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Arno Behrens

The Climate Change Impact of Material Use

With the adoption of the Paris Agreement in December 2015,[1] global and EU climate change policy is entering a new phase. The ambitious target to limit global warming to well below 2°C and possibly even to just 1.5°C above pre-industrial levels mandates substantial reductions in global greenhouse gas (GHG) emissions and gives a new impetus to the EU's long-term objective to reduce GHG emissions by 80-95% from 1990 levels by 2050.

Several strategies exist to reduce GHG emissions. So far, EU decarbonisation strategies have focused mainly on improving energy efficiency and on promoting electricity from renewable energy sources.[2] These policies have proven successful in reducing EU GHG emissions, albeit partially due to the financial and economic crises that started in 2007. In fact, by 2013 the EU had already reduced GHG emissions by 19.8% when compared with 1990,[3] just short of its 20% target set for the year 2020.

However, with energy efficiency and renewable energy policy measures likely to reach limits (e.g. electricity from renewable energy sources is likely to face barriers related to intermittency), the decarbonisation strategy needs to be broadened to promoting higher resource productivity, with the aim of reducing the overall consumption of material inputs. This will allow the addressing of the real challenge of climate change – the increasing physical scale of the global economy.

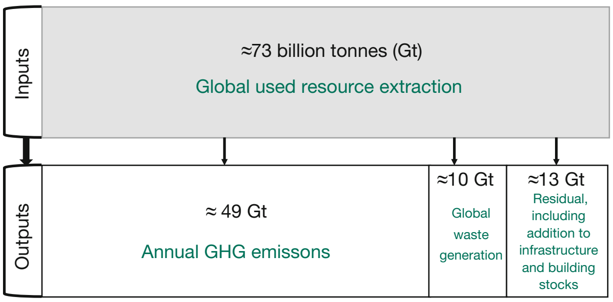
The relationship between global resource use and climate change becomes evident when looking at the numbers (see Figure 1). Global used resource extraction in 2010 was about 73 gigatonnes (Gt),[4] GHG emissions amounted to 49 Gt,[5] and global (industrial and municipal) waste generation was estimated at roughly 10 Gt.[6] This means that more than two-thirds (67%) of annual raw material inputs return to the atmosphere in the form of GHG emissions. The rest represents solid waste and additions to stocks, e.g. in the form of buildings and infrastructure. These figures underline the importance of emissions in the physical output of the global economy: GHG emissions accounted for around 83% of material outflows by weight in 2010 (not taking into account additions to stocks), making the atmosphere by far the largest dumping site for the disposal of global waste.

There is a direct physical relationship between the quantity of raw materials used in industrial processes, the energy required and, hence, GHG emissions. The latter are emitted in all stages of the product lifecycle: extraction, production, consumption and waste management. The production of raw materials, for example, accounts for roughly 19% of global GHG emissions, and the waste sector for another three per cent.[7] Reducing global GHG emissions by at least 60% from 2010 levels by 2050 in order to limit global warming to "well below 2°C above pre-industrial levels" (as stipulated in Art. 2 of the Paris Agreement) will thus require more than a shift to low-carbon energy sources and energy efficiency. Improved resource efficiency, greater recycling and re-use, as well as an absolute reduction of raw material use must become key elements of climate policy in the context of a circular economy. The potential effects on climate change mitigation are substantial. For example, the transition to a circular economy in three of Europe's largest and most resource-intensive value chains (mobility,

1 United Nations Framework Convention on Climate Change: Adoption of the Paris Agreement, FCCC/CP/2015/L.9, 12 December 2015.
2 Key EU policies in this area include the EU Emissions Trading System (ETS), the Effort Sharing Decision on member states' emissions reduction targets in sectors outside of the ETS, the Renewable Energy and Energy Efficiency Directives, regulation on reducing emissions from new cars and vans, and support for carbon capture and storage.
3 Eurostat: Greenhouse gas emission statistics, June 2016.
4 Including only four categories of used materials: metal ores, industrial and construction minerals, fossil fuels and biomass (from agriculture, forestry and fishery). See WU Global Material Flows Database, Vienna University of Economics and Business and the Sustainable Europe Research Institute, 2016, available at www.materialflows.net.
5 O. Edenhofer et al. (eds.): Climate Change 2014: Mitigation of Climate Change. Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, pp. 6-7.
6 P. Bhada-Tatam, D. Hoornweg: What a Waste: A Global Review of Solid Waste Management, Urban development series knowledge papers No. 15, World Bank 2012; and Frost & Sullivan: The Global Industrial Waste Recycling Markets, TEKES Growth Workshop, Helsinki, 2 October 2012.
7 J. Iles: Circular Economy – The Forgotten Low-Carbon Vector, 2 December 2015, available at circulatenews.org.

