VARIOUS ASPECTS OF ANTHROPOGENIC MATERIAL FLOWS IN THE CZECH REPUBLIC: PRESENTATION OF THE PROJECT

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Abstract:

This article presents a project supported by Grant Agency of the Czech Republic and carried out at the Charles University in Prague, Environment Center. The project is being carried out in 2012-2014 and its overall goal is to evaluate various aspects of anthropogenic material flows in the Czech Republic such as the trends of overall environmental pressures related to material flows, the shifts of these pressures among countries due to international trade, efficiency of material use, recycling and product specificity of material-based pressures. The project applies approaches of ecological economics including economy-wide material flow accounting and hybrid input-output life cycle assessment method. These approaches are considered well established and suitable tools for monitoring and evaluation of human-induced material flows and related environmental pressures. The project has four objectives: 1) Extension of time series of economy-wide material flow indicators for the Czech Republic and assessment of their trends; 2) Compiling a material flow indicator related to recycling; 3) Extension of material flow indicators by water accounts; 4) Identification of product groups within the Czech economy, which are related to largest environmental pressures.

The article further shows some first results of the above project, which include the decrease in environmental pressure related to use of materials in 2009 and 2010, increasing rate in recycling and increasing pressure exerted on the environment due to surface water abstraction.

Key Words: Anthropogenic material flows, hybrid input-output life cycle assessment method, EW-MFA indicators, recycling rate, water abstraction

Introduction

This article presents a project supported by Grant Agency of the Czech Republic and carried out at the Charles University in Prague, Environment Center. The project is of highly inter-disciplinary character and deals with various aspects of anthropogenic material flows in the Czech Republic.

The overall environmental pressure and impact caused by human societies is to a large extent induced by the consumption of energy and materials. Arguments supporting this claim have been put forward by a number of authors (e.g. Schmidt-Bleek, 1993; Ayres and Simonis, 1994; Weizsäcker and Lovins, 1997). Materials have to be first extracted from the environment. Then they are used to produce goods or deliver services required to satisfy human needs. Some are recycled, but they are all eventually released back into the environment in the forms of emissions and waste. All these stages of material processing have some environmental pressures and impacts. These include structural landscape changes, loss of biodiversity, acidification, eutrophication, global climate change and others (Giljum et al., 2005). In order to measure material and energy flows and to mitigate the related problems, material flow analysis has been conceived. The aim of this approach is to monitor material and energy flows at various levels of detail, and to provide indicators which contribute to management of resource use and output emission flows from both economic and environmental points of view (OECD, 2008). As convenient measures of sustainability, material flow indicators focusing mostly on an economy-wide level have been compiled for a range of both developed and developing countries (for instance, Adriaanse et al., 1997; Matthews et al., 2000; Giljum, 2004; Weisz et al., 2006; Weisz et al., 2007a).

Conceptual and methodological approaches

The project is based on two major methods: material flow analysis and the hybrid input-output life cycle assessment method.

Material flow analysis (MFA) is considered an approach of ecological economic, which study how ecosystems and economic activity interrelate (Proops, 1989). MFA uses some economic accounting principles and derives indicators, which relates both to economic variables such as gross domestic product (GDP) and to various environmental problems.

As a follow-up to pilot studies such as Steurer (1992), Schütz and Bringezu (1993), the Ministry of the Environment Japan (1992), Adriaanse and colleagues (1997) and Matthews and colleagues (2000), a first attempt to standardize economy-wide material flow analysis (EW-MFA) was undertaken by the statistical office of the European Union, which published a method guide for economy-wide material flow accounts and derived indicators (Eurostat, 2001). The standardization process was continued with the publication of a “compilation guide” for EW- MFA (Weisz et al., 2007b) and with the OECD work program on material flows (OECD, 2008). The aim of the EW-MFA is to quantify the physical exchange between a national economy, the environment and foreign economies on the basis of the total material mass flowing across the boundaries of the national economy. The ultimate goal of the analysis is to get a material balance, i.e., the state when material inputs into the economy equal material outputs summed with additions to the physical stock of the economy (for instance, traffic infrastructure, buildings and durable goods).

