Metal Demand to Meet SDG Energy-related Goals

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Abstract

Ensuring energy access should be at the core of SDGs to support a healthy life for all. Among the SDGs, even though Target 12.2 includes the efficient use of natural resources, there is no explicit goal set for sustainable mineral use. Considering, however, that some metal supplies have drawn much attention in discussions of 'critical metals,' it is important to know their availability for a sustainable energy supply.In this paper, we chose two metals, copper and indium, and estimated their demand under various energy scenarios to see if those metals have sufficient availability. Copper is the most important material resource for the energy-related infrastructure. Indium is an example of a minor but critical metal for energy supply systems, and was therefore analyzed.The demand from energy supply systems accounts for a huge share of total copper demand. Our scenario analysis indicates that if we try to establish good energy access across the world as soon as possible, it may pose serious copper supply problems. An increase in demand that is too rapid would mean an increase not only in the absolute amount of demand but also before scrap could become available. The result is that primary copper demand could be quite huge, especially in the early stages of development. In that sense, copper may be a system-wide concern. Minor elements such as indium with huge applications in specific energy technologies are often called 'energy critical metals,' and our analysis of indium also supports this, because the system's indium demand is huge. We conclude, however, that copper is one of the most critical metals for ensuring energy access for all.

Key words: copper, energy critical metals, energy supply system, Sustainable Development Goals (SDGs)

1. Introduction

In discussions of Sustainable Development Goals (SDGs), ensuring energy access has been proposed as Goal 7 to support a healthy life for all. Target 12.2 includes the efficient resource use, but no explicit goals for sustainable mineral use have not been set. However, considering that certain metal supplies have drawn much attention in discussions of 'critical metals,' we should ascertain whether their availability would be sufficient to support a sustainable energy supply.

'Criticality' of metals is a relatively new term (NRC, 2008) though the concept is old. Even though details of the definition depend on the source (Graedel *et al*., 2012), most definitions assess criticality of a metal with regard to its supply risks and the economy's vulnerability to its supply disruption.

Discussions of criticality sometimes focus more on minor elements. In Japan, in particular, which has its own terminology for them ('rare metals'), these minor elements have been discussed not only by specialists but even by ordinary citizens. One reason these minor elements draw such attention is their application in energy technologies. Therefore, critical metals, the main applications of which are in energy technologies, are often called "energy critical metals." (US DOE, 2010)

In discussions of energy critical metals, once again, minor elements often draw too much attention. Hashimoto and Murakami (2013) offer a comprehensive review of demand forecasts for these "energy critical metals." Many studies have been carried out on this, and Stamp *et al*. (2014) is one such recent research study. Even with highly sophisticated power generation technologies, however, we still need infrastructure for transmission and distribution, so the common metal copper should also be discussed in detail.

In this paper, we chose two metals, copper and indium, and estimated their demand. In this paper, we narrowed our focus to the electricity supply only. We ignored other energy supplies. Because demand for copper for electricity supply systems will be huge no matter which energy sources we choose, it will be affected. Considering there is no existing research with detailed bottom-up demand forecasts for copper for the energy supply, we decided to make copper our main focus. Grid design may change the demand for copper, and discussions on SDGs for energy access include off-grid energy systems. Consideration of off-grid systems, however, is beyond the scope of this paper, simply because no copper demand data are available for such systems.

Estimation of indium demand was carried out with the same assumptions as Stamp *et al*. (2014) while future generation capacity was estimated by our model for the sake of consistency with the estimations for the other two metals.

2. Material Demands for Electricity Supply

2.1. Demand for the Electricity Supply System

In this paper, the electricity supply system is divided into power generation and the grid (transmission from generators to the distribution network, and the distribution network for distributing electricity to end-users).

In our discussion of SDGs, we will set a goal of energy access, which determines the minimum energy demand. In order to estimate the material demand for the power generation system, we need to estimate the needed power generation capacity of each source to fulfill the demand, as shown in equation (1) – (4). The electricity demand and power generation mix will be exogenously given as scenarios.

$$TotalGeneration_{r,i} = \frac{ElectricityDemand_{r,i}}{(1-TransmissionLoss_{r,i})} \quad \textbf{(1)}$$

$$Generation_{r,i,g} = GenerationMix_{r,i,g} \times TotalGgeneration_{r,i} \quad \textbf{(2)}$$

$$GeneratorCapacity_{r,i,g} = \frac{Generation_{r,i,g}}{OperationRate_{i,g}} \times \frac{1}{24[h/day]\times 365[day/year]} \quad \textbf{(3)}$$

$$TotalGenratorCapacityPerCapita_{r,i} = \frac{\sum_g GeneratorCapacity_{r,i,g}}{Population_{r,i}} \quad \textbf{(4)}$$

where r, i, g region, time, power source

Once electricity demand and the needed power generation capacities are obtained for each region, source and time, additional grid capacity demand are estimated.