Arno Behrens, Centre for European Policy Studies, Brussels, Belgium.

Figure 1
Estimates of global material inputs and outputs, 2010



Source: Adapted from A. Behrens: Time to Connect the Dots: What is the Link between Climate Change Policy and the Circular Economy?, CEPS Policy Brief No. 337, 22 January 2016.

food and the built environment)[8] could decrease EU CO_2 emissions from 2012 levels by 48% by 2030 and 83% by 2050.[9]

The contribution of different material categories to climate change

The global amount of natural resources used to create value in economic processes reached over 84 Gt in 2013,[10] equivalent to some 160 tonnes every minute. Addressing the climate change impacts of material use requires an assessment based on different material categories. Behrens et al. established four aggregated material categories, including fossil fuels (coal, oil, gas, peat), biomass (agriculture, forestry and fishery), industrial and construction minerals, and metal ores.[11] Each of these categories contributes directly and/or indirectly to energy use and global GHG emissions. The following sections analyse these contributions.

Fossil fuels

The combustion of coal, oil, gas and peat is the single largest source of GHG emissions. In 2013 fossil fuels accounted for about 15 Gt (or 17%) of global used resource extraction.[12] Despite increasing decarbonisation efforts, fossil fuels still contributed over 81% to the global primary energy mix in 2013[13] and were responsible for over 65% of global GHG emissions in 2010.[14] There is thus an obvious direct link between the consumption of fossil fuels and climate change.

In this context, it is also useful to look at the energy return on investment (EROI) of fossil fuels. EROI puts the energy gained by society from a particular source in relation to the energy invested in providing this energy (e.g. for exploration and drilling).[15] Although the scientific basis on the past and future developments of EROI is still rather weak, there seems to be evidence of a trend of declining average EROIs from oil and gas over the past decade or two. In particular oil, the world's dominant energy source, could already face a steep decline in EROI.[16] This means that more energy needs to be invested to maintain the same output of useful energy (e.g. one barrel of oil) from these resources, leading to increasing energy consumption and thus higher levels of GHG emissions, *ceteris paribus*.

Biomass

Agriculture, forestry and fishery together accounted for some 23 Gt (or 27%) of global used resource extraction in 2013[17] and for 24% of global GHG emissions in 2010.[18] Biomass is often considered carbon-neutral, based on the assumption that its use releases more or less the same amount of CO_2 as was absorbed during the growth phase. However, agricultural activities contribute to GHG emissions mainly through land-use changes and through the use of fossil fuels.

On the one hand, agricultural activities affect terrestrial sinks through land use, land-use change and forestry (LULUCF) activities, with significant impacts on the carbon cycle.[19] For example, the Global Forest Resources Assessment 2015 reports that the world's forests in 2015 stored an estimated 296 Gt of carbon in above- and be-

8 Including electric, shared and autonomous vehicles; food waste reduction; regenerative and healthy food chains; passive houses; urban planning; and renewable energy.
9 Ellen MacArthur Foundation, Stiftungsfonds für Umweltökonomie und Nachhaltigkeit, McKinsey Center for Business and Environment: Growth Within: A Circular Economy Vision for a Competitive Europe, 2015.
10 WU Global Material Flows Database, op. cit.
11 A. Behrens, S. Giljum, J. Kovanda, S. Niza: The Material Basis of the Global Economy – World-wide Patterns in Natural Resource Extraction and their Implications for Sustainable Resource Use Policies, in: Ecological Economics, Vol. 64, No. 2, 2007, pp. 444-453.
12 WU Global Material Flows Database, op. cit.
13 International Energy Agency: World Energy Outlook 2015, Paris 2015.
14 O. Edenhofer et al., op. cit.
15 C.A.S. Hall, J.G. Lambert, S.B. Balogh: EROI of different fuels and the implications for society, in: Energy Policy, Vol. 64, 2014, pp. 141-152.
16 Ibid.
17 WU Global Material Flows Database, op. cit.
18 O. Edenhofer et al., op. cit. This figure refers to Agriculture, Forestry and Other Land Use (AFOLU).
19 United Nations Framework Convention on Climate Change: Land Use, Land-Use Change and Forestry (LULUCF), 2016, available at unfccc.int/land_use_and_climate_change/lulucf/items/1084.php.

low-ground biomass.[20] Since 1990 these carbon stocks have decreased by over 11 Gt, mainly due to the conversion of forests to agricultural and residential land, as well as due to the degradation of forest land.

