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Outsourcing Decarbonization? How Trade Shaped France's Carbon Footprint (2000–14)

Pierre Cotterlaz & Christophe Gouel

Highlights

- France's emissions fell by 18% (2000-14), but its carbon footprint by only 5%.
- Trade-embedded emissions increased from 45% to 54% of France's total carbon footprint.
- Technique effects reduced emissions by 28%, mainly through efficiency gains abroad.
- Geographic shifts to carbon-intensive partners increased emissions by 18%.
- As countries decarbonize domestically, footprint reductions become increasingly dependent on foreign actions.

Abstract

This study examines the evolution of France's carbon footprint from 2000 to 2014, with a particular focus on the role of international trade. During this period, France's territorial emissions decreased by 18%, yet its consumption-based footprint declined by only 5%. This modest reduction reflects an increase in emissions embedded in imports, which grew from 45% to 54% of the total. Employing a novel structural decomposition analysis, we disentangle the contributions of scale, composition, and technique effects from a consumption perspective. Our approach advances traditional methods by explicitly distinguishing between domestic and foreign influences and by separately analyzing trade openness and the geographic reallocation of trade flows. The results underscore the dominance of the technique effect in reducing emissions (-28%), driven primarily by efficiency improvements abroad. However, the geographic composition effect led to a substantial increase in emissions (+18%), especially due to shifts toward more carbon-intensive trading partners prior to 2008. This pattern - characterized by a growing reliance on foreign improvements for emission reductions - likely foreshadows developments in other developed economies as domestic decarbonization advances. It highlights the need for greater coordination between trade and climate policies.

Keywords

Carbon footprint, Structural decomposition analysis, Consumption-based accounting, Scale, composition, and technique effects, France.

JEL

F18, Q54, Q56, C67, F64.

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RESEARCH AND EXPERTISE
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Outsourcing Decarbonization?
How Trade Shaped France's Carbon Footprint (2000–14)

Pierre Cotterlaz* and Christophe Gouel†

1. Introduction

A persistent gap between production-based emissions inventories and consumption-based carbon footprints characterizes most developed economies (Peters et al., 2011; Dugast et al., 2024), raising questions about whether domestic decarbonization represents genuine progress or the outsourcing of emissions to countries with weaker environmental regulations (Levinson, 2023). France offers a particularly instructive case: its relatively low territorial emissions—a result of early and extensive reliance on nuclear power and long-standing de-industrialization—stand in contrast to a growing share of trade-embedded emissions in its overall carbon footprint. In this context, analyzing the influence of international trade dynamics provides valuable insights for designing effective climate policies in a globalized economy.

What forces have shaped the evolution of France's carbon footprint between 2000 and 2014? Although international trade is often cited as a potential driver of footprint trends, its specific role remains difficult to distinguish from other factors such as economic growth, sectoral changes, and technological improvements. To address this question, we adopt a consumption-based perspective and use a decomposition approach to quantify the relative contributions of scale, composition, and technique effects. Our framework explicitly separates domestic and foreign influences and differentiates between two key trade-related mechanisms: greater openness to trade and the geographic reallocation of trade flows. Using detailed input-output data from the World Input-Output Database (WIOD), we provide an in-depth breakdown of emissions by sector, trade region, and consumption pattern. This approach allows for a nuanced understanding of how trade dynamics, in conjunction with other drivers, have shaped the evolution of France's carbon footprint.

The analysis yields three main findings regarding the role of trade in shaping France's carbon footprint. First, while France's territorial emissions declined by 18% between 2000 and 2014, its consumption-based footprint decreased by only 5%. This underscores the growing significance of import-embedded emissions, which increased from 45% to 54% of the total footprint—an unusually high share by international standards. Second, the decomposition reveals that trade

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acted as a substantial countervailing force to emission reductions. Although technique effects—primarily improvements in emission intensity—reduced France's footprint by 149 Mt CO_2e, trade-related geographic composition effects increased it by 127.3 Mt CO_2e. This increase occurred through two distinct channels: greater trade openness (46.7 Mt CO_2e) and a reorientation toward more carbon-intensive trading partners (80.7 Mt CO_2e), particularly China. Third, and perhaps most strikingly, efficiency gains abroad contributed more to overall emission reductions than domestic improvements, highlighting the increasing externalization of mitigation outcomes.

Beyond these France-specific findings, our analysis offers broader insights for countries at various stages of decarbonization. France's situation—characterized by extensive nuclear deployment, significant de-industrialization, and a high share of imported emissions—likely anticipates what may await other developed economies as they deepen their domestic decarbonization efforts. As countries reduce their territorial emissions through cleaner electricity and industrial transformation, the relative importance of emissions embedded in imports naturally rises. Our comparative analysis in section 5 demonstrates this pattern empirically, showing that countries with lower initial emission intensities face larger positive geographic composition effects and greater dependence on foreign emission intensity improvements. France's experience thus previews the challenges that countries further along their decarbonization pathways may encounter.

This work engages with three strands of literature. First, it builds on structural decomposition methods from the industrial ecology literature. Structural decomposition analysis enables the disentangling of an outcome measure from a consumption-based perspective into various drivers identified via an input-output model (Miller and Blair, 2009, Chapter 13). We extend these methods by separately identifying the effects of trade openness and geographic reallocation of trade flows, and by distinguishing domestic and foreign contributions (inspired by Xu and Dietzenbacher, 2014). Unlike Xu and Dietzenbacher (2014), who decompose both purchasing and selling decisions, our focus on consumption-based emissions leads us to distinguish domestic and foreign influences from the perspective of the purchasing country.

Second, we contribute to the environmental economics literature analyzing emissions through the lens of scale, composition, and technique effects, as initiated by Grossman and Krueger (1994) and Copeland and Taylor (1994). While this framework has often been used in trade contexts, it is typically production-based and better suited for model-based counterfactuals (e.g., Copeland and Taylor, 1994; Larch and Wanner, 2017; Pothen and Hübler, 2018) than for empirical analysis of trade's multifaceted role. In practice, empirical applications either abstract from trade (Copeland et al., 2022, Figure 6) or focus narrowly on offshoring (Antweiler et al., 2001; Levinson, 2009), thereby overlooking broader trade-related mechanisms such as changes in trading partners, trade deficits, sector-driven fluctuations in trade flows, or efficiency improvements abroad. A recurring conclusion from this literature is the dominance of the technique effect and the limited role of composition effects (see Cherniwchan and Taylor, 2022). In contrast, we demonstrate how the scale/composition/technique framework can be operationalized within a consumption-based analysis to enable a richer decomposition inclusive of trade-related dimensions. Our results for

France reveal a more complex picture: while technique remains the largest driver of emission reductions, composition effects—especially geographic reallocation—contributed significantly and offset much of the reduction achieved through efficiency gains. Moreover, the technique effect—the main driver of decarbonization—is primarily driven by improvements abroad, indicating that for a country with a large share of imported emissions, decarbonizing the footprint is strongly dependent on the behavior of its trading partners.

Third, our findings intersect with the broader literature on the environmental implications of globalization and the challenges it creates for territorial-based climate policy. A growing body of research has shown that international trade enables developed countries to reduce domestic emissions while increasing their carbon footprint abroad (Davis and Caldeira, 2010; Peters et al., 2011). This has generated sustained interest in consumption-based accounting as a tool for attributing emissions more accurately to final demand and for informing climate policy (Jakob and Marschinski, 2013; Wiedmann and Lenzen, 2018). France's increasing reliance on imported emissions, along with the prominent impact of foreign efficiency improvements on its footprint, illustrates how decarbonization strategies are being reshaped by global dynamics and raises new questions about the effectiveness and equity of national mitigation efforts.

The remainder of the paper is organized as follows. Section 2 presents the methodological framework, detailing the structural decomposition analysis used to disentangle the contributions of scale, composition, and technique effects to the evolution of France's carbon footprint, and describes the data sources, with an emphasis on the advantages of the World Input-Output Database (WIOD) for this analysis. Section 3 provides descriptive statistics on France's emissions and the role of trade-embedded emissions, setting the context for the decomposition results. Section 4 presents the main findings, focusing on the interplay between domestic and international factors and the relative importance of the identified effects. Section 5 offers a comparative analysis of the main results across the countries included in WIOD. Section 6 concludes.

2. Methods

2.1. Structural decomposition methodology

This section presents the structural decomposition framework used to analyze the evolution of France's carbon footprint. Our objective is to quantify the contributions of various drivers to changes in consumption-based emissions. We begin by introducing the notation and structure of the input–output model, before detailing the decomposition of final demand and production requirements. Finally, we explain how domestic and foreign components are separated and how each driver is mapped into the scale–composition–technique taxonomy.

Compared to previous structural decomposition studies, our approach introduces several innovations tailored to a consumption-based analysis. First, we separately identify the effects of trade openness and the geographic reallocation of trade flows—two mechanisms often conflated in the literature. Second, we distinguish between domestic and foreign contributions to each driver, focusing on the location of purchasing decisions, which aligns naturally with a consumption-based perspective and contrasts with approaches that conflate buying and selling (e.g., Xu and Dietzenbacher, 2014). Third, we introduce GDP explicitly in the scale effect, allowing us to isolate the role of trade deficits in enabling consumption beyond domestic production. Together, these features provide a more granular view of how international trade shapes national carbon footprints.

To present the methods, we first have to introduce notations. Our notations follow the standards in matrix algebra and input-output analysis: lower-case bold letters indicate column vectors, upper-case bold letters indicate matrices, $\odot$ and $\oslash$ indicate element-wise product and division, $\otimes$ indicates Kronecker product, and $\cdot$ or juxtaposition indicate a standard matrices multiplication. $\mathbf{i}$ is a column vector of ones and $\mathbf{I}$ is the identity matrix. When it is not ambiguous, the dimensions of these elements are not specified. There are n_i sectors indexed by i and j, and n_r regions indexed by r and s. $n_{ri} = n_r n_i$ is the product of the number of regions and sectors. We define $\boldsymbol{\iota}_{\text{FRA}}$ a n_r-vector of zeros, except for the position corresponding to France where it is 1. We denote Δ the operator of time difference: $\Delta x = x_t - x_{t-1}$, where x_t is always the variable x in year t at the price of year $t-1$.

