Criticality Assessment of Metals for Japan's Resource Strategy

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Criticality assessment of metals has been developed to analyze a country's supply risk and vulnerability to supply restriction. This study presents Japan's criticality of 22 metals during 2012. Whereas a past assessment focused only on minor metals, evaluation targets here included both common and minor metals. In addition, a new analytic method included mineral interest sufficiency as a criticality component. The evaluation framework developed in this study included 13 criticality components within five risk categories: supply risk, price risk, demand risk, recycling restriction, and potential risk. Weighting factors were used to aggregate components into a single score. This framework reflects a recent government announcement about Japan's resource strategy. High criticality was found for neodymium, dysprosium, and indium due to a recent increase in demand. Niobium also had high criticality due to production concentration in Brazil. There were few differences in the aggregated criticality scores between the other minor metals and common metals. For minor metals, aggregated criticality was mainly increased by production concentration and recycling difficulty. For common metals, aggregated criticality was increased by short depletion time and growth in global mine production. Compared with a previous study, in 2012 the criticality of tungsten and tantalum were lower due to reduced domestic demand. The analytic methods and results presented in this study will be useful in developing Japan's resource strategy.

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1. Introduction

Securement of mineral resources has been an important issue for Japan because a large portion of its metal supply is import dependent. In 2012, the Japanese government announced a strategy for resource securement¹⁾ in which 30 minerals were designated "strategic minerals". Strategic minerals were selected against a background of their growing importance in industry and rising supply risk, which resulted in designating both minor metals such as indium, platinum, and rare-earth elements (REEs), and common metals such as iron, copper, and lead. The strategy mentioned the four pillars toward a stable supply of these metals: acquisition of mineral interests, recycling from industrial processes and end-of-life products, developing substitution materials, and stockpiling.

Two criteria for strategic minerals—supply risk and vulnerability of industrial activities to supply restriction—correspond to the concept of "criticality" of materials.²⁾ Criticality was developed to evaluate the relative importance of securing primarily metal resources. The relative importance of different metals should vary across countries depending on their key industries. The degree of supply risk would also differ between countries because such risk could be mitigated by diversifying import partners and obtaining mineral interests in mining companies. As a result, each country would have unique critical metals. The National Research Council³⁾ examined the criticality of 11 materials using a "criticality matrix" with supply risk and impact of supply restriction in horizontal and vertical axes, respectively. Criticalities were evaluated not only for the overall US economy, but also for specific industries (e.g., the criticality of REEs for magnets, electronics, ceramics, etc.). The European Commission⁴⁾ also evaluated supply risk and the economic importance of 41 raw materials in 2010, and found

that 14 of 41 materials were beyond the thresholds of both criteria and were therefore considered critical for the European Union (EU). These results were recently revised; in 2013, 27 of 54 materials were considered critical.⁵⁾ Criticality evaluation and continuous review are expected to contribute to the implementation of resource policy and the construction of robust industrial activities.

Before the announcement concerning strategic minerals, Japan's criticality assessment was reported in 2009 by the New Energy and Industrial Technology Development Organization (NEDO).⁶⁾ By evaluating several factors related to mineral supply risk and expected demand growth, relative criticality scores of minor metals were determined. However, the targets of the assessment was limited to minor metals although Japan's resource strategy designated some common metals as the strategic minerals. Furthermore, among the four pillars of Japan's resource strategy, mineral interests overseas and accompanying resource entitlements was not considered. The goal of this study was to evaluate Japan's criticality of metals taking these factors into account. Our evaluation considered the contribution of different factors to the criticality of different metals. Furthermore, changes in criticality in recent years were evaluated by comparing current results with past assessments.

2. Methodology

2.1 The existing framework for criticality assessment: the approach used for the NEDO assessment

The NEDO assessment⁶⁾ designated elements considered to be risk exposed in resource securement as "important minerals", which were determined by evaluating five risk categories under 12 components (Table 1). Although the assessment report did not use the terms "criticality" or "critical metal/material", the assessment evaluated the critical metals for Japan. In the NEDO assessment, the 12 components were evaluated for 39 minor metals in 2008. The

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Table 1 Criticality components used in the NEDO assessment.

