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Transformations and disruptive changes: Boosting resource efficient economies via saturation and the nexus

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Abstract

This chapter discusses long-term changes in economies and future challenges. It introduces two concepts that may help boosting resource efficiency in the future. First, new insights into the saturation effect, i.e. evidence on how UK, USA, Germany and Japan have been consuming key materials since early stages of their industrialisation. The result is striking: the per capita demand for steel and cement starts to saturate at a per capita average income level of US $12,000 GDP/capita in the four industrialized countries, followed by copper saturating at US $20,000 GDP/capita. Comparing those values with China, we see current indications of saturation in the demand for steel and copper. Chinese per capita consumption for cement is extraordinary and dwarfs the levels determined for industrialized countries. It is questionable whether those levels will be maintained for longer. Accordingly, one can expect a saturation level and, perhaps, a peak in the Chinese demand for primary material resources to come soon. Similar patterns may apply to other emerging economies and development in general. As resource efficiency efforts come on top of such saturation, the long-run implication is a lower resource demand for the future compared with e.g. recent estimates made by UNEP's International Resource Panel. The second booster for the resource efficiency debate stems from acknowledging interlinkages, i.e. the nexus between energy, water, food, materials and land. Beyond accounting for interlinkages, the nexus debate adds a security dimension and it helps to address the Sustainable Development Goals (SDGs). Firms and investments create manifold niches for disruptive changes towards sustainability, as this chapter exemplifies via recent modelling results and new models for mining and steel. Our overall outlook is cautiously optimistic as we depict a mission of bottom-up activities driven by various stakeholders and regional interests. Assuming saturation levels soon to reach for future demand of material resources in key economies such as China and observing how ambitious these countries are combatting air pollution and deploying clean technologies, the hubs of resource efficiency may well be shifting Eastwards. Governing resource efficiency is expected to accelerate.

1. Introduction

The simple notion of resource efficiency as 'doing more with less' can be seen as a straightforward way of relating value creation to physical inputs. Yet, it is often interpreted in a way that is short-term rather than long-term, and at a micro scale for business or single material resources rather than for the transformation of entire economies. This contribution deliberately undertakes an effort to look at the wider picture of resource efficiency through time and space and interlinkages across resources, and it offers an outlook into the future.

Disruption and transformation have been essential features of change in the past, and are very likely to stay as decisive factors for the future. Recent years have witnessed major changes around the globe. Sweeps of aggressive populism and triumphs of a new ethnic nationalism are the other side of a coin in a world where many people feel left behind and mass migration has become the new normal. Being under the pressures of 'Brexit' and other national egoisms, the European Union (EU) appears fragile and hardly able to take strategic decisions. On the other hand, a dawn of a new cooperation may be emerging through both the launch of the Sustainable Development Goals (SDGs) and the Paris Agreement on climate change, and both are bolstered by a number of remarkable trends. However, these signs of hope are at risk of being ditched when big polluters such as the U.S. may pull out of commitments and give others excuses to free ride. As the world right now is increasingly fragmented, there is a need for innovative analyses and new missions able to align actors.

The aim of this contribution is to look at disruption and transformations for the resource efficiency debate. Does the notion of resource efficiency help us to understand long-term changes across countries and time? Could it help to restart the mission to sustainability? What new narrative could help to meet the challenges of implementing the SDGs related to water, energy, and food by the year 2030? Looking at different trends, what may be implications for the years ahead, in particular for emerging economies? What are the implications for key resource-intesnsive industries, assuming long-term transformations driven by resource efficiency will be necessary?

This chapter seeks to address those questions. It adds two new elements to the resource efficiency debate: the saturation effect dealing with a relative decline of material resource use over long-time horizons, and the resource nexus dealing with interlinkages across using resources. Looking at long-term transformation the chapter also summarizes recent modelling results, and introduces new roles for mining and steel that might be of interest for investors. Finally, the chapter will give a fresh outlook into the future. The appraisal of earlier times is kept short, merely done with the intention to familiarise the reader with a line of thinking in long-waves and structural changes across industries and countries, and in distinction to much of the prevailing resource efficiency debate looking at incremental annual changes. The overall message, however, is cautiously optimistic as many of such transformative changes are expected to happen, and this contribution proposes a slightly modified narrative of resource efficiency as one of the drivers for a global green shift.

2. A short look at long-term changes and resources

Ancient societies suffered from a lack of resources, and they did not have sufficient skills to turn natural endowments into well-being. The Romans, for instance, had remarkable knowledge about water management and distributing it to urban citizens. Yet, they had difficulties of maintaining food security over time and deploying new technologies at large scales. The long-term changes from ancient agricultural societies to modern industrial societies have been covered well by research. In particular the research on *societal metabolism* has been able to demonstrate the resource implications and the patterns of change (Fischer-Kowalski and Haberl 2007). Not surprisingly, biomass has been the largest source of resource supply in earlier centuries, and remains to play a vital role in many developing countries nowadays.

Construction materials have been supporting change towards urbanization, along with proto industries of textiles and early metal manufacturing. The French historian Fernand Braudel describes accurately how these processes emerged simultaneously throughout many places in Europe and elsewhere from late Middle Age until the 19^{th} century, and how international trade has been able to interconnect early market-based and capitalist societies.