We rely on a multi-regional input–output (MRIO) model to trace emissions across global value chains and allocate them to final consumption in France. The starting point of the analysis is to note that the footprint f can be calculated as the sum of emissions occurring during the production of goods consumed in France and the emissions occurring when final demand is realized (e.g., cooking, car usage) f_h. The emissions from production are obtained using an MRIO model and, thus, are the product of the emission intensity, the Leontief inverse, and final demand:

$$f = \mathbf{i}' \underbrace{\mathbf{WLy}}_{\mathrm{f}_p} + f_h, \tag{1}$$

where $\mathbf{y}$ is a n_{ri}-vector of France final demand (in which all final demand types have been summed), $\mathbf{L}$ is a $n_{ri} \times n_{ri}$-matrix of Leontief inverse, $\mathbf{W}$ is a n_{ri}-diagonal-matrix of emission intensity (i.e., the quantity of emissions associated to one dollar of production in a country-sector), and $\mathbf{f}_p$ is a n_{ri}-vector detailing France's footprint by region and sector of origin.

We begin by decomposing France's final demand into macroeconomic, sectoral, and trade-related dimensions:

$$\mathbf{y} = p \cdot (g/p) \cdot (y/g) \cdot \mathbf{y}^{\text{sector}} \odot \mathbf{y}^{\text{openness}} \odot \mathbf{y}^{\text{foreign}}, \tag{2}$$

where p is population, g is GDP, $y = \mathbf{i}'\mathbf{y}$ is total final consumption (corresponding to the gross national expenditures), $\mathbf{y}^{\text{sector}}$ is the vector of shares spent on each sector, $\mathbf{y}^{\text{openness}}$ is a vector indicating the share spent on domestic and foreign goods, and $\mathbf{y}^{\text{foreign}}$ is a vector indicating the share spent on each origin countries among foreign origins.[1] In most consumption-based

[1]This decomposition in three shares is reminiscent of the practice in many applied trade models of using nested

decompositions, GDP is omitted, and the scale effect is captured solely by total final consumption. By introducing GDP explicitly, we can disentangle two distinct factors: the wealth generated domestically (GDP) and the additional consumption enabled by trade imbalances, measured by the consumption-to-GDP ratio, with y/g exceeding one in the case of trade deficits (see Jakob and Marschinski, 2013, for another decomposition highlighting the role of trade deficits). Doing this allows to track one more trade-related component in the decomposition.

The three last terms of final demand decomposition are obtained as follows.

- $\mathbf{y}^{\text{sector}}$ is a n_{ri}-vector obtained by calculating the n_i-vector of sectoral shares $(\mathbf{i}_{n_r} \otimes \mathbf{I}_{n_i})' \cdot \mathbf{y}/y$ and by stacking it n_r times.
- $\mathbf{y}^{\text{openness}}$ is a n_{ri}-vector obtained by calculating in a first step $\mathbf{y}^{\text{country}} = \mathbf{y} \oslash (y \cdot \mathbf{y}^{\text{sector}})$, which represents the share of each country of origin (including all countries, domestic and foreign). In a second step, the domestic share is extracted from $\mathbf{y}^{\text{country}}$ by multiplying it (element-wise) with $\boldsymbol{\iota}_{\text{FRA}} \otimes \mathbf{1}_{n_i}$ and the foreign share by multiplying $1 - \mathbf{y}^{\text{country}}$ (element-wise) with $\boldsymbol{\iota}_{\text{FRA}} \otimes \mathbf{1}_{n_i}$. The foreign share is then repeated equally for all foreign countries.
- $\mathbf{y}^{\text{foreign}} = \mathbf{y}^{\text{country}} \oslash \mathbf{y}^{\text{openness}}$, so it contains ones for France and for foreign countries it contains the share of import from each country in total imports.

We now turn to the decomposition of production inputs, captured by the Leontief inverse matrix. This allows us to isolate how changes in intermediate demand structures—both domestic and foreign—affect the carbon footprint. We obtain the Leontief inverse from the requirement matrix $\mathbf{A}$: $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$. Using the requirement matrix, we decompose the Leontief inverse in three components. To do this, we use the well-known identity (Miller and Blair, 2009, Chapter 13)

$$\Delta \mathbf{L} = \mathbf{L}_t \, (\Delta \mathbf{A}) \, \mathbf{L}_{t-1} = \mathbf{L}_{t-1} \, (\Delta \mathbf{A}) \, \mathbf{L}_t, \tag{3}$$

and we follow similar steps as for final demand, decomposing $\mathbf{A}$ as

$$\mathbf{A} = \mathbf{A}^{\text{sector}} \odot \mathbf{A}^{\text{openness}} \odot \mathbf{A}^{\text{foreign}}, \tag{4}$$

where

- $\mathbf{A}^{\text{sector}}$ is a $n_{ri} \times n_{ri}$-matrix obtained by calculating the $n_{ri} \times n_i$-matrix of sectoral shares $(\mathbf{i}_{n_r} \otimes \mathbf{I}_{n_i})' \cdot \mathbf{A}$ and by stacking it n_r times. It represents the share of each sector in the intermediate consumption of a given country-sector.
- $\mathbf{A}^{\text{openness}}$ is a $n_{ri} \times n_{ri}$-matrix. It represents the share of inputs procured domestically or from foreign sources. The domestic shares are present on the block-diagonal matrices of size n_i. For a given importer, all non-block-diagonal matrices are filled with the same foreign shares. It is obtained by calculating in a first step $\mathbf{A}^{\text{country}} = \mathbf{A} \oslash \mathbf{A}^{\text{sector}}$, which represents the share of each country of origin in intermediate inputs. In a second step, the domestic shares are

CES utility functions with three nests where the first nest contains the sectoral choice, the second nest the arbitrage between domestic and foreign goods, and the third nest the choice of origin countries for imports.

extracted from $\mathbf{A}^{\text{country}}$ by multiplying it element-wise with $\mathbf{I}_{n_r} \otimes \mathbf{i}_{n_i}$ and the foreign shares by element-wise multiplication $1 - \mathbf{A}^{\text{country}}$ with $\mathbf{I}_{n_r} \otimes \mathbf{i}_{n_i}$.

- $\mathbf{A}^{\text{foreign}} = \mathbf{A}^{\text{country}} \oslash \mathbf{A}^{\text{openness}}$ is a $n_{ri} \times n_{ri}$-matrix that represents the share spent on each origin countries among foreign origins.

The decomposition of equation (4) is illustrated in equation (5) in which the world is assumed to be composed of three countries (h, f, and g) and two sectors (1 and 2). The A_{ij}^{rs} are the elements of $\mathbf{A}$, the α_{ij}^{s} are the elements of $\mathbf{A}^{\text{sector}}$ with $\sum_i \alpha_{ij}^{s} \leq 1$, the β_{ij}^{s} are the elements of $\mathbf{A}^{\text{openness}}$, and the γ_{ij}^{rs} are the elements of $\mathbf{A}^{\text{foreign}}$ with $\sum_r \gamma_{ij}^{rs} = 1$. This equation clarifies that this decomposition allows to separate the sectoral share, the openness to trade, and the share of each origin country:

$$
\begin{aligned}
\left[\begin{array}{cc|cc|cc}
A_{11}^{hh} & A_{12}^{hh} & A_{11}^{hf} & A_{12}^{hf} & A_{11}^{hg} & A_{12}^{hg} \\
A_{21}^{hh} & A_{22}^{hh} & A_{21}^{hf} & A_{22}^{hf} & A_{21}^{hg} & A_{22}^{hg} \\
\hline
A_{11}^{fh} & A_{12}^{fh} & A_{11}^{ff} & A_{12}^{ff} & A_{11}^{fg} & A_{12}^{fg} \\
A_{21}^{fh} & A_{22}^{fh} & A_{21}^{ff} & A_{22}^{ff} & A_{21}^{fg} & A_{22}^{fg} \\
\hline
A_{11}^{gh} & A_{12}^{gh} & A_{11}^{gf} & A_{12}^{gf} & A_{11}^{gg} & A_{12}^{gg} \\
A_{21}^{gh} & A_{22}^{gh} & A_{21}^{gf} & A_{22}^{gf} & A_{21}^{gg} & A_{22}^{gg}
\end{array}\right]
&=
\left[\begin{array}{cc|cc|cc}
\alpha_{11}^{h} & \alpha_{12}^{h} & \alpha_{11}^{f} & \alpha_{12}^{f} & \alpha_{11}^{g} & \alpha_{12}^{g} \\
\alpha_{21}^{h} & \alpha_{22}^{h} & \alpha_{21}^{f} & \alpha_{22}^{f} & \alpha_{21}^{g} & \alpha_{22}^{g} \\
\hline
\alpha_{11}^{h} & \alpha_{12}^{h} & \alpha_{11}^{f} & \alpha_{12}^{f} & \alpha_{11}^{g} & \alpha_{12}^{g} \\
\alpha_{21}^{h} & \alpha_{22}^{h} & \alpha_{21}^{f} & \alpha_{22}^{f} & \alpha_{21}^{g} & \alpha_{22}^{g} \\
\hline
\alpha_{21}^{h} & \alpha_{22}^{h} & \alpha_{21}^{f} & \alpha_{22}^{f} & \alpha_{21}^{g} & \alpha_{22}^{g} \\
\alpha_{21}^{h} & \alpha_{22}^{h} & \alpha_{21}^{f} & \alpha_{22}^{f} & \alpha_{21}^{g} & \alpha_{22}^{g}
\end{array}\right] \\
&\odot
\left[\begin{array}{cc|cc|cc}
\beta_{11}^{h} & \beta_{12}^{h} & 1-\beta_{11}^{f} & 1-\beta_{12}^{f} & 1-\beta_{11}^{g} & 1-\beta_{12}^{g} \\
\beta_{21}^{h} & \beta_{22}^{h} & 1-\beta_{21}^{f} & 1-\beta_{22}^{f} & 1-\beta_{21}^{g} & 1-\beta_{22}^{g} \\
\hline
1-\beta_{11}^{h} & 1-\beta_{12}^{h} & \beta_{11}^{f} & \beta_{12}^{f} & 1-\beta_{11}^{g} & 1-\beta_{12}^{g} \\
1-\beta_{21}^{h} & 1-\beta_{22}^{h} & \beta_{21}^{f} & \beta_{22}^{f} & 1-\beta_{21}^{g} & 1-\beta_{22}^{g} \\
\hline
1-\beta_{11}^{h} & 1-\beta_{12}^{h} & 1-\beta_{11}^{f} & 1-\beta_{12}^{f} & \beta_{11}^{g} & \beta_{12}^{g} \\
1-\beta_{21}^{h} & 1-\beta_{22}^{h} & 1-\beta_{21}^{f} & 1-\beta_{22}^{f} & \beta_{21}^{g} & \beta_{22}^{g}
\end{array}\right] \\
&\odot
\left[\begin{array}{cc|cc|cc}
1 & 1 & \gamma_{11}^{hf} & \gamma_{12}^{hf} & \gamma_{11}^{hg} & \gamma_{12}^{hg} \\
1 & 1 & \gamma_{21}^{hf} & \gamma_{22}^{hf} & \gamma_{21}^{hg} & \gamma_{22}^{hg} \\
\hline
\gamma_{11}^{fh} & \gamma_{12}^{fh} & 1 & 1 & \gamma_{11}^{fg} & \gamma_{12}^{fg} \\
\gamma_{21}^{fh} & \gamma_{22}^{fh} & 1 & 1 & \gamma_{21}^{fg} & \gamma_{22}^{fg} \\
\hline
\gamma_{11}^{gh} & \gamma_{12}^{gh} & \gamma_{11}^{gf} & \gamma_{12}^{gf} & 1 & 1 \\
\gamma_{21}^{gh} & \gamma_{22}^{gh} & \gamma_{21}^{gf} & \gamma_{22}^{gf} & 1 & 1
\end{array}\right].
\end{aligned}
\tag{5}
$$