Material inputs into the economy consist primarily of extracted raw materials and produced biomass that have entered the economic system. Material outputs consist primarily of emissions to air and water, landfilled wastes and dissipative uses of materials (e.g. fertilizers, pesticides and solvents). The methodology also includes a concept of unused extraction (also called hidden flows). Unused extractions are material flows that have taken place as a result of resource extraction, but which do not directly enter the economic system. Examples include biomass left back in forests after logging, overburden from extraction of raw materials (such as in open-cast coal mining), earth movements resulting from the building of infrastructure, dredged deposits from rivers, etc. Foreign trade also plays an important role in the analysis because it represents an important material flow across the boundaries of the economic system. Imports of commodities are placed on the input side, while exports are placed on the output side of the material balance. Used and unused extraction are associated with foreign trade in the same way that domestic economic activities are (e.g. movement of overburden associated with imported coal), and are identified as indirect or up-stream material flows associated with imports and exports.

Based on the input and output flows, a large array of EW-MFA indicators can be compiled. These indicators include:

- Direct material input (DMI), which equals used domestic extraction (excavated raw materials, harvested biomass) plus imports;
- Raw material input (RMI), which includes used domestic extraction and up-stream material flows of imports related to used extraction (called raw material equivalents of imports - RMEIM);
- Total material requirement (TMR), which includes DMI plus unused domestic extraction and up-stream material flows of imports related both to used and unused extraction;
- Domestic processed output (DPO), which comprises emissions to air, landfilled wastes, the material load in wastewater and dissipative flows;
- Total domestic outputs (TDO), which includes DPO and unused domestic extractions;
- Domestic material consumption (DMC), which is calculated as DMI minus exports;
- Raw material consumption (RMC), which is calculated as RMI minus up-stream material flows of exports related to used extraction (called raw material equivalents of exports – RMEEX);
- Total material consumption (TMC), which equals TMR minus exports and their up-stream material flows related both to used and unused extraction; and
- Net additions to stock (NAS), which measures the physical growth rate of an economy.

EW-MFA indicators can serve various purposes, which include (OECD, 2008):

- Assessment of 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. It can be assumed that growing volume/mass of any material flow indicator will result in growing environmental pressure and impacts (Weizsäcker and Lovins, 1997; Bringezu et al., 2003).

- Assessment of shifts in environmental pressures among countries and regions related to international trade;

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 their up-stream flows.

- Measuring the efficiency of use of materials;

Relating input and consumption material flow indicators to national account aggregates, such as 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. Assessment of material intensity and productivity is complementary to analysis of decoupling, which study whether there is a decoupling between economic goods such as GDP growth and environmental bads such environmental pressures from material use.

- Assessment of foreign material dependency of countries and their 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.

In order to assess environmental pressures related to whole life cycles of materials and products and evaluate properly shifts in environmental pressures between countries and regions it is necessary to include up-stream material flows (Commission of the European Communities, 2005a). This is done for imports and exports, which are then expressed in terms of all materials needed worldwide to produce imported/exported commodities (RMEIM, RMEEX). Two methods can be applied to quantify up-stream flows: a life cycle inventory (LCI) and hybrid input-output life cycle assessment method (hybrid IOA-LCA). The first method is quite straightforward. The volume of imports/exports is multiplied with coefficients, which express the volume of all materials that entered the particular product system throughout its life cycle. Hybrid IOA-LCA, on the other hand, is a combination of LCI and input-output analysis (IOA). IOA was first introduced by Leontief (1936, 1970) in order to monitor economic transactions among sectors. It can be, however, extended by some environmental variable such as extraction of resources or emissions. Hybrid LCA starts with the input-output model (IOM), which is represented by an input-output table (IOT) in monetary units. This model can be described by following equation:

1) $x = (I – A)-1. y$,

Where x is a vector of total product output of the system, I is identity matrix, A is a matrix of technological coeffcients and y is a vector of total final demand.

