Environmental Burden Caused by the Consumption of Czech Households

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Abstract: This paper is the first study quantifying both direct and indirect emission burdens on the environment from households in the Czech Republic. Indirect emissions are released during the manufacture and distribution of goods consumed by the households, while direct emissions stem from the fuels burnt in homes or to propel cars. Emissions of greenhouse gases, gases causing acidification and substances giving rise to photochemical smog attributable to the household consumption are taken into account. To assign the indirect emissions to the particular product group, linkages between detailed household final expenditure categories and industry product groups are made. The Multiregional Environmentally Extended Input-Output Analysis based on the CREEA database in combination with Single Region Input-Output Analysis using national NAMEA and symmetrical input-output tables are used to calculate the indirect emission values in such a way to take advantage of the strengths of both databases in order to get the most precise results possible. Overall, the average Czech household is responsible for 11,100 kg of CO_2 eq., 26.1 kg of SO_2 eq. and 4.6 kg of ethylene eq. smog formatting emissions a year per person. Among product categories, a major part of GHG emissions is stemming from demand on electricity and heat, while food contributes mostly to SO_2eq emissions and transport is mostly responsible for emissions causing photochemical smog.

Resulting emissions are aggregated to 7 groups: food, housing, heating and hot water, electricity, transportation, goods and services so the relevant policies can be suggested. The households are then grouped into deciles according to their expenditures and their emission elasticity of expenditures is calculated.

Keywords: Household expenditures; Environmental impact; Multi Regional Environmentaly Extended Input-Output analysis; Emission intensities; CREEA Climate change; Acidification; Smog formation;

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1 Introduction: Motivation and method overview

Once humans began to use fire, they produced the first manmade emissions. When industries and trade emerged, those emissions were not inherently bound to the place where man lived and his direct activity, but rather to what he or she spent the money on. The flow of products can be caught in a form of a table. Such first table of an economy system was put together by François Quesnay in the seventeenth century. A much more elaborate model was created and calculated using one of the first computers by, future Nobel Prize laureate, Wassily Leontief in the half of the 20th century. He also demonstrated that this model, called input-output, can be used to trace flows of emissions as well.

This has become important, because the amount of human emissions has increased over the course of past centuries to the level, where some of these emissions have significantly negative effects on human health or they affect the whole environment. Since the experiences and research have shown which emissions are noxious, governments started to take measures to push industries and vehicle producers to cut the amount of harmful emissions down or even stop production of particular pollutants completely. The positive trend of relative emission decrease has unfortunately been somewhat balanced by growing wealth enabling higher consumption, which in turn stirs up the production and thus the absolute volume of emissions. Hand in hand with the moderating measures some states introduced compulsory record sheets for industries to record their exhaust gases.

This paper aims to estimate three emissions groups, which were induced by consumption of Czech households. It takes into account major gases causing greenhouse effect, acidification and photochemical smog.

The presented paper combines the above mentioned input-output tables, obtained from the **n**ational account of the Czech Republic or from the CREEA project with national emission sheets NAMEA or international emission sheets from the CREEA, together with Czech Household Expenditure Survey.

One part of household emissions emerges as the direct outcome of fuels burnt to heat up homes, make hot water and propel their vehicles. They are usually referred to as direct emissions (e.g. Kerkhof, 2009). In this paper we calculate them for the most commonly used fuels in the Czech Republic.

Another part of emissions stems from different industrial processes, electricity production and supplying of services. All these commodities are finally consumed by households or government and non-government sectors. To calculate such embodied emissions, we applied a method called Environmentally Extended Input-Output Analysis (EE-IOA).

In principle, there are two approaches possible to follow, when the EE-IOA is employed. The first option is, Single Region EE-IOA (SR EE-IOA), where Input-Output Table (IOT) and industries emissions cover only one single region. This approach assumes that imported products are produced using the same technology as domestic firms. This fact is known as the domestic technology assumption. Consequentially, emissions related to imported products are independent of their origin.

Alternatively, Multi Regional EE-IOA (MR EE-IOA) represents a more complex option of analysis. It uses multi-regional symmetrical input-output tables and emission databases of all participating regions.

The former approach can under- or over-estimate emissions attributable to imports as shown in Andrew (2009). On the other hand, to gather the necessary data for domestic economy only is usually less demanding and, in this case, also provides finer disaggregation and more recent data. This study combines both methods profiting from the strengths of both methods.

Similar studies, where input-output analysis calculates mostly total energy consumption or CO_2 emissions, have already been carried out for some countries. Here is a partial list: Denmark (Wier, 2001), India (Pachauri, 2004), Norway, Sweden, Netherlands and Great Britain (Moll, 2005), Norway (Peters, 2006), Brazil (Cohen, 2006), Japan (Nansai, 2008), USA (Weber and Matthews, 2008), Netherlands (Kerkhof , 2009), Great Britain (Baiocchi, 2010), Italy (Cellura, 2012) or China (Golley and Meng, 2012). No such a calculation, to authors' knowledge, has been carried out for any post-communist country from Europe.

For the Czech Republic, Weinzettel and Kovanda (2009) calculated embodied emissions, or material consumption of industry sectors, without attributing the burden to the consumption of households. In their other work, the same authors focused mainly on material flows, e.g. Weinzettel and Kovanda (2011), Kovanda and Weinzettel (2013). This paper thus fills the gap and computes total household emissions for three categories of air pollutants or green house gases for this country.

As for data uncertainties of indirect emissions, Wiedman (2008) has noticed, that smaller the sector output the higher the uncertainty. On the other hand, the higher less sectors is used the bigger uncertainty from aggregation can arise. In this paper, relatively high number of sectors and product groups, respectively, is used for calculation, but highly aggregated consumption groups are used to draw conclusions, where these uncertainties should cancel out as also mentioned by Biaocchi (2010). In principle, this method is based on large number of statistical surveys, that can all suffer from under or overestimation.

