

Materials Use Across World Regions

Inevitable Pasts and Possible Futures

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It is not surprising that natural resource use is now on the political agenda, and heatedly discussed among the wider public. Pressure points including climate change, water and food availability, price surges for strategic raw materials, and peaking global oil supply are converging rapidly in an unprecedented manner. The current global patterns of production and consumption are hitting the real limits of global ecosystems.

The global economy seems to be at a turning point where decisions are urgent while information is incomplete.

The urgency of addressing issues of industrial metabolism¹ and managing the amount of natural resources used and the waste and emissions generated in our economic activities is reflected in a number of high level policy initiatives. In the year 2000, the Group of Eight (G8) addressed the need for sound information on global resource use and emissions, and commissioned the Organisation for Economic Co-operation and Development (OECD)² to provide guidance in the process of establishing information systems and indicators. A number of countries have moved ahead by establishing high level policy goals and objectives related to sustainable resource use, most notably Japan, the European Union (EU) and China.

The history of resources use, as revealed by current metabolic profiles, has put different world regions on different path dependencies and therefore creates very specific sustainability problems for each region.

In November 2007, the United Nations Environment Programme (UNEP) launched a new scientific panel on sustainable resource management to inform and enable resource efficient growth and innovation. UNEP points out that while climate change tops the environmental agenda of today, the world faces many problems related to dominant production and consumption patterns. For quite some time global resource

use was driven by OECD economies.³ Today's main drivers of resource use, however, are the rapidly developing economies, above all, China and India. These countries, although still having a standard of living way below that of OECD countries, determine the global dynamic through their sheer size and the speed of their industrialization process. This situation has created further challenges to political attempts at governing resource use.

The need for rigorous analysis and up-to-date information on global resource use and emissions, and their current structure and dynamics, is now being widely acknowledged. And this is where industrial ecology comes in. The seminal work of Ayres and Kneese in the 1960s on material flows (Ayres and Kneese 1969; Kneese et al. 1970) was not picked up until the early 1990s, when the first national material flow accounts emerged in Japan (Environment Agency Japan 1993), Germany (Schütz and Bringezu 1993), and Austria (Steurer 1992). The World Resources Institute pioneered the international comparison of national material flows with two reports (Adriaanse et al. 1997,

Matthews et al. 2000) which received wide attention. In 2002, Eurostat published a harmonized material flow data set for the EU-15⁴ (Eurostat 2002), which has been regularly updated since then and is currently being extended to an EU-27⁵ dataset.

More recently, an international effort at methodological coherence and harmonization to compare national resource use profiles has been led by Eurostat and the OECD Working Group on Environmental Information and Outlooks, resulting in a methodological handbook for material flow accounts and a standardized classification system (Weisz et al. 2007).

While the initial material flow studies were data-driven, we now see a variety of analytical approaches that aim to understand the dynamics of resource use at different scales. Material flow research within the larger field of industrial ecology in the last decade has been rich and diverse and, obviously, fair recognition of all aspects of this work cannot be given in one special issue.

We have restricted the scope of this issue to studies that describe and interpret resource use patterns of larger world regions or nation states. By design we did not include articles that explore resource use at lower levels, such as cities, villages, economic sectors, or firms.

The special issue that results brings together contributions that are organized along four major topics: (1) resource use at a global scale, (2) resource use at a national or world region scale, (3) analysis of metal cycles, and (4) policies based on material flow analysis. It is not by chance that the number of articles attributable to each of these topics is very unequal. Although we do not claim that the collection of articles in this special issue is representative of material flow research in its entirety, we do think that it reflects the attention which is given to the four topics mentioned above. We will return to this aspect in the concluding section.

A global Socio-metabolic Perspective

In their opening article, Krausmann and colleagues (2008) argue that a socio-metabolic perspective, focusing on the socio-economic use of materials and energy in its entirety, is required

to fully understand the essence of the global sustainability challenge. In their article they characterize the historical industrialization process as a transition from an agrarian (solar energy-based) to an industrial (fossil fuel-based) socio-metabolic regime. The industrial transition allowed societies to overcome the inherent growth limitations of the agrarian regime and gave way to unprecedented economic and population growth, but also implied a multiplication of the per-capita throughput of materials and energy, which is the primary cause of global environmental change.

Using a newly compiled global flow data set on metabolic and socio-economic indicators for the year 2000 at country level resolution, the authors suggest six country clusters with distinct metabolic profiles. They show that the current per capita use of natural resources in industrial clusters is—by a factor of 3 to 5—higher than in developing regions. A major finding is the high relevance of population density to resource use: regions with high population density have a factor 2 lower per-capita resource use than low population density countries of similar developmental status. However, the local environmental pressures in the densely populated developing cluster are already as high as in the densely populated wealthy industrial cluster. The authors conclude that the transition from an agrarian to an industrial socio-metabolic regime is still ongoing. But now it unfolds under substantially different circumstances when compared to the historical industrialization, which makes the contemporary process a much larger challenge for sustainability than ever experienced before. Current global resource use dynamics will drastically constrain future options for the most vulnerable world regions, namely densely populated developing countries. The history of resource use, as revealed by current metabolic profiles, has put different world regions on different path dependencies and therefore creates very specific sustainability problems for each region.

