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2 Resource constraints

The geopolitics of natural resources are shaped by the growing demand and the more slowly growing supplies. In recent decades the demand for fossil fuels, land and mineral resources has grown exponentially as a result of drivers such as population growth, industrialization and urbanization. According to the Organization of the Petroleum Exporting Countries (OPEC, 2011: 5-8), energy demand will increase by 51% by 2035, most of it from non-OECD countries. The UN Food and Agriculture Organization expects that food production will need to increase up to 70% by 2050 to meet the demand from the world's growing population (OECD/FAO, 2009). The demand for minerals is also expected to increase at a rate of 1% per year, and by 2050 will be 60% higher than it is today (Kesler, 2007).

The demand for natural resources fell temporarily in 2007 as a result of the financial crisis. Worsening economic conditions slowed the demand for energy resources. Lower energy prices also reduced the demand for biofuels and credit limitations reduced the trade in agricultural commodities. Nonetheless, demand has recovered more strongly than expected, especially from the rapidly developing emerging economies. Shortly after the worst dip, demand returned to pre-crisis levels. The resulting imbalance between demand and supply has led to tight mineral commodity markets and an unprecedented boom in the prices of both abiotic and biotic resources.[1]

2.1. A classification of challenges

The environmental and social challenges that face society at large and industry in particular can be classified in various ways. Here we use a categorization of resource-related challenges that has been inspired by two recent reports of the International Panel on the

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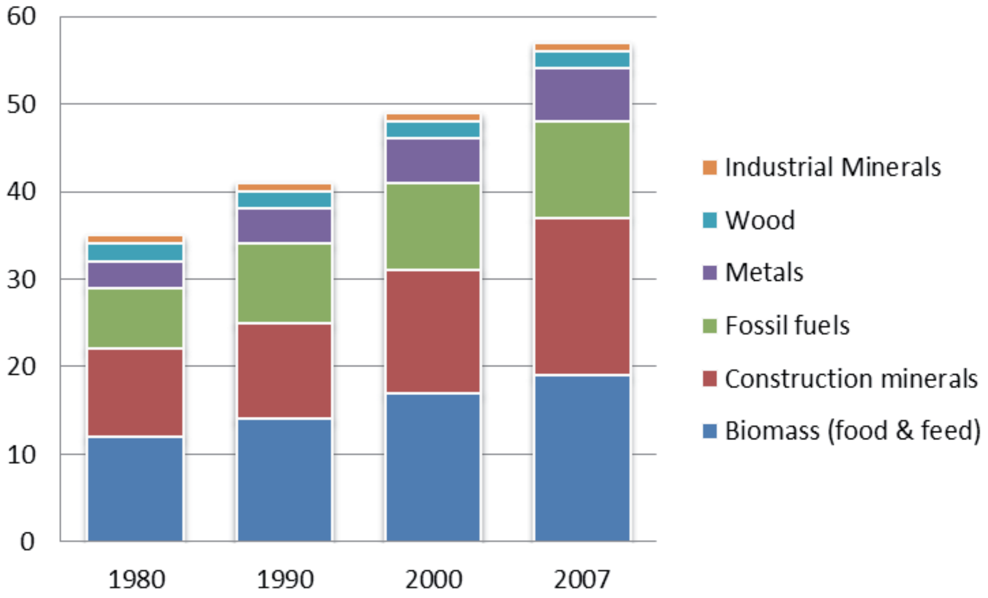
[1] Biotic resources are obtained from living organisms such as plants and animals and include products from agriculture, forestry and fisheries. Abiotic resources are obtained from the physical environment and include minerals and metals.

Sustainable Use of Natural Resources (UNEP, 2010; 2011) and a set of indicators suggested by Giljum et al. (2009) for measuring eco-efficiency, which classifies resource uses and the related constraints according to the main categories identified in an economy-wide material flow analysis (MFA). From the recent trends in global resource extraction shown in Figure 2.1, it can be seen that biotic resources, construction minerals and fossil fuels now make up close to 80% of all materials extracted for human use, excluding water. Note that in this analysis, as well as the typical resources identified in the MFA, we also include water and land use.

This chapter discusses the challenges related to the following groups of resources:

- energy resources: security of supply and climate impacts;
- water and land: depletion and ecosystem degradation;
- abiotic resources:
  - industrial and metallic minerals: security of supply, energy use and ecosystem degradation;
  - construction minerals: energy use and ecosystem degradation; and
- biotic resources: water use and ecosystem degradation.

Figure 2.1 Global resource extraction, 1980-2007



Source: OECD (2008).

The chapter also addresses important linkages between these various resources. As the above list suggests, it may sometimes be possible to overcome the constraints with regard to one resource but at the expense of making significantly more use of another resource. It is therefore essential to apply a systemic view, in which all resource challenges are addressed in combination (Graedel and van der Voet, 2010; Meadows et al., 1972).

2.2. Energy resources: security of supply and climate impacts

In 2005, the world's total final energy consumption was 285 EJ[2], of which manufacturing industry accounted for 33% (including external energy supply from e.g. power plants; IEA, 2008), followed by transport and households. The most energy-intensive sectors include the steel, cement, chemicals and plastics, pulp and paper and aluminium industries.

