Improving Transformation of Emissions from Industries to Products: Product Technology Assumption, Disaggregation of Key Industry and Almon's Procedure

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Abstract

An allocation of emissions from industries to product groups is an inevitable step, wherever the embodied emissions (or energy) of products are calculated with the environmentally extended input-output analysis. Within this paper, we suggest and explain steps for the improvement of commonly used techniques.

First, we explain why the widely applied industry technology assumption to construct product-by-product input-output model is an unsuitable method for the transformation of emissions and why product technology assumption should be used instead. Second, we cope with the resulting negative values, which is the well known limitation of the product technology assumption, by utilizing Almon's procedure. Third, we demonstrate how disaggregation of the industry with dominant emissions and diverse technologies for this kind of emission transformation may improve the results. We apply these steps to emissions from NAMEA for the Czech Republic and discuss the results. Additionally, we provide an easy-to-use VBA tool with Excel interface to calculate Almon's transformation automatically.

Keywords

Input-output tables, product-by-product, product technology assumption, Almon's procedure, transformation of industries to products, industry disaggregation, NAMEA

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INTRODUCTION

Where embodied emissions of products are in scope of the scientific paper and environmentally extended input-output analysis (EE-IOA) is used as a method to calculate them, it is usually necessary to transform emissions from industries to products.[4] It is because environmental data are usually recorded for industries. This is the case of the National Accounting Matrix with Environmental Accounts (NAMEA) which includes emissions to air, that are the main objective of this paper, but it also includes energy or material consumption.

Despite the fact Eurostat (Eurostat, 2008, p. 19) recommends the local kind-of-activity as reporting units, the supply-use table framework is often set up by different types of units. It may cause that industries produce also products which do not belong to its main activity. Those products are commonly called by-products and create the off-diagonal elements of the supply table.

Creating technically sound EE-IOA models, which interlink consumption of products with emissions of industries requires not only linking of industries with products to match their classification mutually but also a transformation from industries to products or vice versa.

The last condition is the trickiest one, as the transformation of industries to products or vice versa must be carried out. Four types of transformation could be theoretically employed for EE-IOA corresponding to four types of transformation of supply and use tables in order they form symmetric input-output tables (IOT). Product-by-product IOT with product technology assumption (Model A) and with industry technology assumption (Model B) and industry-by-industry IOT with fixed industry sales structure assumption (Model C) and fixed product sales structure assumption (Model D) (Eurostat, 2008, p. 351).

The emissions associated with manufacturing are transformed by much the same way as the IOT is created, only by substituting the rows of the use table with emissions of industries.

The literature review shows that some scholars used Model D industry-by-industry technical coefficient matrix (Weber and Matthews, 2008) (Golley and Meng, 2012) and then map emission intensities directly to products without any transformation.[5] This approach has two drawbacks. First, Eurostat recommends (Eurostat, 2008, p. 24) product-by-product IOT, where homogenous product groups are the objective of the analysis, which is the case of these product consumption studies. Second, if emission transformation between industries and consumed product is skipped, it leads to an inconsistency that embodied emissions of manufactured by-products are assigned to their main industry.

Studies with other approach (Wiedmann et al., 2005; Roca and Serrano, 2007; Baiocchi et al., 2010) transforms the emissions from industries to products using Model B product technology assumption and consequently uses Model B product-by-product matrix of technical coefficients for IOA.

However, if product by product input-output tables are compiled, theoretical considerations indicate that the 'Product technology assumption' (Model A) is preferable to the 'Industry technology assumption' (Model B) according to Eurostat recommendation (Eurostat, 2008, p. 24). This is in line with the System of National Accounts which reviews these two assumptions and states that: the industry technology assumption performs rather poorly (UN, 1993, p. 465). The same point of view can be found in Almon (2000) and also ten Raa (2005), who describes that the following axioms are violated in Model B: financial balance, price invariance, scale invariance, in relation to IOT creation. The situation when model B is appropriate for emission transformation is explained in the methodology. The impact of using Model B for emission transformation with inappropriate prerequisites is described in Appendix A.

The serious issue of the preferred model A is the fact that it may create negatives in the IOT as well as for transformed emissions. IOTs are usually prepared by national statistical institutes and the negatives are removed manually. For the transformation of emissions according to Model A, the scholars

[4] Products are sometimes called product groups or commodities.
[5] At least, no trace of such transformation is described in these papers.

performing EE-IOA would have to remove the negatives manually by themselves. This is a long and tedious task, which requires deeper knowledge of the source data that are often not publicly available. This has practically disqualified model A as an option for the emissions transformation.

It is important to realize that the negatives are an outcome of the violation of the theoretical product technology assumption by different technology used for the same product in different industries (resulting in more or less emissions). The product technology assumption can be violated e.g. by actually including different products mix into one product group in different industries due to product heterogeneity (Konijn and Steenge, 1995) or by the errors in recorded data of supply table or use table or emission data, respectively.

