

INDICATORS OF MATERIAL FLOWS: CONCEPTUAL FRAMEWORK, USE AND ASSESSMENT OF TRENDS IN THE CZECH REPUBLIC

1. Socio-economic metabolism

In order for an economic system to function and produce goods and services necessary for meeting human needs, it behaves similarly to a living organism. It absorbs substances from the surrounding environment and transforms them into products, but ultimately all the materials are transformed into some kind of waste and emitted back into the environment. The economic system above all absorbs fossil fuels, other mineral resources, biomass and water on the input side while emits emissions to the air, water and solid wastes on the output side. This flow of materials, which has mostly had one-way direction so far (only 10-15 percent of wastes is recycled globally) (Brown, 2001), is referred to as an industrial or socio-economic metabolism (Baccini and Brunner, 1991; Fischer-Kowalski and Haberl, 1993; Ayres and Simonis, 1994).

The theory of socio-economic metabolism considers socio-economic system to be a sub-system of the environment connected to its surroundings through energy and material flows. These flows burden the environment and along with land use and other biological and social factors they belong to the key source of environmental problems. If the volume of these flows was reduced, a decrease in environmental pressure could be expected (Schmidt-Bleek, 1993; Weizsäcker et al., 1996; Bringezu et al., 2003).

Environmental pressure is already related to the extraction of mineral resources. The crude oil extraction involves leakages both during extraction phase and oil transportation. The negative impacts on the environment take place during the underground and surface extraction of minerals as well (Neužil, 2001). These impacts include air emissions (mostly of CO, CO₂, SO₂, SO₃, CH₄, NO, NO₂, and PM), disturbance of water regimes and water contamination, land appropriation and contamination, direct disturbance of biotopes, noise, vibrations and changes in landscape. Other pressures are related to pre-processing of minerals – sorting, crushing, rinsing and drying.

Much bigger environmental burden is related to the consumption of mineral resources. It is besides others caused by the fact that while number of mineral resources entering the economic system is limited, the number of pollutants emitted due to the consumption of minerals has been growing (Spangenberg et al., 1999). Moreover, these pollutants enter the environment by huge number of gateways: each dumping place, each smokestack and each exhaust pipe presents such a gateway. Consumption of mineral resources contribute, for instance, to global climate change, depletion of stratospheric ozone, eutrophication, acidification, radioactive pollution, etc. (Giljum et al., 2005).

The environment is able, to some extent, to neutralize the environmental pressure imposed on it by human society in relation with the consumption of materials. If the rate of use of renewable resources is lower than the rate of their renewal, or wastes are emitted in such volumes, which can be absorbed by the environment, any severe damage to the environment should not take place (Bringezu, 2006). This rate is, however, often exceeded (World Resource Institute, 2005) and there is a problem with non-renewable resources. Their sustainable rate of use is difficult to determine, above all with respect to their maintenance for future generations.

So far, there has been a positive relation between meeting human needs and pressure exerted on the environment. When standards of living went up, this pressure was growing as well, even though it was often shifted abroad in the case of developed countries (import of resources or transfer of “dirty” industries to developing countries). The environment of developed countries was thus cleaned up (Schütz et al., 2004). On the global level, however, the human society recorded an unprecedented growth in annual material and energy inputs and outputs over the 20th century (Adriaanse et al., 1997). As argued above, this was also accompanied with the growth of environmental pressure. Developed countries within their strategies of sustainable development therefore adopted a goal to break the relation between pressure exerted on the environment and economic growth, i.e. to meet human needs and improve the standard of living. This phenomenon is shortly called decoupling (from longer “decoupling of environmental pressure from economic growth”) (OECD, 2002).

2. Economy-wide material flow analysis, meaning and use of material flow indicators

Material flow analysis belongs among the methods, which allow for quantification of socio-economic metabolism and assessment of environmental pressures related to the use of materials. Nowadays, the attention is above all drawn to economy-wide material flow analysis (EW-MFA). EW-MFA was developed during the 1990s by various research institutes and organizations (principally the World Resources Institute,

the Wuppertal Institute for Climate, Environment and Energy, the Department of Social Ecology at the Faculty for Interdisciplinary Studies of the University in Klagenfurt, Japanese National Institute for Environmental Studies, and Eurostat), and then standardized in a methodological guide (Eurostat, 2001).

The Czech Statistical Office focused on compilation of indicators of material input and material consumption. These are the best developed ones from the methodological point of view and are based on available data. Methodology for their compilation is described in the methodological chapter. Below is the summary of their possible uses (OECD, 2008):

Overall physical scale of the economy and total environmental pressure related to use of materials

To study overall physical scale of the economy over time, it is advisable to refer to material flow indicators in absolute terms. These indicators are considered proxies for environmental pressure related to use of materials and energy.