We can now rewrite the footprint equation using these various components:

$$
f = \mathbf{i}'\mathbf{W}\left(\mathbf{I} - \mathbf{A}^{\text{sector}} \odot \mathbf{A}^{\text{openness}} \odot \mathbf{A}^{\text{foreign}}\right)^{-1}\left[p(g/p)(g/y)\mathbf{y}^{\text{sector}} \odot \mathbf{y}^{\text{openness}} \odot \mathbf{y}^{\text{foreign}}\right] + f_h. \tag{6}
$$

Here, we can note that the matrices $\mathbf{W}$, $\mathbf{A}^{\text{sector}}$, $\mathbf{A}^{\text{openness}}$, and $\mathbf{A}^{\text{foreign}}$ mix elements corresponding to domestic (France-related) and foreign dimensions. To separate these dimensions, we express each matrix as the sum of a domestic and a foreign component, with in the domestic matrix the columns corresponding to France, the rest of columns being filled with zeros, and conversely for the foreign matrix. For $\mathbf{A}^{\text{sector}}$, we have:[2]

$$\mathbf{A}^{\text{sector}} = \mathbf{A}^{\text{sector}}_{\text{FRA}} + \mathbf{A}^{\text{sector}}_{\text{FOR}}. \tag{7}$$

Using the same three-country and two-sector example used in equation (5), and assuming that France corresponds to country h, this decomposition between domestic and foreign components is as follows

$$\underbrace{\left[\begin{array}{cc|cc|cc} \alpha^h_{11} & \alpha^h_{12} & \alpha^f_{11} & \alpha^f_{12} & \alpha^g_{11} & \alpha^g_{12} \\ \alpha^h_{21} & \alpha^h_{22} & \alpha^f_{21} & \alpha^f_{22} & \alpha^g_{21} & \alpha^g_{22} \\ \hline \alpha^h_{11} & \alpha^h_{12} & \alpha^f_{11} & \alpha^f_{12} & \alpha^g_{11} & \alpha^g_{12} \\ \alpha^h_{21} & \alpha^h_{22} & \alpha^f_{21} & \alpha^f_{22} & \alpha^g_{21} & \alpha^g_{22} \\ \hline \alpha^h_{11} & \alpha^h_{12} & \alpha^f_{11} & \alpha^f_{12} & \alpha^g_{11} & \alpha^g_{12} \\ \alpha^h_{21} & \alpha^h_{22} & \alpha^f_{21} & \alpha^f_{22} & \alpha^g_{21} & \alpha^g_{22} \end{array}\right]}_{\text{A}^{\text{sector}}} = \underbrace{\left[\begin{array}{cc|cc|cc} \alpha^h_{11} & \alpha^h_{12} & 0 & 0 & 0 & 0 \\ \alpha^h_{21} & \alpha^h_{22} & 0 & 0 & 0 & 0 \\ \hline \alpha^h_{11} & \alpha^h_{12} & 0 & 0 & 0 & 0 \\ \alpha^h_{21} & \alpha^h_{22} & 0 & 0 & 0 & 0 \\ \hline \alpha^h_{11} & \alpha^h_{12} & 0 & 0 & 0 & 0 \\ \alpha^h_{21} & \alpha^h_{22} & 0 & 0 & 0 & 0 \end{array}\right]}_{\text{A}^{\text{sector}}_{\text{FRA}}} + \underbrace{\left[\begin{array}{cc|cc|cc} 0 & 0 & \alpha^f_{11} & \alpha^f_{12} & \alpha^g_{11} & \alpha^g_{12} \\ 0 & 0 & \alpha^f_{21} & \alpha^f_{22} & \alpha^g_{21} & \alpha^g_{22} \\ \hline 0 & 0 & \alpha^f_{11} & \alpha^f_{12} & \alpha^g_{11} & \alpha^g_{12} \\ 0 & 0 & \alpha^f_{21} & \alpha^f_{22} & \alpha^g_{21} & \alpha^g_{22} \\ \hline 0 & 0 & \alpha^f_{11} & \alpha^f_{12} & \alpha^g_{11} & \alpha^g_{12} \\ 0 & 0 & \alpha^f_{21} & \alpha^f_{22} & \alpha^g_{21} & \alpha^g_{22} \end{array}\right]}_{\text{A}^{\text{sector}}_{\text{FOR}}}. \tag{8}$$

For conciseness, we do not present the complete expression of the footprint with domestic and foreign matrices, but it is clear that it involves a mix of additive and multiplicative terms.

The decomposition of the footprint is carried out in two steps. This is necessary because changes in the Leontief inverse ($\Delta\mathbf{L}$) cannot be decomposed into the different components of the requirement matrix ($\mathbf{A}^{\text{sector}}$, $\mathbf{A}^{\text{openness}}$, and $\mathbf{A}^{\text{foreign}}$) simultaneously with the other components of the footprint expression. To accommodate this constraint, and given the large number of components involved in equation (6), we use the additive polar decomposition discussed in Dietzenbacher and Los (1998). This method is one of the few approaches that permits a two-step decomposition—first isolating the elements of the Leontief inverse, then decomposing the remaining terms. Among such methods, the polar decomposition is especially tractable: it avoids the combinatorial explosion that would result from accounting for all possible interaction paths between the many components in our model. Since the polar decomposition is a standard technique and the expression of the footprint decomposition is long, we do not detail the expression of the decomposition here.[3]

[2] This decomposition takes inspiration from Xu and Dietzenbacher (2014). They propose something similar except that for the domestic matrix they keep both the rows and columns corresponding to the country of interest. Keeping rows and columns mixes selling and buying decisions. Given our consumption-based perspective, it is more natural to keep only the buying decisions.

[3] For an outcome y defined by $y = \prod_{i=1}^{N} x_i$, a polar decomposition of $\Delta y = y_1 - y_0$ is defined by

$$\Delta y = \frac{1}{2}\left[\sum_{i=1}^{N}\left(\prod_{j<i} x_{j,0}\right)(\Delta x_i)\left(\prod_{j>i} x_{j,1}\right) + \sum_{i=1}^{N}\left(\prod_{j<i} x_{j,1}\right)(\Delta x_i)\left(\prod_{j>i} x_{j,0}\right)\right].$$

The final decomposition of the change in footprint $\Delta \mathbf{f}_p$ takes the following form:

$$\begin{aligned}\Delta \mathbf{f}_p = & g_{\mathrm{W}}(\Delta \mathbf{W}) + g_{\mathrm{A}^{\text{sector}}}\left(\Delta \mathbf{A}^{\text{sector}}\right) + g_{\mathrm{A}^{\text{openness}}}\left(\Delta \mathbf{A}^{\text{openness}}\right) + g_{\mathrm{A}^{\text{foreign}}}\left(\Delta \mathbf{A}^{\text{foreign}}\right) + g_p(\Delta p) \\ & + g_{g/p}(\Delta g/p) + g_{g/y}(\Delta g/y) + g_{\mathrm{y}^{\text{sector}}}\left(\Delta \mathbf{y}^{\text{sector}}\right) + g_{\mathrm{y}^{\text{openness}}}\left(\Delta \mathbf{y}^{\text{openness}}\right) + g_{\mathrm{y}^{\text{foreign}}}\left(\Delta \mathbf{y}^{\text{foreign}}\right), \quad (9)\end{aligned}$$

where the function $g_x(x)$ returns a n_{ri}-vector corresponding to the contribution of the component x between two years. So, the evolution of the footprint is exactly decomposed into the contribution of the various components identified above.

Note that in addition to the emissions from production, we could have decomposed the emissions occurring at final demand f_h in terms of scale and technique effects (we lack information about the sectoral origin to have a component related to composition), but given the paper's focus on the role of trade in the footprint evolution we prefer to abstain from such a decomposition that would not contribute to the paper's objective.