2 Description of used databases

This study itself gathers no primary data and uses only existing databases. Nevertheless, most of these databases had to be modified to enable interconnection. The databases are the outcome of Czech national institutions, as well as a scientific project in the case of CREEA. In the following paragraphs, specifics and limitations of used databases are described. All key databases were acquired on demand from the respective institutions, since highly detailed resolutions are not publicly available. All the databases used come from the year 2010, except for the CREEA which was produced for 2007 and transformed as described herein. The Czech Koruna (CZK) is used as a currency for all calculations except for CREEA, where Euro (EUR) is used, and finally for the presentation of results, where EUR is used too to make results internationally comparable.

2.1 Symmetric input-output tables

SR EE-IOT is based on Symmetrical Input-Output Tables for the Czech Repbulic (Czech Statistical Office, 2010a). The tables are created in five-year intervals by the Czech Statistical Office (CZSO) with ESA 1995 methodology. In this paper, we use SIOT product x product (product group x product group) for 2010 for 184 product groups that are based on CPA classification. Compared to its alternative, the CREEA database, it offers more detail on the manufacturing and service product groups and less detail on agriculture, mining and production of metals.

The main limitation of SIOT in respect to EE-IOA is its limited number of product groups. In addition, part of the SIOT flows end in the column of Gross Fixed Capital Formation, and as such this part is not included in the input-output analysis. This introduces underestimation of emissions from these product groups.

2.2 CREEA

The EXIOBASE 2 database (CREEA) includes environmental extensions, supply and use tables for 43 countries and the rest of the world, distinguishing about 166 sectors and 200 product groups with high disaggregation in primary and manufacturing sectors, such as agriculture, mining and processing. The data is directly available also in the format of symmetric environmentally extended product by product MRIO table constructed under industry technology assumption.

We used the lastly mentioned dataset to calculate emission footprints of final use products of Czech households and applied price corrections from the year 2007 into 2010 using deflators obtained from the CZSO on special request. Using this type of MRIO data therefore assumes equal technology in 2007 as in 2010. Therefore, we distinguished two types of products for final use, those coming mainly from abroad and those coming mainly from domestic production and applied either Czech SIOT or CREEA, as we assume, that the error introduced by using three years old technology is better than the domestic technology assumption for mostly imported products and vice versa for products of domestic origin.

To make SIOT compatible with CREEA, we transformed outcomes of both databases to 232 product group resolution. This resolution is called NACE 232 hereinafter. This resolution always encompasses the more detailed product group division of the two. The less detailed database has, as a result, the same outcome for all corresponding product groups.

2.3 Supply- use tables

Supply and use tables (SUT) (Czech Statistical Office, 2011b) provide a detailed description of transactions of goods and services, which occurred in the course of one year. The supply table depicts distribution of the main sector product and its by-products among the sectors, from which products are supplied. The use table includes inputs of products (product groups) to sectors, their added values, taxes, transport and trade margins, imports and final use. It is collected by CZSO. SUT are not symmetrical unlike SIOT. SUT for 2010 is used in this paper.

Taxes and transport and trade margins are used to transform Household Expenditure Survey from final to basic prices. The resolution of 203 sectors was converted to 232 sectors as well in order to be in alignment with SIOT and CREEA.

2.4 Household Expenditure Survey

The Household Expenditure Survey (Czech Statistical Office, 2011c) carried out annually by CZSO contains expenditures for all the variety of products which a household purchases or spends its money on. This paper uses expenditure survey for 2010 for 2930 households in the resolution of 1682 expenditure items. The resolution is based on COICOP classification.

The expenditures are actually recorded in two tables, a detailed table for every second month and for 2 months for food expenditures a year and a less detailed table that includes complete annual expenditures, but only for 211 expenditure items. Their aggregation, which is explained in the methodology, is necessary.

Although participating households should be representative of the complete Czech population, the high income household group is less willing to join and might be under-represented. A household might consume also gifts and home made products and crops of non-specified value. Finally, the completeness of petty everyday expenses might not be complete due to natural human forgetfulness.

2.5 Consumer price index

As CREEA is available only for the year 2007, Consumer Price Index (CPI) (Czech Statistical Office, 2014) is used to transform the household expenditures from 2010 to 2007. The CPI is issued by CZSO each year and has 104 goods categories and thus it had to be spread over all 232 product groups. The CPI is expressed in CZK currency. To get a product group price of 2010 the price from 2007 expenditure in question is simply divided by respective CPI value.

2.6 Currency conversion

For the need of currency conversion between CZK and EUR, the exchange rate of 27.762 CZK/EUR is used. This is average exchange rate for 2007 issued by the Czech National Bank (CNB, 2014). In turn after dividing of 2010 expenditures by CPI, expenditure of 2007 is divided by the exchange rate 27.762 CZK/EUR, thus getting expenditures of 2007 in Eur.

The same exchange rate was also used for the final expression of kg emissions per EUR for 2010. This exchange rate was selected to keep the results consistent with CREEA, which was recorded in 2007. This implicates that emissions per EUR in this paper are virtually related to EUR of 2007.

The exchange rates conversions are not mentioned further in the methodology due to their mathematical simplicity.

2.7 Emission registry and NAMEA

The National Accounting Matrix with Environmental Accounts (NAMEA) (CHMI, 2012), gathered by the Czech Hydrometeorological Institute, includes material flow and emissions to air. Only the emission part is used in this paper. We use three eleven pollutants described in the chapter 3.3. Gas emissions are available in utmost resolution of 88 sectors. Disaggregation to 184 sectors, corresponding with 184 product groups of SIOT, was carried out. This disaggregation is explained in the methodology.

A firm, based on its prevailing production, comes under one specific sector, which makes its by-products outcome of different sectors then they are supposed to be. This might cause certain inconsistency between the sectors of NAMEA and product groups of SIOT.

Regarding emission records, the emissions of stationary non-residential sources smaller than 0.3 MW of heat output are neglected. The same is true for car emissions of companies with less than 20 employees.

2.8 Data sources for direct emissions

One portion of direct emissions arise by burning propellants. Propellants included here covers absolute majority of emissions are petrol, diesel and LPG. Average emission coefficients expressed in kg of emission per kg of fuel are taken mostly from Corinair (2012) and supplemented with Adamec (2005). The average density is taken from a state owned propellant distributional company (Čepro, 2011). The price per liter of propellant is taken from the web pages of CZSO (CZSO, 2015).

