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ANALYSIS

Material flow accounts, balances and derived indicators for the Czech Republic during the 1990s: results and recommendations for methodological improvements

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Abstract

The economy and the environment are connected through material and energy flows. These flows are the key cause of environmental problems (together with land use and other biological and social factors) and can serve as an indirect indicator of pressure on the environment. The leading method for assessing material flows and dematerialisation at a macroeconomic level was developed during the 1990s by a number of research institutes and organisations. The result of this effort was the guide ['Eurostat (2001) 92']. This is a guide for the analysis of the total mass of annual material inputs and outputs for the whole economic system, using accounts, balances and derived indicators of material flows. The manual touches only briefly on the flows between various sectors of the economy. This article describes the application of material flow analysis (MFA) to the economy of the Czech Republic. Relevant indicators were derived on the basis of accounts and balances of material flows compiled for the Czech Republic for 1990–2000. The indicators and analysis of material flows presented here are the first results covering a long time period and a comprehensive set of material flow accounts in a transition economy. The results show that indicators of material flows decreased during the 10-year-period analysed by approximately 30–40%. Material intensity also dropped by 30% (i.e., material efficiency increased by 30%) while the material intensity of other countries such as Germany dropped by 30% in the 15-year-period. Finally it has been possible to demonstrate that economic growth as expressed by GDP has been decoupled from environmental pressure as expressed by material flow indicators. The article proposes further work that should be undertaken in MFA at macroeconomic level in the Czech Republic. In conclusion, recommendations are made on how to improve the methodology used.

Keywords: Material flow analysis; Environmental accounting; Dematerialisation; Decoupling; Material intensity; Czech Republic

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1. Measurement of environmental pressure using the MFA approach

Material and energy flows from the environment as a result of the activities of the socio-economic system are the primary cause of environmental problems. As each material flow represents a certain pressure on the environment, it is possible to assume that an increment in any kind of flow results in an increase in pressure on the environment. If we focus on inputs and outputs flowing to and from the economic system and on increasing resource productivity, we can achieve a decrease in the resulting pressure and environmental load caused by society (the socioeconomic system), whilst at the same time maintaining economic prosperity.

All methods of assessing material and energy flows originate from one philosophy: quantification of material and energy flows at any level, whether for a factory, region, or country, using input–output analysis. There are, however, modifications needed in order to apply this basic approach at each level. Analyses of material and energy flows can thus differ both from a conceptual point of view and according to the scale of the system under observation.

The most significant difference results from whether the given socio-economic unit is considered as a 'black box', i.e., not taking into consideration what happens inside the system. This is the method most widely used for material flow analysis (MFA) at a macro level, whilst at an enterprise or regional level the 'recycle flows' within the company or region are considered.

Methods of MFA can be further divided into two basic groups: those focused on dematerialisation of the economic system and those aimed at its 'detoxification'. The goal of dematerialisation is to change the 'metabolic efficiency' of firms, sectors or regions by identifying the main problems, prioritising these and identifying tools for the more efficient management of resources. Emphasis is laid on the overall nature of the 'metabolic efficiency' of the unit being studied from a sustainable development viewpoint. By contrast 'toxicity' analyses are focused on specific environmental problems analysed within a firm, sector or a region. These analyses can be divided into analysis of flows of elements and compounds, e.g., Cd, Cl, Pb, CFC (substance flow analysis), analysis of material flows (biomass, gravel or wood) and analysis of product flows, e.g., batteries or cars (life cycle analysis) (see van der Voet, 1997; Bringezu, 2000). The results of these analyses are often used as inputs for quantitative risk assessment.

Any classification of methods of MFA must also take into account differences in system boundaries (Daniels and Moore, 2002). Methods can thus be grouped according to system definition. The system can be defined as a functional unit—that is, a product or a firm—or according to its geographical boundaries. In standard MFA, a geographic–economic boundary is considered, associated for instance with the national economy, a region or a city.

The most comprehensive and the most systematic methods for MFA for a specific economic–political system are (i) input–output tables, which open the 'black box' of the economy and attempt to trace material flows between individual economic sectors and (ii) accounts and balances of total material requirements (TMRs) and outputs at a macroeconomic level. The second method was developed during the 1990s by various research institutes and organisations (principally the World Resources Institute, the Wuppertal Institute for Climate, Environment and Energy, 2002, the Austrian Institute for Interdisciplinary Studies and Eurostat), and was then standardised in the methodological guide Economy-wide material flow accounts and derived indicators (Eurostat, 2001). As this method of MFA at macroeconomic level is best developed and there are sufficient data available to enable international comparison, this method was chosen for the MFA of the Czech Republic.

Ščasný and Kovanda (2001) compiled accounts, balances, and derived indicators of material flows for the Czech Republic for 1990–1999, and the development of material intensity and material efficiency for the Czech Republic during the 1990s was evaluated on that basis. Indicators of material flows were internationally compared. For this article, preliminary accounts, balances and indicators of material flows for the year 2000 have been compiled as well.

2. Eurostat methodology for assessment of material flows at macroeconomic level

The aim of the methodology described is to quantify the physical exchange between the national economy and environment on the basis of total material mass flowing across the boundaries of the environment and the national economy (material inputs) and the national economy and the environment (material outputs). Flows inside the economy, for example, products moving between various sectors, are not included; the economy is treated as a 'black box'.

Material flows can be divided into three categories: water, gases and solid materials. Water and air flows are one order of magnitude higher than the total flow of other materials. Water and air account for at least 95% of the total mass of material inputs to the Austrian economy, whilst industrial metabolism on average consists of 85% water, 8% air and 7% other material (Schandl et al., 1999). The Eurostat methodology, therefore, includes only that part of the water and gas flows necessary for overall balance (water contained in solid materials, import and export, emissions to water and to air, gases as balancing elements—see below).

Material inputs consist primarily of extracted raw materials and produced biomass that has entered the economic system (this biomass is composed of, for example, fodder, pasturage, harvested wild fruits and wood). Material outputs consist primarily of emissions to air and water, landfilled wastes and so-called dissipative uses of materials (e.g., fertilisers, pesticides and solvents).

The Eurostat methodology also includes the interesting concept of unused extraction or hidden flows. Unused extractions are material flows that have taken place as the result of resource extraction, but which do not directly enter the economic system. Examples include biomass left 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 inputs side, while exports are placed on the outputs side of the material balance. Unused extraction is associated with foreign trade in the same way as with domestic economic activities (e.g., movement of overburden associated with imported coal) and is identified as indirect flows associated with imports and exports.

For the inputs and outputs to be balanced, it is necessary to insert the balancing items referred to above into the total material balance. These contribute to the transformation of inputs into outputs and without them it would be impossible to compile a balance sheet or to predict changes in physical stocks identified as the difference between material inputs and outputs. Gases from the ambient air (oxygen, nitrogen) that take part in oxidising processes when burning fuel are important examples of such balancing items on the input side, while water vapour from the water and hydrogen content of fuels forms a balancing item on the output side. These inputs and outputs are calculated on stoichiometric principles for emissions to air from combustion and on the basis of the chemical composition of fuel (taking into account its water and hydrogen content). Oxygen is furthermore identified as a balancing item on the input side, where it is needed for 'burning' food consumed by humans and domestic animals, whilst carbon dioxide and water from respiration released during this process are identified as balancing items on the output side.

Material flow accounts compiled on the basis of the described methodology provide an important data source for the derivation of many aggregated environmental indicators and indicators of sustainable development. The most commonly used are as follows:

Input indicators.

- Direct Material Inputs (DMI) equals domestic extraction (excavated raw material, harvested biomass) plus imports.

- Total Material Inputs (TMI) is calculated as DMI plus unused domestic extractions (DUE).
- TMR includes domestic used and unused extractions, imports and their indirect flows.

Output indicators.

- Domestic Processed Output (DPO) comprises emissions to air, landfilled wastes from industrial processes and households, the material load in wastewater and dissipative uses and losses of products.
- Total Domestic Outputs (TDO) includes DPO and unused domestic extractions.

Consumption indicators.

- Domestic Material Consumption (DMC) is calculated as DMI minus exports.
- Total Material Consumption (TMC) is TMR minus exports and their indirect flows.
- Net Additions to Stock (NAS) measures the physical growth rate of the economy. Each year new materials are added to economic stocks, such as new buildings and durable goods, whilst old materials are removed from this stock and become wastes.
- Physical Trade Balance (PTB) measures the surplus or deficit in physical foreign trade. PTB can also be defined for the indirect flows.

Balancing items are not used in calculating the above indicators. The indicators can be calculated in absolute terms as well as in relation to population size (per capita) and to economic performance (per unit GDP). Output indicators can be disaggregated by economic sector (sectoral flows) or according to the media to which the flows are directed (air, water, soil). Indicators of economic efficiency can be related to input or output indicators of material flows. GDP per TDO unit measures economic efficiency in relation to domestic material losses to the environment. On the contrary, if input indicators are related to GDP the result is the material intensity of the economy. A necessary—but not sufficient—condition for sustainable development is a decline in material intensity and growth in material efficiency (which is the mathematical inverse of material intensity). Trends in material inputs and outputs in the majority of developed countries, however, continue to grow in absolute terms, which provides evidence of growing pressure on the environment and of unsustainable development.

3. MFA for the Czech Republic

3.1. Introduction

This section presents the results of the accounts, balances and indicators of material flows compiled for the Czech Republic based on the methodology Eurostat (2001). Some material flow indicators for countries with economies in transition have already been compiled for Poland (Mundl et al., 1999) and Hungary (Hammer, 2001). The indicators presented here for the Czech Republic are, however, the first results for a transitional economy derived from time-series data of balances and accounts over a relatively long period.

Data for MFA of the Czech Republic was acquired from official publications and databases of a large array of organisations, in particular the Czech Statistical Office, Ministry of the Environment, Ministry of Agriculture, Ministry of Finance, Geofond, Czech Hydrometeorological Institute, T.G.M Water Research Institute, Road and Motorway Directorate, Czech University of Agriculture in Prague, etc. Unused extractions associated with imports and exports were calculated on basis of coefficients acquired from the database of the Wuppertal Institute for Climate, Environment and Energy (2002). Some data had to be estimated or adjusted competently (overburdens, physical trade in 1990 and 1992).

For the purpose of international comparison of Czech indicators of material flows, countries or groupings of countries were chosen to reflect their geopolitical importance, and for which the necessary data was available (Germany, Austria, EU-15, Japan, United States and Poland). In the analysis of material flows, one of the most important factors is the development of gross domestic product. GDP fell by a dramatic 12% from 1990 to 1991 and continued to decline more moderately in the following year also. After the first years of decline, we can, therefore, identify three phases in the annual growth of both GDP and material flow indicators:

1) 1992–1993: period of relatively constant economic output—all material flow indicators declined.
2) 1994–1996: period of economic growth (2.2–5.9%)—growth in material flow indicators.
3) 1997–1999: period of economic recession (−0.4 to −1.2%)—first the growth of material flow indicators came to a standstill and they then declined by 10–15% in comparison to their values prior to the recession.
4) Since 2000: period of economic growth (2.9%)—moderate growth in material flow indicators.

3.2. A summary of material flow indicators for the Czech Republic

Table 1 and Fig. 1 present an overview of material flows in the Czech economy during 1990–2000, represented by eight main material flow indicators. All the indicators declined, by 20–40% in comparison to the year 1990, during the years immediately following the Velvet Revolution (1991–1993). Here it apparent fact that all material flow indicators correlate with the development of economic performance as indicated by GDP.

3.3. Direct material inputs and consumption, and the physical balance of foreign trade

DMI during the period analysed (1990–1999), except for the first decline in 1990, fluctuated around a relatively constant level. The total DMI for the Czech Republic during the 1990s was in the range 220–250 Mt (annually), or approximately 22–25 tonnes per capita (Fig. 2).

The DMI per capita of the Czech Republic is comparable with the DMI of other countries: Poland—14 tonnes per capita (1997 data), EU—15 tonnes per capita (1997 data), Germany approximately 23 tonnes per capita (1997 data), Japan approximately 17 tonnes per capita (1991 data), United States approximately 20 tonnes per capita (1991 data).

Analysis of the DMI indicator reveals that the extraction and harvest of natural resources contributed significantly to the structure of DMI in the Czech Republic. Their contribution to the total DMI fluctuated around $85 \pm 2\%$ (first half of the 1990s), later declining to 80%. Imports, which represent the other component of total DMI, thus increased from 15 to 20% of total DMI.

Non-renewable resources, specifically non-renewable domestic resources, dominated DMI in the Czech economy. Even though this item progressively decreased by 10% from its value in 1991, it still composed approximately 63% of the total DMI in 1999. Of this figure, at least half was comprised of coal extraction.

Physical imports to the Czech Republic decreased in 1991 by more than 50% (from 52 to 24 Mt). From 1992 onwards, imports increased year-on-year, except in 1997 and 1999; the recession in the Czech economy during 1997–1999 impacted on physical imports with a time lag. Imports in physical units represent a similar share in DMI as extraction of domestic biomass—17% on average. The two main commodities contributing to physical imports into the Czech Republic were fossil fuels and minerals; exports by contrast were more diverse in composition. In absolute terms, imports fluctuated around 40 Mt. The lowest rate of imports was approximately 24 Mt in 1991, following sharp economic decline. In the period after 1990, imports peaked in 2000 at 49 Mt. Exports reached their lowest level in 1991 (at 22 Mt); the highest level was observed in 1994 (46 Mt) and then fluctuated around 41–43 Mt until 2000 (Fig. 3).

Turning to the physical balance of foreign trade, the Czech economy displayed a relatively high dependency on material imports during the 1990s. In 1990 the surplus of imports over exports was as high as 22 Mt (economists would normally describe a situation where imports exceed exports as a trade deficit; physical and money flows have opposite signs). As the process of economic transformation began, the surplus decreased to about 1 Mt in 1993 and 1995; it then fluctuated around 6 Mt during the second half of the 1990s. Only in 1992 and 1994 did the physical trade

Table 1
Material flow indicators for the Czech Republic, 1990–2000

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Population (thousand)	10 363	10 309	10 318	10 331	10 336	10 331	10 315	10 304	10 295	10 283	10 273
GDP (CZK bn, current prices)	626	754	843	1020	1183	1381	1567	1680	1837	1887	1960
GDP (CZK bn, 1995 prices)	1449.4	1281.1	1274.5	1275.3	1303.6	1381	1440.4	1429.3	1412.2	1406.7	1447.4
Absolute figures (kt)											
DMI	331 673	253 327	238 873	240 176	230 686	237 984	249 950	249 183	233 594	221 505	230 531
DMC	302 307	230 883	206 709	204 005	184 258	193 165	208 309	208 685	193 102	180 199	187 662
PTB	22 254	1928	−1046	797	−7441	681	5416	6399	6635	2766	6088
DPO	217 641	198 309	180 162	172 394	162 085	163 530	166 734	170 971	165 044	157 567	161 026
NAS	194 806	133 817	120 536	119 817	105 043	110 126	125 156	121 860	110 402	101 227	104 470
TDO	739 925	689 741	625 736	592 031	566 581	553 248	543 870	561 807	537 932	483 139	480 505
TMI	853 958	744 759	684 447	659 813	635 182	627 702	627 086	640 019	606 482	547 077	550 009
TMR	986 009	807 954	751 240	754 112	725 328	736 997	744 569	753 071	722 393	672 906	673 468
TMC	872 598	712 263	633 963	596 418	536 567	550 728	569 558	578 386	562 958	514 214	493 804
Relative figures (tonnes per capita)											
DMI	32.01	24.57	23.15	23.25	22.32	23.04	24.23	24.18	22.69	21.54	22.44
DMC	29.17	22.40	20.03	19.75	17.83	18.70	20.19	20.25	18.76	17.52	18.27
DPO	21.00	19.24	17.46	16.69	15.68	15.83	16.16	16.59	16.03	15.32	15.68
NAS	18.80	12.98	11.68	11.60	10.16	10.66	12.13	11.83	10.72	9.84	10.17
TDO	71.40	66.91	60.65	57.31	54.82	53.55	52.72	54.53	52.25	46.99	46.78
TMI	82.41	72.25	66.34	63.87	61.45	60.76	60.79	62.12	58.91	53.20	53.54
TMR	95.15	78.38	72.81	73.00	70.17	71.34	72.18	73.09	70.17	65.44	65.56
TMC	84.21	69.09	61.44	57.73	51.91	53.31	55.21	56.13	54.68	50.01	48.07

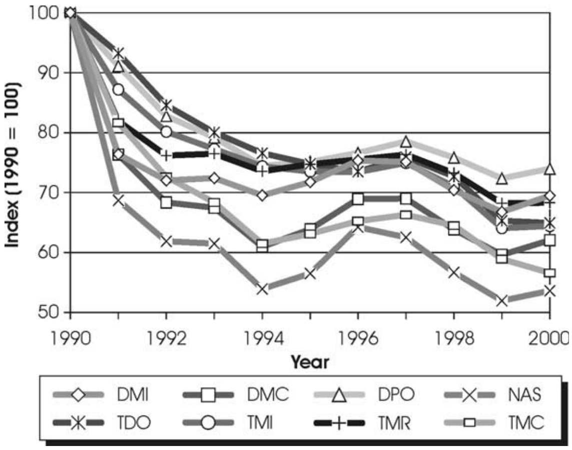

Fig. 1. Trends in material flow indicators, Czech Republic, 1990–2000 (index).

balance become negative at approximately 1 and 7 Mt, respectively.

The category of foreign trade (as defined in Eurostat, 2001; Ščasný and Kovanda, 2001) with the most significant positive balance (import surplus) in physical units consists of minerals and fossil resources (with balances for both of 6–8 Mt). By contrast, the category with the most significant negative balance (export surplus) consisted of semi-manufactured products and finished products made from minerals (2–4 Mt). Semi-manufactured products made from fossil resources, other abiotic and biotic products, and secondary raw materials, showed a relatively stable physical balance of foreign trade. A slightly negative balance in packaging materials (−0.64 Mt average) indicates that sophisticated products contributed more to export than to import (assuming that finished products are more packaged than loose or bulk materials).

MFA also offers interesting insights concerning the countries of origin for imports and of destination for exports. Fig. 4 shows that by far the highest share of raw material was imported into the Czech Republic from countries in transition—94% in 1993 and 83% in 2000. The decline in the share of imports from countries in transition was caused by increased imports from developed countries; in the same period imports from transition countries increased by about 17% in absolute terms, in line with the growth of total physical imports. Finished products on the other hand were exported predominantly to developed countries (66% in 1993 and 70% in 2000) followed by countries in transition (29 and 28%, respectively). Both exports to and imports from developing countries played an insignificant role in the Czech Republic's foreign trade.

DMC declined from 1990 to 1994 from 29 to 17 tonnes per capita; an economic revival led to its increase again in 1995–1997 to 20 tonnes per capita. During 1998–1999 DMC dropped to approximately 18 tonnes per capita. Similarly to

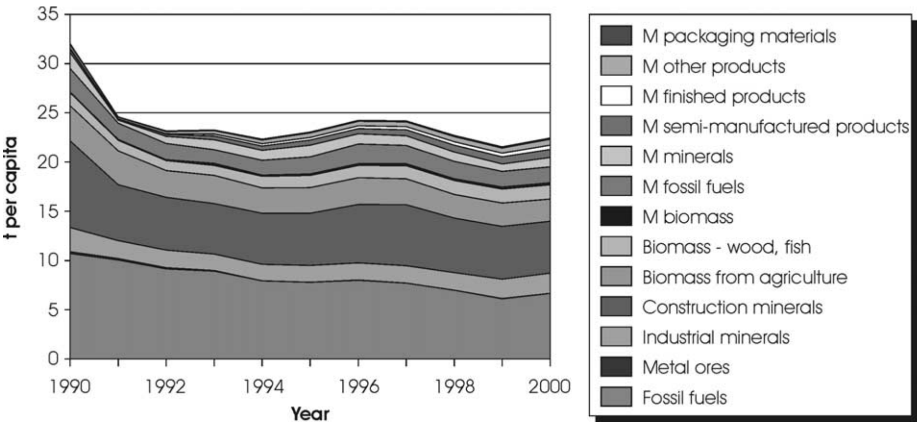

Fig. 2. DMI, Czech Republic, 1990–2000. Note, M-imports.