Material Use Across World Regions

There is probably no country in the world which has given a higher political priority to

its material use patterns than Japan. This is reflected by the inclusion of two articles on Japan in this special issue. The first, by Hashimoto and colleagues (2008), analyzes the evolution of the Japanese national material productivity between 1995 and 2002. Using structural decomposition analysis, the authors calculated the relative influence of four factors—recycling rate, resource efficiency of the production system, shifts in consumption patterns, and the importance of imports vs. domestic production—on the observed improvement in materials productivity, which was 70% between 1980 and 2000. The analysis directly addresses the quantitative goals of Japan's sound material cycle policy enacted in 2000 by using gross domestic product (GDP) per direct material input (DMI) as the resource efficiency indicator (see also below the article by Takiguchi and Takemoto). In recent years, shifts in final demand were the most important factor for the increasing resource productivity of the Japanese economy. The effect of these shifts was as large as the effect of increased production efficiency and recycling combined. Somewhat surprisingly, the increase in imports contributed to a decrease in resource productivity.

While Japan, a densely populated industrial country with limited natural resources, has made numerous political efforts to improve its metabolic performance, Australia, an industrial country with very low population density and rich natural resources, operates in a very different policy context, as Schandl and colleagues (2008) point out in their article. They portray the metabolic profile of Australia in terms of material and energy use for a period of more than three decades (1970 to 2005). Their analysis demonstrates the outstanding resource intensity of Australia's social metabolism. In 2005, domestic extraction of raw materials in Australia was at 60 tonnes per capita,⁶ which is four times larger than the EU-15 average. Domestic material consumption (DMC) was at 35 tonnes per capita, roughly twice as high as the OECD average. The article explains the socio-economic context in which this metabolic pattern has emerged and discusses its social, economic, and environmental implications. The authors identify three main factors that determine Australia's outstanding metabolic profile: huge export-oriented ex-

tractive industries (mainly coal, metal mining, and agriculture), resource-inefficient infrastructures and supply systems, and material-intensive consumption behavior of the wealthy urban population. In the concluding sections, the trade-offs of this metabolic pathway, its sustainability problems, and options for the future are discussed. Overall the article makes a convincing point that Australia has cared too little about its metabolic performance in the past, but should take a different path in the future.

With the article, "Industrialization, Fossil Fuels, and the Transformation of Land Use" we return to a historical perspective of the transition from an agrarian to an industrial metabolic regime. Erb and colleagues (2008) analyze the Austrian carbon metabolism during the years of 1830 to 2000, a timeframe which covers the whole industrialization period in Austria. By constructing time series of the carbon budget, including socioeconomic as well as ecological flows, the authors are able to identify fundamental systemic linkages between the evolution of an industrial metabolism, land use changes, and the combined consequences for net carbon releases to the atmosphere. One of the most compelling results is that from 1880 on, when industrialization took off, Austria's biota served as a carbon sink, mainly because of increases in forest area and density. Furthermore, surges in fossil fuel use did not result in a reduced demand for biomass products, but allowed for steep increases of agricultural production on shrinking agricultural areas and a resulting regrowth of forest area. Still, the net flows of carbon to the atmosphere, mainly due to the massive use of fossil fuels, were enormous. The accumulated net release of carbon in the short 150 years from 1850 to 2000 was about 1,000 million tonnes. As the authors point out, this is about the same amount as the accumulated net carbon release which occurred over the course of 2000 years of Austria's agrarian history. The carbon release of the agrarian period was driven by deforestation caused by a growing demand for agricultural land. The revealed functionality between change in materials use and land cover change suggests that an increase of the capture capacity of terrestrial ecosystems might have only limited potential as a strategy to mitigate climate change.

The next article draws our attention to Latin America. Russi and colleagues (2008) provide a comparative analysis of national material flows for four countries, namely Chile, Mexico, Ecuador, and Peru. The authors compare a set of standard material flow accounting (MFA) indicators and related resource use efficiencies in time series (1980 to 2000). The four countries show quite different metabolic characteristics with regard to the level of resource use, evolution over time, material composition, foreign trade structure, and national material productivity. The article puts an emphasis on the role of foreign trade for the metabolic profiles of these countries. Employing theoretical concepts on unequal trade—mainly the work of Bunker (1985) and Prebisch (1962), who argue that developing countries are resource providers for the benefit of the industrial core and to their own disadvantage because of deteriorating terms of trade—the authors interpret their results. They conclude that the case of Ecuador supports many of the arguments and theories surrounding unequal trade. While the other three countries also followed an exploitative economic path in the 1980s, they have since developed a more diversified export portfolio, away from primary resources to exports from manufacturing, resulting in more favorable trade balances. This move has made these economies less exposed to price instabilities on global commodity markets and has supported the standard of living in all three countries.