Another part is emitted from fuels used for heating up homes and hot water. It includes lignite, bitumen coal, coke, natural gas and wood. Emission coefficients for considered greenhouse gases in kg of emissions per MJ of calorific value are acquired from Bulletin of MZP 8/2013 (2013). The other emission coefficients are taken from Ordinance Appendix no. 2 Statute Book 205/2009. The calorific values are acquired individually. Wood comes in many varieties. The most probable variant was chosen for the calculation: spruce tree wood with 15% humidity in the form of 33 cm logs. The calorific value and average density of wood was taken from TZB-info (2015). As for the coal, extra information regarding its sulfur content was needed. Again, the most common variants were selected and the sulfur contents, calorific values and densities were recorded (Top Palivo Teplo, 2015a, Top Palivo Teplo, 2015b). A fixed fee, estimated as 10 % of total price paid for natural gas, is paid for connection to the network. This ratio is the same for all households regardless of its expenditures. The average prices of coal and wood were taken from Ministry of Industry and Trade (2011) and price of natural gas from TZB-info web pages (TZB-info, 2014).

Emissions of NH_3, HFCs, PFCs, SF_6 as well as emissions of N_2O for natural gas are regarded as negligible and thus equal to 0.

2.9 General issues

Despite the method used tries to mitigate limitations of IOA by combining two data sources, occasional high differences between the set of CREEA and SIOT plus NAMEA indirect emission coefficients suggests, that underlying data sets can be encumbered with an error. In general, CREEA tends to have higher indirect emission coefficients, but this is not a rule as there are several hundreds of them used and elaboration of differences comparison is out of scope of this paper.

3 Methodology

3.1 Description of notation used

We use the following notation of variables:

a	is a one-dimensional variable a
$\mathbf{a}$	is a column vector $\mathbf{a}$, n × 1
a_i	is the i-th entry of the vector $\mathbf{a}$
$\mathbf{a}^\mathbf{T}$	is a transposed vector $\mathbf{a}$, 1 × n
$\mathbf{A}$	is a matrix A
A_{ij}	is the i-th row a j-th column entry of the matrix $\mathbf{A}$
$\mathbf{A}^\mathbf{T}$	is a transposed matrix $\mathbf{A}$

diag(a) is a diagonal matrix with the vector **a** on the main diagonal

Production groups, sectors and expenditure items start with a capital letter to ease the orientation.

3.2 Direct and indirect emissions

This paper differentiates between direct emissions, which arise from burning fuels at households or propellants in household owned vehicles, and indirect emissions, which stem from the production and distribution of goods and services consumed by those households. For each of considered expenditure here, total emissions of a particular pollutant e_{tot} (kg) are the summation of direct emissions e_{dir} (kg) and indirect emissions e_{ind} (kg).

$$e_{tot} = e_{dir} + e_{ind} \quad (1)$$

Naturally, e_{dir} equals to 0 for product categories with no direct emissions. On the contrary, indirect emissions e_{ind} attributable to the expenditure with direct emissions need to be taken into account when calculating their total emissions. In this case, the indirect emissions for these products are usually relatively smaller than their direct counterparts.

3.3 Pollutant groups

The main aim of this paper is to quantify environmental burden caused by household consumption. For this purpose, three groups of emissions causing respective environmental effects are used:

(1) Climate change: CO_2, CH_4, N_2O, HFCs, PFCs, SF_6
(2) Acidification: SO_2, $NH_{3,}$ NO_X, N_2O
(3) Smog formation: NMVOC, CO

Environmental effects were chosen with consideration for availability of the emission data for direct and indirect emission calculations.

Each of the emissions is calculated one at time and then merged together into the respective environmental effect. For that purpose, emission potentials are used to transform them to substituting equivalent of each environmental effect: CO_{2eq} for climate change, SO_{2eq} for acidification, ethylene (ethene) C_2H_{2eq} for smog formation.

Only emissions from production and utilization phase are considered in this paper, because pollutants released from landfills and incinerators from disposed goods are not traced in this way.

3.4 Calculation steps to get to the final results

This paper gathers single values and complex databases from a variety of sources and combines them in calculations. The calculations consist mainly of matrix calculations, aggregations, disaggregations and matching between different classifications. They are carried out step by step as described below. The final results of these calculations are individual emission amounts for every household and in each product group, which a household spends the money in, as well as its merged version combined in 7 consumption groups.

The calculation process is done through the following steps:

(1) Calculation of embodied direct emission coefficients for the fuels used by households
(2) Disaggregation of NAMEA sector emissions into 184 sectors
(3) Calculation of embodied indirect emission coefficients from SIOT and NAMEA
(4) Calculation of embodied indirect emission coefficients from CREEA

(5) Merging of embodied emission coefficients into the resolution of 232 product groups, so that it includes more detailed product groups from both SIOT plus NAMEA and CREEA coefficients
(6) Re-calculating embodied emission coefficients to include emission potentials
(7) Disaggregation of the records from Household Expenditure Survey into 390 expenditure items
(8) Transformation between 1682 expenditure items and 232 product groups
(9) Conversion of prices from 2010 to 2007 (for CREEA only)
(10) Conversion from final prices of expenditures to basic prices of input output tables by subtracting taxes and transferring of trade and transport margins into their own product groups (done individually for SIOT plus NAMEA and CREEA)
(11) Dividing product groups to prevailingly domestic, where SIOT plus NAMEA is used or imported, where CREEA is used and construction of embodied emission matrix from its combination.
(12) Multiplication of embodied emission coefficients from step 10 with expenditures from step 9
(13) Aggregation of individual household emissions to 7 consumption groups

These steps are described in detail in the following subchapters.

The results serve for statistical evaluation. They are also merged into a more compact version and printed in graphs and tables to give a synoptic overview.

3.5 Direct emissions coefficients

Direct emissions e_{dir} are calculated for eight major fuels used in Czech households: natural gas, lignite, bituminous coal, coke, fuel wood, gasoline, diesel fuel and LPG. Emissions of one product category are product of emission intensity g_{fuel} (g_{em}/CZK) and the amount of money spent on that category m_{fuel} (CZK)

$$e_{dir} = g_{fuel}\ m_{fuel}$$

where g_{fuel} is product of emission coefficient c_{dir} (kg_{em}/kg_{fuel}), and its price p_{fuel} (CZK/kg).

$$g_{fuel} = c_{fuel}\ p_{fuel}$$

Since some emission coefficients are not expressed kg_{em} per kg_{fuel}, other trivial calculations must be carried out. Because of their simple character, they are not described here in further detail.

