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METHODOLOGY

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Estimating low-carbon GDP and employment effects of green expenditures

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Abstract

I propose a simple input–output framework for estimating gross domestic product (GDP) and employment generated in sectors with low greenhouse gas (GHG) intensity as a result of green expenditures. In addition to the analytical derivation, I also walk through a numerical example (based on Hungarian data), pointing out a number of issues that need to be addressed during a practical implementation. Providing easily calculable and highly transparent indicators, the framework is a useful tool for (primarily sovereign) bond issuers when preparing impact reports on green bonds or other use-of-proceeds bonds. To facilitate practical implementation, I also included an easy-to-use Excel calculator.

Keywords: Input–output modelling, Green expenditure, GDP and employment effects, GHG intensity, Green bond reporting, Excel calculator

1 Introduction

The global green transition is not proceeding along the ideals previously envisioned. This failure has direct implications for green finance, in particular, tightening requirements for green bonds. A growing number of green investors want to take a deeper look at how their money is being spent, i.e. not only what it was allocated for, but also what impact it had. In other words, due to the stalling of green transition, the impact component is becoming increasingly prominent. Moreover, with the spread of the holistic approach, there is also a growing need to demonstrate social or socioeconomic co-benefits.

The spectrum of impact indicators can be incredibly wide. Although the related guidelines (primarily ICMA's Harmonised Framework for Impact Reporting [11]) are dynamically evolving, they cover only a limited segment of the theoretical possibilities. In this paper, I propose a simple multi-sector methodology utilising Leontief's [16] input–output model for estimating the low-carbon content of GDP and employment effects of green expenditures.[1] In light of the market trends outlined above, these two macro-level performance indicators can be useful additions to standard indicators (e.g. GHG emissions avoided) to broaden and deepen the context. Of course, they fit not only into the impact reports of green bonds, but also into the impact reports of social or sustainability bonds.

[1] Although greenhouse gases are not exclusively carbon compounds, for the sake of simplicity, terms 'carbon' and 'GHG' are used interchangeably in this paper. The same applies to terms 'sector' and 'industry'.

The history of environmentally extended input–output (EEIO) analyses dates back to the 1970s. The EEIO framework links economic activities with environmental impacts to provide a comprehensive picture of the economy's environmental footprint (for a historical survey of applications, see Shmelev [24]). Doing so, it is a competitive framework for, e.g., carbon footprint analysis, i.e. determining the total upstream greenhouse gas emissions of economic activities (for an overview, see Minx et al. [22]). It should be noted that such environmental impacts are typically assessed over longer time (e.g. lifecycle analyses, sustainability pathways), meaning a forward-looking rather than a snapshot-based interpretation. In such cases, however, the assumption of static input–output ratios (technical coefficients) cannot be maintained due to technological progress. Therefore, environmental assessments using EEIO frameworks are nowadays dynamic (for an overview of static and dynamic approaches, see Forssell and Polenske [10]). In this context, the combination of integrated assessment modelling (a vital tool for assessing interactions between physical and human systems) and input–output modelling is an important recent development (for an overview, see Malik and Schaeffer [18]).

Another important area is the multi-regional input–output (MRIO) modelling, which deepens the complexity of interdependencies. It plays a key role in carbon footprint accounting (Andrew et al. [1]) or water footprint accounting (Daniels et al. [3]). By implementing existing climate scenarios in MRIO models, the analysis of conditional pathways is also possible (Wiebe et al. [26]). Although the growing number of MRIO databases (for a review, see Tukker and Dietzenbacher [25]) contributes to the development of the field, it also creates new risks, as studies based on databases with potentially very different underlying assumptions can lead to very different conclusions (Inomata and Owen [12]).

In this paper, I also link economic and environmental factors, but I do so for a completely different purpose. The above approaches aim to present the environmental impact of economic activities, while my goal is to present the economic and employment impact (of the allocated green bond proceeds) under given environmental boundary conditions. Moreover, they try to capture long-term effects, while I focus on annual effects. From the narrow time window, it organically follows that my framework is static.