It is theoretically impossible to correct the errors and product technology assumption violations in supply and use tables without very detailed knowledge of the original data and practically impossible even with this knowledge at hand. Thus several methods for the elimination of negatives were developed, for overview see e. g. ten Raa and Rueda-Cantuche (2013).

As a solution of emission transformation for the purpose of EE-IOA, we suggest transformation of emissions from industries to product with Almon's procedure (Almon, 2000) which reflects the model A but automatically eliminates the negatives, by decreasing the extent of by-products individually for each product and industry.

We see this method as the best solution due to its simplicity and compatibility with model A. Even though some papers criticized this method for arbitrary manipulation the source data (de Mesnard, 2009; ten Raa, Rueda-Cantuche, 2013), in our point of view, it is inevitable step of automated error correction.

Disaggregation of products/industries is another way to gain the results that catch the reality more accurately and potentially remove the unwanted negatives (Konijn and Steenge, 1995; Vollebregt and van Dalen, 2002). Here, we carried out this disaggregation of electricity production industry and electricity product to demonstrate how beneficial such disaggregation can be in the case of emission disaggregation. The real data of the Czech supply table and NAMEA was used.

1 METHODOLOGY

1.1 Transformation of emission – deciding between product and industry technology assumption

Supply and use tables are used to create a symmetrical input-output table with four different assumptions designated as models A, B, C, D (Eurostat, 2008, p. 351). In order to calculate emissions using model A or B, we substitute each row of the use matrix $\boldsymbol{U}$, representing intermediate inputs of one type of product to all industries, with emission data of one type of emissions. In notation, $\boldsymbol{U}$ becomes $\boldsymbol{U_E}$ and $\boldsymbol{R}$ becomes $\boldsymbol{R_E}$ (see the Appendix A for the full legend). Monetary units (CZK, EUR, etc.) become mass units (kg, tonnes) or possibly energy units (kJ, MJ). Since each row represents one sort of emission, the matrices $\boldsymbol{U_E}$ and $\boldsymbol{R_E}$ have as many rows as there are types of emissions.[6]

Hereinafter in this section, we explain when and why the product technology assumption (model A) should be preferred over industry technology-assumption (model B) in the case of emissions transformation.

We base our idea on the fact that despite the recommendation of Eurostat to use local kind-of-activity units for the compilation of supply and use tables, many national statistical institutes use rather institutional units (enterprises) for that purpose since it is easier to report financial transactions for the whole enterprise (Eurostat, 2015). This is also the case of the Czech Republic (Sixta, 2013). Consequently, the by-products are rather an outcome of the separable subsidiary production, defined as an independent production process (UN, 1993) (e.g. coal mining and electricity production). Then also emissions from product production stem from an independent process, which is bound to the particular product and which is not influenced by the industry in which it is recorded. This corresponds to the production

6 National emission databases, such as NAMEA, are usually the source of data here.

technology assumption (model A), which states that "each product is produced in its own specific way, irrespective of the industry where it is produced". The production process for one particular product can in reality be different within one as well as across more industries, yet it should describe the product better than industry in which it was produced, because an industry serves rather as an administrative unit for reporting purposes with a varying scale of by-products.

An exception to this rule is the joint production, defined as the case where coproducts cannot be easily separated (UN, 1993) (e.g. brick and heat production), because the products are coming from one production process. Then model B might be seen as a suitable solution for emission transformation, since it divides the emissions in the proportion of the coproducts supply (turnover). According to our educated guess, subsidiary production largely prevails over joint production in the case where supply tables are compiled by enterprises, therefore we neglect the later option. Other and more suitable option would be the mixed technology assumption, which we do not have enough background information for to benefit from it.

The mathematical explanation and the consequences of choosing one model or another for the scenario with subsidiary production is explained in the Appendix A.

1.2 Transformation of emissions from industries to products with Almon's procedure

The transformation of emissions, described within this paper, is an analogy to the Almon's procedure (Almon, 2000). It uses the same mathematical steps. Only use matrix $\boldsymbol{U}$ is substituted with emissions by industries $\boldsymbol{U_E}$, recipe matrix $\boldsymbol{R}$ with emissions by products $\boldsymbol{R_E}$ and $\boldsymbol{T_A}$ is denoted as $\boldsymbol{M}$ in Almon's notation.

The following equations show the brief derivation of Almon's procedure (Almon, 2000), which is based on model A. For further details of model A see the Table A1 in the Appendix A.

Almon's starts his derivation with this equations:

$$\boldsymbol{M} = \boldsymbol{V}(diag(\boldsymbol{q}))^{-1}, \tag{1}$$

$$\boldsymbol{R} = \boldsymbol{U}\,(\boldsymbol{M}^T)^{-1}. \tag{2}$$

To derive his procedure, Almon first takes the inverse form of Formula (2), transposes it and segments $\boldsymbol{U}$ and $\boldsymbol{R}$ by lines representing individual products:

$$\boldsymbol{u} = \boldsymbol{Mr}, \tag{3}$$

then rewrites the Formula (3) in the following form:

$$\boldsymbol{r} = (\boldsymbol{I} - \boldsymbol{M})\boldsymbol{r}+\boldsymbol{u}, \tag{4}$$

and approximate the Formula (4) with Seidel iterative process as:

$$\boldsymbol{r}^{(k+1)} = (\boldsymbol{I} - \boldsymbol{M})\boldsymbol{r}^{(k)} + \boldsymbol{u}, \tag{5}$$

where $r^{(k)}$ represents the k-th approximation of r and $r^{(0)} = u$.