In a similar vein, Kovanda and Hak (2008) use national MFA indicators to characterize the metabolic changes that have occurred since 1990 in three Eastern European countries (Czech Republic, Hungary and Poland) during their rapid transition from centrally planned economies to market economies. The authors specifically ask if there has been a convergence in the metabolic profile of these three economies. While there appears to be convergence, at least at an aggregated level, the details of the material consumption patterns have been quite different among these three countries. An IPAT⁷ decomposition analysis reveals that economic growth and technology change have been the major drivers of the observed evolution in domestic material consumption.

Metals: Core Strategic Raw Materials of an Industrial Metabolism

Metals are key ingredients of the industrial metabolism. Their production structure has been heavily globalized in the past decades, resulting in a spatial separation of production and consumption and an increased reliance on imports for most industrial economies. Environmental and health threats associated with the production and use of metals, as well as potential scarcity has made metals a priority research topic in industrial ecology (c.f. von Gleich et al. 2006, Graedel 2002, Müller et al. 2006). This special issue presents two case studies on the industrial ecology of metals and one methodological article.

Johnson and Graedel (2008) quantified the amounts of copper, lead, zinc, chromium, and silver in US trade flows. Their analysis is innovative in that they did not restrict their account to traded ores and refined metals, as has often been done, but also quantified the metals contained in semi-manufactured and finished goods (thus the term "hidden trade"). They found that this latter fraction can represent a large part of a country's metal trade flows. For chromium, copper, lead, silver, and zinc the authors calculated the metals contained in traded goods to be well over 50% for most of them. Based on these findings the authors calculated what they call "end user net import reliance" which was found to be particularly high (above 60%) for chromium and copper.

Saurat and Bringezu (2008) present a detailed account of supply-demand relationships for the platinum group metals (PGMs) and discuss the environmental impacts associated with their use in Europe. They have identified the automotive industry as the single most important user of PGMs and are able to show how the reduction of air pollution in Europe by means of catalytic converters contributes to negative environmental impacts in those countries where primary metals are extracted and refined. The article supports the notion of unequal burden in global supply-demand chains and makes a point for more comprehensive approaches for assessing environmental impacts of new technologies.

The article by Harper (2008) has a methodological focus. The author presents two models, "the end use sector" model and "the finished product" model, which she has applied to study the historical tungsten cycle of the USA. While the empirical findings have been published elsewhere, this article focuses on a detailed description of the approaches that will be useful for the MFA researcher. It becomes obvious that these models can be applied to improving the study of the cycles of other metals.

Policy Experiences

Material flow work has always aimed at having policy relevance and impact, though this has sometimes been hard to achieve. As yet, the policy implications have been far from being fully understood by scientists and policy makers alike. Two articles relate to this discussion, focusing on the US and Japanese experiences.

Allen (2008) points out that a national system of material flow accounts in the US would be a useful step to inform resource sustainability, but has not yet been created in a systematic manner. To understand why this has been the case, one has to look at the logic of the public sector rather than the technicalities of the accounts themselves. Applying a model for public sector innovation, which distinguishes between methods, organizational capacities, demand, and actual use, the author explains the levers and obstacles for the implementation of a national material flow accounting system in the USA.

Policies supporting the sustainable use of resources have had a different history in Japan. The article by Takiguchi and Takemoto (2008) describes and explains the political context of the Fundamental Law to Establish a Sound Material Cycle Society, adopted by the Japanese government in 2000, and the subsequently implemented 3R (reduce, reuse, recycle) policy. These policies are based on material flow analysis and include quantitative targets for resource productivity, recycling and final disposal of waste. The article also discusses the progress achieved so far and the G8 initiative to promote a 3R policy.

These discussions of the policy dimensions of MFA are intentionally limited because the *Journal of Industrial Ecology* will be publishing a spe-

cial issue next year specifically devoted to applications of MFA for business and government decision making.

