

Technical Documentation | August 2025

Technical Documentation for the Financial Carbon Footprint of loans by GLS Bank in 2024

Scope 3.15 Emission Intensities &
Methodology

Dr. Jens Teubler
Christian Buschbeck

This report is the result of work conducted on behalf of GLS Bank in 2025. The corresponding work package aims to calculate and operationalize the Financial Carbon Footprint of GLS Bank loans (indirect GHG emissions under Scope 3.15).

The document at hand constitutes the 'technical documentation' for this work.

Please cite the report as follows:

Teubler, J.; Buschbeck, C. (2025). Technical Documentation for the Financial Carbon Footprint of loans by GLS Bank in 2024 – Scope 3.15 Emission Intensities & Methodology. Wuppertal, 2025.

Project term: June 2022 – December 2025

Wuppertal Institut für Klima, Umwelt, Energie gGmbH:

Dr. Jens Teubler; jens.teubler@wupperinst.org

Christian Buschbeck; christian.buschbeck@wupperinst.org

This work is licensed under Creative Commons Attributions 4.0 International license (CC BY 4.0).

The license is available at: <https://creativecommons.org/licenses/by/4.0/>



Table of Contents

Table of Contents	3
List of Abbreviations, Units and Symbols	4
List of Tables	4
List of Figures	4
1 Scope and Overview of Document	5
2 Approach and Data	6
2.1 Components and Requirements	6
2.2 Approach	8
3 MRIO Model and Intensities	10
3.1 MRIO Model (absolute S1/S2/S3 emissions)	10
3.2 Generic MRIO GHG intensities (relative S1/S2/S3 emissions)	11
4 Hybrid Models	12
4.1 Renewable Energies	12
4.2 Organic Farming	13
5 Limitations	15
6 Bibliography	16
7 Appendix	18
7.1 GHG-Intensities from energy hybrid model	18
7.2 Generic MRIO emission intensities	18
7.3 MRIO Script (see following pages)	21

List of Abbreviations, Units and Symbols

Abbreviations

BMEL	Bundesministerium für Ernährung und Landwirtschaft
BOELW	Bund Ökologische Lebensmittelwirtschaft
EF	Emission Factor
FCF	Financial Carbon Footprint
GHG	Greenhouse gas
GHG-P	GHG Protocol
MRIO	multi regional input output
NACE	Nomenclature statistique des activités économiques dans la Communauté européenne
PCAF	Partnership for Carbon Accounting Financials
S1/S2/S3	Scope 1 / Scope 2 / Scope 3 emissions according to GHG-P
UBA	Umweltbundesamt

Units and Symbols

bnEUR	billion euro
CO ₂ e	CO ₂ equivalents
ha	hectare
kWh	Kilowatt hour
mEUR	million euro
t	metric tons

List of Tables

Table 4-1: key results from hybrid model for 'organic agriculture'-----	14
Table 7-1: GHG emission factors for 1 million EURO loan-----	18
Table 7-2: Generic GHG-Intensities from MRIO Model-----	18

List of Figures

Figure 2-1: Components, Data and Steps for Financial Carbon Footprint (FCF) of GLS Bank loans-----	9
--	---

1 Scope and Overview of Document

The client, GLS BANK, assigned the contractor, Wuppertal Institut, with the calculation of the Scope 3.15 emissions of their loan programme in 2024. Moreover, they also asked for a set of calculation rules and background data to conduct such a calculation for future loan periods as well. Such GHG intensities usually estimate the emissions of an actor on the basis of the economic activity, the underlying value-chain-related emissions of this activity as well as some monetary reference unit so that each unit of greenhouse gas emissions (GHG) can be directly associated with the loan value (e.g. as tons of CO₂-equivalents per million Euro).

This has been an continuation of previous work conducted by Wuppertal Institut in the same area. Namely, the first such calculation by the contractor in 2019 (on the basis of EXIOBASE) as well as the first update of the methodology in 2022 in coordination with liminalytics (on the basis of EUROSTAT and with the first hybridisation solutions).

The current loan programme refers to circa 17,700 items in the 2024 data-set (mostly loans). These loans are distinct from loans by other banks in the following way:

- 1 | Loans are only attributed to German companies and German private customers.
- 2 | Loans are only attributed for purposes that are deemed sustainable in such a way, that they are a part, enable, facilitate or contribute to social or environmental improvements.
- 3 | Company lenders are mostly SMEs and as such not required to report on their Corporate Carbon Footprint

It follows that in cases in which there is no primary data by these borrowers (e.g. in form of Corporate Carbon Footprints), average GHG intensities must be used, but that these intensities or emission factors

- should be limited to economic activities in Germany and their corresponding emissions,
- will exclude emission sources with high GHG intensities from e.g. fossil fuels or conventional agriculture (both of which are not funded by GLS loans).

Thus, any generic or average intensity factor should at least (i) account for the economic activity and (ii) refer to Germany. And moreover, (iii) in cases where the GHG emissions of GLS customers are likely to deviate strongly from these average values, more specific intensity factors are needed. A further requirement (iv) is that the calculation is aligned with the recommendation for such emission calculations by the Partnership for Carbon Accounting Financials (PCAF-Standard) (PCAF, 2022). Namely, such Financial Carbon Footprints or FCFs should refer to the total balance of companies when attributing the value of a loan to these emissions.

The following document describes the solution to achieve these objectives. It is divided into a chapter on the overall approach and available data (chapter 2), the methodology and calculation of generic values from multi-regional-input-output-models (chapter 3), the methodology and calculation of hybrid values for energy and agriculture (chapter 4), and a brief discussion of the limitations (chapter 5).

It is further planned to publish this methodology and discuss its result in a peer-reviewed journal article.

2 Approach and Data

2.1 Components and Requirements

2.1.1 Loan Data

The available loan data¹ set includes circa 17,700 loans with information on the original loan value, the outstanding loan value as well as year of reference. Each loan is further attributed to private versus corporate entities, the internal GLS loan classification system and additional information on loan purposes (e.g. loans for installation of photovoltaic systems in the category of renewable energy) as well as matched to a classification of economic activities according to NACE REV 2.0². This matching has been conducted by the client.

2.1.2 PCAF Standard and PCAF economic activity-based emission factors

The 'Global GHG Accounting and Reporting Standard for the Financial Industry' (PCAF, 2022) is published by the Partnership for Carbon Accounting Financials (PCAF). It provides guidance on measuring and disclosing GHG emissions of financial institutions across seven different asset classes.