Category	Component
Supply risk	Depletion time
	Concentration of reserves
	Concentration of ore production
	Concentration of import trading partners
Price risk	Price change
	Price variation
Demand risk	Mine production change
	Domestic demand growth
	Domestic demand growth for specific uses
Recycling restriction	Stockpiles
	Recyclability
Potential risk	Possibility of usage restrictions

results for respective metals were then aggregated into single criticality scores. The NEDO assessment finally designated 14 of 39 metals with high criticality scores as important minerals.

For each of the 12 components, scores representing their securement importance were designated with 0, 1, 2, or 3 points. For “depletion time”, for example, 3 points were rated for metals with less than 50 years of depletion time; 2 points for 50–100 years; 1 point for 100–150 years; 0 points for over 150 years. For “stockpiles”, metals with stockpiles built up through governmental policy were evaluated as 0 points, and 1 point was designated for other metals.

Scores for each of the 12 components were aggregated into a single criticality score using weighting factors. Factors employed in the NEDO assessment comprised 25% of the contribution to the aggregated scores for each of supply risk, price risk, and demand risk, 20% for recycling restriction, and 5% for potential risk. Weighting among components within each risk category were equivalent. Finally, comprehensive criticality scores were calculated with a maximum of 32 points possible for each of 39 metals. Metals with 18 points or higher were regarded as important minerals.

2.2 The framework developed for criticality assessment in this study

The framework for the NEDO assessment was designed according to existing criticality assessments. However, the framework and evaluation target did not fully accommodate Japan's resource strategy. The strategy designated 30 common and minor metals as strategic minerals, whereas the NEDO assessment evaluated only minor metals. Therefore, the criticalities for common metals should be a significant concern. Another shortcoming of the NEDO assessment was that the framework did not reflect a difference in degree of secured resource entitlements between metals. Holding many entitlements by resource development and investment in foreign mines has been considered an effective measure for supply stability. One example of the recent increase in entitlement reinforcement is the Araxa mine project, in which Japan Oil, Gas and Metals National Corporation (JOGMEC) and Japanese steel companies acquired 10% of entitlements of niobium with some Korean

Table 2 Target metals for criticality assessment.

Target metals	
Evaluated in the NEDO assessment	Newly evaluated in this study
Chromium (Cr), Manganese (Mn), Cobalt (Co), Nickel (Ni), Niobium (Nb), Molybdenum (Mo), Rhodium (Rd), Palladium (Pd), Indium (In), Neodymium (Nd), Dysprosium (Dy), Tantalum (Ta), Tungsten (W), Platinum (Pt)	Aluminum (Al), Iron (Fe), Copper (Cu), Zinc (Zn), Silver (Ag), Tin (Sn), Gold (Au), Lead (Pb)

steel companies.⁷⁾ However, as shown in Table 1, the NEDO supply risk assessment did not consider mineral interests or accompanying resource entitlements. Thus, building a criticality component that includes sufficiency of mineral interest is necessary for criticality mitigation through policy actions.

With these methodological improvements, evaluation should be reviewed over time as the EU reports criticality status in 2010 and again in 2014.^{4,5)} Thus, we analyzed the criticalities of metals in 2012, four years after the target year of the NEDO assessment.

2.2.1 Expansion of the evaluation targets

We evaluated the criticality of 22 metals (Table 2). Compared with the NEDO assessment, eight metals (mainly common metals) were newly considered in our study.

2.2.2 Development of the evaluation method

The criticality of metals was evaluated by aggregating several criticality components. We referred to the 12 components employed in the NEDO assessment (Table 1) and used the same scoring strategy for each component. We also took into account an additional component representing Japanese companies' sufficiency of mineral interest holdings. Sufficiency was evaluated using the index “reserve entitlements to demand (RE/D) ratio”.⁸⁾ When a company holds a capital contribution of a mining company, the holding company can receive the benefit of the entitlement to control mined resources. Given that R_{mj} indicates the amount of reserves of metal m in mining project j and r_{ij} indicates the investment ratio in the project j by Japanese company i , Japan's reserve entitlements are calculated as in eq. (1).