Book Reviews

The four book reviews, wrapping up this special issue, deal with various aspects of a sustainable use of resources. Helmut Haberl (2008) reviews Mark Jaccard's *Sustainable use of Fossil Fuels*, a book about the future of the global energy system which gained enormous public attention and for which the author received the 2005 Donner Prize for best policy book in Canada. Julia Steinberger (2008) reviews the volume *Sustainability Indicators: A Scientific Assessment*, edited by Tomas Hak, Bedrich Moldan, and Arthur Lyon Dahl under the auspices of the Scientific Committee on Problems of the Environment (SCOPE). The book includes a number of articles directly relevant to the topics discussed in this special issue. The World Resources Institute, as indicated earlier, traditionally a strong voice on material flows in the US, has published a new report on the topic, *Material Flow Accounts: A Tool for Making Environmental Policy*, authored by Iddo Wernick. It is reviewed by Graham Turner (2008). Last but not least, Arnold Tukker (2008) reviews *Socioecological Transitions and Global Change*, edited by Marina Fischer-Kowalski and Helmut Haberl, the most comprehensive presentation of a socio-metabolic perspective of global environmental change to date.

Conclusion and Outlook

In a recent recommendation, the OECD Council on Resource Productivity recognized the need for member countries to strengthen their capacity for analyzing resource flows and associated environmental impacts by improving scientific knowledge and upgrading the extent and quality of data. While data provision is usually the domain of statistical offices, industrial ecology research is contributing to the broadening of scientific insights into resource flow related issues. In our understanding, important areas for future scientific investigation are:

- Improving the understanding of resource use governance for integrated economic-environmental policies at different scales.
- Improving our understanding of the functional linkages and trade-offs between material, energy, water, and land use.
- Linking these dimensions of the societal metabolism to economic models in order to be able to run socio-metabolic scenarios for the future.
- Strengthening and harmonizing metabolic analysis and models beyond the national scale. An urban metabolic perspective is especially important here.⁸ Today almost 50% of the world population is urban (United Nations 2008), while 70% of the world's energy is consumed in urban areas (Global Energy Assessment 2008). According to UN projections, the urban population will continue to rise, while the rural population will stagnate in the medium term. This means the metabolic future of our planet will be determined by the urban metabolism.
- Understanding the stocks and flows dynamics of the material system, at different scales and for different materials. Most important here is to investigate and quantify the role of infrastructures and urban form in determining future metabolic flows and the limits to substitution.
- Agreeing on a harmonized approach for assessing dematerialization. Because international trade has been the most rapidly growing component of resource use, dematerialization measures need to incorporate indirect (embodied) flows⁹ to capture the primary resources and emissions arising from a country's consumption pattern.
- Focusing on strategic materials and their supply-demand chains as well as their regional economic, social and environmental impacts.

This special issue sheds light on some of the issues identified, but more effort is required to fully understand the current and future dynamics of natural resource use and the institutional requirements for guiding global resource use—if achievable at all—onto a sustainable path. The

international research community of industrial ecology is well suited to further drive this important research agenda.

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Notes

1. Industrial metabolism is an approach which looks at industrial societies in terms of the entirety of their physical exchanges with the environment, comprising the use of energy and raw materials, their internal transformation, and final release back to the environment as wastes, emissions, and heat. Societal metabolism (sometimes also denoted as social or socio-economic metabolism) is essentially the same concept but not restricted to industrial societies (Ayres and Simonis 1994; Fischer-Kowalski 1998). See also endnote 3 in the article by Schandl and colleagues (2008) in this special issue.
2. The OECD is an association of the governments of 30 industrialized countries.
3. The membership of the OECD is often used by researchers as a way to identify industrial economies.
4. EU-15 refers to the 15 countries which represented the member states of the European Union between 1995 and 2004. These countries are: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, and the United Kingdom.
5. EU-27 refers to the 27 countries which constitute the European Union since 2007. These countries are: the EU-15 countries plus the new member states Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, and Slovenia, which joined the European Union in two waves, in 2004 and in 2007.
6. One tonne (t) = 10³ kilograms (kg, SI) ≈ 1.102 short tons.
7. The IPAT equation, developed in the early 1970s, is a widely used mathematical identity for specifying socio-economic drivers of environmental impact. The equation states that environmental impact (I) equals population size (P) times affluence per capita

- (A) times available technology (T). For a review, see the article by Chertow (2000).
8. For a review of research on urban metabolism, see the article by Kennedy and colleagues (2007) in the special issue of this journal on the global impact of cities (volume 11, number 2).
 9. The terms indirect or embodied refer to the resources used and/or emissions generated in the production of goods and services.
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Future rescuers 5. Discredited myth Origin of the superstition 6. Distress call Risky sport 7. Visible obstacle Oldest creatures 8. Significant difference. "When men first flew in space, they were amazed to discover that the only man-made object visible from orbit was the Great Wall of China." This is a nice idea, but it's not true. The Great Wall is mostly grey stone in a grey landscape and, in fact, is very difficult to see even from an airplane flying at a mere 15 kilometres above. The term "Mayday" is an internationally recognized radio signal which is only used when a ship is in great dan