1 Illustrative Application of the Input-Output Model

Following the formal derivation of the environmentally extended input-output (EEIO) model, this section presents an illustrative application of the framework to household carbon footprint estimation. The aim is to operationalize the Leontief-based formulation:

$$\mathbf{E} = \mathbf{C}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{F}$$

where $\mathbf{F}$ denotes the final demand vector, here represented by annual household consumption expenditure by category; $(\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief inverse, capturing direct and indirect production requirements to satisfy $\mathbf{F}$; $\mathbf{C}$ is the vector of direct emission intensities (kg CO_2e per unit output).

In this illustration, pre-calculated environmentally extended emission intensities (kg CO_2e per euro spent) are applied to household consumption data for France, Spain, and Germany for 2021. These intensities represent the aggregated effect of $\mathbf{C}(\mathbf{I} - \mathbf{A})^{-1}$ and are derived from the EXIOBASE multi-regional input-output (MRIO) model, as accessed via Climatiq.io. The method aligns with the tier-3 comprehensive accounting approach discussed in Matthews et al. (2008), Long et al. (2019), and Sheng et al. (2024).

1.1 Data and Methodology

Household final consumption expenditure data were obtained from Eurostat and supplementary sources, converted to euros at the 2021 average exchange rate (1 USD = 0.85 EUR). Table 1 summarizes the emission intensities applied.

Table 1: Spend-Based Emission Factors (EXIOBASE via Climatiq.io)

Category	**Emission Factor (kgCO_2e/€)**
Housing, water, electricity, gas	0.30
Food and non-alcoholic beverages	0.48
Transport	0.40
Other goods and services	0.18
Recreation and culture	0.20
Restaurants and hotels	0.45
Furnishings and household equipment	0.25
Health	0.20
Alcoholic beverages and tobacco	0.42
Clothing and footwear	0.25
Communications	0.15
Education	0.15

For each country c, and for each category i, the household carbon footprint is calculated as:

$$E_{i,c} = F_{i,c} \cdot EF_i$$

where:

- $F_{i,c}$ is the household expenditure in euros for category i in country c;
- EF_i is the spend-based emission factor for category i;
- $E_{i,c}$ is the resulting emissions (kg CO_2e).

1.2 Explicit Calculation Example

For France, the household expenditure on food and non-alcoholic beverages is:

$$F_{\text{food,FR}} = 1.322 \times 10^9 \cdot 0.139 = 183.8 \times 10^9 \text{ EUR}$$

The corresponding emissions are:

$$E_{\text{food,FR}} = 183.8 \times 10^9 \cdot 0.48 = 88.2 \times 10^6 \text{ tonnes } CO_2e$$

Analogously, calculations are performed for all categories and countries.

1.3 Results

Table 2: Estimated Household Carbon Footprints by Category (Million Tonnes CO_2e)

Category	**France**	**Spain**	**Germany**
Housing, water, electricity, gas	109.5	50.4	137.3
Food and non-alcoholic beverages	88.2	47.1	100.7
Transport	66.6	30.4	94.1
Other goods and services	29.8	12.8	42.3
Recreation and culture	20.4	9.1	34.1
Restaurants and hotels	37.3	37.3	32.3
Furnishings and household equipment	16.2	8.5	31.4
Health	11.1	6.1	20.1
Alcoholic beverages and tobacco	22.8	12.8	27.1
Clothing and footwear	10.9	6.0	17.1
Communications	5.0	2.8	6.2
Education	1.0	1.5	2.2
Total	**419.0**	**223.0**	**544.9**

1.4 Discussion

This illustration demonstrates how the IO model framework, when combined with spend-based emission intensities, yields a comprehensive household carbon footprint that captures both direct and indirect emissions. The method is widely applied due to its ability to integrate complex supply chain interactions, incorporate international trade adjustments

(Long et al. 2019), and support policy-relevant analyses of consumption-based emissions (Matthews et al. 2008; Sheng et al. 2024).

Table 3: Household Expenditure Share by Category (% of Total, 2021)

Category	**France**	**Spain**	**Germany**
Housing, water, electricity, gas	27.6	24.3	25.5
Food and non-alcoholic beverages	13.9	14.2	11.7
Transport	12.6	11.0	13.1
Other goods and services	12.5	10.3	13.1
Recreation and culture	7.7	6.6	9.5
Restaurants and hotels	6.2	12.0	4.0
Furnishings, household equipment	4.9	4.9	7.0
Health	4.2	4.4	5.6
Alcoholic beverages, tobacco	4.1	4.4	3.6
Clothing and footwear	3.3	3.5	3.8
Communications	2.5	2.7	2.3
Education	0.5	1.4	0.8