Japan's reserve entitlements of metal m

$$= \sum_j \left(\sum_i r_{ij} R_{mj} \right) \quad (1)$$

This represents the amount of resources preferentially available to Japanese industry if the companies i maintain the same investment ratio in the future. Finally, the RE/D ratio is obtained by dividing the reserve entitlements by annual demand for mineral resources (eq. (2)). The value of RE/D ratio will be increased by both securing reserve entitlements through investment and resource development in foreign mines, and by decreasing demand for mineral resources through recycling promotion and resource saving of the products.

$$\text{RE/D ratio} = (\text{reserve entitlements}) / (\text{demand for mineral resources}) \quad (2)$$

Table 3 Rating rules and weighting factors.

Category	Component	Rating rules				Weighting factors
		0	1	2	3	
Supply risk	Depletion time	>150 yrs	100–150 yrs	50–100 yrs	50 yrs>	0.58
	Concentration of reserves	<70%	70–80%	80–90%	90%<	0.58
	Concentration of ore production	<70%	70–80%	80–90%	90%<	0.58
	Concentration of import trading partners	<70%	70–80%	80–90%	90%<	0.58
	Sufficiency of mineral interest	>75	50–75	25–50	25>	0.58
Price risk	Price change	<125%	125–150%	150–200%	200%<	1.46
	Price variation	<125%	125–150%	150–200%	200%<	1.46
Demand risk	Mine production change	<125%	125–150%	150–200%	200%<	0.97
	Domestic demand growth	<125%	125–150%	150–200%	200%<	0.97
	Domestic demand growth for specific uses	<125%	125–150%	150–200%	200%<	0.97
Recycling restriction	Stockpiles	Prepared	None			2.33
	Recyclability	Implemented	Partly implemented	Quite limited		2.33
Potential risk	Possibility of usage restrictions	Safe	Potentially harmful	Harmful		0.88

The RE/D ratio is meaningful for evaluating the relative sufficiency of mineral interest of different metals. We found that RE/D ratios for Japan in 2012 were high for metals such as niobium (164.6), lead (44.9), and tungsten (40.8).⁸⁾ RE/D ratios were calculated for 17 metals for which Japanese companies hold entitlements; RE/D ratios for the remaining metals were evaluated to be zero. As with other criticality components, we evaluated the sufficiency of mineral interest as 0, 1, 2, or 3, depending on the RE/D ratio.

2.3 Rating rules, weighting factors, and data used for evaluation

With the addition of the component “sufficiency of mineral interest” to the supply risk, we evaluated the criticality of 22 metals for Japan in 2012 with 13 components. Rating rules are given in Table 3. The same rating rules used in the NEDO assessment were applied in this study, with the exception of sufficiency of mineral interest.

With no weighting factors, a maximum of 35 points would include 15 points for supply risk, 6 points for price risk, 9 points for demand risk, 3 points for recycling restriction, and 2 points for potential risk. We adhered to the NEDO assessment weighting rules and weighting factors so that 25% each came from supply risk, price risk, and demand risk, 20% from recycling restriction, and 5% from potential risk.

2.3.1 Depletion time

Static depletion time was calculated as the ratio of the amount of reserves to global mine production in 2012. The data on reserves and mine production were obtained from the U.S. Geological Survey (USGS).⁹⁾

2.3.2 Concentration of reserves/ore production

Reserves/production share of the top country in 2012 was calculated from the USGS.⁹⁾ The data on indium reserves were not available from the USGS and were therefore obtained from JOGMEC,¹⁰⁾ which estimated the data from zinc ore reserves.