To ease interpretation, we organize our decomposition into the scale, composition, and technique effects commonly used in environmental economics. However, it is important to note that our decomposition differs from the ones usually done in environmental economics where these three effects are calculated from a production perspective (Grossman and Krueger, 1994), while here we do the calculation from a consumption perspective. We detail below the content of each effect:

Scale Scale effect is represented by three dimensions:
- Population, p.
- GDP per capita, g/p.
- Ratio of total consumption to GDP, y/g.

Composition Composition effect is composed of two dimensions: sectoral and regional:
- **Sectoral** Sectoral composition of final demand: the change in emissions related to the change in sectoral consumption at constant expenditures, $\mathbf{y}^{\text{sector}}$.
- **Regional** Regional composition relates to changes in the country trade openness and the share of each exporting country in total imports, for final and intermediate consumption separately: $\mathbf{y}^{\text{openness}}$, $\mathbf{y}^{\text{foreign}}$, $\mathbf{A}^{\text{openness}}$, and $\mathbf{A}^{\text{foreign}}$.

Technique Technique effect is represented by two dimensions
- The change in emission intensity for a given product, $\mathbf{W}$.
- The change in product mix in intermediate consumption, $\mathbf{A}^{\text{sector}}$.

Note that we will also decompose the elements of the composition and technique effects into their domestic and foreign components, which allows identifying if the changes in emissions are related to domestic or foreign changes.

2.2. Data sources

Our analysis relies on the World Input-Output Database (WIOD), version 2016 (Timmer et al., 2015), which provides harmonized international input–output and environmental data at previous-year prices. Among existing MRIO databases, WIOD is the only one that allows for a proper structural decomposition by neutralizing price effects—essential for ensuring that changes in emissions are not conflated with inflation and sectoral price changes (Xu and Dietzenbacher, 2014).[4] Using data at current prices would bias the decomposition: for instance, increases in GDP per capita (g/p) due to inflation would be misinterpreted as real growth, and the emission intensity of production (W) would be overstated as output values rise with sectoral prices. This is why working with previous-year prices is essential for accurate attribution of emissions drivers in a structural decomposition analysis.

The WIOD database is publicly available for 2000–14. It consists of 44 countries (28 EU,[5] 15 non-EU, and one Rest of the World region) and 56 industries.

To construct a consistent GHG emissions dataset, we harmonize multiple sources. CO_2 emissions primarily come from Eurostat's air pollution data. For countries not covered, we complement this with WIOD 2016 environmental accounts produced by the JRC (Corsatea et al., 2019). Non-CO_2 emissions (CH_4 and N_2O) are sourced from EXIOBASE (Stadler et al., 2018), mapped to WIOD sectors using a concordance. These three gases allow us to account for more than 96% of GHG emissions (excluding CO_2 emissions from land use, land-use change, and forestry). Non-CO_2 emissions are converted to CO_2-equivalents (CO_2e) using global warming potentials with a 100-year time horizon from the IPCC Sixth Assessment Report (2023).

We make two adjustments to the WIOD data. We remove from final demand "Changes in inventories and valuables". This final demand is very sensitive to the business cycle, which could change results for non-structural reasons, and it contains a lot of negative values, with some occasionally so large that they can drive total final demand in a sector to be negative. We also remove negative values from "Gross fixed capital formation". As before, they can lead to total final demand for a sector to be negative. After these adjustments, we re-balance the data.

3. Descriptive statistics

Before turning to the decomposition analysis, we present key statistics about France's territorial emissions, carbon footprint, and the role of international trade. This descriptive overview provides

[4] The 2013 version of WIOD provides the same type of information but there are important differences in carbon footprints over the overlapping years, which prevents us from combining both sources. At the time of this writing, the FIGARO database from Eurostat, which provides data similar to WIOD for recent years, was not available at previous-year prices.

[5] Given that the database covers the period prior to Brexit, this article refers to the European Union at 28 with the United Kingdom.

context for interpreting the results in sections 4 and 5 and helps clarify how France compares to other advanced economies in terms of emissions outsourcing and trade dependence.

We begin by examining per-capita emissions, in terms of national inventory and consumption-based footprint. Figure 1 displays these values for 2014, plotted against GDP per capita for all countries included in WIOD. France emerges as one of the countries with the lowest emissions per capita relative to its development level. In terms of its emissions inventory, France emits 6.8 t CO_2e per capita, placing it near the frontier, with only Switzerland recording lower per-capita emissions at a comparable level of GDP. The frontier here refers to the bottom-right envelope, representing the lowest achievable emissions for a given level of economic development. A similar pattern is observed for its carbon footprint, with no other countries surpassing France in low per-capita emissions at its GDP level. Breaking these emissions down into CO_2 and non-CO_2 components highlights the underlying drivers of France's position. France's low CO_2 emissions and footprint (5.2 and 7.7 t CO_2 per capita, respectively) contrast with its non-CO_2 emissions and footprint (1.6 and 2.6 t CO_2e per capita, respectively), which are less remarkable for its development level. This distinction is largely attributable to France's reliance on low-carbon electricity production, made possible by its extensive nuclear energy infrastructure.

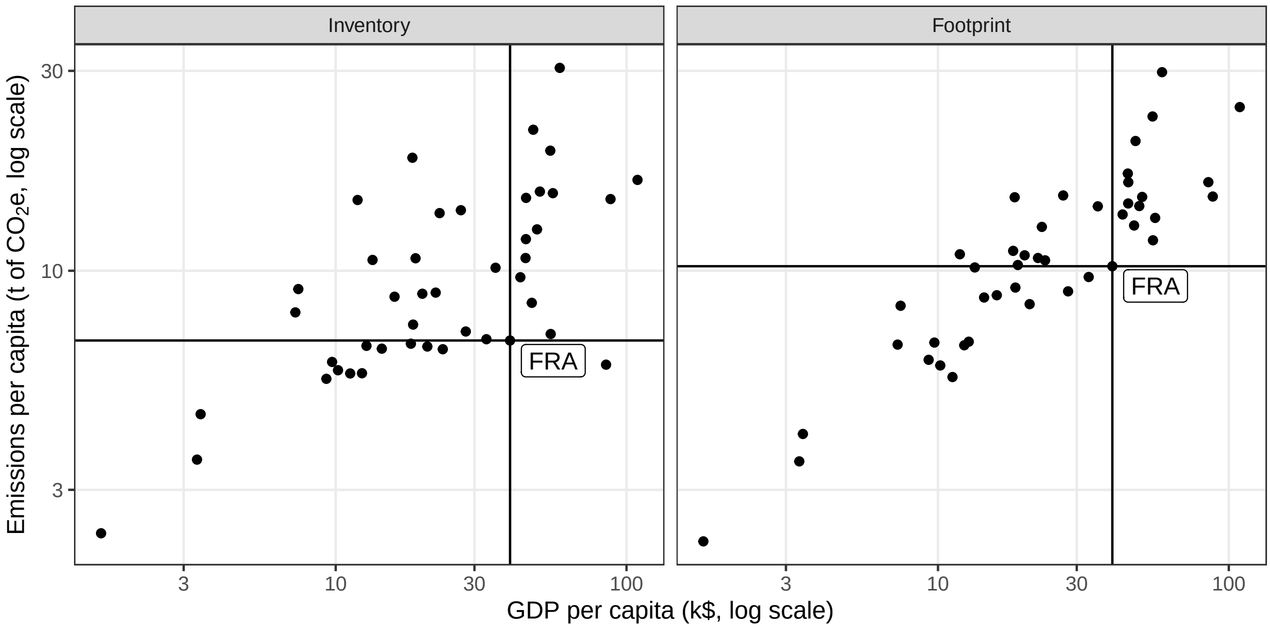
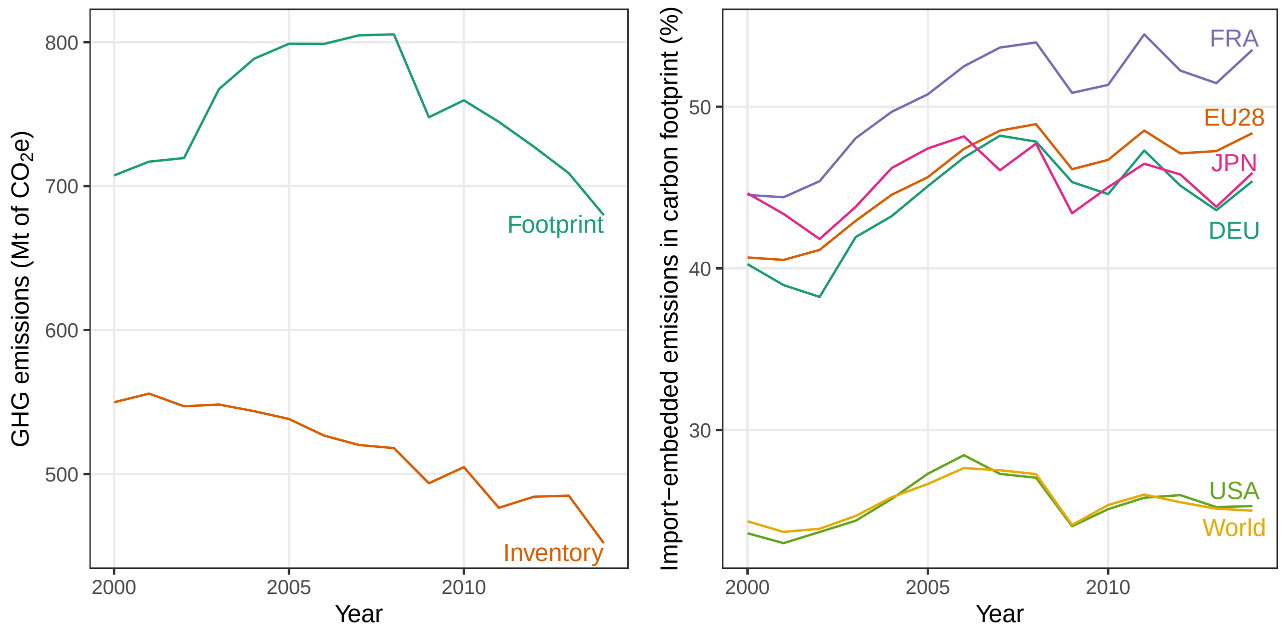


Figure 1 – Emissions inventory and footprint per capita in 2014. The black horizontal and vertical lines crosses at the situation of France.