Resource interlinkages played a role: As wood was became scarce due to diminishing forests in the 18^{th} century, efforts to establish sustainable forestry originated from the mining industry and from a shift of the energy base towards using coal (Sieferle 2001; Wrigley 2013). To make a point: without the mining and coal industries, clearly both being resource-intensive and polluting, forest-based ecosystems might well have disappeared from the industrializing part of the world at that time. During those years, researchers and practitioners established principles of sustainable forestry, most notably the principle of maximum sustainable yield – one should not extract more than what is renewed by nature – motivated by interests to maintain a sustainable supply of inputs into their production processes (mining) and by deploying a more efficient resource base (coal). One may learn a lesson on unusual alliances here! During the industrialisation of the 19^{th} century, however, classical economics shifted the understanding of productivity towards labour and away from natural resources (Bleischwitz 2001).

Nobel laureates Douglas C. North, Oliver E. Williamson, Ronald Coase and other economic historians such as Paul David have established those long-term changes as being driven by a combination of technological and institutional changes. New Institutional Economics acknowledges human beings able to pursue purposeful actions as problem-solvers equipped with limited rationality, and actors' powerful attempts to innovate despite manifold constraints. These attempts evidently result in experiments with uncertain outcomes. Evolution over time and across societies is seen as a continuous and dynamic process of selecting superior knowledge. New technologies are being adopted and deployed only, if institutions are being adapted too and facilitate changes – that's the shortcut for today's challenges, and well taken up by more recent theories of transition management.

The findings on *long waves* in development are striking. Nikolai Kondratieff, Joseph Schumpeter and others have established thinking about cycles of approximately 50 years of ups and downs shaping economic performance. These long waves have been centred around disruptive productivity enhancements driven by resource-based industries: the steam engine driving an energy revolution from 1780 onwards, followed by railways and steel initiating a new cycle around the year 1830. The next wave started with the electrification and chemicals after the year 1880, and another one emerged with automotive industry and related petrochemicals around 1930. Closer to our times, consumer electronics and ICT have been drivers since the 1970s. All these long waves have been accompanied by changing modes of financing and business organisations, economic and political crises, and shifting preferences within and across societies.

INSERT FIGURE 1 ABOUT HERE

Patterns of societal waves of advancements since the birth of the industrialisation

Source: Wilenius (forthcoming)

Those long waves maybe understood as inherent and dynamic components of development, occurring with a certain regularity and opening up new horizons for analysing transformations of societies. A key to understand is general productivity increases as being embedded in larger technological and institutional changes, and the various interconnections with key industries. Such general mechanism might explain why most economies have experienced high productivity increases of > 5% per annum at certain stages of their development, over one or two decades, while such dynamics tend to slow down and arrive at much lower average rates of 1 – 2 % per annum for a more maturing phase afterwards. It also explains why development processes happen at uneven speeds across societies, and methodologies of time series analysis have to be applied and interpreted with great care.

3. The saturation effect: yet a neglected booster for lower demand

Looking at development of countries over such time horizons and studying growth patterns as a heuristic of transformations is a relatively new field for resource efficiency analysis. An interesting phenomenon is the *saturation effect* (Malenbaum 1978; Auty 1985), often also referred to as 'Environmental Kuznets Curve (EKC) for material resources'. The EKC illustrates a hypothesis on the relationship between development, environmental quality, and the use of material resources. It is portrayed as an inverted U curve and suggests that environmental quality decreases with development up to a certain income level and then begins to improve. However, the findings for environmental indicators are fairly selective and not entirely convincing, as just a few indicators seem to improve while climate change and biodiversity losses continue. But the story for material resources may be different. Causes for a saturation effect in the use of material resources are close to general development patterns, be it through having established a physical infrastructure in an economy, or substitutions towards less material-intensive technologies, or structural changes between sectors, general technological change, or social changes.

We have analysed the material resource-specific demand trends over a time horizon of a century for four key material resources – steel, cement, aluminium, and copper – for the UK, USA, Germany, and Japan, together with China, as the most pre-eminent emerging economy (Bleischwitz and Nechifor 2016). The result is striking: the per capita demand for steel and cement starts to saturate at a per capita average income level of US $12,000 GDP/capita in the four industrialized countries, followed by copper saturating at US $20,000 GDP/capita reflecting the numerous applications of this technology metal. The evidence for aluminium is weaker as it kicks in at later stages of development through a very wide range of applications.

Comparing those values with China, we see current indications of saturation in the demand for steel and copper. Chinese per capita consumption for cement is extraordinary and dwarfs the levels determined for industrialized countries. It is questionable whether the current 2.5t/capita consumption level will be maintained for longer, as those values in the other countries are just at a level of about 0.4–0.7 tonnes per capita. One would thus expect the Chinese cement production to cut production rather than maintaining such values or continuing to grow.

Indeed, a key in assessing any saturation effect is to account for *apparent domestic consumption* rather than production. Otherwise, countries importing raw materials and pre-products would appear as performing well in terms of decoupling resource use from GDP growth, while in reality they are just shifting parts of their production base abroad. Our analysis includes main indirect flows of material resources through the international trade of goods, an issue which has been a major shortcoming in earlier analyses (Cleveland and Ruth 1998). These hidden flows are also severely underrepresented in the core indicator 'Domestic Material Consumption' that is often used in the analysis of resource efficiency. We use the full range of the UN COMTRADE database from 1962 onwards, as well as calculations for the decades before. In addition, we make use of available data on the material resource intensity of internationally traded goods. Clearly, this approach still comes with a number of limitations, but the point stands about new evidence compared to

- Previous analysis on the saturation effect using production data rather than our consumption approach incorporating international trade;
- The prevailing analysis on decoupling using a database about aggregated material resource flows (material flow analysis, MFA) with a usual starting date of 1990 – much after any such saturation has taken place in the majority of developed countries. Applying time series from 1970 has clear advantages – yet saturation levels in some countries have started to occur before this year.