On the other hand, fossil fuels play a large role in agricultural production. They are directly used in agricultural processes in the form of fuel and electricity, e.g. for heating, lighting, transport, etc. They are also indirectly used for the manufacturing of production means, such as fertilisers and pesticides, as well as for farm machinery and buildings.[21] In fact, indirect energy use can contribute over 50% to the total energy use in agricultural production.[22]

The intensification and industrialisation of agriculture has led to an increase in the ratio between energy input and energy output of agricultural products, thus reducing the energy efficiency of production.[23] Reasons include an increase in industrially produced inputs (e.g. industrial fertilisers) and a reduction in the share of subsistence farming. Furthermore, transport intensity has significantly increased due to the geographical separation between cultivation of land and stock farming, as well as between production and consumption.[24] An example for this development is the change of the energy input-to-output ratio over time for the cultivation of maize.[25] While in the year 1700 this ratio was 1:10.5 (i.e. 1 Joule of input was required to produce 10.5 Joules of output), it had almost doubled to 1:5.8 by 1910 and doubled again to 1:2.9 by 1985. In reverse, declining energy efficiency also means that more energy is required to produce the same level of energy output.

Two key conclusions can be drawn from these observations. First, the intensification and industrialisation of agriculture leads to increasing emission levels. Second, and related to the first conclusion, the substitution of fossil fuels with biomass can only make a limited contribution to the overall reduction of GHG emissions. However, this might change with the potential development of second (and third) generation biofuels, which might have a substantially improved energy input-to-output ratio.

Industrial and construction minerals

With almost 39 Gt, industrial and construction minerals constituted the largest share (46%) of global used resource extraction in 2013.[26] Construction minerals can be indirectly linked to GHG emissions mainly through housing, energy and transport infrastructure. In 2009 the cement sector alone was responsible for about five per cent of global anthropogenic CO_2 emissions.[27] In the EU, the building sector is the largest energy end-use sector, responsible for almost 41% of final energy consumption in 2013 and with similar contributions to CO_2 emissions.[28] Managing and improving the energy performance of buildings is thus key to reducing GHG emissions.

EU useful floor space is increasing at a rate of approximately one per cent per year.[29] This expansion of the stock leads to an increase in energy and material flows. Energy is of course required for using the buildings (i.e. heating/cooling, lighting, etc.), and material requirements grow along with construction activities, but also due to the future material flows required to keep the increasing building stock intact, as a larger building stock requires larger physical (and economic) flows for reconstruction and renovation. At the same time, the positive benefits of renovating buildings should also be noted, which include substantial increases in energy efficiency. Indeed, the application of energy efficiency measures to buildings through retrofitting could save up to 75% of energy consumption.[30] However, with a realistic average refurbishment rate of around one per cent per year, most of which

20 Food and Agriculture Organization of the United Nations: Global Forest Resources Assessment 2015, Rome 2015.

21 J. Gołaszewski et al.: State of the Art of Energy Efficiency in Agriculture, Agriculture and Energy Efficiency, 2012.

22 J. Woods, A. Williams, J.K. Hughes, M. Black, R. Murphy: Energy and the food system, in: Philosophical Transactions of the Royal Society B: Biological Sciences, Vol. 365, No. 1554, 2010, pp. 2991-3006; N. Pelletier et al.: Energy intensity of agriculture and food systems, in: Annual Review of Environment and Resources, Vol. 36, 2011, pp. 233-246.

23 F. Krausmann, H. Haberl: Land-use change and socioeconomic metabolism: a macro view of Austria 1830-2000, in: M. Fischer-Kowalksi, H. Haberl (eds.): Socioecological Transitions and Global Change – Trajectories of Social Metabolism and Land Use, Cheltenham, Northampton 2007, Edward Elgar Publishing.

24 F. Krausmann, H. Haberl, N. Schulz, K.H. Erb, E. Darge, V. Gaube: Land-Use Change and Socioeconomic Metabolism in Austria, Part I: Driving Forces of Land-Use Change 1950-1995, in: Land Use Policy, Vol. 20, No. 1, 2003, pp. 1-20.

25 D. Pimentel, W. Dazhong, M. Giampietro: Technological Changes in Energy Use in the U.S. Agricultural Production, in: S.R. Gliessmann (ed.): Agroecology, Researching the Ecological Basis for Sustainable Agriculture, New York 1990, Springer, pp. 305-321.