2.3.3 Concentration of import trading partners

The share of the largest importing partner for materials derived from mineral resources. Not only mineral ores but also the commodities derived from minerals such as primary ingots and semis were counted in this calculation. The import amounts of each commodity were obtained from trade statistics of Japan¹¹⁾ and metal content for each commodity assumed in the past study⁸⁾ were used.

2.3.4 Sufficiency of mineral interest

The values of RE/D ratio were taken from our past study.⁸⁾ Sufficiency of mineral interest was determined using the conceptually similar depletion time, whereas Japan's mineral supply depends not only on entitled resources. Therefore, we determined the threshold value for each score as half of the depletion times.

2.3.5 Price change/price variation

In the NEDO assessment, price change, price variation, mine production change (2.3.6), and domestic demand growth (2.3.7) were evaluated from the changes during the ten years preceding the year of evaluation. Annual average price between 2003 and 2012 was obtained from the literature.¹²⁾ Price change was calculated as a percentage of price in 2012 over that in 2003, while price variation was calculated as a percentage of the highest to the lowest during those 10 years.

2.3.6 Mine production change

The percent of global mine productions in 2012 compared with 2003 were calculated from the USGS.⁹⁾

2.3.7 Domestic demand growth (total/specific use)

Data on metal consumption by end use from 2003 to 2012 were gathered from previous statistical reports.^{11,13–21)} Non-zero values were rated when a percent of consumption in 2012 compared with 2003 exceeded 125%.

2.3.8 Stockpiles

Government policy calls for stockpiles of some metals in preparation for sudden supply interruption. Stockpiles are built up by both government and private sectors, and are expected to

satisfy at least a 60-day demand. Current stockpile targets are regarded to be vanadium, chromium, manganese, cobalt, nickel, gallium, molybdenum, indium, and tungsten, which was inferred from the record of governmental meeting.²²⁾

2.3.9 Recyclability

The NEDO assessment evaluated recycling performance at three levels and used the same scores for each of 14 metals evaluated. We determined the scores for other metals based on recent status on recycling from end-of-life products.²³⁾ In consequence, 0 points were given to aluminum, iron, and lead because recycling of these common metals is well implemented; 2 point was given to tin because recovery of tin from solder in end-of-life products is rarely implemented; 1 point was given for other metals (i.e., copper, zinc, silver, and gold).

2.3.10 Possibility of restriction on usage

The NEDO assessment considered a potential ecotoxicity of metals that could result in restricted future use. The same scores were used for 14 metals considered in the NEDO assessment. Among metals newly considered in this study, toxicity of lead has been significantly observed and examined compared with the other metals.²⁴⁾ Therefore, we assigned 1 point to lead and 0 points to the other newly-considered metals.

3. Results and Discussion

3.1 Criticality of 22 metals in 2012

Indicators for supply risk, price risk, and demand risk are given in Table 4. For domestic demand growth for specific uses, values over 125% were found for four metals: cobalt for lithium-ion batteries, indium for ITO targets, and neodymium and dysprosium for magnets used in automobiles.

From the results in Table 4, criticality scores for Japan in 2012 were evaluated as shown in Table 5 and Fig. 1. The average of the aggregate scores was 17.9, and half of the 22 metals had aggregate scores between 16 and 18. High criticality was observed for neodymium, dysprosium, indium, and niobium. Indium, neodymium, and dysprosium faced high demand risks, which resulted in their higher aggregated scores. The main reason for a high criticality for niobium was supply risk. At present, reserves and production of niobium are highly concentrated in Brazil. Furthermore, risk from depletion time is high, unlike neodymium, dysprosium, and indium. Japanese steel companies acquired the mineral interest of niobium mines in Brazil in 2011,⁷⁾ which led to a low sufficiency of mineral interest score. Nevertheless, short depletion time and concentration in Brazil contribute to a high supply risk in the aggregate.