The temporal evolution of France's emissions is shown in figure 2. When discussing this evolution and for the following decomposition, it is useful to distinguish two periods: 2000–08 and 2009–14. The first period coincides with China's emergence as a dominant global supplier (i.e., the first China shock), while the second follows the 2008 global financial crisis and corresponds to the subsequent trade slowdown. Over the entire period, the French emissions inventory steadily decreased from 550 Mt CO_2e in 2000 to 452 Mt CO_2e in 2014, reflecting an average annual reduction of 2.4% (figure 2a). In contrast, the dynamics of the carbon footprint diverge significantly. After increasing until 2008, the footprint begins to decline, falling to 680 Mt CO_2e in 2014, below its 2000 level of 707 Mt CO_2e. So, over the period, there is only a modest decrease of footprint.



(a) France emissions

(b) Share of import-embedded emissions in the footprint

Figure 2 – Evolution of France emissions and import-embedded emissions share

This divergence between inventory and footprint has resulted in a marked increase in the share of import-embedded emissions in France's carbon footprint,[6] rising from 45% in 2000 to 54% in 2008, and stabilizing around this value until 2014 (figure 2b). Notably, this increase is not unique to France but is also observed across the European Union; but, globally, the increase of trade-embedded emissions between 2000 and 2008 is mostly reversed in 2014. France stands out with a high share of embedded emissions. In 2014, only a few countries of smaller size, including Luxembourg, Switzerland, Belgium, Sweden, and Austria, recorded a higher proportion of import-embedded emissions. France's reliance on nuclear energy explains its relatively high initial share of trade-embedded emissions, as nuclear energy lowers the emissions inventory without a corresponding reduction in the imported emissions. However, this factor does not account for the observed increase.

While this section considers all French emissions, outside of land use, the remainder of this paper

[6] The share of import-embedded emissions is defined as the proportion of the footprint f corresponding to emissions occurring abroad.

focuses on the footprint associated with the production of goods, denoted as $\mathbf{f}_p$ in equation (1), and excludes emissions produced during final consumption, f_h. The latter is only tangentially related to trade, is less detailed in the data, and has remained relatively stable over the study period, starting and ending at approximately 115 Mt CO_2e. Excluding the emissions produced during final consumption, the French footprint has decreased by 26.4 Mt CO_2e during the period, close to the 27.6 Mt CO_2e decrease of the total footprint.

Taken together, these trends underscore the need to move beyond aggregate footprint indicators and understand the underlying drivers of change. In the next section, we disentangle the roles of scale, composition, and technique—both domestically and internationally—in shaping the evolution of France's carbon footprint.

4. Results

In this section, we decompose the evolution of France's footprint using the methodology presented in section 2. The decomposition is calculated on a yearly basis, and the various components are then chained over time to obtain their temporal evolution.

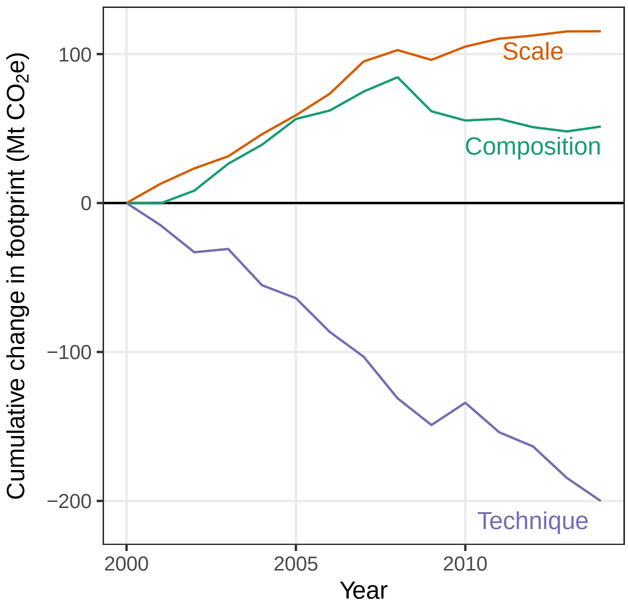
4.1. Scale, composition, and technique decomposition

To make the decomposition interpretable, we first group the numerous terms into three effects: scale, composition, and technique. These categories allow us to systematically analyze the drivers of changes in France's carbon footprint. Figure 3a illustrates the cumulative contributions of these effects over the study period.[7]

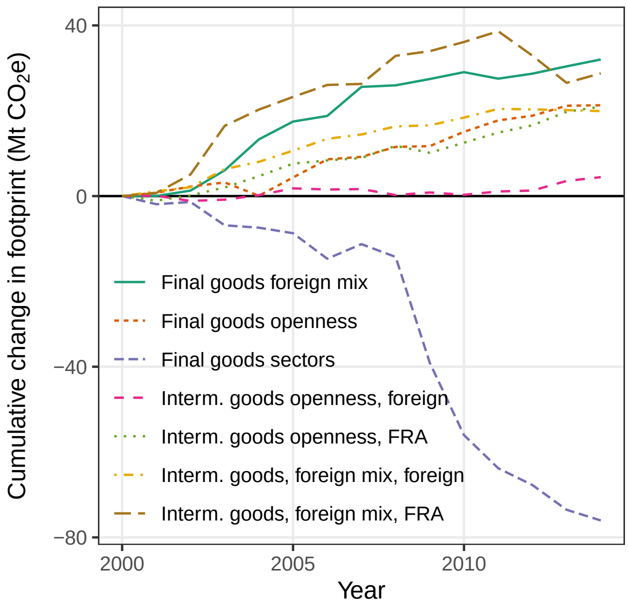
The results reveal that the technique effect is the most dominant driver of emission changes, followed by the scale effect. The composition effect, while significant, has a relatively minor role in comparison. This ordering is consistent with findings from similar decomposition analyses in environmental economics.

Examining the scale effect, the contributions of population growth and GDP per capita were nearly equivalent, adding 53 Mt CO_2e and 57 Mt CO_2e, respectively, to the carbon footprint. Over this period, an increase in France's trade deficit also influenced the scale effect. The ratio of total consumption to GDP rose from 0.979 to 1.006, leading to an additional 5 Mt CO_2e in emissions.

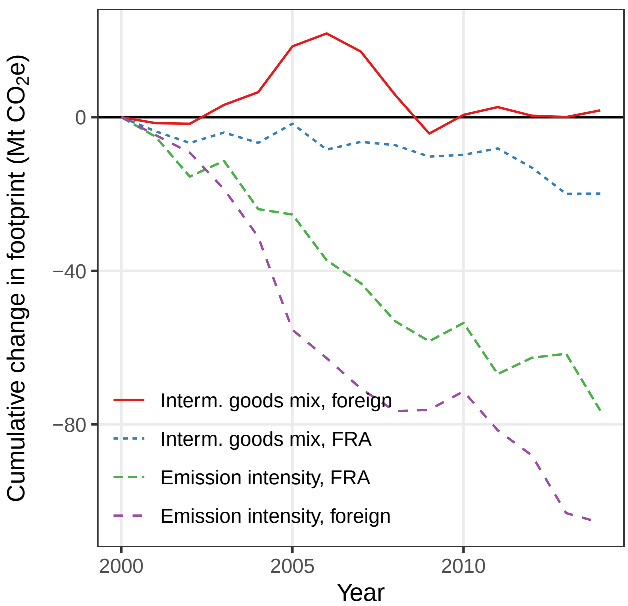
[7] The total change in France's footprint is different in this section than exposed in the previous section: -33.5 instead of -26.4 Mt CO_2e. This change is caused by the use of information at previous-year prices to do the decomposition. Using information at previous-year prices changes country-level footprints while keeping the global value constant. The changes in footprints are relatively small. However, since we focus here on the evolution of France's footprint, which in 2014 is not very different from its 2000 value, the discrepancy may seem bigger in this setting.



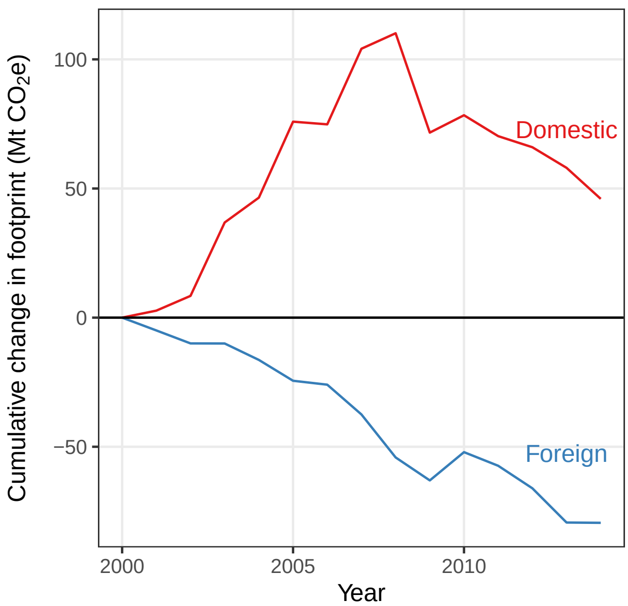
(a) Scale, composition, and technique decomposition



(b) Composition effects



(c) Technique effects



(d) Geographic origin of footprint changes (origin classified based on where the purchasing is made)

Figure 3 – Decomposition of France consumption-based emissions

The composition and technique effects are explored further in subsequent sections, as they provide deeper insights into the interplay of trade, sectoral shifts, and technological advancements.

