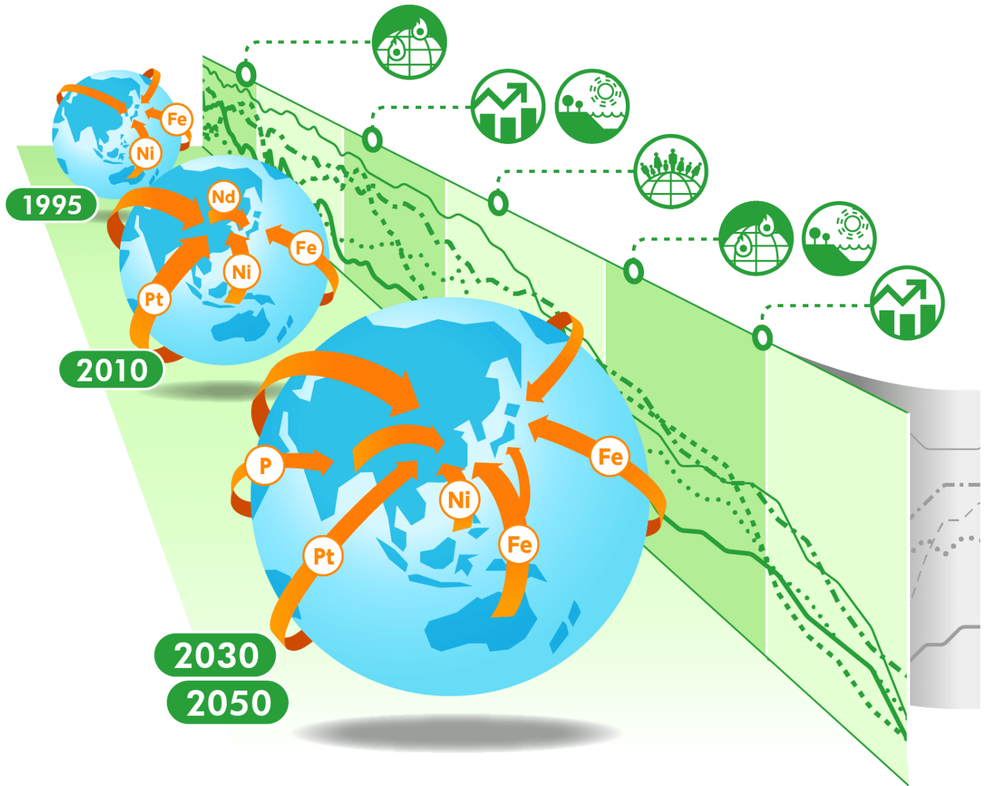
13th Society And Materials International Conference (SAM13)
20-21 May 2019, Pisa, ITALY

Toward environmentally sustainable patterns of resource consumption and production



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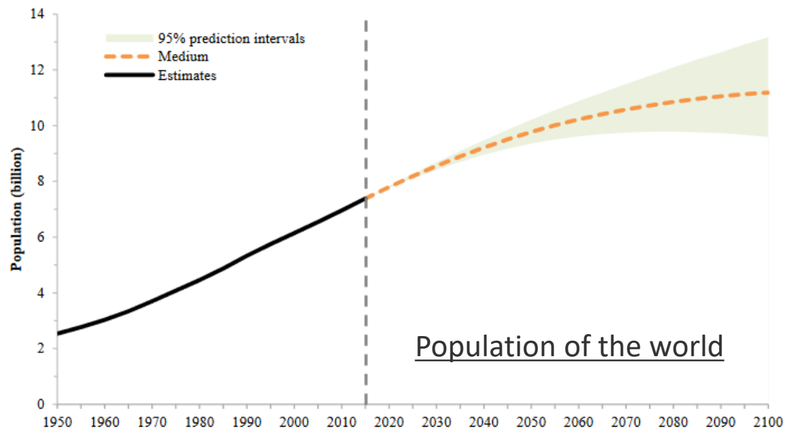
Toward environmentally sustainable patterns of resource use

The world population is expected to increase from 7.6 billion in 2017 to 9.8 billion in 2050 and to reach 11 billion in 2100.

- United Nations, World population prospects, the 2017 revision



Source: United Nations, Department of Economic and Social Affairs, Population Division (2017). *World Population Prospects: The 2017 Revision.* New York: United Nations.

The global demand for mineral resources & metals is increasing sharply.

- Consumption (e.g. Nakajima et al. 2018, Reck and Graedel 2012)
- Stocks (e.g. Wiedenhofer et al. 2019, Krausmann et al. 2017, Nakajima et al. 2017, Pauliuk 2013)

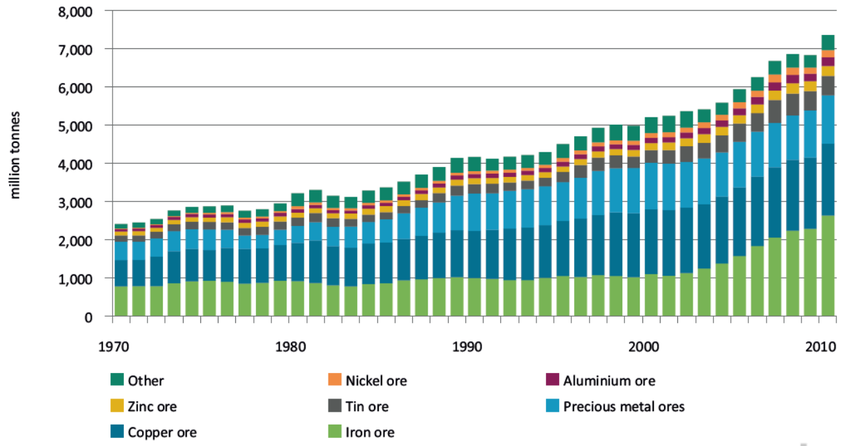


Figure 16. Global extraction (DE) of metal ores by material subcategories, 1970–2010, million tonnes

Global issues on

Sustainable resource management

- UNEP International resource panel
  Decoupling Natural Resource Use and Environmental Impacts from Economic Growth (2011)
  Global Material Flows and Resource Productivity (2016) …etc.

Ensure sustainable consumption and production patterns (Goal 12, SDGs)

- United Nations, Transforming our world: the 2030 Agenda for Sustainable Development (2015)

Global trends in natural resource extraction

The global extraction of natural resources has rapidly increased as the global economy has grown. Decoupling material use and related environmental impacts from economic growth has not occurred over the past decades.

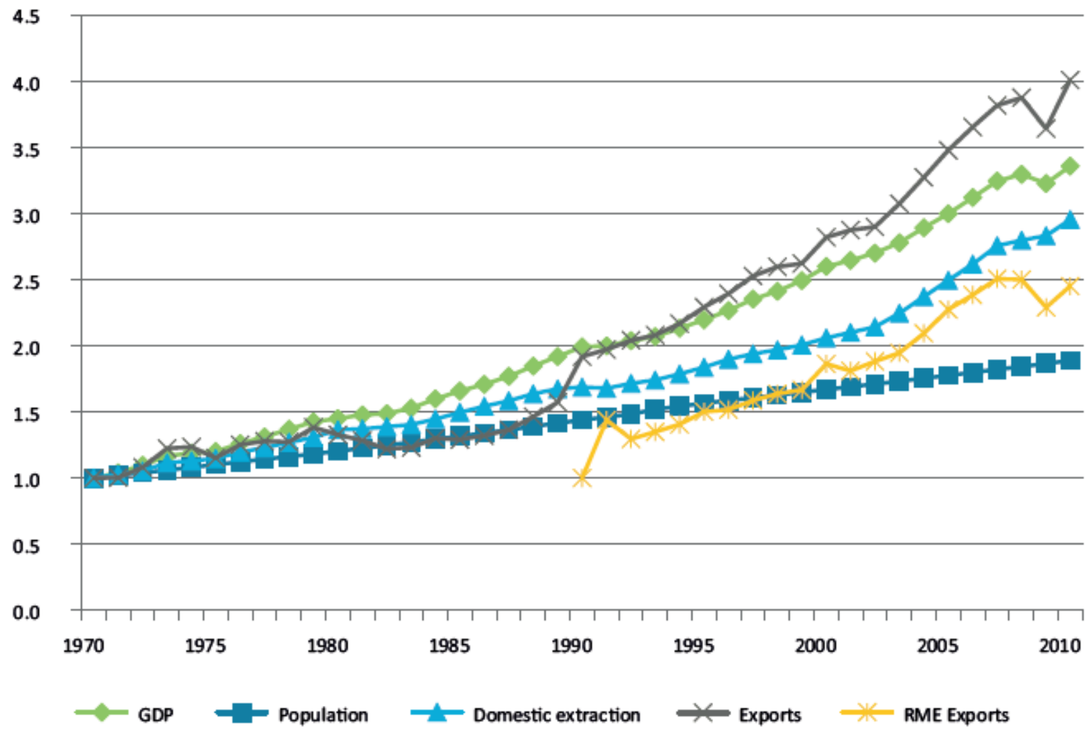
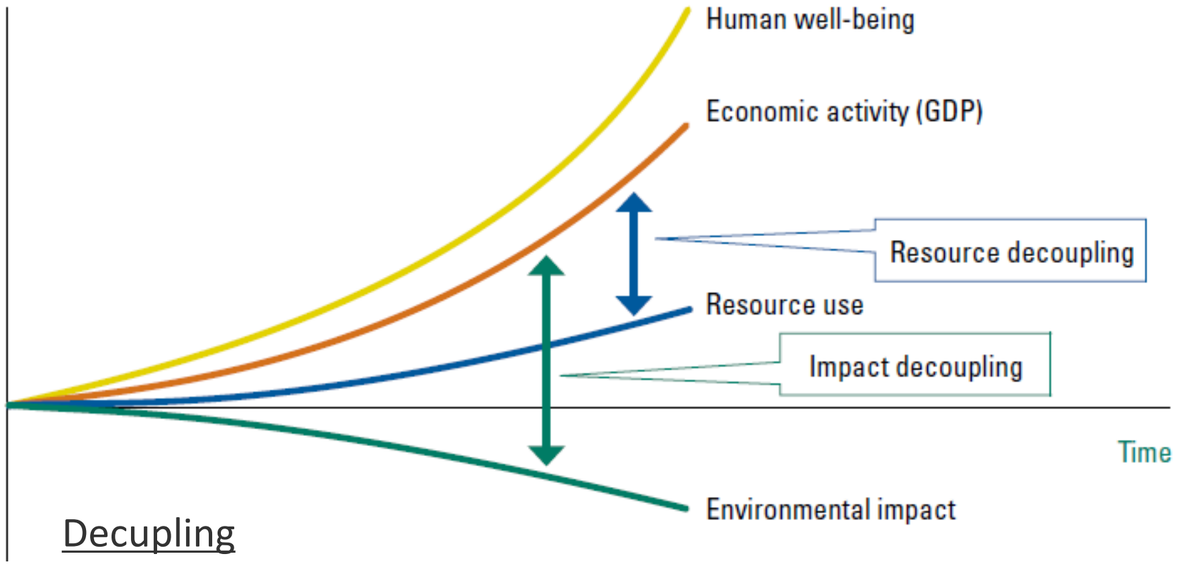


Figure 6. Trends in GDP, population, domestic extraction (DE), exports and raw material equivalents (RME) of exports, 1970–2010, index 1970 = 1



UNEP Global Material Flows and Resource Productivity(2016), Decoupling Natural Resource Use and Environmental Impacts from Economic Growth (2011)