For all of these industries, the main challenges include security of supply and energy prices. Competition over access to fossil fuels has already led to rising prices. Particularly for oil, a key 'portable' fuel that is essential for transport systems, newly discovered deposits tend to be smaller and require greater investments to access them. The International Energy Agency predicts that oil production will reach a plateau of 10.5 million barrels per day by 2017, after which it will no longer grow proportional with the economy or even decline slightly (IEA, 2011). New fossil energy resources such as tar sands require much more energy for their exploitation than conventional oil and gas. All of these trends indicate that energy is likely to become more expensive in the future; indeed, in its *World Energy Outlook 2011,* the IEA notes that 'Rising transport demand and upstream costs reconfirm the end of cheap oil'.

Another challenge is the concentration of ownership of energy supplies, which in the past has occasionally led to supply disruptions. Examples include the Arab oil embargo of the 1970s, and the dispute between the Russian Federation and the Ukraine over natural gas prices that began in 2005. With the phenomenal economic growth of China and India, where the demand for primary energy is expected to rise by at least one-third by 2035 (IEA, 2011), such problems are likely to become even greater. The challenges of security of supply and rising prices will hit industry in any case – there is no way that such costs can be externalized.

Climate change is another issue that will impact industry, but in quite different ways. In the absence of policies aimed at limiting carbon emissions, these impacts are externalized and there is no clear boundary within which industry has to operate. Although recent attempts to agree on global carbon emission reduction targets have been unsuccessful, it is probably naïve to assume that industry will not be affected by climate policies. The EU's Emissions Trading Scheme, which puts a price on carbon emissions, for example, has been operational since 2005.

Even institutes such as the IEA have provided clear warnings about climate change (IEA, 2011):

> We cannot afford to delay further action to tackle climate change if the long-term target of limiting the global average temperature increase to 2°C, as analysed in the 450 Scenario, is to be achieved at reasonable cost. In the New Policies Scenario, the world is on a trajectory that results in a level of emissions consistent with a long-term average temperature increase of more than 3.5°C. Without these new policies, we are on an even more dangerous track, for a temperature increase of 6°C or more.

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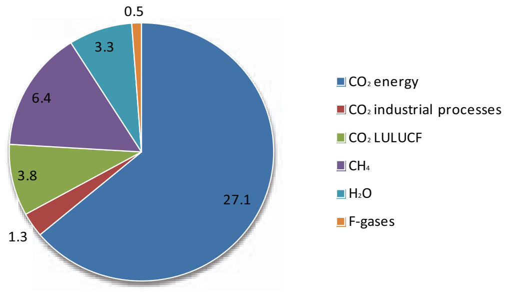
[2] 1 EJ (exajoule) = 10^{18} J.

In 2005, total global CO_2 emissions were 28.4 Gt. Industry, in particular the energy-intensive industries mentioned above, was responsible for over 35% of these emissions, both direct and indirect (see Figures 2.2. and 2.3), followed by power plants, transport and the built environment. Agriculture and the food production system are responsible for almost one-third of greenhouse gas emissions via changes in land use and the methane (CH_4) produced by livestock (IPCC, 2007). From a final consumption perspective, housing, leisure, electrical appliances, transport, food and agriculture drive 80% of the life-cycle climate impacts (Tukker and Jansen, 2006; Hertwich, 2005). Significant transitions in all of these sectors and areas of consumption are essential if any policy aimed at limiting global warming to 2°C is to be effective.

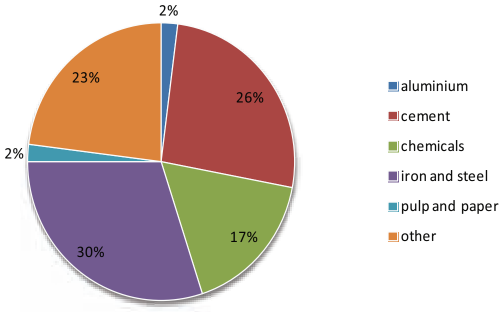
Unfortunately, a shift to alternative energy systems that could reduce security of supply problems and climate impacts is likely to involve trade-offs with other resource constraints. Even a modest switch to biofuels, for example, would create enormous pressures on land in many parts of the world (UNEP, 2009; Erb et al. 2009; Westhoek et al., 2011). A massive switch to renewable energy sources such as wind and solar power would need unprecedented amounts of critical raw materials such as Neodymium and Lithium that would soon exceed the known resource base (Kleijn, 2012).

Figure 2.2 Global anthropogenic greenhouse gas emissions by source, 2005



Source: IEA, 2009b. LULUCF = land use, land use change and forestry.

Figure 2.3 Global direct CO_2 emissions (7.2 Gt) by industry, 2006



Source: IEA, 2009a.