This includes the category of 'Business loans and unlisted equity' (chapter 5.2 in the standard). The basic attribution principle for these loans (and thus GLS Bank loans in the documentation at hand) is the ratio between the outstanding amount (numerator) and the value of the financed company (denominator). It can be summarized in the following formula to calculate 'financed emissions' for 'business loans' (see also (PCAF, 2022, p. 71)):

$$\text{Financed emissions} = \sum_c \frac{\text{Outstanding amount}_c}{\text{Total equity} + \text{debt}_c} \times \text{Company emissions}_c$$

with

c: borrower or investee company

'total equity + debt' being equivalent to the total balance of a company

A further source related to PCAF comprises of their methodology used to derive activity-based economic emission factors. Although this method uses another database (EXIOBASE instead of FIGARO), it is used to justify that the production 'output' in Input-/Output-Tables of a sector is equivalent to the total revenue and the total costs of companies in that sector (PCAF, 2023, p. 12).

¹ Not each line in the dataset can be considered to be a 'loan' in the technical sense, but will be treated as such.

² All models use NACE REV 2.0 as a main point of reference. Applying the models to a loan matching according to e.g. NACE REV 2.1 will therefore not lead to the same results. The main reason for that is that the internal matching of economic activities to underlying data as well as the resulting intensity factors relies on unambiguous relationships between different parts of the model. However, the model can and will be adapted to other classification schemes if the need for this arises.

2.1.3 Emission accounts by EUROSTAT

EUROSTAT provides data tables containing GHG emission accounts for 64 industries (according to NACE 2) and 32 European Countries. From this data, Scope 1 Emission for German Industries could be extracted easily. For scope 2 and 3 emission accounts need to be combined with IO-tables in the form of “GHG satellites accounts”. The IO-table provided by EUROSTAT (called FIGARO) covers 45 geographical entities (countries as well as regions), which means GHG emission accounts for the missing geographical entities need to be compiled from other sources. This has been done before by EUROSTAT to calculate country and industry specific carbon footprints (European Commission, 2024a). Although these values are not published directly, the resulting footprint values can be used to re-calculate GHG emission accounts for all 45 geographical entities (European Commission, 2024b).

2.1.4 Input-Output-Table by FIGARO

EUROSTAT publishes annual inter-country supply, use and input-output tables in the framework of the FIGARO (Full International and Global Accounts for Research in input-Output) project. These tables represent all domestic and international flows in NACE Rev. 2 classification (64*64 activities/products) and covers 45 countries (including the 27 EU Member States), plus a ‘rest of the world’ aggregate (EUROSTAT, 2024).

2.1.5 Physical emission intensity of energy systems

The emission intensity of energy systems in Germany is derived by data from UBA, which is the German Federal Environmental Agency. UBA regularly (annual reports) reports on the emission balance of renewable energy sources in Germany. The most recent report (as of development of the method in this documentation) refers to 2023 (Lauf et al., 2025) and includes emission factors for all renewable energy systems. These emission factors distinguish between upstream emissions, direct emissions and emissions from the use of auxiliary energy.

2.1.6 Physical emission intensity of agricultural production

The agricultural hybrid model relies on the GHG emission intensity of the German agricultural industry (in tons CO₂e per hectare) as well as an approximation of emission savings from organic farming compared to conventional practices (without animal products).

The first is derived from the generic emissions in the MRIO model, but relies on an approximation of the total cultivated area for organic and conventional farming based on data by the German association of organic food producers (BOELW, 2023). The latter (emission savings) is based on a 2019 study on the benefits of organic farming for the environment and society (Sanders & Heß, 2019).

2.1.7 Other data sources

Other data sources and methods are directly referenced throughout this document.

2.2 Approach

The goal of the work is to attribute each loan to the Scope 1, Scope 2 and Scope 3 emissions of the most appropriate approximation of each type of customer. This constitutes the Scope 3.15 emissions by GLS Bank, such that these three categories of emission could also be described as Scope-1_{3.15GLS}, Scope-2_{3.15GLS}, and Scope-3_{3.15GLS}. From here on out, the abbreviations of S1, S2, and S3 correspond to these categories.

To achieve this goal, we approach the problem by going from specificity to generality. That is, if and only if a loan cannot be attributed to the most specific and most robust intensity factor, a more generic intensity factor is selected. The final product thus applies to the following rules for each loan in the dataset in the following order (with the use of direct primary Corporate Carbon Footprint data by customers planned for future iterations of the method):

- Rule [1] If there is primary information on the S1/S2/S3 emissions of a customer, these emissions should be used as a data source and related to the total balance of this entity.
- Rule [2] If the specific purpose of a loan is known, if this purpose is expected to deviate from average German intensities, and if this purpose has been operationalized in this methodology, the specific and corresponding hybrid S1/S2/S3 emission intensities should be used.
- Rule [3] If the specific purpose of a loan is known, and this purpose deviates clearly from the attributed economic activity, the first takes precedence over the latter (e.g. purpose of building acquisition overruling the match to some economic sector).
- Rule [4] If none of the previous rules apply and if the economic activity of the customer is known, and if there is a corresponding generic intensity in the model, this GHG intensity should be selected for.
- Rule [5] All other loans are excluded for the calculation of the FCF.