Equity and equal resource sharing

Relating material flow indicators to population allows for a comparison of material use and disposal of pollutants from the viewpoint of equity and equal resource sharing. Generally speaking, all people should have equal rights to consume natural resources and use the environment for assimilation of waste flows (Moldan (ed.), 1993).

Land use intensity

Consumption of materials can be related to the area needed for materials production. This issue has above all been developed for renewable resources and is well-known as a concept of Ecological Footprint (Wackernagel et al., 1996) and Human Appropriation of Net Primary Production (Vitousek et al., 1986). For cities, area for production of consumed materials is always larger than the area of a particular city. This is caused by high population density and low share of bioproductive areas. For countries and regions, the situation may be reverse.

Efficiency of use of materials and decoupling of environmental pressure from economic growth

Relating input and consumption material flow indicators to national account aggregates, such as gross domestic product (GDP), allows for measuring the efficiency by which an economic system transforms used materials into economic output. Such indicators reflect material productivity, i.e. the ratio of GDP over the material flow indicator, or material intensity, i.e. the ratio of the material flow indicator over GDP. These two measures are compatible with the inverse time development.

Assessment of material intensity and productivity is complementary to analysis of decoupling of environmental pressure from economic growth (see text above).

Shifting of environmental pressure between states and world regions

Many industrialized countries have decreased their amounts of domestically extracted and processed materials by importing them from other countries. The shift of pressure related to extraction and processing of these materials has taken place between states and world regions mainly to the detriment of developing countries (Schütz et al., 2004). To capture these shifts, it is necessary to study physical imports and exports and related flows.

Foreign material dependency and material security

Material flow indicators can be further used for monitoring of foreign material dependency. Economies fulfil their material demands partly from their own territory and partly by importing materials from other countries. The higher the share of imports in domestic material input and domestic material consumption is, the more the economy is susceptible to incidental shortage of particular commodities abroad, increase in their price or to upheaval of other barriers to foreign trade.

Potential for future waste flows

All input material flows, which are going to be accumulated in form of physical stocks, will change into waste flows sooner or later. Knowing the volume of physical stocks in particular cities, regions and states and their durability, one can model waste flows to come. This is useful for planning of capacities for waste treatment within the waste management plans both in short, medium and long-term perspective.

Use of renewable and non-renewable materials

It is acknowledged internationally that the sustainable supply of materials should be based on renewable materials to a certain extent. This refers not only to scarcity of non-renewable materials but also to the fact that use of non-renewable materials is generally linked to comparatively higher negative impact on the environment (EEA, 2006). This issue can be captured by input and consumption material flow indicators by monitoring ratios of renewable materials in particular indicators.

3. Assessment of development of selected material flow indicators in the Czech Republic in 2003-2008

The used domestic extraction went up by 8.8 percent from 171,8 million tonnes to 188.3 million tonnes in 2003-2008 (Table A-1). It is meaningful to relate used domestic extraction to the area of the Czech Republic – it expresses pressure coming from the extraction of resources exerted on one unit of the country's area. This pressure grew from 2.2 thousand tonnes per km² to 2.4 thousand tonnes per km² in 2002-2007. The pressure covers structural changes of landscape related to extraction of non-renewable resources (moving of overburden, undermining) and pressures on biodiversity and landuse in the case of extraction of renewable resources (above all when producing biomass in large-scale agroecosystems).

Breakdown of used domestic extraction by groups of materials shows that the growth was mostly caused by an increase in construction minerals, which went up from 67.0 million tonnes to 86.3 million tonnes. This growth was related to an increase in construction branch, which gross value added in constant prices went up by 14.6 percent in 2003-2008 (Czech Statistical Office, yearly national accounts, internet application). Fossil fuels recorded a slight decrease from 64.2 million tonnes to 60.4 million tonnes in 2003-2008, industrial minerals a decrease from 12.3 million tonnes to 7.7 million tonnes and metallic minerals an increase from 92 thousand tonnes to 117 thousand tonnes. The volume of the latter material category was, however, very small (it comprised only mining of uranium ores, other ores are not mined in the Czech Republic at all), and it therefore influenced the overall development of used domestic extraction only insignificantly.

Share of renewable resources in used domestic extraction went up from 16.4 percent to 17.9 percent in the observed period. Considering that consumption of renewable resource is usually related to lower environmental impacts, this trend could be reported as positive.

Both physical import and export recorded a significant growth by 30.6 percent and 38.5 percent, respectively, in 2003-2008. The physical import went up from 51.2 million tonnes to 66,8 million tonnes while physical export went up from 44.5 million tonnes to 61,7 million tonnes (Table A-2). The most significant growth took place in 2004 as a result of the Czech Republic accession to the European Union and consequent removal of barriers in foreign trade. Physical import can be viewed as a first indication of environmental pressure, which is shifted from importing countries to exporting ones – production of this import is related to environmental pressure in the exporting country (pressure from extraction of resources and production of commodities) and the driving force of this pressure is the importing country, which demands these commodities. Similarly, the physical export indicates shifts of environmental pressure from abroad to the Czech Republic. The shifts of environmental pressure were growing in the observed period, and this was true both for import and export.