3.6 Disaggregation of NAMEA emissions

In order to obtain emissions in the resolution of 184 sectors for stationary emission sources higher than 0.3 MW of heat output, records of individual firms are summed. New sectors are based on the first 3 digits of their NACE code, so that they are equal to the CPA codes of

SIOT. Minor stationary combustion heat sources under 0.3 MW of heat output and mobile sources, which are recorded in NAMEA in 88 sectors, are disaggregated in the ratio of total outputs of product groups in SIOT, since they are not collected for individual companies. The total outputs are used, because they reflect the turnover of each product group and thus its relative size. Flows of fuels into other product groups would be more suitable, but they were zero for several product groups and as such unusable.

3.7 Indirect embodied emission coefficients from NAMEA and SIOT

When calculating indirect emissions e_{ind} (kg), first direct emission intensity of a whole industry sector $d_{i,sec}$ (kg_{em}/CZK) is calculated, where f_i (kg) are total emissions released by sector i, gained from NAMEA, and m_i (CZK) stands for total output of that product group, gained from SIOT.

$$d_{i,sec} = \frac{f_i}{m_i}$$

The values of intensities $d_{i,sec}$ (kg_{em}/CZK) are then used in the row vector $\boldsymbol{d_{sec}}$ in Leontief's input-output transformation in order to yield the row vector of embodied emission coefficients (also called intensities).

A (-) is a matrix of technical coefficients. It is calculated by dividing column-wise total intermediate matrix **S** (CZK) from SIOT with the vector records of domestic total outputs **q** (CZK).

$$A_{ij} \; = \frac{S_{ij}}{q_j}$$

The matrix **S** includes both import and domestic transactions in this case.

The vector of embodied emission intensities **i** (kg_{em}/CZK) is then calculated as follows

$$\mathbf{i}_{\mathbf{ind}}^{\mathbf{T}} = \; \mathbf{d}_{\mathbf{sec}}^{\mathbf{T}}(\mathbf{I}-\mathbf{A})^{-\mathbf{1}}$$

where **A** together with an identity matrix **I** create Leontief's inverse matrix $(\mathbf{I} - \mathbf{A})^{-1}$ (for explanation of this mathematical operation see e.g. Allenby).

3.8 Indirect embodied emission coefficients from CREEA

Indirect embodied coefficients from CREEA are calculated exactly in the same way as using NAMEA and SIOT. The only difference is the data source and the fact that CREEA includes data (i.e. environmental extension and input-output table) for the whole world without a limitation to one single region. However, the calculation procedure is the same, departing from emission intensities of product groups and ending by the use of the Leontief inverse matrix as described in the last equation.

3.9 Merging of embodied emission coefficients into the resolution of 232 product groups

Because a combination of both above mentioned embodied intensities, from SIOT and CREEA, is used, a conversion to their common resolution must be carried out. Such a resolution always contains the more detailed product group of the two.

In this case, the product group from the less detailed database is then assigned to more newly created NACE 232 product groups. E.g. CREEA contains Rice, Wheat and Other crops as an individual product group, while SIOT contains only Crop production. Then this Crop production product group is assigned to Rice, Wheat and Other crops sectors for NACE 232.

The conversion itself is then done by multiplying of embodied emission intensity vector with one of the conversion matrixes **C** (-). The matrixes **C** consist of ones "1", where an original product group should be assigned to the new product group, and zeros elsewhere. The relation between original resolutions and more detailed resolution is mathematically expressed as:

$$\mathbf{i}^{\mathbf{T}}_{\mathbf{232indNAMEA}} = \mathbf{i}^{\mathbf{T}}_{\mathbf{indNAMEA}}\mathbf{C}_{\mathbf{NAMEA}}$$

respectively

$$\mathbf{i}^{\mathbf{T}}_{\mathbf{232indCREEA}} = \mathbf{i}^{\mathbf{T}}_{\mathbf{indCREEA}}\mathbf{C}_{\mathbf{CREEA}}$$

3.10 Inclusion of emission potentials

An emission potential expresses the intensity of a specific gas in respect to the standard of each environmental effect. Therefore global warming, acidification and smog formation potentials of all gases included here are taken into account and summed by these effects. Environmental effect is calculated for a designed time interval. For this paper, 100 years is the time horizon adopted for all environmental effects. To obtain embedded emission intensity inclusive of its potential, the original intensities were simply multiplied with their gas potentials p (-).

$$\mathbf{i}^{\mathbf{T}}_{\mathbf{p232indNAMEA}} = \mathrm{p}\mathbf{i}^{\mathbf{T}}_{\mathbf{232indNAMEA}}$$

or

$$\mathbf{i}^{\mathbf{T}}_{\mathbf{p232indCREEA}} = \mathrm{p}\mathbf{i}^{\mathbf{T}}_{\mathbf{232indCREEA}}$$

3.11 Disaggregation of records from Household Expenditure Survey

The complete annual table, with 211 expenditure items, is not sufficient in two cases, firstly, where NACE 232 is more detailed than those 211 items, for instance, Drug store products would be useful to divide into the Soap and shower gel etc. category, which would fall into the product group of Soap, detergents, perfumes, and to Toiletries, which would come under the Paper. Secondly, in the case of fuels, where e.g. the Propellant item is divided to Petrol and Diesel fuel, it is always necessary to divide the whole expenditure item into all its sub-items.

Items are disaggregated in the ratio of sub-items. By means of this disaggregation, 390 expenditure items are created for each of 2930 households.

3.12 Transformation between expenditure items and product groups

Creation of the transformation matrix **T** between 1682 expenditure items and 232 product groups and the transformation itself is a crucial part of the whole calculation process. The transformation is mathematically carried out through a matrix, in a similar way as in the 3.9. This matrix consists of ones, where an expenditure item comes under the respective product group, e.g. both expenditure items New cars and Used cars come under Motor vehicles product group, thus they have "1" in this product group's column and zeros "0" elsewhere in the New cars and Used cars rows.