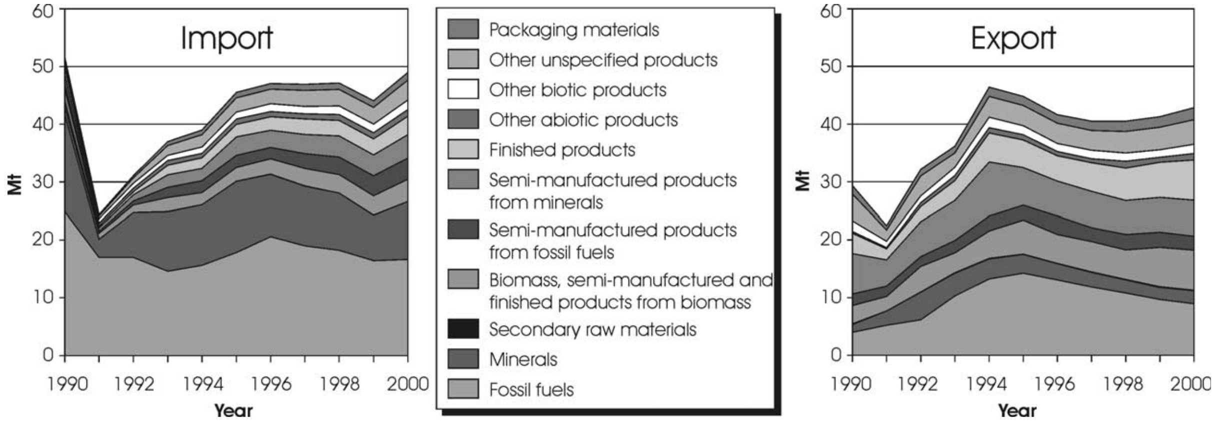

Fig. 3. Structure of (physical) import and export, Czech Republic, 1990–2000.

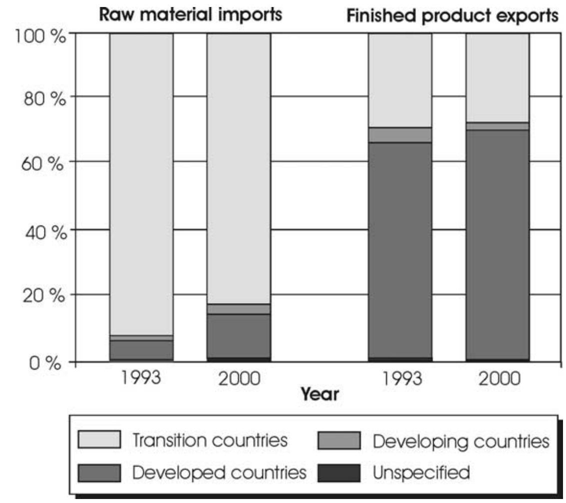

Fig. 4. Raw material imports and finished product exports, Czech Republic, 1993 and 2000. Note, raw materials and finished products according to HS codes as defined in Eurostat, (2001) methodological guide. Transition countries include Russia.

DMI, DMC for the Czech Republic is comparable with other industrial economies. Its structure is similar to that of DMI.

3.4. Domestic unused extractions

In the 1990s unused extractions dropped sharply in the Czech Republic, from 522 Mt (50.4 tonnes per capita) in 1990 to 325 Mt (31.7 tonnes per capita) in 1999. This drop was caused mainly by decreasing the category 'overburden from extraction of minerals and fossil fuels' which represented 90% of DUE during the last decade. About 97% of overburden from extraction of minerals and fossil fuels came from open pit lignite mining. Fig. 5 presents an international comparison of unused domestic extractions.

3.5. Total material requirements

The TMR for the Czech Republic during 1990–1999 fluctuated between 722 and 986 Mt annually

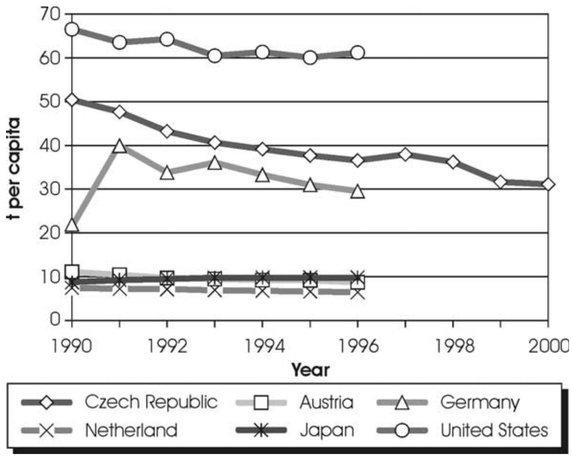

Fig. 5. Domestic unused extractions, international comparison, 1990–2000. Note, the figure for DUE in the Czech Republic excludes erosion, which is approximately 2 tonnes per capita. The figure for Austrian DUE also excludes erosion. Up to 1990, data for Germany refers to the Federal Republic of Germany only.

(70–95 tonnes per capita), with an upward trend from 1990. The difference between TMR and TMC, given by exports and indirect flows related to them, amounted to 100 Mt (10 tonnes per capita) during the period 1990–1992, and around 150–170 Mt (15–17 tonnes per capita) during 1993–1999. When compared internationally, the TMR of the Czech Republic for 1994 (Poland 1995) was higher than the corresponding figure for the EU-15 (approximately 53 tonnes per capita) or Poland (approximately 28 tonnes per capita), but lower than in Germany (circa 80 tonnes per capita), Finland (approximately 86 tonnes per capita) or the United States (circa 82 tonnes per capita).

The components of TMR can be analysed by the origins of flows (domestic, imports), by the types of flows (direct, indirect), or by examining the individual components, which make up the TMR. Hidden flows—excavations, overburdens and other unused extractions—dominate the TMR of the Czech Republic (Fig. 6).

3.6. Material outputs

The domestic material output of the Czech Republic dropped sharply in 1990–1994 (from 218 to 162 Mt), after which it maintained a relatively constant level. Its value per capita varied between 21 t in 1990 and 15 t in 1999 (in the EU-15 12 t, in Germany 13 t, in Japan 11 t and in the US 25 t for 1996; see Fig. 7).

The share of emissions of CO_2 in DPO is dominant, as in other industrial economies. Although CO_2 emissions decreased from approximately 16 tonnes to 11.6 tonnes per capita through the 1990s they still made up around 80% of DPO throughout this period.

TDO exhibited a similar trend, declining considerably during the 1990s from 740 Mt (71.4 tonnes per capita) in the year 1990 to 483 Mt (47 tonnes per capita) in the year 1999. Unused domestic extractions contributed significantly to this fall.

During the 1990s the DPO/GDP and TDO/GDP ratios declined in the Czech Republic. DPO/GDP dropped from 149.2 kg/1000 CZK in the year 1990 to 111.3 kg/1000 CZK in the year 1999 (a fall of 25.4%), whilst TDO dropped from 509.5 kg/1000 CZK in the year 1990 to 342.7 kg/1000 CZK in the year 1999 (a fall of 32.7%), making the latter decline somewhat more significant.

International comparison of the absolute values of the DPO/GDP ratio and TDO/GDP ratio, expressed as kg per 1 USD, reflects unfavourably on the Czech Republic. This is because, while the DPO and the total output in tonnes per capita of the Czech Republic were comparable with other

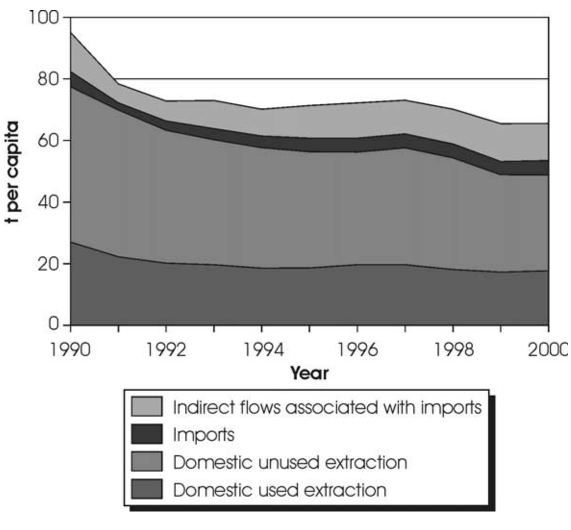

Fig. 6. TMR, Czech Republic, 1990–2000.

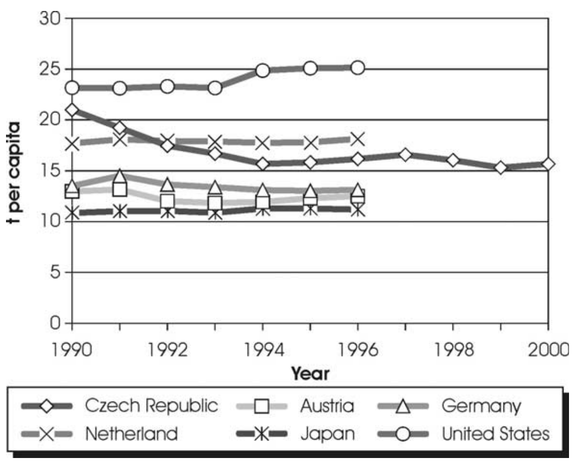

Fig. 7. DPO, international comparison, 1990–2000. Note, up to 1990, data for Germany refers to the Federal Republic of Germany only.

countries, economic performance (GDP per capita) was poor. The United States represents an exception in that TDO per capita is very high. The situation is much more favourable when considering the trends in DPO/GDP and TDO/GDP (see Fig. 8).

3.7. Net additions to physical stock

NAS for the Czech Republic was assessed as the difference between direct material inputs and total material outputs. NAS dropped significantly during the years 1991 and 1992 (from 195 to 121 Mt, approximately) and after that remained relatively constant, showing slight growth during the period of economic expansion during 1994–1996 and a slight drop during the period of economic recession during the years 1997–1999. Its per capita value varied between 9.8 tonnes per capita in 1999 and 18.8 tonnes per capita in 1990. Comparing NAS for the Czech Republic internationally we see that it differed from that of other countries by ± 4 tonnes per capita in the year 1996.

3.8. Material intensity and material efficiency

All indicators show that material intensity has been falling, for input indicators during 1990–1999 by approximately 30% and for consumption indicators by 40%. Graph 5 presents an international comparison of material intensity. The countries for which data are presented have reduced their material intensities by 20–30% within about 15 years (this finding applies also to Germany, excluding the effects of re-unification with the German Democratic Republic). The Czech Republic succeeded in decreasing its material intensity, as measured by the indicator TMR per unit GDP, by 30% within 10 years (Fig. 9).

As material intensity dropped, material efficiency—as represented by all indicators of material input and consumption—increased. An international comparison of trends is similarly favourable to the Czech Republic. But the opposite is true when comparing absolute values. At the end of the period analysed, material efficiency (expressed as DMI/GDP PPP) in the Czech Republic equalled just half of the comparable figure for Greece, and one quarter of that for Austria, Germany and the EU-15. Measured using

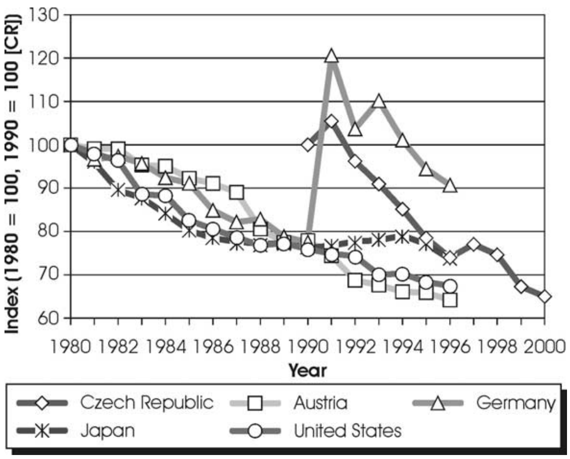

Fig. 8. TDO per GDP (TDO/GDP). International comparison, 1980–2000 (index). Note, GDP in 1996 prices; GDP-CR purchasing power parity. TDO of the Czech Republic does not include domestic erosion that was approx. 2 tonnes per capita, TDO of Austria also excludes erosion. Up to 1990, data for Germany refers to the Federal Republic of Germany only.

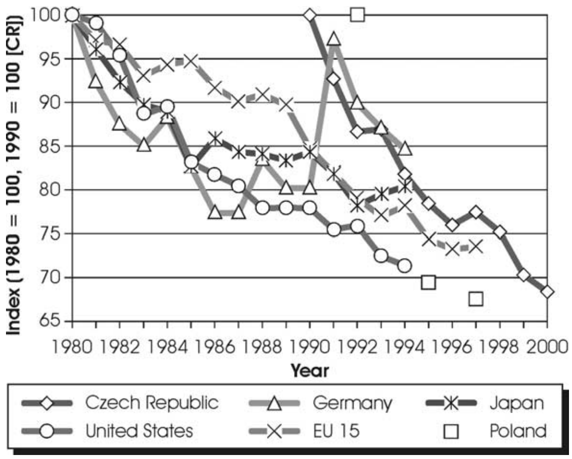

Fig. 9. Material intensity (TMR/HDP), international comparison, 1980–2000. Note, GDP in 1996 prices; GDP-CR purchasing power parity. TMR of the Czech republic excludes erosion (domestic, as indirect flow of import) that is approximately 2.5 tonnes per capita. Up to 1990, data for Germany refers to the Federal Republic of Germany only.

market exchange rates, the material efficiency of the Czech economy was even worse.

3.9. Decoupling of environmental pressure and economic performance of the Czech Republic

During the 1990s indicators for the Czech Republic of direct material inputs, consumption and outputs decoupled from economic performance as expressed by GDP (Fig. 10). Analysis of material intensity and efficiency reveals that relative decoupling occurred in most of the 1990s, i.e., that GDP growth was associated with a lesser increase in material flow indicators (or a contraction in GDP was associated with a sharper fall in material flow indicators). Decoupling of economic performance and emitted pollution was to be seen throughout the whole of the 1990s. Decoupling occurred for both DPO and TDO, though more notably for TDO (where there was a greater drop in TDO/GDP).

Absolute decoupling (growth of GDP accompanied by a fall in material flow indicators) occurred only in 1993 and 1994, when GDP grew whilst indicators of direct material inputs, consumption and outputs decreased. For TDO specifically, absolute decoupling can also be observed in 1995–1996.

Relative decoupling (higher growth of economic performance than growth of environmental pressure) occurred in 1995–1996 and 2000, except

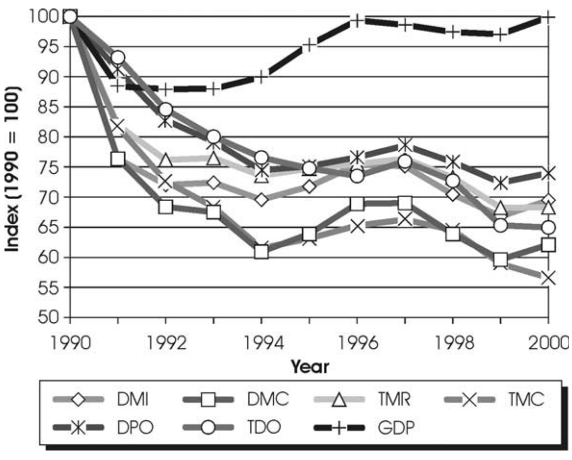

Fig. 10. Decoupling, Czech Republic, 1990–2000.

DMI and DMC in 1996 and 2000 when these indicators increased by higher rate than GDP growth.

The positive decrease in indicators of material inputs, consumption, and outputs was associated with a drop in economic performance in 1998–1999 as well as 1991–1992. We call this situation as a negative relative decoupling—lesser drop of GDP than a fall of environmental pressure.

The worst outcome, absolute convergence (opposite to absolute decoupling), occurred in 1997 when a year-on-year GDP fall of −0.8% was associated with an increase in TDO (+3.3%) and DPO (+2.5%), as well as a moderate increase in DMC (+0.2%), TMR (+1,1%).

3.10. The relationship between economic development and material flows during the 1990s

November 1989 saw the overthrow of the Communist system in Czechoslovakia with the so-called 'Velvet Revolution'. At that time the former Czechoslovakia set out on the process of transition towards democracy and a free market economy. This process was accompanied initially by a sharp drop in economic output. Gross domestic product decreased year-on-year by about 12% in 1991 followed by a further 1% decline in 1992. During the rest of the decade the Czech Republic recorded positive economic growth with the exception of a recession in 1997–1999, and reached approximately its 1990 level of economic output in 2000. The transition process was associated with a considerable change in the structure of GDP, expressed as the share of various sectors in GDP (in 1995 constant prices). The share of agriculture decreased slightly from 5.4 to 5.3% between 1991 and 2000, and the share of industry and construction decreased from 42.3 to 38.6% in the same period. On the other hand, the share of services in economic output grew from 52.2 to 56.1% (MoE, 2001a). The economic transformation resulted in a decrease in the mining of lignite, coal and minerals by about 36% (Geofond, 1995, 2000, 2001). The structure of primary energy sources shifted in favour of cleaner fuels, notably towards more use of natural gas—the share of solid fuels fell from 65% of domestic consumption of primary energy sources in 1990 to 51% in 2000. In the same period, the share of liquid fuels share increased by 3% and that of gaseous fuels by 9%. (MoE, 2001b). Gross manufacturing value added decreased by 25% after 1990 and by a further 15% after the division of the former Czechoslovakia in 1993. The decline later returned to growth, but in 2000 gross manufacturing value added had still not reached the 1990 level (MIT, 2001). Agricultural production expressed as gross agricultural output decreased from 106 billion in 1990 to 74 billion in 2000 (CZK, 1989 constant prices) (CSO, 1991–2001).

During the transition process, the sectoral structure of Czech industry gradually converged with the EU average. The largest changes took place in metallurgy, the electro-technical industry, transport, engineering and the textile industry. Investment in new capacity resulted in the production of a new and competitive array of components for the transport and electro-technical industries. Simultaneously, labour productivity increased in all these industrial sectors as a consequence of the restructuring process (e.g., in the manufacturing of motor vehicles, trailers and semi-trailers, labour productivity—expressed as value added per employee—increased from 181.4 in 1994 to 541.9 in 2000, measured in thousand CZK in 1994 constant prices). At the end of the 1990s nearly 800 companies with foreign equity participation operated in the Czech Republic and employed approximately 55,000 employees (MIT, 2001). Much new production capacity was associated with foreign direct investment, which was encouraged especially at the end of 1990s by the 1999 Act on Investment Incentives.

The catastrophic state of the environment in the Czech Republic after 1989 was dramatically improved during the transition period, especially as a result of the massive introduction of costly end-of-pipe technologies in the energy sector, the best example being the installation of desulphurisation plant for essentially all large thermal power plants. This investment represented a major share of the total investment in air protection, which reached 4.2 billion USD in the years 1993–2000; and total investment in air protection in turn represented about 52% of total environmental investments in this period. Even though there was no significant effort to support systematically the development and implementation of environmentally sound technologies, many companies gradually implemented measures increasing material and energy efficiency (for instance, 135 firms gained certification for their environmental management systems in line with international standards up to July 2001, MoE, 2001b).

Fig. 10 shows that trends in material flow indicators tend to follow the course of GDP: when GDP is undergoing prolonged growth, material flow indicators start to grow also; and vice-versa. Changes in GDP trends, however, show up in material flow indicators with a certain inertia: for instance, the sharp decrease in material flow indicators in 1991 and 1992 was induced particularly by the decrease in economic output starting in 1990, and the concomitant decrease in industrial production, mining, foreign trade etc. Many heavy industries reduced production in response to the loss of Eastern bloc markets and other export possibilities, or were even forced to close. A significant decrease in import of fossil fuels and raw materials for dilapidated Czech heavy industry is obvious in the foreign trade statistics for 1991. As regards output indicators, decreases in later years can be partly attributed to the introduction of end-of-pipe technologies and partly to the modernisation of the industrial base of the Czech economy. On the other hand, the decrease in input and consumption indicators is linked primarily with the introduction of modern technologies (demanding fewer material and energy resources). This analysis is in line with official statistics showing that the energy intensity of the national economy also decreased by about 27% during the 1990s (MoE, 2001b).

The potential of end-of-pipe technologies has already been exploited to the extent that for output indicators, no additional improvements can be achieved through their further application. The solution lies in technological innovation and implementation of environmentally sound technologies on a much larger scale, which also represents an essential condition for a further decrease in input and consumption indicators.