2.3. Water and land: ecological footprint

The growing scarcity of water and the availability of land will soon become significant factors that may constrain economic growth in the future. Forestry, agriculture and food production are responsible for some 90% of present (managed) land use. Industrial production or residential and infrastructural land use make up for the remaining 10% (UNEP, 2010). Additional pressure on land use and water use will be caused by the production of biomass for biofuels and biofeedstocks for industry (UNEP, 2009), as discussed above an issue related to energy use and climate change. In the agricultural sector the increasing use of fertilizers will cause further problems. The use of artificial nitrogen-based fertilizers leads to emissions of N_2O, a potent greenhouse gas, and to the eutrophication of lakes, while phosphorus-based fertilizers rely on natural phosphate deposits that are rapidly being depleted.

An interesting way of looking at land use is the 'ecological footprint' (WWF, 2010), an indicator that measures the land currently used for human purposes (for food production, buildings and infrastructure) but adds to it the land that would be needed to generate sustainable energy or to store CO_2 emissions from fossil fuels as biomass. It is then possible to compare the area of productive land available with the area that is needed – not surprisingly leading to the conclusion that there is an overshoot: more than one Earth is already needed to support the existing economic system.[3]

Both agriculture and industry face significant challenges with regard to water. Currently, the process water used by industry accounts for less than 10% of the volume used globally. By far the largest volume is used for agriculture (70%), followed by cooling water in the energy sector (10%) and drinking water (10%) (UNESCO, 2009). With the expected growth of industrial production, the demand for process water could grow to over 20% of global demand by 2030 (Water Resources Group, 2009; OECD, 2008). By that time, the demand for water is expected to exceed the maximum sustainable supply, leading to an absolute water shortfall of 40% at the global level (Water Resources Group, 2009). The extent of the shortfall will vary considerably at the regional and river basin levels (see Figure 2.4), as also will the extent to which industry drives water demand (see Figure 2.5; World Bank, 2008). Note that the above assessment focuses on quantitative estimates of water availability, but maintaining water quality is equally important. Again, there are likely to be enormous regional variations in water quality, but it is beyond the scope of this brief review to discuss them in detail. Finally, the use of water for cooling in power stations is of little concern as problems are related to the water temperature and not its quality.

Millions of people in large parts of the developing world still have limited or no access to potable drinking water, leading to significant health problems (Griffioen, 2012). Problems with regard to the quality of waste water from mining and manufacturing industries are highly dependent on the water management practices they employ.

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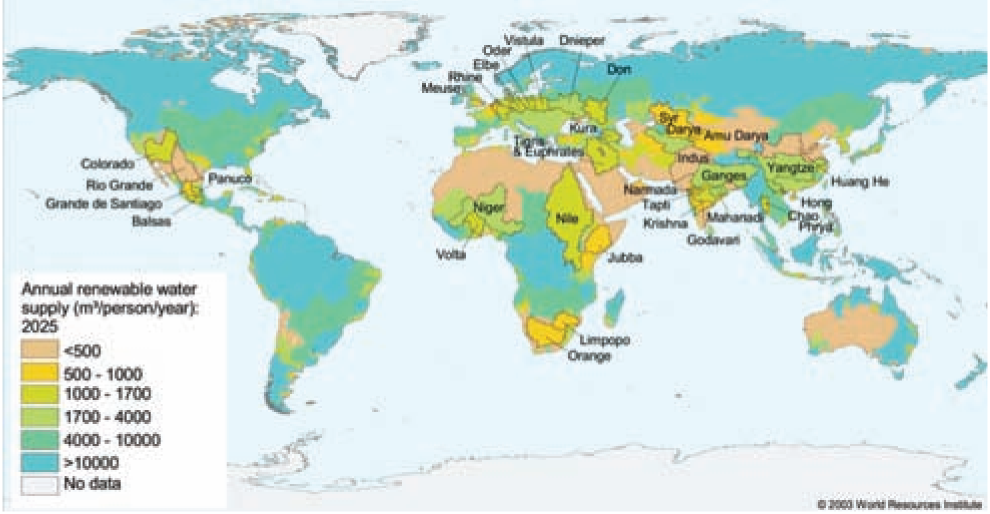
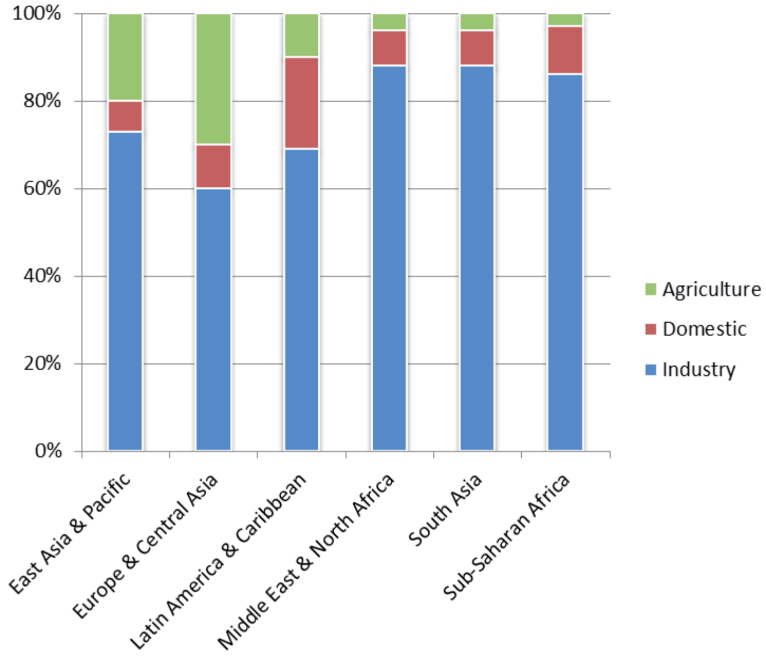
[3] Although the 'ecological footprint' may be a persuasive concept that is easy to communicate, it has been criticized, in particular for expressing energy use in terms of land area.