Given the geographical differences among countries, we decided to estimate the transmission system and distribution system independently.

We could obtain transmission length data for only 46 countries, even though we surveyed sources ranging from governmental information to industrial associations, even including individual companies. Data on GDP, population and total land area were obtained from UN statistics while the U.S. Energy Information Administration (USEIA) database was the source for energy-related data. Throughout our analysis, we found that per capita transmission cable length depended on per capita generation capacity, population density and GDP per capita. We divided transmission systems into two subcategories of "transmission" and "sub-transmission" systems. The factors affecting these two categories were same. The reason we divided them this way was that the material contents differed completely between these two. We then estimated the sub-transmission cable length as a function of transmission cable length, as shown in Equation (7).

The length of the distribution system depends only on the generator's capacity. The regression equations obtained, which were utilized in the estimation of material demands, are shown in Equations (5) – (10). The estimated coefficients of c_1 to c_8 are shown in Table 1.

$$TransmissionLengthPerCapita_{r,i} = c_1 + c_2 \times totalGenratorCapacityPerCapita_{r,i} + c_3 \times AreaPerCapita_{r,i} - c_4 \times GDPPerCapita_{r,i} \quad \textbf{(5)}$$

$$TransmissionLength_{r,i} = transmissionLengthPerCapita_{r,i} \times Population_{r,i} \quad \textbf{(6)}$$

$$SubTransmissionLengthPerCapita_{r,i} = c_5 + c_6 \times TransmissionLengthPerCapita_{r,i} \quad \textbf{(7)}$$

$$SubTransmissionLength_{r,i} = SubTransmissionLengthPerCapita_{r,i} \times Population_{r,i} \quad \textbf{(8)}$$

$$DistributionLengthPerCapita_{r,i} = c_7 \times ln(c_8 \times TotalGeneratorCapacityPerCapita_{r,i} + 1) \quad \textbf{(9)}$$

$$DistributionLength_{r,i} = DistributionLengthPerCapita_{r,i} \times Population_{r,i} \quad \textbf{(10)}$$

Table 1 Coefficient estimation results.

	Estimated coefficient	t-value
c_1	0.1913	3.036***
c_2	0.2547	5.463***
c_3	0.0227	3.784***
c_4	0.0029	1.095
c_5	0.0088	−0.044
c_6	2.2091	3.506*
c_7	8.0004	2.608*
c_8	1.725	1.326

(*, **, *** denote statistical significances of 10%, 1%, 0.1%, respectively.)

2.2. Demand for Mineral Resources

Estimated values, such as generator capacity and cable length, gave us fundamental information on in-use stock of materials. After that, we needed to estimate the inflows, which are demands for material resources. We assumed a Weibull distribution of the lifespans of generators and cables, as in many studies. (Murakami *et al.*, 2010). In order to estimate the outflows from existing stocks, we needed to know the historical inflows for these goods. The historical inflows for all regions, however, were simply unavailable, so the inflows were assumed to be constant. Thus the relationship between capacity and material demand remained constant (Equations (11) – (13)).

The new and old scrap generations were estimated as follows.

$$NewConstruction_{r,i} = TotalCapacityDemand_{r,i+1} - \sum_{age} RemainedCapacity_{r,i+1,age} \quad (11)$$

$$Capacity_{r,i+1,age=0} = NewConstruction_{r,i} \quad (12)$$

$$MaterialDemand_{r,i,m} = NewConstruction_{r,i} \times MaterialComposition_{m} \quad (13)$$

$$NewScrap_{r,i,m} = MaterialDemand_{r,i,m} \times \left[\frac{1}{(1 - YieldRate_{m})} - 1\right] \quad (14)$$

$$ReplacedCapacity_{r,i} = \sum_{age} Capacity_{r,i,age} \times (1 - RemainedRatio(age)) \quad (15)$$

$$OldScrap_{r,i,m} = ReplacedCapacity_{r,i} \times MaterialComposition_{m} \quad (16)$$

We assumed that not all generated scraps were recovered. The recovery ratio considers both technological and socio-economic factors to limit the recovery. Finally, we successfully estimated the demand for natural resources by subtracting recovered scraps from material demand.