Taking these insights from historic evidence into account, we argue that the Chinese economy is unlikely to continue its trajectories of the last fifteen years in the use of those commodities. Following pathways of other developed countries and considering the projected stagnation or even reduction in population, it is now more likely that future Chinese consumption for steel, cement, and copper will flatten or even decline in absolute terms. Such decline in consumption is even more likely with ongoing efforts towards an ecological civilisation and a circular economy in China (McDowall et al. 2017), which will enhance process innovation and resource efficiency in manufacturing in general, recycling and the use of secondary material resources, as well as the development of new goods and services that should use less primary material resources. China is also about to realize efficiency gains in the primary sector and subsequent industries of the Chinese economy for the years ahead. Thus, we expect a saturation level and, perhaps, a peak in the Chinese demand for primary material resources to come soon. Similar patterns may apply to other emerging economies and development in general. Investors thus may look out for new foresight approaches and business models taking into account such combination of saturation and resource efficiency.

INSERT FIGURE 2 ABOUT HERE

Two Scenarios for China: Growth as usual or Saturation?

Source: Bleischwitz and Nechifor 2016.

We conclude here by questioning the few available forecasts for world-wide resource demand in the future. The UNEP's International Resource Panel expects a tripling of resource extraction by the year 2050 compared to the year 2000 (UNEP 2017). This is based on modelling work that seems to extrapolate from the recent past based on the limited time series available for material resource flows (Hatfield-Dodds et al. 2017), rather than looking at long waves in economic development and evidence for a saturation effect. Instead, we propose any extrapolation of previous trends of the last 10 or 20 years for material resource consumption should *not* be regarded as a guiding rule for future market trends and investments. China and other emerging economies can rather be expected to decouple GDP from resource use through drivers of such saturation effect, *as well as* through resource efficiency, circular economy, and low-carbon economy efforts. In particular, for steel, copper, and cement in China we would suggest future scenarios with demand that is much flatter than extrapolations from the past 10 – 20 years.

4. New narratives and interlinkages through the resource nexus

While evidence on the saturation effect may sound like good news in terms of expecting lower demand for resources world-wide compared to prevailing 'business as usual' assumptions, a closer look reveals a number of challenges for the future, in particular related to the use of energy, water and land. Accordingly, the reasoning for resource efficiency should be widened and address more than 'cost savings'.

The narrative of resource efficiency as 'cost savings' has been quite compelling in the past years of high commodity prices and within countries or regions importing relevant shares of their demand, such as the EU, Japan, and China. With moderate commodity price levels and so many changes occurring in the world nowadays, better narratives are needed to bolster the drivers towards green economies. What is it that might be needed? Resource efficiency plays out well in manufacturing and attempts of modernizing industrialized economies towards green goals.

The *resource nexus* entails many ingredients for a new and strong narrative. It can be seen as a powerful additional booster for the resource efficiency debate. Being a relatively new field of research, the nexus addresses the interlinkages across how natural resources are being used, in particular water, energy, and food (Bazilian et al. 2015; Biggs et al. 2015; Green et al. 2016). The concept has been formulated as a response to "silo" thinking in traditional planning, where the provision of these resources had been treated separately. It emphasises the importance of looking at trade-offs and synergies in the use of resources in a more integrated manner, thus widening the notion of resource efficiency. Recent discussions include land and material resources in the nexus (Andrews-Speed at al. 2015; Bleischwitz et al. forthcoming). The nexus can be defined as the set of context-specific, critical interlinkages between two or more natural resources used in socio-economic systems. Its novel narrative can be seen in addressing:

- The interlinkages across systems of provision, such as water needed for energy systems, mineral fertilizers as inputs into food systems, and the resources needed for renewable energies;
- Human security, a 'nexus on the ground,' and livelihoods of the one billion plus people living below the poverty line, as it looks at the access to these life-supporting resources;
- Political security, mainly as tool for analysing conflicts related to natural resources within regions or across borders.

FIGURE 3 ABOUT HERE

The Resource Nexus
Source: Adapted from Andrews-Speed at al. 2015.

Figure 3 illustrates the main resource interlinkages between five essential resources and how these provide a basis for societies and sustainable development. Looking at those interlinkages, some may be more obvious to many readers than others, such as the bi-directional connections between energy and water. Others become more critical during periods of rapid increase in the use when typical silo approaches lack the tools to assess the future availability of core inputs from other resources that are in demand from other users, such as the material resources needed for energy production.

Systems thinking is key. Implicitly the nexus goes beyond primary resources and is about life-cycle thinking along and across systems providing food to eradicate hunger, material resources for shelter and being a backbone to manufacturing, land as an input into all other categories, etc. The nexus approach acknowledges that integration adds complexity and hence is difficult to implement, and that addressing all interlinkages is next-to-impossible. Yet it rests on the assumptions that (i) identification and assessment of critical interlinkages is essential, and (ii) managing and governing such interlinkages is key to achieving the SDGs, clearly superior to managing single resources in silos. Thus, a nexus approach seeks more efficient resource governance that addresses multiple targets in a more integrated manner.