Which expenditure item belongs to which product group, was decided based on the CZ-NACE classification [1] detailed list and personal judgment.

This interconnection has limitations for some categories listed below:

a) When the expenditure item is relatively homogenous and falls whole under one product group, e. g. Eggs comes under Poultry, but Poultry meat is dominant here. This problem is noticeable in agriculture product groups for SIOT and in manufacture sectors for CREEA, where databases are less detailed.
b) When the expenditure item can be produced from more different materials or when the item is largely produced from the set of different materials, e. g. Bathroom sets can be produced from plastic, metals, wood or glass as well as from their combination. Such a category is then usually assigned to the product group of Other manufactured products.
c) When the price of the item is considerably larger or smaller than the rest of the items from that product group, while material and energy demand for these products is similar. Such a case can include Jewelry and watches in the case of CREEA, where it falls under Other manufactured products.

When it is possible to make a qualified estimate, in order to express how much the item expenditure is over- or undervalued compared to the average of that product group, a different ratio than "1" is selected. These exceptions include the following examples:

a) A service with high labor demand compared to material or energy consumption of that product group, such as repair services. E.g. Plumber service is assigned to Other metalwork products, with coefficient of 0.2, as metal products are assumed to be responsible for 0.2 of total price and emission demand for labor is assumed to be zero.
b) When one item falls under more product groups, e.g. Electricity category is divided into the following product groups in the ratios of 0.65 for the Electricity from coal, 0.22 for the Electricity from nuclear plants and 0.13 for the Electricity from water. This corresponds to the ratios of electricity production for the Czech Republic in 2010.
c) When costs of an item are subsidized, e. g. Prescribed pharmaceutical medicine, which are on average half paid by common health insurance. Thus the coefficient is 0.5 here. Unlike, public transportation, this subsidy does not come from the state budget and thus is not included in SUT.

d) When expenditure is more of an investment, which is later returned to the household, the coefficient is 0. For instance, Life insurance.

The matrix of household expenditures $\mathbf{E_{232}}$ distributed in sectors is gained from multiplication of matrix of household expenditure items $\mathbf{E_{1682}}$ with transformation matrix $\mathbf{T}$.

$$\mathbf{E_{232}} = \mathbf{E_{1682}}\,\mathbf{T}$$

After this calculation, the prices are converted from the prices 2010 to 2007 and converted from CZK to EUR, in order to interconnect $\mathbf{E_{232}}$ with CREEA as described in the chapters 2.5 and 2.6.

For NAMEA, $\mathbf{E_{232}}$is left unchanged.

3.13 Conversion from final prices of expenditures to basic prices

The expenditure survey is collected in purchasers' prices unlike SIOT and CREEA, which are recorded in basic prices. For that reason, transformation of expenditures to basic prices must be carried out. Compared to purchasers' prices, basic prices do not include taxes, subsidies and transport and trade margins. All their values for individual sectors are recorded in SUT.

Taxes and subsidies are deducted in one step first, as subsidies can be considered as taxes with a negative sign. All taxes and subsidies are summed for each product group. Taxes are only deducted and not transferred to any other product group as they all go to the government budget, which is not a part of the IOT.

Trade margins are deducted and the deducted amounts divided into wholesale and retail trade sectors in the ratio of their relative mutual margin sizes times relative part of the price responsible for the trade margin of that product group.

Trade margins for vehicles product group and fuel product groups are done in the same way, but separately as source product groups are vehicles or fuel product groups and destination sectors for trade margins are wholesale and retail trade of motor vehicles and fuel sectors.

Transport margins are divided according to the same principle as trade margins. In this case, all product groups' transport margins are divided between one destination group of sectors consisting of railway transportation, land transportation, pipeline, coastal and inland transportation.

This process is done individually for SIOT and CREEA expenditures $\mathbf{E_{232}}$, because both SIOT and CREEA have different values for taxes and subsidies and for margins, as they are based on two different resolutions and data sources.

3.14 Combining NAMEA and CREEA embodied emission coefficients

Two sets of embodied emission coefficients are gained in the chapter 3.10. As CREEA coefficients also include foreign production chains and emissions from different countries and regions it is more convenient for product groups that are prevailingly imported. They are also beneficial in the case of agriculture product groups, where they have more detailed resolution than NAMEA.

On the other hand, when the product group is mostly domestic, NAMEA coefficients are more suitable because of their higher precision, since they are based on locally collected databases. NAMEA coefficients are also beneficial for the manufacturing product groups, where they possess higher detail than CREEA.

Based on these presumptions, a mixed table made from more suitable records of whether NAMEA or CREEA embodied emission coefficients was made.

3.15 Calculation of individual household emission amounts

A compact matrix $\mathbf{I}$ of embodied coefficients combined from NAMEA and CREEA, inclusive of emission potentials, is multiplied by expenditures of all households in basic prices $\mathbf{E_{232}}$. Both are in the resolution of 232 product groups. This results in the matrix of emissions $\mathbf{M}$ (kg) with individual emission amounts for every household and in each product group.

$$\mathbf{M_{232}} = \mathbf{I_{232}^{T}} \mathbf{E_{232}}$$

Then these emissions are summed up in groups for all three environmental effects: global warming potential, acidification potential and smog formation.

3.16 Grouping of household emissions

For the sake of clarity and subsequent depiction, emissions are merged into 7 consumption groups. The groups were selected so they represent parts that are easy to imagine, logically defined and most importantly have roughly even emission intensities. The groups are: food, housing, heating and hot water, electricity, transportation, goods and services.

Food costs consist of groceries and canteen and restaurant meals. Housing includes rent, cost to buy, build or renovate real estate. Heating includes both local heating and central heating. It does not include electricity, the purpose of which cannot be discerned and thus it is all assigned to its own consumption group. Electricity for heating is used in 7 % of households only (ČSÚ, 2011d). Transport includes propellants costs, public transportation and air transport but does not include vehicle purchase.

4 Results

The sets of results are presented in the form of charts and tables with key implications pointed out. The total amount of emissions per person is 7.785 kg of CO_{2eq} for greenhouse gases, 26.1 kg of SO_{2eq} for acidification gases and 4.6 kg of C_2H_{2eq} for smog formation gases per capita.