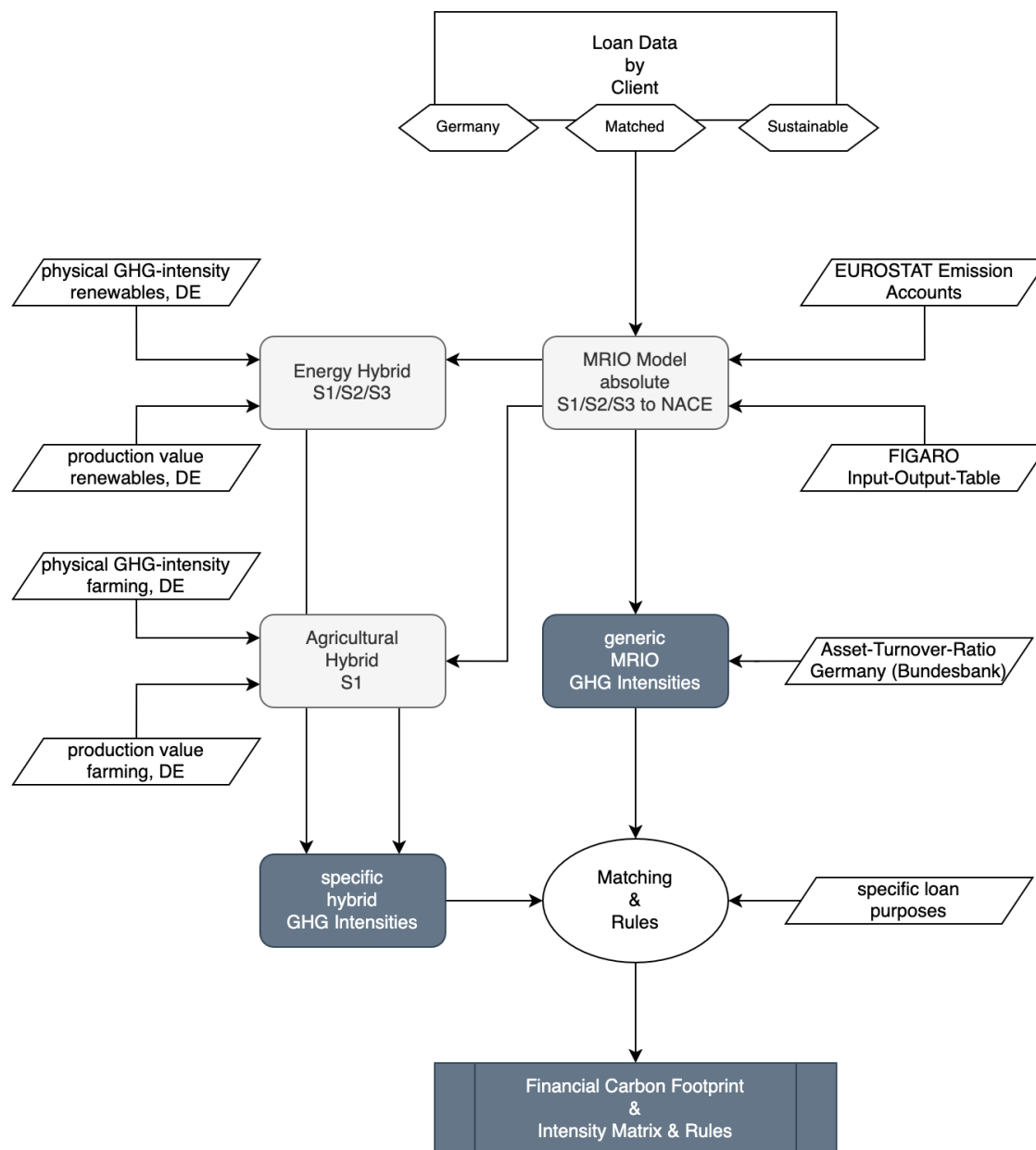
The following Figure 2-1 depicts the approach. It consists of

- the generic GHG-Intensities (S1/S2/S3) derived from a multi-regional-input-output model ('generic MRIO-model'),
- the specific GHG-intensities (S1/S2/S3) for the 'energy hybrid' derived from a bottom-up model for renewable energy production in Germany,
- the specific GHG-intensity (S1) for the 'agricultural hybrid' derived from a bottom-up model for conventional compared to organic farming in Germany,
- matching processes and rules,
- as well as additional data sources.

In this approach, the MRIO model is informed by annualized and reliable data from EUROSTAT and the European Commission (FIGARO). This data is then combined with economic statistics by the German Bundesbank to relate these absolute S1/S2/S3 emissions to the balance of companies according to NACE. The two hybrid models on the other hand rely on the absolute 'top-down' emissions from the MRIO-model, but apply a bottom-up approach and use additional data to derive the specific

intensities of renewable energy systems and organic farming (in line with the absolute values).

Figure 2-1: Components, Data and Steps for Financial Carbon Footprint (FCF) of GLS Bank loans



source: own compilation

3 MRIO Model and Intensities

3.1 MRIO Model (absolute S1/S2/S3 emissions)

The MRIO Model is based on the IO-table FIGARO (EUROSTAT, 2024) and GHG emission accounts for the respective 45 countries and 64 industries (European Commission, 2024a). With these tables the calculation of scope 1 and 2 emissions is comparably simple. The calculation of scope 3 emissions however, is more complex and can be tackled in different, but mathematically identical ways. In this study, Emissions for scope 3 are calculated according to a framework provided by the OECD (OECD, 2024), which replaces the methodology used in the previous study.

3.1.1 Emission factors and emission multipliers

IO-tables contain information on which sector provides good for another in terms of financial units. To link physical properties like GHG emissions to IO-tables, **emission factors** (EF) need to be derived. These factors reflect the amount of GHGs that are emitted (EM) within an industry (i) of a country (c) per gross output of that industry (X).

$$EF_{i,c} = \frac{EM_{i,c}}{X_{i,c}}$$

As result, EF is a vector of length 45 * 64 (number of countries times number of industries)

For the calculation of scope 1 emissions, emission factors are sufficient. For scope 2 and 3 the interconnectivity of the different industries needs to be regarded. This is done by creating an **emission multiplier**, which is defined as the matrix product of the diagonalised EF vector (as matrix) and the Leontief Inverse derived from the IO-table

$$B = (I - A)^{-1}$$

$$eB = \text{diag}(EF) B$$

As result, eB is a matrix with number of columns and number of rows being 45 * 64 (number of countries times number of industries)

3.1.2 Emissions according to GHG-P Scopes

Scope 1

For scope 1 emissions a simple multiplication of emission factors and gross output yields the emissions per industry (basically a recalculation).

$$\text{Scope } 1_{i,c} = EF_{i,c} X_{i,c}$$

Scope 2

Scope 2 emissions are calculated by multiplying the column of the emission multiplier, which refers to the electricity sector of the respective country ($eB_{e,c}$), with the intermediate transaction of domestic purchases of electricity by industry i of country c ($Z_{ei,cc}$).

$$Scope\ 2_{i,c} = u\ eB_{e,c} Z_{ei,cc}$$

The multiplier u is a row vector used to aggregate the column vector $eB_{e,c} Z_{ei,cc}$ into a scalar, representing total Scope 2 emissions associated with industry i in country c .