4. Ongoing research and recommendations for improvements

Based on our experience in compiling material flow balances and accounts we recommend the following improvements to the methods used:

1) It should be unambiguously stated which items are included in particular accounts and derived indicators. This note applies especially to erosion. In most studies to date erosion has been included as a component of material flow indicators (Adriaanse et al., 1997; Matthews et al., 2000, Bringezu and Schütz, 2001a,b). According to the Eurostat methodology, however, erosion should represent just a complementary memorandum item and should not be included in the derived indicators. Given the approach of previous studies and the value of comparability, it is worth considering whether erosion should not be included into the MFA indicators.
2) The means of disaggregation of output flows against individual sectors should be set unambiguously. Should the NACE classification or some other system be used? Since output flows connected to particular sectors differ between studies for industrialised economies, in some cases by about an order of magnitude (see Matthews et al., 2000), it is probable that even in these cases the same classification was not used.
3) It is important to specify unambiguously which CO_2 emissions should be included in material flow accounts. The Eurostat (2001) recommends taking these data from the International Panel on Climate Change (IPCC) inventory, but does not specify in detail which CO_2 emissions should be included. Our proposed grouping of emissions into particular sectors, based on the IPCC inventories, which we also used when compiling material flow accounts and indicators for the Czech Republic, is shown in Appendix 1.
4) For comparability of indicators, it should be clearly stated whether CO_2 emissions should be recorded on the output side and input of oxygen in the balancing item on the input side, or whether only carbon content on the output side should be recorded.
5) Water flows present a problem for MFA at macroeconomic level, because of the water content of materials and the use of drinking water for production. This problem becomes particularly evident when compiling a material balance that should respect the following identity: total inputs = total outputs + change of physical stock. We propose putting as many flows as possible into balancing items, which could then be used to resolve this problem. This problem is not resolved in the guide Eurostat (2001) yet presents a serious methodological omission, especially in the case of foreign trade. Imported drinks and other liquids consumed within the boundaries of the state concerned are not calculated on the output side and, therefore, they act to increase the net additional stock. Similarly the volume of exported drinks and liquids that were produced in that state is not calculated on the input side, resulting in a greater decrease in NAS than there should be in reality. This issue is negligible only in the case of a neutral PTB for all drinks and liquid items. The same problem also occurs when including biomass from agriculture reported in its fresh weight, that is, with its water content.
6) When estimating the water released in the combustion of fossil fuels it could be beneficial to use the GEMIS model (Global Emission Model for Integrated Systems, see web site of Öko-Institut, 2002), which includes a database of many fuels and processes used.
7) Air emissions should also include other pollutants such as heavy metals.
8) The current calculations of TMR are in some respects misleading because TMR calculations for various countries are based on more or less the same database of coefficients of unused extractions related to imports (from the Wuppertal Institute). This problem is particularly associated with the absolute

TMR figure for any country; it is not so significant when comparing different countries. Similarly the value of the TMI indicator (i.e., direct material inputs plus unused domestic extraction) may be understood more as an indication of a better database for the country in question than as an indication of a relatively higher volume of flows of unused extractions. For this reason, analysis and decision-making should focus on indicators that do not include unused extraction. Unused extraction should be analysed independently.

9) Data on the dry mass of emissions to water, including sewage sludge, are particularly problematic to obtain. So as to ensure the material balance of biomass used for human food consumption, a check of output flows (and simultaneously net additional stock) could be based on the estimation of average human consumption of particular food types.
10) When analysing a given time series of material flow indicators related to GDP (e.g., material intensity and efficiency), GDP should be calculated in constant prices for an explicitly mentioned and arbitrarily chosen year. When making international comparisons of time-series indicators, GDP should be calculated in USD or EUR using both the annual average market exchange rate and a purchasing power parity rate.

There remains a series of open, unresolved questions. These include the following:

1) The Eurostat methodology suggests that the packaging associated with imports should be included as part of direct input flows. Some materials are imported and exported in containers, and foreign trade thus involves a material flow (of containers) across the border. The same problem also applies to vehicles. The problem of 'moving stocks' is particularly associated with transport where the means of transport enters and exits the domestic economy in a manner similar to imports and exports of commodities.
2) How should specific CO_2 emissions and emissions of other greenhouse gases (such as fugitive emissions and emissions from rice cultivation) be included in material flow accounts?
3) In this MFA for the Czech Republic electricity was included as part of the indirect flows associated with imports only as the amount of materials necessary for its generation. Can this method be justified? How can we solve the problem that electricity can be generated from renewable resources or from nuclear energy, neither of which involves the direct use of fossil fuels, without using lifecycle analysis?
4) Decreasing material throughput should be a primary objective of any sustainable development strategy. In some systems, however, especially natural ones, large material flows do not always have to cause problems (e.g., in rainforests). Examining the metabolism of natural systems is a great source of inspiration. The volume of material and energy flows in mature and undisturbed ecosystems may represent a model that can be imitated in the technosphere or industrial metabolisms. The two examples above trigger a whole series of questions for the formulation of policy and for the assessment of industrial metabolisms. What material and energy throughput is sufficient for a given socioeconomic system? What is the 'correct' level of independence between regions? Should it be an objective to achieve a certain level of regional autarchy and thus to achieve a drop in all flows between regions, at the expense of an increase of flows within individual regions? It is difficult to find answers to these questions, but MFA provides a tool which could help to find answers to them or at least to understand the questions better.

Further research in the Czech Republic should focus on two areas:

1) Improving the quality of MFA data for the period 1990–2000, compiling accounts and balances for other years, and quantifying uncertainties in the indicators.

2) A more profound analysis of the links between economic development and material flows.

Since the period 2000–2002 witnessed an economic turnaround in the Czech Republic after the economic recession during 1997–1999, the MFA and derivation of indicators for these years should provide a very useful output for future development strategies in the Czech Republic. The work on this subject is in progress.

Acknowledgements

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Appendix A: Annex 1

IPCC classification of GHG emissions and their relevance for the material flow balance.

Sectoral tables for GHG emission	Classification according to the IPCC-description	Sector for MFA
1A1	Energy: energy industries	AIR-energy
1A2	Energy: manufacture and construct	AIR-energy
1A3	Energy: transport	AIR-transport
1A4a	Energy: other—commercial/institute	AIR-others
1A4b	Energy: other—residential	AIR-households
1A4c	Energy: other—agriculture/forestry/fisheries	AIR-agriculture
1A5a	Energy: other—stationary	AIR-others
1A5b	Energy: other—mobile	AIR-agriculture
1B	Energy: fugitive emissions[1]	Memo/UDE
Bunkers	Energy: memo items—inter. bunkers	AIR-bunkers
2	Industrial processes	AIR-industry
3	Solvent and other product use[2]	in ‘dissip. use of products’
	—60101, 60108, 60200, 60300, 60401–60405	Industry
	—60130, 60105, 60107, 60109, 60406	Construction
	—60104, 60408	Transport
	—60412	Agriculture
	—60102, 60106, 60407, 60409–60411	Others
4A	Agriculture: enteric fermentation	AIR-agriculture
4B	Agriculture: manure management	NON
4C	Agriculture: rice cultivation[1]	Memo/UDE
4D	Agriculture: agricultural soils	NON
4E–F	Agriculture: burning of Savanas/fields	NON
5	Land-use change and forestry	NON
6A	Waste: waste disposal	NON
6B1	Waste: wastewater—Industrial	AIR-industry
6B2	Waste: wastewater—domestic/commercial	AIR-households

Table 1 (*Continued*)

Sectoral tables for GHG emission	Classification according to the IPCC-description	Sector for MFA
6B3	Waste: wastewater—other	AIR-others
6C	Waste: waste incineration	AIR-households and industry[3]

Notes:

IPCC categories that should not be included in MFA accounts and balances are marked with 'NON'. The note 'AIR' refers to the emissions to air which are included in DPO indicators.

1) Fugitive emissions resulting from excavation of fossil resources and emissions of greenhouse gases from paddy fields should be stated in the memorandum item. If they are included in material flow indicators they should be a part of unused domestic extractions. They are caused by economic activities—by coal mining and by cultivation of rice—but they do not enter the economic system.
2) Solvents are divided into sectors according to the SNAP classification—sector 60000. They are included under the dissipative use of products category in MFA.
3) Emissions of CO_2 are divided into domestic and industrial according to their contribution to the production of incinerated wastes.

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What are the possibilities for graphical presentation of decoupling? An example of economy-wide material flow indicators in the Czech Republic

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Abstract

The relationship between the environmental and economic domains has attracted researchers and politicians for at least several decades [Boulding, K., 1966. The economics of the coming spaceship earth. In: Boulding. K., et al. (Eds.), Environmental Quality in Growing Economy. Hopkins University Press, Baltimore, Marylang; Meadows, D.H., Meadows, D.L., Randers, J., Behrens, W.W., 1972. The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind. Universe Books, New York; Schmidt-Bleek, F., 1994. Wieviel Umwelt Braucht der Mensch? MIPS—Das Mass für Ökologisches Wirtschaften. Birkhäuser-Verlag, Berlin, Basel, Boston]. The overall goal of sustainable economies is to reach a state where the general quality of life is growing while the environmental pressures go down [EC, 2001. A Sustainable Europe for a Better World: A European union Strategy for Sustainable Development. Commission of the European Communites, Brussels; EC, 2002. The Sixth Community Environment Action Programme. Commission of the European Communities, Brussels; EC, 2003a. 2003 Environmental Policy Review. Commission of the European Communities, Brussels; EC, 2003b. Towards a thematic strategy on the sustainable use of natural resources. Commission of the European Communities. Brussels; UN, 2002. Plan of Implementation of the World Sunnit on Sustainable Development. United Nations, New York.]. This phenomenon is called decoupling. To express decoupling, one usually aims to capture the mutual relation between an indicator of economic driving forces (most commonly Gross Domestic Product/GDP/, which is usually taken as a proxy of quality of life here) and an indicator of environmental pressure. When analysing decoupling, it is not quite clear how to proceed in terms of both selection of appropriate pressure indicators and presentation of decoupling. In this article, we focus on the issue of graphical presentation of decoupling analysis, particularly using economy-wide material flow indicators (EW-MFI) [Eurostat, 2001. Economy-Wide Material Flow Accounts And Derived Indicators: A Methodological Guide. Eurostat, Luxembourg]. One of the most commonly used methods for graphical presentation of decoupling by EW-MFI is to plot time series of indexed values of these indicators and GDP in a single chart. Here, however, it is difficult or even impossible to analyse causes of the different decoupling for particular indicators—to do this we propose to analyse time series of their components. To show the contribution of the components to the overall decoupling of an indicator, we suggest expressing the weighted share of particular components in overall indicator decoupling. For that we have tested the direct material input indicator (DMI), which is also recommended by OECD for decoupling analysis [OECD, 2002. Indicators to Measure Decoupling of Environmental Pressures from Economic

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Growth. OECD, Paris]. The expression of the weighted share of the indicator components in indicator decoupling has proved to be especially transparent in the case of this indicator, because the DMI belongs to the least aggregated material flow indicators. Nevertheless, the proposed method of expression can also be applied to other material flow indicators, as exemplified by the domestic material consumption indicator (DMC).

Keywords: Social/societal metabolism; Economy-wide material flow analysis; Decoupling of environmental pressure from economic performance; Graphical presentation of decoupling; Czech Republic

1. Introduction

In order for an economic system to function and produce goods and services necessary to meet human needs, it behaves similarly to a living organism. It absorbs materials and energy 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. On the input side the economic system principally absorbs fossil fuels, minerals, harvested biomass, water, and oxygen, while on the output side it discharges gaseous and liquid emissions into the water, air and soil, and solid wastes to landfills. This one-way flow of materials is typical for an industrial or social/societal metabolism (Moldan, 1983; Baccini and Brunner, 1991; Fischer-Kowalski and Haberl, 1993; Ayres and Simonis, 1994).

Both input and output flows associated with social metabolism exert some pressure on the environment. So far, there has been a positive relation between meeting human needs (improvement in quality of life) and this pressure. The overall goal of sustainable economies is to reach a state where the general quality of life goes up while the environmental pressures go down (EC, 2001, 2002, 2003a,b; UN, 2002) (Fig. 1). This phenomenon is called decoupling.

It seems that there is a large array of indicators representing environmental pressures which are suitable for decoupling analysis. OECD (2002) arranges these indicators into subject areas such as climate change, air pollution, water quality, waste management and material use. It is acknowledged internationally (EEA, 2000; OECD, 2002; Bringezu, 2002) that indicators derived on the basis of economy-wide material flow analysis (EW-MFA) (Eurostat, 2001) are an appropriate tool for decoupling analysis in the area of material requirements and material throughput of economies.

Research into decoupling of EW-MFI from GDP has so far been predominately focused on driving forces influencing different extent of decoupling in different countries (Bringezu et al., 2004; Bringezu and Moll, 2005). In this article, however, we focus on the often ignored issue of graphical presentation of decoupling analysis using EW-MFI. Section 2 briefly

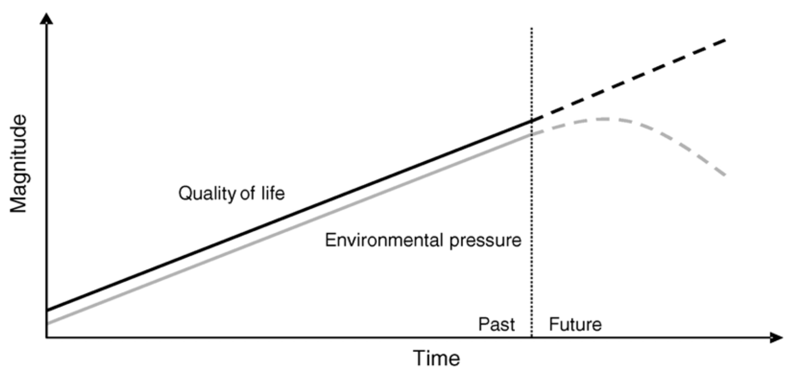

Fig. 1. Decoupling of environmental pressure from quality of life (source: EEA, 1999, modified).

presents the methodology of EW-MFA standardised by Eurostat (2001) and main indicators based on this analysis. Section 3 describes the decoupling concept and currently used means of graphical presentation of the decoupling information. In Section 4.1, we use this graphical presentation of decoupling in an example of EW-MFI derived for the Czech Republic. We argue that, to answer why some EW-MFI decoupled more than others, we have to analyse trends of their components and not only visualise the time series of the indicators themselves. This is why we suggest a new means of visualisation of decoupling analysis using EW-MFI: first, a separate image for the indicators and their components (Section 4.2.), and then an integrated image (Section 4.3.). In Section 5, we make some conclusions about different means of graphical presentation of decoupling information in relation to their suitability for various purposes and audiences.

2. Methodology for material flow analysis at a macroeconomic level

Economies and the environment are linked predominantly through material and energy flows. These flows are the key cause of serious environmental problems (together with human appropriation of areas or spaces, in the broader sense of the word) and can serve as an indirect indicator of human pressure on the environment. Methods assessing human-induced material and energy flows are based on their quantification using the input-output analysis.

The most comprehensive and systematic methods for material flow analysis for a specific economic-political system are: (i) input–output tables that open the ‘‘black box’’ of the economy by tracing material flows among individual economic sectors and (ii) accounts and balances of total material requirements and outputs at a macroeconomic level. The latter method, referred to as economy-wide material flow analysis (EW-MFA), was developed during the 1990s by several research institutes (principally the World Resources Institute; the Wuppertal Institute for Climate, Environment and Energy; the Austrian Institute for Interdisciplinary Studies and Eurostat); it was subsequently standardised by Eurostat (2001).

The Eurostat methodology quantifies physical exchange between the national economy, the environment and foreign economies on the basis of total material mass flowing across the boundaries of the national economy. Flows inside the economy, for example materials or products moving between various sectors, are not included; the economy is treated as a ‘‘black box’’. Material inputs into the economy consist primarily of extracted raw materials and produced biomass that have entered the economic system (this biomass is composed of, for example, harvested crops and wood). Material outputs consist primarily of emissions to air and water, landfilled wastes and dissipative uses of materials (e.g. fertilisers, pesticides and solvents).

The methodology also includes an interesting 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 flows associated with imports and exports.

Based on the input and output flows described above, a large array of EW-MFI can be compiled. The most commonly used EW-MFI are usually divided into several groups.

2.1. Input indicators

- Direct material inputs (DMI) equals used domestic extraction (excavated raw material, harvested biomass) plus imports.
- Total material requirements (TMR) includes domestic used and unused extractions, imports and their indirect flows.

2.2. Output indicators

- Domestic processed output (DPO) comprises emissions to air, landfilled wastes from industrial processes and households, the material load in wastewater and dissipative uses and losses of products.
- Total domestic outputs (TDO) includes DPO and unused domestic extractions.

2.3. Consumption indicators

- Domestic material consumption (DMC) is calculated as DMI minus exports.
- Total material consumption (TMC) is TMR minus exports and their indirect flows.
- Net additions to stock (NAS) measures the physical growth rate of the economy. Each year new materials are added to economic stocks, such as new buildings and durable goods, whilst old materials are removed from this stock and become wastes.

The EW-MFI are usually presented and analysed in time series. To deepen their analytical potential and/or allow their comparability across countries, they can be further related to some reference scales such as population, area or economic output.

3. Methods for expressing decoupling of environmental pressure from economic performance

The relationship between the environmental and economic domains has attracted researchers and politicians for at least several decades (Boulding, 1966; Meadows et al., 1972; Schmidt-Bleek, 1994). To express decoupling, one usually aims to capture the mutual relation between an indicator of economic driving forces and one of environmental pressure. Environmental pressure can be represented, for instance, by consumption of energy or materials, traffic intensity, released emissions or generation of wastes, while gross domestic product (GDP) is often taken as a proxy for standard of living, welfare or even quality of life in these analyses and it is used as the indicator of economic driving forces.

Decoupling can be *relative* or *absolute* (EC, 2003a,b). When a relative decoupling occurs, either the economic growth is accompanied by a lower growth in the environmental pressure indicator, or a decrease in the economic growth is accompanied by a larger decrease in the released pollution. When an absolute decoupling occurs, the economic growth goes up while the absolute volumes of pollution or resource extractions go down.

What are the possibilities for communicating decoupling? OECD (2002) suggests using the decoupling factor (K_{dec}), which can be plotted in a chart for better visualisation. This factor is calculated as follows:

$$\begin{aligned} K_{\mathrm{dec}} &\\ = 1 - {}&(\text{environmental pressure variable}/\\ &\text{variable of economic driving forces})_{\text{end of period}}/\\ &(\text{environmental pressure variable}/\\ &\text{variable of economic driving forces})_{\text{start of period}} \end{aligned} \tag{1}$$

Decoupling occurs when K_{dec} is higher than zero. The maximum value of K_{dec} equals 1; in such a case the environmental pressure variable equals zero. The decoupling factor does not allow distinguishing between relative or absolute decoupling; it just shows the ‘‘decoupling rates’’ of two particular variables. However, the decoupling factor is convenient for e.g. international comparison. A simple table and/or chart can show what would otherwise have to be expressed by several charts or a long text (Fig. 2).

Fig. 2 shows that the most pronounced decoupling of greenhouse gases from GDP among selected countries occurred in Luxembourg and the least notable in Belgium.

The most direct manner of displaying decoupling between an environmental pressure and an economic driving force is to plot two indexed time-series representing these phenomena in the same image. From such a chart, it is immediately clear whether the economic driving force is growing or shrinking, whether decoupling – absolute or relative – is occurring, when it started and whether it is continuing. Here, decoupling for the whole period of time since a starting year is shown in a chart (e.g. for 1990–1991, 1990–1992 or 1990–2000), and not decoupling between two consecutive years (1991–1992, 1992–1993, etc.). Fig. 3, which plots greenhouse gas emissions and GDP in the Czech Republic in 1990–2000, shows that

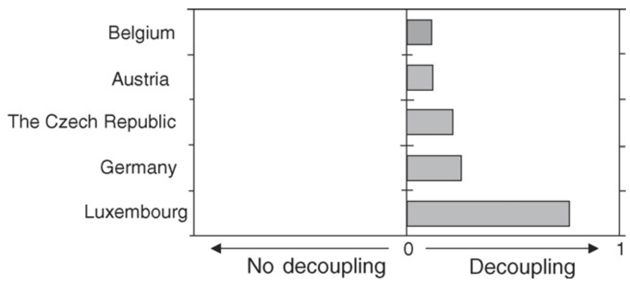

Fig. 2. Decoupling factors for greenhouse gas emissions and GDP, international comparison, 1990/1999 (source: OECD, 2002).

an absolute decoupling occurred between 1990 and 2000 (in 2000, GDP was slightly higher and emissions deep below the 1990 levels) and that the most positive development was recorded in 1993–1995.