The next step of Almon's procedure decomposes the Formula (5) in the form suitable for calculation of each element j (product j):

$$r_j^{(k+1)} = u_j - \sum_{\substack{h=1 \\ h\neq j}}^{n} m_{jh} r_h^{(k)} + \sum_{\substack{h=1 \\ h\neq j}}^{n} m_{hj} r_j^{(k)}. \tag{6}$$

Here, we rewrite this equation directly with emissions of industries u_{Ej} and products r_{Ej}:

$$r_{Ej}^{(k+1)} = u_{Ej} - \sum_{\substack{h=1 \\ h \neq j}}^{n} m_{jh} r_{Eh}^{(k)} + \sum_{\substack{h=1 \\ h \neq j}}^{n} m_{hj} r_{Ej}^{(k)} . \quad (7)$$

To understand the principle of the Formula (7), it is important to remember that each column of the matrix $\boldsymbol{M}$ represents the ratio between the shares of one unit of a product between industries in which this product is produced. Any element on the diagonal represents the ratio of the industry's own product, e. g. coal produced in the coal mining industry. The elements in the row to its left and right represent the ratios of by-products produced by that industry, e.g. electricity coming from the coal mining industry. Finally, the elements in the column above and below it represent the ratios of its own product created in other industries, e. g. coal produced in the electricity generation industry. Note that these elements are actually by-products of other industries from their perspective. When the ratio m_{jh} is multiplied by the total emissions of its industry r_{Eh}, we get emissions stemming from the production of that product (the index of r_{Eh} corresponds to the row index of m_{jh}).

The overall interpretation of the right side of this equation can be interpreted as follows. The element u_{Ej}, is the original amount of emissions emitted by each respective industry *j*. For each such industry *j*, the second term removes emissions emitted during production of its by-products of the first order. The third term adds emissions which arose during the production of industry's own product but were created in other industries. Through this process, the emissions of by-products are gradually removed and reassigned to the products, where they actually belong.

The final and key point of the Almon's procedure adds scaling factors, for the case where the second term is bigger than u_{Ej} to ensure that the negative values never appear. The scaling factor actually lowers the second term so it does not remove more emissions, stemming from by-products production, than is actually recorded for that industry in total. The fact that the scaling factor is uniform for one industry (a row of $\boldsymbol{M}$) guarantees the balance between emissions of by-products removed from the industry in the second term and added back to the industry (product), where these emissions actually belong, in the third term.

$$r_{Ej}^{(k+1)} = u_{Ej} - s_j^{(k)} \sum_{\substack{h=1 \\ h \neq j}}^{n} m_{jh} r_{Eh}^{(k)} + \sum_{\substack{h=1 \\ h \neq j}}^{n} s_h^{(k)} m_{hj} r_{Ej}^{(k)} . \quad (8)$$

The scaling factors are gained from comparing u_{Ej} and the second term:[7]

$$s_j^{(k)} = 1 \ if \, u_j \geq \sum\nolimits_{\substack{h=1 \\ h \neq j}}^{n} m_{jh} r_{Eh}^{(k)} , \quad (9)$$

or:

$$s_j^{(k)} = \frac{u_j}{\sum\nolimits_{\substack{h=1 \\ h \neq j}}^{n} m_{jh} r_{Eh}^{(k)}} . \quad (10)$$

1.3 Real world numerical example

We carried out two demonstrative examples. Both apply Almon's method in order to transform Czech NAMEA 2010 (CHMI, 2012)emissions from industries to products with utilization of the Czech Supply table 2010 (CZSO, 2012). The first example uses unaltered version of the NAMEA and Supply matrix

[7] Almon (2000) instructs to base the scaling factor on the second term, but then in the formula uses the third term instead. We believe, it is only a typographical error, since the difference is only in the order of *j* and *h* indexes at *m*. Eurostat (2008) uses the second term, as do we in this paper.

with 184 industries and products as a source data. The second example uses the very same source of data, but with manually disaggregated Electricity gaining 185 industries and products.

1.4 Almon's transformation tool

We programmed a tool which calculates the Almon's transformation automatically. The IOA practitioners can carry out this procedure without deeper knowledge of the underlying formulas and without any additional programming. Despite it is designed primarily for transformation of emissions, it can be used for transformation of use and supply tables into input-output tables as well, by substituting emissions with rows of use table. It is programmed in VBA with MS Excel user interface. The application is accompanied with an embedded guide and is designed to be easy to use. The application is freely available. The comments in the application code include explanation of the calculation and manipulation steps. For further details see the Appendix B.