Scope 3

According to the former methodology, scope 3 emissions are calculated based on the transposed emission vector, the leonthief inverse, the intermediate input of industry i and country c ($v_{i,c}$) and the previous determined Scope 2 emissions (to account for double counting in the electricity sector).

$$Scope\ 3_{i,c} = EF^t(I - A)^{-1}v_{i,c} - Scope\ 2_{i,c}$$

This is mathematically identical to calculating Scope 3 emissions according to the OECD framework: Here, the column of the emission multiplier that corresponds to a certain industry is multiplied with the gross output of that industry and transformed into a scalar (with u) to reflect the sum of scope 1, 2 and 3 emissions. Subtracting scope 1 and 2 emissions then yields scope 3 emissions.

$$Scope\ 3_{i,c} = u\ eB_{i,c}X_{i,c} - Scope\ 1_{i,c} - Scope\ 2_{i,c}$$

3.2 Generic MRIO GHG intensities (relative S1/S2/S3 emissions)

Based on the formulas presented in 3.1, generic GHG emissions for scope 1, 2 and 3 were calculated for 64 industries in Germany. These emissions now need to be related to investments in a specific industry, by looking at the amount of invested capital and the total amount of capital in assets. The latter can be calculated from asset turnover ratios (ATR), which are defined as quotient of the revenue of a company or industry (R_i) and the amount of total assets in that company or industry (A_i).

$$ATR_i = \frac{R_i}{A_i}$$

Within the PCAF methodology for emission factors (PCAF, 2023), revenue and gross output of an industry are treated equally. Thus, we can formulate:

$$A_i = \frac{X_i}{ATR_i}$$

The gross output is given in the IO-tables. ATR values for each of the 64 industries in Germany were taken from data by the German central bank 'Deutsche Bundesbank' (Deutsche Bundesbank, 2024).

The amount of GHG emissions (Scope 1, 2 and 3), which are allocated to a loan volume of 1 EURm to a specific German industry (representing the generic GHG intensity of loans in this industry) is then calculated as:

$$GHG\ intensity_{Scope\ 1,i,D} = \frac{1}{A_{i,D}} * Scope\ 1_{i,D}$$

$$GHG\ intensity_{Scope\ 2,i,D} = \frac{1}{A_{i,D}} * Scope\ 2_{i,D}$$

$$GHG\ intensity_{Scope\ 3,i,D} = \frac{1}{A_{i,D}} * Scope\ 3_{i,D}$$

These GHG intensities are shown in the Appendix.

4 Hybrid Models

4.1 Renewable Energies

The first step (1) of the hybrid model for 'renewable energies' is to derive the absolute emissions of the energy sector in Germany from the MRIO Model, (2) the production value of this sector and (3) relate these emissions to the total electricity and heat production in Germany. The gross electricity production is drawn from the German Statistical Office and provided by 'Arbeitsgemeinschaft Energiebilanzen' (514.6 TWh in 2023³) (AGEB, 2024). The net heat production (171.5 TWh in 2022) is from the German Statistical Office as well (DESTATIS, 2024).

AGEB (2024) also further differentiates between different energy sources for electricity production, including

- wind power,
- water power,
- biomass,
- photovoltaics,
- geothermal energy.

For heat production, DESTATIS (2024) also further differentiates between different energy sources for net heat productions, including

- biogenic fuels
- biogas
- waste

In order to associate the energy production with the production value of each energy source (step 4), such values on the production value of the energy-economy in Germany were drawn from a recent study by GWS and DLR (O'Sullivan et al., 2023). The results from step 1 to step 4 thus results in a coherent mapping of economic value for each renewable energy carrier to its related physical energy production.

For the final two steps, an empirical relationship to the GHG intensities of these energy carriers had to be established (5) and related to the Scopes of the GHG Protocol (6). We used the most recent data by the annual report on the emission balance of renewables in Germany by the German Federal Environmental Agency UBA (Lauf et al., 2025) and attributed these physical emission intensities according to the following rules:

Rule [1] If more than one type of energy production technology matches the energy source, the most common one is used.

³ This value has changed this it was first sourced from 514.6 to 511.3 TWh.

Rule [2] Scope 1 emission directly map to the direct emissions in Lauf et. al, 2025

Rule [3] Scope 2 emission directly map to the emission from auxiliary energy (German, "Hilfsenergie")

Rule [4] Scope 3 emission comprise of the reminder of indirect emissions.

The following equation summarizes the calculation procedure for the GHG intensity in the hybrid model for energy for one particular energy carrier and one particular scope in the GHG protocol (GHG-I_{e,S}):

$$GHG - I_{e,S} = ghg_{e,S} \times \frac{E_e}{p_e \times P_{MRIO}} \text{ in [t CO2e / Million EUR]}$$

with

GHG-I _{e,S} :	economic GHG-intensity of energy source (e) over Scope (S)
ghg _{e,S} :	physical, relative GHG-intensity of e for S in [g CO2e/kWh]
E _{e,S} :	Energy production in given year for e in [kWh]
p _{e,S} :	share of production value of e in [%]
P _{MRIO} :	production value of energy sector in NACE D from MRIO Model in [EUR]

Limitations of this approach are manifold. Firstly, not all annual data precisely matches each of the other related annualized datapoints. Secondly, there is always some mismatch between emissions from net heat production and gross GHG emissions that includes combined heat and power plants. Thirdly, metrics in input-output-tables can deviate from statistical metrics such as production output and any error deviation in the MRIO-model also translates to the hybrid model. Fourthly, physical accounts of emissions from energy power plants in a territorial view do not map directly onto the scopes of the GHG protocol in a corporate view. Any error from attribution rules thus proliferates to the final results as well.

However, we are convinced that, even in light of these significant limitations, such a model still provides a more accurate account of the emissions induced by the GLS clients that put loans to the purpose of renewable energy production than the generic MRIO intensities that entails the entire German energy sector and thus all fossil-fuelled energy sources.

4.2 Organic Farming

The first step (1) of the hybrid model for 'organic agriculture' is to derive the absolute emissions of the agricultural sector in Germany from the MRIO Model (NACE A01), (2) to derive the revenues of conventional and organic agricultural products in Germany and to (3) relate these emissions and sales revenues to the area that these products require from plant and animal products. The final step (4) then connects differences in GHG intensities between organic and conventional farming to these areas and these back to revenues and turnover in the industries. As a result, it can be estimated by how much the total direct emissions (S1) of a 100% organic production differs from the total in both types of production.

The shares of revenues (organic versus conventional) are first drawn from BOELW, (2023) (93.5% conventional; 6.5% organic), and then scaled to the total sales revenues in Germany according to the Federal Ministry of Food and Agriculture (60.12 bnEUR in 2024 according to BMEL, (2024)).

Production values per hectare and product type (animal; plant) are derived from BOELW, (2023) as well in regard to sales revenues in these four types of industries (each product from conventional and organic production). This in turn, allows to estimate the total area needed for that turnover in each category.

For differences in GHG emissions per area and product, we rely on a study by Sanders & Heß, (2019). As this value (reduction of 1.082 tons of CO₂e per hectare) only accounts for organic plant production, any estimated saving is limited to plant production in Germany as well. Thus, animal production is not treated differently and thus does not contribute to either higher or lower GHG emissions in the hybrid model.