Global material stocks rise 23-fold over the 20th Century

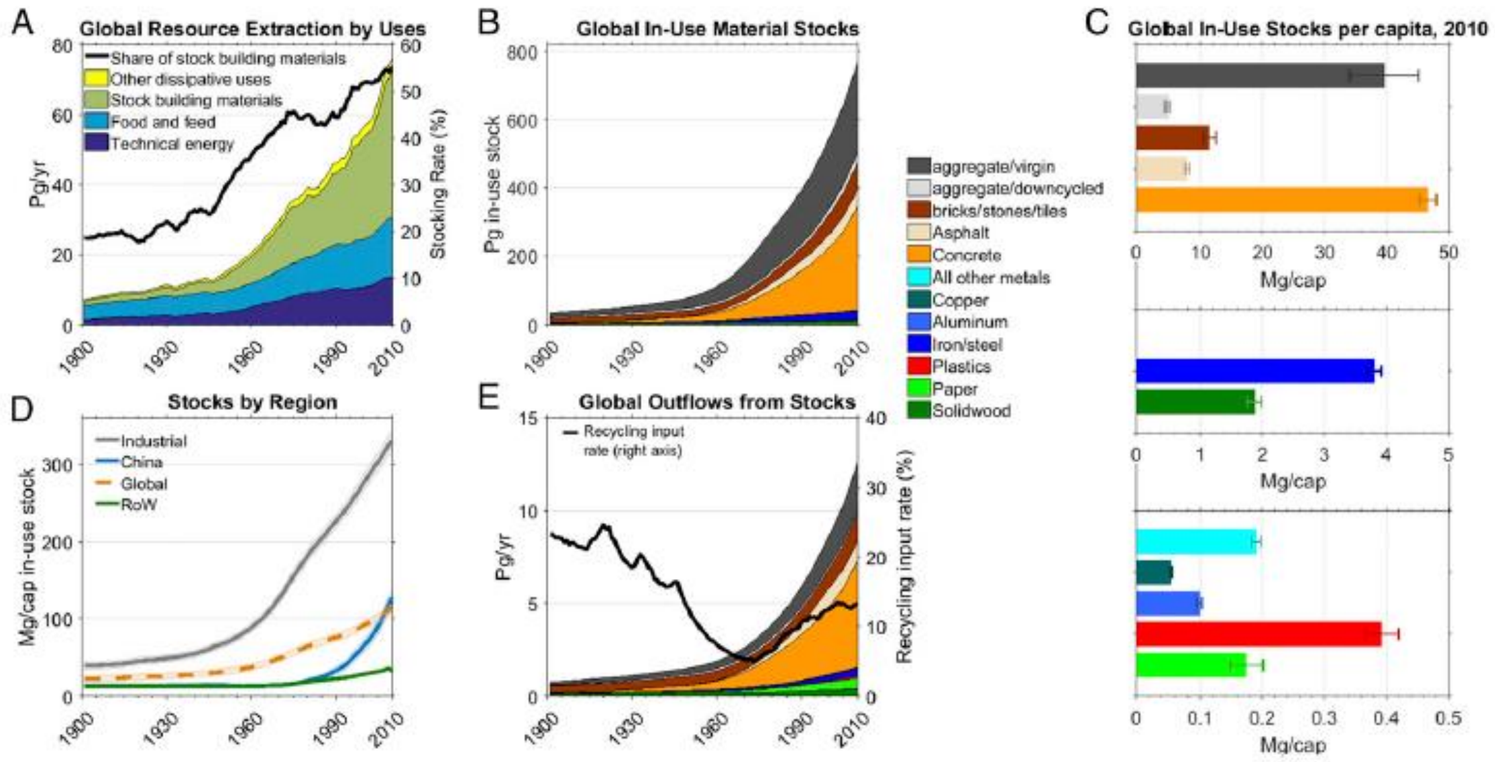


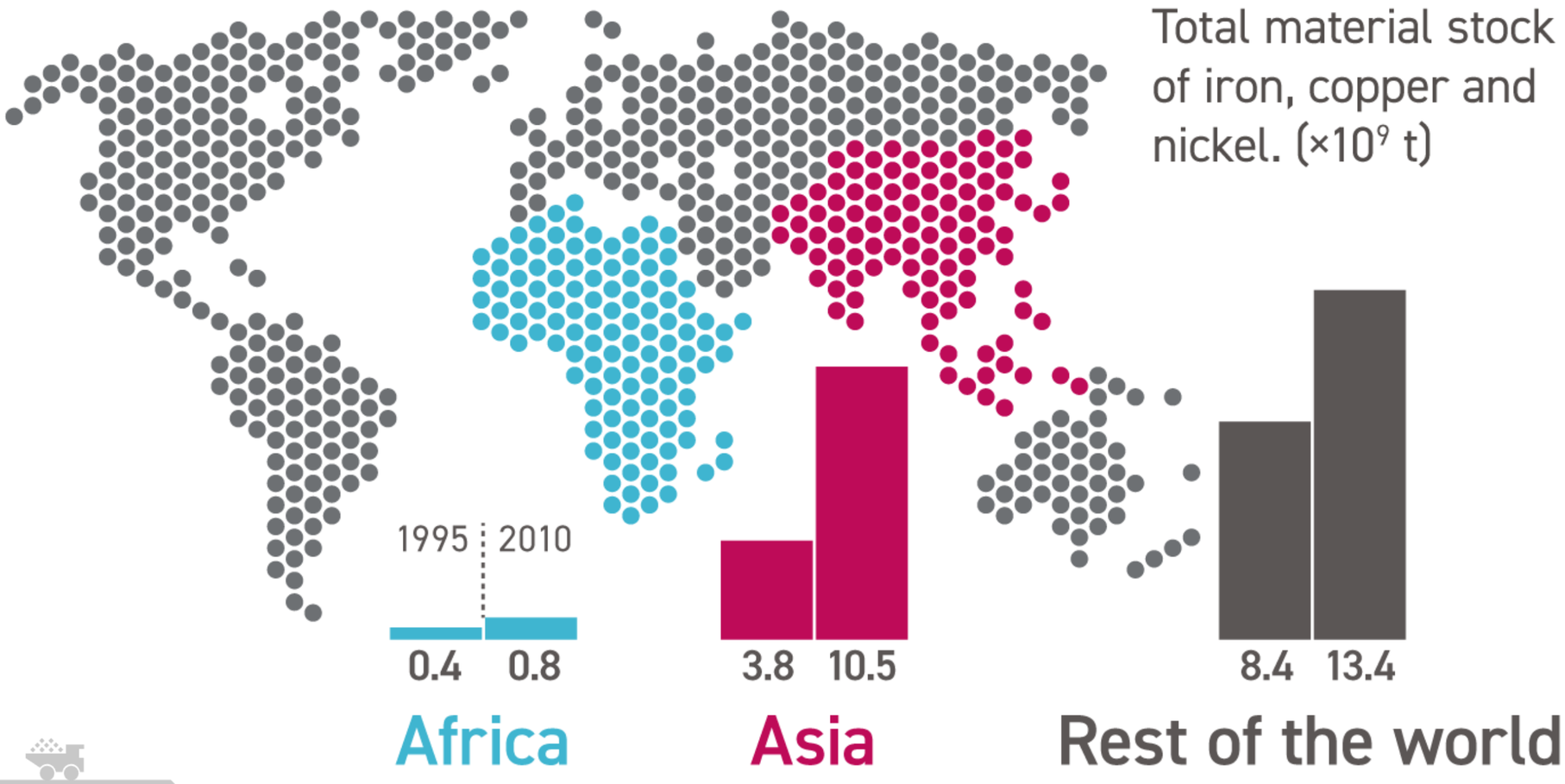
Fig. 1. Development of global material stocks and flows from 1900 to 2010. (*A*) Annual global extraction of materials by use and share of stock-building materials in total extraction (right axis). (*B*) Development of global in-use stocks of materials by 12 main material groups. (*C*) Global material stocks in 2010 including uncertainty ranges (note that the scales in *C* differ by a factor of 10). (*D*) Development of total stock per capita in the group of industrial countries, China, and the rest of the world (RoW). (*E*) Global end-of-life outputs from discarded stocks and recycling input rate (i.e., share of recycled and down-cycled end-of-life outputs from stocks in total inputs to stocks). Note that *B*, *C*, and *E* share the same legend.

"Fostering a transition toward environmentally sustainable patterns of resource use requires a more complete understanding of stock-flow relations. ……from 1900 to 2010. Over this period, global material stocks increased 23-fold, reaching 792 Pg (±5%) in 2010. Despite efforts to improve recycling rates, continuous stock growth precludes closing material loops; recycling still only contributes 12% of inflows to stocks."

Worldwide material stocks; Iron, Copper, and Nickel

Drastic increase (almost doubled) from 1995 to 2010, which coincided with an increase in demand for materials in Asia.

The material stocks in Asia increased almost threefold.



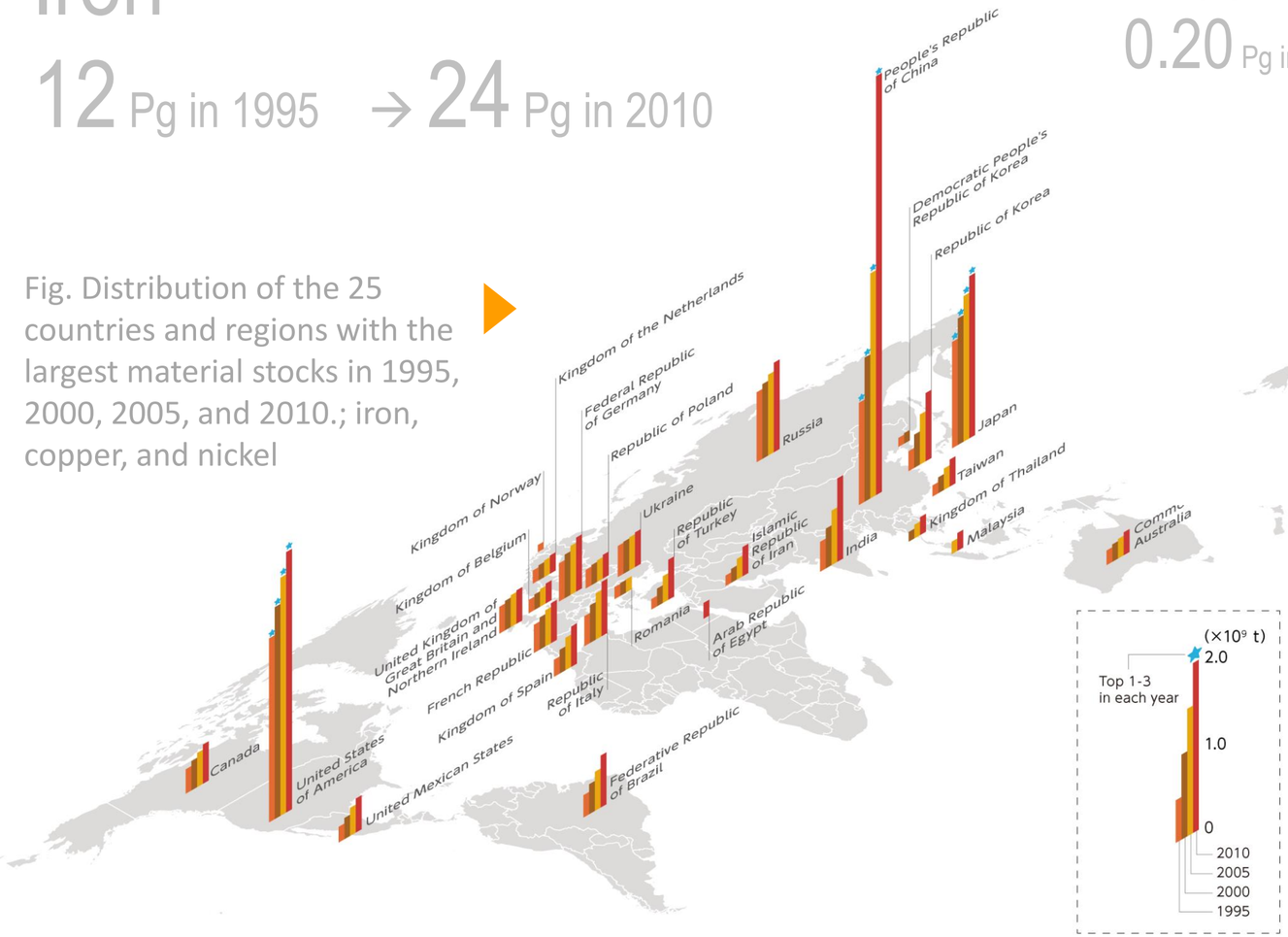
Nakajima K., et al. (2017) Global distribution of material stocks: iron, copper, and nickel. Matériaux & Techniques, 105, 511

Global distribution of material stocks; Iron, Copper, and Nickel

Iron

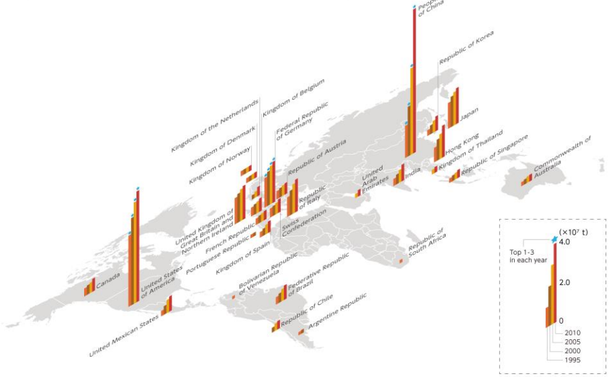
12 Pg in 1995 → 24 Pg in 2010

Fig. Distribution of the 25 countries and regions with the largest material stocks in 1995, 2000, 2005, and 2010.; iron, copper, and nickel



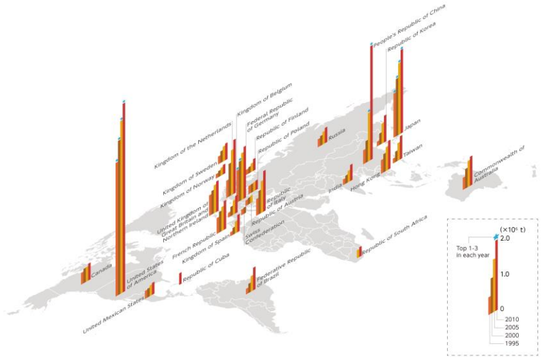
Copper

0.20 Pg in 1995 → 0.37 Pg in 2010



Nickel

13 Tg in 1995 → 29 Tg in 2010

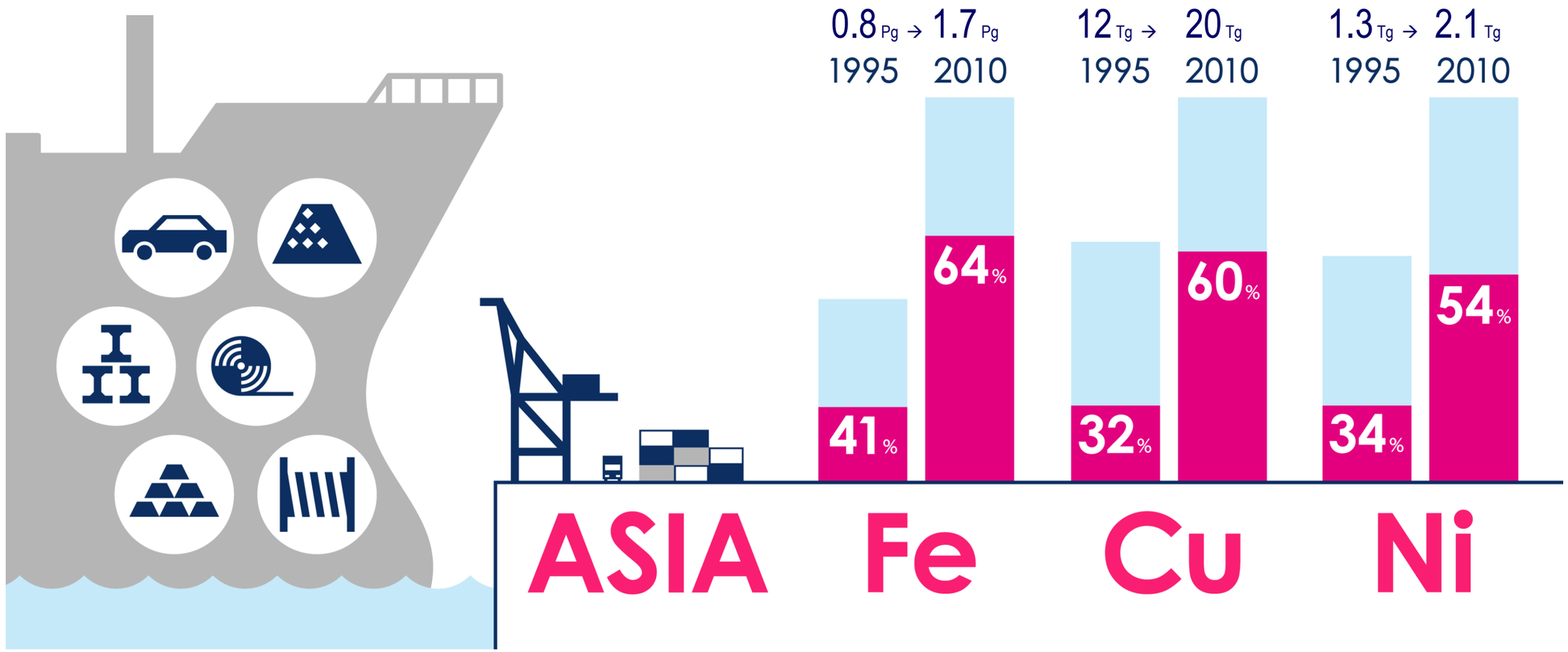


The material stock of iron, copper, and nickel in Asia accounted for 30%, 26%, and 20% of the world total in 1995, respectively, but these percentages increased to 42%, 37%, and 32% in 2010, respectively.

Nakajima K., et al. (2017) Global distribution of material stocks: iron, copper, and nickel. Matériaux & Techniques, 105, 511

Worldwide material consumption; Iron, Copper, and Nickel

Drastic increase from 1995 to 2010, which corresponded with the increase in demand for materials in China.



The levels of apparent consumption of iron, copper, and nickel were 1.7 Pg, 20 Tg, and 2.1 Tg, respectively, in 2010, which represented increases by a factor of 2.1, 1.6, and 1.7, respectively, from 1995.

Nakajima K., et al. (2018) Global distribution of material consumption: Nickel, copper, and iron. Resources, Conservation and Recycling, 133, 369-374

Global distribution of material consumption; Iron, Copper, and Nickel

Iron

0.8 Pg in 1995

→ 1.7 Pg in 2010

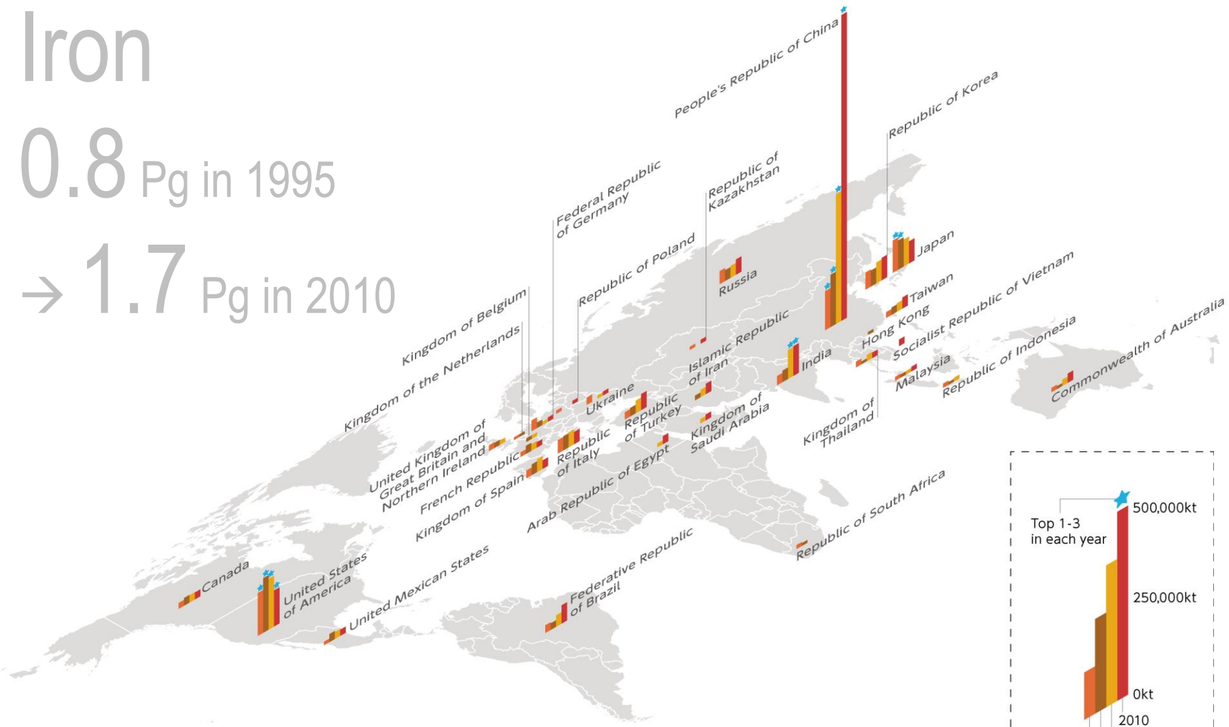
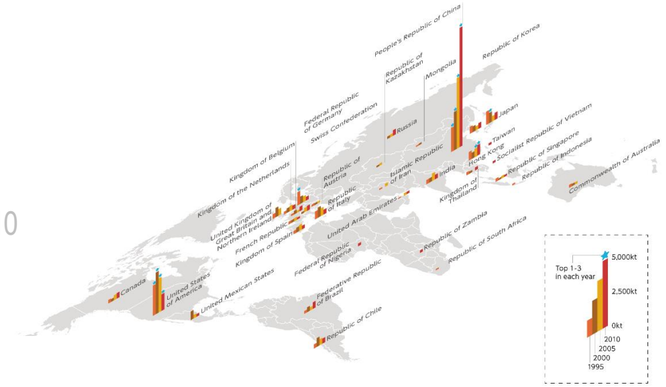


Fig. Distribution of the 25 countries and regions with the largest apparent consumption of iron in 1995, 2000, 2005 and 2010; iron, copper, and nickel.