A matrix can be compiled for a product-by-product model or a sector-by-sector model, each of them can be further broken down into two types according to the assumed technology of production/sales of products. A sector-by-sector model under the assumption of fixed product sales structure of products will be used in this project. For this model, A matrix is calculated as follows:

2) $A = ST. (diag(t - IM))-1. U . (diag(g))-1$

Where S is a supply matrix as appears in the supply table, T denotes matrix transposition, t is the vector of total product use, IM is a vector of imports, U is a use matrix as shown in the use table and g is a vector of total sector output.

In the next step, an environmental extension represented by matrix F will be added to the model.

3) $e = F. (I – A)-1. y$

4) $F = F\_r . (diag(g))−1$

Where e is a vector of total induced material flows in the form of raw material equivalents and F_r is a matrix of used domestic extraction (DE) in physical units broken down by economic sectors.

The above calculation would assume that the imported commodities are produced abroad using the same production technology as the corresponding commodities in the domestic economy. Since this assumption need not hold for a range of products (especially when taking into account imports from developing), the results can be significantly distorted. To overcome this shortcoming, there are in general two possibilities: to build a multi-regional input output model, which uses country specific input output tables for the exporting countries, or to integrate life cycle inventory (LCI) data into the model for commodities, for which the domestic technology assumption does not hold. In this project, the second approach will be applied and LCI data will be used for natural gas, crude oil, metal ores and basic metals, which are not produced in the Czech Republic at all or only in minor quantities. These data will be integrated into the F_r matrix, use tables, supply tables and the vector of imports. This integration is denoted as ‘ in the following equations.

RMEIM and RMEEX are calculated for product groups, but there is a sector-by-sector model so far. It is therefore necessary to transform the total final demand according to the sectors into the total final demand according to the products. This will be done by following equation:

5) y = S‘T . (diag(t – IM‘))−1 . y_p

Where y_p is a vector of total final demand according to the product groups.

To calculate RMEIM and RMEEX the vector y_p will be sequentially substituted by the vectors of imports (the original vector of imports) and exports.

6) RMEIM = F‘. (I – A‘)-1. S‘T . (diag(t − IM‘))−1 . IM

7) RMEEX = F‘. (I – A‘)-1. S‘T . (diag(t − IM‘))−1 . EX

It is also possible to calculate directly RMI and RMC indicators, which comprise RMEIM and RMEEX, by using vectors of total final demand and domestic final demand.

8) RMI = F‘. (I – A‘)-1. S‘T . (diag(t − IM‘))−1 . y_p = DE + RMEIM

9) RMC = F‘. (I – A‘)-1. S‘T . (diag(t − IM‘))−1 . y_pd = DE + RMEIM - RMEEX

Where y_pd is a vector of domestic final demand according to the product groups.

For more detailed description of the calculation procedure including discussion on various types of the model, which can be employed for calculation, see Weinzettel and Kovanda (2009).

Project objectives

The project has several objectives which contribute to the solution of selected research questions relevant for material flow analysis. Selection of these objectives takes into account current state of the art and previous Czech and international projects related to this topic. The objectives are principally fourfold:

1) Extension of time series of EW-MFA indicators available for the Czech Republic and assessment of their trends

EW-MFA indicators for the Czech Republic have been compiled within previous research and development projects of Ministry of the Environment (10/2/00, 320/2/03, 1C/7/14/04, SP/4i2/141/08) and Grant Agency of the Czech Republic (205/04/0582, 205/08/1475), which were worked on by applicant of this project proposal. Some of these indicators, namely DMI and DMC, are now calculated by the Czech Statistical Office (e.g. Czech Statistical Office, 2010a). This is not however true for more complex indicators such as RMC, TMR, TDO and TMC, which will be in the core of this objective. Time series of these indicators are now available up to 2008. Their extension for 2009-2012 within this project will help, for instance, to answer a question how world economic crisis of 2009 and 2010 has influenced material flows and related pressures in the Czech Republic. The indicators including up-stream flows will be calculated using both simple LCI and hybrid LCA, the results will be compared and it will be suggested which method delivers the more precise results. The calculated indicators will be analysed to answer following questions:

- Was there a change in the overall physical scale of the economy and total environmental pressure related to use of materials?
- Was there an increase in shifts in environmental pressures between the Czech Republic and other countries?
- Was there an increase in the efficiency of use of materials?