The first table Tab. 1 Average expenditure and total emission intensities for 7 consumption groups. Annual average values per capita, the Czech Republic, 2010 (1 EUR was equal 25.3 CZK in 2010). shows the expenditures and environmental impact categories in 7 consumption groups. Both direct and indirect emissions are taken into account by the average emissions intensities. Some consumption groups have emissions of one order higher than the others, which makes them dominant in total, when these expenses are multiplied with their intensities.

Consumption groups	Expenditure EUR	Climate change CO_2 kg eq./EUR	Acidification SO_2 g eq./EUR	Smog formation C_2H_2 g eq./EUR
Food	1384	0.97	10.50	0.74
Housing	709	0.35	0.74	0.20
Electricity	272	7.27	4.52	0.25
Heat & Hot W.	550	4.03	4.28	0.67
Transport	555	1.63	2.27	1.41
Goods	1261	0.65	3.23	1.10
Services	603	0.47	0.57	0.25

Tab. 1 Average expenditure and total emission intensities for 7 consumption groups. Annual average values per capita, the Czech Republic, 2010 (1 EUR was equal 25.3 CZK in 2010).

The total emissions percentages are depicted in the graphs in the Fig. 1. Expenditures are dominated by food and goods, whereas electricity and heating are together responsible only for 14 % of all expenditures.

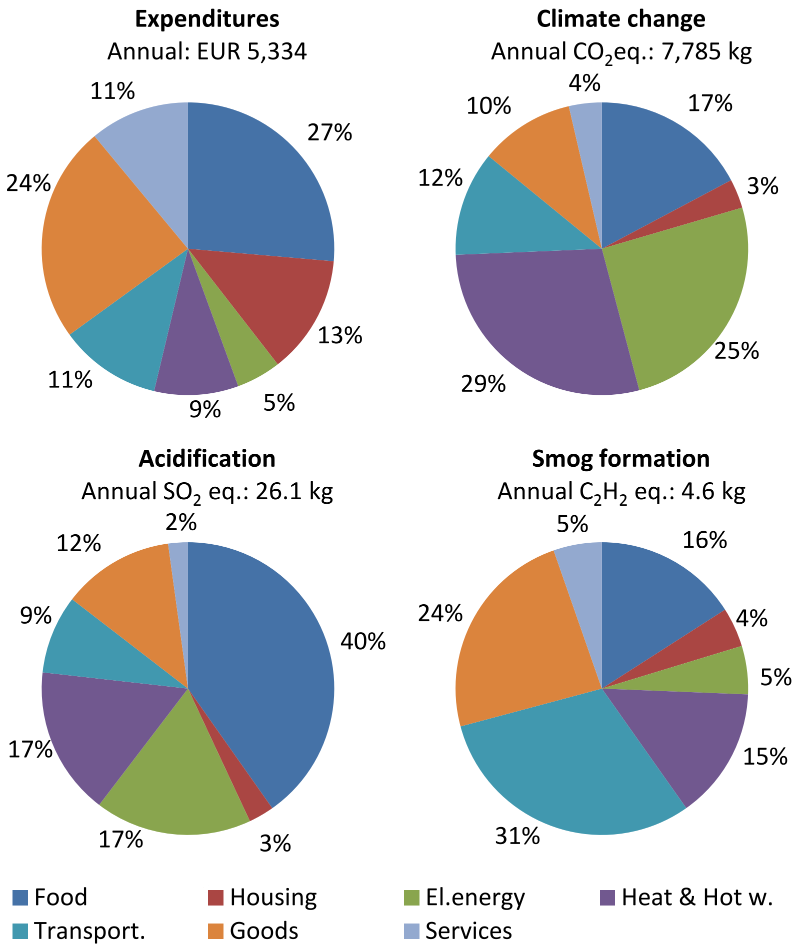

Fig. 1 Expenditures and emission impact categories in 7 consumption groups. Annual average values per capita, the Czech Republic, 2010.

Turning to climate change greenhouse gases, the most dominant are heat and electricity consumption, accounting for more than half of the total GHG emissions. Food, goods and transportation, despite having quite low emission intensity, have in total considerable emissions due to their expenditure extent. Goods in particular are very heterogeneous and, as such, can vary significantly even across one category. With regard to transportation, half of the emission is charged to individual transportation and the rest goes to passenger and freight transportation on buses, lorries, trains, airplanes and ships. Approximately a half of emissions from food originate from N_2O and CH_4. The vast majority of N_2O comes from agriculture from fertilized soils and livestock manure. Almost 40 % of CH_4 comes from the breeding of ruminant animals. The rest is divided between Heat and hot water, Electricity and the remaining categories having its origin in coal mines.

Acidification is nearly entirely determined by SO_2, NH_3 and NO_x. Emissions of SO_2 come overwhelmingly from coal burnt in heating plants and boilers. Almost the sole source of NH_3 emissions is animal breeding and application of ammonia fertilizers in agriculture. The sources of NO_x are mainly diesel propelled freight and public transportation vehicles and agricultural machinery. The food consumption group is in total dominant in the acidification impact category, because of its NH_3 and NO_x emissions. It is followed by heating and electricity consumption groups.

Smog formation is mostly induced by NMVOC emissions from traffic especially from gasoline. The graph also shows that a fair portion comes from the production of goods. These values were gained from imported product groups, whose emission intensities are based on the CREEA database for their calculation. They have a few times higher indirect emission intensities compared to the domestic ones, which have a perceptible influence upon them.

The Fig. 2 Expenditures and emission impact categories by deciles, all 7 consumption groups in one column. Annual average values per capita, the Czech Republic, 2010. Fig. 3 Expenditures and emission impact categories by deciles – comparison between 7 consumption groups. Annual average values per capita, the Czech Republic, 2010.depict the relation between expenditure deciles and their emissions. Fig. 2 shows total values consisting of contributions from 7 consumption groups, while Fig. 3 compares separate contributions between each other.