The nexus typically involves actors from infrastructure planning units for water and energy, development agencies and international organizations. This is a relevant addition to resource efficiency as being supported by environmental groups and like-minded manufacturers. At the same time, it should help to bring voices of environmental sustainability into a debate on sustainable resource governance that often focuses on socio-economic issues (see, for instance, the work of the Natural Resource Governance Institute, NRGI).

A real-world example are anaerobic digestion reactors applied in rural areas of developing countries. They are able to produce biogas, i.e. energy, out of waste and wastewater while also co-producing fertilizers and purified water. Indeed, this comes with a broader and compelling understanding of improving the efficiency of all resources needed as inputs into the production, and creating values that go beyond energy.

Looking at resource efficiency and in particular how it is being measured, the nexus thus suggests including resources beyond the MFA indicators, in particular water and land. If the nexus concept gets better aligned with resource efficiency, such an enlarged narrative offers an opportunity to realize co-benefits and address a number of challenges more synergistically:

- Deliver the Sustainable Development Goals 2 (food), 6 (water), 7 (energy), 9 (infrastructure and industrialization), 12 (sustainable consumption and production) in a more integrated manner;
- Develop business niches especially with local people at the Bottom of the Pyramid – a socio-eonomic concept looking at the vast segment of the world's poorest citizens and seeking to offer opportunities (following books written by C.K. Prahalad and Stuart Hart and – towards eco-innovations with a potential to grow and become interconnected;
- Enable new alliances for collaborations with international companies seeking for community involvement and eco-innovation across borders with local benefits;

- Engage with investors, large companies, and international organizations that are under pressure to serve long-term goals with more short-term returns.
- Potentially contribute to the reduction of migratory processes.

At the end of the day we pledge for such broader resource efficiency agenda in order to account for resource interlinkages beyond material flows and to address more target groups beyond manufacturing. Doing so will enable actors to deal with real challenges. The saturation effect as described above is a much welcome driver, but given water stress and energy challenges such additional dynamics will be needed towards sustainable levels of demand for materials resources in line with SDG 12. Thus a combination of saturation levels and the resource nexus is decisive for setting a direction towards a global green shift driven by bottom-up processes of transformative innovation, in particular for investments into resource-intensive industries and infrastructures.

Boosting resource efficiency via the nexus is likely to rewire climate action from a previous top-down approach that emerged from global environmental public goods and multilateralism towards transformative action from the bottom up and more decentral collaborations. Such shift is actually emerging through the recent COPs of Copenhagen and the Paris accord on climate change compared to the Kyoto-Protocol of 1997, but will also benefit from such new narrative and related investments.

5. Recent modelling on structural changes

Economic analysis is useful in trying to grasp potential changes ahead. There will be winners and losers resulting from resource efficiency increases (see Chapter 10 for more details). Research projects carried out with funding from the EU reveal potentially positive macro-economic outcomes. Yet it is important to look at the details. Macro-economic models differ in main characteristics, the scenarios differ too, and some assumptions have policy implications that are worth discussing. Plus, overall positive outcomes may have severe negative implications for regions and parts of the economies.

Seeing positive economic outcomes, however, is agreeably better than economic modelling results of the past where any environmental policy induces compliance costs and crowds out more 'productive' investments against a 'business as usual' (BaU) case with high GDP growth rates. Debunking such biased economics has clearly been the merit of today's mainstream of environmental and resource economics. Such progress has emerged through acknowledging (i) the cost saving potential through the manifold energy and resource efficiency measures, and (ii) assessing the marked development for clean technologies along with increasing demand for it.

For many people, contemporary modelling attempts may come across as a magic box. In fact, however, understanding basic features of modelling should be seen as a key skillset for future strategies. Good modelling helps to understand complexity and gives an estimate about various impacys, many of which may come as a surprise and deserve further debates. Thus our chapter will deal with a few key modelling results.

The POLFREE modelling results (Distelkamp et al. 2016) for the scenario 'EU goes ahead' depicting a leadership role for the EU in worldwide efforts towards resource efficiency arrives at the following results for 2050: increased and sustainable growth rates of 12.2% compared with BaU, a rise in employment of 1.2%, reduced national debts, and resource savings of 55% along with greenhouse gas emission reductions of 80%. The underlying GINFORS model from

GWS Osnabrueck, a dynamic input-output model, has a broad representation of physical data for material resource flows and main emissions. The POLFREE 'business as usual' scenario has been developed jointly with the Potsdam Institute PIK, and can be seen as one of the very first attempts to include climate change risks and damage costs into such a scenario. If no action is taken, climate change will happen – such reference path would need to become mainstream for all economic assessments. The implications have been lower GDP growth rates, fewer jobs, and higher food prices in the reference case – and thus a favourable baseline for any resource efficiency scenario.

There are clearly good reasons for such new baseline scenario thinking – thus it should become part of a public debate beyond modelling resource efficiency. Other results of the POLFREE scenarios are striking too. The scenario 'Civil society leads', kind of a new lifestyles of sufficiency scenario, leads to lower growth but higher employment and a trade surplus due to reduced imports. Clearly, this implies critical choices to be made!