Growth in physical import came mainly from metallic minerals category (raw materials, semi-manufactured and final products from metallic minerals – 31.4 percent of physical import in 2008), which increased from 15.2 million tonnes to 21 million tonnes in 2003-2008. In the case of export the most significant growth was caused by biomass category (raw materials, semi-manufactured and final products from biomass – 33,5 percent of physical export in 2008), which increased from 13.6 million tonnes to 20.7 million tonnes in the observed period. The growth was recorded in the case of other categories of import and export as well - fossil fuels, non metallic minerals, other unspecified products and waste.

The DMI indicator went up by 14.4 percent from 222.9 million tonnes to 255,1 million tonnes in 2003-2008, the DMC indicator grew by 8.4 percent from 178.4 million tonnes to 193.4 million tonnes in the same period. Expressed in per capita terms, DMI increased from 21.9 tonnes per capita to 24,5 tonnes per capita while DMC went up from 17.5 tonnes per capita to 18.6 tonnes per capita (Table A-3). These two indicators can be understood as proxies for total environmental pressure related to use of materials in the Czech Republic (pressure related to extraction of raw materials, their processing and output waste flows). The DMC indicator represents pressure, which is driven by the consumption in the Czech Republic while the DMI also comprises pressure, which is driven by consumption in the countries the Czech Republic exports to. The DMC indicator is often interpreted as a waste potential, because all consumed materials will turn into waste sooner or later. This shows the linkage between input and output indicators of material flows and the fact that the only way how to effectively decrease output material flows is to reduce material consumption. As both the DMI and DMC grew in the observed period, there was a growth both in the total environmental pressure related to material consumption and in the potential for waste flows in the years to come.

All material categories grew in the case of the DMI with the exception of fossil fuels, which was stagnating in 2003-2008. In the case of DMC, categories biomass, metallic and non-metallic minerals went up, and decreasing categories were fossil fuels and other unspecified products, which category was highly fluctuating in the observed period. Waste is a special case of foreign trade because it can be observed only since 2006. Export of waste was much higher than import and the DMC category waste took the minus values. With respect to structure of the DMI, there was a decrease in the shares of fossil fuels and an

increase in the shares of biomass, metallic minerals and non-metallic minerals. In the case of the DMC, there was a decrease in the shares of biomass and fossil fuels and an increase in the shares metallic minerals and non-metallic minerals (Tables A-4 and A-5).

Material intensity expressed as DMI to GDP ratio went down by 11.7 percent from 94.2 kg per 1 000 CZK to 83.1 kg per 1 000 CZK, material intensity expressed as DMC to GDP ratio decreased by 16.4 percent from 75,4 kg per 1 000 CZK to 63,0 kg per 1 000 CZK in 2003-2008. Material productivity, which time development is an inverse of the time development of material intensity, went up by 13.3 percent from 10.6 kg per 1 000 CZK to 12.0 kg per 1 000 CZK in the case of DMI to GDP ratio and by 19.6 percent from 13.3 kg per 1 000 CZK to 15.9 kg per 1 000 CZK in the case of DMC to GDP ratio (Tables A-4 and A-5, Charts 11 and 12). It can be assumed from the decrease of material intensity and the increase of material productivity that the efficiency by which an economic system transformed used materials into economic output was growing and that there was a decrease of environmental pressure per unit of GDP. This was allowed by implementation of modern technologies and an increase in recycling. Moreover, it is also possible to assume a growing competitiveness due to decrease in production costs related to purchasing of raw materials and other materials needed for production.

DMI and DMC indicators can be represented in a single chart together with GDP, when an index value of 100 is attributed to all indicators for the starting year and the percentage change of this index is shown for the following years. This allows for expression of decoupling of environmental pressure (represented by DMI and DMC, respectively) from economic growth (represented by GDP) (Chart A-10). There was a quite significant decoupling in the Czech Republic in 2003-2008, but it was "only" a relative decoupling – GDP grew faster than the indicators of material flows. In the case of absolute decoupling an absolute decrease in DMI and DMC would take place.

The PTB indicator fluctuated in 2003-2008 with a minimum value in 2008 (5.2 million tonnes), maximum value in 2006 (8.8 million tonnes) and an average value of 7.0 million tonnes (Table A-3). In per capita expression, the average value amounted to 0.7 tonnes per capita. The PTB indicator indicates whether or not there are shifts of environmental pressure from the Czech Republic abroad and vice versa. It is possible to assume from the positive values that there was a net export of environmental pressure in 2003-2008 (the pressure exerted by the Czech Republic abroad by means of import was bigger than the pressure exerted on the Czech Republic by foreign countries by means of export)¹. The PTB indicator further indicates foreign material dependency of the Czech Republic. When PTB shows high positive values the country may encounter problems if there is a scarcity or a steep increase in prices of commodities on international markets.