The purpose of this paper is twofold. On the one hand, to provide an easy-to-implement and easy-to-use tool for bond issuers, which does not require any special mathematical apparatus and can even be implemented in Excel (without VBA). On the other hand, to do all this with utmost transparency, meaning that investors can also learn the necessary details. This approach is mostly evident in the academic world, but unfortunately not in the world of green bond reporting.

By the end of 2025, only two EU Member States had reported on the GDP and employment effects of green bonds: Italy and Hungary (see Lukács [17]). Based on input–output modelling, Italy was the first to present the total effects in its annual green bond reports [19, 20]. The methodology has recently been further developed by integrating national-level results with MRIO modelling, i.e., taking into account economic interdependencies between regions [21]. In its latest green bond report [2], Hungary reported the low-carbon GDP and employment effects based on the fully transparent national-level input–output model presented in this paper. Of the two, the latter approach is less complex but more stringent, because it only reports the low-carbon effect (i.e. a part of the total effect) as a positive implication of green bonds.

Section 2 presents the methodology in detail. Section 3 discusses its practical application using Hungarian data, paying particular attention to pitfalls. Section 4 briefly describes the implementation of the methodology in Excel (the file is available under Supplementary Information). Section 5 concludes.

2 Methodology

Suppose an economy with n industries $(i, j = 1, 2, ..., n)$. In domestic concept, let $\mathbf{Z} = [z_{ij}]$ denote the $n \times n$ square matrix of cross-industry flows, $\mathbf{f} = [f_i]$ the column vector of final use (final consumption expenditure of households, non-profit institutions serving households, and government; gross capital formation; export), $\mathbf{x} = [x_i]$ the column vector of output, $\mathbf{m} = [m_j]$ the row vector of import for intermediate use, $\mathbf{t} = [t_j]$ the row vector of taxes less subsidies on products for intermediate use, τ the value of taxes less subsidies on products for final use, and $\mathbf{v} = [v_j]$ the row vector of gross value added or GVA (operating surplus and mixed income; compensation of employees; other taxes less other subsidies on production). Table 1 outlines the corresponding symmetric input–output table (T in the superscript denotes transpose).[2]

The matrix of technical coefficients is $\mathbf{A} = \left[\frac{z_{ij}}{x_j}\right]$. The output can be expressed from identity $\mathbf{Ax} + \mathbf{f} = \mathbf{x}$ as

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f},$$

where $\mathbf{I}$ is the n-dimensional identity matrix, and $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief inverse. With static technology, modified final use $(\hat{\mathbf{f}})$ defines modified output,

$$\hat{\mathbf{x}} = \mathbf{L}\hat{\mathbf{f}}.$$

Table 1 Symmetric input–output table

$\mathbf{Z}$	$\mathbf{f}$	$\mathbf{x}$
$\mathbf{m}$		
$\mathbf{t}$	τ	
$\mathbf{v}$		
$\mathbf{x}^{\mathrm{T}}$		

[2] I omitted the import for final use, the total imports and the total net product tax (the cross-hatched cells in the table), because we will not need them in our calculations.

Assuming static ratios for the import, i.e. that the row vector of import coefficients is $\mathbf{b} = \left[\frac{m_j}{x_j}\right]$, the modified import is

$$\hat{\mathbf{m}} = \mathbf{b} \circ \hat{\mathbf{x}}^{\mathrm{T}},$$

where $\circ$ is the Hadamard product operator. Similarly, assuming the row vector of net product tax coefficients as $\mathbf{c} = \left[\frac{t_j}{x_j}\right]$, the modified tax vector becomes

$$\hat{\mathbf{t}} = \mathbf{c} \circ \hat{\mathbf{x}}^{\mathrm{T}}. \quad (1)$$

It necessarily follows from the defined technical, import and tax coefficients that the row vector of GVA coefficients is $\mathbf{d} = \left[\frac{v_j}{x_j}\right]$. Thus, the row vector of modified GVA can be calculated as[3]

$$\hat{\mathbf{v}} = \mathbf{d} \circ \hat{\mathbf{x}}^{\mathrm{T}}. \quad (2)$$

2.1 Low-carbon GDP effect

From the production side, the GDP is calculated as[4]

$$\mathrm{GDP} = \mathbf{v}\vec{\mathbf{1}} + \mathbf{t}\vec{\mathbf{1}} + \tau = \sum_{j=1}^{n} v_j + \sum_{j=1}^{n} t_j + \tau. \quad (3)$$