The lowest criticality was for aluminum. Bauxite is widely distributed in the world in large amounts and therefore supply risk is low. In addition, settled domestic demands indicate a low supply risk. However, such a “common” metal does not necessarily indicate low criticality. Aggregated scores of iron, zinc, and lead are around 17–18, which are close to the scores for minor metals such as cobalt, tantalum, and platinum group metals, and higher than nickel, molybdenum, and tungsten. During the 10 years preceding 2012, a rise in metal prices occurred in both common and minor metals; therefore, price risk is high for almost all metals shown in Table 5. In

terms of demand risk, mine production change is high for common metals due to the demand growth in developing countries. Furthermore, depletion times of common metals are generally shorter than those of minor metals. Conversely, criticality of minor metals is likely high because of their production concentration and difficulty in recycling. These varied backgrounds lead to similar criticality levels between common and minor metals.

3.2 Change in criticalities from 2005 to 2012

The values in Table 4 reflect shifts in mineral production circumstances, demand, and price trends, and new products and technologies. The NEDO assessment reported the criticality scores of minor metals in 2005 and 2008. Table 6 indicates the aggregated criticality scores in 2005 and 2008 reported by the NEDO and in 2012 from this study. The highest score was 32 points for the NEDO assessment and 35 points for the 2012 analyses. Compared with 2005, the criticality of tantalum has been reduced. In 2005, increasing demand for tantalum led to high scores on demand risk. However, elevated prices in the early 2000s and global concern about conflict in mining countries provoked a reduction in tantalum usage in products such as cell phones. As a result, the criticality score for demand risk was reduced from 7 points in 2005 to 5 points in 2008 and then to 0 points in 2012. The situation is similar for tungsten: mitigation of growing consumption decreased the score for demand risk from 5 points in 2008 to 0 points in 2012.

In contrast, an increase in the aggregated score was observed for both neodymium and dysprosium due to the increasing demand of rare-earth magnets for automobiles and home electrical appliances. For these metals, mining ventures overseas, improvements in material efficiency in manufacturing, and recycling from end-of-life products have been developed. These factors may contribute to a mitigated future criticality.

3.3 Toward a criticality mitigation

Aggregated criticality scores describe a wide scope of risk factors. Components listed in Table 3 consider both global and domestic risks along both short- and long-term scales. Using such a comprehensive assessment, we revealed a similar level of criticality among common metals (e.g., iron, zinc, and lead) and minor metals. This is consistent with the present resource strategy designating both common and minor metals as strategic minerals.

Although criticality must be a key concept in constructing a resource strategy, assessment methods are still under development. This study used 13 components to evaluate criticality but component choices are diverse across studies.²⁵⁾ The determination of weighting factors should also be discussed further. Simple and arbitrary weightings have been used in many criticality assessments because of our limited knowledge about how to determine adequate weighting factors. Strategies based on objective data, a distance-to-target approach,²⁶⁾ and price-centric analysis²⁷⁾ have been proposed. Moreover, agreement between stakeholders including policy makers, manufacturers, recyclers, and users should be explored to develop criticality assessment as a decision-making tool in resource strategies.

Table 4 2012 indicators calculated for evaluating supply risk, price risk, and demand risk.