The final step then involves the estimation of the total area in use for all four categories, and then comparing the two cases of a 100% production with conventional means and a 100% production with organic means for plants only. The following Table shows the results of this calculation. It follows that S1 Emissions of loans in the GLS BANK loan programmes for the purpose of organic agriculture are expected to be 21.4% lower compared to loans to companies with conventional methods.

Table 4-1: key results from hybrid model for 'organic agriculture'

Case (differences limited to plant production)	Cultivated Area (on the basis of total sales revenue in DE)	GHG emissions (on the basis of GHG-intensity differences and total S1 emissions)
Base-Case MRIO, combined production Germany	-	62.5 million t CO ₂ e
Case 1 100% conventional production Germany	40.24 million ha	64.1 million t CO ₂ e
Case 2 100% organic production	40.19 million ha	50.4 million t CO ₂ e

source: own calculation

5 Limitations

The limitations of the methodology can be divided into two types:

- (1) general limitations from estimates and
- (2) specific limitations from calculation conventions, assumptions, data and premisses.

Ad (1): Any method that tries to derive an estimate of the emissions of a company will lack accuracy and robustness by definition. This general limitation applies to all methods, but does not affect every method to the same degree. The most accurate Financial Carbon Footprint would stem from Corporate Carbon Footprints calculations of each borrower, that are external reviewed by experts and that apply the same consistent set of rules and emission factors. The next best approximation would then be a data-set that relies on estimates, simplifications or differences in calculation rules, but still relies on primary input data by these companies. This is something the client GLS BANK is currently in the process of capturing, but could not finalize in due course for the current FCF calculations. However, this means that any method that deviates from this best-practice is necessarily less accurate, and less accurate to a unknown degree. Since the majority of values in the current data rely on MRIO-model data, and since such an approach requires additional data from matching, statistics, and input-output-tables, the accuracy and robustness of the results are severely limited. Moreover, we can further assume that such an approach will likely overestimate emissions if the majority of clients do not represent the 'conventional' average in terms of energy-use or production practises. Our approach thus increases this accuracy (since it accounts for some of the borrower-specific factors), but cannot be considered to lie 'in the middle' between these two extremes. Rather, the overall limitations from the MRIO-models are merely less severe or more moderate for loans that are covered by the two hybrid models.

Ad (2): As to the specific limitations, there are several factors that affect the severity of them. First and foremost, any type of matching will inevitably have effects on the results. That is, each loan that could be matched to a more specific economic activity financed, but was not matched due to other constraints (e.g. from the low granularity of the underlying emission statistics), represents a limitation in terms of accuracy. The same is true for loans that have the potential to be represented more accurately in terms of loan-purpose rather than receiving industry, but could not be matched thus due to lack of data on the side of the lending bank.

More moderate, but still strong limitations, stem from the data used and conventions applied in the two hybrid models. Since there are no direct, and verified, accounts of the economic-physical relationships between the activities and their emissions (e.g. producing renewable electricity), such relationships had to be modelled first on the basis of different types of data sources and sometimes referring to different timelines. Each and every assumption, or premise, in this context therefore affects the robustness of the results to an unknown degree. This is true of the models as a whole, but also true to differences within the models. For example, it is easier to model the economic-physical relationship for renewable electricity production and consumption than for heat production, conversion and use.

6 Bibliography

- AGEB. (2024, March 7). *Bruttostromerzeugung in Deutschland*. Statistisches Bundesamt. <https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Energie/Erzeugung/Tabellen/bruttostromerzeugung.html>
- BMEL. (2024). *117. Wertschöpfung der Landwirtschaft* [Dataset]. <https://www.bmel-statistik.de/fileadmin/daten/3130500-0000.xlsx>
- BOELW. (2023, February). *BRANCHEN REPORT 2023 Ökologische Lebensmittelwirtschaft*. https://www.boelw.de/fileadmin/user_upload/Dokumente/Zahlen_und_Fakten/Broschuere_2023/BOELW_Branchenreport2023.pdf
- DESTATIS. (2024, February 2). *Elektrizitäts- und Wärmeerzeugung nach Energieträgern*. Statistisches Bundesamt. <https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Energie/Erzeugung/Tabellen/kw-insgesamt.html>
- Deutsche Bundesbank. (2024, May). *Financial statement statistics: I. Enterprises by economic sector*. <https://www.bundesbank.de/resource/blob/830056/d45943678af734f930bfdbao186d806b/472B63F073F071307366337C94F8C870/ua3e0001-data.pdf>
- European Commission. (2024a). *FIGARO – Greenhouse gas emission estimates*. EUROSTAT. https://ec.europa.eu/eurostat/documents/1798247/6191529/Methodological+Note_GHG_estimates_FIGARO_21_June_2024.pdf/b23da1a7-d8bb-6834-0608-7fc9bb293ddc?t=1719303162181
- European Commission. (2024b). *Reference metadata Greenhouse gas emission footprints (in CO₂ equivalent, FIGARO application) (env_ac_ghgfp)*. https://ec.europa.eu/eurostat/cache/metadata/en/env_ac_ghgfp_esms.htm
- EUROSTAT. (2024). *FIGARO tables (2024 edition): Annual EU inter-country supply, use and input-output tables* [Dataset]. <https://ec.europa.eu/eurostat/web/esa-supply-use-input-tables/database>
- Lauf, T., Memmler, M., & Schneider, S. (2025). *Emissionsbilanz erneuerbarer Energieträger 2023* (p. 173). Umweltbundesamt. <https://doi.org/10.60810/OPENUMWELT-7687>
- OECD. (2024). *Measuring greenhouse gas footprints in global production networks: New perspectives on emissions embodied in production chains*

and final demand patterns. OECD.

file:///Users/christian.buschbeck/Downloads/fc426ab9-en%20(2).pdf

O’Sullivan, M., Eschmann, J., Edler, D., & Ulrich, P. (2023). *Ökonomische Indikatoren des Energiesystems – Produktion, Investitionen und Beschäftigung*. <https://papers.gws-os.com/gws-researchreport23-4.pdf>

PCAF. (2022). *The Global GHG Accounting and Reporting Standard for the Financial Industry*.
<https://carbonaccountingfinancials.com/files/downloads/PCAF-Global-GHG-Standard.pdf>

PCAF. (2023, January). *Further information on EXIOBASE data Database methodology*.

