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 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; Bringezu et al., 2003; Weizsäcker et al., 2009).

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 limitted, 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 consuption 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 and Bleischwitz, 2009). 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 (Giljum et al., 2009; 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 (Krausman et al., 2009). As argued above, this was also accompanied with the growh 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“) (Fischer-Kowalski et al., 2011; 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 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). Afterwards, EW-MFA was standardized in methodological guides of Eurostat (Eurostat, 2001, 2012).

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). Decoupling can be relative or absolute. When a relative decoupling occurs, there is a decrease in material consumption per unit of GDP, but the absolute material consumption is still growing. When an absolute decoupling occurs, the economy is growing while the absolute volume of resource consumption goes down. We should aim at absolute decoupling, as total environmental pressure is determined by absolute material consumption.

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 (Giljum et al., 2009; 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 2009-2014

The used domestic extraction went down by 8.8 percent from 173 million tonnes to 157.7 million tonnes in 2009-2014 (Table 1). It went down in all years with the exception of 2011 and 2014. The decrease in 2009 and 2010 can be attributed to global economic crisis, which was reflected also in the Czech Republic, where GDP went down by 4.8 percent in 2009 (Czech Statistical Office, yearly national accounts, internet application). While GDP grew in 2010 and 2011, this growth was not maintained in 2012 and 2013, which was reflected by next decrease in used domestic extraction in these years. The growth of both GDP and used domestic extraction was then renewed in 2014. 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 decreased from 2 193 tonnes per km^2 to 1 999 tonnes per km^2 in 2009-2014. The pressure covers structural changes of landscape related to extraction of non-renewable resources (moving of overburden, undermining) and pressures on biodiversity and land use in the case of extraction of renewable resources (above all when producing biomass in large-scale agro-ecosystems).

Breakdown of used domestic extraction by groups of materials shows that the decrease was caused by a decrease in fossil fuels and construction minerals, which went down from 56.6 million tonnes to 47 million tonnes (17 percent) and from 73.4 million tonnes to 61.5 million tonnes (16.2 percent), respectively. Other material categories went up: biomass from 32.9 million tonnes to 38 million tonnes (15.7 percent), industrial minerals from 10 million tonnes to 11 million tonnes (10.8 percent) and metal ores from 133 thousand tonnes to 137 thousand tonnes (3 percent). The mass 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 (biomass) in used domestic extraction went up from 19 percent to 24.1 percent in the monitored period. . Considering that consumption of renewable resource is usually related to lower environmental impacts, this trend could be reported as favourable.

Both physical import and export recorded a growth by 24.7 percent and 29.1 percent, respectively, in 2009-2014. The physical import went up from 58.2 million tonnes to 72.5 million tonnes while physical export went up from 54.6 million tonnes to 70.5 million tonnes in this period (Table 2). The growth of foreign trade occurred in all years with the exception of import in 2012. The decrease in import in 2012 can be attributed to decrease in economic performance in this year. 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 monitored period, and this was true both for import and export.

Growth in physical import came mainly from metal ores category (raw material, semi-manufactured products and manufactured products from metal ores), which increased from 14.9 million tonnes to 20.6 million tonnes (39 percent). The growth of export was caused mostly by biomass material category, which went up from 19.7 million tonnes to 27.6 million tonnes (40.2 percent). The growth of import and export was also recorded for material categories of fossil fuels, non-metallic minerals and other unspecified products and in the case of export also for waste while a decrease was only recorded for import of waste, which dropped from 868 tonnes to 31 tonnes (96.4 percent). Similarly to used domestic extraction of metal ores, however, the absolute mass of waste is very small and influences the total volume of import (and also of export) only insignificantly.

The DMI indicator went only slightly down by 0.7 percent from 231.1 million tonnes to 230.2 million tonnes in 2009-2014, the DMC indicator decreased more significantly by 9.5 percent from 176.5 million tonnes to 159.7 million tonnes in the same period. Expressed in per capita terms, DMI decreased from 22 tonnes to 21.9 tonnes per capita while DMC went down from 16.8 tonnes to 15.2 tonnes per capita (Table 3). Taking into account how these two indicators are calculated, it is not surprizing that the most pronounced decrease was recorded in 2012 when both used domestic extraction and foreign trade declined – DMI went down by 7.7 percent and DMC by 11.1 percent, respectively, in this year.