Let $\hat{\mathbf{f}}$ denote the final use vector without the green expenditure under consideration. Assuming that the net product tax on final use is proportional to the final use,

$$\frac{\hat{\tau}}{\tau} = \frac{\hat{\mathbf{f}}^{\mathrm{T}}\vec{\mathbf{1}}}{\mathbf{f}^{\mathrm{T}}\vec{\mathbf{1}}} = \frac{\sum_{i=1}^{n}\hat{f}_i}{\sum_{i=1}^{n} f_i} \rightarrow \hat{\tau} = \tau\frac{\hat{\mathbf{f}}^{\mathrm{T}}\vec{\mathbf{1}}}{\mathbf{f}^{\mathrm{T}}\vec{\mathbf{1}}}, \quad (4)$$

each term of Eq. 3 is available to calculate $\widehat{\mathrm{GDP}}$ (see Eqs. 1, 2, 4). The total GDP effect is then

$$\Delta\mathrm{GDP} = \mathrm{GDP} - \widehat{\mathrm{GDP}} = (\mathbf{v} - \hat{\mathbf{v}})\vec{\mathbf{1}} + (\mathbf{t} - \hat{\mathbf{t}})\vec{\mathbf{1}} + \tau - \hat{\tau}. \quad (5)$$

If we do not examine the effect of an existing expenditure (ex post analysis), but the effect of a non-existing expenditure (ex ante analysis), than the final use is bigger in the modified case, so the difference should be reversed accordingly (i.e. $\widehat{\mathrm{GDP}} - \mathrm{GDP}$). Note that this has no practical relevance, because the result is the same in both cases. Even if we express the effect as a percentage of GDP, the issue is still not particularly relevant as the numerator is typically small relative to the denominator. With a schematic example, $\frac{\Delta\mathrm{GDP}}{\widehat{\mathrm{GDP}}}\left[\text{if GDP} > \widehat{\mathrm{GDP}}\right] = \frac{1000-999}{999} \approx \frac{1001-1000}{1000} = \frac{\Delta\mathrm{GDP}}{\mathrm{GDP}}\left[\text{if GDP} < \widehat{\mathrm{GDP}}\right]$.

To estimate the low-carbon content of ΔGDP, the concept of GHG intensity needs to be introduced: it measures the mass of greenhouse gas emissions per unit of economic

[3] Alternatively, as $\hat{\mathbf{Z}} = \left[\hat{x}_j \frac{z_{ij}}{x_j}\right]$ is known, $\hat{\mathbf{v}}$ can also be calculated from identity $\left(\hat{\mathbf{Z}}^{\mathrm{T}}\vec{\mathbf{1}}\right)^{\mathrm{T}} + \hat{\mathbf{m}} + \hat{\mathbf{t}} + \hat{\mathbf{v}} = \hat{\mathbf{x}}^{\mathrm{T}}$, where $\vec{\mathbf{1}}$ is the n-element column vector of all ones.

[4] It can also be calculated from the expenditure side, $\mathrm{GDP} = \mathbf{f}^{\mathrm{T}}\vec{\mathbf{1}} - \mathbf{m}\vec{\mathbf{1}} + \tau$, but this is not the right approach for us, because later we are interested in certain sectoral elements of GDP, not just the whole.

activity. The economic activity can be output or GVA. Let g_j denote the GHG intensity of sector j, and g^* the threshold that separates low and high intensity. Taking into account that a green expenditure finances low-carbon projects regardless of the GHG intensity of the sector concerned, the corresponding logical vector of sectors is

$$\mathbf{s} = \left[s_j\right] = \begin{cases} 1 \text{ if } g_j < g^* \text{or } \hat{f}_k \neq f_k \\ 0 \text{ if } g_j \geq g^* \text{and } \hat{f}_k = f_k \end{cases}, \tag{6}$$

where k denotes the sector of the green expenditure. Thus, the low-carbon GDP effect can be obtained as (using Eqs. 5, 6)

$$\Delta \text{GDP}^{\text{lc}} = ((\mathbf{v} - \hat{\mathbf{v}}) \circ \mathbf{s})\vec{\mathbf{1}} + ((\mathbf{t} - \hat{\mathbf{t}}) \circ \mathbf{s})\vec{\mathbf{1}} + \tau - \hat{\tau}, \tag{7}$$

where of course the difference between the final-use tax levels fully belongs to the green expenditure (recall Eq. 4).