Another model, the global general equilibrium model ICES from FEEM Italy, arrives at positive results via endogenous technical change and cuts in labour taxes while re-using revenues of increased resource taxation (Bosello et al. 2016). Interestingly, their model comes with positive results for agriculture in general, except meat production. Results differ throughout EU member states.

The study on effects of a circular economy done by Cambridge Econometrics and BioIS (2014) arrives at positive results for the EU stemming from such policies, if resource productivity improvements can be managed in a corridor of 2 % - 2.5 % per annum; beyond, however, further improvements may be associated with net costs to GDP as the abatement options are expected to become more expensive. They also feature winners and losers at the sectoral level, with gains expected for construction industry, retailers, manufacturing, utilities, transport, communication, and services. Losses are expected for agriculture (in contrast to the modelling results above), forestry, fishery, and in particular non-energy mining.

All models agree on the relevance of investments as drivers of any change. However, this is a frontier in research. What matters are e.g. the adaptive flexibility of industries and the production system in general, the use of any tax revenues as public investments in a certain direction, and undesired rebounds effects due to intra and international trade dynamics. Two cases in point of the latter could be (i) an EU pesticide tax that might simply redirect EU pesticide production abroad, or (ii) an increased public investment for material resource efficiency R&D that may trigger a "production scale" larger than a "material resource use decline" effect.

Another critical variable stems from putting elasticities into the model. Parameters can be taken from the literature, or be calculated via econometrics – but all these efforts may be flawed through a bias in the literature, or choosing time series where data is available, and not through studying transformations over time. Bringing our topics – Kontradieff cycles, the saturation effect, and the resource nexus – into modelling is a frontier of research, not yet a common practice.

Furthermore, as economies are expected to adapt to price signals from commodity markets – where do these price assumptions for future commodity markets come from? Do they account for water stress leading to higher production prices, and to the very uncertain political impacts that may or may not occur (recalling the two energy price peaks in the 70s being caused by political moments)? Surely, all these critical variables need methodological reflections and should be subject to a broader analysis. The 'Shared Socioeconomic Pathways (SSPs)' approach thus is a useful undertaking.

It is fascinating to see sophisticated modelling attempts grappling with long-standing issues in economics. The modelling world of mainstream equilibrium approaches differs from the Schumpeterian world of more disruptive changes. Questions such as "do markets tend to equilibrium, and under which conditions do they change at what pace?" "How do markets interact with non-market actors and their activities, and how do they interact with nature?" "What is the role of policies and decision-making?" – they are all with us in research and business and public administration, and they require comparative analyses with methodological pluralism, including transdisciplinary approaches.

Some markets are actually changing at a very fast pace. Wind and solar energy have been driving disruptive changes in international energy markets since the 1990's, and with a take-off happening since 2005. Between 2010 and 2014 more than US$ one trillion has been invested to install over 300 GW. Goldmann Sachs (2016), among others, expects steady growth in global installations for the years ahead. By 2020, they expect the share of wind and solar in global electricity generation (c.10%) to exceed today's share of ecommerce in global retail (c.8%), and that of US shale in global oil production (c.6%). Another case is LED light bulbs, which continue to revolutionize markets for lighting. Sharp cost declines have made them increasingly competitive, and analysts expect a market share of approximately 90% for 2025, which means a complete market transformation in just about 15 years.

The general lessons here may be summarized as follows. Realizing cost savings is essential and feasible, both for existing industrial processes and for novel products with new features. Following our observations about the saturation effect and the resource nexus, relevant cost savings are to be expected from making key material industries more resource efficient (incl. water and energy) and customer-oriented, especially in areas such as smart and sustainable housing and infrastructures. As regards to disruptive innovations, one can take from earlier debates insights into how low entry barriers are helpful in scaling up markets, with a take-off more likely to occur, if end users and consumers are ready to purchase, and if policies facilitate changes. Applying those thoughts to the Global South will require strategies on water-energy-food securities and inclusive institutions. Under such circumstances, the following figure applies:

INSERT FIGURE 4 ABOUT HERE

Figure 4: The long and winding road to resource-efficient dynamics

Source: own compilation

6. Potential transition strategies for key industries

Wind and solar energies, LED lighting systems, clean water technologies, and recycling technologies have been spearheading the success of green economies across the world over the last years. At the same time, most countries have realized some decoupling of resource use from GDP (UNEP 2017; see Chapter 3). All these positive trends, however, are to be accelerated and enlarged, if the world is to become serious about combatting climate change and staying within the safe operating space of planetary boundaries.

This chapter pledges for a new narrative of resource efficiency to address the needs of the world's poor more directly via nexus innovations, and to unfold a broader dynamic. Key sectors need to become more transformative in order to adapt to saturation levels and nexus challenges, in particular the mining and metals sector.