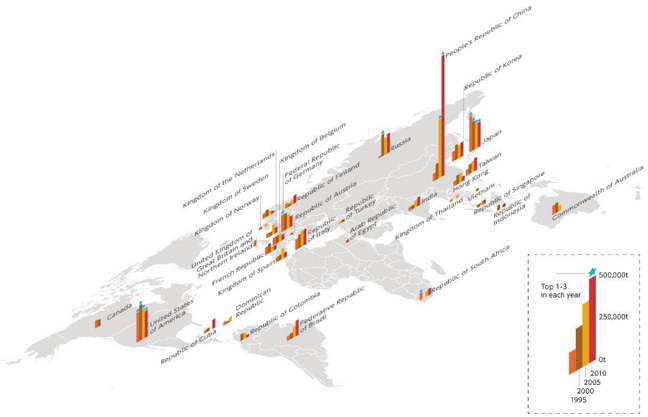
Copper

12 Tg in 1995 → 20 Tg in 2010



Nickel

1.3 Tg in 1995 → 2.1 Tg in 2010



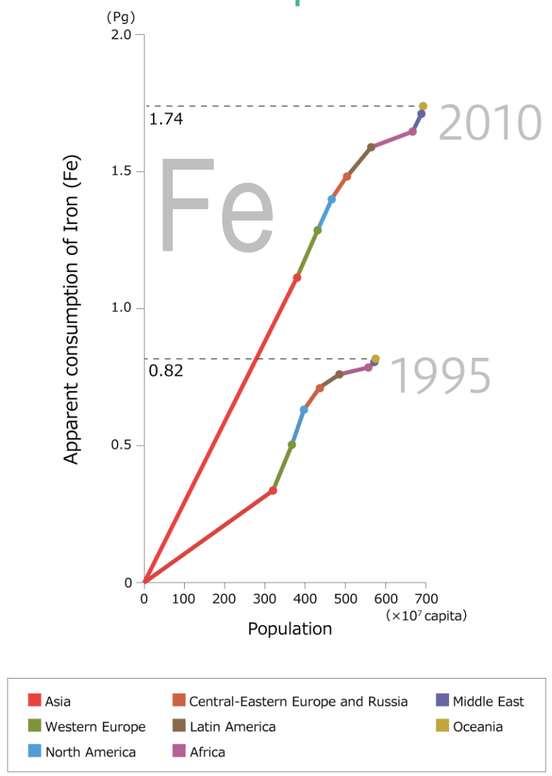
The percentage of global consumption of iron, copper, and nickel in Asia accounted for 41%, 32%, and 34% of the total in 1995, respectively, and reached 64%, 60%, and 54% in 2010.

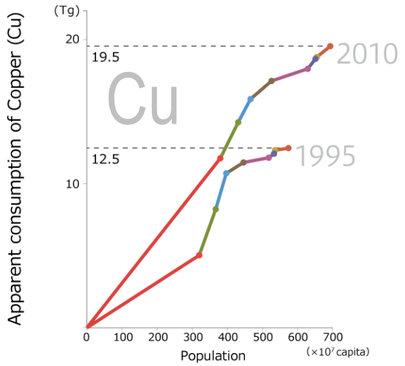
Nakajima K., et al. (2018) Global distribution of material consumption: Nickel, copper, and iron. Resources, Conservation and Recycling, 133, 369-374

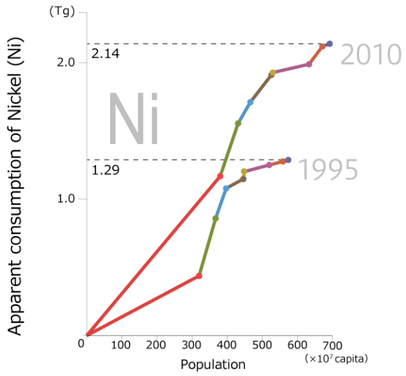
Per-capita consumption & Per-capita stock

Asia has already become the largest world user of iron, copper, and nickel, and economic growth in China accelerated the rapid rise of worldwide demand of these resources.

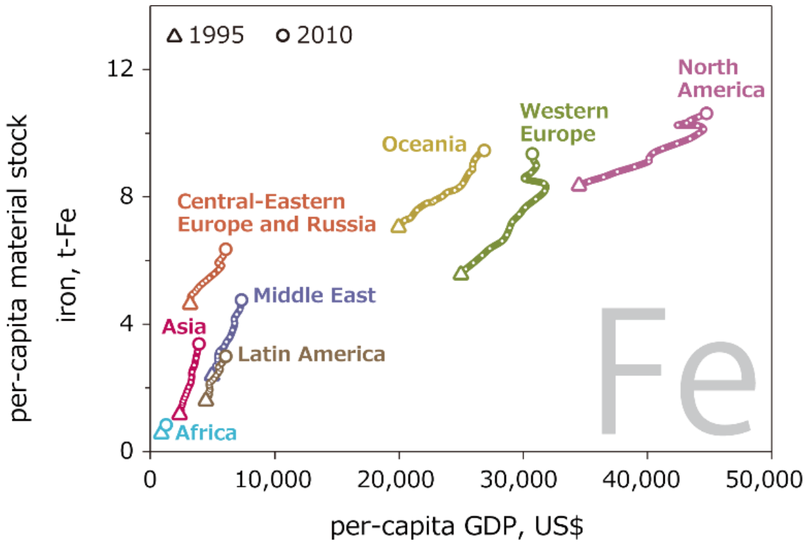
▼ Consumptions

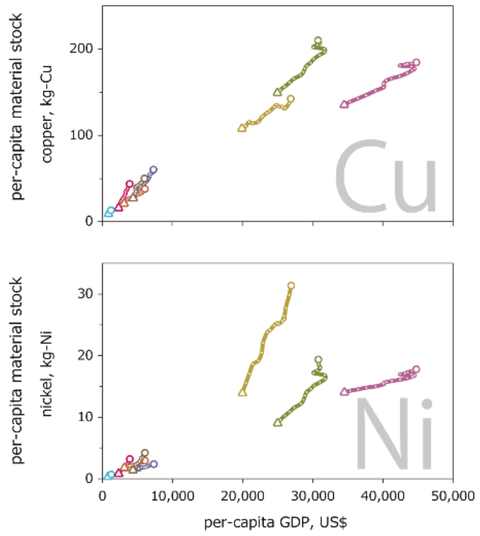






▼ Stocks





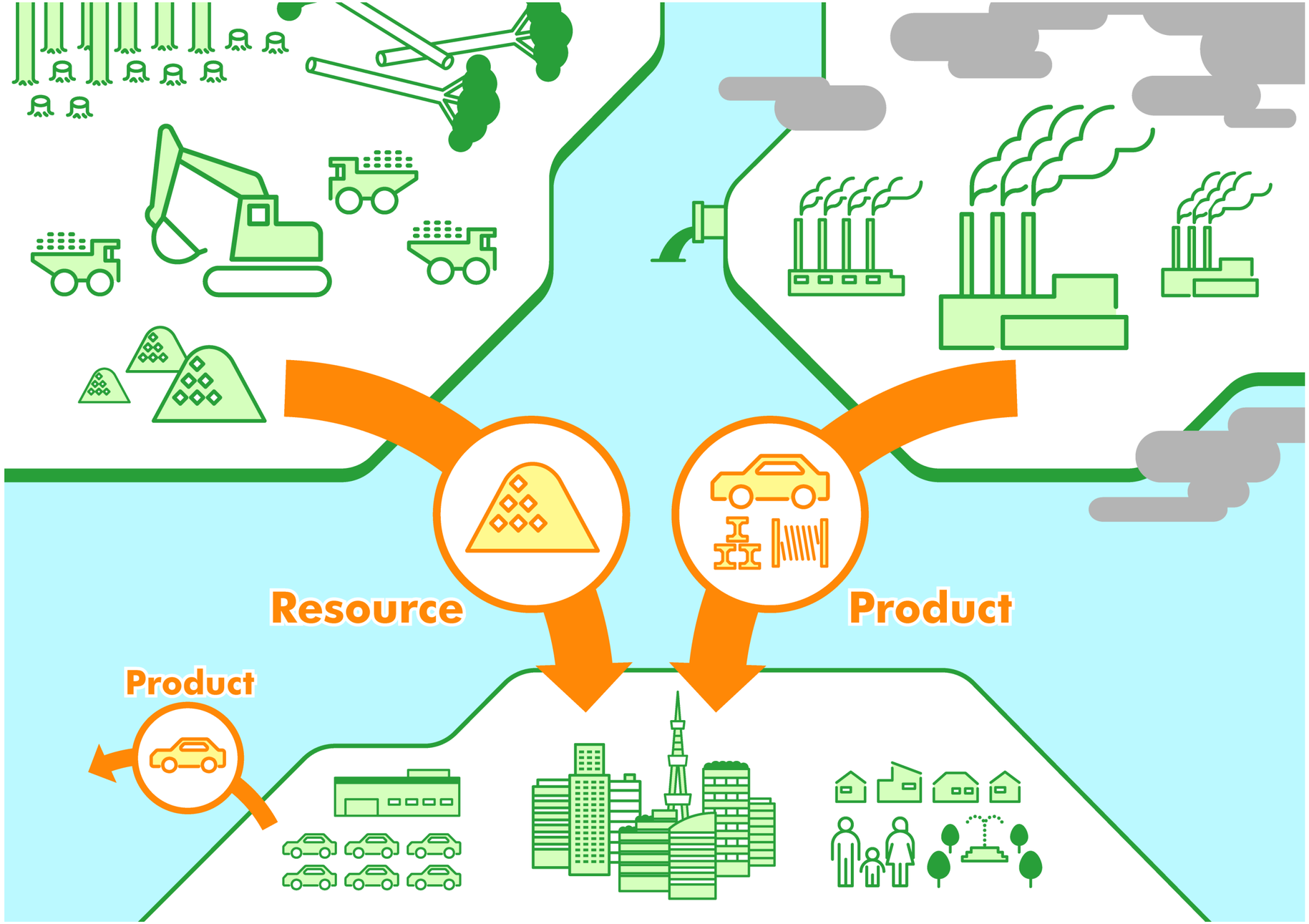
- CONSUMPTION: The per-capita apparent consumption of iron in Asia has already reached that of North America and Western Europe, and the per-capita apparent consumption of copper and nickel is following a similar path.
- STOCK: but the per-capita material stock of each of these substances in Asia has not yet reached that of North America and Western Europe.

The world population is projected to increase, with much of that growth concentrated in Asia and Africa. This situation shows the potential for a greatly increased demand as a result of population and economic growth in Asia and Africa.

Nakajima K., et al. (2017) Global distribution of material stocks: iron, copper, and nickel. Matériaux & Techniques, 105, 511
Nakajima K., et al. (2018) Global distribution of material consumption: Nickel, copper, and iron. Resources, Conservation and Recycling, 133, 369-374

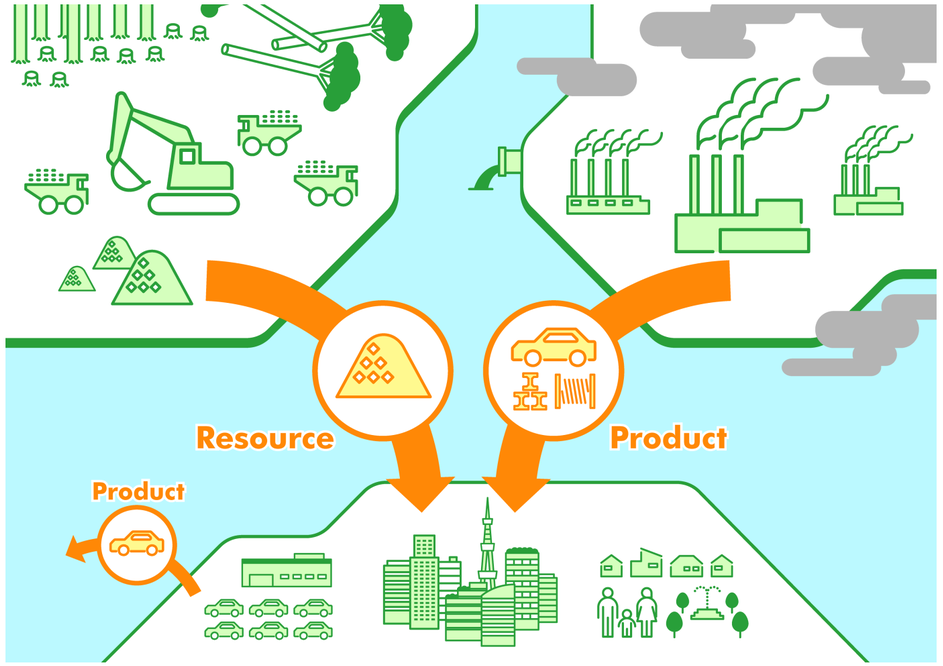
Global extraction hidden behind national economy:

Global changes caused by resource consumption



In today's globalized economy, each country has indirect flows supporting its economic activities, and international trade chains influence environmental burdens far removed from the place of consumption.