4.2. Composition effect: sectoral vs. geographical trade patterns

The composition effect captures the changes in France's carbon footprint arising from shifts in the sectoral structure of consumption and the geographic distribution of trade flows. These two dimensions—sectoral composition and geographic composition—act in opposing directions, resulting in the overall smaller contribution of the composition effect compared to the scale and technique effects. Figure 3b presents the breakdown of the composition effect into its main components.

Sectoral composition effect. The sectoral composition effect contributes significantly to reducing France's carbon footprint, with a cumulative decline of 76 Mt CO_2e over the period. This reduction is particularly striking after 2008, with a marked acceleration between 2008 and 2011. To better understand this dynamic, we perform a separate decomposition of the sectoral effect across different final demand categories: household consumption, government expenditure, and capital formation.

The results indicate that three-quarters of the sectoral composition effect is associated with household demand, while the remaining portion stems from capital formation. Notably, the emissions reductions linked to capital formation are concentrated between 2008 and 2010, reflecting a structural shift in investment patterns. During this period, capital expenditures moved away from emission-intensive manufacturing sectors, such as vehicles and machinery, toward the services sector. Within services, there was also a significant reallocation, with reduced spending on construction and increased investment in information technology services.

For household consumption, the decline in emissions reflects two concurrent trends. First, a secular structural transformation occurred, with households allocating a progressively smaller share of their expenditures to food and manufactured goods—sectors typically associated with higher carbon intensities—while increasing their spending on services (Comin et al., 2021). Second, the 2008 global financial crisis accelerated this shift, as the economic slowdown led to a sharp reduction in the consumption of durable goods, which are typically more carbon-intensive. Overall, the spending share on primary sectors and manufacturing goods declined from 21% to 15% between 2000 and 2014. Given that these sectors had in 2014 an intensity of 0.63 t CO_2e per thousand dollars, compared to 0.14 for services, such a sectoral shift has profound implications in terms of emissions.

These findings are consistent with broader evidence on the Global Trade Slowdown, which followed the 2008 crisis. Capital goods and durable manufacturing goods experienced a significant drop in trade flows during this period, contributing to the observed decrease in emissions associated with final demand (Hoekman, 2015).

Geographic composition effect. In contrast to the sectoral composition effect, the geographic composition effect contributes positively to France's carbon footprint, adding a cumulative 127.3 Mt CO_2e over the period. This important increase, combined with the modest overall footprint decrease, explains the large increase in the share of trade-embedded emissions over the period. The increase associated with the geographic composition effect arises from two mechanisms: greater openness to trade (the substitution of domestic production in consumption with imported goods) and shifts in the geographic mix of imports (the share of imports sourced from different countries).

The contribution of trade openness accounts for 46.7 Mt CO_2e. Between 2000 and 2014, the share of goods consumed in France that were imported rather than produced domestically rose from 39% to 47% (when considering both goods and services together, imports rose from 13.8% to 15.4% of total consumption). Given that France is among the least carbon-intensive economies for its level of development (see figure 1), this substitution of domestic production with imports naturally increased the carbon footprint. Further analysis reveals that the increase in emissions related to openness stems entirely from domestic trade openness, with equal contributions from final and intermediate demand. By contrast, foreign trade openness—referring to the sourcing of intermediate goods by foreign countries—made no contribution to the observed changes (flat dashed curve in figure 3b).

The foreign mix effect accounts for the remaining 80.7 Mt CO_2e and reflects the shift in imports toward relatively more carbon-intensive trading partners. This effect is primarily driven by domestic changes, with only 20 Mt CO_2e attributable to shifts in the foreign mix of intermediate goods consumed abroad. Importantly, the majority of this increase (93%) occurred before 2008, suggesting that the geographic reallocation of trade flows was largely complete by the time of the global financial crisis.

The positive contribution of the foreign mix indicates that imports increasingly originated from countries with higher emission intensities. A decomposition by country (table 1) reveals that two-thirds of the increase can be attributed to shifting imports toward China. The Rest of the World (ROW), which includes several oil-producing nations, represents the second-largest contributor. By contrast, traditional trade partners such as the United Kingdom, the United States, and Belgium exhibit small negative contributions. These negative values reflect a reduction in the shares of imports from these countries, which have relatively lower carbon intensities compared to the new trade partners that replaced them.

Table 1 – Main contributions (in absolute value) to the foreign mix component, $\mathbf{y}^{\text{foreign}}$ and $\mathbf{A}^{\text{foreign}}$ (Mt CO_2e cumulated over 2000–14)

	CHN	ROW	RUS	POL	IND	TUR	CZE	BEL	USA	GBR	Other countries	Total
Contribution	53	16	7	6	4	3	2	−2	−3	−5	−0	81

4.3. Technique effect: domestic vs. foreign efficiency improvements

The technique effect, which accounts for a cumulative reduction of 200 Mt CO_2e in France's carbon footprint between 2000 and 2014, comprises two distinct components: changes in emission intensity and shifts in the sectoral mix of intermediate demand. Changes in intermediate demand represent a technical shift comparable to emission intensity improvements—for example, firms can reduce emissions either by lowering their fossil fuel consumption or by switching their energy demand to electricity. Both components can be decomposed into domestic and foreign dimensions, offering insights into where emission-reducing technological improvements occur.

The emission intensity component dominates the technique effect, with changes in the intermediate goods mix playing a relatively modest role. As shown in figure 3c, the contribution of the intermediate goods mix is almost negligible for foreign inputs, while amounting to approximately -20 Mt CO_2e for domestic goods. This limited contribution understates the importance of intermediate input substitution in reducing emissions due to a methodological limitation. The relatively coarse sectoral classification in WIOD causes many intermediate goods substitutions to be captured within the emission intensity term. For instance, since fossil fuel sectors are grouped together under "Mining and quarrying", a shift from coal to natural gas appears as a reduction in emission intensity rather than a change in intermediate goods mix.

A striking result emerges when examining the geographical origin of emission intensity improvements: more than half of the reduction in France's carbon footprint through the technique effect comes from abroad. This result is a natural consequence of the large share of France's footprint that corresponds to imported emissions (figure 2b); 45% in 2000 and more if excluding emissions produced during final consumption as done in this decomposition. As long as France's partners improved their emission efficiency at the same pace as France, their contribution should have been at least half of the reduction associated with emission intensity.

Unlike the composition effect, which displays distinct temporal dynamics with a clear break in 2008, the emission intensity component shows a more consistent pattern over time. While 2008–10 marks a period of stagnation and slight increase in emission intensity, the overall trend remains similar before and after this period, reflecting ongoing technological improvements and energy efficiency gains across both domestic and foreign producers.

Table 2 decomposes the contribution of emission intensity improvements by sector and country of origin. The results reveal significant concentration both geographically and sectorally. The Rest of the World and China emerge as the largest contributors to emission intensity reductions, each accounting for approximately 24 Mt CO_2e. Among EU countries, which collectively account for the majority of the decrease, Germany stands out with a contribution comparable to that of Russia. Sectorally, the decarbonization of electricity generation dominates, contributing 51 Mt CO_2e to the overall reduction. This substantial contribution reflects the upstream position of electricity in production chains and its historically high emission intensity. The second largest contribution comes from the "Mining and quarrying" sector, which includes fossil fuel extraction—a highly emissions-intensive activity concentrated in countries aggregated within the Rest of World category.

Table 2 – Main contributions to the emission intensity component, W (Mt CO_2e cumulated over 2000–14)

		Foreign contributions								
Sector	FRA	Other EU28	ROW	CHN	RUS	TWN	USA	Other countries	Total foreign	Total
Electricity	−25	−12	−5	−8	−0	−1	1	−0	−26	−51
Mining and quarrying	−0	−2	−18	−3	−5	0	−0	2	−26	−26
Manufacture of basic metals	−2	−8	−2	−1	−1	−0	−1	−0	−13	−15
Manufacture of chemicals	0	−3	−0	−4	−0	−0	−1	−1	−10	−9
Land transport	−8	0	−1	−0	−1	−0	0	−0	−1	−9
Air transport	−6	0	−1	−0	0	−0	−0	0	−2	−8
Non-metallic mineral prod. mfg.	−0	−2	−0	−4	−0	−0	0	−0	−6	−6
Wholesale trade	−5	−0	−0	−0	−0	−0	−0	−0	−1	−6
Other sectors	−25	−13	3	−4	−1	−1	−2	−5	−21	−46
Total	−71	−40	−24	−24	−8	−3	−2	−5	−106	−176

These findings of an emission intensity reduction dominated by foreign, non-Western countries align with global evidence from Meng et al. (2023) indicating a narrowing gap between developing and developed countries' emission intensities. This convergence, driven by improvements in manufacturing efficiency and cleaner energy production across emerging economies, has played a crucial role in moderating the carbon footprint of developed nations like France.

4.4. Decision-based vs. origin-based decomposition

In this section, we present two complementary methods for analyzing the geographic dimension of carbon footprint changes, each offering distinct insights into the role of international factors in France's emissions trajectory. The first approach, which we refer to as decision-based, assigns changes in emission footprint according to the location where decisions—purchasing and emission intensity—are made. The second approach, which we call origin-based, attributes changes to the country in which emissions physically occur. This perspective highlights how foreign producers contribute to France's footprint and captures how production-side changes affect emissions embodied in imports. Together, these two decompositions offer a richer understanding of the geographic structure of footprint dynamics and the relative contributions of domestic and foreign factors.

Decision-based decomposition. In the decision-based approach, we reorganize our decomposition components according to whether purchasing and decarbonation decisions occur domestically or abroad, rather than by effect type (scale, composition, technique). The domestic origin encompasses all elements related to final demand, the allocation of intermediate consumption (sectoral shares, openness, and foreign country choices) occurring in France ($\mathbf{A}^{\text{sector}}_{\text{FRA}}$, $\mathbf{A}^{\text{openness}}_{\text{FRA}}$, and $\mathbf{A}^{\text{foreign}}_{\text{FRA}}$), and the emission intensity of production within France ($\mathbf{W}_{\text{FRA}}$).