Category	Component	Al	Cr	Mn	Fe	Co	Ni	Cu	Zn	Nb	Mo	Rh	Pd	Ag	In	Sn	Nd	Dy	Ta	W	Pt	Au	Pb
Supply risk	Depletion time (years)	106.5	19.2	39.4	62.0	68.2	35.7	40.0	19.2	58.0	44.0	174.1	174.1	22.5	145.0	21.3	1000.0	1000.0	196.1	43.8	174.1	19.3	17.1
	Concentration of reserves	26%	46%	24%	21%	45%	27%	28%	28%	95%	39%	95%	95%	22%	16%	31%	50%	50%	59%	59%	95%	19%	40%
	Concentration of ore production	28%	46%	22%	43%	55%	16%	32%	35%	91%	42%	53%	53%	18%	58%	43%	86%	86%	34%	85%	53%	24%	50%
	Concentration of import trading partners	28%	43%	45%	62%	46%	43%	48%	32%	96%	54%	62%	62%	51%	54%	55%	62%	62%	31%	76%	62%	22%	51%
	Sufficiency of mineral interest	19.0	9.4	13.9	23.2	20.5	24.8	27.8	13.6	164.6	31.4	0.0	1.1	5.8	0.0	0.1	0.0	0.0	0.0	40.8	2.4	14.1	44.9
Price risk	Price change	143%	191%	249%	313%	143%	182%	442%	235%	219%	238%	246%	323%	659%	294%	431%	368%	368%	367%	601%	222%	459%	343%
	Price variation	187%	469%	553%	313%	354%	386%	490%	396%	265%	584%	1281%	365%	733%	535%	533%	368%	368%	417%	601%	253%	459%	488%
Demand risk	Mine production change	180%	155%	195%	259%	227%	150%	125%	144%	210%	200%	98%	110%	128%	181%	111%	112%	112%	63%	118%	87%	104%	176%
	Domestic demand growth	96%	96%	114%	84%	101%	103%	81%	89%	106%	117%	69%	86%	147%	307%	82%	294%	314%	92%	104%	99%	102%	104%
	Domestic demand growth for specific uses														321%		426%	426%					

Table 5 Criticality scores for Japan in 2012.

	Component	Weighting factor	Al	Cr	Mn	Fe	Co	Ni	Cu	Zn	Nb	Mo	Rh	Pd	Ag	In	Sn	Nd	Dy	Ta	W	Pt	Au	Pb
Supply risk	Depletion time	0.58	1	3	3	2	2	3	3	3	2	3	0	0	3	0	3	0	0	0	3	0	3	3
	Concentration of reserves	0.58	0	0	0	0	0	0	0	0	3	0	3	3	0	0	0	0	0	0	0	3	0	0
	Concentration of ore production	0.58	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	2	2	0	2	0	0	0
	Concentration of import trading partners	0.58	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	1	0	0	0
	Sufficiency of mineral interest	0.58	3	3	3	3	3	3	2	3	0	2	3	3	3	3	3	3	3	3	2	3	3	2
Price risk	Price change	1.46	1	2	3	3	1	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	Price variation	1.46	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Demand risk	Mine production change	0.97	2	2	2	3	3	1	0	1	3	2	0	0	1	2	0	0	0	0	0	0	0	2
	Domestic demand growth	0.97	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	3	3	0	0	0	0	0
	Domestic demand growth for specific uses	0.97	0	0	0	0	1	0	0	0	0	0	0	0	0	3	0	3	3	0	0	0	0	0
	Stockpiles	2.33	1	0	0	1	0	0	1	1	1	0	1	1	1	0	1	1	1	1	0	1	1	1
Potential risk	Recyclability	2.33	0	1	1	0	2	1	1	1	1	1	1	1	1	2	2	2	2	2	1	1	1	0
	Possibility of usage restrictions	0.88	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Aggregated total			11.0	15.9	17.4	16.9	17.3	15.0	16.3	17.9	22.8	15.9	16.9	16.9	18.9	22.9	19.3	24.5	24.5	17.5	15.8	16.9	16.9	16.8

	Supply risk	Price risk	Demand risk	Recycling restriction	Potential risk	Aggregated score
Al	2.3	4.4	1.9	2.3	0.0	11.0
Cr	3.5	7.3	1.9	2.3	0.9	15.9
Mn	3.5	8.8	1.9	2.3	0.9	17.4
Fe	2.9	8.8	2.9	2.3	0.0	16.9
Co	2.9	5.8	3.9	4.7	0.0	17.3
Ni	3.5	7.3	1.0	2.3	0.9	15.0
Cu	2.9	8.8	0.0	4.7	0.0	16.3
Zn	3.5	8.8	1.0	4.7	0.0	17.9
Nb	6.4	8.8	2.9	4.7	0.0	22.8
Mo	2.9	8.8	1.9	2.3	0.0	15.9
Rh	3.5	8.8	0.0	4.7	0.0	16.9
Pd	3.5	8.8	0.0	4.7	0.0	16.9
Ag	3.5	8.8	1.9	4.7	0.0	18.9
In	1.8	8.8	7.8	4.7	0.0	22.9
Sn	3.5	8.8	0.0	7.0	0.0	19.3
Nd	2.9	8.8	5.8	7.0	0.0	24.5
Dy	2.9	8.8	5.8	7.0	0.0	24.5
Ta	1.8	8.8	0.0	7.0	0.0	17.5
W	4.7	8.8	0.0	2.3	0.0	15.8
Pt	3.5	8.8	0.0	4.7	0.0	16.9
Au	3.5	8.8	0.0	4.7	0.0	16.9
Pb	2.9	8.8	1.9	2.3	0.9	16.8