Global change caused by natural resource consumption



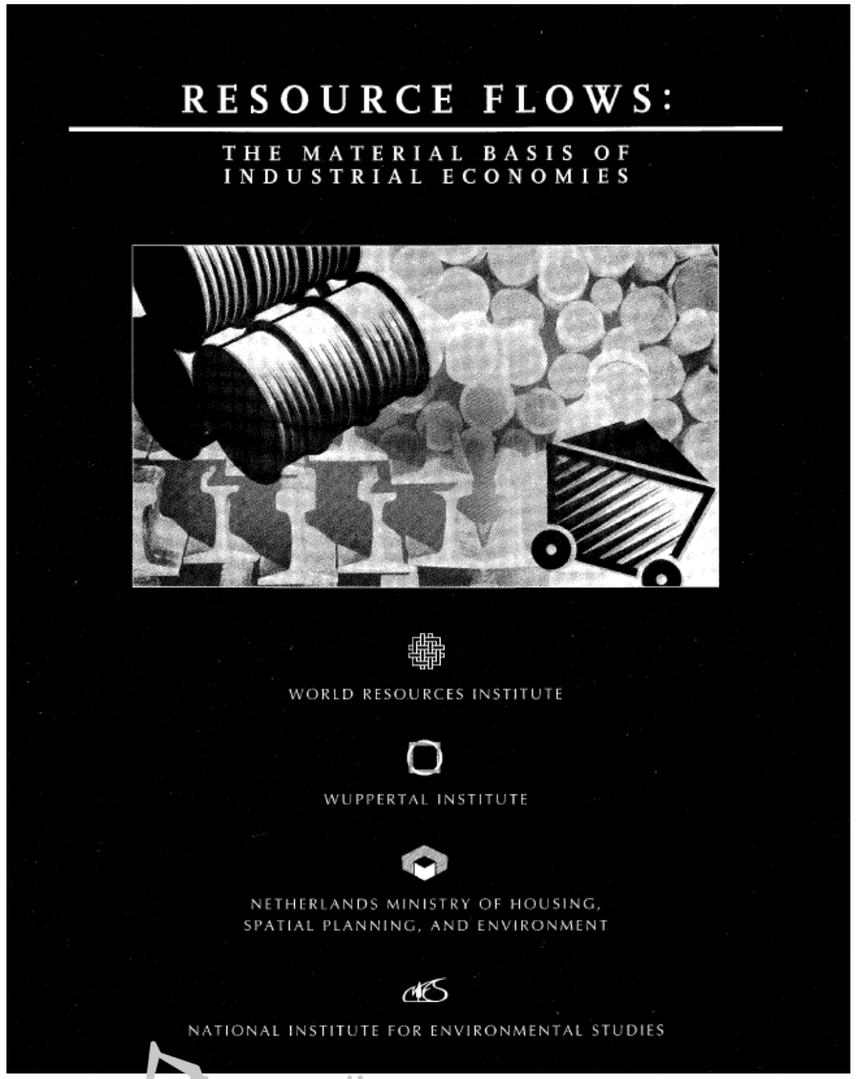
Giant Machine: The Bagger 288, largest nonstationary machine in the world, removing “Overburden” prior to coal mining in Tagebau Hambach, Germany; © Achim Blum

Toxic Landscape: Aerial view of the tar sands region, where mining operations and tailings ponds are so vast they can be seen from outer space; Alberta, Canada; © Garth Lenz

This situation emphasizes the importance to detect and manage environmental burdens as a global systemic phenomenon.

Photos: https://populationspeakout.org/the-book/view-book/

The Weight of Nations, material out flows from industrial economies



"Total Material Requirement (TMR): This is the sum of the total material input and the hidden or indirect material flows, including deliberate landscape alterations. ……TMR gives the best overall estimate for the potential environmental impact associated with natural resource extraction and use."

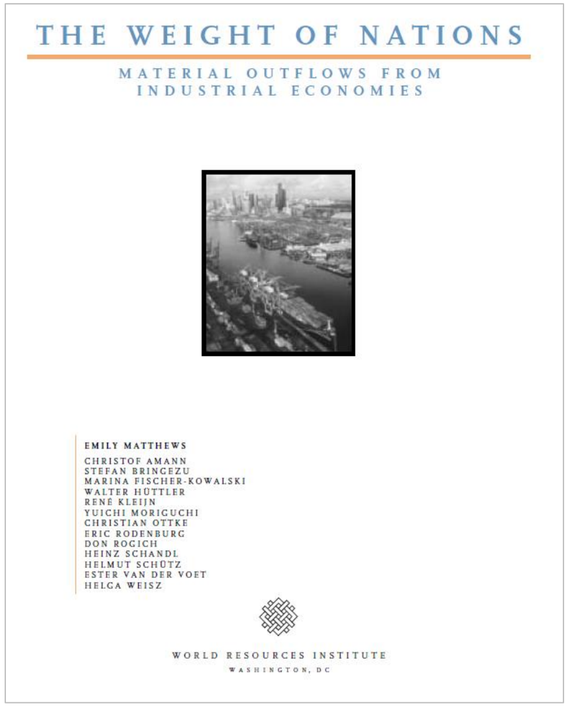
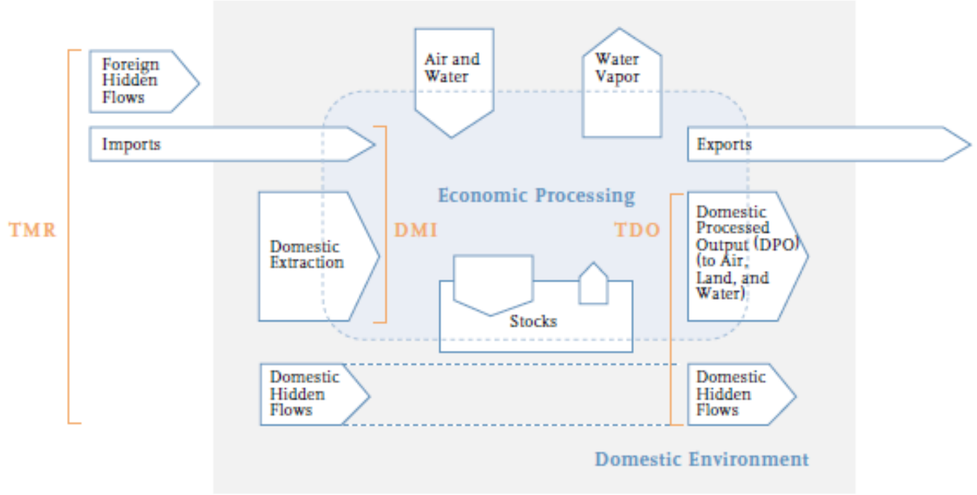


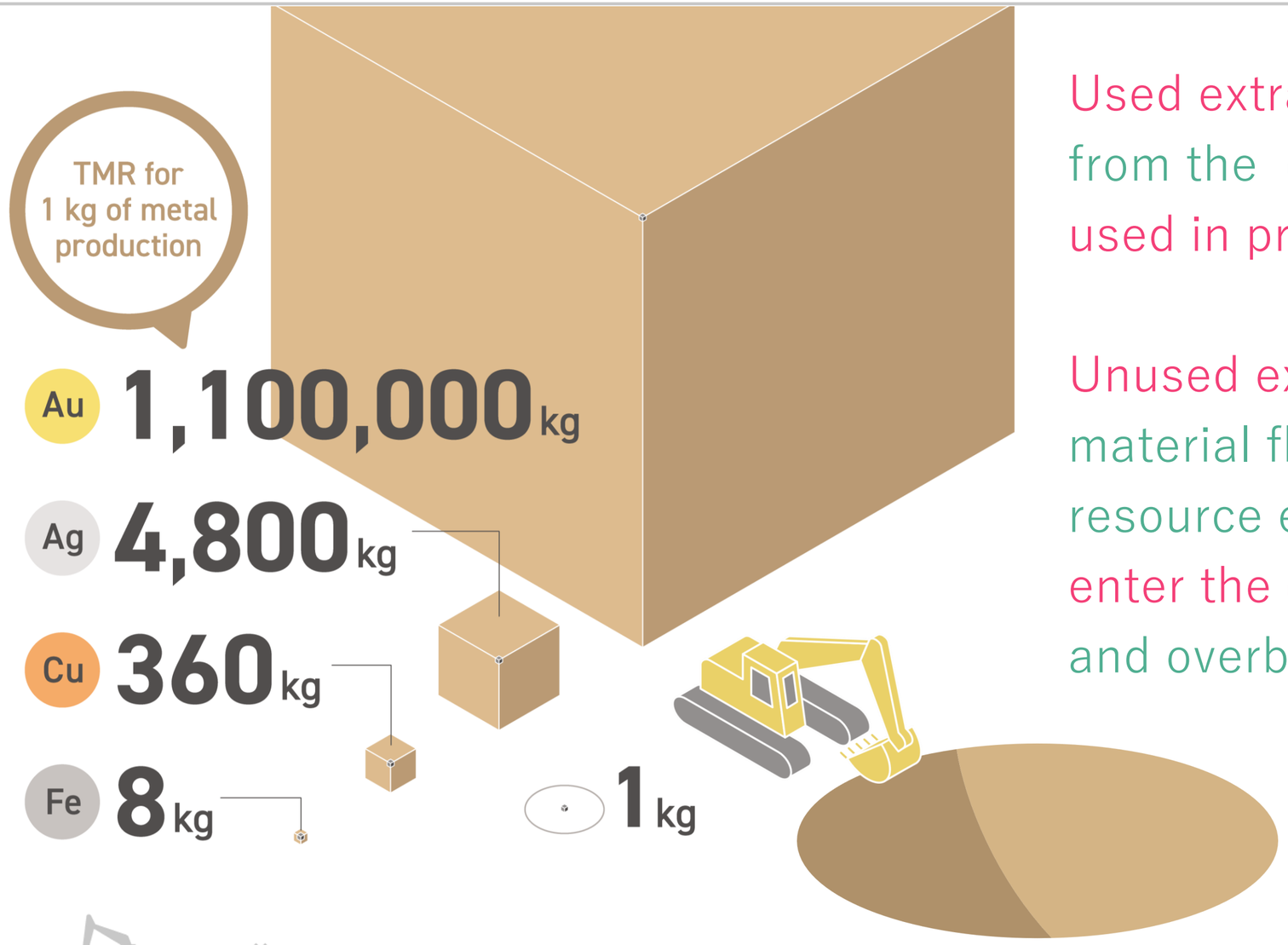
FIGURE 1 THE MATERIAL CYCLE



TMR (Total Material Requirement)=DMI+Domestic Hidden Flows+Foreign Hidden Flows
DMI (Direct Material Input)=Domestic Extraction+Imports
NAS (Net Additions to Stock)=DMI−DPO−Exports
TDO (Total Domestic Output)=DPO+Domestic Hidden Flows
DPO (Domestic Processed Output)=DMI−Net Additions to Stock−Export

Adriaanse et al. (1997) Resource flows - The material basis of industrial economies, World Resource Institute (2000) Weight of nations – Material outflows from industrial economies

TMR: Used and unused extracted materials that we should manage



Used extraction: materials that are extracted from the environment and subsequently used in production processes.

Unused extraction (i.e., hidden flow): material flows that occur in the course of resource extraction but that do not directly enter the economic system (e.g., waste rock and overburden from mining operations).

Data: Halada, K. et al. (2001) An Approximate Estimation of Total Material Requirement of Metals. J.Japan Inst.Met.Mater.), 65, 564–570.

The material foot print of nations by expressing national resource consumption as RMEs

The multiregional input-output (MRIO) model incorporating economy-wide MFA data provides a consumption perspective of resource use for that nation. The MRIO model bridged the gap between human activities and the related extraction amounts caused by mining activities.

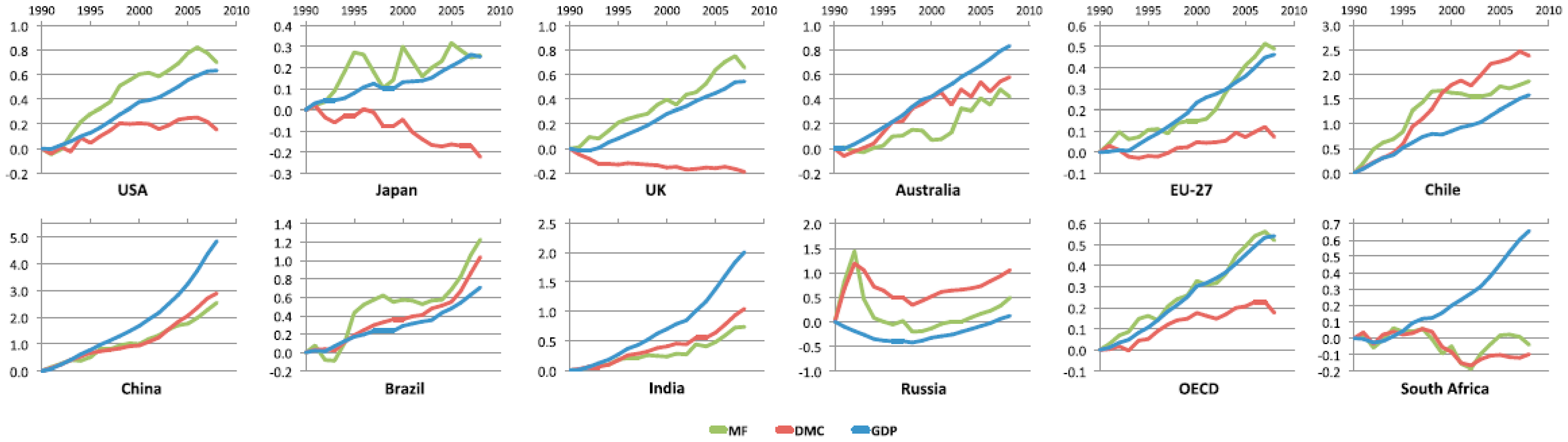


Fig. 3. Relative changes in total resource use (MF and DMC) and GDP-PPP-2005 between 1990 and 2008 [values are plotted as $\Delta X = (X_{t2} - X_{t1})/X_{t1}$; $t_1 = 1990$].

Wiedmann, T. O. et al. (2013) The material footprint of nations. PNAS, 112, 6271–6276.

National Institute for Environmental Studies, Japan

Used and Unused Extracted Materials Induced by Consumption of Iron, Copper, and Nickel

Methods: Annual amount of used and unused extraction caused by mining

Caused by mining activities in each country and region($L_{q,i}$) : $L_{q,i} = g_{q,i} t_i$

amount of substance i embodied in extracted minerals mined in country q as published in United States Geological Survey (USGS) mineral statistics

material intensity factor (TMR coefficient) of substance i embodied in the extracted minerals (NIMS2009)

Caused by mining activities in country q induced by Japanese economy($L_{q,i}^{JPD}$) : $L_{q,i}^{JPD} = g_{q,i}^{JPD} t_i$

amount of substance i embodied in extracted minerals mined in country q that is induced by Japanese economy, with a GLIO model (Nansai et al. 2015).

Global Link Input-Output model (GLIO), Detection of flow induced by national economy

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Global Distribution of Used and Unused Extracted Materials Induced by Consumption of Iron, Copper, and Nickel

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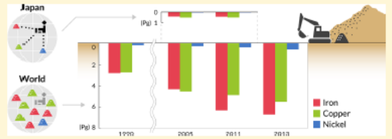
Supporting Information



ABSTRACT: In today's global economy, sustainable resource management requires a consumption perspective of resource use and insight into actual resource use through the global supply chain. The estimated global amount of used and unused extraction caused by mineral extraction of iron, copper, and nickel more than doubled from 1990 to 2013 (iron, 2.8−6.7 Pg; copper, 2.7−5.5 Pg; nickel, 0.19−0.60 Pg). By incorporating global material flow into a global link input−output model (GLIO, a hybrid multiregional IO model), we estimated the total used and unused extraction caused by iron, copper, and nickel mining induced by Japanese final demand to be 0.44, 0.52, and 0.043 Pg in 2011, respectively, equivalent to 7.1% of the total global extraction amount caused by iron mining, 11% of the amount caused by copper mining, and 10% of the amount caused by nickel mining. Whereas the world extraction total caused by iron, copper, and nickel mining rapidly increased from 2005 to 2011, the extraction amount induced by Japanese final demand for the same period either stayed about the same (iron) or decreased slightly (copper, 99% of the 2005 amount; nickel, 92%).

1. INTRODUCTION

Economic growth is associated with a rapid rise in the use of natural resources within the economy,[1−5] and sometimes greater implementation of green technologies has triggered a rapid rise in the use of some metals and minerals. Because the successful achievement of the United Nations Sustainable Development Goals and the implementation of the Paris Agreement will require technologies that utilize vast quantities of a wide range of minerals, global resource governance to achieve sustainable and responsible mining will be required for sustainable development.[3]

Although the materials refined from minerals play a crucial role in modern society, the rising demand for them has been tailored to the current high levels of mineral extraction and emission. In recent years, the mining industry has been under considerable pressure to improve its environmental and social performance. Halada et al.[4] clarified huge amounts of "hidden" extractions underlying mineral production, and the World Resource Institute (WRI)[5] and Durán et al.[6] mapped global indicators of ecosystems and communities that are vulnerable to the negative impacts of mining. These reports indicated a significant overlap between the world's active mines and strictly protected areas. Each of these studies indicates the

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Global land-use change hidden behind nickel consumption

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HIGHLIGHTS

- Worldwide nickel flow among 231 countries and regions was clarified.
- Land-use changes far removed from the place of consumption were detected.
- Links between Japan's final demand and the global supply chain were quantified.
- A global link input–output model (GLIO, a hybrid multiregional model) was used.