1.5 Disaggregation

The disaggregation of supply and use table is described e.g. by Konijn and Steenge (1995). They suggest, ideally, to split up a product into as many products as there are ways to produce it and then to assign the products to newly emerged industries[8] with regard to their input structure. In case of emission disaggregation, the input structure defining the production technology is substituted with the output of the emissions. It is important to realize that the different input structure basically means different output of emissions as well.

An analogous recommendation to split an industry, when the industry is in fact a mixture of two very heterogeneous production processes which should be considered separately, is also stated by Vollebregt and van Dalen (2002). In the case of NAMEA emissions transformation, this should be considered especially for industries with diverse product technologies from an emission perspective and with high volumes of emissions, due to their importance. Diverse technologies and relative importance of an industry are general criteria for decision if the industry should be split, which are applicable for other environmental extensions such as energy or material flows. A typical example is the power generation industry, because it is often the most significant industry in terms of carbon dioxide (CO_2) and other emissions and also this industry can be obviously separated according to two radically different group of technologies. The first group generates electricity by the burning of fossil fuels, emitting vast amounts of CO_2 and other emissions. The second group emits no emissions during the electricity generation or includes activities which only transmit or redistribute the electricity with no CO_2 emissions as well. In addition, the overview of local kind-of-activity units[9] is usually available from the electrical regulatory authority. This makes the separation feasible using just publicly accessible data.

Within the supply table matrix $\boldsymbol{V^T}$ in our study, we disaggregate both industry and product of *electricity* to *electricity from fossil fuels* and *electricity others*. In general, we build up the disaggregation on "trick 5" from Vollebregt and van Dalen (2002). An industry is split into two new industries. Some outputs are assigned uniquely to the first new industry and some uniquely to the second. All other products are distributed over the two new industries in the same proportion as the uniquely assigned products. General assumptions for $\boldsymbol{V^T}$ disaggregation are as follows:

a) The newly formed industry *generation of electricity from fossil fuels* produces electricity in coal or gas power plants.[10] The second newly emerged industry *generation of electricity others* includes

[8] Newly created industries are called activities by Konijn and Steenge (1995).

[9] Local kind-of-activity units according to Eurostat nomenclature (Eurostat, 1998) or units of homogeneous production, according to SNA nomenclature (SNA, 1993). In this paper, local kind-of-activity units are individual power or heating plants.

[10] The gas power plants constitute less than 1% of the GWh produced in the Czech Republic in 2010.

generation of electricity from nuclear, water and renewable resources plus all other activities such as electricity distribution. In reality, one energy producing enterprise may own both types of power plants (fossil and non-fossil).

b) The original main product of *electricity generation*, the element on diagonal of supply table, is disaggregated between *electricity from fossil fuels* industry and *electricity others* industry in the ratio of 0.3:0.7. The share of turnover assigned to *electricity from fossil fuels* is calculated based on publicly traded electricity and its weighted average of prices for 2010 (PXE, 2008, 2009, 2010) and the net production of *fossil fuel electricity* for that year (ERU, 2011). Consequently, *electricity from fossil fuels* is not to be produced in *generation of electricity others* industry and vice versa, making the value of each other's by-product 0.
c) *Electricity* product disaggregation where electricity is in the role of by-product of other industries forms the row elements of supply table to the left and right from the main diagonal element. As long as the industry in question owns coal or gas power plant we assume that it is dominant and as a consequence all production is assigned to *electricity from fossil fuels*. The opposite situation is when the industry in question owns a hydro-power plant or distribution of the electricity dominates in this industry. The rest, where no dominant source of turnovers can be identified, is divided in the same ratio as the main product 0.3:0.7.
d) For disaggregation of *electric generation* industry by-products laying under and above the main diagonal element we use the general ratio 0.3:0.7, since we lack the necessary information on how to split the electricity non-related by-products here. The only exception is *heat and hot water generation*, which is divided between coal and nuclear electric power plants, and their respective industries, in the ratio of their heat production (IEA, 2011).

General assumptions for matrix $\boldsymbol{V}^T$ disaggregation are as follows:

e) All emissions of the *electricity* industry in the $\boldsymbol{U}_E$ matrix from NAMEA are assigned to the *electricity from fossil fuels*, thus no emissions of the *electricity* industry in the $\boldsymbol{U}_E$ matrix are assigned to the *electricity others*.

2 RESULTS

The main outcome of the calculation process is that emissions from the NAMEA 2010 for the Czech Republic (CHMI, 2012) are transformed to products in such a way that the reality is captured as reliably as possible. Using the supply table with 184 industries and products from 2010 for the Czech Republic (CZSO, 2012),[11] we applied the method described in the methodology carrying out a disaggregation of electricity followed by Almon's procedure. This disaggregation was performed for an unaltered source set of emissions data and supply matrix as well as for 185 industries and products where *electricity* is manually disaggregated. The full results are available in the Appendix C. The Almon's procedure transformation eliminates 49 negatives in CO_2 emissions from regular model A. For the others, of the total 11 emissions,[12] it ranges from 36 to 104 negatives. The difference is caused, from our perspective, by the breaking product technology assumption in a different manner for each emission type and especially zero reported emissions in case of HFC, PFC, SF_6 for industries with low volumes of these emissions. The volume of negative emissions of CO_2 from model A, which is eliminated with Almon's procedure, accounts for 16% of the total emission volume.