- Was there an increase in foreign material dependency of the Czech Republic?

2) Compiling a material flow indicator related to recycling

EW-MFA indicators as defined by Eurostat (2001) focuses on use of primary materials and on the flows of material back into the nature. The cyclical use of materials is not taken into account, as it is considered a flow, which does not cross the system boundary between economy and the nature. On the other hand it is widely acknowledged that the higher the recycling, the lower the need for primary materials (Commission of the European Communities, 2005b). The EW-MFA indicators and cyclical use of materials are therefore mutually interdependent. This was faced by Japanese "Fundamental plan for establishing a sound material-cycle society" (Ministry of the Environment Japan, 2003), which designed a new indicator bringing together EW-MFA and recycling. It is named cyclical use rate and is defined as amount of cyclical use of materials divided by the sum of cyclical use of materials and DMI indicator. Since the "Fundamental plan for establishing a sound material-cycle society" has been approved in 2003, the Japanese Ministry of the Environment monitors this indicator with the goal to reach 15 percent cyclical use rate by 2015.

The aim of this task is to compile cyclical use rate indicator for the Czech Republic for 2001-2012 (data on recycling are not consistent before and after 2001 due to changes in waste statistics) and to answer following questions:

- Is there an increasing trend in cyclical use rate in the Czech Republic?
- Is the cyclical use rate in the Czech Republic comparable to countries like Japan? Providing that not, what are the major barriers to reach similar cyclical use rate?

3) Extension of material flow indicators by water accounts

Material flow accounts usually exclude water and air flows (Eurostat, 2001). This is because water flows are typically ten times more voluminous than flows of other materials, which would be hardly visible in the total material balance. This is the reason why it is suggested to establish and keep water flow accounts separately from material flow accounts (Schandl et al., 1999). Within this project objective we establish the water accounts parallel to material flow accounts, which will be based on the same accounting principles as EW-MFA. The length of the time series will depend on data availability, but will go back to the your of 2000 at least. The water accounts will open the opportunity for further research under the "water footprint" methodology (Chapagain and Hoekstra, 2004). Besides the analysis of trend of water use, the major question to answer by establishing the water flow accounts will be as follows:

- What is the relation between consumption of water and the overall availability of water resources in the Czech Republic?

4) Identification of product groups within the Czech economy, which are related to largest environmental pressures

As acknowledged by various current research projects, the management of material flows and related pressures and impacts could be much more effective when focusing on products with highest material flows mobilized during their whole lifecycles. This issue has been addressed on the European level (Moll and Watson, 2009), but no similar study has been available for the Czech Republic yet. The lifecycle-wide material flows and emissions related to product groups will be calculated using a hybrid LCA approach by placing import, export and final demand vectors in equations 6)-9) on a diagonal. The results will be analysed from the following viewpoints:

- What are the products groups responsible for highest material flows? Are these the same in the Czech Republic as on the European level?
- Based on the review of the best available techniques for these product groups, what are the suggestions for reduction of related material flows and emissions?

Due the data intensity of this work, this analysis will be carried out for one pilot year for which the most recent data will be available.

First project results

The project is being carried out in the period 2012-2014. There are, however, some first results available already by now.

1) Extension of time series of EW-MFA indicators available for the Czech Republic and assessment of their trends

The analysis of trends of EW-MFA indicators revealed that many indicators went down in newly compiled years – the decrease was obvious above all in 2009 and could be attributed to global economic crisis. The overall physical size of economy and related environmental pressure therefore shrank in 2009 and 2010 (Figure 1).