If an environmental expenditure affects several sectors, the effect must be calculated separately for each of the sub-expenditures concerned. The necessity of this multi-step approach can be easily understood through an exaggerated example: if a green spending affected all industries and the calculation were done in a single step, then according to Eq. 6, all effects would be incorrectly classified as low carbon.

2.2 Low-carbon employment effect

Now let us estimate how many persons were employed in low-carbon sectors as a result of the green expenditure. Let $\mathbf{e} = \left[e_j\right]$ denote the row vector of employment levels. Assuming that the sectoral employment is proportional to the sectoral output,

$$\frac{\hat{e}_j}{e_j} = \frac{\hat{x}_j}{x_j} \rightarrow \hat{e}_j = e_j \frac{\hat{x}_j}{x_j}, \tag{8}$$

the vector of modified employment levels becomes $\hat{\mathbf{e}} = \left[e_j \frac{\hat{x}_j}{x_j}\right]$. The total employment effect is then (using Eq. 8)

$$\Delta \text{EMP} = (\mathbf{e} - \hat{\mathbf{e}})\vec{\mathbf{1}} = \sum_{j=1}^{n} (e_j - e_j \frac{\hat{x}_j}{x_j}), \tag{9}$$

and thus the employment effect in low-carbon activities can be calculated as (using Eqs. 6, 9)

$$\Delta \text{EMP}^{\text{lc}} = ((\mathbf{e} - \hat{\mathbf{e}}) \circ \mathbf{s})\vec{\mathbf{1}}.$$

3 A numerical example

In this section, I apply the methodology on Hungarian data. In the meantime, I will draw attention to several important practical issues and dilemmas.

Every 5 years, Hungarian Central Statistical Office (Központi Statisztikai Hivatal, KSH) publishes the symmetric input–output table of the country with a granularity of 65 broader or narrower sectors (to be precise, sections, merged divisions and divisions according to NACE Rev. 2; see [5]). The latest input–output table is for year 2020, outlined in Table 2.

Question 1 *Suppose that an (imaginary) railway electrification project is done in 2022 at a cost of HUF 100 billion. What is the low-carbon GDP effect of this project in that year? Hint: from the production side, GDP is calculated as the sum of the yellow cells (Table 2).*

As the input–output table is in 2020 prices, while the examined expenditure is in 2022 prices, it follows that a price adjustment is needed to get its 2020 value. The project in question is a domestic final use, i.e. the implicit price index of domestic final use should be applied for discounting ([14]: 2021 108.8, 2022 119.8; 100 = previous year):

$$\mathrm{PV}_{2020}(\text{green\_expenditure}_{2022}) = \frac{100{,}000\ \mathrm{M}}{1.088 \cdot 1.198} = 76{,}721\ \mathrm{M}.$$

Railway electrification is a construction project, i.e. it can be classified into Section F 'Construction' of NACE Rev. 2. More precisely, in Division 42 'Civil Engineering', Group 42.1 'Construction of roads and railways', Class 42.12 'Construction of railways and underground railways'.[5] Note, however, that Section F in our input–output table is not subdivided into lower categories. That is, by replacing value 5,125,920 to 5,125,920–76,721 = 5,049,199, we get modified final use ($\hat{\mathbf{f}}$), and thus the modified net product tax on final use ($\hat{\tau}$). After calculating the technical coefficients (**A**, and thus the Leontief inverse, **L**), everything is given to calculate the modified output ($\hat{\mathbf{x}}$). As for the production side, after calculating the coefficients for import, net product tax on intermediate use, and GVA (**b**, **c** and **d**), the corresponding modified vectors ($\hat{\mathbf{m}}, \hat{\mathbf{t}}$ and $\hat{\mathbf{v}}$) can also be recovered. It follows that the original and modified GDPs can be calculated as well. Table 3 outlines the modified input–output table: the modified final use is marked in red, and the blocks that change as a result are marked in grey (sector U is all zero, i.e. it is not linked to any other sector, and therefore it does not change when they change).