2.3. Energy Scenario and Data for Metal Demand Forecast

The Jazz scenario by the World Energy Council (WEC, 2013) was chosen for the business as usual (BaU) case energy demand and generation mix scenario. Since Jazz scenario focuses on energy equity, with priority given to achieving individual access and affordable energy through economic growth, we believe this scenario is consistent with our purpose of ensuring stable energy access, while its counterpart, the Symphony scenario, focuses on achieving environmental sustainability through internationally coordinated policies and practices. The Jazz scenario has been developed to 2050. In North America, per capita energy consumption will be saturated at around 12 MWh before 2050. We took this value as a reference and all other regional scenarios were fitted into the logistic function. Then using the estimated parameters of the logistic functions for each region, scenarios from 2050 to 2100 were generated. An average lifespan of 40 years for generators was obtained from CRIEPI (2010), while the Japan Ferrous Raw Materials Association (2012) provided a construction yield ratio of 90%.

Regarding mineral demand, we focused on copper in cables and transmission/ distribution wire systems and indium in CIGS (Copper-Indium-Gallium-Selenide) solar modules. Data on the copper in wire and cables were obtained from TEPCO and JCMA (1989), who also provided lifespan information. Data on indium in CIGS were obtained from Stamp *et al.* (2014).

Both population and population density data were obtained from United Nations (UN) (2012), while Gaffin *et al.* (2004) provided the GDP forecast.

3. Results

3.1. BaU Case

All equations introduced in the previous section were modeled with JAVA in the form of a system dynamics model.

The power generation capacity from the model estimation is shown in Fig.1. Asia dominates the capacity growth for the first half of this century, while Africa overtakes from the middle of the century. The results for cable length, however, differ slightly. Compared to the case of generation capacity, Asian cable length saturates much earlier and the African value starts rising in the middle of this century. Figure 2 shows primary and secondary copper consumption. The most notable result is the overall growth ratio. Considering the growth of generation capacity and cable length, the growth for primary copper demand seems quite slow. In total, the

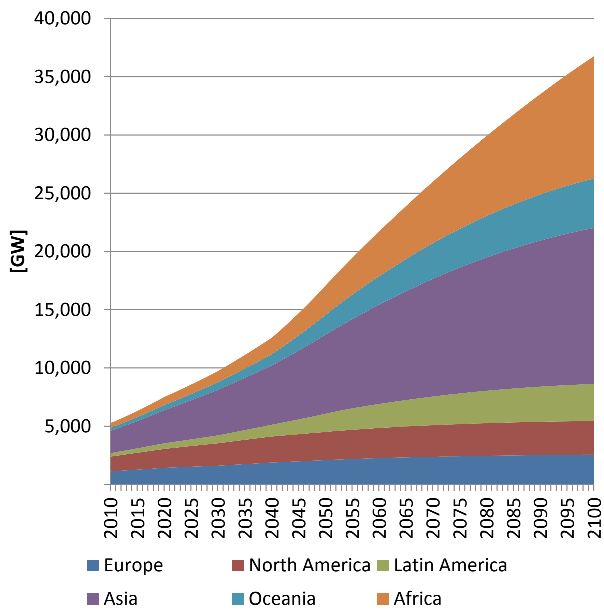

Fig. 1 Power generation capacities (BaU).

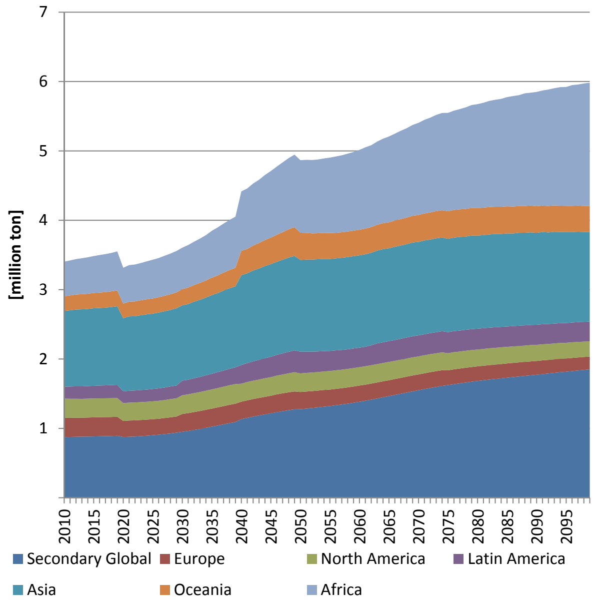

Fig. 2 Regional primary copper consumption and global secondary copper consumption (BaU).