The case of mining

As long as mining supplies primary material resources to the economies at a price that does not reflect negative externalities, all resource efficiency measures in downstream industries face an uphill battle of price distortions and misleading expectations of abundancy. Fortunately, the mining industry realizes the winds of change and has started to adapt. The following features are elements of a proposed new mission for the mining industry, a mission towards supplying sustainable material resources for the SDGs:

1. Nexus-innovation push: Most ore grades are declining, forcing industry to become more energy and resource efficient in order to reduce capital expenditures. Faced in addition with water stress, the mining industry can be expected to adopt more eco-innovations than in the past. Chilean copper mining, for instance, will be re-oriented to run on desalinated water. As Chile undergoes a transformation towards renewable energies in order to cope with energy insecurities, mining industry may pioneer the application of renewable energy in desalination projects, a combined technology much in demand in water stress regions around the world.
2. Asymmetrical regulatory pull: The real transformation can be expected to happen for fossil fuels, in particular for coal. Companies with a large portfolio in fossil fuels are likely to be seen as based on 'stranded assets', and investors may change their risk assessments accordingly. Large mining companies, however, can shift extraction from fossil fuels to other material resources such as iron ore, copper, bauxite, speciality metals, mineral fertilizers – all required to meet essential SDGs. Sustainable energy systems will need metals, overcoming hunger requires mineral fertilizers applied in the most sustainable manner in agriculture, and infrastructures for water distribution and sustainable cities will also require substantial amounts of resources. Phasing out coal in times of latent overproduction may actually be done at a profit and maintain long-term value.
3. Global assessments: extracting material resources from the ground comes with a trade-off in biosphere integrity and triggers biodiversity losses, albeit at a relatively small scale compared with global trends in agriculture and urbanisation. But hot spots exist. In the future and enhanced by resource efficiency efforts, one may expect more global collaboration on decision-making about suitable mining sites. Geology and sustainability are key knowledge areas here; and integrated assessments of subsoil assets, groundwater, and biosphere integrity are yet to be developed. Environmental valuation, water stress, and exposure to other climate impacts, motivates companies to re-assess risk criteria and opt for low environmental risk activities. There may be fewer and more intensive mining activities, predominantly in regions with stabile governance conditions. Such activities may help to develop guidelines for planetary resource consumption, as suggested by Nickless (2016) and Ali et al. (2017).
4. Integrating value chains: In the long run, mining might overcome the current linear model of extracting primary material resources and engage in value creating more downstream. Establishing models of material resource flows – such as the ones existing for aluminium and steel – and interlinking them with macro-economic models are

useful in understanding demand trends. On the business side, integrating the next step in the supply chain could become rational, i.e. refinery and smelting, which is decisive for the quality of the material resources provided. A more radical change to the current business model could come from a serious engagement in markets for secondary material resources. Knowledge and technologies for urban mining are not too far away from current core activities, i.e. demolition and deconstruction of outdated infrastructures with a recovery of useful material resources, processing and upcycling activities, and accompanying logistics to deliver those to new customers. In a few decades, current mining companies might transform themselves into material resource suppliers and providers of sustainable values based on sustainable material resources.

The case of steel

Steel is the key material resource for construction and automotive industries and, thus for industrialization. World steel production grew roughly tenfold from 1950 till 2015, with China now producing roughly half of world steel. Other relevant producers are Japan, India, USA, Russia, South Korea, Germany, Brazil, Turkey, and Ukraine.

On the environmental side, steelmaking is a large source of greenhouse gas emissions. On average, 1.9 tons of CO_2 are emitted for every ton of steel produced. 6.6% of world greenhouse gas emissions in 2014 have been associated to steel industry, making it one of the biggest polluters. Yet, steel can be applied in light-weight and lead to significant reductions in energy use downstream; it can be considered a permanent material resource with high functionality for a circular economy. The use of by-products, recovery and scrap steel performance is of utmost relevance for green economies. Europe is the leading exporter of scrap steel worldwide, both Asia and Europe are trading hubs for scrap steel; biggest importer in 2015 has been Turkey.

Shifting from the primary production route of steelmaking towards reprocessing steel and applying secondary steel (so-called EAF route) can be seen as future global green transformation, as the secondary route value chain uses much less material resources and energy, and generate less emissions and pollutants. The high amount of electricity needed for the secondary route should increasingly come from renewable energy sources. The vision would be globally connected societies with steel production based on renewable energies and circular water use, zero steel waste and 100% re-use including steel stocks. Early modelling results indicate feasibility and positive impacts (Allwood 2013; Pauliuk et al. 2017; Winning et al. 2017).

As indicated above, such changes can be expected to be disruptive and uneven across sectors and countries. Current global steel recovery rates vary by sector and by country. China, for instance, applies steel from the secondary route currently at a rate of just 15%, while Latin America is at 40%, Indonesia at 50%, and other countries at 60% and above. A catch-up of China seems rational, reducing current over capacities and helping to deliver on infrastructure developments and mobility. A change within the steel sector would also help coping with the social issue of pension systems in China being related to industries, a system acting as an impediment to large-scale lay-offs at the prefectural level, unless changes are within the sector itself.

With all caution, we expect the saturation effect kicking in for steel (see section above) and steel shifting towards a circular economy model within regions and at a global scale. Resource efficiency can act both as a global driver and as a useful tool at a micro-level when decisions about by-products, new products, and recovery routes are to be made.

New alliances and missions

Many disruptions and transformative changes have been driven by single industries: Henry Ford's introduction of the assembly line for automotive industries and beyond, Bill Gates and the introduction of PCs at private homes, and all the changes occurring via internet and mobile communications. Yet, they usually benefitted from innovation made in time elsewhere, and from institutional changes. Often, unusual coalitions were emerging, such as sustainable forestry driven in the 18th century through the 'dirty' industries of mining and coal; or electrification of the railway systems some fifty years ago bringing down air pollution more effectively than well-intended measures.