GRAPHICAL ABSTRACT

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Nickel
Mining
Land-use change
Input–output analysis
Global supply chain

ABSTRACT

Economic growth is associated with a rapid rise in the use of natural resources within the economy, and has potential environmental impacts at local and/or global scales. In today's globalized economy, each country has indirect flows supporting its economic activities, and natural resource consumption through supply chains influences environmental impacts far removed from the place of consumption. One way to control environmental impacts associated with consumption of natural resources is to identify the consumption of natural resources and the associated environmental impacts through the global supply chain. In this study, we used a global link input–output model (GLIO, a hybrid multiregional input–output model) to detect the linkages between national nickel consumption and mining-associated global land-use changes. We focused on nickel, whose global demand has risen rapidly in recent years, as a case study. The estimated area of land-use change around the world caused by nickel mining in 2005 was 1.9 km^2, and that induced by Japanese final demand for nickel was 0.38 km^2. Our modeling also revealed that the areas of greatest land-use change associated with nickel mining were concentrated in only a few countries and regions far removed from the place of consumption. For example, 57.7% of the world's land-use changes caused by nickel mining were concentrated in five countries in 2005: Australia, 13.7%; Russia, 12.9%; Indonesia, 12.5%; New Caledonia, 10.4%; and Colombia, 8.2%. The mining-associated land-use change induced by Japanese final demand accounted for 19.5% of the total area affected by land-use change caused by nickel mining. The top three countries accounted for 70.0% (Indonesia: 47.0%, New Caledonia: 16.0%, and Australia: 7.7%), and the top five accounted for 82.4% (the Philippines: 7.5%, and Canada: 4.3%, in addition to the top three countries and regions).

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Global Mining Risk Footprint of Critical Metals Necessary for Low-Carbon Technologies: The Case of Neodymium, Cobalt, and Platinum in Japan

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Supporting Information

ABSTRACT: Meeting the 2-degree global warming target requires wide adoption of low-carbon energy technologies. Many such technologies rely on the use of precious metals, however, increasing the dependence of national economies on these resources. Among such metals, those with supply security concerns are referred to as critical metals. Using the Policy Potential Index developed by the Fraser Institute, this study developed a new footprint indicator, the mining risk footprint (MRF), to quantify the mining risk directly and indirectly affecting a national economy through its consumption of critical metals. We formulated the MRF as a product of the material footprint (MF) of the consuming country and the mining risks of the countries where the materials are mined. A case study was conducted for the 2005 Japanese economy to determine the MF and MRF for three critical metals essential for emerging energy technologies: neodymium, cobalt and platinum. The results indicate that in 2005 the MFs generated by Japanese domestic final demand, that is, the consumption-based metal output of Japan, were 1.0×10^3 t for neodymium, 9.4×10^3 t for cobalt, and 2.1×10 t for platinum. Export demand contributes most to the MF, accounting for 3.0×10^3 t, 1.3×10^4 t, and 3.1×10 t, respectively. The MRFs of Japanese total final demand (domestic plus export) were calculated to be 1.7×10 points for neodymium, 4.5×10^{-2} points for cobalt, and 5.6 points for platinum, implying that the Japanese economy is incurring a high mining risk through its use of neodymium. This country's MRFs are all dominated by export demand. The paper concludes by discussing the policy implications and future research directions for measuring the MFs and MRFs of critical metals. For countries poorly endowed with mineral resources, adopting low-carbon energy technologies may imply a shifting of risk from carbon resources to other natural resources, in particular critical metals, and a trade-off between increased mining risk and deployment of such technologies. Our analysis constitutes a first step toward quantifying and managing the risks associated with natural resource mining.

1. INTRODUCTION

The life cycle of a metal resource begins with mining and proceeds through the phases of processing, production, recycling, and then disposal. Today, however, there are virtually no instances in which this entire series of processes occurs within the borders of a single country. In the global supply chains that have been formed through international trade, metal resources move around the world as they go through the various phases of their life cycles. Since many metals are mined in a limited number of countries and numerous other nations are exhibiting a growing demand for products using these metals, understanding the relationship between use of these resources and the global supply chains that begin with the mining process is becoming increasingly important.

One material index for quantitatively understanding the resources used in the economy of a single country via these kinds of global supply chains is the index known as the material footprint (MF) of a nation that was recently proposed by Wiedmann et al.[1] Using the Eora multiregional input−output (MRIO) model developed by Lenzen et al.,[2] the MFs for 186

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Economic Systems Research, 2009, Vol. 21(3), September, pp. 267–290 Routledge

IMPROVING THE COMPLETENESS OF PRODUCT CARBON FOOTPRINTS USING A GLOBAL LINK INPUT–OUTPUT MODEL: THE CASE OF JAPAN

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This paper is concerned with the main activities of Japan's 'Disclosure of CO_2 emissions' programme, aimed at illustrating the CO_2 emissions associated with consumer products as a 'carbon footprint' (CF). Although the current, provisional guidelines for calculating product carbon footprints specify that only the bottom-up approach is to be used for this purpose, this paper presents useful applications of input–output analysis that can improve the reliability of the method considerably, by taking full advantage of the strengths of input–output analysis. To this end, we first estimated the global carbon footprint (GCF) of food and consumables in Japan, using a global link input–output (GLIO) model comprising 804 economic sectors in Japan and 230 foreign countries and regions. By visualizing the GCF on a world map, the global distribution (including Middle East and African countries) of the induced CO_2 emissions of each of the Japanese sectors were identified. To investigate the scope for reducing the data collection burden for CF practitioners, GCFs were compared with CFs obtained using a single-region input–output model. This showed that there are certain commodity groups with a CF equating to 70% to over 90% of the corresponding GCF, even if the imported goods used for producing a Japanese domestic product are considered environmentally equivalent to their domestically produced counterparts. Furthermore, it was identified which data should preferably be collected by the bottom-up approach to secure CO_2 emissions coverage greater than a certain predefined level and keep data and labour costs at a minimum.

Keywords: Carbon footprint; Product category rules; Completeness; Embodied carbon intensity; Multiregional model; System boundary; Input–output analysis; Global model

1 INTRODUCTION

1.1 Recent Japanese Trends in 'Environmental Burden Disclosure'

In Japan, a quantitative indication of the environmental burden of consumer products has thus far been provided by a 'Type III' environmental label. For example, the 'Ecoleaf' label (JEMAI, 2009), that has been widely implemented since April 2002, assigns a code to a product. Entering the code on the Ecoleaf homepage, reveals the resources

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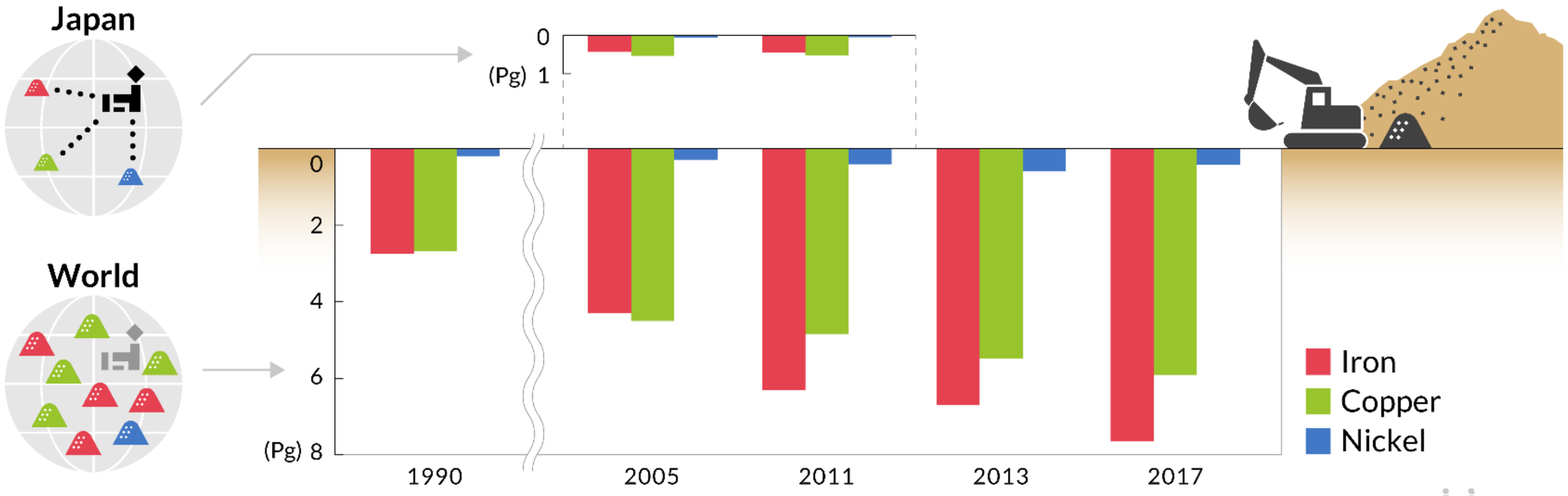
National Institute for Environmental Studies, Japan

Used and Unused Extracted Materials Induced by Consumption of Iron, Copper, and Nickel

- The estimated global amount of used and unused extraction caused by mineral extraction of iron, copper, and nickel more than doubled from 1990 to 2013 (iron, 2.8-6.7 Pg; copper, 2.7-5.5 Pg; nickel, 0.19-0.60 Pg).
- Whereas the world extraction total caused by iron, copper, and nickel mining rapidly increased from 2005 to 2011, the extraction amount induced by Japanese final demand for the same period either stayed about the same (iron) or decreased slightly (copper, 99% of the 2005 amount; nickel, 92%).



Nakajima K., et al.. (2019) Global Distribution of Used and Unused Extracted Materials Induced by Consumption of Iron, Copper, and Nickel. Environ. Sci. Technol., 53, 1555-1563

Used and unused extraction Induced by the “global economy”, 1990 and 2013

The total extraction caused by iron, copper, and nickel mining were estimated to be 6.7, 5.5, and 0.6 Pg in 2013, which increased by factors of 2.4, 2.0, and 3.1 since 1990, respectively.

Oceania and Asia had the largest amount of extraction in 2013, followed by Latin America. Used and unused extraction caused by iron, copper, and nickel mining in these three regions have drastically increased since 1990.

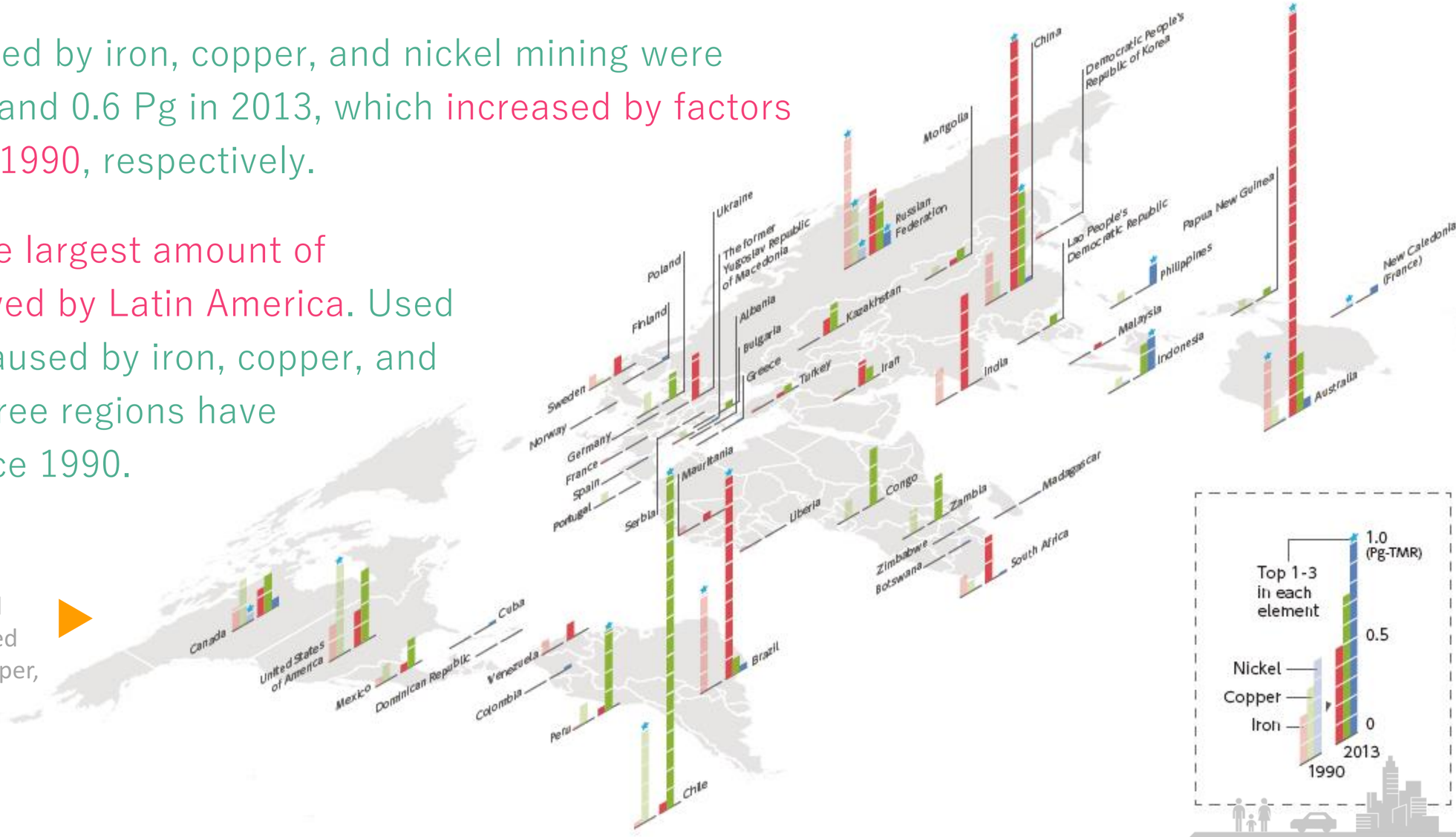


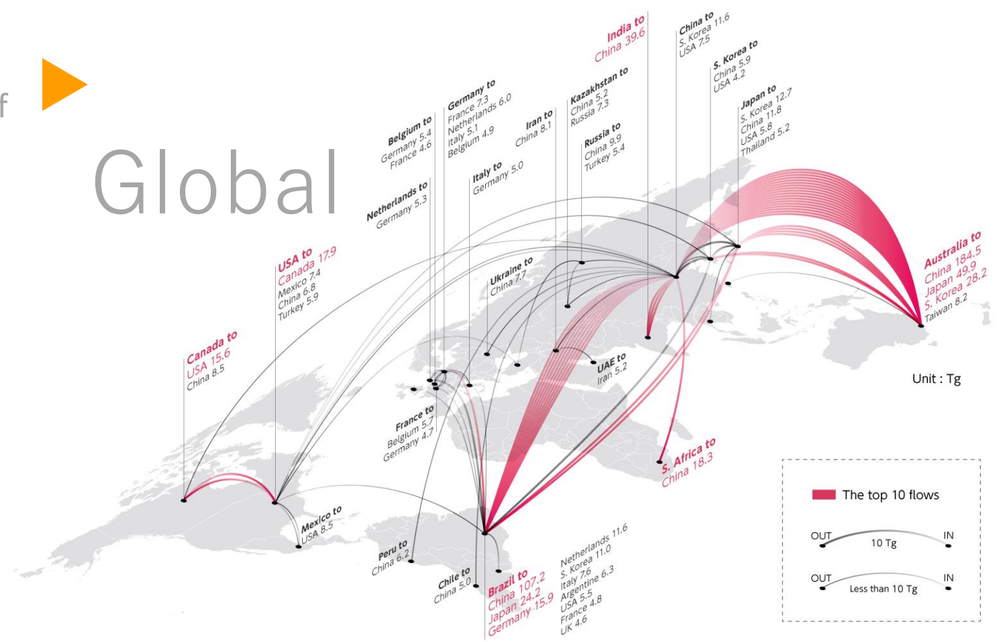
Fig. Distribution of the 20 countries and regions with the largest used and unused extraction amounts caused by iron, copper, and nickel mining in 1990 and 2013.