Figure 2.4 Availability of renewable water supplies in 2025, in m³ per capita



Source: World Resources Institute, IUCN, IWMI, Ramsar (2003).

Figure 2.5 Water consumption by end use and region, 2008 (World Bank, 2008, table 3.5). Note that 'Industry' includes the electricity sector, whose use of water for cooling and other purposes accounts for more than half the consumption shown here



Source: UNESCO, 2009.

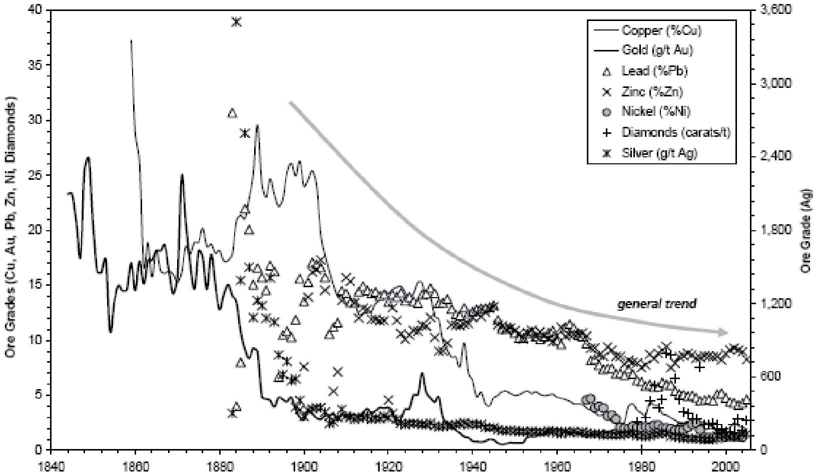
The growing scarcity of water has a number of obvious implications. Agriculture, the most important sector, will certainly need to change. Agricultural production must double by 2050 to meet the growing demands of populations that are becoming wealthier and so can afford diets rich in animal protein. Industries operating in regions where water systems are already under stress, and where industrial water demand is significant compared with other areas of demand, must dramatically improve their water use efficiency. This is particularly urgent for industries that use large volumes of water, such as pulp and paper, textiles and steel production, but less so for industries in regions where levels of water stress are lower, or where demand is dominated by sectors such as agriculture.

In addition to efficiency improvements to reduce the use of water, technical solutions such as desalination are available, but they are expensive and involve important trade-offs in terms of energy use and related greenhouse gas emissions (Water Resources Group, 2009; Graedel and van der Voet, 2010). Climate change, in turn, may have implications for the security of water supplies. Glaciers are expected to recede and become smaller. They will serve less as buffers for precipitation, which may imply certain river basins will be supplied less with water, or are supplied with the same amount in more concentrated time periods (IPCC, 2007).

2.4. Abiotic resources: metal ores and industrial minerals

Resource intensive industrial sectors face at least four challenges. First, emerging economies such as China are developing rapidly and their demand for resources is rising. Each year, China produces and consumes close to half of the global cement and over one third of steel. Competition for access to resources is likely to grow.

Figure 2.6 Grades of metal ores extracted from Australian mines, 1840-2005



Source: Mudd, 2009.

Second, as high-grade metal ores are gradually depleted (Figure 2.6), lower-grade deposits must be used that need much more energy to extract the useful metal component, in turn leading to higher costs and prices, and adding to climate change. Third, at the local level, resource extraction can have significant detrimental impacts on ecosystems, landscapes, watercourses, etc.

Fourth, there may be issues of security of supply. For some materials, the richest sources may be located in politically unstable areas, have been (partially) depleted, or are currently needed in such limited quantities that one or a few sources can supply them, potentially leading to monopolistic situations. China, for instance, is currently the main supplier of rare earth elements, but it needs most of its production for domestic use. The Chinese government has therefore restricted exports of these elements. This results in significant supply problems for non-Chinese users, although – according to the US Geological Survey – global reserves of rare earth elements are 800 times or more than current production (Graedel, 2011).