Platforms have been introduced to bring actors together in the research, development, and innovation (RDI) of large-scale technologies. In a wider perspective, platforms need to involve a variety of stakeholders bringing in diverse perceptions, understandings and interests that explain how they frame the problem, and organize themselves towards new missions. Water management, food security, sustainable energy systems, transitions for resource-intensive industries, sustainable urban development, and their interlinkages through a nexus lens could become key missions. In such areas, developing a variety of scenarios and a shared vision of the future are necessary. Shared visions should be based on various perspectives, and combine potentially conflicting interests into joint endeavours by creating short- and long-term incentives for key actors. These missions also need to be translated into more tangible strategies on how to kick-start the process and organize quick wins, identify potential asset losses and sunk investments, and follow up on it in the medium to long term.

As explained above, it will be essential to bring new valuation perspectives in such stakeholder missions, in order to identify resource efficiency opportunities, as well as risks and gains of eradicating poverty and enabling access to key resources for the world's poor. Research should support these processes via modelling efforts, potentially by soft linking biophysical tools with macro-economic modelling and applying system dynamics as appropriate.

This all suggests new forms of policy and governance for resource efficiency taking into account leadership as well as organizational capacities, training, technical competences and financing. In a global perspective, the governance catered for those challenges is likely to evolve out of regionalized polycentric collective actions and international missions towards a global coordination. Our regionalized bottom-up perspective thus complements other planetary governance approaches, such as 'earth system governance' (Frank Biermann) that appear more top-down. Indeed, global resource efficiency governance approaches need to combine both bottom-up and top-down.

7. Conclusions

Resource efficiency has become established as a concept aligning business and entire economies with broader value creation and environmental goals. However, there should be a broader debate about transformations and disruptive changes as well as about missions to sustainability. There is much to learn from research about interlinked institutional and technological changes and long waves occurring in the past. More specifically, we expect two boosters kicking in and supporting investments and action towards radical resource efficiency improvements: the saturation effect and the resource nexus.

Historic evidence of using steel, cement and copper in industrialized countries is setting the path towards saturation levels soon to reach for future demand of material resources in key economies such as China. In order to remain competitive and avoid 'zombie industries' these industries and related value chains will be pushed towards enhancing resource efficiency. Given how ambitious these countries are combatting air pollution and deploying clean technologies it might well be that the hubs of resource efficiency will be shifting eastwards in the future.

Furthermore, the nexus debate on resource interlinkages is seen helpful in aligning security and development interests with the resource efficiency agenda. Accordingly we propose a wider notion of resource efficiency beyond the scope of MFA to include water and land use. Looking towards 2030 – the year when the SDGs are supposed to be accomplished – sustainable value creation could become a core mission for firms. If so, it will have to address the needs of the world's poor more directly via what we have dubbed 'nexus innovations'.

Amidst sweeping nationalism, global fragmentation and estimates into more and more demand for resources, our outlook is cautiously optimistic. Both the saturation effect and the nexus can well become 'the new normal' in key industries such as mining and steel, energy and water, and in large parts of the world. After all, this is a programme of bottom-up activities driven by firms, investors and other stakeholders and by regional interests, not one of heroic global multilateralism. Observing manifold niches for disruptive changes towards sustainability, knowledge exchange about systemic changes and good governance is well under way and should be on top of the agenda of international organisations. Governing and scaling up resource efficiency across time and space is likely to be a fascinating journey.

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FIGURE 1
Patterns of societal waves of advancements since the birth of the industrialisation
Source: Wilenius, Global change and K-waves: exploring the pattern of the future (in: Bleischwitz et al., Handbook of the resource nexus, forthcoming)

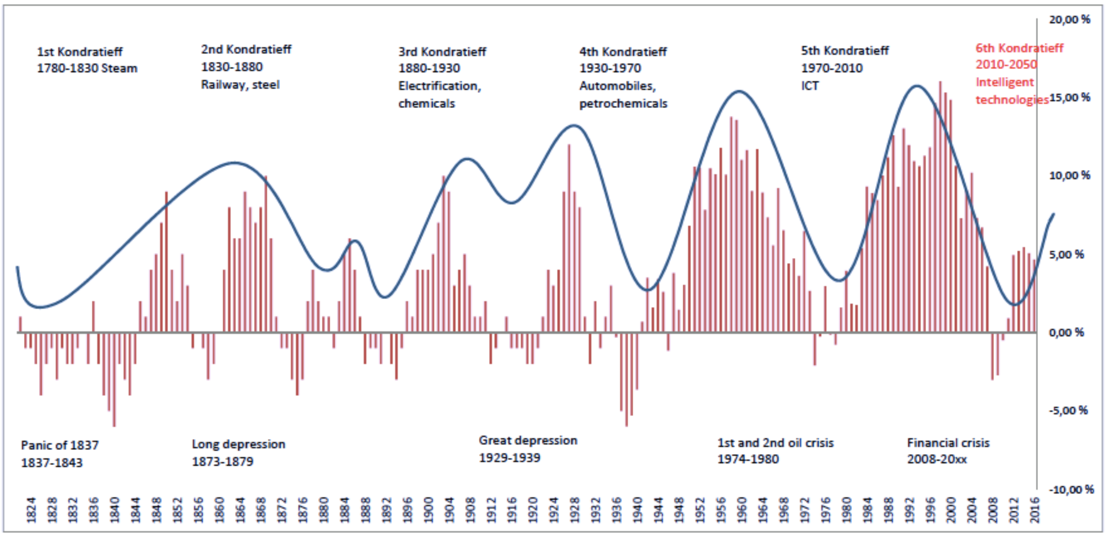

FIGURE 2

Two Scenarios for China: Growth as usual or Saturation?