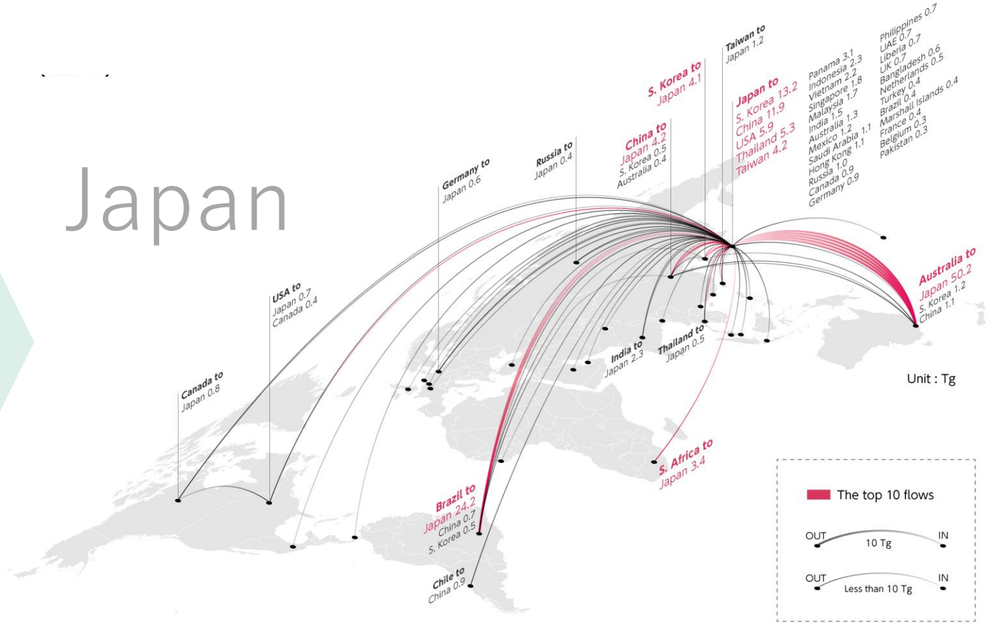
Nakajima K., et al.. (2019) Global Distribution of Used and Unused Extracted Materials Induced by Consumption of Iron, Copper, and Nickel. Environ. Sci. Technol., 53, 1555-1563

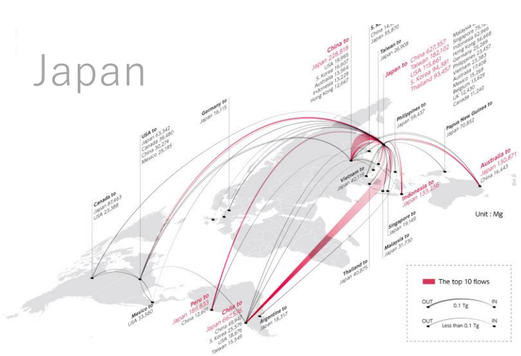
Used and unused extraction, The 50 largest flows in 2011

The 50 largest global flows of iron through international trade in 2011;

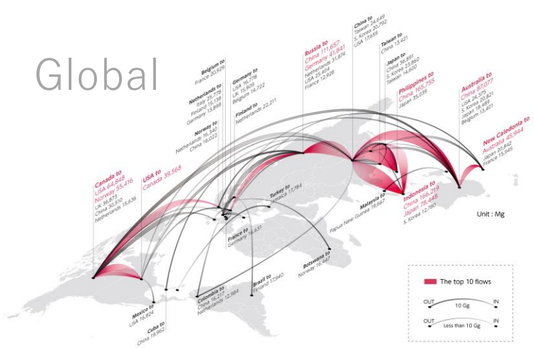
a. Global economy, b. Induced by Japanese economy

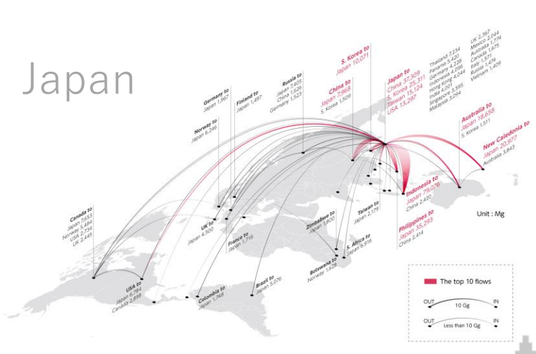






The 50 largest global flows of copper through international trade in 2011.





The 50 largest global flows of nickel through international trade in 2011.

Nakajima K., et al.. (2019) Global Distribution of Used and Unused Extracted Materials Induced by Consumption of Iron, Copper, and Nickel. Environ. Sci. Technol., 53, 1555-1563

Used and unused extraction Induced by the “Japanese economy”, 2011

Although these materials are not mined domestically, Japan should still be involved in their sustainable resource management.

The extracted materials induced by final demand in Japan accounts for 7.1% of the total global extraction caused by iron mining, 11% by copper mining, and 10% by nickel mining.

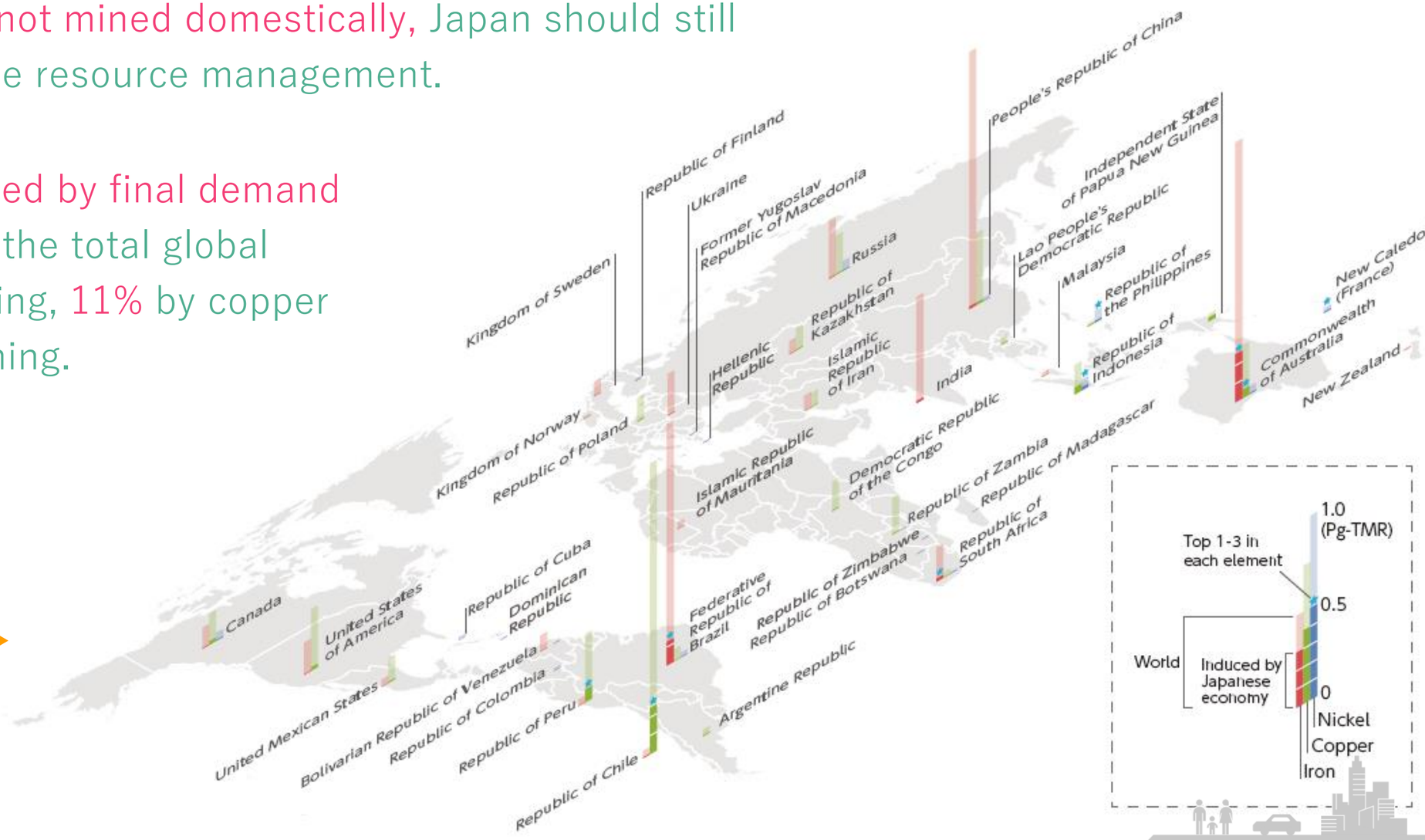


Fig. Distribution of the 20 countries and regions with the largest used and unused extraction amounts caused by iron, copper, and nickel mining induced by the Japanese economy in 2011.

Nakajima K., et al.. (2019) Global Distribution of Used and Unused Extracted Materials Induced by Consumption of Iron, Copper, and Nickel. Environ. Sci. Technol., 53, 1555-1563

Used and unused extraction Induced by the “Japanese economy”, 2011

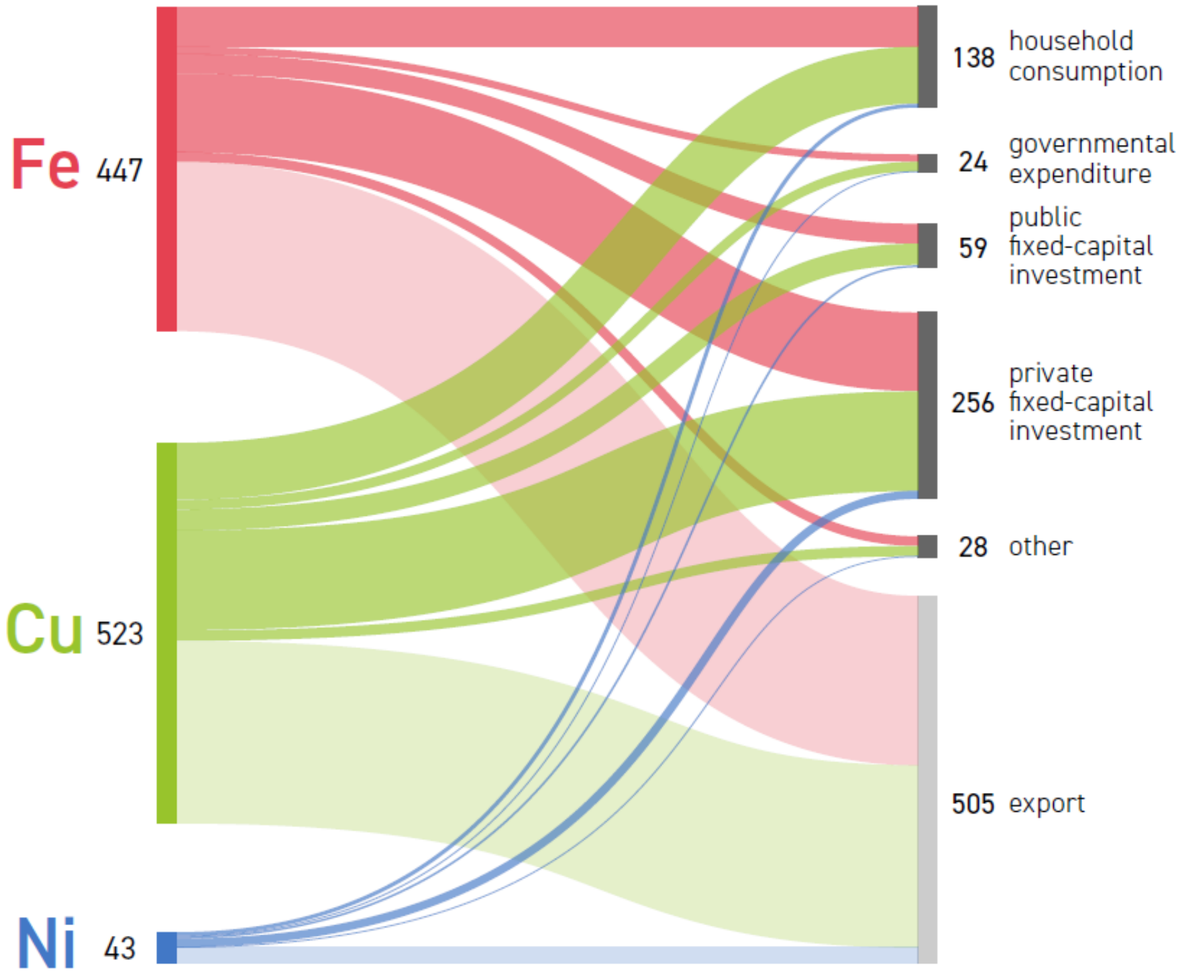


Fig. Amount of Used and Unused Extraction Induced by Japanese Final Demand by Category in 2011. [unit: Tg]

Export, private fixed-capital investments(domestic), and household consumption(domestic) strongly influenced on the amounts of used and unused material extraction induced by Japanese final demand.

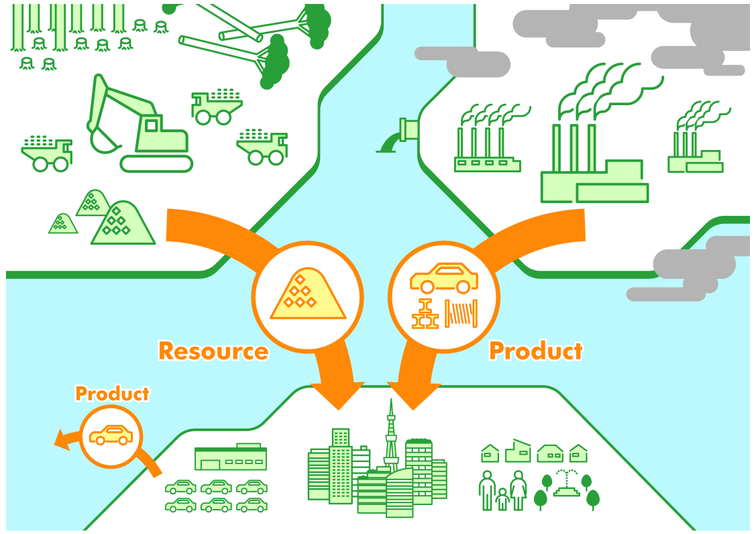
A reduction of material intensity in each production sector induced by these final demands would reduce natural resource extraction outside of Japan. Minimization of material losses induced by the demand would also work toward closing the loop of material cycle.

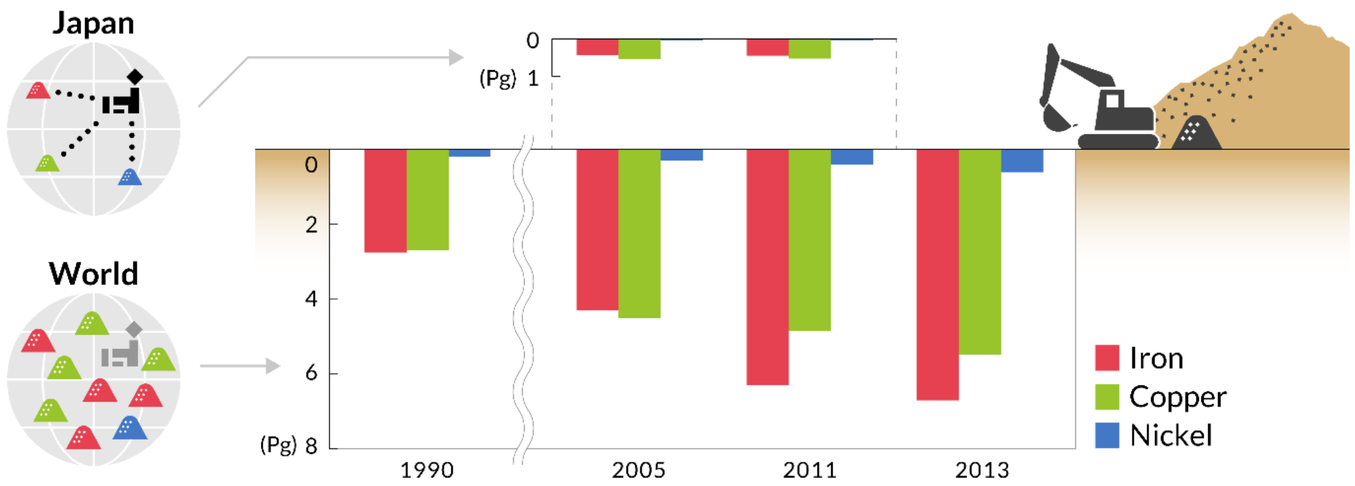
Nakajima K., et al.. (2019) Global Distribution of Used and Unused Extracted Materials Induced by Consumption of Iron, Copper, and Nickel. Environ. Sci. Technol., 53, 1555-1563

Used and unused extracted materials Induced by Consumption of Iron, Copper, and Nickel

The cumulative amounts of used and unused extraction caused by iron, copper, and nickel mining around the world from 1990 to 2013 were 95 Pg, 95 Pg, and 6.8 Pg, respectively. And the amounts reached 118 Pg, 118 Pg, and 8.6 Pg in 2017, respectively.