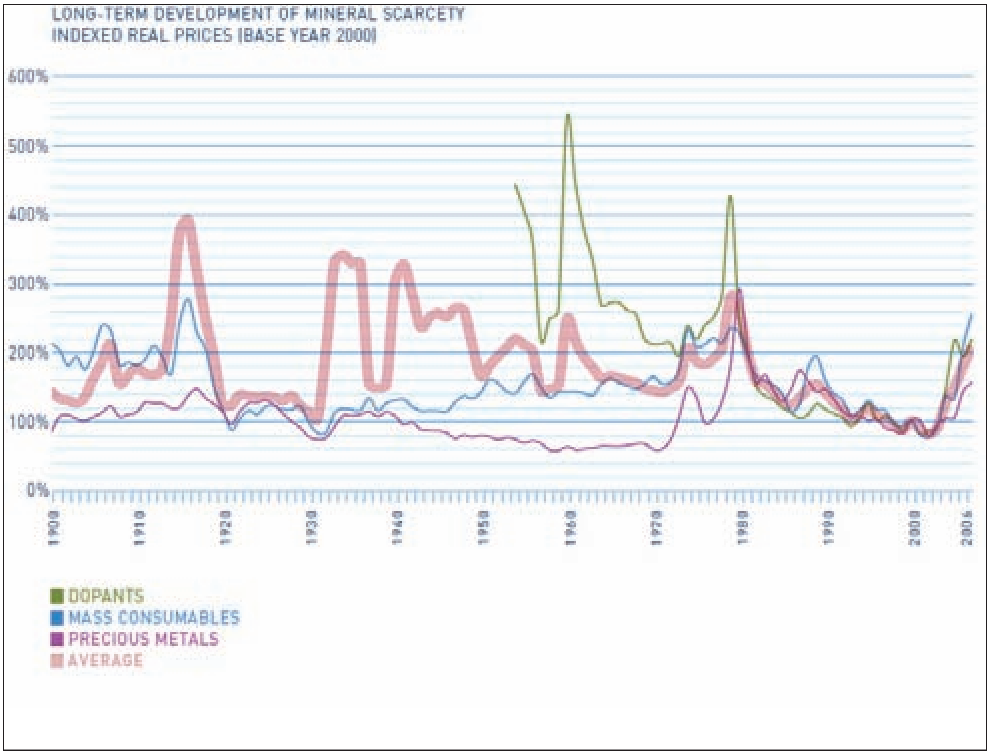
Not all industrial sectors will be equally affected by scarcity or security of supply issues, and not all materials are equally important in terms of their environmental impacts. Some fundamental challenges for the steel, aluminium and particularly electrical and electronics industries may be expected, however. The steel and aluminium industries are already responsible for some 5% of global energy consumption and the related carbon emissions. As high-grade ores become scarcer, they will have to be replaced by low-grade ores that are more difficult to extract and require more energy to refine. For some critical materials such as lithium and rare earths, used in the electrical and electronics industries, there are already problems with security of supply. If there were to be a significant transition to alternative (e.g. solar-based) energy systems and electric cars, the production of such critical materials would have to rise, leading to unprecedented levels of demand that would exceed the currently proven resource base (Kleijn, 2012).

Having said this, the prices of most materials still seem to be within their historical ranges (see Figure 2.7), so that suggestions of absolute scarcity are questionable or maybe relevant only to a particular set of critical materials (UNEP, 2010; EU, 2010). The jury is still out on whether this time the situation is different and that ‘limits to growth’ resource pessimists are indeed right, or whether, as reflected in the saying ‘the Stone Age didn’t end because we ran out of stones’, humanity will once again be able to innovate itself out of these impending scarcity problems (Kleijn, 2012).

2.5. Abiotic resources: construction minerals

As shown in Figure 2.1, in terms of volume, construction minerals are much more important than industrial and metallic minerals – in fact, the former dominate global material use. At the same time, there is ample evidence that they may be the least problematic resources used by society, although there are some notable exceptions. Construction