Table 2 Symmetric input–output table of Hungary (2020, million HUF)

	A01	…	F	…	U	Total final use	Total use
A01 Crop and animal production	586,423	…	20,471	…	0	1,529,099	3,480,386
…	…	…	…	…	…	…	…
F Construction	3,345	…	641,242	…	0	5,125,920	6,447,723
…	…	…	…	…	…	…	…
U Extraterritorial organisations	0	…	0	…	0	0	0
Use of imported products	513,619	…	1,350,462	…	0		
Taxes less subsidies on products	75,711	…	140,035	…	0	5,800,046	
Gross value added	1,552,111	…	2,327,776	…	0		
Output	3,480,386	…	6,447,723	…	0		

Source: [13]

[5] From 2025, NACE Rev. 2.1 is in force [6]. Nevertheless, the classification of the activity in our example is not affected by this update.

For Hungary, being an EU Member State, both GHG emissions [7] and GHG emissions per unit of economic activity, i.e. GHG intensity [8], are available on an annual basis. The intensity data are available for both output and GVA. An important question is which data should be used to calculate low-carbon effects. Each one has disadvantages, but some have advantages as well:

- At first glance, it may seem tempting to use the intensity data of 2022 as they reflect the technological level at the time of the expenditure. However, pairing the economic structure of 2020 with the technological structure of 2022 could lead to contradictions as the supply and demand structure would have been something else under different technology and different prices.
- On the other hand, using intensity data of 2020 does not take into account two years of technological progress, which means that greenhouse gas emissions are likely to be overestimated. Therefore, applying a threshold to these values that would be used for 2022 is considered a prudent approach. Alternatively, a higher threshold could be set to consider this technological discrepancy.
- Using emissions of 2020 for calculating intensities (dividing by output or GVA of 2020) is equivalent to the previous solution.
- Using emissions of 2022 for calculating intensities seems the most problematic solution. In this case, when calculating the intensity, there is already a mismatch between the structure of the economy (2020) and the structure of emissions (2022), i.e. the intensity itself would be questionable.

For the sake of consistency and prudence, I propose the second or third option, i.e. to use the same year of GHG data as the one to which the input–output table refers. Note that Eurostat reports GHG intensity data in euro. Since we are calculating in forint in this example, this means that we either convert the euro-based intensity data into forint-based data (using the annual average EURHUF exchange rate reported by Magyar Nemzeti Bank, MNB) or calculate the intensity ourselves in forint dividing the sectoral emissions by the corresponding sectoral output or GVA. Fig. 1 shows the calculated GHG intensities for all 65 sectors.

The question immediately arises as to what counts as ‘low’ intensity. If we think in natural science terms, this seems easier to define. For example, according to the EU

Table 3 Modified symmetric input–output table of Hungary (2020, million HUF)

	A01	…	F	…	U	Total final use	Total use
A01 Crop and animal production	586,307	…	20,199	…	0	1,529,099	3,479,698
…	…	…	…	…	…	…	…
F Construction	3,344	…	632,731	…	0	5,049,199	6,362,145
…	…	…	…	…	…	…	…
U Extraterritorial organisations	0	…	0	…	0	0	0
Use of imported products	513,517	…	1,332,538	…	0		
Taxes less subsidies on products	75,696	…	138,176	…	0	5,793,578	
Gross value added	1,551,804	…	2,296,880	…	0		
Output	3,479,698	…	6,362,145	…	0		

Source: author’s calculation [13, 14]

Taxonomy Climate Delegated Act [4], a 100 gCO_2e/kWh intensity limit on the lifecycle GHG emissions of the power sector is believed to enable the EU to meet the net-zero goal by 2050. As for the output or GVA-based intensities, I argue that the status of an economy's green transition can help to set the threshold. A relatively lenient (i.e. relatively high) threshold should be set if a country is overachieving its GHG reduction target, and a relatively strict (i.e. relatively low) threshold should be set if it is underachieving it, bearing in mind the technological feasibility at any given time.