[11] The supply matrix is available only on demand from CZSO.

[12] The calculations were performed for greenhouse gasses (CO_2, CH_4, $_N2O$, HFCs – hydrofluorocarbons, PFCs – perfluorinated compounds, SF_6), pollutants causing acidification (SO_2, NH_3, NO_X), and precursors of photochemical smog formation (NMVOC, CO).

Since the overall result would be too large for an interpretation of disaggregation, we extracted only a part of supply table with 7 or 8 industries respectively, which have results affected with the disaggregation to the highest degree, and performed the very same transformation. The disparity between these resulting emissions in Table 2 and those in the original tables with 184 and 185 industries is small, making less than 10% for CO_2 for all industries (with exception of *water treatment*). We consider this sufficient for the illustrative purpose.

Table 1 The segment of the Czech supply table displaying 8 industries including the disaggregated electricity

Supply table (mil. CZK)	Lignite production	Cellulose and paper production	Basic chemical substances production	Iron and steal production	Electricity from fossil fuels generation	Electricity others generation	Heat generation	Water treatment
Lignite	17 902	0	0	0	0	0	0	0
Cellulose and paper	0	18 897	0	45	0	0	0	0
Basic chemical substances	48	40	72 412	246	0	77	184	0
Iron and steal	0	0	0	70 678	0	0	0	0
Electricity from fossil fuels	4 684	592	920	739	67 573	0	9 979	0
Electricity others	0	0	0	0	0	157 669	0	542
Heat	438	228	1 435	454	8 406	59	44 299	0
Water	17	1	21	4	0	550	492	18 516

Source: CZSO, own calculations

Table 1 shows the supply matrix used for the transformation. Table 2 displays the original emission values from NAMEA and the resulting values after Almon's transformation[13] with non-disaggregated (7 indust.) and disaggregated *electricity* for the purpose of Almon's procedure (8 indust.). The disaggregated variant is merged back after the Almon's procedure.

Table 2 Model A – CO_2 in the original segmentation into industries and in the segmentation into products after Almon's procedure of non-disaggregated (7 indust.) and disaggregated electricity (8 indust.)

Model A Industry/Product	NACE	Original CO_2 (kt)	7 indust. CO_2 (kt)	Change CO_2 (%)	8 indust. CO_2 (kt)	Change CO_2 (%)	Difference CO_2 (%)	Difference CO_2 (kt)
Lignite	052	3 716	2 721	–26.8%	667	–82.0%	–55.3%	–2 053.6
Cellulose and paper	171	1 472	1 302	–11.6%	1 059	–28.1%	–16.5%	–242.6
Basic chemical substances	201	5 530	5 020	–9.2%	4 745	–14.2%	–5.0%	–275.0
Iron and steal	241	12 733	12 455	–2.2%	12 171	–4.4%	–2.2%	–283.8
Electricity (total)	351	44 356	45 378	2.3%	53 720	21.1%	18.8%	8 342.0
Heat	353	13 572	14 600	7.6%	9 001	–33.7%	–41.3%	–5 599.2
Water treatment	360	172	75	–56.5%	177	2.8%	59.3%	102.0

Source: CHMI, own calculations

[13] Almon's transformations gives the same results as the model A here, since it is not necessary to downscale emissions in these two cases.

The disaggregation implies that the two different technologies are used for producing of *electricity from fossil fuels* and *electricity others*. The different technologies can be viewed as two different emission volumes to produce one unit of the output. On the one hand, the volume of emissions of the *electricity from fossil fuels* is bigger then of the original non-disaggregated *electricity*, and on the other, the *electricity others* has no emissions at all. In the model A, this becomes the decisive factor for industries with a substantial electricity by-product, because only in the disaggregated scenario does it show what "type" of the electricity the by-products represent.

The disaggregation of electricity has the following consequences here:

a) The industries which produce electricity in coal power plants as a by-product (coming under *electricity from fossil fuels*) with emissions emitting technologies have consequently more emissions reassigned to *electricity industry* in the disaggregated scenario. This is the case of *lignite mining, chemical industry, steel production* and *paper production*. The most significant emission transfer takes place for *lignite mining* in which the detailed information reveals, that one of the lignite mining companies is also in possession of an important coal power plant from which the majority *lignite mining industry* CO_2 emissions come from and thus the transfer of these emission to *electricity from fossil fuels product* is in order.

b) Vice versa, where the electricity is produced with emissionless technology, as is the case of *water treatment industry* which owns water power plants, the emissions are rather kept within that industry. This signifies that they stem from other source then electricity generation. Neither of these two differences were discerned before disaggregation.

c) The *heat industry* produces electricity and vice versa. Both of them are predominantly produced with emission emitting technologies and the emissions are reassigned both ways. What changes and becomes the decisive factor in the disaggregated scenario is again the volume of emissions of *electricity from fossil fuels* by-product, which is higher then the non-disaggregated *electricity*. As a consequence more emissions is reassigned from heat industry to *electricity from fossil fuels industry*.

d) *Electricity from fossil fuels* has more emissions after disaggregation, because electricity coming from fossil fuels from other industries prevails.

e) *Electricity others* has neither emissions before and nor after disaggregation by its definition.