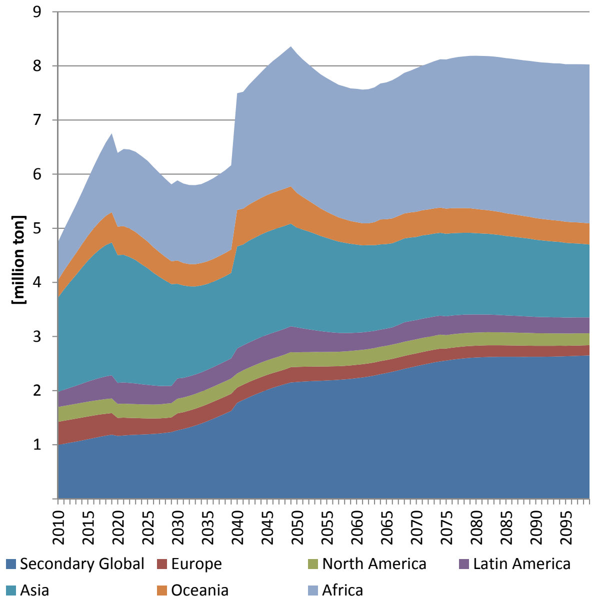

Fig. 3 Regional primary copper consumption and global secondary copper consumption in Scenario A.

copper demand for power generation and transmission/distribution cables is estimated at 3.4 million tons. According to IWCC (2012) the copper demand for this sector is 3.1 million tons. Our estimation seems reasonably good. Indium will be discussed below in Section 3.3.

3.2. Rapidly Increasing Grid Access

As an extreme example, we examined what would happen if we tried to improve grid access for all nations to the same level as in developed nations in 2030 (Scenario A). We also estimated demand for the cases of 2060 and 2100 (Scenarios B and C.) Figure 3 gives the copper consumption estimations for Scenario A. Compared to Fig. 2, the peak demand would occur much earlier, around 2050, whereas the demand in Fig. 2 keeps increasing even in 2100. A more important finding, however, is a huge spike in demand. We would face a sharp increase until 2020 to boost the capacity by 2030 and then demand would decrease slightly. It would spike once again, however, toward 2050, partially because the capacity introduced in the early years would need to be replaced between 2040 and 2050. The peak copper demand around 2050 would be about 8 million tons, while in the BaU scenario, we would not face that much demand until 2100. Even if the accumulated consumption of primary copper did not differ much, the huge demand at a certain point in time would mean we would need to prepare a huge copper supply capacity, which might be an enormous problem.

Future mineral supply predictions vary among sources. If we take a slightly pessimistic prediction as our benchmark, however, the amount of copper demand for this sector seems problematic. Northey *et al*. (2013) predict that copper production will peak around 2040 and then decrease. If we assume the demand for copper among sectors to remain the same, which means roughly 17% of total production could be allocated to this sector (appearing as 'Available Primary Cu' in Figs. 4 and 5), as can be seen in Fig. 4, the BaU scenario would seem feasible until around 2090. This does not seem likely in the other three scenarios, though, especially for Scenario A. In the case of Scenario A, the sharp demand increase around 2020 would not be fulfilled according to this assumption (Fig. 5). The excessively huge demand for copper material is primary reason for this. Too rapid of a demand increase, however, would mean a reduced copper scrap supply, which would force us to consume more primary resources, because scrap generation needs a lead time, especially in the case of infrastructure applications with longer lifespans. As shown in Fig. 5, the secondary copper supply in Scenario A does not differ much from those of the other scenarios. Too rapid of a demand increase would mean demand would increase before scrap became available. This does not sound like efficient resource use. We need, however, to improve energy access across the world. We need to find a way to improve energy access with efficient material resource use, such as by increasing copper recycling from other final products or reducing the amount of copper used for transmitting the same amount of electricity.