DMI and DMC 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 further 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 decreased in the monitored period, there was a drop both in the total environmental pressure related to material consumption and in the potential for waste flows in the years to come. Research of the Charles University in Prague, Environment Center (2013) indicates that from socio-economic factors influencing time development of material flow indicators the volume of final demand (above all consumption of households, creation of gross fixed capital and export) stimulates the growth of the indicators while technology of production tends to decrease them. Changes in structure of final demand cause a growth of some material categories (fossil fuels, metal ores) and decrease the others (non-metallic minerals, biomass).*

The most significant decrease in absolute values was recorded for non-metallic minerals in the case of both DMI and DMC (from 89.4 million tonnes to 80.6 million tonnes, i.e. by 9.8 percent, and from 83.2 million tonnes to 72 million tonnes, i.e. by 13.5 percent, respectively). Both indicators further saw a decrease in fossil fuels (from 79.8 million tonnes to 72.8 million tonnes, i.e. by 8.8 percent, and from 67.2 million tonnes to 60 million tonnes, i.e. by 10.7 percent, respectively), DMC further decreased in other unspecified products material category (from 237.4 thousand tonnes to -30.3 thousand tonnes, i.e. by 112.8 percent). On the other hand an increase was recorded for biomass (from 42.5 million tonnes to 50.9 million tonnes, i.e. by 19.7 percent, and from 22.8 million tonnes to 23.2 million tonnes, i.e. by 2 percent, respectively), for metal ores (from 15 million tonnes to 20.8 million tonnes, i.e. by 38.7 percent, and from 3.1 million tonnes to 4.5 million tonnes, i.e. by 44.8 percent, respectively) for other unspecified products in the case of DMI (from 4.4 million tonnes to 5.1 million tonnes, i.e. by 16.2 percent). Waste constitutes a special item, which showed a significant relative decrease in both DMI and DMC (by 96.4 percent and 53.2 percent, respectively), but their absolute decrease is small (by 837 tonnes and 1 135 tonnes, respectively). Since export is significantly higher compared to import for waste and also other unspecified products in 2014, DMC indicator shows negative values for these material categories. From the viewpoint of DMI structure, there was a decrease in shares of fossil fuels and non-metallic minerals and an increase in shares of biomass and metal ores. The development was similar in the case DMC (Tables 4 and 5).

Material intensity expressed as DMI to GDP ratio went down by 5 percent from 59.8 kg per 1 000 CZK to 56.8 kg per 1 000 CZK, material intensity expressed as DMC to GDP ratio decreased by 13.7 percent from 45.7 kg per 1 000 CZK to 39.4 kg per 1 000 CZK in 2008-2013. Material productivity expressed as GDP per DMI and DMC, which time development is an inverse of the time development of material intensity, went up by 5.3 percent from 16.7 kg per 1 000 CZK to 17.6 kg per 1 000 CZK in the case of DMI and by 15.9 percent from 21.9 kg per 1 000 CZK to 25.4 kg per 1 000 CZK in the case of DMC (Tables 4 and 5, Graphs 11 and 12). It can be assumed from the decrease in material intensity and the increase in 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, changes in structure of the economy and by 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. There is currently a discussion if GDP is a proper indicator to calculate material intensity and productivity. In order to maintain consistency an indicator should be used which contains similar items in monetary units that are comprised in material flow indicators in physical units. Alternative indicators to GDP which are mentioned in these discussions include, for instance, economic output or GDP plus import for DMI and GDP plus import minus export for DMC (OECD, 2008; Hirschnitz-Garbers et al., 2014).

DMI and DMC indicators can be represented in a single graph 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)(Graph 10), which is mentioned in the previous chapter. There was a decoupling in the Czech Republic in 2009-2014 and it was a slight absolute decoupling for DMI (DMI decreased by 0.7 percent) and a more significant absolute decoupling for DMC (DMC decreased by 9.5 percent) over the whole period. This development can be considered favourable especially for DMC.

The PTB indicator showed a decrease from 3.6 million tonnes to 2 million tonnes (42.8 percent) in 2009-2014. The extreme decrease was especially recorded between 2011 and 2012 when PTB dropped from 5 million tonnes to 236 thousand tonnes (95.2 percent). The indicator again significantly grew to 2.7 million tonnes in 2013. In per capita expression, PTB ranged from 22.5 kilograms to 472.7 kilograms per capita (Table 6). 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 2009-2014 (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]. This fact could be controversial from the viewpoint of sustainable development. The PTB indicator further shows 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. The decrease in PTB in the monitored period, an especially in 2012, can therefore be considered favourable.*

Looking at the PTB material categories, fossil fuels and metal ores 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. PTB of fossil fuels showed an increase by 22.7 percent in 2009-2014, PTB of metal ores grew by 46.7 percent. On the other hand PTB of biomass recorded significantly negative values, which even decreased in the monitored period. It means that the biomass export was exceeding biomass import at a growing rate in the Czech Republic. Physical trade balance was negative also for non-metallic minerals in 2009-2014.

[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.

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