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, 2013).

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 2011-2016

The used domestic extraction went down by 7.1% from 172.1 million tonnes to 159.8 million tonnes in 2011-2016 (Table 1). The trend of used domestic extraction was unbalanced despite the overall decrease: it went down to 152.3 million tonnes in 2012 and 2013, it grew up to 160.1 million tonnes in next two years and decreased a bit to 159.8 million tonnes in the last year 2016. The linkage between domestic used extraction and GDP was proved again, as with the exception of the last year GDP went down and grew, respectively, in the same years as domestic used extraction. In 2016, domestic used extraction somewhat decreased even though GDP went up, which can be attributed to a decrease in extraction of construction minerals. This in turn was in line with a decrease in gross value added from construction in 2016 (Czech Statistical Office, yearly national accounts, internet application). 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 2 182 tonnes per km^2 to 2 027 tonnes per km^2 in 2011-2016. 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 overall decrease was mostly caused by development in fossil fuels and construction minerals material categories which went down from 58.1 million tonnes to 45 million tonnes (22.6%) and from 67.1 million tonnes to 64.9 million tonnes (3.4%), respectively. A decrease from 142 thousand tonnes to 73 thousand tonnes, i.e. by 48.6%, was recorded also for metal ores; their mining was, however, very small in absolute terms (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. Other material categories went up: biomass from 35.3 million tonnes to 38.3 million tonnes (8.7%) and industrial minerals from 11.4 million tonnes to 11.6 million tonnes (1.6%).

Both physical import and export recorded a growth by 8% and 8.7%, respectively, in 2011-2016. The physical import went up from 70.6 million tonnes to 76.3 million tonnes while physical export went up from 65.5 million tonnes to 71.2 million tonnes in this period (Table 2). 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 and export came mainly from biomass category (raw material, semi-manufactured products and manufactured products from biomass), which grew from 10.7 million tonnes to 13.8 million tonnes (28.9%) in the case of physical import and from 22.6 million tonnes to 27.2 million tonnes (20.4%) in the case of physical export. An increase in volume of physical import and export was recorded also for all other material categories with the exception of export of fossil fuels (a decrease from 14 million tonnes to 12.4 million tonnes, i.e. by 11.9%) and export of waste which went down from 2 832 tonnes to 73 tonnes (97.4%). Similarly to used domestic extraction of metal ores, however, the absolute mass of waste is very small and influences the total volume and trend of physical import (and also of physical export) only insignificantly.

The DMI indicator decreased by 2.7% from 242.7 million tonnes to 236.1 million tonnes in 2011-2016 while the DMC indicator decreased by 6.9% from 177.1 million tonnes to 164.9 million tonnes in the same period. Expressed in per capita terms, DMI decreased from 23.1 tonnes to 22.3 tonnes per capita while DMC went down from 16.9 tonnes to 15.6 tonnes per capita (Table 3). Taking into account how these two indicators are calculated, it is not surprizing that the most pronounced change was recorded in 2012 when both used domestic extraction and physical import declined. DMI went down by 7.7% and DMC by 11.1%, 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 DMI and DMC decreased in the monitored period, there was a decrease in environmental pressure driven by consumption in countries we export to as well as a drop in environmental pressure related to material consumption in the Czech Republic. At the same time the potential for waste flows in the years to come was declining.*

Overall trend of the DMI indicator was mostly determined by fossil fuels which went down from 84.2 million tonnes to 71.8 million tonnes (14.7%) and partially also by non-metallic minerals which decreased from 86 million tonnes to 84.3 million tonnes (1.9%). Other material categories grew: biomass from 46 million tonnes to 52.2 million tonnes (13.4%), metal ores from 21.3 million tonnes to 21.8 million tonnes (2.5%) and other unspecified products from 5.2 million tonnes to 5.9 million tonnes (14.5%). Most material categories went down in the case of DMC: fossil fuels decreased from 70.2 million tonnes to 59.5 million tonnes (15.3%), metal ores from 5.4 million tonnes to 4.5 million tonnes (16.3%), non-metallic minerals from 77.4 million tonnes to 75.6 million tonnes (2.3%) and other unspecified products from 656.4 thousand tonnes to 233.9 thousand tonnes (64.4%). Only biomass grew for DMC: it went up from 23.4 million tonnes to 25 million tonnes (6.7%). Waste constitutes a special item, which showed a relative increase in both DMI and DMC by hundreds of percent, but their absolute increase is small (by 361 tonnes and by 3 121 tonnes, respectively). Since physical export is significantly higher compared to physical import for waste in 2011-2014, DMC indicator shows negative values for this material category. From the viewpoint of DMI structure, there was a decrease in shares of fossil fuels and an increase in shares of all other material categories. Regarding DMC, it recorded a decrease in shares of fossil fuels, but also in shares of metal ores and other unspecified products (Tables 4 and 5).