We have shown that the results of Almon's procedure in Table 2, equal to model A in this case, performed the requested transfer of emissions properly in the case of *mining industry* subtracting 82.0% of CO_2 emissions, as they overwhelmingly come from coal power plants. Nevertheless such considerable emission transfer is done only in the instance of disaggregated *electricity* industry to *electricity from*

Table 3 Model B – CO_2 in the original segmentation into industries and in the segmentation into products after transformation with model B of non-disaggregated (7 indust.) and disaggregated electricity (8 indust.)

Model B Industry/Product	NACE	Original CO_2 (kt)	7 indust. CO_2 (kt)	Change CO_2 (%)	8 indust. CO_2 (kt)	Change CO_2 (%)	Difference CO_2 (%)	Difference CO_2 (kt)
Lignite	052	3 716	2 881	–22.5%	2 880.9	–22.5%	0.0%	0
Cellulose and paper	171	1 472	1 416	–3.8%	1 416.3	–3.8%	0.0%	0
Basic chemical substances	201	5 530	5 454	–1.4%	5 468.5	–1.1%	–0.3%	–15
Iron and steal	241	12 733	12 470	–2.1%	12 470.4	–2.1%	0.0%	0
Electricity (total)	351	44 356	42 914	–3.3%	46 100.3	3.9%	–7.2%	–3 186
Heat	353	13 572	16 122	18.8%	12 816.7	–5.6%	24.4%	3 305
Water treatment	360	172	294	70.7%	397.8	131.3%	–60.5%	–104

Source: CHMI, own calculations

fossil fuels and *electricity others*. When the average emissions of non-disaggregated *electricity generation* industry are used instead, the effect of transformation is considerably lower and only 26.8% of the original CO_2 emissions is transformed.

Table 3 depicts the results of model B transformation for the same source data. When focusing on emissions of the *lignite mining* industry, model B subtracts only 22.5% of the original CO_2 emissions as it considers the supply of the *lignite* and *electricity from fossil fuels* has the same emission intensity.

Overall, we see that the model A with disaggregated emissions gives the more realistic picture compared to the non-disaggregated model A and both variants of model B for the *lignite mining* industry. We cannot verify if the same is true for other emissions since the production data of individual enterprises is under non-disclosure agreement. Such verification would be interesting especially for *electricity* and *heat* since these two industries are dominant sources of emissions and, at the same time, their production is closely interconnected.

CONCLUSION

In this paper, we present a suitable technique for transformation of emissions from industries to products, which might be an essential step in the process of gaining product's embodied emissions. The first, optional but beneficial, step of this technique is to disaggregate one or more crucial industries and products. The crucial industries are those with significant portion of emissions and diverse technology of production. The second step is to transform emissions with Almon's procedure which modifies product technology assumption (model A) in such way that it eliminates its resulting negatives, in case they appear. The third, also optional, phase is to merge back the resulting disaggregated emissions of products.

Apart from description of these steps, we explain when and why product technology assumption (model A) and consequently also its modified version, the Almon's procedure, should be preferred over industry technology assumption (model B) in the process of emissions transformation. We supplement this explanation with numerical illustrations showing the difference between model A and B.

To see practical consequences of the disaggregation, we utilize a section of the non-disaggregated and disaggregated Czech NAMEA and supply table from 2010 to demonstrate the effect of disaggregation on the transformation. The actual full process was than performed on data including 11 types of emissions in 184 industries for the Czech Republic for the year 2010.

Since Almon's iterative procedure is labour demanding from computational perspective, we programmed a VBA script embedded in Excel file to calculate this procedure automatically. This tool is designed with intuitive user interface so everyone can use it without knowledge of VBA and is freely available, see the Appendix B.

Although, to transform emissions by following the advices in this paper should ease the emission transformation work, one must be aware of the methods' conditions and limitations. The necessary condition is the consistency between the emission database and supply table in order model A or Almon's procedure perform correctly in transforming the emissions. Second, if Almon's algorithm turns out not to converge, we have to make sure that half of the production of each product is in the supply table in its main industry (Almon, 2000). The negatives in resulting products emissions are a sign of an error in source data and it is always better to correct the source values than to rectify the resulting negatives automatically with Almon's procedure. It is actually recommended by Almon to remove large negatives manually. Nevertheless, detailed background information for that procedure must be available. It has been properly pointed out (ten Raa, Rueda-Cantuche, 2013) that resulting values gained trough Almon's procedure do not have to necessarily converge to the correct values, thus Almon's procedure does not mean automatic virtual fix of errors of source values.