Sanders, J., & Heß, J. (Eds.). (2019). *Leistungen des ökologischen Landbaus für Umwelt und Gesellschaft [2. Überarbeitete und ergänzte Auflage]*. Johann Heinrich von Thünen-Institut. <https://doi.org/10.3220/REP1576488624000>

7 Appendix

7.1 GHG-Intensities from energy hybrid model

Table 7-1: GHG emission factors for 1 million EURO loan

Energy source service	Scope 1 [t CO ₂ e/mEUR]	Scope 2 [t CO ₂ e/mEUR]	Scope 3 [t CO ₂ e/mEUR]
photovoltaics	0.0	1.1	141.6
wind energy	0.0	2.3	43.5
biogas	128.9	15.0	291.9
biomass (wood)	0.0	29.8	36.1
water power	0.0	0.0	6.7
solar thermal	0.0	36.5	52.3
energy provider	30.4	0.0	117.0

source: own calculation based on model described in section 4.1

7.2 Generic MRIO emission intensities

The following Table shows the generic emission intensities (GHG-I) for the available NACE-codes. Since some NACE categories in the original data source comprised of more than one NACE category on the same level, each sub-set is attributed with the same intensity in these cases.

Table 7-2: Generic GHG-Intensities from MRIO Model

NACE	GHG-I Scope 1 [t CO ₂ e/mEUR]	GHG-I Scope 2 [t CO ₂ e/mEUR]	GHG-I Scope 3 [t CO ₂ e/mEUR]
A01	281.1	9.5	68.2
A02	42.4	1.4	91.5
A03	46.6	14.5	63.9
B	297.6	44.6	158.9
C10	98.4	52.0	1,048.9
C11	98.4	52.0	1,048.9
C12	98.4	52.0	1,048.9
C13	106.1	79.5	437.5
C14	106.1	79.5	437.5
C15	106.1	79.5	437.5
C16	18.8	39.6	260.0
C17	256.5	94.8	361.1
C18	18.7	21.6	128.0
C19	1,142.9	106.6	1,247.7
C20	77.6	18.6	144.9
C21	25.8	23.8	279.8

NACE	GHG-I Scope 1 [t CO₂e/mEUR]	GHG-I Scope 2 [t CO₂e/mEUR]	GHG-I Scope 3 [t CO₂e/mEUR]
C22	19.4	40.4	320.9
C23	1,009.5	119.5	450.2
C24	548.2	107.3	768.2
C25	8.2	14.0	148.0
C26	7.7	11.6	155.7
C27	7.1	21.4	249.8
C28	6.0	9.8	170.7
C29	11.0	10.1	195.2
C30	13.4	12.3	373.6
C31	21.4	29.2	351.6
C32	21.4	29.2	351.6
C33	9.5	18.5	360.7
D	716.8	181.9	80.5
E36	4.4	177.7	87.6
E37	117.1	13.3	140.9
E38	117.1	13.3	140.9
E39	117.1	13.3	140.9
F	11.4	11.6	144.6
G45	27.4	51.5	293.4
G46	47.3	53.7	353.2
G47	18.8	27.6	61.0
H49	100.2	51.6	140.1
H50	709.1	1.8	484.8
H51	593.1	0.6	305.0
H52	46.0	10.3	172.1
H53	30.2	11.5	89.7
I	23.9	33.6	124.9
J58	1.8	6.1	60.1
J59	1.0	6.5	42.8
J60	1.0	6.5	42.8
J61	5.3	18.9	69.5
J62	1.9	3.3	29.4
J63	1.9	3.3	29.4
K64	3.0	8.9	47.8
K65	3.0	6.0	66.8
K66	1.7	7.7	74.4
L	1.0	6.7	52.0
M69	7.3	6.5	36.4
M70	7.3	6.5	36.4

NACE	GHG-I Scope 1 [t CO₂e/mEUR]	GHG-I Scope 2 [t CO₂e/mEUR]	GHG-I Scope 3 [t CO₂e/mEUR]
M71	5.2	10.0	41.1
M72	3.1	27.3	213.6
M73	4.6	4.6	44.5
M74	5.5	11.6	62.1
M75	5.5	11.6	62.1
N77	12.9	35.9	231.2
N78	4.1	2.3	28.0
N79	48.9	6.5	1,051.1
N80	9.0	25.5	148.3
N81	9.0	25.5	148.3
N82	9.0	25.5	148.3
O	10.1	15.8	79.1
P	14.6	13.6	35.0
Q86	11.1	24.0	77.1
Q87	15.0	29.4	88.2
Q88	15.0	29.4	88.2
R90	1.5	7.4	26.8
R91	1.5	7.4	26.8
R92	1.5	7.4	26.8

source: own calculation based on methods described in section 3

7.3 MRIO Script (see following pages)

GLS-CF-Dokumentation

2025-01-02

Diese Dokumentation beschreibt das vorgehen, mit dem generische Werte für den carbon footprint unterschiedlicher deutscher Wirtschaftszweige (nach NACE Kategorie) ermittelt werden können. Dazu werden hauptsächlich Eurostat- und FIGARO Tabellen verwendet und mit R verarbeitet. Die Emissionen sind nach Scope 1, 2 und 3 aufgeteilt.

Pakete und Daten einladen

```
require(stringr)      # Für String-manipulationen
require(exvatoools)    # Für MRIO Berechnung (Scope 3)
library(eurostat)      # Zum Importieren von eurostat Daten
library(readxl)        # Zum Importieren von Excel Tabellen

# Pfad des Scripts um die Pfade zu den Files zu verkürzen
path <- str_split(rstudioapi::getSourceEditorContext()$path,"02 CALCULATION")[[1]][1]

# Die Eurostat Tabellen werden mit der Funktion get_eurostat importiert
estat_air_em <- get_eurostat("env_ac_ainah_r2", time_format = "num") # Luftemissionen
estat_energy <- get_eurostat("env_ac_pegasu", time_format = "num")   # Energieaufwand
bip <- get_eurostat("nama_10_a64", time_format = "num")              # Volkswirtschaftliche Gesamtrechnung

# Die FIGARO Tabelle wird mithilfe der make_wio funktion importiert
wio_p <- make_wio(wiotype="figaro2024p",
                  year = 2022,
                  src_dir=paste(path,"01 INPUT",sep=""))

# Die FIGARO Tabelle wird ebenfalls als csv eingeladen
io_raw <- read.csv(paste(path,"/01 INPUT/matrix_eu-ic-io_prod-by-prod_24ed_2022.csv",sep=""))

save.image(paste(path,"/02 CALCULATION/Rdata/tables.Rdata",sep=""))
```