It is important to note that this approach has limitations—while it distinguishes components based on where purchasing and decarbonation actions occur, many international trade decisions take place within multinational value chains, where decisions may be made in a different country from where the transaction is recorded. Nevertheless, this perspective offers valuable insights into the role of domestic versus foreign drivers in shaping France's emissions trajectory.

As shown in figure 3d, the domestic and foreign contributions to France's carbon footprint evolution reveal a striking contrast: domestic components have had a large positive contribution (increasing emissions), while foreign contributions have been strongly negative (decreasing emissions). The foreign contribution is dominated by emission intensity improvements, with the reshuffling of trade flows in foreign countries contributing positively but insufficient to counterbalance the substantial efficiency gains achieved abroad.

The domestic component exhibits distinct temporal patterns, increasing before 2008 and decreasing afterward. This shift largely reflects the accelerated transition in final demand from emission-intensive to cleaner sectors following the global financial crisis. This figure underscores France's growing dependence on foreign countries' actions for its decarbonization efforts, as domestic drivers alone would have led to higher emissions over the period studied.

Origin-based decomposition. Complementing this demand-side perspective, we can also analyze the contributions to France's footprint by emission origin country—where the emissions physically occurred rather than where purchasing decisions were made. This approach groups the components of footprint change ($\Delta \mathbf{f}_p$ in equation (9)) by origin country r. Figure 4 illustrates the evolution of these contributions for major countries.

The analysis reveals that the emission changes associated with most foreign countries are close to zero, with two notable exceptions: China and the Rest of the World aggregate, which contributed 32 and 21 Mt CO_2e respectively to France's footprint. China's contribution is particularly significant, nearly matching the entire decrease in France's overall footprint.

The Chinese contribution follows a distinct two-phase pattern. Until 2007, emissions associated with Chinese production rose sharply, driven by France's increasing openness to imports and reorientation toward Chinese suppliers (as shown in figure 3b and table 1). This upward trajectory ended with the global financial crisis, after which Chinese emissions began to decrease, due to significant improvements in emission intensity (table 2). A similar pattern is observed for emissions originating from the Rest of the World, reflecting parallel dynamics in trade relationships and emission intensity improvements.

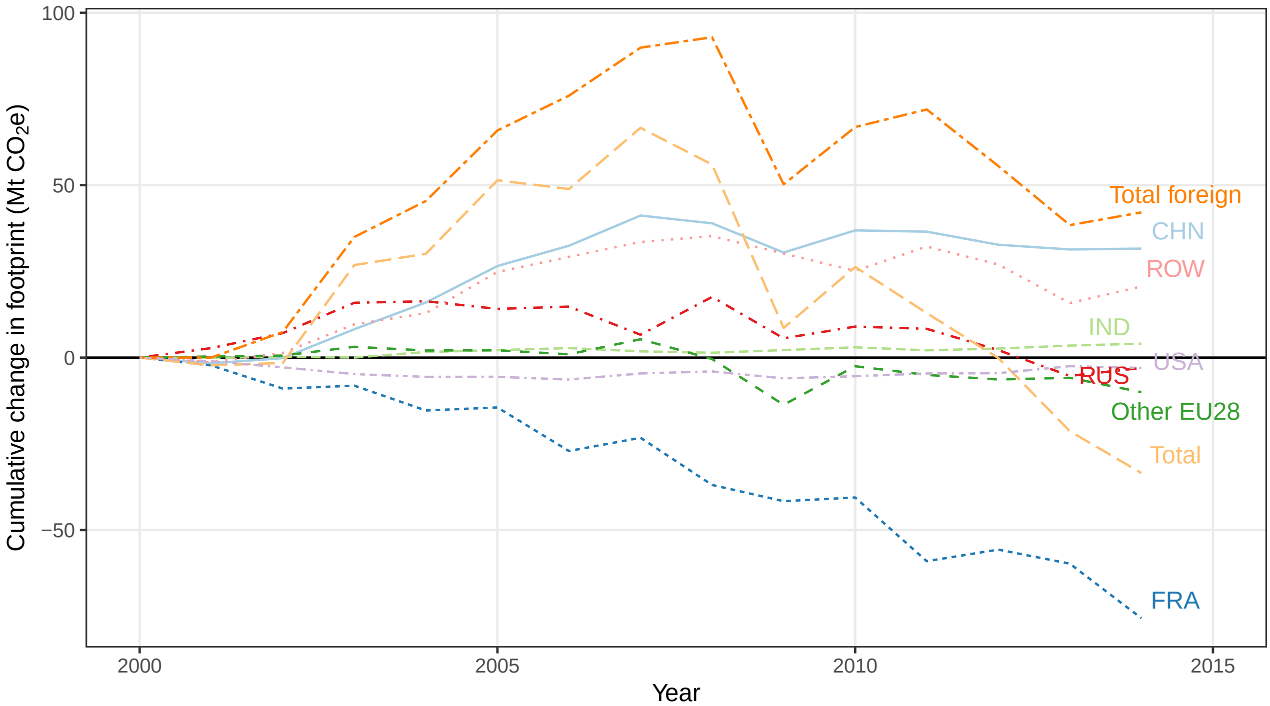


Figure 4 – Contributions to footprint changes by origin country

This dual perspective—examining both where decisions are made and where emissions occur—reveals the complex interplay between domestic consumption choices, global trade patterns, and technological improvements that collectively shape France's carbon footprint. While domestic consumption decisions have generally pushed emissions upward, improvements in production efficiency abroad, particularly in emerging economies, have acted as a crucial counterbalance.

5. Cross-country comparison of scale, composition, and technique effects

To contextualize France's carbon footprint evolution within the broader international landscape, this section examines how the drivers identified in our decomposition analysis compare across countries. This comparative perspective allows us to determine whether the strong influence of trade on France's emissions is exceptional or part of a broader international pattern. Table 3 presents the decomposition of carbon footprints for all countries included in the WIOD database. To facilitate meaningful cross-country comparison, we express emission changes relative to each country's 2000 footprint level, providing a standardized metric of relative change.

The table displays the total change in emissions alongside the scale, composition, and technique effects, highlighting the sub-components that proved most significant in our analysis of France. Additionally, it shows the contribution of emissions originating from China and the Rest of the World, as measured in figure 4, offering insights into the geographic origins of carbon footprint changes across countries.

Table 3 – Main components of footprint changes across countries (cumulated over 2000–14 and expressed in percentage of 2000 GHG emission footprints)

			Composition			Technique			Origin	
Country	Total	Scale	Total	Sect.	Geo.	Total	$W_{domestic}$	$W_{foreign}$	CHN	ROW
AUS	29	60	3	−8	11	−33	−22	−11	10	14
AUT	−12	13	6	−5	11	−31	−13	−18	4	3
BEL	−5	13	10	−10	20	−28	−8	−18	4	9
BGR	−27	38	−29	−17	−13	−36	−17	−7	2	3
BRA	33	48	1	−6	7	−17	−7	−6	6	7
CAN	22	37	9	−1	10	−24	−10	−11	9	4
CHE	14	20	18	−2	20	−24	−4	−19	6	14
CHN	140	209	3	−3	6	−72	−77	−3	118	13
CYP	−19	11	3	−11	14	−32	−23	−17	3	4
CZE	−23	22	−6	−7	1	−39	−20	−10	4	2
DEU	−5	8	11	−1	12	−24	−12	−12	5	0
DNK	−1	14	9	−6	15	−24	−8	−16	6	6
ESP	−14	14	2	−10	12	−31	−23	−13	4	3
EST	−7	40	−23	−13	−10	−25	−10	−12	4	−0
FIN	−8	21	10	−5	16	−39	−23	−14	5	5
FRA	−5	16	7	−11	18	−28	−11	−15	4	3
GBR	−2	24	−1	−11	9	−24	−18	−11	5	3
GRC	−34	−6	−1	−10	9	−27	−11	−11	2	−4
HRV	−8	29	−2	−5	3	−35	−17	−15	4	7
HUN	−35	14	−8	−7	−1	−41	−30	−11	2	4
IDN	60	88	7	−1	8	−35	−23	−8	5	7
IND	82	120	−11	−11	0	−27	−9	−4	5	11
IRL	−1	25	1	−15	15	−27	−8	−16	5	6
ITA	−25	−4	0	−13	13	−21	−7	−13	3	−6
JPN	6	6	12	−3	15	−12	4	−13	6	3
KOR	23	47	8	−2	10	−32	−28	−14	11	7
LTU	3	50	−1	2	−2	−45	−25	−15	5	15
LUX	17	35	10	−4	14	−29	−10	−19	3	8
LVA	−10	42	2	−10	12	−54	−28	−18	5	3
MEX	20	33	7	2	4	−20	−21	−7	6	4
MLT	−26	8	−10	−21	12	−24	−14	−15	5	−9
NLD	−0	6	17	−6	23	−24	−8	−17	10	3
NOR	31	45	17	−4	21	−31	−4	−21	8	8
POL	−2	34	−7	−8	1	−29	−17	−7	3	3
PRT	−29	−7	1	−7	8	−23	−15	−11	2	−3
ROU	9	68	−5	−3	−2	−54	−35	−11	3	8
RUS	28	81	−10	−12	2	−43	−15	−5	6	5
SVK	−24	29	−4	−6	2	−49	−12	−14	4	11
SVN	−19	8	5	−6	11	−32	−13	−15	5	6
SWE	4	25	16	−2	18	−37	−15	−18	8	3
TUR	30	49	5	−2	7	−23	−7	−12	8	6
TWN	1	20	2	−1	2	−21	−32	−12	7	7
USA	−3	19	1	−5	7	−24	−2	−7	5	−0
ROW	57	65	1	−5	5	−8	−5	−10	9	42
EU28	−9	15	3	−8	11	−27	−14	−13	4	1
World	35	61	2	−5	7	−28	−17	−9	21	12

With a 5% reduction in its carbon footprint between 2000 and 2014, France has experienced a more modest improvement compared to the European Union average, where emissions decreased by 9%. This finding can be partly explained by France's extensive adoption of nuclear power, which created a relatively low-carbon economy at the start of our study period, leaving less room for domestic efficiency improvements compared to more carbon-intensive EU economies.