Decoupling can also be expressed as ecological efficiency. In this case, only one curve shows the time series of the ratio between an environmental pressure variable and a variable of economic driving forces (ecological intensity) or vice versa (ecological efficiency). This ratio can be expressed in absolute terms or as indexed values. The goal of the presentation in Fig. 4 is just to track the trend: a desirable trend is observed when the ecological intensity goes down (or the ecological efficiency goes up). However, this picture does not allow distinguishing between relative or absolute decoupling occurring.

The mutual relation between both ways of expressing the decoupling phenomenon is clearly evident by comparing Figs. 3 and 4. Where the curve goes up in Fig. 4 (the ecological intensity increases), decoupling does not occur in Fig. 3 (1990–1991, 1995–1997, 1999–2000). On the contrary, where this ratio goes down in Fig. 4, an absolute or relative decoupling can be observed in Fig. 3 (1991–1995, 1997–1999). Decoupling and ecological efficiency can therefore be considered complementary concepts.

4. How to plot decoupling using economy-wide material flow indicators

4.1. Current methods of graphical presentation of decoupling

In general, the indicators compiled on the basis of the EW-MFA are considered appropriate tools for expressing decoupling. Various researchers have used, e.g. DPO and TDO (Bringezu and Schutz, 2000), TMR (Bringezu, 2002) or DMI and TMR (EEA, 2000) indicators for this purpose. In its subject-focused

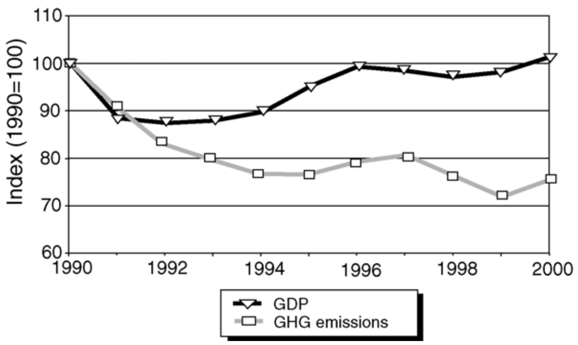

Fig. 3. Decoupling of environmental pressure from economic growth—greenhouse gas emissions (as $CO_{2eq.}$) and GDP, Czech Republic, 1990–2000 (source: Fott et al., 2002/$CO_{2eq.}$/; Czech Statistical Office, 2003/GDP/).

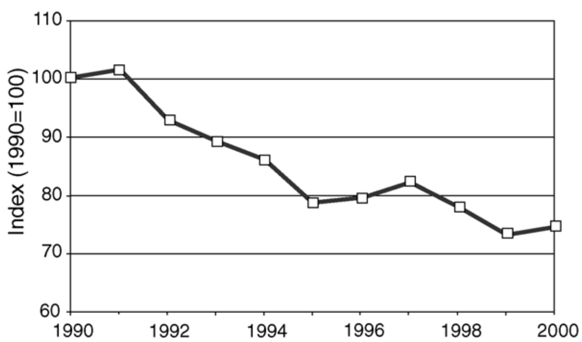

Fig. 4. Ecological intensity (ratio of greenhouse gas emissions and GDP), Czech Republic, 1990–2000 (source: Fott et al., 2002/$CO_{2eq.}$/; Czech Statistical Office, 2003/GDP/).

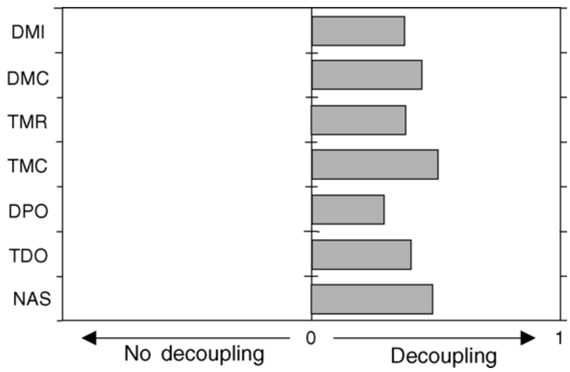

Fig. 5. Decoupling factors (K_{dec}) for EW-MFI and GDP, Czech Republic, 1990–2001 (2002) (source: Kovanda et al., 2004/EW-MFI/; Czech Statistical Office, 2003/GDP/).

paper, OECD (2002) prefers DMI because its calculation is not as data-demanding as TMR, and moreover, it seems that DMI is highly correlated with TMR. However, the question which material flow indicators are the most suitable for expressing decoupling still remains open for further research.

Presentation of decoupling using EW-MFI is exemplified on data for the Czech Republic. Data for 1990–2000 were compiled by Ščasný et al. (2003) and further extended by Kovanda et al. (2004). Various methods of expressing decoupling of environmental pressure from economic performance are shown in Figs. 5–7.

As evident from Figs. 5–7, all EW-MFI decoupled from economic performance between 1990 and 2001 (1990–2002), ecological intensity (called material intensity herein) thus decreasing. The most pronounced decoupling occurred in the case of TMC, the least pronounced in the case of DPO.

When we plot decoupling of more EW-MFI in a single chart (Fig. 6), we get a rather puzzling tangle of curves: only the main trends of the variables can be seen. Moreover, the analytical potential of this method is limited. For example, no conclusions can be deduced from the interesting fact that ‘‘different’’ decoupling occurred in case of DMI and DMC, and DPO and TDO. We have to analyse the time development of their components to be able to answer why some material flow indicators decoupled more notably than others.

In the following text, we will focus on the simple method of graphical presentation of decoupling (Fig. 6), which is the most commonly used (OECD, 2002; EEA, 1999), and we will elaborate on its possible modifications.

4.2. *Decoupling analysis by means of examining the components of economy-wide material flow indicators: separate images for indicators and their components*

In order to analyse the development of various components of EW-MFI, we can follow a few different paths. First, we can examine the trends of the components (in the form of indexed values) in a separate image (Fig. 8).

Indicator component analysis based on Fig. 8 elucidates the different extent of decoupling of some EW-MFI. For example, it is possible to explain the fact that consumption indicators (DMC, TMC) decoupled,

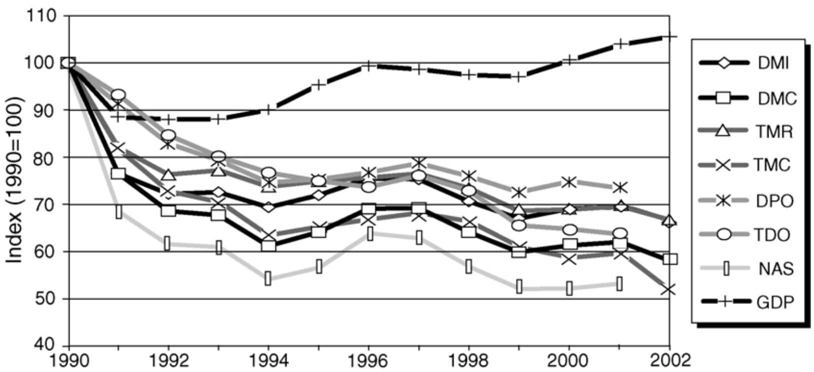

Fig. 6. Decoupling of environmental pressure from economic growth (EW-MFI and GDP), Czech Republic, 1990–2001 (2002) (source: Kovanda et al., 2004/EW-MFI/; Czech Statistical Office, 2003/GDP/).

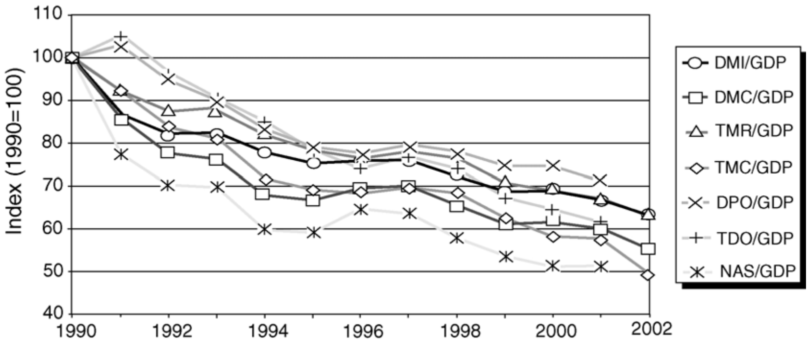

Fig. 7. Material intensity, Czech Republic, 1990–2001 (2002) (source: Kovanda et al., 2004/EW-MFI/; Czech Statistical Office, 2003/GDP/).

on average, to a larger extent than input indicators (DMI, TMR) (see Fig. 5). This was caused by a growth in exports (EX) and indirect flows associated with the exports (IFEX) between 1990 and 2002. (These components are subtracted from input indicators. Therefore more pronounced decoupling of consumption indicators occurs when exports and their indirect flows grow.)

However, this approach is not sufficient for a deeper analysis. For instance, if we wished to explain a degree of DMI and TMR decoupling on the basis of their component analysis, we would be heading for a blind alley. This is because we are not tracking the absolute values of domestic extraction (DE), imports (IM), unused domestic extraction (UDE) and indirect flows associated with imports (IFIM), but their relative changes (Fig. 8). Plotting the material flow indicator components with their absolute values does not help in this respect: the effect of these components on decoupling is not obvious, because the annual change is not distinctive enough; moreover, their absolute values differ too much and that is why one cannot choose an appropriate scale of reproduction to show the time development of all the components in a single chart.

4.3. Decoupling analysis by means of examining the components of economy-wide material flow indicators: an integrated image for indicators and their components

Another path of expressing decoupling by means of EW-MFI is to present a particular material flow indicator together with weighted shares of its components in this decoupling. We call these shares ‘‘weighted’’, as absolute values of components and

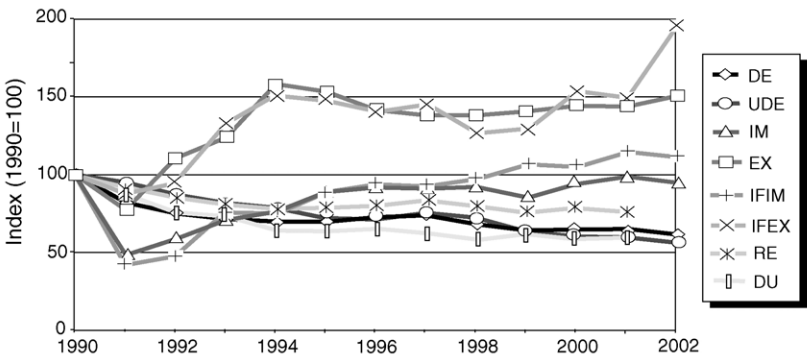

Fig. 8. Development of components of EW-MFI, Czech Republic, 1990–2001 (2002) (source: Kovanda et al., 2004). *Note*: DE, used domestic extraction; UDE, unused domestic extraction; IM, imports; EX, exports; IFIM, indirect flows of imports; IFEX, indirect flows of exports; RE, released emissions, i.e. emissions to air, water and landfilled waste; DU, dissipative use of products.

their contribution to the absolute decrease in the indicator are taken into account and not just relative decreases in these components. For instance, imports can decrease by 50% relatively, but the share of the absolute value of the imports in the absolute value of DMI is only 20%, so that only 10% (0.5 × 0.2) of the DMI decrease is attributed to the imports. These weighted shares allow showing the contribution of the components of an indicator to its overall decoupling. In the following, we will continue plotting the indexed (relative) values of both an indicator and its components.

As an example, we will apply this method to the DMI indicator, which is one of the least aggregated material flow indicators. The value of the weighted shares of the DMI components in the decoupling of DMI for a period elapsed since the starting year can be calculated as follows:

$$DE_{s,t_k} = (DE_a/DMI_a DMI_i)_{t_0} - (DE_a/DMI_a DMI_i)_{t_k} \tag{2}$$

$$IM_{s,t_k} = (IM_a/DMI_a DMI_i)_{t_0} - (IM_a/DMI_a DMI_i)_{t_k} \tag{3}$$

where t_0 is the value of variables in time t_0 (starting year), $t_k = t_0 + kD$; $k = 1, \ldots, n - 1$; $D = 1$ year, n the number of observations, DE_s the weighted share of used domestic extraction in the decoupling of DMI between t_0 and t_k, IM_s the weighted share of imports in the decoupling of DMI between t_0 and t_k, DMI_a the absolute value of DMI, DMI_i the indexed value of DMI (starting year/t_0/ = 100), DE_a the absolute value of DE and IM_a is the absolute value of IM.

To calculate the weighted shares of the components in percentages (DE_{sp}, IM_{sp}), we can proceed according to the following equations:

$$DE_{sp} = (DE_s/(DE_s + IM_s)) \times 100 \tag{4}$$

$$IM_{sp} = (IM_s/(DE_s + IM_s)) \times 100 \tag{5}$$

The described calculation is illustrated in Fig. 9, which shows the weighted shares of the components in the decoupling of DMI. It can be seen that the contribution of the imports to the overall decoupling was mostly decreasing throughout the monitored period. While its maximum share in the decoupling was 35% for 1990–1991, it was only approximately 2.1% for the entire period 1990–2002.

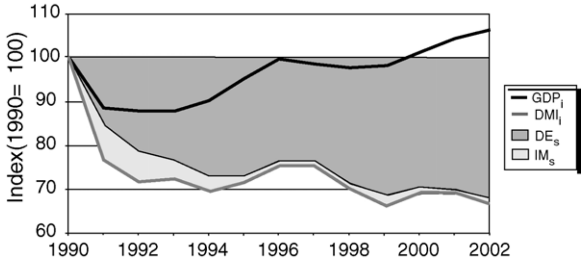

Fig. 9. Weighted share of used domestic extraction and imports in the decoupling of DMI, Czech Republic, 1990–2002. *Note*: GDP_i, indexed value of GDP (starting year = 100); DMI_i, indexed value of DMI (starting year = 100); DE_s, weighted share of used domestic extraction in the decoupling of DMI for a period elapsed since the starting year; IM_s, weighted share of imports in the decoupling of DMI for a period elapsed since the starting year.

A similar method can be applied to other material flow indicators. However, we have encountered some differences in the case of DMC and TMC. Since some components are subtracted when calculating these two indicators (EX in the case of DMC and EX and IFEX in the case of TMC), the values of EX_s and $IFEX_s$ have to be multiplied by (−1). As exemplified below on the TMC indicator, the relevant equations for calculation of EX_s and $IFEX_s$ have then the following forms:

$$EX_{s,t_k} = [(EX_a/TMC_a TMC_i)_{t_0} - (EX_a/TMC_a TMC_i)_{t_k}] \times (-1) \tag{6}$$

$$IFEX_{s,t_k} = [(IFEX_a/TMC_a TMC_i)_{t_0} - (IFEX_a/TMC_a TMC_i)_{t_k}] \times (-1) \tag{7}$$

where t_0 is the value of variables in time t_0 (starting year), $t_k = t_0 + kD$; $k = 1, \ldots, n - 1$; $D = 1$ year, n the number of observations, EX_s the weighted share of exports in the decoupling of TMC between t_0 and t_k, $IFEX_s$ the weighted share of indirect flows associated with exports in the decoupling of TMC between t_0 and t_k, TMC_a the absolute value of TMC, TMC_i the indexed value of TMC (starting year/t_0/ = 100), EX_a the absolute value of EX, and $IFEX_a$ is the absolute value of IFEX.

The calculation of the weighted shares of indicator components in the decoupling of DMC is illustrated in Fig. 10. The contribution of exports to the overall decoupling of DMC was negative at the beginning of the studied period (1990–1991). This is why the

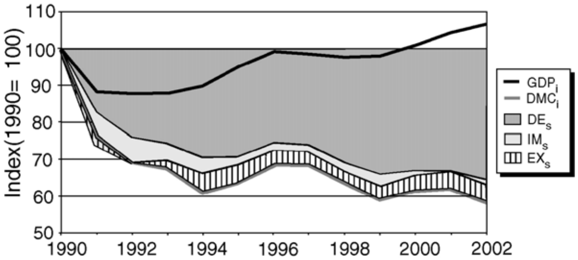

Fig. 10. Weighted share of used domestic extraction, imports and exports in the decoupling of DMC, Czech Republic, 1990–2002. *Note*: GDP_i, indexed value of GDP (starting year = 100); DMC_i, indexed value of DMC (starting year = 100); DE_s, weighted share of used domestic extraction in the decoupling of DMC for a period elapsed since the starting year; IM_s, weighted share of imports in the decoupling of DMC for a period elapsed since the starting year; EX_s, weighted share of exports in the decoupling of DMC for a period elapsed since the starting year.

decoupling of DMC is lower than the decoupling of summed used domestic extraction and weighted shares of imports in 1990–1991. In 1990–1992 and the later periods (1990–1993, 1990–1994, . . .), however, the contribution of all DMC components was already positive.

Concerning other EW-MFI, the more components an indicator has, the less lucid the aforementioned expression will be. This applies especially to TMC indicator, being the most complicated of the EW-MFI regarding the number of components.

5. Conclusions

Graphical presentation of decoupling analysis by means of EW-MFI was demonstrated by several methods that have been already in use in reporting by national governments and international agencies. However, all the screened methods have serious limitations in terms of their informative and analytical capabilities/potentials: (i) decoupling factors (K_{dec}) provide exact numbers but do not allow trend analysis nor provide important information on the type of decoupling; (ii) computation of ecological effectiveness does not indicate the type of decoupling and (iii) plotting indicators of environmental pressure and an economic driving force as indexed time-series in a single chart allows to see only the main trends. On the other hand, all these methods are adequate when one only needs to know the decoupling rate, to show differences among countries or to make a simple and convincing picture for educational, non-analytical purposes.

The main reason for looking for new methods of graphical presentation of decoupling by EW-MFI is to deliver the decoupling information in a more analytical and, at the same time, more user-friendly manner. We propose tracking development of the indicator components. An indicator component analysis using separate images for each indicator and its components was demonstrated on some material flow indicators. In the case of working with the relative values of the indicators and their components, tracking of relative changes does not provide any information on the contribution of the components to the overall decoupling of an indicator. Indicator component analysis with absolute terms encounters another difficulty: graphical imaging in terms of its scale of reproduction.

Another proposed method is decoupling analysis by examining the material flow indicator components in an integrated image (for the indicators and their components). The necessary computation of the weighted shares of the components in the decoupling of a particular indicator can be easily done as demonstrated on data for the Czech Republic on DMI and DMC indicators. Although this approach seems to be rather promising, as it shows the contribution of components to the overall decoupling of an indicator, the main critical point here could be the number of components in an indicator.

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Economy-wide material flow indicators in the Czech Republic: trends, decoupling analysis and uncertainties

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Abstract: Material and energy flows (together with human appropriation of land) are considered the key cause of environmental problems. This paper describes the application of economy-wide material flow accounting and analysis to the economy of the Czech Republic for 1990–2002. The results show a decrease of material intensity and decoupling of the economic growth from environmental pressure. The second part of the paper treats an important issue of uncertainties related to economy-wide material flow indicators in the Czech Republic. The results point out that the high uncertainties related to some material flow indicators may be an obstacle to their applicability.

Keywords: environmental pressure; material flow analysis and indicators; decoupling analysis; uncertainty assessment.

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1 Introduction

An economy and the environment are connected through material and energy flows. These flows, together with human appropriation of areas (or spaces in the broader sense of the word), are the key cause of environmental problems and can serve as an indirect indicator of pressure exerted on the environment by humans. 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; Bringezu, 2002). First, any extraction of a primary material exerts a certain pressure to the environment, e.g., through landscape disruption with effects on water cycle, flora and fauna etc. Secondly, the higher the material resource inputs, the higher must be the material outputs (emissions, waste etc.) owing to the law of conservation of matter. Hence the higher the material turnover of economies, the greater are the environmental pressures exerted by that economy.