Figure 2.7 Long-term trends in mineral prices, 1900-2006, base year 2000

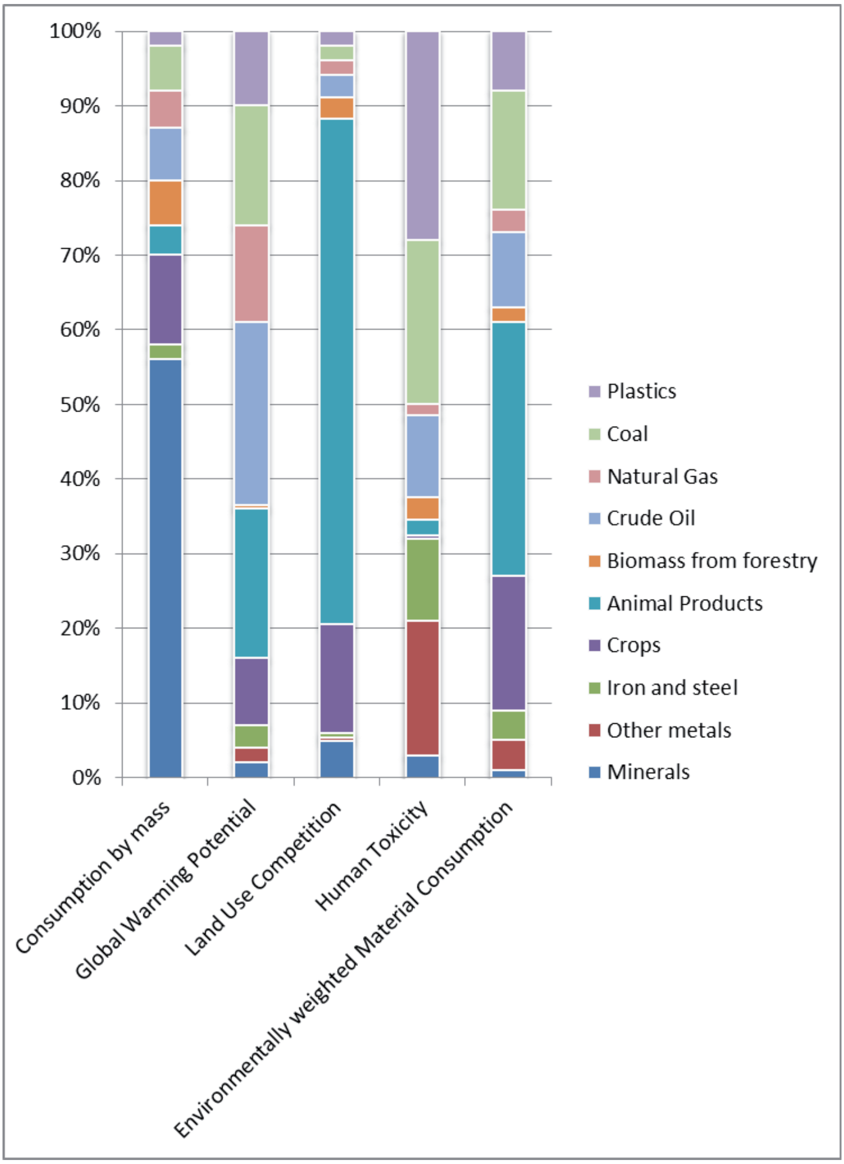


Source: Kooroshy et al., 2010.

minerals such as sand, gravel, stone, limestone and clay are not scarce; indeed, they can be found almost anywhere, and Europe is virtually self-sufficient (EU, 2010). It is only in small, densely populated countries such as the Netherlands that competition and trade-offs (e.g. between sand and gravel extraction and other forms of land use) may impose limits on extraction.

Also, in terms of their environmental impacts, construction minerals are not a priority problem. This can be seen in Figure 2.8, which combines information about the uses of these materials in Europe with their life-cycle environmental impacts per kilogram (UNEP, 2010). Whereas construction minerals dominate consumption by mass, they are of marginal importance in relation to global warming, toxicity to humans, land use, or integrated 'environmentally weighted material consumption'. The latter indicator combines volume of material use with the cradle-to-gate life-cycle impacts of that material (van der Voet, 2005). The main exceptions are construction minerals produced in high-temperature processes, most notably cement, steel and to a lesser extent glass and ceramics. As shown in section 2.2, such energy-intensive construction minerals contribute significantly to global warming impacts, and this is the main reason for limiting their use or changing production practices in the future.

Figure 2.8 Relative contributions of various materials to environmental problems, EU-27 + Turkey, 2000



Source: UNEP, 2010.

2.6. Biotic resources: HANPP and biodiversity problems

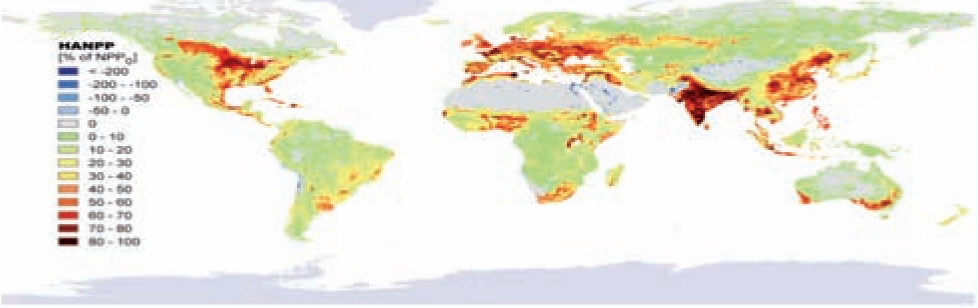
With regard to the use of biotic materials, the potential constraints can be derived from studies such the Millennium Ecosystem Assessment (MEA, 2005) and indicators such as the Human Appropriation of Net Primary Production (HANPP).

Produced by more than 1300 scientists from all parts of the world, the Millennium Ecosystem Assessment (MEA) is widely regarded as the most authoritative analysis of the status of global ecosystems. The MEA found that humans have changed ecosystems more rapidly and extensively over the past 50 years than at any other time in human history, largely to meet the growing demand for food, fresh water, timber, fibre and fuel. This has resulted in a substantial and largely irreversible loss of diversity of life on Earth. According to the MEA, the most significant causes of ecosystem degradation include:

- habitat changes (related to e.g. the conversion of natural areas to agricultural land, changes in water supply);
- pollution (particularly nitrogen and phosphorus);
- overexploitation of biotic resources such as fisheries and forests; and
- the spread of invasive species.