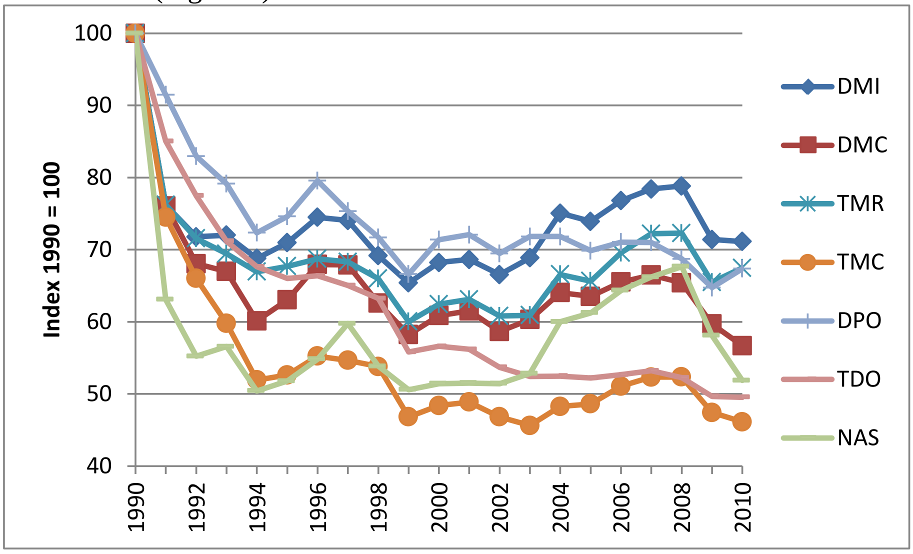

Figure 1: Overall trends of selected EW-MFA indicators, Czech Republic, 1990-2010

The indirect flows of imports and exports dropped in 2009, but grew again in 2010 on the levels of 2008. It means that there were not more profound changes in terms of shifts in environmental pressure between the Czech Republic and other countries. Conversely, the material productivity continued to grow in 2009 and 2010. This trend was, however, connected to unfavorable increase in foreign trade dependency, which grew by 3 percentage points between 2008 and 2010.

2) Compiling a material flow indicator related to recycling

The indicator of cyclical use rate was calculated in a standard and in a modified form, where cyclical use of materials included also imports of wastes, secondary materials and scarp while the same imports were subtracted from DMI. This modification can be substantiated by the fact that one of the goals of the indicator is to express the ratio of consumption of secondary (recycled) materials and primary raw materials.

The compilation and analysis of the indicator showed that it grew in the Czech Republic - it was 1.32 % in 2002, but 2.86 % in 2010. The modified form of the indicator showed values higher by 32 % on average and a very similar trend - it went up from 1.89 % in 2002 to 3.56 % in 2010 (Figure 2). The modification was therefore reasonable: the indicator attained significantly different values and stressed the importance of imports of waste and scrap for cyclical use of materials.