In this example, I set the threshold separating low and high intensity industries (i.e. g^*) to 0.5 g/HUF if the intensity is output-based and 1 g/HUF if the intensity is GVA-based, which are about 175 g/EUR or 350 g/EUR, respectively ([23]: 1 EUR = 351.17 HUF, 2020). With these thresholds, 50 or 47 of the 65 sectors are classified as low carbon. It should be noted that this configuration excludes not only the 15 or 18 sectors with the highest emission intensity, but also nine of the largest emitters in absolute terms.

As we already have the original and modified vectors of GVA and net product tax, the element-wise multiplication of the sum of these vectors with the logical vector of low-carbon sectors (**s**), and then the summation of the elements (plus delta tau) gives us the low-carbon GDP effect on 2020 prices: HUF 52.03 billion (output-based) or HUF 51.93 billion (GVA-based).

To answer our first question, as a final step, we need to convert these 2020 values to 2022 values. Since we are dealing with a wide range of GDP elements, the best possible solution is to use the GDP deflator for this purpose ([14]: 2021 106.2, 2022 114.2; 100 = previous year):

$$\mathrm{FV}_{2022}\left(\Delta\mathrm{GDP}_{2020}^{\mathrm{lc\,(output\text{-}based)}}\right) = 52.03\,\mathrm{bn}\cdot 1.062\cdot 1.142 = 63.11\,\mathrm{bn}$$

or

$$\mathrm{FV}_{2022}\left(\Delta\mathrm{GDP}_{2020}^{\mathrm{lc\,(GVA\text{-}based)}}\right) = 51.93\,\mathrm{bn}\cdot 1.062\cdot 1.142 = 62.98\,\mathrm{bn}.$$

That is, the low-carbon GDP effect of the HUF 100 billion railway electrification in 2022 is approximately HUF 63 billion, which is about 92 percent of the total GDP effect, HUF 68.40 billion. The sensitivity of the results to the threshold values is shown in Fig. 2.

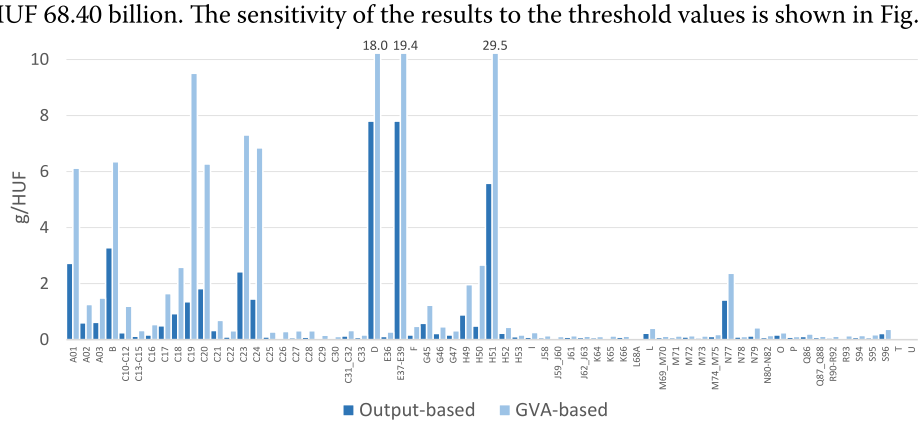

Fig. 1 GHG intensities in Hungary (2020). Source: author's calculation [7, 13]

The effects seem quite robust over a wide range around the selected thresholds. For example, if they were half as high (i.e. 0.25 and 0.5 g/HUF), the results would be very similar: HUF 62.88 billion (output-based) or HUF 62.53 billion (GVA-based). Recall that the lower bound in our example shows the effect for sector F 'Construction' (HUF 47.57 billion).

Finally, four practical remarks. First, the intensity of H51 'Air transport' shows extreme volatility due to the high volatility of both the numerator and the denominator. Nevertheless, from our point of view, this is of little practical relevance, as it is a GHG intensive industry, which means that even in a downturn it will not be considered low carbon (unless, of course, the threshold is set too high).