An alternative way to identify the potential limits on the use of biotic materials is the HANPP, an indicator that measures the percentage of the net primary production of biomass (or energy or carbon embodied in it) that is used by humans, by land conversion and biomass harvesting (e.g. Vitousek et al., 1986; Haberl et al., 2007). These authors estimate that humanity now appropriates around 30-40% of the net primary production of biomass (see Figure 2.9 for the regional distribution). A HANPP of 100% is obviously destructive since this would mean that all resources would be appropriated for human purposes, leaving none for other species (Haberl et al., 2004).

Figure 2.9 The global Human Appropriation of Net Primary Production (HANPP) in 2000 (from Haberl et al., 2007)



Both the MEA and the HANPP signal that there are important constraints that will limit the use of more biotic materials. It will be difficult to convert even more land for the production of biotic materials, since habitat change is a major factor leading to ecosystem degradation. Even the more intensive use of biotic materials will also soon reach its limits – the overexploitation of many fisheries and forests is already a reality. The HANPP points out that the current level of exploitation (30-40%) is dangerously close to the theoretical maximum (100%). Enhancing (agricultural) productivity is the only way out, but this will involve trade-offs with regard to the use of more water and energy-intensive products such as fertilizers (Graedel and van der Voet, 2010).

2.7. Linkages and trade-offs

As shown above, the growing scarcity of different resources will have different impacts and give rise to different problems. Or, as noted in the recent report of the working group on decoupling to the UNEP Resource Panel: 'The degree to which resource use causes detrimental environmental impacts depends not only on the amount of resources used, but also on the types of resources used and on the ways in which they are used' (UNEP, 2011).

Industry seems reluctant to accept 'one-size-fits-all' indicators and policy packages that do not acknowledge the crucial differences between resources (e.g. Euromines, undated). Based on the previous sections, Table 2.1 summarizes what constraints may arise, and Table 2.2 shows which sectors and areas of final consumption may be most affected (compare also Fischer-Kowalski et al., 2010). It should be noted that to a significant extent, consumption in Western countries drives resource extraction and impacts abroad. In other words, Western countries depend on resources from other countries for their wealth. This dependence has been demonstrated for energy use and climate impacts (Hertwich and Peters, 2009), for biodiversity impacts (Lenzen, 2012) and water use (Hoekstra and Chapagain, 2007). Studies by the EU's EXIOPOL[4] project have shown how enormous this dependence is (Tukker et al., 2013). European consumption depends for over 50% of the land use, 40% of the water use and 30% of the raw material use on other countries (see Table 2.3).

In formulating solutions to address these challenges, the potential trade-offs should not be underestimated. All resource constraints are interlinked, so that an approach that aims to resolve problems with regard to one resource may cause even worse problems for other resources. Some of the most prominent trade-offs may be between (Graedel and van der Voet, 2010):

- Energy/greenhouse gas emissions and land use: a significant switch to biomass-based energy may lead to a prohibitive level of demand for agricultural land, and increase water scarcity.
- Land use/biotic material use and water use plus energy/greenhouse gas emissions: the area of land required for the production of food, biofuel and biofeedstocks could

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[4] EXIOPOL – A New Environmental Accounting Framework Using Externality Data and Input-Output Tools for Policy Analysis – is an integrated project funded by the EU. www.feem-project.net/exiopol/

Table 2.1 Potential resource constraints

Type of resource	*Fraction of global mass of resources extracted*	*Basis for planetary limits*	*Potential limits*	*References*
Fossil fuels	20%	Absolute scarcity CO_2 emissions targets	EU targets 20% greenhouse gas emissions reduction by 2020 Scientific targets: >80% reduction by 2050	EC (2008, 2010); Meinshausen et al. (2009); IPCC (2007)
Biomass	30%	Maximum Human Appropriation of Net Primary Production (HANPP)	Currently, 30-35% of available biomass is extracted by humans. Target may be stabilization or minor growth	Vitousek et al. (1986); Haberl et al. (2007)
Metal ores and industrial minerals	10%	Absolute scarcity (different for each metal). The high levels of energy needed for refining most metal ores implies a 'linkage' to CO_2 emissions targets and energy constraints	Focus on 14 critical raw materials identified by the EU's Raw Materials Initiative. Changes in energy and transport infrastructures (solar cells, batteries) will determine future criticality	EU (2010) For linkages with energy use, see Graedel and van der Voet (2010)
Construction minerals	40%	Absolute scarcity not relevant, except in densely populated areas where space for sand, clay and gravel winning is limited	Implicit targets for construction minerals whose production requires high levels of energy (e.g. cement, ceramics)	
Land	Not expressed as mass	Available productive land, with areas reserved for nature (e.g. rainforests)	Conflicting information about remaining areas that can be converted to agricultural use	Erb et al. (2009); WWF (2010); OECD/FAO (2009)
Water	Usually not included in MFA	Renewable supply (varies by region); agriculture is dominant user	A global 'water gap' of 30% expected in 2030	Water Resources Group (2009); Hoekstra and Chapagain (2007)