All expenditures grow by some degree. The electricity grows least, which can be caused by cheaper tariffs for higher electricity consumption on one hand and fixed costs for fuses on the other, in addition to other things. Total expenditures grow evenly except for the last decile, where a significant increase occurs. The reason for that is that a household qualifies itself into the 10^{th} decile by real estate or car purchase, which in turn inflates the expenditure values. For the same reason the decile composition is also influenced. It is highly improbable that such constitution is steady for these households in all years, as a house or a car is a long term investment.

The emission graphs reflects direct and indirect emission intensities multiplied by amount of money spent in that product categories . Thus it reflects expenditures to certain degree. All emissions grow with increasing expenditure.

The increase of greenhouse gases is influenced mostly by heat and electricity where these categories are mostly dominant compared to their expenses. Total emission intensity descends slightly. This is caused by shifts from coal to natural gas in the heating group and to less emission intensive services within the services group. The emission intensity of other categories is stable.

The increase of acidification within deciles is rapidly influenced by food consumption. Total emission intensity descends slightly. The only cause is a shift from coal to natural gas in for heating. The emission intensity of other categories is stable.

The rise of smog forming gases with expenditures is largely due to transportation emissions. They decrease with increasing expenditure, due to the shift from diesel propelled public transportation towards private gasoline cars. Emission intensities of smog formation precursors decrease in all deciles, the cause would need additional examination.

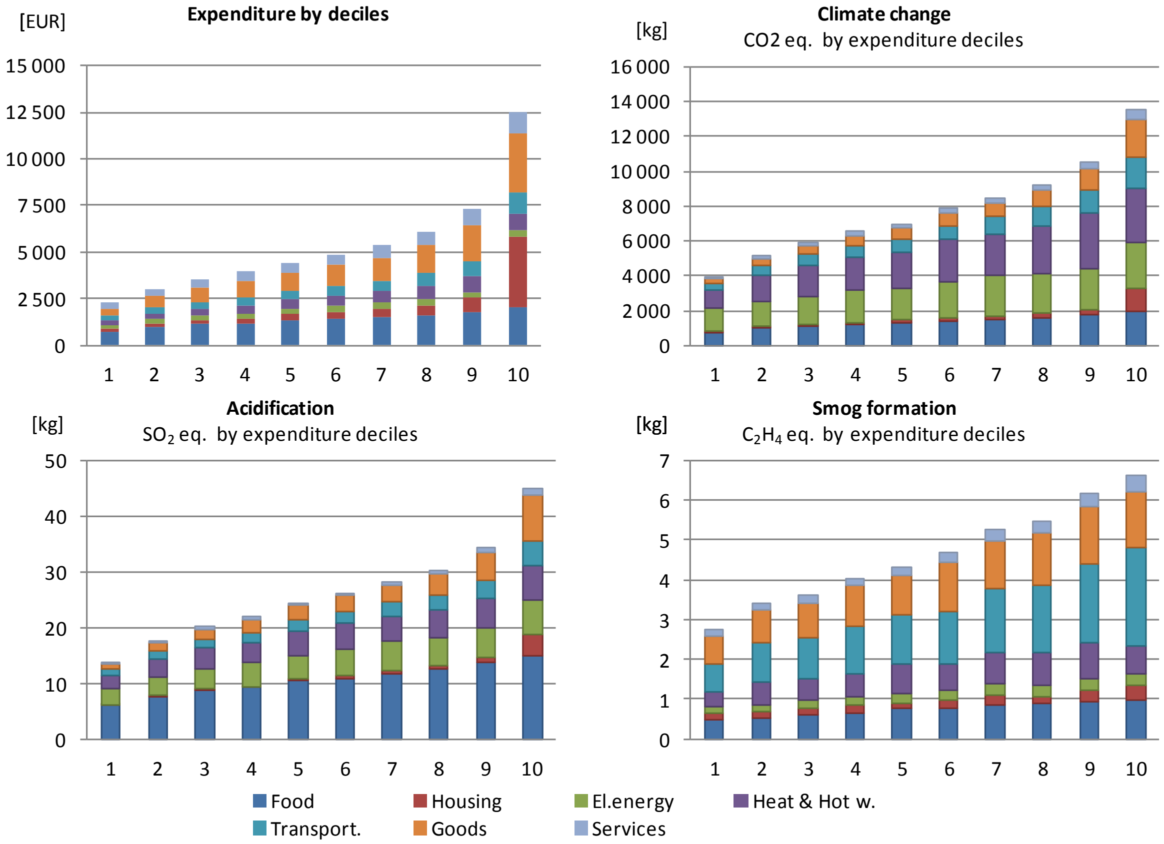

Fig. 2 Expenditures and emission impact categories by deciles, all 7 consumption groups in one column. Annual average values per capita, the Czech Republic, 2010.