Second, in the EU, the sectoral categories of the input–output table is a true subset of the sectoral categories of the GHG dataset. In other words, there is no sector to which GHG data cannot be assigned. However, there may be countries in the world, where the granularity of the GHG dataset is lower than that of the input–output table. In this case, the relevant categories in the input–output table should be adjusted (aggregated) to reflect the structure of the available GHG data. In general, the higher resolution dataset should be downscaled to match its lower resolution counterpart. For an in-depth discussion of the consequences of aggregation and disaggregation, see Lenzen [15].

Third, in our example, the input–output table is for a year that was hit by a global lockdown due to COVID-19 pandemic, which could have significantly distorted the 'normal' industry correlations. Such outliers are much less of an issue for countries that produce the table more frequently, say every 2 years.

Fourth, the effect of a project can be significantly under- or overestimated if the project is highly atypical, i.e. if it differs greatly from the industry average. However, the expenditures reported in a green bond report generally cover a wide range of projects in multiple industries. Thus, at the portfolio level, the risk of bias is lower, as project-level biases are expected to (at least partially) cancel each other out.

Question 2 *What is the low-carbon employment effect of the green expenditure in Question 1?*

Again, the dilemma immediately arises as to which year's employment data should be used as a starting point. Recall that the modified employment levels are derived using

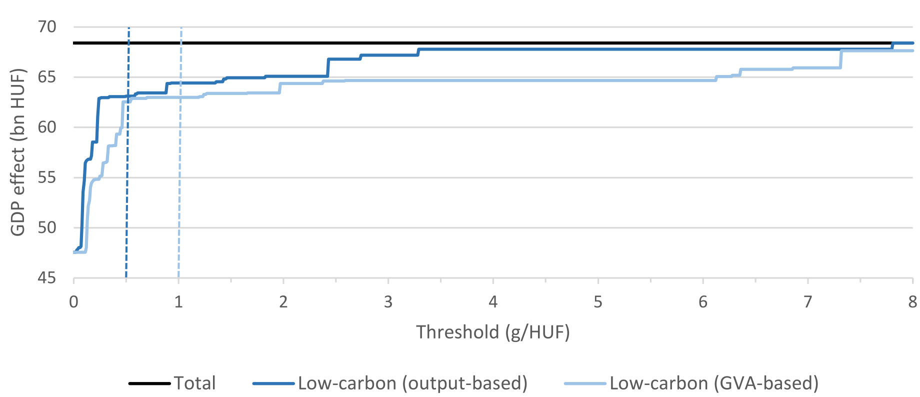

Fig. 2 Sensitivity of GDP effect to low-carbon threshold (step size: 0.01 g/HUF). Source: author's calculation [7, 13, 14]

sectoral outputs (see Eq. 8). Therefore, to be consistent with the economic structure, I use employment data of 2020, i.e. the year to which our input–output table refers. Eurostat provides highly granular sectoral employment data, both in national and domestic concepts [9]. As the scope of the model is the domestic production, the data based on latter concept is to be used.

We have the original employment and output vectors, and already calculated the modified output vector. It follows that we can calculate the modified employment vector: the original sectoral employments are scaled by the corresponding ratios of the modified and original sectoral outputs. 6689 persons were employed as a result of the expenditure, of which 6311 (output-based) or 6298 (GVA-based) are related to low-carbon activities.

These 2020 values are to be scaled with the growth of aggregate employment levels ([9]: 2021 1.8%, 2022 1.5%). That is, the low-carbon employment effect of the HUF 100 billion railway electrification in 2022 is 6311·1.018·1.015 = 6521 or 6298·1.018·1.015 = 6508 persons. The sensitivity of these results to threshold values is shown in Fig. 3. The overall picture is, of course, very similar to what we saw in the case of GDP, as labour is a key factor in economic performance (the lower bound here is 5067 persons).