Scope 1

Die Scope 1 Emissionen können einfach aus der Eurostat Tabelle für Luftemissionen (Tabellenname: env_ac_ainah_r2) ausgelesen werden.

```
scope_1 <- as.data.frame(subset(estat_air_em, # Die Tabelle wird gefiltert nach:
                               airpol=="GHG" # Treibhausgasen
                               & geo == "DE" # Deutschland als Geographie
                               & unit == "T" # Tonnen als einheit
                               & TIME_PERIOD == 2022)[c("nace_r2","values")])

colnames(scope_1) <- c("NACE","CF [t CO2-eq.]")
```

Scope 2

Um die Scope 2 Emissionen zu berechnen, wird neben den Luftemissionen auch eine Eurostat Tabelle zum Aufkommen und der Verwendung von Energie verwendet (Tabellenname: env_ac_pegasu). Die Berechnung folgt der Formel: $T_{Scope2,j,c,n} = \frac{T_{Scope1,j,c,D35}}{E_{SUP,j,c,D35}} * E_{USE,j,c,D35}$ wobei j das Jahr, c das Land und n den Wirtschaftszweig nach NACE Kategorie angibt.

```

scope_2 <- scope_1
scope_2$`CF [t C02-eq.]` <- numeric(nrow(scope_2))

for(n in scope_2$NACE){
  print(n)

  T_scope_1_DE_D35 <- subset(estat_air_em,      # Die Tabelle wird gefiltert nach;
                             airpol == "GHG"    # Treibhausgasen
                             & geo == "DE"      # Deutschland als Geographie
                             & unit == "T"      # Tonnen als Einheit
                             & TIME_PERIOD == 2022 # 2022 als Jahr
                             & nace_r2 == "D")  # Deutschland als Geographie

  E_use_DE_n <- subset(estat_energy,          # Die Tabelle wird gefiltert nach:
                       stk_flow == "USE"      # Verwendung der Energie
                       & geo == "DE"         # Deutschland als Geographie
                       & is.element(prod_nrg,c("P26","P27")) # Energieträger
                       & TIME_PERIOD == 2022 # 2022 als Jahr
                       & nace_r2 == n)       # NACE Kategorie

  E_sup_DE_D35 <- subset(estat_energy,        # Die Tabelle wird gefiltert nach:
                         stk_flow == "SUP"    # Aufkommen der Energie
                         & geo == "DE"       # Deutschland als Geographie
                         & is.element(prod_nrg,c("P26","P27")) # Energieträger
                         & TIME_PERIOD == 2022 # 2022 als Jahr
                         & nace_r2 == "D")   # NACE Kategorie

  # Berechnung nach obiger Formel
  T_scope_2_DE <- (T_scope_1_DE_D35$values / sum(E_sup_DE_D35$values)) * sum(E_use_DE_n$values)

  # Speichern im data frame
  NACE_idx <- which(scope_2$NACE == n)
  scope_2[NACE_idx,"CF [t C02-eq.]"] <- as.numeric(T_scope_2_DE)
}

```

Scope 3

Um die Scope 3 Emissionen zu berechnen, werden die Eurostat Tabellen für Luftemissionen, die Volkswirtschaftliche Gesamtrechnung, und die Input-Output Tabelle FIGARO verwendet. Alle drei wurde oben schon importiert. Beim Import der FIGARO tabelle erstellt das Paket exvatools direkt verschiedene Matrizen, sodass die benötigten lediglich ausgewählt werden müssen.

```

L <- wio_p$B # Leonthief inverse bzw. L-Matrix wird extrahiert
Z <- wio_p$Z # Die Z-Matrix wird extrahiert

```

Mapping

Leider ändert das Paket exvatools beim Import die Namen der NACE Kategorien und Geographien. Bevor also Berechnungen vorgenommen werden können, müssen die Namen der NACE Kategorien und Geographien gemappt werden. Dafür werden zwei data frames erstellt, die jeweils das NACE- bzw. Geographien-mapping enthalten.

```

# NACE Mapping

# Zunächst werden drei character Vektoren erstellt.
# 1. NACE Kategorien wie sie in den Eurostat Tabellen vorkommen
# 2. Die Namen nach dem Import durch exvatoools
# 3. Die Namen der original FIGARO Tabelle
NACE      <- unique(estat_air_em$nace_r2)
exva      <- colnames(Z)[which(str_detect(colnames(Z),"DEU"))]
figaro_names <- colnames(io_raw)[which(str_detect(colnames(io_raw),"DE"))][1:64]

# Ein data frame, für das Mapping wird erstellt
mapping_exva_NACE <- data.frame("NACE"      = NACE,
                                "exva"      = character(length(NACE)),
                                "figaro_names" = character(length(NACE)))

# Die Namen der original Figaro Tabelle werden in mehreren Schritten so manipuliert,
# dass sie den NACE Kategorien gleichen. In einem nächsten Schritt wird dann der Ursprüngliche
# Name mit der entsprechenden NACE Kategorie gematcht.
for(n in 1:nrow(mapping_exva_NACE)){

  figaro_names_str <- str_remove_all(figaro_names,"DE_CPA_")

  figaro_names_str <- str_replace_all(figaro_names_str,"C10T12", "C10-C12")
  figaro_names_str <- str_replace_all(figaro_names_str,"C13T15", "C13-C15")
  figaro_names_str <- str_replace_all(figaro_names_str,"E37T39", "E37-E39")
  figaro_names_str <- str_replace_all(figaro_names_str,"C31_32", "C31_C32")
  figaro_names_str <- str_replace_all(figaro_names_str,"J59_60", "J59_J60")
  figaro_names_str <- str_replace_all(figaro_names_str,"J62_63", "J62_J63")
  figaro_names_str <- str_replace_all(figaro_names_str,"M74_75", "M74_M75")
  figaro_names_str <- str_replace_all(figaro_names_str,"M69_70", "M69_M70")
  figaro_names_str <- str_replace_all(figaro_names_str,"N80T82", "N80-N82")
  figaro_names_str <- str_replace_all(figaro_names_str,"Q87_88", "Q87_Q88")
  figaro_names_str <- str_replace_all(figaro_names_str,"R90T92", "R90-R92")

  figaro_names_str <- str_replace_all(figaro_names_str,"D35", "D")
  figaro_names_str <- str_replace_all(figaro_names_str,"084", "O")
  figaro_names_str <- str_replace_all(figaro_names_str,"P85", "P")

  idx <- which(figaro_names_str == mapping_exva_NACE[n,"NACE"])

  if(length(idx)>0){

    mapping_exva_NACE[n,"exva"]      <- exva[idx]
    mapping_exva_NACE[n,"figaro_names"] <- figaro_names[idx]
  }
}

# Im mapping data frame sind nur die Namen der Wirtschaftszweige, ohne die Länderbezeichnung
# abgespeichert
mapping_exva_NACE$exva      <- str_remove_all(mapping_exva_NACE$exva,"DEU_")
mapping_exva_NACE$figaro_names <- str_remove_all(mapping_exva_NACE$figaro_names,"DE_")

# Geographie Mapping
geo_io_raw <- NULL
for(i in 1:length(colnames(io_raw))){
  print(i)
  nam = colnames(io_raw)[i]
  if(nam == "rowLabels")next
  geog = str_split(nam,"_")[[1]][1]
  geo_io_raw <- unique(c(geo_io_raw,geog))
}

geo_io_exva <- NULL
for(i in 1:length(colnames(Z))){
  print(i)
  nam = colnames(Z)[i]
  geog = str_split(nam,"_")[[1]][1]
  geo_io_exva <- unique(c(geo_io_exva,geog))
}

geography_mapping <- data.frame("io_raw"=geo_io_raw,
                                "exva"=geo_io_exva)