3.3. Indium Demand

In our BaU scenario, demand for indium, which is used in CIGS solar modules starts increasing around 2040, partially due to the rapid increase of PV introduction in the WEC Jazz scenario. Since the Jazz scenario does not allow for strong political intervention, the share of fossil fuels would remain high at 77% even in 2050 and the share of PV would suddenly start increasing around 2040. Regarding detailed scenario parameters, we basically followed Stamp *et al*. (2014). One huge concern regarding the production processes is

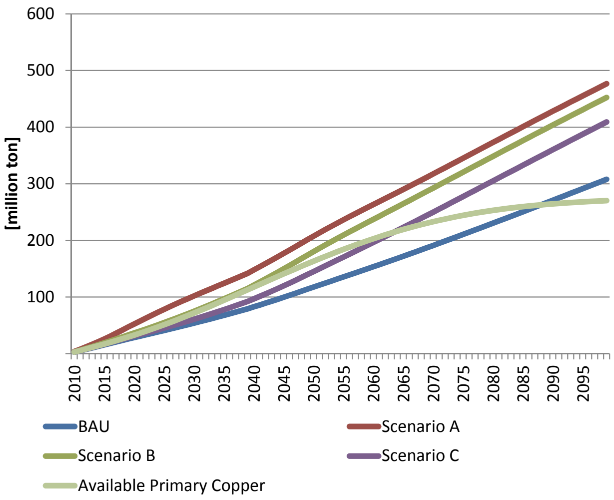

Fig. 4 Cumulative primary copper supply in different scenarios.

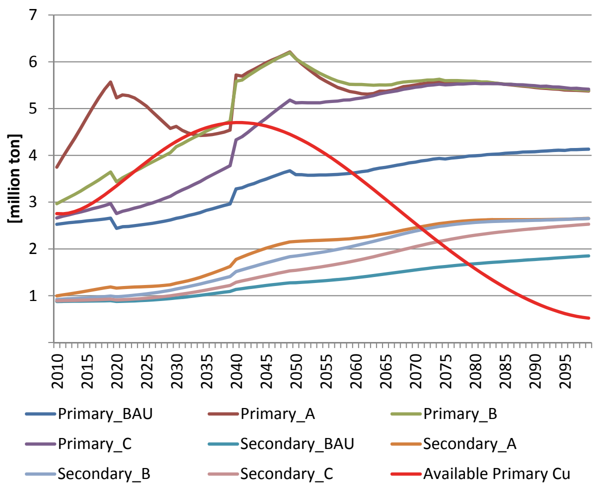

Fig. 5 Primary/secondary copper supply in different scenarios.

that the material utilization rate is quite low.

Indium demand in the BaU scenario would gradually increase to 630 tons in 2030. Then, it would suddenly increase to more than 6,949 tons in 2050. This result is consistent with those of previous works. Considering that current indium production was 820 tons as of 2014, we can say indium will be one of the 'energy critical' minor elements. In the case of indium, for this application, old scrap recycling will not be available much until late in the 21st century. Thus, our problem will be how to increase the material utilization ratio in the production stages.

3.4 Rapid Diffusion of Renewable Energy

We also carried out some scenario changes to increase renewable energies, as they seem to be a possible measure for achieving a low-carbon society. Indium demand would increase just according to the ratio of increase of CIGS type PV capacity, for example, to 13,898 tons for 2050 in the scenario in which the share of CIGS has doubled compared to the BaU case. This is a prototypical energy critical and minor elements concern: its demand rapidly increases due to the increasing capacity of energy technologies. Copper, however, poses a more important and unexpected problem once again. Since the unstable power generation of PVs (*OperationRate* in Equation (3) is bigger than that of other conventional power sources), we would need to prepare a bigger maximum PV capacity, and therefore a bigger transmission/ distribution system capacity. The grid design might contribute to reduced copper demand for the system, though this point should be studied in detail.

4. Conclusions

Ensuring a sustainable energy access for all as soon as possible is, of course, important and should comprise the core of the SDGs. It would require, however, non-negligible amounts of material resources such as copper. Substituting other materials for copper in the electricity supply system seems difficult, so we must seriously consider measures for tackling this issue. Recycling is a potential solution. As already noted in Section 3.2, however, too sharp of a material demand increase would force us to use more natural resources, simply because scrap would not be available for a while, as shown in Fig. 5.

Regarding so-called 'energy critical' and minor elements such as indium, their demand would increase sharply, depending on the technologies we employed. Many studies, however, suggest that there is plenty of room to improve the material efficiency of these relatively new technologies. Also, we can choose which technologies we want for power generation. As discussed in Section 3.4, the introduction of renewable energy has the potential to aggravate concerns regarding copper.

In short, our analysis suggests that copper seems critical, depending on the scenario. The demand is huge and hard to substitute. In order to ensure energy access for all as soon as possible while continuing to use minerals efficiently, we need to manage minerals such as copper carefully, because they must be used in infrastructure for society. Discovering other applications in which other materials can be substituted might be a solution to this issue, but this is obviously beyond the scope of this paper and therefore remains our future task.

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