. Not only deep ocean mining, but also recycling will give an opportunity for stakeholders to discuss, decide or work towards domestic mineral production, and it is important to provide information about the resource supply system and alternatives for people.

Co-development of deep ocean mining and recycling may be a sustainable resource strategy for Japan, under certain conditions, as discussed in this study.

7.3. Limitations of this study

This study focused on providing a methodology to evaluate the impacts of domestic mineral production, but there are apparent limitations.

First, methodological issues for assessing economic impacts are considered to be a limitation. In this study, input-output analysis was applied to assess the economic impacts. The Input-Output table is a useful tool however, because it is a snapshot of a single year, it cannot assess the dynamic transition towards a society which has actualised domestic mineral production. Transitioning the source of supply would also require capital investment, but this study has not assessed this aspect, in part due to the wide uncertainty of capital costs of DOM. Also, it was assumed that GDP remains stable in this study. This assumption may affect the calculated labor requirement. Thus, this study may not fully capture the impacts of domestic mineral production. As one extension, future studies should apply CGE analysis to understand the impacts of changes over time.

Another limitation is the temporal change in resource capacity of recycling. This study assumes that copper scrap can be provided constantly though, in a practical sense, scrap production would fluctuate. It is not realistic to try to evaluate final usage of copper to the level of each tonne, but final usage can be estimated at least at the sectoral level. By using this data and product lifetime distributions, recycling capacity and impacts of recycling over time could be further assessed.

7.4. Conclusion

This study has provided the following conclusions:

① A methodology for assessing the impacts of domestic mineral production in terms of environmental, economic and social aspects from the whole supply chain perspective was developed

② From MFA analysis focusing on the full supply chain of copper, domestic mineral production is likely to mitigate energy consumption and CO_2 emissions but raise waste issues

③ From an extended I-O assessment for alternative mineral supply, it was demonstrated that recycling in today's labor-intensive industry structure requires high levels of labor, which is likely to be infeasible given the costs and availability of a sufficient labor pool.

④ From a stakeholder survey, it was identified that people prefer recycling as a resource acquisition method, over DOM or imports, but they have little knowledge about DOM, so there is a need for further education.

Therefore, recycling-oriented supply with mitigated labor-intensity can be considered the most preferable system configuration from a holistic consideration. However, there will be a material gap due to the export of raw materials as products. How to fill this gap – with DOM or imported ores, or focusing on reducing demand, is an important political decision. Also, mitigating the labor-intensity of the recycling system must be considered, as there is a trade-off between employment and automation-based economic efficiency.

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Appendix

Table A 1 Step-by-Step Energy Consumption

Energy	**CONV**	**DOM Cu-Only**	**DOM Multiple**	**REC Cu-Only**	**REC All Materials**
Mining	15,500	132,100	7000	0	0
Transport	2300	12,500	700	14,600	600
Beneficiation	16,000	48,700	2600	3100	400
Smelting	8700	8700	8700	11,400	1500
Refining	1100	1100	1100	1100	1100
	43,600	203,100	20,100	30,200	3600

Figure A 1 Smelters and Retailers in Japan.

List of Publications

Original Papers

1. Motoori, Ran; McLellan, Benjamin C.; Tezuka, Tetsuo. 2018. "Environmental Implications of Resource Security Strategies for Critical Minerals: A Case Study of Copper in Japan" Minerals 8, no. 12: 558.
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1. Motoori, Ran; McLellan, Benjamin; Tezuka, Tetsuo.2015. “Economic Feasibility Impacts of Waste and Waste Water Treatment Regulations for Deep Ocean Hydrothermal Ore Mining in Japan” The Proceedings of The Twenty-fifth (2015) International Ocean and Polar Engineering Conference, The International Society of Offshore and Polar Engineers, pp179-185.
2. McLellan, Benjamin; Motoori, Ran; Tezuka, Tetsuo. 2015. “Comparison of Lifecycle Impacts of Seafloor Mining with Onshore Equivalents” The Proceedings of The Twenty-fifth (2015) International Ocean and Polar Engineering Conference, The International Society of Offshore and Polar Engineers, pp174-178.

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1. 本告蘭，Benjamin C. McLellan，手塚哲央. 2016. “亜鉛供給制約下における海底熱水鉱床開発の評価” 第 32 回エネルギーシステム・経済・環境コンファレンス講演論文要旨集，エネルギー・資源学会，p55.
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1. ○Motoori, Ran., McLellan, Benjamin., Tezuka, Tetsuo. Economic Feasibility Impacts of Waste and Waste Water Treatment Regulations for Deep Ocean Hydrothermal Ore Mining in Japan, The Twenty-fifth (2015) International Ocean and Polar Engineering Conference, Hilton Waikoloa Village, Hawaii, United States, June 2015.
2. ○McLellan, Benjamin. Motoori, Ran. Tezuka, Tetsuo. Comparison of Lifecycle Impacts of Seafloor Mining with Onshore Equivalents, The Twenty-fifth (2015) International Ocean and Polar Engineering Conference, Hilton Waikoloa Village, Hawaii, United States, June 2015.
3. 本告蘭，Benjamin C. McLellan，手塚哲央，亜鉛供給制約下における海底熱水鉱床開発の評価，第 32 回エネルギーシステム・経済・環境コンファレンス，東京，2016 年 2 月.
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7. 本告蘭, Benjamin C. McLellan, 日本における銅資源の代替戦略の国内環境への影響の検討、第 35 回エネルギー・資源学会研究発表会, 東京. 2019 年 2 月