Material and energy flows can be studied as such, but also in relation to economic indicators, namely Gross Domestic Product (GDP) or Gross Value Added (GVA). In this case, we speak of analysis of material/energy intensity or productivity (when wishing to study the efficiency of an economic system to transform material and energy inflows into economic output) or decoupling analysis (when studying whether economic output has decoupled from environmental pressure). Both concepts nowadays occupy a prominent place in the majority of environmental policies on the national as well as international levels (EC, 2001, 2002, 2003; OECD, 2002).

Material flow indicators for the Czech Republic treated in this paper were based on Economy-Wide Material Flow Accounting (EW-MFA) and analysis. Since its standardisation in 2001 (Eurostat, 2001), EW-MFA has become quite widespread, because it provides a foundation for making and evaluating environmental policy decisions at both strategic and operational levels (Wernick and Irwin, 2005). As EW-MFI monitor the size of the system, they can be used to set quantitative targets. Germany, Italy and Japan are among the countries where such target settings have been made with the help of EW-MFI (Federal Government Germany, 2002; Ministero dell'Ambientee della Tutela del Territorio, 2002; Government of Japan, 2003). EW-MFA and EW-MFI have been promoted by OECD, mainly through the activities of the Working Group on Environmental Information and Outlooks (WGEIO). As far as Europe is concerned, this is done in cooperation with the European Environment Agency (EEA) and Eurostat, which has revived the task force handling this issue, also for the purpose of contributing to a further international harmonisation of EW-MFA (Femia and

Moll, 2005). It can be therefore expected that policy demand for EW-MFI will further increase.

In this paper we first briefly describe the EW-MFA methodology and the approach we took to calculating uncertainties related to EW-MFI in the Czech Republic. Then we discuss the trends of EW-MFI compiled for the Czech Republic for 1990–2002 and relate them to GDP, thus carrying out both material intensity and decoupling analyses. Finally, we assess uncertainties related to these indicators, as the uncertainties can be perceived as a crucial factor influencing their credibility and applicability.

2 Methodological approaches used in the paper

2.1 Methodology of Economy-Wide Material Flow Accounting (E-W MFA) and analysis

EW-MFA was developed during the 1990s by various research institutes and organisations (principally the World Resources Institute, the Wuppertal Institute for Climate, Environment and Energy, the Austrian Institute for Interdisciplinary Studies and Eurostat), and then standardised in a methodological guide (Eurostat, 2001).

The aim of the methodology 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. Flows within the economy, for example, products moving between various sectors, are not included; the economy is treated as a ‘black box’. 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 physical stock of the economy (e.g., traffic infrastructure, buildings and durable goods).

Material flows can be divided into three categories: water, gases and solid materials. Water and airflows are one order of magnitude higher than the total flow of other materials. Water and air account for at least 95% of the total mass of material inputs to the Austrian economy, while the industrial metabolism on an average consists of 85% water, 8% air and 7% other material (Schandl et al., 1999). The Eurostat methodology therefore includes only that part of the water and gas flows necessary for an overall balance (water contained in solid materials, import and export, emissions to water and to air).

Material flows within the EW-MFA consist of the single components called accounts. Domestic material inputs consist primarily of extracted raw materials and produced biomass that has entered the economic system (this biomass is composed of, for example, fodder, pasturage, harvested wild fruits and wood). These flows are called “domestic extraction used” account. Domestic material outputs consist primarily of emissions to air and water, land-filled wastes (“emissions and wastes” account) and use of, for instance, fertilisers, pesticides and solvents (“dissipative use of products and dissipative losses” account).

The Eurostat methodology also includes the interesting concept of unused extraction or hidden flows. “Unused domestic extraction” account consists of 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 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 (‘import’ and ‘export’ accounts) 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 inputs side, while exports are placed on the outputs side of the material balance. Used and unused extraction is associated with foreign trade in the same way as with domestic economic activities (e.g., movement of overburden associated with imported coal) and is identified as “indirect flows associated with imports” and “indirect flows associated with exports” accounts.

For the inputs and outputs to be balanced, it is necessary to insert the balancing items into the total material balance (“input balancing items” and “output balancing items” accounts). These contribute to the transformation of inputs into outputs and without them, it would be impossible to compile a balance sheet and to calculate changes in physical stocks identified as the difference between material inputs and outputs. Gases from the ambient air (oxygen and nitrogen) that take part in oxidising processes when burning fuels are important examples of such balancing items on the input side, while water vapour generated from the water and hydrogen content of fuels in combustion constitute a balancing item on the output side. These inputs and outputs are calculated on the stoichiometric principles for emissions to air from combustion and on the basis of the chemical composition of the fuel (taking into account its water and hydrogen content). Oxygen is furthermore identified as a balancing item on the input side, where it is needed for ‘burning’ food consumed by humans and domestic animals, whilst the carbon dioxide and water from respiration released during this process are identified as balancing items on the output side.

The most commonly used material flow indicators compiled on the basis of EW-MFA are as follows:

Input indicators

- Direct Material Inputs (DMI) equals domestic extraction used plus imports.
- Total Material Requirements (TMR) includes domestic extraction used and unused domestic extraction, imports and their indirect flows

Output indicators

- Domestic Processed Output (DPO) comprises emissions and wastes and dissipative use of products.
- Total Domestic Outputs (TDO) includes DPO and unused domestic extraction.

Consumption indicators

- Domestic Material Consumption (DMC) is calculated as DMI minus exports.
- Total Material Consumption (TMC) is TMR minus exports and their indirect flows.

Balance indicators

- Net Additions to Stock (NAS) measures the physical growth rate of the economy. The indirect method of calculation is a simple difference between input and output flows (including input and output balancing items). The direct method involves measuring the amount of materials added to particular categories of the physical stock ("gross additions to stock" account) and amount of waste flows from these stocks ("removals from stocks" account). NAS is then calculated as difference between these two accounts.

The EW-MFI can be calculated in absolute terms as well as in relation to population size (per capita) and to economic performance (per unit GDP) carrying out material efficiency and/or decoupling analysis. Output indicators can be further disaggregated by economic sector (sectoral flows) or according to the media to which the flows are directed (air, water and soil).

2.2 Assessment of uncertainties

For the purposes of this paper, we use the term uncertainties for intervals of values within which the real values of particular indicators lie with a certain probability (CMI, 2005). This probability was set to $p = 95\%$. The uncertainties in question are thus affected by all factors influencing the data (errors of measurements, errors related to statistical surveys, etc.).

Assessing uncertainties, we first made educated guesses of uncertainties related to particular material flow accounts, i.e., to domestic used extraction, domestic unused extraction, imports, exports, indirect flows associated to imports and exports, emission flows, dissipative use of products and dissipative losses and input and output balancing items. These guesses were based on

- examination of methods used for collecting of data for these accounts and estimation of data uncertainties related to these methods
- analysis of the Czech material flow accounts including their weak points in terms of non-inclusion of some data at all owing to their unavailability.

The identified methods of data gathering were above all statistical surveys (both complete and partial), calculations and estimations by experts. As the methods used for collecting of particular data and overall data availability changed over time in some cases, the estimated uncertainties for particular accounts could also change over time.

The uncertainties attributed to material flow accounts are summarised in Table 1.

We attributed the lowest uncertainties to the used domestic extraction data and foreign trade data. After discussion with their providers, we considered the methods of their collection (predominately statistical surveys) very reliable, and also the overall data availability was very good.

The unused domestic extraction data have much higher uncertainties. They were partly acquired by statistical surveys, but some of them had to be estimated by experts (unused extraction related to road construction) and some of them have not been counted in at all (dredging). Similar is true for emissions and wastes as well as dissipative use of products and dissipative losses, where, however, the share of data acquired by statistical surveys was higher than in the case of unused domestic extraction.

Table 1 Uncertainties attributed to material flow accounts (in percentage), Czech Republic, 1990–2002

	DE	*UDE*	*IM*	*EX*	*IFIM*	*IFEX*	*EW*	*DU*	*IBI*	*OBI*
1990	+8/–3	+35/–6	+15/–15	+15/–15	+100/–5	+100/–30	+15/–15	+10/–30	+15/–15	+15/–15
1991	+8/–3	+35/–6	+15/–15	+15/–15	+100/–5	+100/–30	+15/–15	+10/–30	+15/–15	+15/–15
1992	+8/–3	+35/–6	+15/–15	+15/–15	+100/–5	+100/–30	+15/–15	+10/–30	+15/–15	+15/–15
1993	+8/–3	+30/–4	+5/–5	+5/–5	+100/–5	+100/–30	+15/–15	+10/–30	+15/–15	+15/–15
1994	+8/–3	+30/–4	+5/–5	+5/–5	+100/–5	+100/–30	+10/–10	+10/–30	+15/–15	+15/–15
1995	+8/–3	+30/–4	+5/–5	+5/–5	+100/–5	+100/–30	+10/–10	+10/–30	+15/–15	+15/–15
1996	+8/–3	+30/–4	+5/–5	+5/–5	+100/–5	+100/–30	+10/–10	+10/–30	+15/–15	+15/–15
1997	+8/–3	+30/–4	+5/–5	+5/–5	+100/–5	+100/–30	+10/–10	+10/–30	+15/–15	+15/–15
1998	+8/–3	+30/–4	+5/–5	+5/–5	+100/–5	+100/–30	+10/–10	+10/–30	+15/–15	+15/–15
1999	+8/–3	+25/–2	+5/–5	+5/–5	+100/–5	+100/–30	+10/–10	+10/–30	+15/–15	+15/–15
2000	+8/–3	+25/–2	+5/–5	+5/–5	+100/–5	+100/–30	+10/–10	+10/–30	+15/–15	+15/–15
2001	+8/–3	+25/–2	+5/–5	+5/–5	+100/–5	+100/–30	+10/–10	+10/–30	+15/–15	+15/–15
2002	+8/–3	+25/–2	+5/–5	+5/–5	+100/–5	+100/–30	+10/–10	+10/–30	+15/–15	+15/–15

DE: used domestic extraction; UDE: unused domestic extraction; IM: import; EX: export; IFIM: indirect flows associated with imports; IFEX: indirect flows associated with exports; EW: emissions and wastes; DU: dissipative use of products and dissipative losses; IBI: input balancing items; OBI: output balancing items.

The highest uncertainties were attributed to indirect flows of foreign trade, which are only estimated using coefficients expressing their volumes per unit of various categories of imports and exports. The lower estimation of the negative uncertainties of indirect flows associated to imports, in comparison with the uncertainties related to indirect flows associated to exports, stemmed from the fact that the exports in contrast to the imports contained some items with huge indirect flows (precious metals), which we considered overestimated (which was not taken into account in the case of direct foreign trade data, as the direct foreign trade flows of these items were quite small). The category of indirect flows of foreign trade was particularly a problem, as we were not the producers of the coefficients used for their calculation, but just took them over from literature. Thus, we only present the first estimation of the uncertainties related to these coefficients, which would need further revision.

The input/output balancing items were based to a large extent on stochiometric calculations. Some of them were also based on per capita consumption of food, fodder and water and per capita release of CO_2, manure and perspiration. The uncertainties +15/–15% seemed to us adequate for these accounts.

The lower and upper boundaries of uncertainties differ in the case of several material flow accounts. For instance, we presumed that the probability of underestimation of unused domestic extraction was much higher than the probability of its overestimation (we were aware of not counting in some flows owing to a lack of data and we considered this fact more pronounced than the possible overestimation of domestic unused extraction flows). On the other hand, the probability of overestimation of dissipative use of products and dissipative losses was higher than its underestimation (since, for instance, we counted in manure production instead of manure consumption).

As the material flow account data are biased estimates of the real values (see the previous paragraph), we take as the new unbiased estimates the averages of the account data based on their uncertainty intervals. The 95% intervals of indicator values were calculated assuming normal distribution and mutual independence of particular material flow accounts. We calculated the upper and lower boundaries of the accounts by using estimated values of related uncertainties, and divided their differences by 2×1.96 to get their standard deviations. The standard deviations of the indicators were then calculated as a square root of the sum of the squares of the standard deviations of the particular accounts. Having done this, we calculated the centres of the accounts as a means of their upper and lower boundaries and used these centres to calculate the centres of the particular indicators. To get the upper and lower boundaries of the indicators we summed/subtracted their centres and 1.96 multiples of their standard deviations and centres. Finally, we used the upper and lower boundaries and real values of the indicators to calculate their uncertainties.

3 Economy-Wide Material Flow Accounting (E-W MFA) and indicators in the Czech Republic: results and discussion

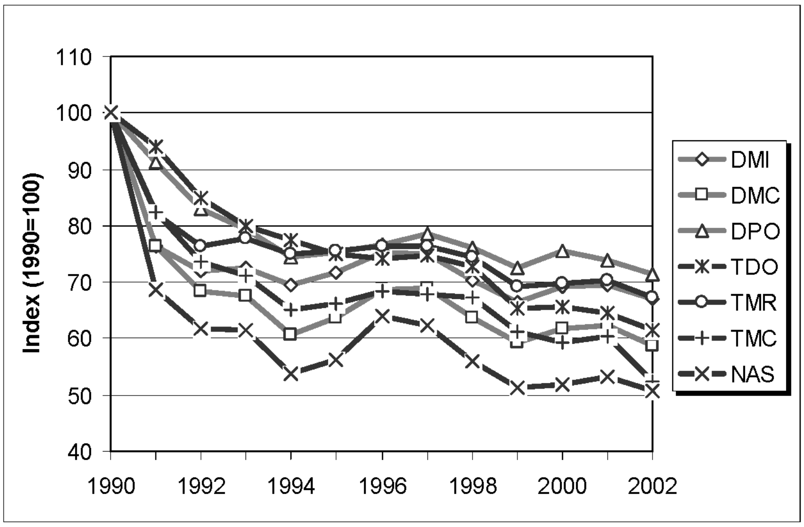
3.1 State-of-the-art

In the Czech Republic, EW-MFA and EW-MFI were compiled for 1990–1999 under the project "Methodology of state assessment and prediction of the environment by the material and energy flow (Direct as well as hidden) balances" funded by the Czech Ministry of the Environment in 2000–2001. Later on, the data for 2000 were added and the results were published (Scasny et al., 2003). After that, the 2003–2004 project "Economy-wide material flow analysis, its application on regional and micro-economic level and its use in elaboration of sustainability indicators" funded by the same ministry was finished. The goal of this project was to extend the time series of EW-MFI in the Czech Republic up to 2002 and to develop a methodology for 'transforming' selected EW-MFI to the regional and corporate level (Kovanda et al., 2004). Finally, the 2004–2006 project "State assessment of the environment by the material and energy flow analysis" funded by the Grant Agency of the Czech Republic has been carried out, one of its research subjects being the use of EW-MFI for material intensity/productivity and decoupling analysis.

3.2 Trends of main Economy-Wide Material Flow Indicators (E-W MFI) in 1990–2002

All the main EW-MFI went down significantly in the Czech Republic between 1990 and 2002, above all in the years immediately following the 'Velvet Revolution' (1991–1993). The most pronounced decrease was recorded in the case of NAS in 1990–2002, the least pronounced in the case of DPO (Figure 1).

Figure 1 Trends in EW-MFI, Czech Republic, 1990–2002



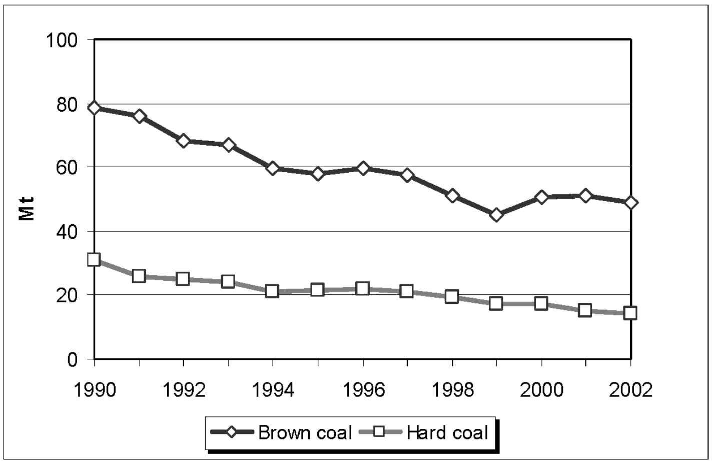
Source: Kovanda et al. (2004)

The impulsion for this decreasing trend at the beginning of the 1990s was the vast decrease in overall economic output and the consequent lower demand for material inputs reflected in lower material outputs. In the following years, however, GDP started to grow again, but the overall decreasing trend of the EW-MFI was maintained. It was owing to structural changes in the economy, which happened as a result of the transition from centrally planned to market-based economy. At the beginning of the 1990s, the Czech economy had several prominent features:

- Low share of services compared with other industrialised countries (approx. 43% in 1990).
- Large extent of heavy industry, especially iron and steel production. Czechoslovakia produced almost 1000 kg of steel per capita per year, which was close to the world's record figures.
- These (and other) industries were technologically obsolete, heavily polluting and energy inefficient.
- The energy base of the economy was heavily dependent on local solid fuel, mainly brown coal with low energy content and high content of pollutants, above all sulphur (Klarer and Moldan, 1997).

This picture changed rather significantly over the 1990s, above all in the first half of the decade. The share of services was 52% in 1995 and 56% in 2002. The heavy industry was dampened and manufacturing industries, especially electrotechnical and transport, flourished. The modernisation of the production base was underway and there was a huge shift from brown and hard coal towards gas in power engineering (MoE, 2003). In fact, it was the brown and hard coal domestic mining (Figure 2), which influenced the development of the EW-MFI most decisively.

Figure 2 Brown and hard coal domestic mining, Czech Republic, 1990–2002



Source: Kovanda et al. (2004)

The strong decrease in coal mining was enabled by the shift from energy-intensive heavy industries to manufacturing industries and to services, overall increase in energy efficiency owing to the implementation of modern technologies and massive installation of gas. As a result of the installation of gas infrastructure, consumption of natural gas increased. As more energy can be produced from one ton of gas than from one ton of coal, the decrease in coal consumption was more pronounced than the increase in gas consumption.

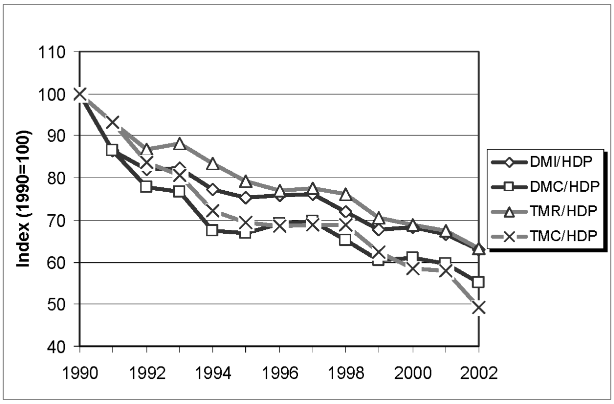
Brown and hard coal mining – as the most decreasing sub-flows – directly influenced all EW-MFI in the Czech Republic except for NAS.[1] It influenced those dominated by domestic used extraction (DMI, DMC), as well as those dominated by domestic unused extraction (TMR, TMC, TDO). That was caused by the fact that about 90% of domestic unused extraction was composed of overburden from brown coal mining, which decreased proportionally to brown coal mining itself. Imports, exports and their indirect flows had been growing from 1991, thus reflecting the growing openness of the Czech economy toward foreign countries. Their growth, however, was by far outweighed by a decrease in brown and hard coal mining. Regarding DPO, its main component – CO_2 emissions from burning of fossil fuels – went down more pronouncedly than the others. It was primarily caused by the shift from heavy industries to manufacturing and to services, and also because of installation of gas (with less CO_2 from the gas burnt than from coal per unit of energy produced).

3.3 Material intensity and decoupling analysis

Material intensity (share of input/consumption EW-MFI in GDP) or material productivity (share of GDP in input/consumption EW-MFI) shows the efficiency of the economic system to transform material inputs into economic output (GDP).

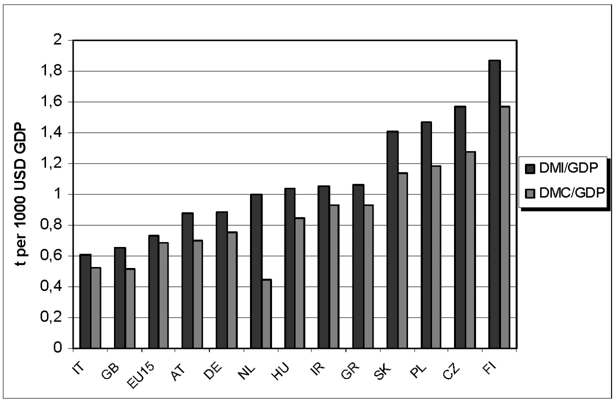
Figure 3 shows that the volume of materials needed per unit of GDP was going down significantly and thus the efficiency of the transformation of materials into economic output was growing. However, the situation is much dimmer in an international comparison (Figure 4).