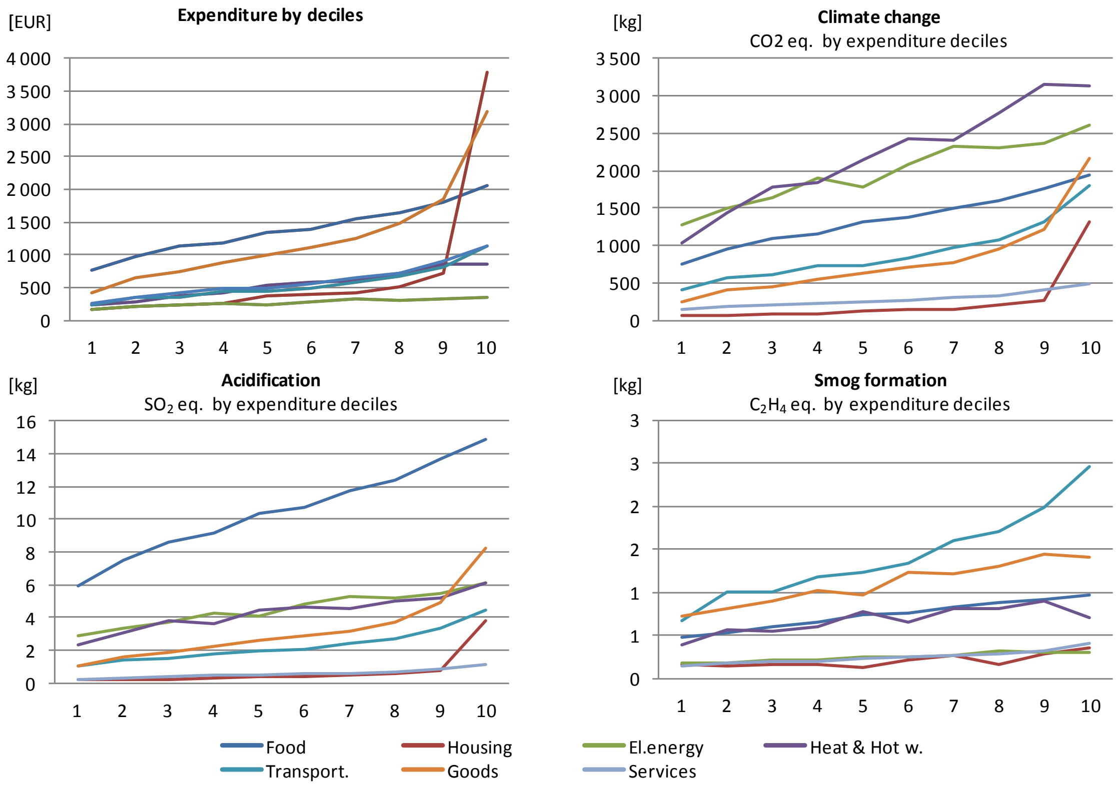

Fig. 3 Expenditures and emission impact categories by deciles – comparison between 7 consumption groups. Annual average values per capita, the Czech Republic, 2010.

Expenditure elasticity Tab. 2. describe emission elasticities of total expenditures. All three environmental emission intensities decreases relatively with increasing expenditure.

	Expenditure elasticity	Standard Error	95% Confidence Limits	
Climate change	0,7418	0,0104	1.00	0,7622
Acidification	0,7037	0,0102	0,683	0,7236
Smog formation	0,544	1.00	1.00	0,5918

Tab. 2 Expenditure elasticities of three environmental impacts

5 Discussion

5.1 Determining factors of the Czech Republic

There are some important characteristics of the country, that influence results of household emissions, and thus they are important to consider when comparing the results between different countries. These features for the Czech Republic are listed further. Firstly, electricity production mix, which in 65 % originates from the coal power plants, followed by nuclear and water power sources. Secondly, the temperate climate showed average temperature 2.7 °C in 2010 in the months during the heating season from September until the end of April and few days with extremely hot weather, thus it is not common to have air-conditioning at homes. Thirdly, 55 % of housing units are in apartment buildings from historical reasons. Natural gas boilers followed by mostly coal powered central heating stations are main sources of heat.

Regarding commuting, an extensive public bus and train transportation network and its relatively lower price compared to gasoline needed for the same distance keep public transport still relatively utilized. However, a significant outflow of passengers occurred in the two decades after the fall of Communism in 1989. Also the state’s relatively small size results in rather smaller travelling distances.

From the standpoint of overall wealth, the Czech Republic ranked on 41st place of GDP per capita with $ 19.764 in 2010 with relatively low income disparity typical of European post-communist countries.

5.2 Policy implications

The strength of EE-IOA lies in its compact overview of consumption from an emission perspective. It clearly depicts which product groups give rise to products with the highest emission intensity per Euro, as well as absolute emission volumes from each of the product groups.

The downside of EE-IOA is that it cannot differentiate emission-wise between two products within one product group. When comparison between two similar products is needed, in order to find environmentally friendlier option, the Life Cycle Assessment method is more suitable as each product can be defined according to specific input.

Nevertheless, the results of EE-IOA can give the first impression to a policy maker or anyone else of how much emission is produced for a certain amount of cash spent in a particular product group. Overall, this estimation is quite accurate if the money is spent in the product groups with one product only such as Electricity or Motor vehicles product groups or similar product groups.

Generally recommended steps for emission mitigation include greening of production through changes in production methods, greening products and services by decreasing material and energy use per functional unit, sharing of products and services, a shift to less emission intensive patterns (Tukker, 2010) or extension of product usage.

As for policies, the highest volumes of emissions, which stem from the following product groups, should be the number one target in policy measures aiming at their mitigation. Such policies can include taxation of fuels directly as emission sources, removing subsidies supporting emission intensive products and vice versa introducing subsidies using emission less intensive forms of products and services (e.g. individual transportation versus public transportation and cycling), supporting investments into research aiming at low-emission technologies, regulations encouraging savings in emission intensive product groups (e.g. compulsory meters of heat consumption in shared apartment houses), subsidies for low-emission alternatives (e. g. solar water heating) and support of public education on these issues.

6 Conclusion

This study is, to our knowledge, the first study using the combination of MR EE-IOA in combination with SR EE-IOA to calculate indirect emissions of households and also the first study of its kind in post-communist European countries. The main reason for combining two different sources is to minimize two weak points of the IOA method: the domestic assumption technology for imported products and the insufficient number of the product groups of production. The CREEA database is used for primarily imported products as it considers unequal technologies in different countries and regions of the world. For products from dominantly domestic product groups, the emission coefficient of more detailed product group is selected from CREEA or SIOT and NAMEA. This gives 232 product groups of which 102 are effectively utilized for household consumption. Indirect emissions are combined with direct household emissions from 8 fuels used by households.

In turn, it gives individual household emissions of nearly 3000 of Czech households for 11 different gases sorted in three environmental effects climate change, acidification and smog formation. They are grouped into 7 logical consumption groups: food, housing, electricity, heating and hot water, transportation, goods and services for graphical comparison.

The most important findings are that for climate change about 50 % of all greenhouse gases arise from heating and hot water and electricity, 41 % of acidification is caused by food production, where electricity gives rise to 17 % and 15 % respectively. Smog formation is mostly triggered by transportation, which emits 34 % of emissions.

These results are in approximate alignment with conclusions of other European studies, reflecting similar, needs, climate, affluence and technologies as in other “west European” countries. The result discrepancies could possibly be caused by the abundance of locally mined coal used for heating, the still relatively well-utilized and cheap public transportation and the smaller amount of expenditure spent on traveling. All the emissions investigated in this paper grow with increasing expenditures, but all less than proportionally to expenses.

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