Source: Bleischwitz and Nechifor 2016.

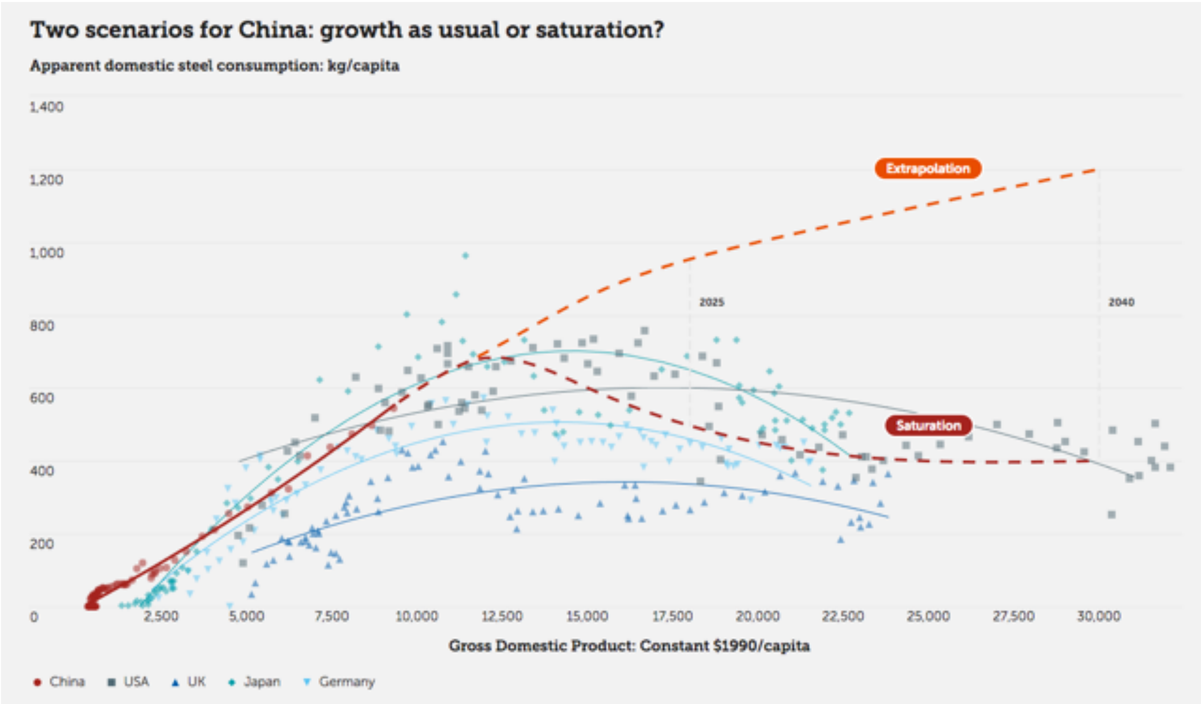

FIGURE 3

The Resource Nexus

Source: Adapted from Andrews-Speed at al. 2015

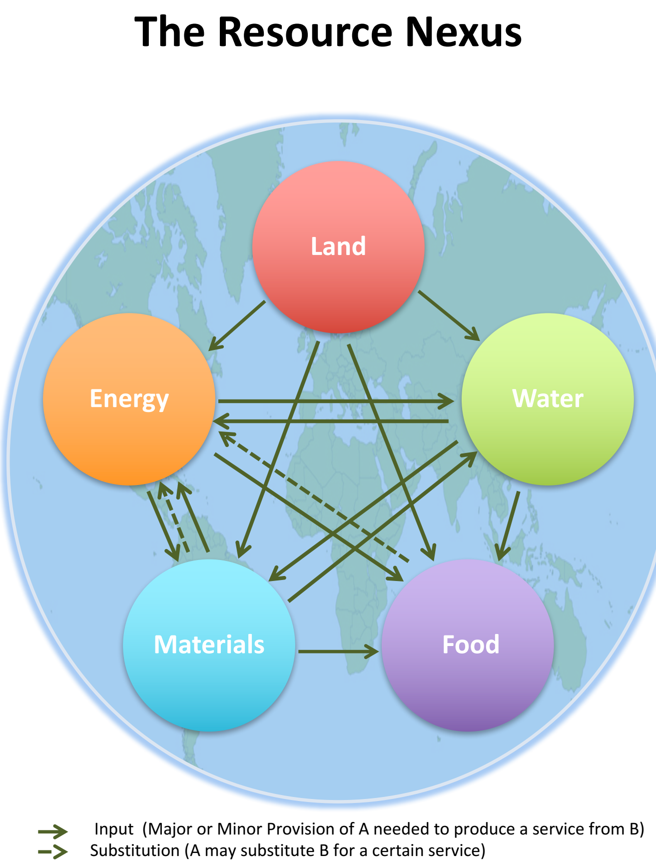

FIGURE 4

Figure 4: The long and winding road to resource-efficient dynamics

Source: Own compilation.