Figure 3 Material intensity (DMI/GDP, DMC/GDP, TMR/GDP, TMC/GDP), Czech Republic, 1990–2002



Source: Kovanda et al. (2004): material flow indicators; Czech Statistical Office (2003): GDP

Figure 4 Material intensity (DMI/GDP, DMC/GDP), international comparison, 1999

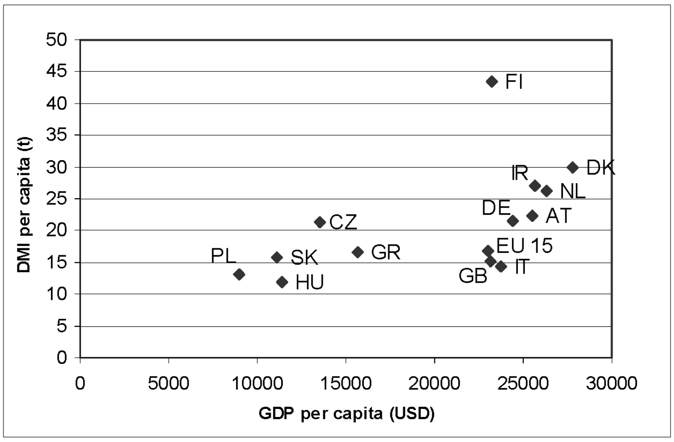


1999 prices; recalculation of national currencies into USD using PPP; IT: Italy; GB: UK; AT: Austria; DE: Germany; NL: The Netherlands; HU: Hungary; IR: Ireland; GR: Greece; SK: Slovakia; PL: Poland; CZ: Czech Republic; FI: Finland.

Source: Eurostat (2002): DMI of the EU 15 countries; Kovanda et al. (2004): DMI of the Czech Republic; Moll et al. (2002): DMI of new EU member states with the exception of the Czech Republic; Czech Statistical Office (2003): GDP

Material intensity is slightly higher in the Czech Republic than in the other new EU member states (except for Hungary, whose material intensity is significantly lower), but much higher than in the former EU 15 countries with the exception of Finland. Material intensity is so high in the Czech Republic, as the DMI and DMC per capita are comparable with the EU 15 countries, but the GDP per capita is much lower. This situation is illustrated in Figure 5, which features both DMI per capita and GDP per capita. The reason why Finland has higher material intensity than the Czech Republic is its huge per capita material input/consumption.

Figure 5 Domestic Material Input (DMI) and Gross Domestic Product (GDP) per capita, international comparison, 1999

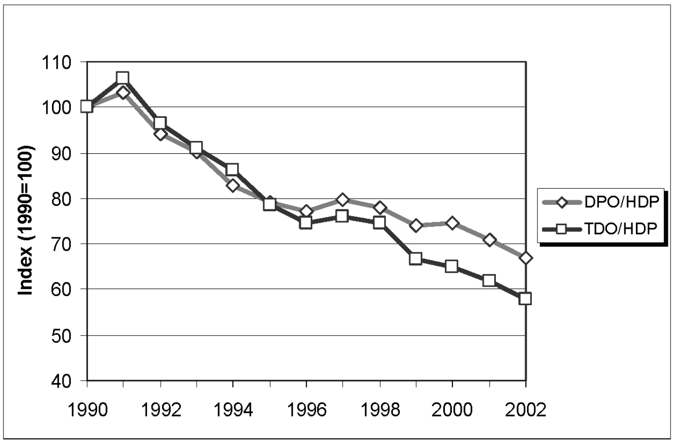


1999 prices; recalculation of national currencies into USD using PPP; IT: Italy; GB: UK; AT: Austria; DE: Germany; NL: The Netherlands; HU: Hungary; IR: Ireland; GR: Greece; SK: Slovakia; PL: Poland; CZ: Czech Republic; FI: Finland.

Source: Eurostat (2002): DMI of the EU 15 countries; Kovanda et al. (2004): DMI of the Czech Republic; Moll et al. (2002): DMI of new EU member states with the exception of the Czech Republic; Czech Statistical Office (2003): GDP

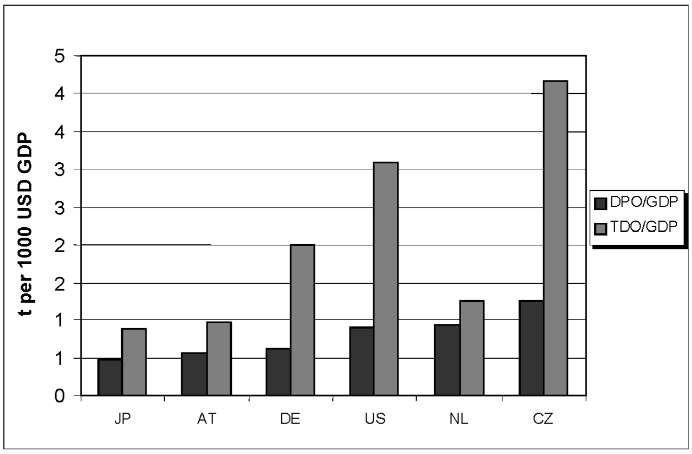
The share of DPO or TDO in GDP shows the volume of output flows emitted into the environment per unit of GDP. For the Czech Republic, the situation here is similar to that of material intensity: The trend of this share is quite positive (Figure 6), but it is still very high when compared to other industrialised countries (Figure 7). The reasons for this are also identical: comparable DPO and TDO per capita and much lower GDP in the Czech Republic (Figure 8).

Figure 6 Domestic Processed Output and Total Domestic Output per GDP (DPO/GDP, TDO/GDP), Czech Republic, 1990–2002



Source: Kovanda et al. (2004): material flow indicators; Czech Statistical Office (2003): GDP

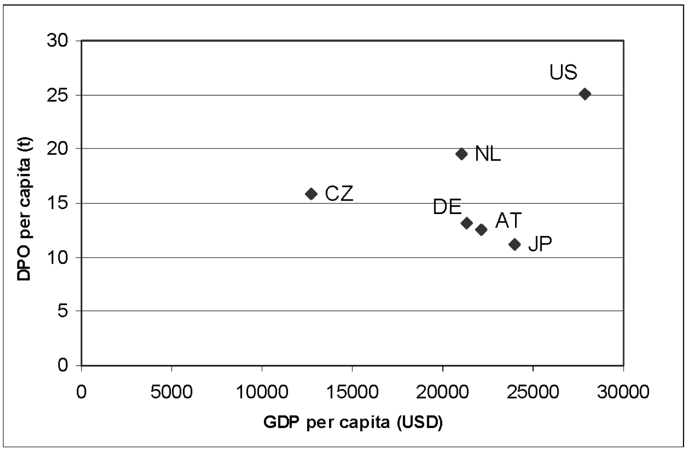
Figure 7 Domestic Processed Output and Total Domestic Output per GDP (DPO/GDP, TDO/GDP), international comparison, 1996



1996 prices; recalculation of national currencies into USD using PPP; JP: Japan; AT: Austria; DE: Germany; NL: The Netherlands; CZ: Czech Republic.

Source: Matthews et al. (2000): DPO and TDO with the exception of the Czech Republic; Kovanda et al. (2004): DPO and TDO of the Czech Republic; Czech Statistical Office (2003): GDP

Figure 8 Domestic Processed Output (DPO) and Gross Domestic Product (GDP) per capita, international comparison, 1996



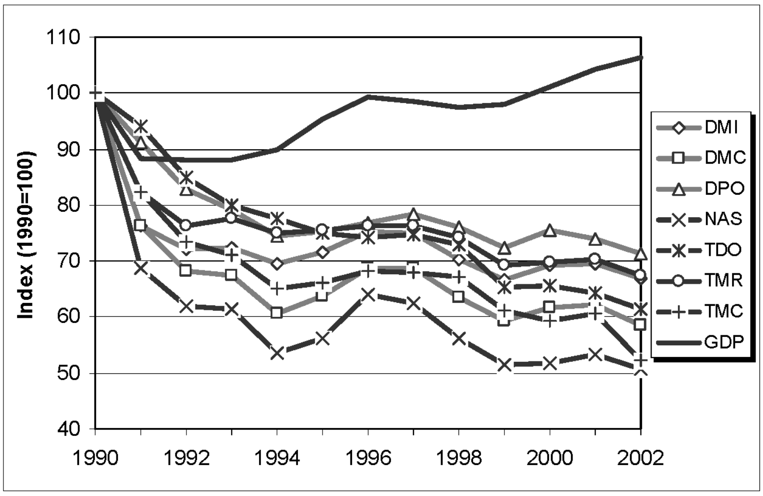
1996 prices; recalculation of national currencies into USD using PPP; JP: Japan; AT: Austria; DE: Germany; NL: The Netherlands; CZ: Czech Republic.

Source: Matthews et al. (2000): DPO with the exception of the Czech Republic; Kovanda et al. (2004): DPO of the Czech Republic; Czech Statistical Office (2003): GDP

The reasons for the positive trends in the development of both material intensity and DPO/TDO shares in GDP seen in Figures 2 and 5 are those identified in Section 3.2: the shift from heavy industries to manufacturing and to services, the installation of gas and the consequent decrease in domestic coal mining and modernisation of the production base. These reasons contributed to decrease in EW-MFI and some of them, for instance shift to services and modernisation, also to increase in GDP (EEA, 2005).

Carrying out a decoupling analysis we once more plot the trends of the EW-MFI – this time together with the GDP trend (Figure 9).

Figure 9 Decoupling of environmental pressure from economic growth – EW-MFI and GDP, Czech Republic, 1990–2002



Source: Kovanda et al. (2004): material flow indicators; Czech Statistical Office (2003): GDP

We see a rather pronounced decoupling of the environmental pressure from the economic growth in the Czech Republic when using the EW-MFI (as a proxy for environmental pressure) and GDP for a decoupling analysis. Above all, owing to the GDP growing from 1999, absolute decoupling (growth in GDP and contemporary decrease in environmental pressure) was recorded between 1990 and 2002. It is also seen in Figure 8 that the indicators have a tendency to follow the course of GDP: when GDP is undergoing prolonged growth, EW-MFI start to grow as well and vice versa. From this point of view, the development of the EW-MFI seemed promising in 2002, as all of them went down in spite of the fact that GDP had been growing from 1999.

3.4 Uncertainties related to Economy-Wide Material Flow Indicators (E-W MFI)

The uncertainties calculated for particular EW-MFI are summarised in Table 2.

The lowest positive uncertainties were calculated for DMI and DMC. These two indicators also have very low negative uncertainties. Taking into account both the positive and negative uncertainties, DMI and DMC seem to be the most correct EW-MFI. Rather low uncertainties, both positive and negative ones, were calculated also for DPO. The other indicators, except for NAS, have high positive uncertainties and quite low negative uncertainties. Both positive and negative uncertainties are very high for NAS, which is caused by the large number of accounts it consists of. It can be argued that the high uncertainties related particularly to NAS, TMC, TMR and TDO may be a serious obstacle to their applicability, e.g., use in material intensity and decoupling analyses when they may deliver distorted results.

Table 2 Uncertainties related to EW-MFI (in percentage), Czech Republic, 1990–2002

	DMI	*DMC*	*TMR*	*TMC*	*DPO*	*TDO*	*NAS*
1990	7/–3	8/–4	27/0	28/–3	11/–15	25/–5	30/–19
1991	7/–3	8/–3	26/0	27/–5	11/–15	25/–5	38/–25
1992	7/–3	9/–4	26/0	28/–6	12/–15	25/–5	40/–27
1993	7/–3	8/–3	26/0	29/–8	8/–15	21/–5	38/–25
1994	7/–3	9/–3	25/0	31/–2	8/–10	21/–5	38/–24
1995	7/–3	8/–3	26/0	31/–10	8/–10	21/–5	36/–23
1996	7/–3	8/–3	26/0	31/–9	8/–10	21/–5	33/–21
1997	7/–3	8/–3	26/0	31/–9	8/–10	21/–5	34/–22
1998	7/–3	8/–3	27/0	31/–8	8/–10	21/–5	36/–24
1999	7/–3	8/–3	27/0	32/–9	8/–10	17/–5	38/–25
2000	7/–3	8/–3	26/0	33/–12	8/–10	17/–5	38/–25
2001	6/–3	8/–3	28/0	34/–11	8/–10	17/–5	37/–24
2002	6/–3	8/–3	28/0	39/–20	8/–11	16/–5	38/–25

The uncertainties calculated for the Czech EW-MFI will certainly differ from uncertainties calculated for EW-MFI in other countries. This difference, however, might not be so large owing to a high level of harmonisation of statistical systems, especially in the European Union. Concerning the methodology used for the calculation of the uncertainties, the presumption of mutual independence of material flow accounts is simplifying, as the Czech data suggest there is a pronounced correlation between some accounts (e.g., between used domestic extraction and unused domestic extraction). It causes, for instance, the fact that uncertainties of some indicators (e.g., DMI) are lower than uncertainties of the accounts they are composed of. Also the presumption of normal distribution of material flow accounts seems simplifying, causing the fact that the negative uncertainties of some indicators (namely TMR) were slightly positive (they were set equal to 0 in Table 2). It is a goal for further research to tackle these shortcomings and improve the methodology used.

4 Conclusions

All EW-MFI went down significantly in the Czech Republic in 1990–2002. The most pronounced decrease was recorded in the case of NAS, the least pronounced in the case of DPO. The principal reason for the decrease in all the indicators dominated by used and/or unused domestic extraction (DMI, TMR, TMR, TMC, TDO) was the drop in domestic brown and coal mining. This drop was enabled by the shift from energy intensive heavy industries to manufacturing industries and services, an overall increase in energy efficiency owing to the implementation of modern technologies and installation of gas. The same factors played a crucial role in the decreased CO_2 emissions that stood behind the decrease in DPO. All these structural changes occurred within the transition from the centrally planned to market-based economy that the Czech Republic underwent during the 1990s. As it is planned to approximate structure of the Czech economy to such economies as Germany or Austria (Government of the Czech Republic, 2005), the shifts to manufacturing industries and services together with implementation of modern technologies could continue also in the future and we can thus expect also stable development or further decrease in EW-MFI.

Besides standing as proxies for overall environmental pressure related to consumption of materials and their use for material intensity and decoupling analysis, EW-MFI can be further used for assessing equity in resource sharing by international comparison of indicators per capita values, assessment of both material dependency and problem shifting between states and world regions by studying ratios of domestic and imported materials consumed, reviewing problem shifting between sectors by sectoral dis-aggregation of EW-MFI, monitoring of land use intensity by relating EW-MFI to area, etc.

The material intensity analysis showed that the material intensity was decreasing significantly in the Czech Republic, meaning that the efficiency of the transformation of material inputs into economic output was growing. The same applied to material output, the ratio of which to economic output was going down as well. However, the situation is much less favourable when looking at material intensity and DPO or TDO ratios to economic output in international comparison. The results are comparable with some new EU member states but much higher than in the majority of the old EU member states and some other industrialised countries. While the per capita values of the Czech EW-MFI do not differ too much between these countries and the Czech Republic, the Czech GDP per capita is much lower. The decoupling analysis revealed an absolute decoupling of the environmental pressure from the economic growth in the Czech Republic between 1990 and 2002. To continue this trend and achieve pronounced gains in material productivity, further changes in the structure of the economy in favour of services and implementation of modern technologies (which are less demanding for material and energy and produce less emissions) as well as recycling could be very helpful, as these seem to contribute both to decrease in EW-MFI and GDP growth (EEA, 2005).

The analysis of uncertainties of the EW-MFI for the Czech Republic showed that highest uncertainties could be attributed to NAS, TMC, TMR and TDO, while the lowest to DMI and DMC. It can be argued that the high uncertainties related to the former EW-MFI may be an obstacle to their overall credibility and their applicability, e.g., use in material intensity and decoupling analyses. It is an objective for further research to assess whether and to what extent the uncertainties of the Czech EW-MFI differ from uncertainties calculated for MFA indicators in other countries. It also seems feasible to elaborate on the methodology used for the assessment of uncertainties, for e.g., taking into account mutual relations of particular material flow accounts and other than normal distribution of material flow accounts.

Acknowledgements

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Note

[1]The reasons for the decrease in NAS are not discussed at all in this paper.

Calculation of the "Net Additions to Stock" Indicator for the Czech Republic Using a Direct Method

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Keywords

buildings
durable goods
economy-wide material flow analysis (EW-MFA)
industrial ecology
industrial metabolism
infrastructure

e-supplement available on the *JIE* Web site

Summary

Net additions to stock (NAS) are an indicator based on economy-wide material flow accounting and analysis. NAS, a measure of the physical growth rate of an economy, can be used for estimates of future waste flows. It is calculated using two methods: The indirect method of calculation is a simple difference between all input and output flows, whereas the direct method involves measuring the amounts of materials added to particular categories of physical stock and the amounts of waste flows from these stocks.

The study described in this article had one leading objective: to make available direct NAS data for the Czech Republic, which could later be used for predicting future waste flows. Two additional objectives emerged from the first: (1) to develop a method for direct NAS calculation from data availability in the Czech Republic; (2) to calculate NAS directly, compare the results with those achieved in indirect NAS calculation, and discuss the identified differences.

The NAS for the Czech Republic calculated by the direct method is equal to approximately 65 million tonnes on average in 2000–2002 and is approximately 27% lower than the NAS acquired by the indirect method of calculation. The actual values of directly calculated NAS and its uncertainties suggest that the indirect NAS is more likely to be an overestimation than an underestimation. Durables account for about 2% of the total direct NAS, whereas the rest is attributed to infrastructure and buildings. The direct NAS is dominated by nonmetal construction commodities such as building stone and bricks, which equal approximately 89% of the total direct NAS.

Calculation of NAS by the direct method has been proved to be feasible in the Czech Republic. Moreover, uncertainties related to direct NAS are lower than those related to indirectly acquired NAS.

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Introduction

An economic system absorbs energy and materials from the surrounding environment and transforms them into products (goods and services) needed for meeting human needs. At some time, though, all these products are released back into the environment in the form of emissions and wastes. This flow of materials and energy, so far largely one-way, is often called industrial, social/societal, or socioeconomic metabolism (Moldan 1983; Baccini and Brunner 1991; Fischer-Kowalski and Haberl 1993; Ayres and Simonis 1994). Input flows into the economy consist of raw materials such as fossil fuels and minerals, biomass, manufactured and semimanufactured imported products, water, and air, whereas output flows comprise emissions to air and water, landfilled waste, dissipative use of products such as pesticides and fertilizers, and exports. Both input and output energy and material flows are associated with certain pressures exerted on the environment by humans.

To quantify this pressure, we have various methods of material and energy analysis at hand (Bringezu 2000; Haberl 2001a, 2001b). All of them are based on the same philosophy: quantification of material and energy flows for a factory, region, or country using mass balance analysis. The quantification is usually done in physical units such as tonnes or energy units such as joules, and its numerical expression represents the potential of a given material or energy flow to cause harm to the environment. Only a few attempts have been made to translate this potential into real impacts (e.g., Van der Voet et al. 2004).

The most comprehensive and elaborate method for assessing material flows was developed by various research institutes and organizations during the 1990s and is referred to as economy-wide material flow accounting and analysis (EW-MFA) (Eurostat 2001). Its aim is to quantify the physical exchange between a national economy, the environment, and foreign economies on the basis of the mass of material flowing across the boundaries of the national economy. The ultimate goal of the analysis is to obtain a material balance, that is, a state in which material inputs into the economy equal material output plus net changes in physical stocks of the economy (e.g., traffic infrastructure, buildings, durable goods).