Several patterns observed in France's footprint decomposition are also evident across other countries, indicating common global trends. First, as demonstrated in section 4.1, the technique effect dominates emission reductions across virtually all economies, confirming that technological improvements have been the primary driver of emission reductions. Second, the sectoral composition effect consistently contributes to emission reductions across countries, showing that a broad shift toward service-based economies represents a global trend with environmental benefits. Third, the geographical composition effect has consistently increased emission footprints across countries, with Chinese emissions playing a particularly significant role.

However, France exhibits distinct characteristics that support our central thesis about the particular role of trade in its emissions profile. Most strikingly, France's geographical composition effect is larger than average, increasing its footprint by 18% compared to 2000 levels—approximately 7 percentage points higher than the EU average. This pronounced effect provides evidence for our argument that France's trade relationships have been particularly consequential for its carbon footprint, driven by both increased openness and the shift toward carbon-intensive trading partners identified in section 4.2, particularly China.

The comparison validates also our finding regarding the geographic origin of emission reductions. While the magnitude of France's technique effect is comparable to the international average, its unusual composition—with more than half attributed to foreign emission intensity improvements—distinguishes France from other major economies. This dependence on foreign technical progress for footprint reduction is typically observed only in smaller, trade-dependent economies, underscoring France's unique position as a major economy with early specialization in low-carbon electricity generation through nuclear power and unusually high reliance on imported goods. This pattern provides further evidence for our earlier observation that France's footprint reductions have become increasingly dependent on actions taken abroad rather than domestic initiatives.

To understand how France's decarbonization experience could be indicative of the path other countries might follow once they reach similar emission intensity levels, we examine the relationship between initial emission intensity and the key components related to international relationships. Figure 5 plots these relationships across countries in our sample. To make countries comparable in terms of emission intensity despite different sectoral specializations, we calculate the emission intensity in 2000 by combining each country's sectoral emission intensities with the global share of each sector in total production. This approach purges the emission intensity measure from countries' specialization patterns. For countries with zero production in certain sectors (and thus no emission intensity), we apply the global emission intensity for those sectors.

The figure reveals clear patterns: countries with lower emission intensity present a larger positive role for the geographical composition component and a larger negative role for the foreign emission intensity component. These relationships hold even when controlling for development

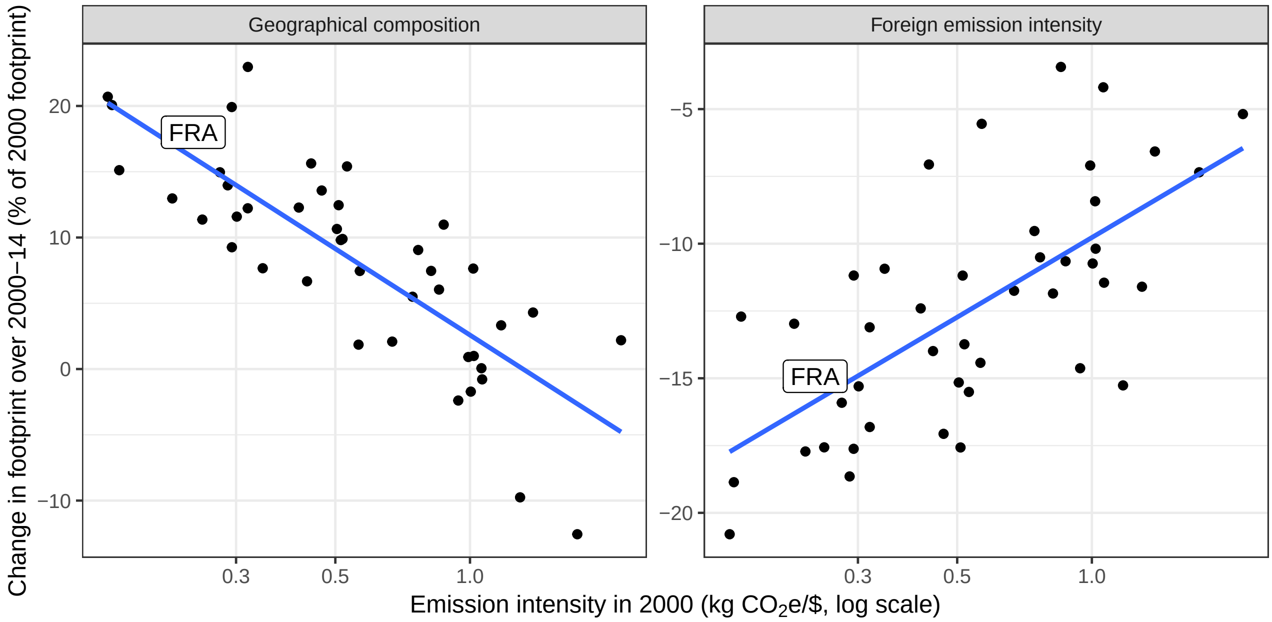


Figure 5 – Relationship between two decomposition elements (geographical composition and foreign emission intensity) and initial emission intensity (calculated using global sectoral shares)

level (using GDP per capita) and for country size (using population).

In 2000, France was among the countries with the lowest emission intensity: on average, each dollar of production in France was associated with the emission of 0.18 kg CO_2e, whereas the global average was 0.51 kg CO_2e/\$. In the sample of countries available in our database, only 4 countries in 2000 emitted less per dollar produced than France. This early decarbonization profile places France in an emblematic position, foreshadowing what other developed economies might face as they advance in their ecological transformation. In this context, domestic decarbonization becomes more costly, and imported products are mechanically likely to be manufactured with a higher emission intensity level than domestic production.

6. Conclusions

This paper has examined the evolution of France's carbon footprint between 2000 and 2014, with a particular focus on the role of international trade. By developing a novel structural decomposition approach that disentangles the influences of trade openness and the geographic origin of emission changes, we reveal the complex interplay of factors that shaped France's emissions trajectory during this period.

Our analysis began by noting France's exceptional position regarding trade-embedded emissions. The share of emissions associated with imports in France's carbon footprint increased from 45% in 2000 to 54% in 2014—a level significantly higher than that of most comparable economies.

This distinctive feature reflects both France's early adoption of low-carbon electricity generation through nuclear power and its increasing integration into global value chains over the study period. Consistent with the sharp rise in the share of trade-embedded emissions, France's total carbon footprint decreased only modestly over the period (by approximately 5%), compared to a much sharper decrease of 18% in its domestic emissions. While these trends might initially suggest that developed economies have primarily reduced their domestic emissions by outsourcing pollution to countries with weaker environmental regulations, our decomposition instead reveals a more nuanced picture characterized by multiple offsetting drivers.

Although the technique effect dominates emissions reduction—accounting for a cumulative decrease of 28% compared to 2000—trade-related factors have largely counteracted these improvements. The geographic composition effect contributed to increasing France's footprint by 18%. This substantial positive contribution is primarily the result of two distinct trade mechanisms: a 7% increase from greater trade openness (as imports replaced domestic production, given France's relatively clean production profile), and an 11% increase from a shift in imports toward countries with higher emission intensities, particularly China. The temporal pattern of these trade effects is especially revealing: the geographic reallocation of France's imports toward more carbon-intensive countries was largely complete before the 2008 global financial crisis.

This increase in the share of imported emissions in France's footprint has another important consequence: it makes any further reductions increasingly dependent on actions taken abroad. This was evident during the study period, as more than half of the technique effect (15% out of the 28% reduction) was driven by improvements in foreign emission intensities. Without these foreign efficiency gains—particularly in electricity generation and fossil fuel extraction in emerging economies—France's footprint would have increased significantly.

Our comparative analysis places France's experience in a broader international context. While many trends evident in France—such as the dominance of technique effects and the importance of sectoral shifts—are also observed across other developed economies, France stands out due to its large geographic composition effect and its reliance on foreign emission intensity improvements. These distinctive features are rooted in France's particular development trajectory, marked by early nuclear deployment, significant de-industrialization, and increased economic integration with more carbon-intensive economies.

Our findings carry important implications for climate policy. They demonstrate that recent globalization has increasingly decoupled the determinants of emission inventories from those of carbon footprints, making the latter strongly dependent on partners' actions. While France's situation may appear exceptional in this comparative analysis, it likely offers a preview of what other developed economies will face as they make progress in decarbonizing their domestic economies. France's extensive adoption of nuclear energy and significant de-industrialization have simply accelerated a transition that many developed countries are likely to encounter: as domestic emissions decline, the relative importance of emissions embedded in imports naturally increases. This development signals a fundamental shift in climate policy priorities as decarbonization advances. In the early stages, countries can achieve substantial reductions in their carbon footprint through domestic action. However, once significant domestic decarbonization has been achieved—as in France's case with low-carbon electricity—further consumption-based emission reductions increasingly depend on improved production efficiencies in trading partner countries. At this stage, international cooperation, technology transfer, and trade policy considerations become central, rather than peripheral, to climate mitigation efforts (Dugast et al., 2024). France's experience thus offers valuable lessons for other developed economies: existing climate policy frameworks that focus primarily on territorial emissions may become progressively less effective at reducing carbon footprints as domestic decarbonization advances. As more countries reach advanced stages of domestic decarbonization, the global climate regime will need to evolve toward greater coordination of trade and climate policies to address the growing importance of embedded emissions.

Despite its comprehensive approach, this study has several limitations related to the role of international trade. First, it excludes certain emissions, such as those associated with international transport, which are present in the input-output tables but not explicitly linked to trade margins, potentially underestimating the role of trade. Second, emissions from land use, land-use change, and forestry are omitted, leaving out a key element of the global carbon cycle strongly linked to agricultural production for export in tropical countries, which also risks underestimating the role of trade. Finally, the focus on the French carbon footprint does not consider the potential global benefits of French exports in reducing emissions abroad, as those benefits are incorporated in the footprints of other countries. These constraints underscore the need for cautious interpretation of the findings and highlight avenues for future refinement.

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