Table 2.2 Priority industries and final consumption categories by type of resource (based on TNO analysis from EXIOBASE* and UNEP, 2010)

Type of resource	*Fraction of global mass of resources extracted*	*Most relevant intermediate industries (by NACE code**)*	*Most relevant categories of final consumption*
Fossil fuels	20%	Electrical energy, gas, steam and hot water Various industrial processes (steel, cement, chemicals) Land transport	Heating and cooling, personal transport, energy using products
Biomass	30%	Agriculture, forestry and fisheries, food products and beverages Construction work	Food, hotel and restaurant services, real estate
Metal ores and industrial minerals	10%	Basic iron and steel and ferro-alloys and first products thereof Aluminium and aluminium products Other non-ferrous metal products	Real estate, gross fixed capital formation (infrastructure). Energy using products
Construction minerals	40%	Ceramic goods Bricks, tiles and construction products, in baked clay Cement, lime and plaster Construction work	Real estate, gross fixed capital formation (infrastructure)
Land, water	p.m.	Agriculture	Food consumption

* EXIOBASE is the EU's Multi-regional Environmentally Extended Supply and Use/Input-Output database.

** The NACE code system is the European standard for industry classifications.

Table 2.3 Environmental impacts related to the final demand, and to imports and exports per capita in the EU, 2000.* For instance, the final demand of each European citizen required the extraction and use of 17 tonnes of primary materials, of which 6.5 tonnes were provided by non-EU countries. This figure is much higher than the 2.6 tonnes of primary materials embedded in European exports

Impact type	Unit	Final demand per capita	Imports per capita	Exports per capita
Land footprint	ha	1.7	1.0	0.1
Water consumption blue (ground- or surface water)	m^3	767	335	75
Water consumption green (rainwater)	m^3	4446	2301	367
Primary materials extracted/ used	Tonnes	17.0	6.5	2.6
Global warming potential	Tonnes of CO_2 equivalent	12.4	2.3	1.6

* Assuming an EU-27 population of 483 million in 2000 (Eurostat, 2009).

be reduced (significantly) by raising productivity. However, this usually involves a significant rise in the use of water for irrigation, artificial fertilizers produced in energy-intensive processes or practices such as production in greenhouses.

- Land use/biotic material use and non-renewable material use: biotic materials could in principle replace non-renewable materials, but again would involve the above-mentioned trade-offs between water use and energy use/greenhouse gas emissions.
- Energy/greenhouse gas emissions and water use: increasing water supplies by introducing desalination on a large scale would require prohibitive amounts of energy.
- Energy/greenhouse gas emissions and industrial mineral resource use: the resource base may be extended, often by using lower-grade ore, which in turn will require significantly more energy for mining and refining. Conversely, a switch to carbon-neutral energy and transport systems may require unprecedented amounts of critical materials such as platinum, neodymium and dysprosium that would exceed the known resource base.

These ‘linkages of sustainability’ indicate that preventive approaches are probably preferable, but that systemic prospective analyses of the impacts of proposed solutions and strategies are essential.

2.8. Conclusions

This chapter has sketched the potential resource constraints on the one hand, and the significant demand for resources due to drivers such as population growth and increasing wealth on the other. The resulting picture is worrying.

We are not the first to provide such a picture. Almost four decades ago, Meadows et al. (1972) did so in *The Limits to Growth,* and many others have done so since then. But until now true resource limits have not materialized and the global economy was doing remarkably well until the financial crisis of 2007. So the question is, to paraphrase the concluding chapter of René Kleijn's (2012) thesis on critical materials, why should it be different this time? Will the 'resource optimists' who point out that humankind has always managed to engineer itself out of problems be proved wrong?

On the emissions side, we would argue that the battle against climate change is close to being lost. Meinshausen et al. (2009) calculated that in order to limit global warming to 2°C, a maximum of 1000 Gt of CO_2 could be emitted between 2000 and 2050. But even by 2006 emissions had already reached 246 Gt, leaving only 750 Gt to emit. Davis et al. (2010) showed that if we use all existing energy and transport infrastructures to the end of their economic lives, they would account for as much as 500 Gt of this emissions budget. So even if we were to invest 100% in carbon-neutral energy systems from now on, we would still reach (almost) the maximum threshold. But the worst impacts of climate change will only become apparent over decades, and it is unclear whether policy makers will support strong measures to mitigate them in the near future.

With regard to resources, we would argue that even resource optimists must agree that significant efforts will be needed to engineer humankind out of these problems. Water and land constraints, in combination with the need to increase agricultural production, pose formidable challenges. The same applies to some metal ores and industrial minerals, for which demand is likely to rise steeply even under a business-as-usual scenario, while the quality of these resources is falling, and the energy and other costs of mining and refining them are likely to rise. It seems obvious that companies that become more efficient in their use of increasingly scarce resources, or are able to develop alternatives using more abundant raw materials, will have the competitive edge in the future.