For the inputs and outputs to be balanced, it is necessary to insert the balancing items into the material balance. These contribute to the transformation of inputs into outputs; therefore it would be impossible to compile a balance sheet without them, or to predict changes in physical stocks, identified as the difference between material inputs and outputs. Gases from the ambient air (oxygen, nitrogen), which take part in oxidizing processes when fuels are burned, are important examples of such balancing items on the input side, whereas water vapor from the water and hydrogen content of fuels forms a balancing item on the output side. These inputs and outputs are calculated on stoichiometric principles and based on the chemical composition of the fuels. Oxygen is furthermore identified as a balancing item on the input side, where it is needed for "burning" food consumed by humans and domestic animals, whereas carbon dioxide and water from respiration released during this process are identified as balancing items on the output side.

Domestic material inputs consist primarily of extracted raw materials and harvested (or human-produced) biomass that have entered the economic system (this biomass being composed of, for example, crops and wood). Domestic material outputs consist primarily of emissions to air and water, landfilled wastes, and so-called dissipative use of materials (e.g., fertilizers, pesticides, and solvents). Foreign trade also plays an important role in the analysis because it represents an important material flow across the boundaries of an economic system. Imports of commodities are placed on the inputs side, whereas exports are placed on the outputs side of the material balance.

EW-MFA provides an important database with which to calculate a series of environmental pressure indicators. These can be divided into several groups: input indicators, output indicators, and consumption indicators. Among the input indicators, "direct material input" (DMI) measures materials directly used in the economy (mined raw materials, produced biomass, imports). Among the output indicators, "domestic processed output" (DPO) represents the total volume of materials entering the environment after being used in the home economy (water and air emissions, disposed-of waste, dissipative use of products). Consumption indicators include "domestic material consumption" (DMC), which measures the total quantity of materials directly consumed in the economy (it is calculated as DMI minus exports). Furthermore, this group also includes "net additions to stock" (NAS), an indicator that describes the rate of physical growth of the economy, that is, the quantity of materials put annually into buildings and other infrastructure and materials contained in new durable goods. The indicators can be calculated in absolute terms as well as in relation to population size (per capita) and to economic performance (per unit of GDP). Output indicators can be disaggregated by the economic sector (sectoral flows) or according to the media toward which the flows are directed (air, water, soil).

Stocks within EW-MFA are considered human-made fixed assets. They are classified into "infrastructures and buildings" and "durables," such as machinery, vehicles, and other goods. In principle, the stocks of human bodies and livestock should also be included, but in practice they may be ignored, as they usually account for less than 0.1% of the total material stocks (Matthews et al. 2000). Unlike in the System of National Accounts (SNA), items such as nonnatural forests, plants grown on fields, and landfill sites are not considered to be parts of a socioeconomic system under EW-MFA, and are therefore not classified as physical stocks (Eurostat 2001).

The net additions to stocks (NAS) indicator can be calculated using two methods, which are usually applied on a yearly basis. The indirect method of calculation is a simple difference between input and output flows (including input and output balancing items). The direct method involves measuring the amounts of materials added to particular categories of the physical stock (gross additions to stock) and the amounts of waste flows from these stocks (removals from stocks). NAS is then calculated as gross additions to stocks minus removals from these stocks (Eurostat 2001). The crucial difference between these two methods lies in data used. The indirect method works with all material input and output flows relevant to the socioeconomic system in question, whereas the direct one

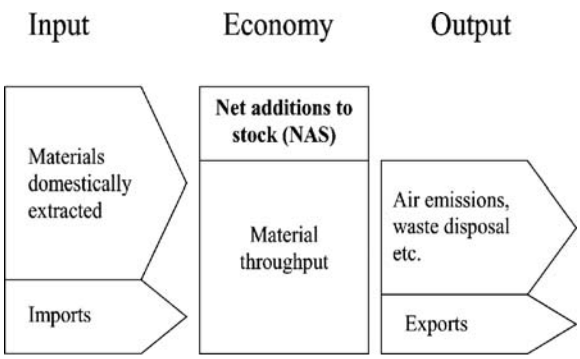

Figure 1 Position of NAS indicator within EW-MFA.

only works with flows moving directly into or out of the physical stocks. The indirect method of calculation is much less accurate, because it is based on a greater number of data in comparison with the direct method (as all data are subject to uncertainties, it is likely that the final uncertainty related to NAS calculated directly is much lower). Moreover, the indirect method of calculation does not allow recognizing the main material components of the stock changes. The position of NAS within EW-MFA is shown in figure 1.

NAS and the total stock accounts can be used for estimating future waste flows, as all infrastructure and products we use will become wastes at some time in the future (Eurostat 2001; Bringezu et al. 2003; Brunner and Rechberger 2004; Moll and Femia 2005). For this estimation we need to know the structure and lifetimes of the stocks. This is only enabled by direct NAS calculation, as indirect NAS calculation delivers one aggregated number, which cannot be correctly broken down by particular NAS elements. Moreover, directly calculated NAS helps to validate indirect NAS data, as we arrive at this indicator by a method complementary to indirect NAS calculation. Both direct and indirect NAS are also proxy measures for built-up area, because stocks always occupy some space. As the area of the Earth is finite, the cessation in growth of NAS can be perceived as a prerequisite for long-term sustainability (Bringezu 2006).

Countries studied so far show a NAS ranging between 7 and 28 tonnes[1] per capita (Bringezu and Schütz 2001; Barbiero et al. 2003; Matthews et al. 2000; Kovanda et al. 2004). An

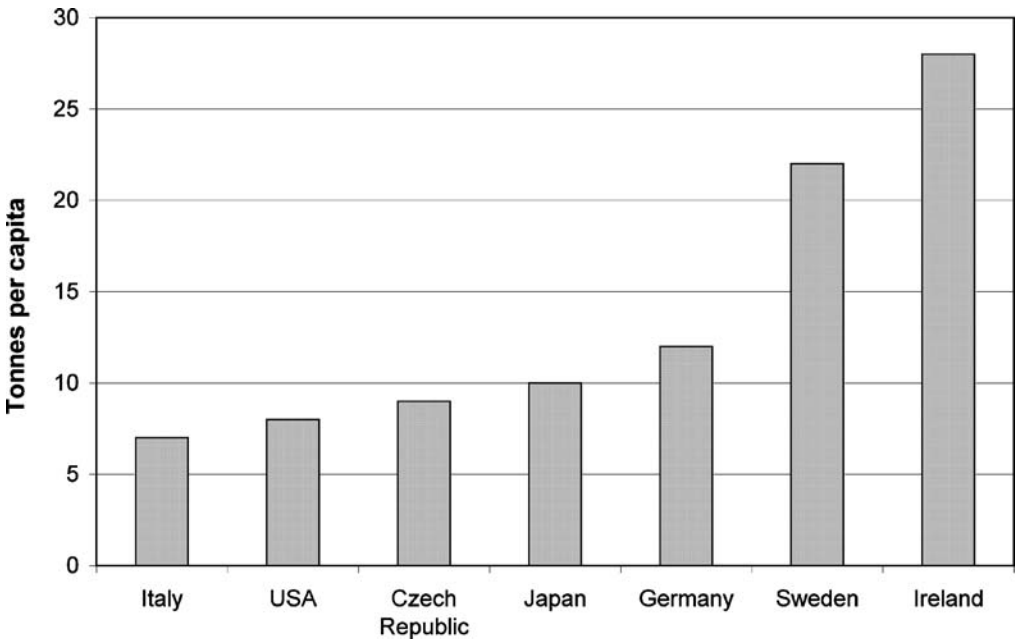

Figure 2 Net Additions to Stock (NAS), international comparison, 1996. *Source:* Bringezu and Schütz, 2001: Italy, Germany, Sweden, Ireland; Matthews et al., 2000: USA, Japan; Kovanda et al., 2004: the Czech Republic.

international comparison of NAS for selected countries is shown in figure 2.

The values of NAS indicate that the disposal of waste will show a rising tendency in the future and also that the pressures exerted on land (or, broadly speaking, space) are growing. This is most evident in the case of Ireland and least in the case of Italy among the selected countries. The NAS of the Czech Republic lies below the average value of this indicator and thus also the waste and land-pressure consequences of NAS should be below the average in this country.

Only a few studies have calculated NAS directly (Matthews et al. 2000, only for the United States; Barbiero et al. 2003), and to our knowledge none of these authors have used their data for modeling future total output flows. But there are studies that tried to do such modeling for single substances such as heavy metals (van der Voet et al. 2002; Binder et al. 2006), plastics (Patel et al. 1998), and wood (Hashimoto et al. 2004).

In the Czech Republic, the EW-MFA indicators were compiled for 1990–2002 within projects funded by the Czech Ministry of the Environment (Scasny et al. 2003; Kovanda et al. 2004). The NAS indicator was calculated by the indirect method. The following sections of this article describe the first attempt to calculate this indicator directly. The study had one leading objective: to make direct NAS data available for the Czech Republic, which could later be used for predicting future waste flows, for example, through dynamic material flow modeling. The use of direct NAS data for this purpose is a pending goal, irrespective of whether it is done by the authors of this article or some other researchers. Two additional objectives emerged from the first: (1) to develop a method for direct calculation of NAS with regard to data that is available in the Czech Republic; (2) to calculate NAS directly, compare the results with those acquired by indirect NAS calculations, and discuss the differences identified.

Data and Methods

We did our pilot calculation for 2000–2002 because the most recent and accurate data were available for this period. In line with the previous studies on the issue, we identified two main categories of stocks: infrastructures and buildings, and durables.

For calculation of NAS in a direct way we would ideally need data in physical units (such as tonnes or cubic meters) referring to consumption of construction commodities and durables (which equals gross additions to stock) and physical data on disposal of durables as well as construction and demolition waste (which equals removals from those stocks). Concerning consumption, these data were rather sparse and unreliable in the Czech Republic, so that very often we had to find methods of calculating the gross additions to stock from existing data instead of simply looking them up in statistical compendia. Concerning the waste flows, the data coverage was much better. The structure of data used for the direct NAS calculation is evident from Appendix 1 (which is available as an e-supplement on the Journal's Web site).

Infrastructures and Buildings

The infrastructures and buildings category represents a rather homogeneous group of stocks including transport infrastructures (roads, parking lots, airports) as well as residential and commercial buildings and their infrastructures (i.e., plumbing, electrical wiring, and sewerage).

Collecting the data on gross additions, we had in mind the problem of double counting; therefore we did not include, for instance, both bricks and brick clays, or concrete and sands. Moreover, we also corrected consumption of some construction materials such as sand and gravel by deducting materials used for other than construction purposes, for example, road gritting (Fuchs 2003).

We compared the data on direct consumption of construction commodities (Czech Statistical Office 2001a, 2002a, 2003a; Ministry of Agriculture 2001, 2002, 2003) with their consumption based on an equation in which consumption equaled production plus imports minus exports. We used a few data sources for these calculations for production of construction commodities (Czech Geological Survey 2001, 2002, 2003; Czech Statistical Office 2001b, 2002b, 2003b, 2001c, 2002c, 2003c) and a database on foreign trade (Czech Statistical Office various years). We found out that calculated data were three times higher in some cases than direct consumption data, with the exception of timber, where the figures were more or less the same. After discussion with the data providers and checking the methods of gathering all these data, we considered the calculated figures to be more precise and based the gross additions to stock predominantly on the calculations. Direct consumption data were used only for timber and some other commodities for which the calculated data were not available (see Appendix 1).

Concerning construction and demolition waste, we used the data provided by the Czech Statistical Office on waste generation and disposal (Czech Statistical Office 2001d, 2002d, 2003d). We took the total generation of construction and demolition waste broken down by treatment methods as defined by Waste Acts (Act No. 125/1997 Coll., on Waste, as amended; Act No. 185/2001 Coll., on Waste, as amended). We strove to include just treatment methods, which did not mean recycling of waste, because recycled waste remained part of the physical stocks. These treatment methods were as follows for 2000–2001: composting, incineration (both with and without energy recovery), landfilling, underground deposition (placement of containers in mines, for instance), and exportation. For 2002, because there was a change in the categorization of treatment methods between 2001 and 2002, we included the following treatment methods: land treatment resulting in benefit to agriculture or ecological improvement (biodegradation of liquid waste or sludge in soils, etc.), deposits into or onto land (landfill, etc.), deep injection (injection of pumpable liquid waste into wells, salt domes or naturally occurring repositories, etc.), specially engineered landfilling (placement into lined discrete cells that are capped and isolated from one another and the environment, etc.), incineration on land, permanent storage (placement of containers in mines, for instance), use for land reclamation and landscaping, and exportation. Unlike in classical EW-MFA, where incinerated waste is counted in the form of emissions from the incineration (Eurostat 2001), we included the amount of incinerated waste in our calculations. It was more straightforward to include incinerated waste as a waste flow and not as an emission to air. This approach was also better from the viewpoint of data availability, as it was not always possible to attribute the relevant part of emissions to air to waste incineration. Ideally, the waste flow data should also contain data on material removals related to corrosion of infrastructures and buildings. But they were not available for the Czech Republic.

The final NAS for the infrastructure and building category was calculated as the gross additions to the stock minus the removals (waste flows) from this stock. Reflecting the structure and availability of the data used for the calculation, we further distinguished among materials added to the infrastructures and buildings, that is, timber, metals, nonmetal construction commodities (e.g., building stone and bricks), and other construction commodities (e.g., asphalt and plastics).

Durables

The durables category represents a highly heterogeneous group of various products including machinery, cars, and other goods such as textiles, clothing, furniture, ceramics, glass products, paper products, and electrotechnical equipment.

Collecting the data on gross additions, we included only durables with a lifespan longer than a year, as the NAS indicator is calculated on a yearly basis (we did not need to consider this in the case of construction materials, as the lifespan of buildings and transport infrastructures is predominantly longer than a year). That means that commodities such as food products, beverages, and chemicals such as soaps or cleaning compounds were excluded. We also took care to include just final products whenever possible and not semiproducts such as basic chemicals used in industries (e.g., sulfuric acid, oxygen, and nitrogen) or component parts of final products (e.g., bodies for motor vehicles), to avoid double counting.

At first, we intended to apply the same approach for durables that we had used in the case of the infrastructures and buildings category and to calculate the gross additions to the stock using production and foreign-trade data. Unlike the case with construction commodities, though, we encountered some serious difficulties here. The data on production of durables in physical units (Czech Statistical Office 2001b, 2002b, 2003b) covered only some of the categories of durables, and in addition, these were very often reported in units difficult to convert into mass units (such as pairs, pieces, or square meters). We made a precalculation with the data available in mass units and we arrived at rather small numbers, namely, just about 3.7% of the gross additions in the infrastructures and buildings category. This was why we also used disaggregated data on consumption of durables from manufacturing industries reported in monetary units (Ministry of Industry and Trade of the Czech Republic 2003). The level of disaggregation of these data was, however, not high enough and one category of durables sometimes contained both final products and semimanufactured products. Therefore, we counted in categories containing some semimanufactured products provided the final products prevailed. Conversely, we did not include categories comprising final products if the semimanufactured products tipped the scale. We set the level of "domination" of semimanufactured or final products at 80%. The coefficients for conversion of monetary data into tonnes were recalculated using the foreign trade data, which were reported in both monetary and physical units (Czech Statistical Office various years). We took the average share of monetary values in weights for relevant categories of durables for the whole period 2000–2002 to level off the influence of inflation, and we did this both for imports and exports. Final coefficients for each category were calculated as means of the import and export coefficients.

The results obtained using monetary data and foreign trade coefficients were equivalent to 6% of the gross additions in the infrastructures and buildings category and were about 60% higher than the figures acquired with the use of data on production of durables reported in physical units (Czech Statistical Office 2001b, 2002b, 2003b). This seemed to represent durables expressed in nonconvertible units or not covered at all by this data source.

We took the data on disposal of durables from the Czech Statistical Office (2001d, 2002d, 2003d) for discarded machinery, discarded transport vehicles, and municipal waste from the commercial sphere, and we considered the same treatment methods as in the case of construction and demolition waste. As this data source did not contain any data on municipal waste from households

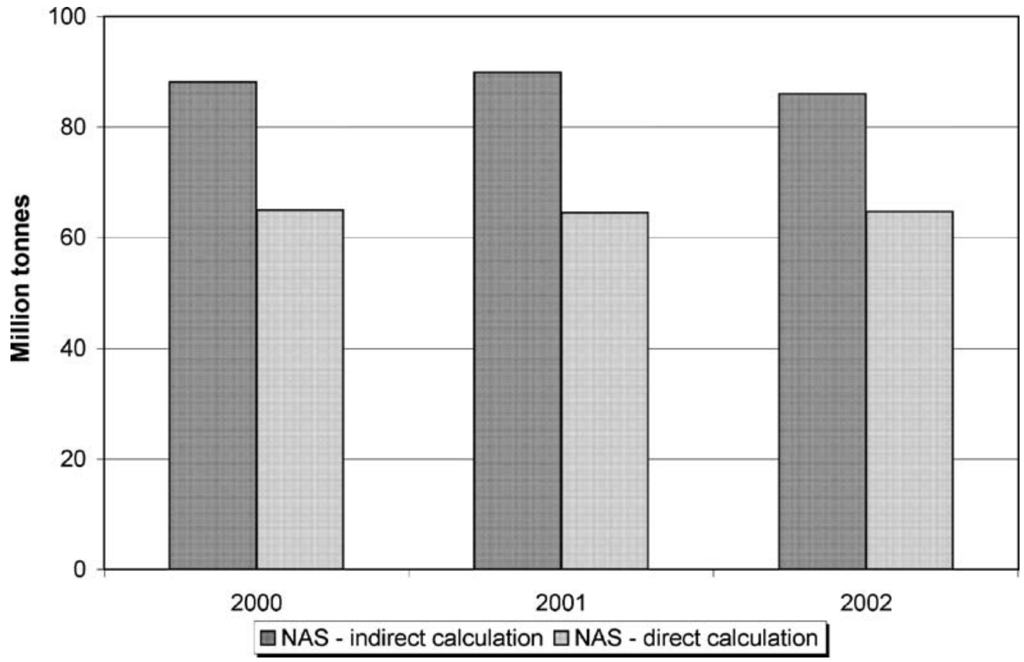

Figure 3 Comparison of the direct and indirect NAS calculations, Czech Republic, 2000–2002.

disaggregated according to the type of treatment, we took these data from the waste database operated by the T. G. Masaryk Water Research Institute (data on some treatment categories for 2000–2001 had to be estimated) (T. G. Masaryk Water Research Institute various years). Regarding municipal waste, we excluded disposed durables with a lifespan shorter than a year. They were easily detectable for commercial municipal waste due to the structure of the data provided by the Czech Statistical Office, whereas for municipal waste from households we used coefficients expressing the average share of this type of municipal waste in the total amount of municipal waste generated (Bruha et al. 2004; Dvoran 2004; ISES 2004). Ideally, the waste flow data should also contain data on material removals related to corrosion of durables. But those were not available for the Czech Republic.

In a manner similar to the method for infrastructures and buildings, we calculated the final NAS for the durables as the gross additions to this stock minus the removals (waste flows) from this stock. We further distinguished transport vehicles, machinery, and other durables within this category. For the sake of comparison with the infrastructure and building category, it would have been better to organize durables according to the materials used for their production (wood, metals, glass, etc.), but that was not allowed by the structure of the underlying data.

Results and Discussion

Overview

The detailed data used for direct NAS calculation are shown in the e-supplement. Figures 3 to 6 show the comparison of the NAS calculated by the direct and the indirect methods and the structure of the NAS calculated directly.

The indirect method of NAS calculation allows distinguishing among the NAS attributed to fossil fuels, metals, minerals, and biomass to some extent, as the EW-MFA database is organized according to these broad categories. This division, though, is just tentative, because EW-MFA also comprises semimanufactured and manufactured products (imported), the attribution of which to one of the above categories is rather artificial (they consist of a mix of various materials). Also the attribution of balancing items to these categories must be considered quite rough. The estimated structure of NAS based on indirect calculation (Kovanda et al. 2004) is shown in figure 7.