Despite all mentioned shortcomings, we would recommend to use Almon's procedure for the emission transformation, since we see it still as sufficient and easily applicable option.

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APPENDIX A

COMPARISON OF MODEL A AND B

In the model B, the resulting emissions (r_{Eij}) of a particular product within one industry are proportional to the share of the product's turnover (v_{ij}) related to the total turnover of this industry (g_i). The ratio of shares is actually based on supply (turnover) of different products within one particular industry – a row of the make table.[14] This means that this model does not consider different technologies within one industry. This reflects the model B definition that "Each industry has its own specific way of production, irrespective of its product mix". As a consequence, this model unrealistically expects that all products manufactured within one industry are produced with the same emission intensity per monetary unit.

In the model A, the source emissions of a particular product within one industry (r_{Eij}) is proportional to the share of product's turnover (v_{ij}) related to the resulting product's total across all industries (q_j). The ratio of shares is based on turnovers of the same product within different industries – a column of the make table. Because the shares are, in this case, related to the resulting products, the inverse transformation must be carried out for getting from industries to products. If the theoretical assumption of model A that "Each product is produced in its own specific way, irrespective of the industry where it is produced" is valid, than the volumes of a product as well as its associated emissions are proportional to the product shares and each product has its own emission intensity, which is the same across all industries. For that reason, model A should be used for the emissions calculations. The transformation equations and its transformation matrices are in the Table A1.

Table A1 Transformation equations for model A and model B

	Model A	Model B
Transformation of emissions from industries to products	$\boldsymbol{R_E} = \boldsymbol{U_E}\,\boldsymbol{T_A}^{-1}$	$\boldsymbol{R_E} = \boldsymbol{U_E}\,\boldsymbol{T_B}$
Transformation matrix	$\boldsymbol{T_A} = \boldsymbol{V}\,(\mathrm{diag}(\boldsymbol{q}))^{-1}$	$\boldsymbol{T_B} = (\mathrm{diag}(\boldsymbol{g}))^{-1}\,\boldsymbol{V} = \boldsymbol{V^T}\,(\mathrm{diag}(\boldsymbol{g}))^{-1}$
Inverse transformation	$\boldsymbol{T_A}^{-1} = \boldsymbol{V}^{-1}\,\mathrm{diag}(\boldsymbol{q})$	$\boldsymbol{T_B}^{-1} = (\boldsymbol{V^T})^{-1}\,\mathrm{diag}(\boldsymbol{g})$

Source: Eurostat (2008)

Alternatively, Almon uses the following notation of transformation for model A:

$$\boldsymbol{R_E} = \boldsymbol{U_E}\,(\boldsymbol{M^T})^{-1},$$

and

$$\boldsymbol{M} = \boldsymbol{V}(\mathrm{diag}(\boldsymbol{q}))^{-1}.$$

Legend for input-output analysis

The following legend defines the variables which are used in the transformation:

$\boldsymbol{U}$ use table intermediates,
$\boldsymbol{U_E}$ emissions of industries,
u_{Eij} one type of emission of one industry,

[14] Since the make matrix of make table is equal to transposed supply matrix of supply table, the transposed supply matrix is interchangeable with make matrix. Consequently, rows of make table are columns of the supply table.

$\boldsymbol{R}$ resulting Almon's recipe matrix,[15]
$\boldsymbol{R_E}$ resulting matrix of emissions of products,
r_{Eij} emissions of one product within one industry,
$\boldsymbol{V^T}$ supply table intermediates,
$\boldsymbol{V}$ make table intermediates,
v_{ij} element of make table intermediates,
$\boldsymbol{g}$ sums of rows of the make table,
g_i sum of a row of the make table,
$\boldsymbol{q}$ sums of columns of the make table,
q_j sum of a column of the make table,
$\boldsymbol{T_A}$ transformation matrix of the model A, equal to $\boldsymbol{M}$,[16]
$\boldsymbol{M}$ $\boldsymbol{M}$ matrix of Almon's procedure, equal to $\boldsymbol{T_A}$,[17] it has industries in rows and products in columns,
$\boldsymbol{T_B}$ transformation matrix of the model B.[18]

ILLUSTRATIVE NUMERICAL EXAMPLE OF MODEL A AND B

The following Tables A2a–A2f illustrates the difference between model A and B. We present the scenario where we suppose that all emissions are coming from electricity production of which part is produced in the power plant recorded in the electricity generation industry. Model A correctly transforms all emission to the electricity, whereas model B only a certain part, as it assumes that both production processes in electricity generation industry have the same emission intensity.