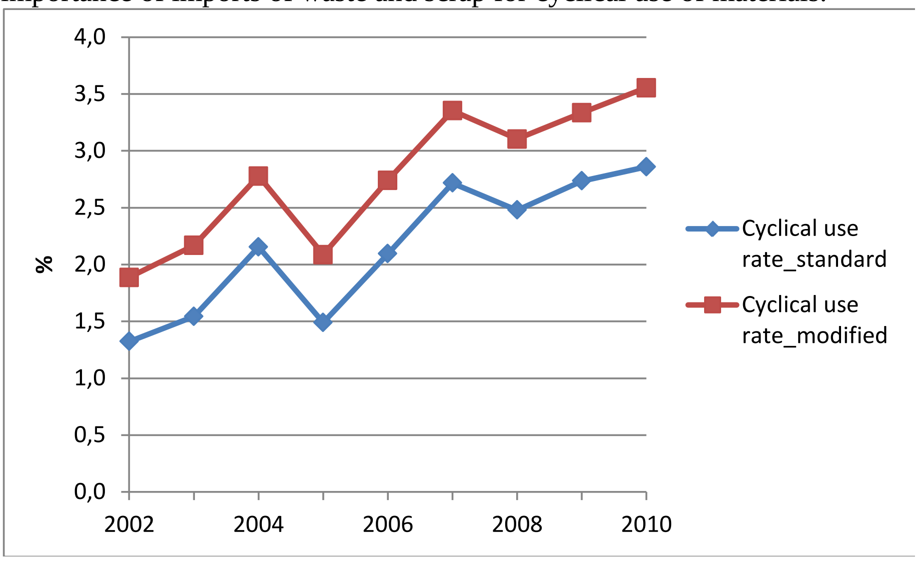

Figure 2: Cyclical use rate indicator (standard and modified form), Czech Republic, 2002-2010

Compared to Japan, for instance, the indicator recorded significantly lower values in the Czech Republic – only 2.72 % as compared to 13.5 % in 2007. The breakdown of the indicator by particular material groups revealed that the Czech Republic lagged especially behind in the cyclical use of biomass and non-metallic minerals (construction minerals). On the other hand the difference was not so large in the case of the cyclical use rate of metals (Ministry of the Environment Japan, 2010).

3) Extension of material flow indicators by water accounts

We have compiled water accounts for the Czech Republic for 2000-2011 so far. The water accounts comprised water abstraction in million cubic meters (m3) broken down by particular river basins (Labe, Vltava, Ohře, Odra, Morava), by surface water and ground water and by particular purchasers (water supply systems for public use, agriculture, energetics, industry, other including construction). Moreover, the renewable water resources were determined, which can be defined as the available volume of water for consumption in every year. They were determined as flow rate in major water courses with 95% security for surface water and as an educated guess of Ministry of Agriculture for ground water.

With the exception of Labe and Morava river basins, the volume of water abstraction from surface sources went slightly down in 2000-2011, but the increase in abstraction from Labe river basin was so profound, that the total water abstraction from surface water sources went up in this period (Figure 3). On the other hand, the total water abstraction from ground water sources went down in 2000-2011. The only river basin which showed an increase in ground water abstraction was Vltava (Figure 4).