```

Um die Scope 3 Emissionen der unterschiedlichen Wirtschaftszweige in Deutschland zu berechnen, werden die indirekten Emissionen nach folgender Formel bestimmt:

$$T_{indirect,j,c,n} = e^t(1 - A)^{-1} * v$$

wobei j das Jahr, c das Land und n den Wirtschaftszweig nach NACE Kategorie angibt. Wie die einzelnen Bestandteile dieser Formel bestimmt werden, wird im Folgenden beschrieben.

Leonthief Inverse

Das Leonthief Inverse $(1 - A)^{-1}$ haben wir oben bereits extrahiert (L-Matrix).

Vektor e

Die FIGARO Tabelle enthält lediglich monetäre Einträge, sodass ein Bezug von eingesetztem Geld und THG-Emissionen mithilfe von sog. Satellitenkonten hergestellt werden muss. Dies wird durch den Vektor e realisiert, der aus den Scope1 THG-Emissionen pro Produktionswert des jeweiligen Wirtschaftszweigs ($\frac{T_{Scope1,j,d,m}}{P_{j,d,m}}$) besteht. Die Werte für e werden mithilfe der Tabelle für Luftemissionen und der Tabelle für die Volkswirtschaftliche Gesamtrechnung (Tabellenname: nama_10_a64) bestimmt.

```
e_vec <- numeric(length(colnames(Z)))

for(i in 1:length(colnames(Z))){
  print(i)
  nam      = colnames(Z)[i]

  # Extrahieren der Geographie aus dem Mapping
  geog_exva = str_split(nam,"_")[[1]][1]
  geog_raw  = geography_mapping[which(geography_mapping$exva==geog_exva),"io_raw"]

  # Extrahieren der NACE Kategorie aus dem Mapping
  sec  = str_split(nam,"_")[[1]][2]
  nace = mapping_exva_NACE$NACE[which(mapping_exva_NACE$exva == sec)]

  # Bestimmung der Scope 1 Emissionen
  e = subset(estat_air_em,                # Die Tabelle wird gefiltert nach:
             nace_r2 == nace              # NACE Kategorie
             & airpol=="GHG"             # Treibhausgase
             & geo == geog_raw           # Geographie
             & unit == "T"               # Tonnen als Einheit
             & TIME_PERIOD == 2022)$values # Das Jahr 2022

  # Bestimmung des Produktionswertes
  p = subset(bip,                        # Die Tabelle wird gefiltert nach:
             nace_r2 == nace             # NACE Kategorie
             & na_item == "P1"          # Produktionswert
             & geo == geog_raw          # Geographie
             & unit == "CP_MEUR"        # Preis in Mio Euro als Einheit
             & TIME_PERIOD == 2022)$values # Das Jahr 2022

  # Falls der Quotient aus Emissionen und Produktionswert gebildet werden kann, wird er gespeichert
  if(length(e)==1 & length(p)==1 & p>0 ){e_vec[i] <- e/p}else{e_vec[i] <- 0}
}

save(e_vec,file=paste(path,"/02_CALCULATION/Rdata/e_vec.Rdata",sep=""))
```

Vektor v

Der Vektor v enthält für jeden Wirtschaftszweig die Vorleistungen der entsprechenden anderen Wirtschaftszweige. Er kann für jeden Wirtschaftszweig direkt aus der Z matrix entnommen werden, da die Spalten der Z Matrix jeweils die direkten Vorleistungen der anderen Wirtschaftszweige beschreiben.

Berechnung

```

scope_3 <- scope_1
scope_3$`CF [t C02-eq.]` <- numeric(nrow(scope_3))

# Filtern jener Spalten bzw. Reihen, die Deutsche Wirtschaftszweige abbilden
sektor_idx <- which(str_detect(colnames(Z), "DEU"))
# Filtern jener Spalten bzw. Reihen, die den Energiesektor abbilden (alle Länder)
energy_idx <- which(str_detect(colnames(Z), "_35"))

for(i in 1:length(sektor_idx)){

  # Der v Vektor wird extrahiert
  v_vec = Z[,sektor_idx[i]]

  # Die indirekten Emissionen werden nach obiger Formel berechnet
  # Der Operator %*% stellt eine Matrixmultiplikation dar
  # Die Funktion t() transponiert den Vektor e
  T_indirect = t(e_vec) %*% L %*% v_vec
  T_indirect = as.numeric(T_indirect)

  # Ein vektor k, wird extrahiert (als alternativer vektor v)
  k = Z[,sektor_idx[i]]
  # Alle einträge von k, die nicht zum Energiesektor gehören, werden auf 0 gesetzt
  k[which(is.element(c(1:nrow(Z)),energy_idx)==F)] <- 0

  # Die Emissionen der Energiesektoren werden bestimmt
  T_energy = t(e_vec) %*% v_vec
  T_energy = as.numeric(T_energy)

  SC3_em = T_indirect - T_energy
  NACE_idx = which(paste("DEU_",mapping_exva_NACE$exva,sep="")==colnames(Z)[sektor_idx[i]])
  NACE_kat = mapping_exva_NACE[NACE_idx,"NACE"]

  scope_3[i,"NACE"] <- NACE_kat
  scope_3[i,"CF [t C02-eq.]"] <- SC3_em
}
rownames(scope_3) <- NULL
head(scope_3)

```

```

##      NACE CF [t C02-eq.]
## 1    A01    5970760.99
## 2    A02    646497.27
## 3    A03     50830.79
## 4      B    1444524.71
## 5 C10-C12   34088949.25
## 6 C13-C15    2260318.30

```

Loading [MathJax]/jax/output/HTML-CSS/fonts/TeX/fontdata.js