Mining activities have impacts on the removal of native vegetation and its destruction by the deposition of mine waste (e.g. overburden, waste rock, tailings). Actions for sustainable resource management will be required to achieve sustainable development.





Nakajima K., et al.. (2019) Global Distribution of Used and Unused Extracted Materials Induced by Consumption of Iron, Copper, and Nickel. Environ. Sci. Technol., 53, 1555-1563

Closing the loop of material cycle：

Toward environmentally sustainable patterns of resource use

Closing the loop of material cycle

Thinking in terms of a "Circular economy" and "Sound material cycle" would help to significantly reduce pressure on natural resources and lead a transition to a sustainable economic system that encompasses the concept of decoupling resource use and economic growth.

Circular Economy Strategy

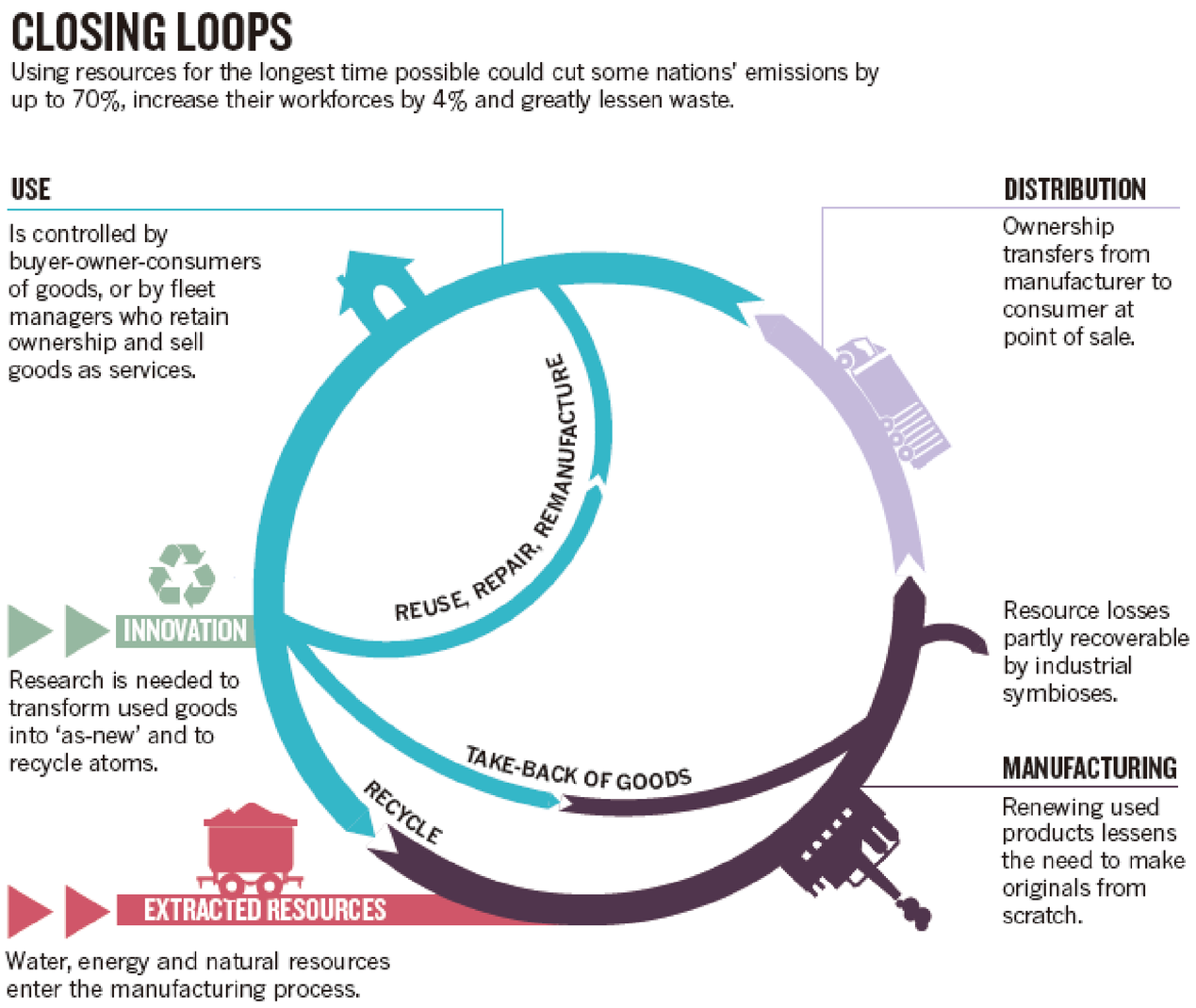
- "Closing the loop - An EU action plan for the Circular Economy" (European Commission 2015)

Sound Material-cycle Society

- "Fundamental Law for Establishing a Sound Material-Cycle Society" (Japan, 2000)

RRRDR (Remanufacturing, refurbishment, and repair and direct reuse) practices to expand product's service-life would play key roles in any transition. In addition to the implementation of RRRDR practices, improved material recycling and closing material cycle loops would reduce the consumption of natural resources and contribute to the reduction of negative impacts on the environment and human health.

Closing the loop: Key concept to ensure sustainable pattern of resource use



"Conventional waste management is driven by minimizing the costs of collection and disposal - landfill versus recycling or incineration. In a circular economy, the objective is to maximize value at each point in a product's life. New jobs will be created and systems are needed at each step."

Possible options:

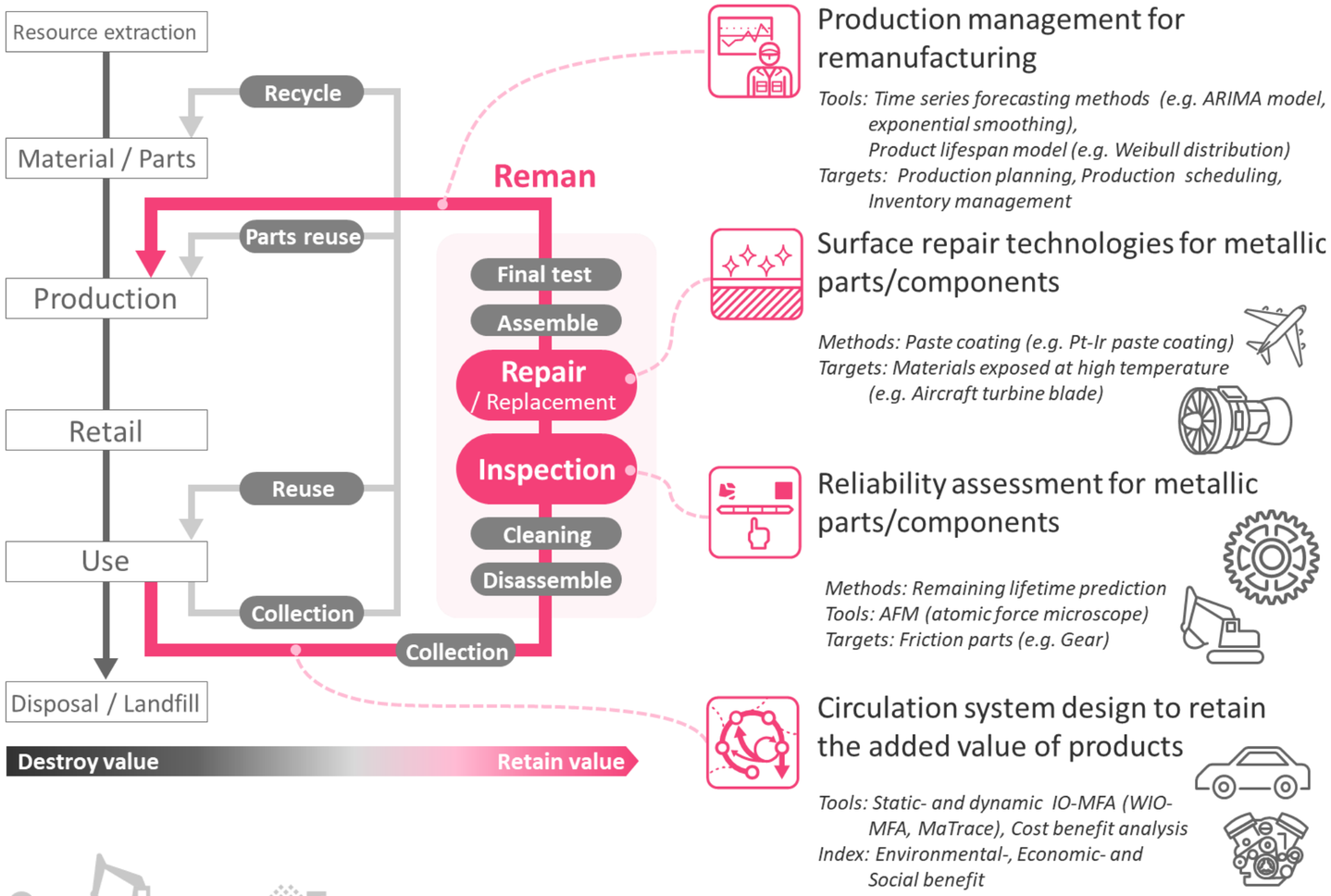
- ✓ RRRDR

  (Remanufacturing, refurbishment, and repair and direct reuse)
- ✓ Recycle

Ref. Stahel W. R. Circular economy, Nature, 531(2016), 435-438

Development of Multi-value Circulation based on Remanufacturing

Aim: Technological developments to promote reman



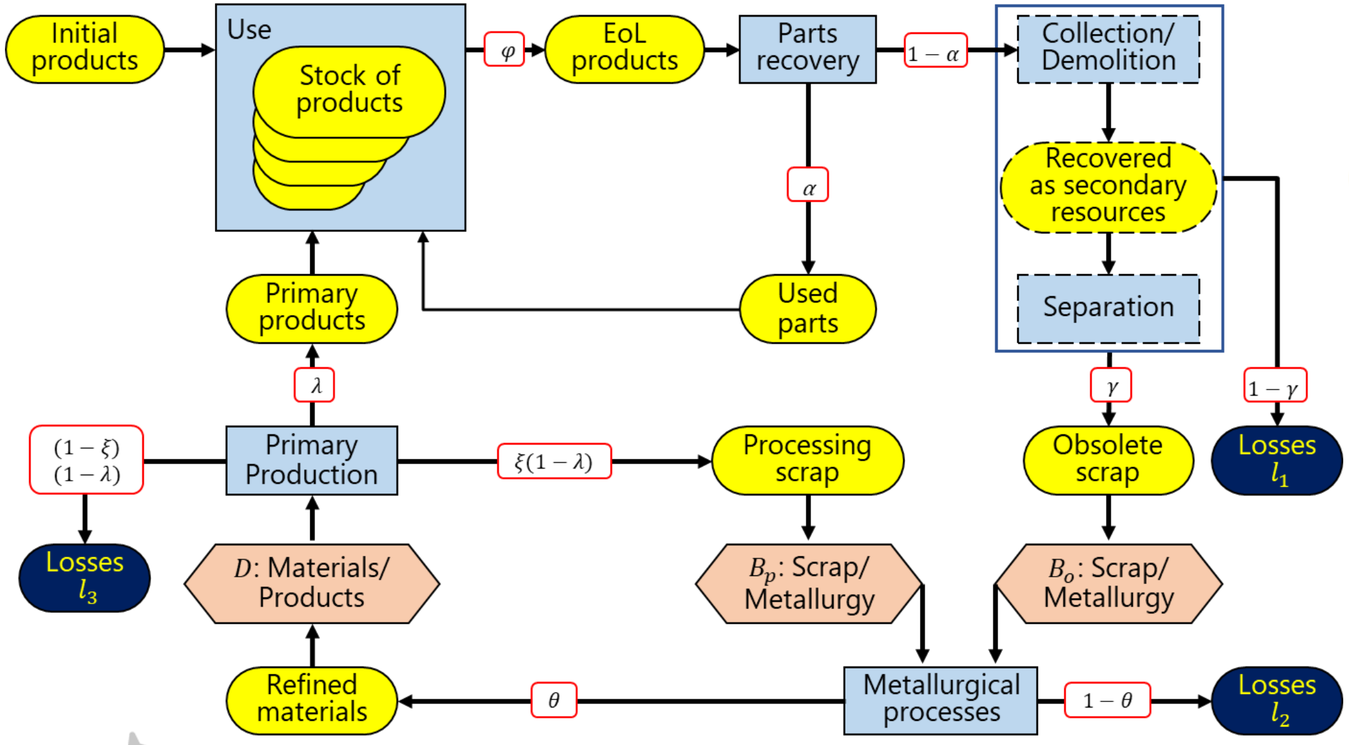
Remanufacturing is an industrial process that turns used products into new ones with the same quality, functionality, and warranty as new products; it is a critical element for realizing a resource-efficient manufacturing industry and a circular economy.

It is generally superior to material recycling in terms of energy and material savings. In addition to the environmental benefits, remanufacturing is expected to create highly skilled jobs and economic growth.

Nakajima K., et al.. (2018) DEVELOPMENT OF MULTI-VALUE CIRCULATION BASED ON RE-MANUFACTURING. Matériaux & Techniques., in press

Mitigated impacts on material losses and the effects of extending product service-life by reuse/reman, The case of automobile engine

Although the impacts on the reduction of material losses remained nearly the same after replacing material recycling to parts reuse, greater possibilities could be achieved with respect to the service life extension of products when compared with recycling.