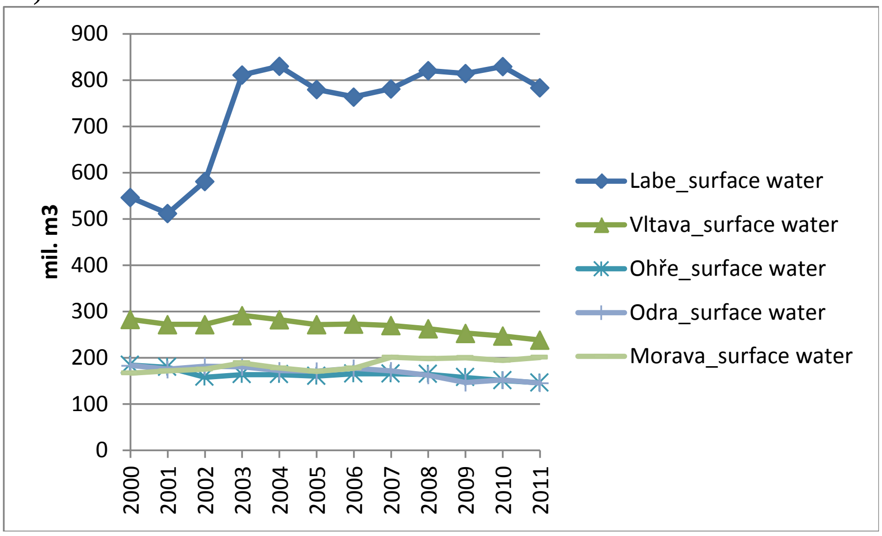

Figure 3: Water abstraction from surface sources, Czech Republic, 2000-2011

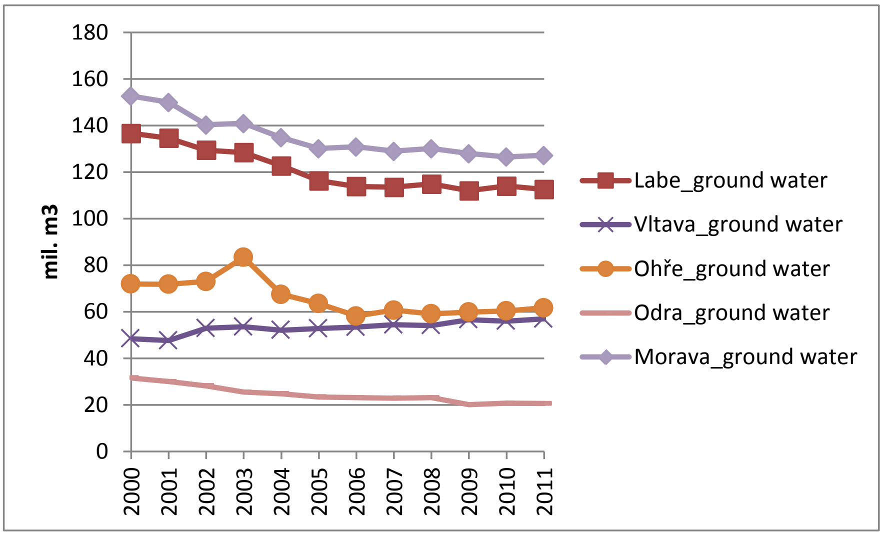

Figure 4: Water abstraction from ground water sources, Czech Republic, 2000-2011

4) Identification of product groups within the Czech economy, which are related to largest environmental pressures

From the viewpoint of raw material extraction, the most demanding product groups included motor vehicles, basic metals, buildings, machinery and equipment, hard and brown coal, electricity and gas, food, chemical substances and products, civil engineering works, agricultural products, non-metallic mineral products, computers and optical appliances, fabricated metal products, electrical appliances, non-metallic raw materials, real estate services, coke and refinery products. Taking into account the fact that environmental pressure related to non-metallic minerals is lower compared to fossil fuels, biomass and most significantly to metal ores, lower priory from above product groups could be given to buildings, civil engineering works, non-metallic raw materials and non-metallic products, as their production is linked to non-metallic minerals. The most emission intensive product groups are quite similar to the most raw material intensive product groups, but their order is different and for emissions to the air also land transport showed up as very important: it reached 9th position in case of greenhouse gases and PM total, 14th position in case of SO2, 7th position for NOx and 8th position for CO.

Conclusion

Although the project described in this article has not been finalized yet, there are some first project results available right now. It can be concluded that many EW-MFA indicators in the Czech Republic went down in newly compiled years and due to this fact the overall physical size of the economy and related environmental pressure shrank in 2009 and 2010. It further showed that the Czech Republic suffered from increasing foreign trade dependency, but the efficiency of transformation of material inputs into economic output grew. The work on the cyclical use rate indicator proved that the recycling is on the upswing in the Czech Republic, but compared e.g. to Japan, the overall recycling rate is still much lower. The calculation of modified version of this indicator also emphasized the significance of imported wastes, secondary materials and scrap for overall recycling. We have further compiled the water accounts, which showed an increase in total surface water abstraction in 2000-2011 mostly due to growth in water abstraction from Labe river basin. Unlike pressure on the environment related to material flows of solid materials covered by EW-MFA, the environmental pressure related to surface water abstraction thus went up quite significantly in the first decade of the 21st century. Regarding the product groups most demanding on extraction of raw materials, they include basic metals, fabricated metal products, motor vehicles and machinery. These commodities require large amounts of metal ores to be mined and processed. This is not a favorable discovery, as mining and processing of metal ores is usually related to significant impacts on the environment and human health.

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