Finally, a technical remark for cases where the effects of multiple years need to be aggregated, e.g. for years t and $t+1$. GDP is a flow variable, and hence the sum of annual effects is self-evident, $\Delta\text{GDP}_{[t,t+1]} = \Delta\text{GDP}_t + \Delta\text{GDP}_{t+1}$. In contrast, employment level is a stock variable, therefore the sum of annual effects conveys the upper limit of individuals affected, $\Delta\text{EMP}_{[t,t+1]} \leq \Delta\text{EMP}_t + \Delta\text{EMP}_{t+1}$. In other words, equality exists if the set of employees concerned in the two years are disjoint. This issue can be avoided by calculating with hours worked rather than the number of employees, as hours worked is a flow variable. Moreover, it addresses the issue of full-time versus part-time work.[6] However, as it does not specify the number of persons concerned, it may seem less appealing to some as a social indicator.

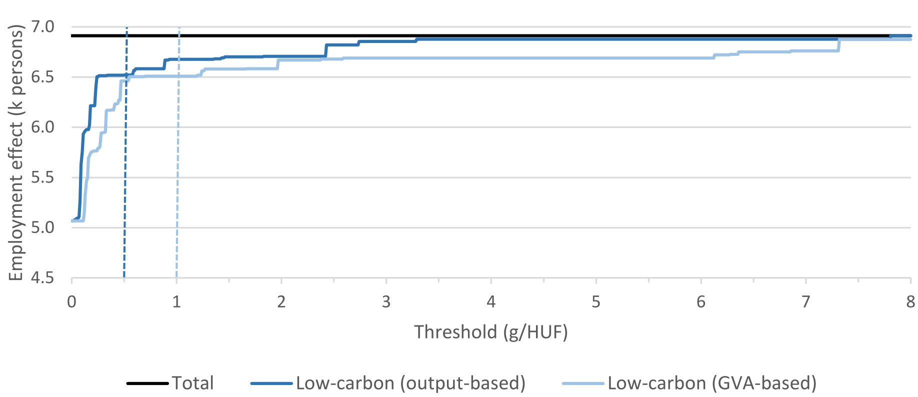

Fig. 3 Sensitivity of employment effect to low-carbon threshold (step size: 0.01 g/HUF). Source: author's calculation [7, 9, 13, 14]

[6] In our case, this is not of great importance, as the proportion of part-time employment in Hungary is less than five percent.

4 Implementation in Excel

I implemented the numerical example in Excel in a flexible, user-friendly way (the file is available under Supplementary Information). The variables and parameters, and thus the formulae, are defined according to the symbols used in this paper (see 'Info' sheet). The cells are colour-coded, which makes it easier to navigate the workbook, i.e. which data to enter ('Data' sheet), which variables and parameters can be changed ('Control' sheet), and what the results are. By modifying the attributes of green expenditure (year, NACE code, amount) and the low-carbon threshold, users can freely experiment to see how the calculated effects change.

To eliminate typos, I also introduced some basic restrictions on control cells: the green expenditure and the low-carbon threshold cannot be negative, and the NACE code of green expenditure must be selected from a drop-down menu. There is also an error message if green expenditure is greater than final use. For flexibility, I configured the formulae so that the year of green expenditure can differ by ± 2 from the year of input–output table. In our case, the table is from 2020, so green expenditures can be selected between 2018 and 2022 from a drop-down menu.

Note that the structure of the data may differ in countries outside the EU. Since no VBA is used, only minimal Excel skills are required to customise the calculator according to the structure of the available data. The most important consideration here is that it may be necessary to update the cell ranges of the defined names.

5 Conclusions

I presented a simple multi-sector approach to estimating the low-carbon content of GDP and employment effects of green expenditures. The methodology uses simple mathematical operations, and it can be implemented even in a simple spreadsheet software. Consequently, the challenge is not primarily technical but lies in the availability and correct use of data. Therefore, I discussed how the model works in practice through a very detailed example using Hungarian data. I addressed several issues that could have a significant impact on the results and their defensibility. I also provided a flexible, easy-to-use Excel calculator.

I argue that such highly transparent approaches should form the basis for reporting on green bonds. Transparency naturally entails contestability, but that is precisely the point. Only what is properly presented can be discussed and improved, building on the lessons learned from the debate.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1007/s44274-026-00682-8.

Below is the link to the electronic supplementary material.Supplementary Material 1.

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