Fig. 1 Criticality scores for the five risk categories.

Table 6 Aggregated criticality scores in 2005, 2008, and 2012.

	2012	2008 (NEDO) ⁶⁾	2005 (NEDO) ⁶⁾
Al	11.0	n.a.	n.a.
Cr	15.9	13	14
Mn	17.4	14	17
Fe	16.9	n.a.	n.a.
Co	17.3	16	15
Ni	15.0	14	13
Cu	16.3	n.a.	n.a.
Zn	17.9	n.a.	n.a.
Nb	22.8	19	15
Mo	15.9	17	15
Rh	16.9	18	n.a.
Pd	16.9	13	12
Ag	18.9	n.a.	n.a.
In	22.9	25	18
Sn	19.3	n.a.	n.a.
Nd	24.5	22	17
Dy	24.5	24	17
Ta	17.5	17	23
W	15.8	21	18
Pt	16.9	18	17
Au	16.9	n.a.	n.a.
Pb	16.8	n.a.	n.a.

n.a.: not assessed.

Scores were rounded to units in the NEDO assessment.

Our results show four metals with aggregate scores over 22 points in 2012. Except for aluminum and nickel, scores for the other 16 metals are between 15.9 and 17.9 points. Clearly, the four metals have higher criticality than the other metals; however, it is not very meaningful to discuss relative merits across these 16 metals. Under the rules in Table 3, for the

case of depletion time, 50 and 90 years result in the same aggregated score, while the score increases by 0.58 points with a decrease from 50 to 49 years. For the component “recyclability”, evaluation was subjective although the component has significant weight in the aggregated scores. Fair criteria supported by objective information are required for further methodology development.

Although aggregated scores help to identify critical metals, they should be interpreted by referencing the components. It appears that a rise in aggregated score induced by shortened depletion time can be mitigated by building stockpiles. In reality, a stockpile of 60 days’ demand will not lead to a resolution of a global shortage of mineral resources. As mentioned, the concept of criticality explains contrasting aspects: global or nationwide matters, and short-term shock or long-term stress (in this context, the words “shock” and “stress” are used within the construct of resilience²⁸⁾). Understanding the nature of respective components will foster more effective application of the criticality assessment to resource strategy planning.

4. Conclusions

Criticality assessment has been developed to measure the significance of resource securement for various metals. In this study, we evaluated the criticality of 22 metals for Japan in 2012. This is the first criticality assessment of Japan’s common metals, which are designated as strategic minerals in the governmental strategy for resource securement. Furthermore, methodological development has been achieved by using the sufficiency of mineral interest as a criticality component. The framework of our assessment thus corresponds to Japan’s resource strategy and will therefore contribute to resource strategy planning.

Our assessment clarifies the high criticality for some minor metals such as neodymium, dysprosium, indium, and

niobium. In contrast, the criticality of other minor metals is close to that of common metals. However, the composition of each criticality was diverse among metals; common metals are likely to have a high risk of long-term stress, whereas minor metals have a risk of short-term shock. In applying this criticality assessment, understanding the respective components is more important than the aggregated results.

Japan's resource strategy recommends a variety of measures such as resource development overseas, recycling, material substitution, and stockpiling. All of these measures would mitigate criticality. However, adequate measures should be chosen for each critical metal by examining its influential criticality components.

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