26 WU Global Material Flows Database, op. cit.

27 World Business Council for Sustainable Development and International Energy Agency: Cement Technology Roadmap 2009, Carbon emissions reductions up to 2050, 2009.

28 European Commission: EU Energy in Figures, Statistical Pocketbook 2015, 2015.

29 M. Economidou et al.: Europe's Buildings under the Microscope – A country-by-country review of the energy performance of buildings, Buildings Performance Institute Europe, 2011.

30 Spatial Planning and Energy for Communities In All Landscapes: Energy efficient Buildings and Retrofitting, 2016, available online at http://www.special-eu.org/knowledge-pool/module-4-implementation-of-sustainable-planning/energy-efficiency-retrofitting/.

does not go towards addressing energy efficiency,[31] these benefits still seem to be rather small.

Finally, it is worthwhile mentioning the interlinkages between buildings and infrastructure, and in particular transport infrastructure. The phenomenon of urban sprawl is a good example of increased transport requirements associated with new buildings.

Metal ores

Almost 9 Gt of metal ores were extracted and used for creating value in economic processes in 2013. This represents some ten per cent of global used resource extraction.[32] Similar to other material categories, the impacts of metal usage on climate change can be both negative and positive.

Metals have the highest supply chain carbon intensity of all the commodities used in an economy.[33] Mining, processing (removing non-metallic waste rock), extracting the metal and refining are estimated to account for seven to eight per cent of the world's total energy consumption.[34] Future energy requirements and related GHG emissions from the production of primary metals are likely to increase due to the increasing need to access lower-grade ores (e.g. for gold, copper and nickel), smaller metal seams with higher over-burden layers, ores with higher chemical energy, and remote deposits.

However, there are two ways to reduce energy requirements: improvement of technology and the production of metal from scrap material, or secondary production. Technology improvements mainly include advancements in energy efficiency, process efficiency and in the supply chain processes themselves. It is difficult to predict the extent to which these improvements will reduce energy consumption in the future. As regards recycling, energy consumption reduction potentials range from 55-98%, depending on the metal. Steel recycling, for example, can reduce energy consumption by 60-75% compared to primary production, while aluminium recycling can save 90-97%.[35] Although recycling can greatly improve the energy balance of metals, recycling rates remain much too low. In Europe, for example, only slightly more than half of the aluminium produced originates from recycled aluminium.[36] A particular challenge will also be to increase the recycling rates of metals used in small quantities in complex products (e.g. in mobile phones).[37]

Apart from their contribution to climate change, many metals are also crucial for the fight against it by providing the necessary inputs for several low-carbon energy technologies. For example, wind turbines, photovoltaic panels, battery packs for hybrid cars, fuel cells and energy efficient lighting systems all require special metals (rare earth metals) for their manufacture. Securing the availability of these metals as well as their sustainable production is thus important for achieving a higher share of low-carbon energy sources in the future.

Conclusions

An analysis of the interlinkages between natural resource use and climate change is important to recognise the potential co-benefits of reduced resource consumption and decarbonisation policies. This paper identified a clear link between the material inputs of an economy and its outputs, showing that GHG emissions account for over 80% by weight of global material output (not taking into account additions to stocks). A credible decarbonisation strategy in line with the targets outlined in the Paris Agreement will thus need to go beyond current energy efficiency and renewable energy policies by adopting a more compehensive approach aimed at decoupling material use and related environmental impacts from economic growth. The key to reaching ambitious climate change targets will be to shift the focus to promoting higher resource productivity, to increasing recycling and reuse rates, and more generally to reducing the overall consumption of material inputs. This will lead to immediate reductions in GHG emissions. The environmental benefits of a circular economy also need to be viewed in conjunction with the economic and security benefits of such an economy, which can substantially contribute to increasing the sustainability of European economies.

31 N. Shaw, R. Loossens: RESIDE – Boosting innovation in the European building REfurbishment sector through roadmaps for demand SIDE policy measures, Deliverable 1.1 – A baseline scenario for energy efficiency renovations in Europe's residential buildings, 16 February 2015.

32 WU Global Material Flows Database, op. cit.

33 Aldersgate Group: Beyond Carbon: Towards a Resource Efficient Future, London 2010.

34 United Nations Environment Programme: Environmental Risks and Challenges of Anthropogenic Metals Flows and Cycles, 2013.

35 Ibid.

36 European Aluminium Association: Recycling Aluminium – A Pathway to a Sustainable Economy, 2015.

37 United Nations Environment Programme: Recycling Rates of Metals – A Status Report, 2011.