Looking at the PTB material categories, fossil fuels and metallic minerals recorded the most positive values. These commodities have to be imported, because their sources are either insufficient in the Czech Republic or their mining is not profitable. These two material categories showed a growth in 2003-2008. On the contrary, the PTB of biomass took considerably negative values and was intensifying from 2003 to 2008, consequently physical export of biomass (raw materials, semi-manufactured and final products from biomass) was much higher than physical import in the Czech Republic. The other categories of PTB – non-metallic minerals and other unspecified products took ambiguous trends from 2003 to 2008 and a lot of changes in their development were observed in this period.

¹ For more precise quantification of shifts in environmental pressure, it is advisable to figure out the import, export and PTB in the form of raw materials, which were needed for their production. These raw materials are called raw material equivalents of import and export.

Použitá literatura / References

1. Adriaanse, A., Bringezu, S., Hammond, A., Moriguchi, Y., Rodenburg, E., Rogich, D., Schütz, H. (1997): Resource flows – The material basis of industrial economies. WRI, Washington, D.C.
2. Ayres, R. U., Simonis, L. (1994): Industrial metabolism: Restructuring for sustainable development. UNU Press, Tokyo.
3. Baccini, P., Brunner, P., H. (1991): Metabolism of the anthroposphere. Springer Verlag, Berlin, New York, Tokio.
4. Bringezu, S. (2006): Materializing policies for sustainable use and economy-wide management of resources: Biophysical perspectives, socio-economic options and a dual approach for the European Union. Wuppertal Paper No. 160, Wuppertal Institute, Wuppertal.
5. Bringezu, S., Schütz, H., Moll, S. (2003): Rationale for and interpretation of economy-wide material flow analysis and derived indicators. *Journal of Industrial Ecology* 2 (7): 43-64.
6. Brown, L. R. et al. (2001): State of the world 2001. Worldwatch Institute, Washington, D.C.
7. Czech Statistical Office, yearly national accounts, internet application: <http://dw.czso.cz/pls/rocenka/rocenka.indexnu>
8. EEA (2006): Sustainable use and management of natural resources. European Environment Agency, Copenhagen.
9. Eurostat (2001): Economy-wide material flow accounts and derived indicators. A methodological Guide. Eurostat, Luxembourg.
10. Fischer-Kowalski, M., Haberl, H. (1993): Metabolism and colonization. Modes of production and the physical exchange between societies and nature. *Innovation: The European Journal of Social Sciences* 6 (4): 415-442.
11. Giljum, S., Hak, T., Hinterberger, F. and Kovanda, J. (2005): Environmental governance in the European Union: strategies and instruments for absolute decoupling. *Int. J. Sustainable Development* 8 (1/2): 31–46.
12. Moldan, B. (ed.) (1993): UN Conference on the environment and development. Documents and commentaries. Management Press, Prague.
13. Neužil, M. (2001): Influence of underground mining on the environment. *Reporter of EIA* VI, 3, s. 5-9.
14. OECD (2002): Indicators to measure decoupling of environmental pressures from economic growth. OECD, Paris.
15. OECD (2008): The OECD guide: Measuring material flows and resource productivity. OECD, Paris.
16. Schmidt-Bleek, F. (1994): *Wieviel Umwelt braucht der Mensch? MIPS – Das Mass für ökologisches Wirtschaften*. Birkhäuser Verlag, Berlin, Basel, Boston.
17. Schütz, H., Moll, S., Bringezu, S. (2004): Globalisation and the shifting environmental burden. Material trade flows of the European Union. *Wuppertal Papers* 134, Wuppertal.
18. Spangenberg, J. H., Femia, A., Hinterberger, F., Schütz, H. (1999): Material flow-based indicators in environmental reporting. European Environment Agency, Copenhagen.
19. Vitousek, P., M., Ehrlich, P., R., Ehrlich, A., H., and Matson, P., A. (1986): Human appropriation of products of photosynthesis. *Bioscience* 36: 368-373.
20. Wackernagel, M. et. Rees, W. (1996): *Our ecological footprint. Reducing human impact on the Earth*. Gabriola Island, BC, New Society Publishers.
21. Weizsäcker, E.U., Lovins, A.B., Lovins, L.H. (1996): *Factor four. Doubling wealth, halving resource use*. New report of the Rome Club. Earthscan, London.
22. World Resource Institute (2005): *Millennium ecosystem assessment. Ecosystems and human well-being: Synthesis*. Island Press, Washington, D.C.