Share of renewable resources (biomass) in DMI and DMC went up from 19% to 22.1% and from 13.2% to 15.2%, respectively, in the monitored period. Taking into account that consumption of renewable resource is usually related to lower environmental impacts, this trend can be considered favourable. Also a decrease in share of fossil fuels is favourable, since consumption of fossil fuels is related to emissions of greenhouse gases which contributes to global climate change. The share of fossil fuels in DMI and DMC went down from 34.7% to 30.4% and from 39.6% to 36.1%, respectively, in 2011-2016.

Material intensity expressed as DMI to GDP ratio went down by 11.2% from 60.2 kg per 1 000 CZK to 53.4 kg per 1 000 CZK, material intensity expressed as DMC to GDP ratio decreased by 15% from 43.94 kg per 1 000 CZK to 37.3 kg per 1 000 CZK in 2011-2016. 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 12.6% from 16.6 kg per 1 000 CZK to 18.7 kg per 1 000 CZK in the case of DMI and by 17.7% from 22.8 kg per 1 000 CZK to 26.8 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 an absolute decoupling in the Czech Republic in 2011-2016 in the case of DMI and DMC: both indicators went down and GDP grew at the same time. This development can be considered favourable.

The PTB indicator showed a slight decrease from 5.09 million tonnes to 5.06 million tonnes (0.6%) in 2011-2016. An extreme decrease was recorded between 2011 and 2012 when PTB dropped from 5.09 million tonnes to 395 thousand tonnes (92.2%). The indicator again significantly grew to 2.8 million tonnes in 2013, remained on the level of 2.7 million tonnes in 2014, grew steeply up to 7 million tonnes in 2015 and went down to 5.06 million tonnes in 2016. In per capita expression, PTB ranged from 37.6 kilograms to 668 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 2011-2016 (the pressure exerted by the Czech Republic abroad by import was bigger than the pressure exerted on the Czech Republic by foreign countries by their export). 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.*

Looking at the PTB material categories, fossil fuels and metal ores recorded the most positive values and mostly positive values were also recorded for other unspecified products (they only showed a negative value in 2014). 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 grew by 20% while PTB of metal ores and of other unspecified products decreased by 15.4% and 64.4%, respectively, in 2011-2016. 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 and for waste (with the exception of 2015 and 2016).

DMI and DMC are internally inconsistent indicators, as one of their parts – used domestic extraction – is accounted for in terms of raw materials while physical imports and exports are accounted for in terms of products. It can therefore happen that a country decreases its material consumption measured by DMI and DMC by ceasing manufacturing of some products from domestic raw materials and importing them from abroad. The thing is that the weight of raw materials which needs to be extracted for manufacturing and which is accounted for into used domestic extraction is always higher than the weight of manufactured products which are parts of physical imports and exports. This is true because a part of extracted raw materials is transformed into waste flows already during manufacturing and a part is used for covering energy needs of manufacturing. In order to overcome these distortions in measuring material consumption new indicators have currently been under development which include imported and exported products in terms of all raw materials needed for their manufacturing, i.e. in terms of raw material equivalents (RME). These indicators are called Raw Material Input (RMI) which is calculated as a sum of used domestic extraction and raw material equivalents of imports and Raw Material Consumption (RMC) which is calculated as used domestic extraction plus raw material equivalents of imports minus raw material equivalents of exports. RME of imports and exports can be used also for calculation of physical trade balance and evaluation of shifts of environmental pressures between countries which is more precise than using PTB based on simple weight of imports and exports.

Methodology of calculation of raw material equivalents of imports and exports has still been under development by various international institutions and research organizations. Eurostat is currently the most advanced as regards implementation of the standardized approach for calculation, as it has been involved in this kind of research since 2009. Eurostat developed a model calculating RME, RMI and RMC for the European Union as a whole. It also developed a country tool based on this model which allows for an estimation of raw material equivalents for particular EU countries. This is the reason why Eurostat plans in next years to include data entries on physical imports and exports in terms of RME into a questionnaire by which it collects data on material flows from EU countries. Details on the Eurostat RME project, material consumption in the EU in terms of RME and about the country tool can be find at http://ec.europa.eu/eurostat/statistics-explained/index.php/Material_flow_accounts_-_flows_in_raw_material_equivalents.

Calculation of raw material equivalents for the Czech Republic is carried out by Charles University Environment Centre in its research projects. The results show that raw material equivalents of imports and exports, respectively, are approx. 3 times higher in the Czech Republic compared to the simple weight of imported/exported commodities. The largest part of raw material equivalents of both imports and exports is composed of fossil fuels. The second position is held by metal ores for imports and by non-metallic minerals for exports and the third position is occupied by non-metallic minerals for imports and metal ores for exports. The smallest part of raw material equivalents of both imports and exports is composed of biomass. Due to increase in weight of raw material equivalents of imports compared to simple weight of imports RMI indicator is by more than 50% higher compared to DMI indicator. On the other hand RMC and DMC indicators do not differ much, as similar increase in raw material equivalents of imports and exports is cancelled out during the calculation of RMC.

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