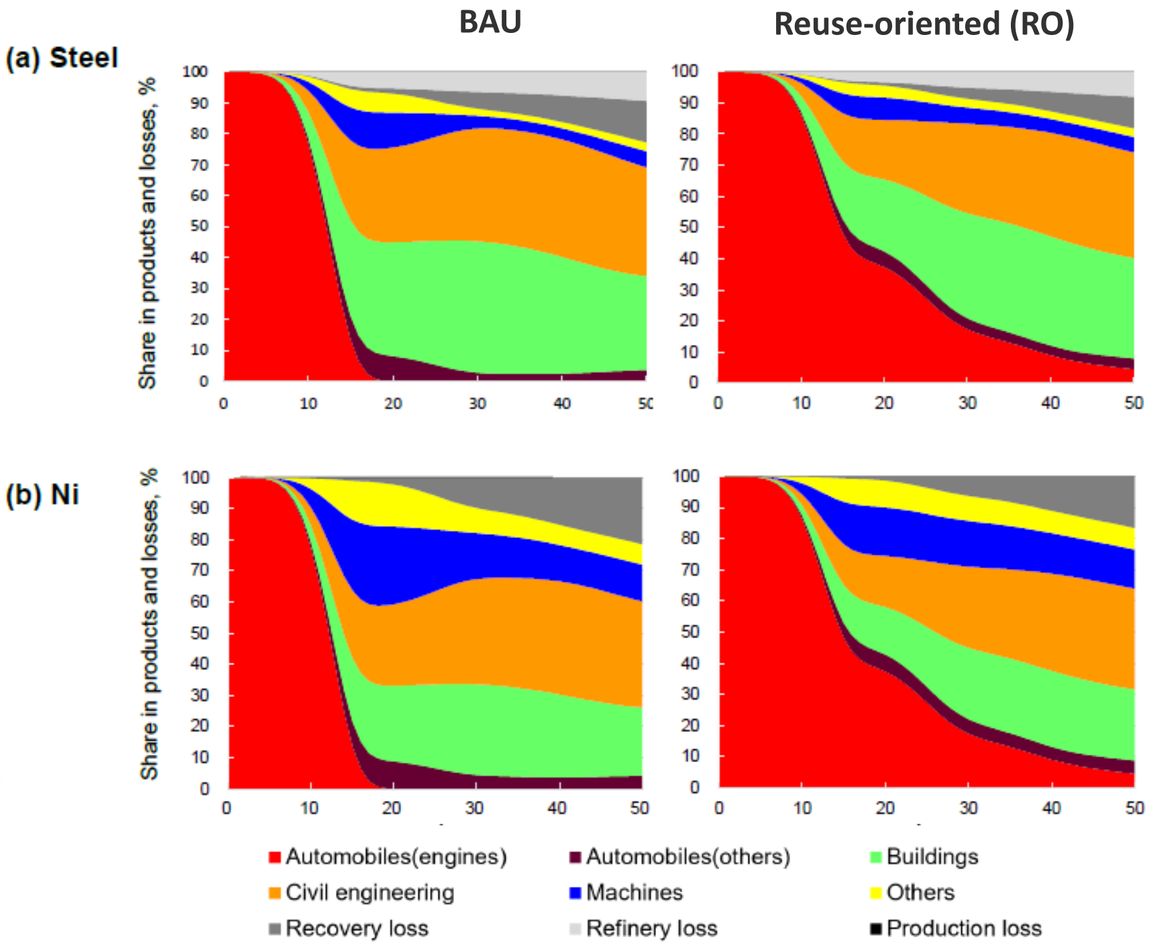
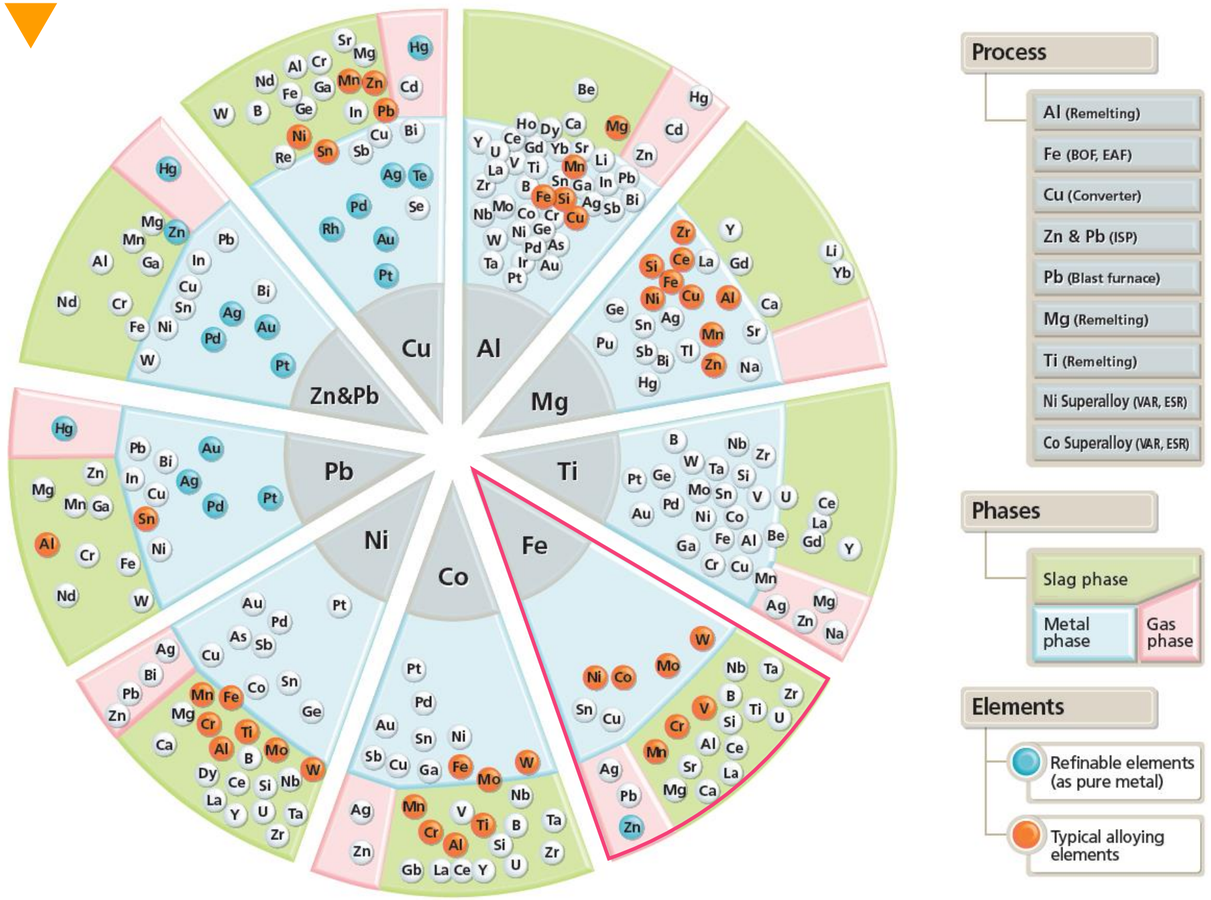


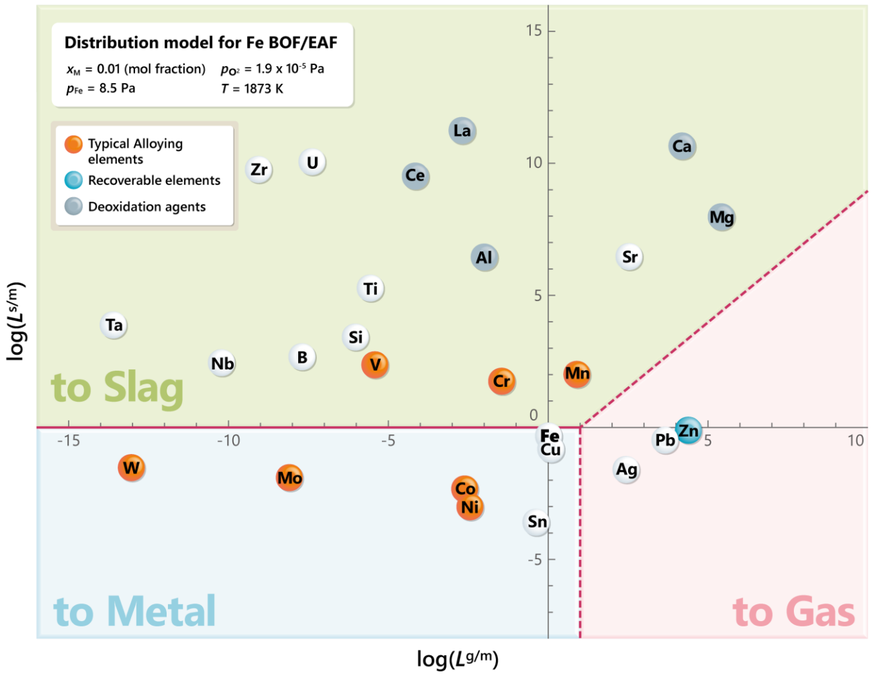
Fig. Transitions in the compositions of the stocks and losses of steel and Ni during the modeling period (50 years). The horizontal axis denotes the year after initial production; the vertical axis denotes the percentage of the distribution of materials in 6 product categories and 3 loss categories.

Zhang, Z. et al. (2018) An estimation of the amount of dissipated alloy elements in special steel from automobile recycling process. 12th International Conference on Society & Materials

Development of Advanced metal recycling system for Closing the loop of material cycle

Losses in metal recycling: Element distribution in metallurgical process





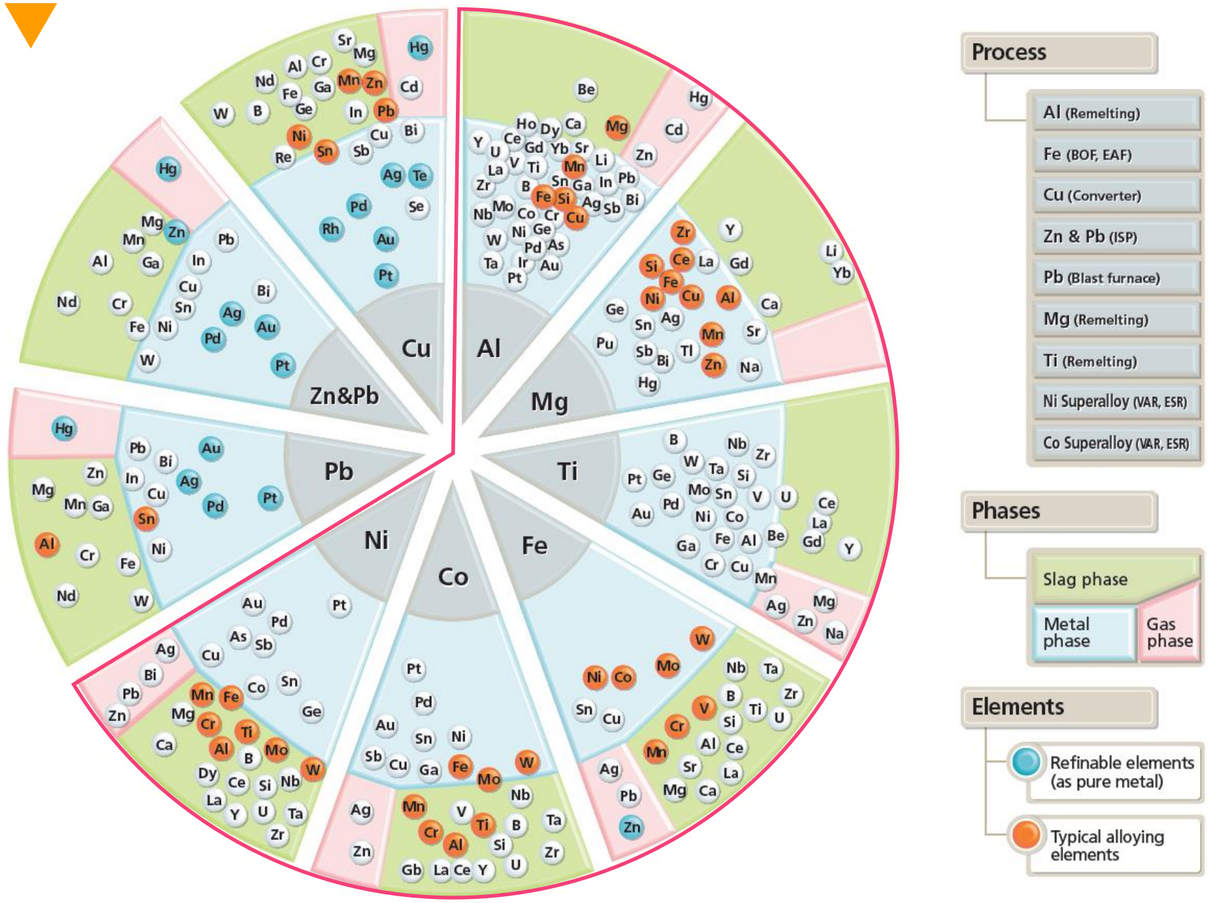
Distribution chart of elements among gas, slag, and metal phases for the metal recovery under the simulated atmosphere of basic oxygen furnace (BOF) and electric arc furnace (EAF) for steel.

Among the four major alloying elements for steel, Mo and Ni are very stable in molten iron, whereas most Mn and some Cr are easily oxidized and distributed into the slag phase. If the distribution ratio of a given element is much lower than unity, it will become a contaminant in metal. Open-loop recycling of steel could result in quality loss and material loss. The removal or control of impurities is essential in steel recycling.

Nakajima, K. et al. (2011), Thermodynamic Analysis for the Controllability of Elements in the Recycling Process of Metals, Environmental Science & Technology, 45, 4929-4936

Development of Advanced metal recycling system for Closing the loop of material cycle

Losses in metal recycling: Element distribution in metallurgical process



The disadvantage of steel making processing, remelting of aluminum, remelting of magnesium, etc. is that the processes cannot effectively recover impurities/contaminants as resources.

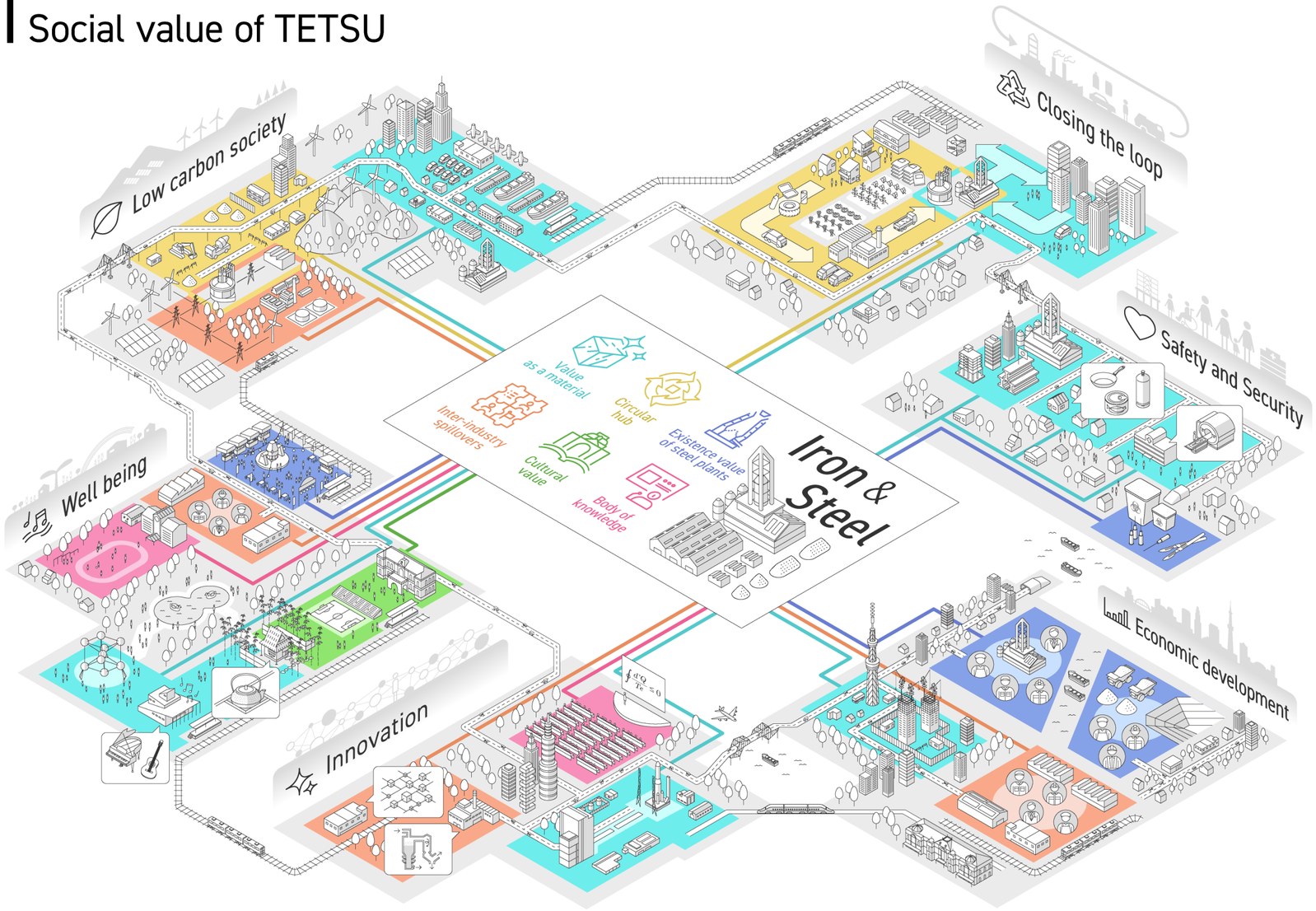
The removal or control of impurities is essential in this type of system. In order to effectively use these elements as important alloying elements rather than contaminations, it is important to develop a sorting system for scrap aimed at alloy to alloy recycling.

Nakajima, K. et al. (2011), Thermodynamic Analysis for the Controllability of Elements in the Recycling Process of Metals, Environmental Science & Technology, 45, 4929-4936

In today's globalized economy, each country has indirect flows supporting its economic activities, and international trade chains influence environmental burdens far removed from the place of consumption.

Enrico Mazzanti, Le Avventure di Pinocchio

Social value of TETSU



Thank you for your kind attention!