Table A2a Source emissions of industries – $\boldsymbol{U_E}$

Industry	Coal mining	Electricity
CO_2	10 000	generation

Table A2b Make table – $\boldsymbol{V}$

Industry \ Product	Coal	Electricity
Coal mining	12 000	20 000
Electricity generation	0	80 000

Table A2c Transformation matrix – $\boldsymbol{T_A}$

Industry \ Product	Coal	Electricity
Coal mining	1	0.2
Electricity generation	0	0.8

Table A2d Transformation matrix – $\boldsymbol{T_B}$

Industry \ Product	Coal	Electricity
Coal mining	0.375	0.625
Electricity generation	0	1

Table A2e Resulting emissions – **Model A**

Product	Coal	Electricity
CO_2	0	50 000

Table A2f Resulting emissions – **Model B**

Product	Coal	Electricity
CO_2	3 750	46 250

Source: Own construction (demonstrative examples)

[15] $\boldsymbol{R}$ matrix is equal to the symmetrical input-output matrix of intermediates S of model A in Eurostat (2008).
[16] $\boldsymbol{T_A}$ matrix is equal to the transposed inverse of the transformation matrix $(\boldsymbol{T^T})^{-1}$ of the Model A in Eurostat (2008).
[17] $\boldsymbol{M}$ matrix is also equal to the matrix $\boldsymbol{D}$ – Market shares (contribution of each industry to the output of a product) in Eurostat (2008).
[18] $\boldsymbol{T_B}$ matrix is equal to the transformation matrix $\boldsymbol{T}$ of the Model B in Eurostat (2008).

ILLUSTRATIVE NUMERICAL EXAMPLE OF MODEL A AND ALMON'S PROCEDURE

Unfortunately, the resulting emissions of products from model A can suffer from the same shortcoming as the symmetrical-input output table from this model, the negatives in the resulting matrix, as shown below in the Tables A3a–A3e.

Table A3a Emissions in industries – U_E

Industry	Coal mining	Electricity
CO_2	4 000	40 000

Table A3b Make table – V

Industry \ Product	Coal	Electricity
Coal mining	12 000	20 000
Electricity generation	0	80 000

Table A3c M matrix

Industry \ Product	Coal	Electricity
Coal mining	1	0.2
Electricity generation	0	0.8

Table A3d Inverse transposed M matrix

Industry \ Product	Coal	Electricity
Coal mining	1	0
Electricity generation	–0.25	1.25

Table A3e Resulting emissions – **Model A**

Product	Coal mining	Electricity production
CO_2	–6 000	50 000

Source: Own construction (demonstrative examples)

This is the point where we can make use of Almon's procedure in the same way as with the creation of the symmetrical input-output table. For a trivial illustrative example of Almon's procedure we use the same source values as in the example of the model A transformation with negative values. We proceed as follows:

$$r_{E1}^{(1)} = u_{E1} - s_1^{(0)}\, m_{12}\, r_{E2}^{(0)} + s_2^{(0)}\, m_{21}\, r_{E1}^{(0)}, \qquad \text{(A1)}$$

$$s_1^{(0)} = \frac{u_{E1}}{m_{12}\, r_{E2}^{(0)}},$$

$$s_1^{(0)} = \frac{4\,000}{0.2 \times 40\,000} = 0.5,$$

$$s_2^{(0)} = 1,$$

$$r_{E1}^{(1)} = 4\,000 - 0.5 \times 0.2 \times 40\,000 + 1 \times 0 \times 4\,000 = 0,$$

$$r_{E2}^{(1)} = u_{E2} - s_2^{(0)}\, m_{21}\, r_{E1}^{(0)} + s_1^{(0)}\, m_{12}\, r_{E2}^{(0)}, \qquad \text{(A2)}$$

$$r_{E2}^{(1)} = 40\,000 - 1 \times 0 \times 4\,000 + 0.5 \times 0.2 \times 40\,000 = 44\,000.$$

Table A4 Resulting emissions of products gained from Almon's procedure

Product	Coal mining	Electricity
CO_2	0	44 000

Source: Own construction (demonstrative examples)

It is not necessary to calculate approximations of higher orders here, since it would make no difference to the result in this example. This trivial example in Formulas (A1) and (A2) shows how Almon's procedure scales down transferred emissions to prevent the product emissions r_{Ej} from becoming a negative number, see the Table A4.

Legend for Almon's procedure

$\boldsymbol{u_E}$ vector of emissions of industries for one type of emissions,
u_E element of $\boldsymbol{u_E}$,
$\boldsymbol{r_E}$ resulting vector of emissions of products for one type of emissions,
r_{Ei} element of $\boldsymbol{r_E}$,
m_{ij} element of $\boldsymbol{M}$ matrix,
s_i scaling factor.

APPENDIX B

The tool for Almon's transformation in Excel and VBA is available at the webpage of *Statistika: Statistics and Economy Journal*, see the online version of No. 2/2017 (Excel file) at: <http://www.czso.cz/statistika_journal>.

APPENDIX C

Original and resulting values for 184 and 185 industries can be found online at the webpage of *Statistika: Statistics and Economy Journal*, see the online version of No. 2/2017 (Excel file) at: <http://www.czso.cz/statistika_journal>.