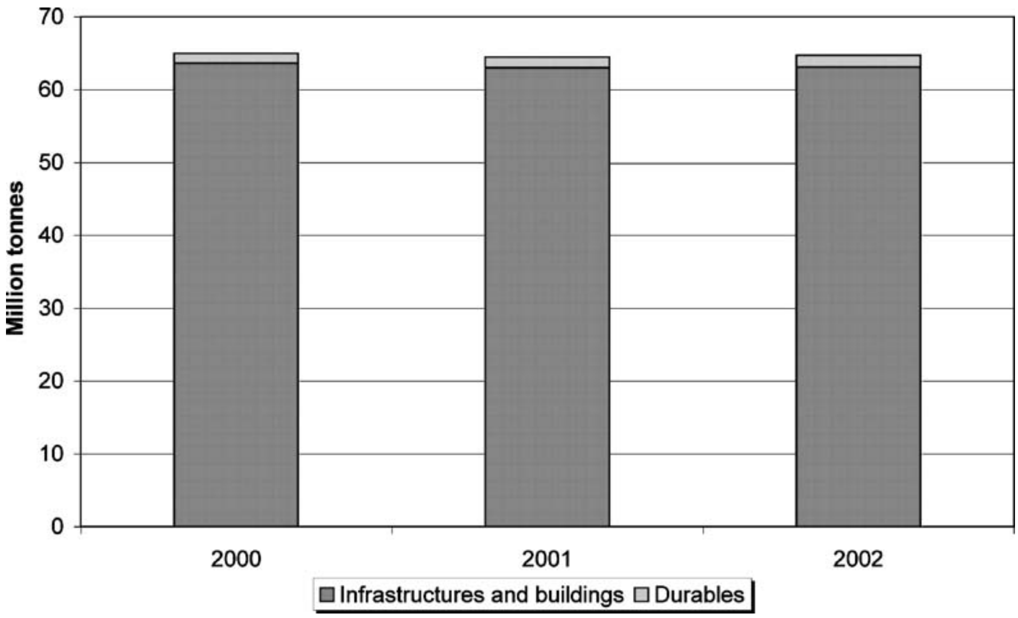

Figure 4 Direct NAS calculation: Structure of NAS, Czech Republic, 2000–2002.

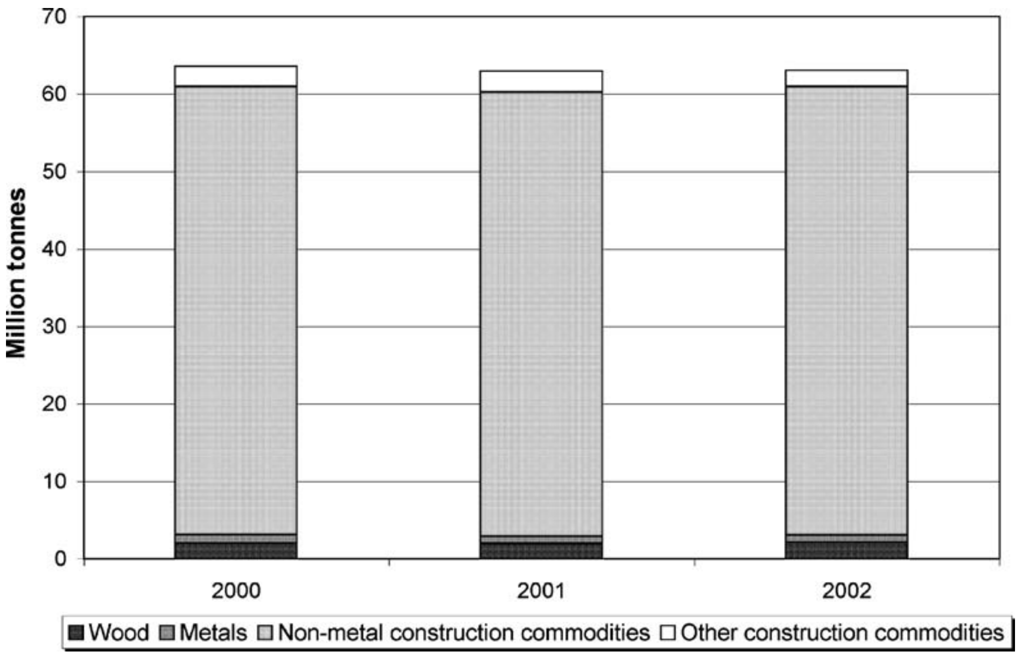

Figure 5 Direct NAS calculation: Structure of NAS for infrastructures and buildings, Czech Republic, 2000–2002.

Uncertainties Related to the Method Used and the Quality of the Data Used

We only used officially published data for the calculations, predominately produced by the Czech Statistical Office, the Ministry of Industry and Trade of the Czech Republic, the Ministry of Agriculture of the Czech Republic, and the Czech Geological Survey. They were acquired in complete or partial statistical surveys using statistical calculation methods. Unfortunately, none of those organizations determined uncertainties related to their data. We identified apparently wrong data (underestimated, in this case) on consumption of construction commodities (Czech Statistical Office 2001a, 2002a,

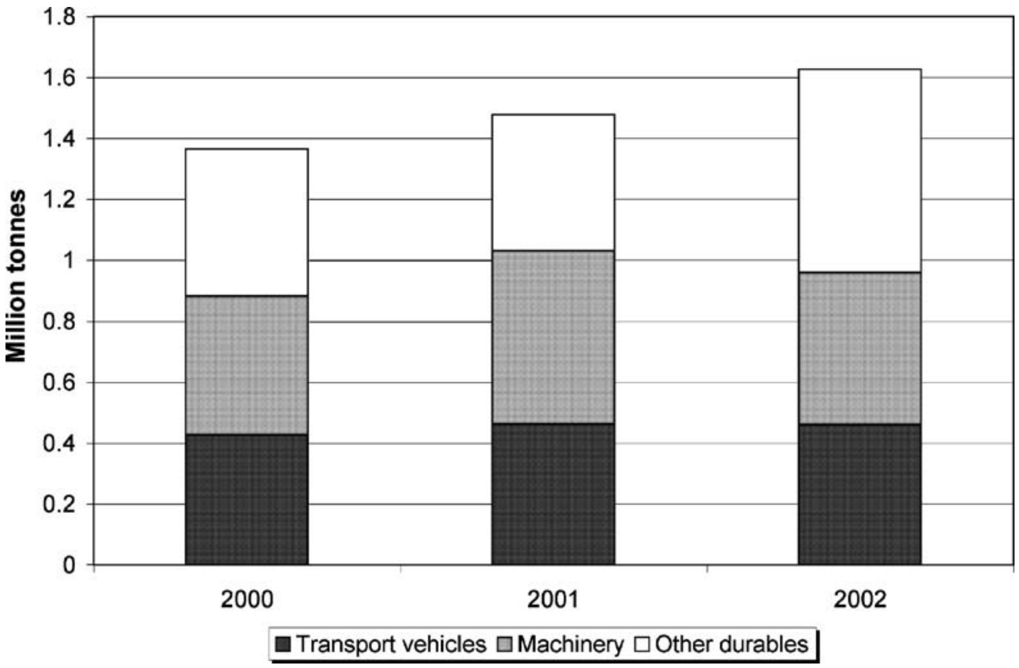

Figure 6 Direct NAS calculation: Structure of NAS for durables, Czech Republic, 2000–2002.

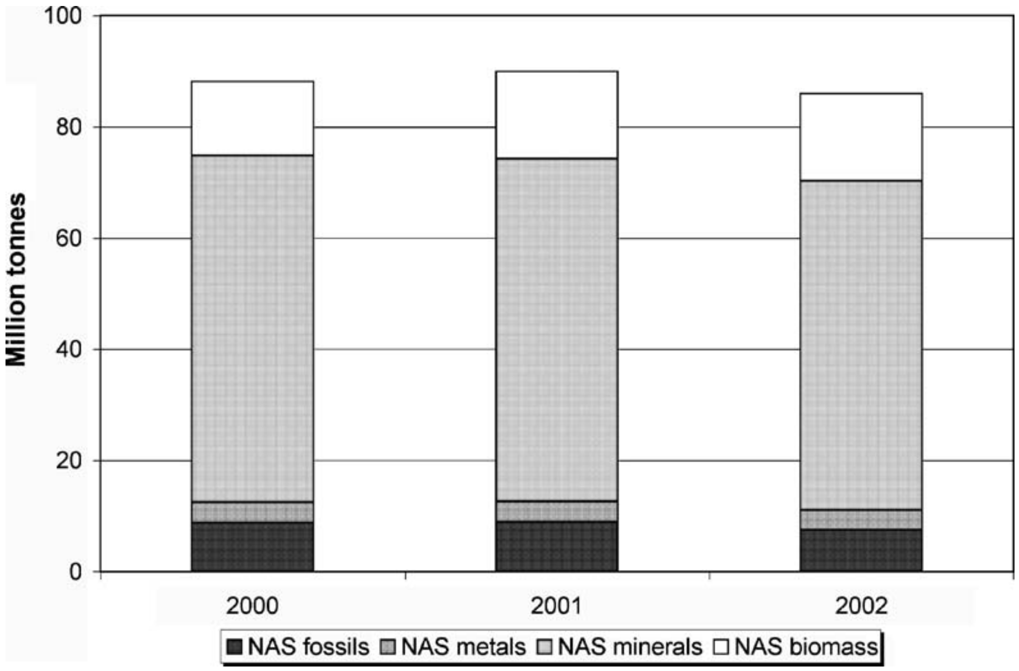

Figure 7 Structure of NAS, indirect calculation, Czech Republic, 2000–2002.

2003a). We cross-checked them with data on production of relevant commodities (corrected with imports and exports) (Czech Geological Survey 2001, 2002, 2003; Czech Statistical Office 2001b, 2002b, 2003b, 2001c, 2002c, 2003c, various years), and the latter were shown to be three times higher in some cases. Another problem we encountered was the low level of data disaggregation. Above all, that was a problem in the case of monetary data on consumption of durables, as one category of durables sometimes contained both final products and semi-manufactured products. We settled this problem by setting the level of "domination" of either semimanufactured or final products, making particular durable categories ineligible for further calculations (see the section on *Data and Methods*). We then estimated that the error arising from this procedure would burden the gross additions to stock within the durable category by up to 10%.

We applied three main approaches to gathering data on gross additions to stock: (1) taking physical data on consumption of construction commodities, which were identified with gross additions; (2) calculating construction commodities consumption as their production plus imports minus exports, all in physical data; and (3) using monetary data on consumption of durables and their conversion into physical data by means of foreign trade data. The first approach is completely in line with the idea of gross additions to stocks. The shortcoming of the second approach might be a certain delay between the production of the construction commodities (corrected with imports and exports) and their actual use for infrastructures and building purposes. Even so, stored construction commodities also present a type of stock, so this shortcoming should be taken into account but does not constitute a conceptual error. Most open to discussion is the third approach, as we did not know to what extent the shares of monetary values of foreign trade in physical trade data reflected such shares for consumption of durables. To assess this, we did some cross-checking for a few durable groups that were included by both the Czech Statistical Office (2001b, 2002b, 2003b) and the Ministry of Industry and Trade of the Czech Republic (2003). We applied approaches 2 and 3 to them and obtained quite comparable figures, which differed by no more than 15%. The degree of error related to groups of durables for which this cross-checking was impossible is not known and may be higher. The approach based on monetary data and foreign trade coefficients, however, does not seem to deliver any highly inaccurate results.

The methodological problem related to data collection on waste flows could stem from the definition of the waste categories. We adhered strictly to the waste categories flowing directly from physical stocks and not coming from production processes (e.g., wastes from metallurgy or the energy sector). Thus, we counted in data on demolition wastes, discarded transport vehicles, discarded machinery, and municipal-type waste. The data on demolition wastes were distinctive enough, but there were some waste categories, for example, inorganic wastes containing metals, the attribution of which either to stocks of durables or to production processes was impossible due to the structure of the waste database. Had we counted them in, the total waste flows for durable stocks would have been up to 10% higher. Another problem was related to the chosen waste treatment methods. We only included those causing flows of wastes into the environment and not their recycling within the socioeconomic system (for a listing of these treatment methods, see the section on *Data and Methods*). Unfortunately, the categorization of the treatment methods has changed, so the years 2000 and 2001 are not entirely comparable with the year 2002. A significant part of the uncertainties in the data on municipal waste from households might also stem from the coefficients for the share of disposed-of durables with a lifespan shorter than a year. The coefficients were only based on a few case studies (Bruha et al. 2004; Dvoran 2004; ISES 2004), and the total amounts of waste flows were rather sensitive to them.

If we compare the uncertainties of NAS stemming from data quality and methods used, they are much larger for durables than for buildings and infrastructures. In the case of durables they were caused by the following factors: (1) the low level of disaggregation of data on consumption of durables leading to inclusion of some semimanufactured products and omission of some final products; (2) the use of monetary data on consumption of durables and their recalculation based on foreign trade data; (3) not counting in waste data for which the attribution either to stocks or production processes was impossible; and (4) the use of coefficients to calculate the component of municipal waste from households that consists of all durables that had a lifespan longer than a year. All these factors summed up, the uncertainties related to NAS of durables may range ±30%. This estimate was based on knowledge on shares of semimanufactured/final products in particular durable categories, cross-checking of monetary-based durables consumption with their physical consumption (see above), and knowledge of volumes of wastes not attributed either to stocks or to production processes, municipal wastes and total wastes flows. Moreover, this exercise was underpinned by knowledge of methods by which these data were collected (complete and partial statistical surveys, calculations, educated guesses, etc.) and estimation of data uncertainties related to these methods. On the other hand, uncertainties related to buildings and infrastructures were caused by (1) inclusion of the highly underestimated data on consumption of construction commodities (Czech Statistical Office 2001a, 2002a, 2003a) and (2) a certain delay between the production of the construction commodities (corrected with imports and exports) and their actual use for building purposes. Based on knowledge of how much the construction commodities in question may be underestimated (see the section on *Data and Methods*) and knowledge of methods by which all data on construction commodities were collected, the uncertainties related to buildings and infrastructures were set at ±10% As durables account for about 2% of the total NAS, we estimate the uncertainties of NAS as a whole very close to the buildings and infrastructures category, that is, ±10%. This figure is much lower than the uncertainties estimated for indirectly calculated NAS for the Czech Republic, which equal approximately +38/−25% (Kovanda et al. forthcoming).

Differences between the NAS Calculated by the Direct and Indirect Methods

The NAS calculated by the direct method is approximately 27% lower than the NAS acquired by the indirect method of calculation (figure 1). The actual values of directly calculated NAS and its uncertainties suggest that overestimation of the indirect NAS is more likely than its underestimation. Even though the full comparison of the structure of the two NAS is not possible due to different categorization, we can make some rough comparisons.

In the indirect NAS calculation, fossil fuels account for approx. 8.4 million tonnes of the total NAS (figure 5). Fossil fuels in the form of semi-manufactured and final products are a component of durables (car tires, plastics) and also other construction commodities (asphalt). As durables and other construction commodities acquired by the direct calculation amounted just to 4 million tonnes in total, they could not cover the fossil fuels in their entirety. Something similar applies to other material categories. Metals, nonmetal minerals, and biomass account for approximately 3.7 million tonnes, 61.1 million tonnes, and 14.9 million tonnes, respectively, in the indirect NAS, whereas the corresponding parts of the direct NAS are 1 million tonnes, 57.7 million tonnes, and 2 million tonnes, respectively. Once again, metals, nonmetal minerals, and biomass also form a part of durables, but their overall amount is too small (ca 1.5 million tonnes) to compensate for the above discrepancies. The difference is most pronounced in the case of biomass, as indirect biomass NAS is 14.9 million tonnes, whereas the direct biomass NAS could not be higher than 3.5 million tonnes (under the extreme assumption that all durables are of biomass nature).

As the uncertainties related to the directly-calculated NAS that stems from the data and calculation method used are estimated at no more than ±10%, there must be some other reasons for such distinctive discrepancies. We identified two of them: (1) omission of some secondary construction commodities in the direct calculation; and (2) overestimation of the NAS acquired by the indirect method of calculation.

Omission of Secondary Construction Commodities in the Direct Calculation

We included all the categories of primary additions to stocks that we considered important. But some other materials are counted on the input side of the EW-MFA during indirect NAS calculation but are used primarily neither for construction purposes nor for production of durables. They first have to become secondary materials. These secondary materials include, above all, combustion residues from burning of fossil fuels and slag from industrial processes. When NAS is calculated indirectly, these materials remain within the “black box” of a socioeconomic system and constitute the NAS. That means they should also be counted in the direct NAS calculation. This was the case with durables, where we took into account their total consumption (i.e., consumption

Table 1 Factors causing over- and underestimation of NAS indicators

NAS Indicator	*Source of overestimation*	*Source of underestimation*
Biomass	Incorrect estimation of balancing items	Omission of some durables produced from biomass due to low level of disaggregation of data on consumption of durables
Fossil fuels	Incorrect estimation of balancing items	Omission of some durables produced from fossil fuels due to low level of disaggregation of data on consumption of durables
		Omission of some secondary construction commodities in gross additions to stock
Metals		Omission of some durables produced from metals due to the low level of disaggregation of data on consumption of durables
Nonmetal minerals		Omission of some secondary construction commodities in gross additions to stock

of both products from primary materials and products from secondary materials), but not the case of construction commodities, where we counted in just the primary construction commodities and not consumption of ash from burning of fossil fuels, for instance. On the other hand, the case of recycled construction and demolition waste further used for construction purposes (mainly brick and concrete) is a different matter. They are considered on the input side in the direct NAS calculation when they enter the system in the form of primary construction commodities. As we do not include recycled construction and demolition waste on the waste side, counting in this waste on the input side would mean double counting.

Unfortunately, no data are available on consumption of relevant secondary commodities in construction in the Czech Republic except the data on their overall consumption (2001d, 2002d, 2003d). In 2000, that was 5 million tonnes. As these materials were dominated by materials from burning of fossil fuels (ash) and mineral industrial waste (slag), this number can, above all, elucidate the lower values of the directly calculated NAS attributed to fossils and nonmetal minerals.

Overestimation of the NAS Calculated by the Indirect Method

To enable an indirect calculation of NAS, it is necessary to insert the balancing items into the material balance (see the section on the Eurostat methodology for assessment of material flows at the macroeconomic level). The role of nonmetal minerals and metals is minor. It was beyond the scope of this study to analyze the balancing items used for the indirect NAS calculation in detail, but it seemed apparent that either overestimation of input balancing items or underestimation of output balancing items (or both) could lead to significant NAS overestimation for fossil and biomass material categories. For calculation of the balancing items we used stoichiometric principles, but also coefficients expressing, for example, O_2, H_2, and H_2O content of burned fossil fuels, ratios between the amount of consumed food and the O_2 needed for its oxidation, and the livestock and human demands on drinking water (Kartak 2003; Blaha 2003; Schütz 1999). We checked the stoichiometry to find it satisfactory; the coefficients should therefore be the main drawback. This seemed true especially regarding the biomass category. In this case the indirectly calculated NAS is too huge to be correct in our opinion, as we simply could not conceive of any form of additions to stock that the biomass should have.

Table 1 summarizes all the reasons (in this and the previous section) that the indirectly calculated NAS figures are higher than the directly calculated NAS.

As infrastructures and buildings by far dominate the total NAS, omission of secondary construction commodities from fossil fuels and nonmetal minerals from gross additions to stock seems to be the most important factor that could have led to underestimation of the direct NAS data.

Conclusions

The study described in this article made available the direct NAS data for the Czech Republic, showing that calculation of NAS using a direct method is possible in this country, with respect to data availability. The discussion of data and methods used for direct NAS calculation arrived at an estimate of uncertainties related to direct NAS, which should be close to ±10%. These uncertainties are lower than those estimated for indirectly calculated NAS, which equal approximately +38/−25%. Uncertainties related to direct NAS stem, above all, from the poor quality and availability of data that can be directly used for calculations. This leads to the necessity of developing proxy calculation methods for these data (such as calculating gross additions to stock of durables using monetary data on their consumption and data on foreign trade) rather than simply looking them up in statistical compendia. In this respect, it would be especially helpful to improve statistics and quality of data on consumption of construction commodities (including secondary construction commodities) and the coverage of durables whose production is reported in physical units.

Direct calculation of NAS also provides some useful hints for calculation of NAS using the indirect method. This is especially valid for balancing items, which have to be introduced when NAS is calculated indirectly. A comparison of direct and indirect NAS indicated that the under-/overestimation of these items is highly probable. This notion will be applied in further revisions of the Czech indirect NAS.

To summarize, the future work in this area will be focused, above all, on decreasing uncertainties related to both indirect and direct NAS figures. The pending objective is elaboration and application of a methodology allowing use of direct NAS data for prediction of future waste flows.

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Note

1. All tonnes mentioned in this article are metric. One metric tonne (t) = 10^3 kilograms (kg, SI) ≈ 1.102 short tons.

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