Estimer l'empreinte carbone de la France de 1990 à 2024 : une méthodologie pour la statistique publique basée sur FIGARO

Insee Méthodes

N° 148 – Septembre 2026

Insee
Mesurer pour comprendre

Résumé

Ce document de travail présente la méthodologie utilisée par l'Insee et le ministère de la Transition écologique pour estimer l'empreinte en gaz à effet de serre (GES) de la France, telle que publiée en octobre 2025. Elle repose sur une approche dite « *SNAC simplifiée* » (*Single-country National Accounts Consistent*), s'appuyant sur les tableaux internationaux entrées-sorties (TIES) FIGARO publiées par Eurostat. Ce document s'adresse à deux publics : les utilisateurs experts souhaitant comprendre les sources de données et les hypothèses sous-jacentes, ainsi que les compilateurs internationaux d'empreintes intéressés par les innovations techniques proposées.

La méthodologie aborde des défis clés liés à l'adaptation des TIES au contexte national, notamment la cohérence statistique (réconciliation des données économiques nationales et mondiales), les écarts de valorisation (alignement des prix de base des TIES avec les prix CAF des comptes nationaux) et la fraîcheur des données (utilisation de méthodes de prévision pour estimer l'empreinte de l'année N-1). L'approche française s'inspire de travaux antérieurs tout en introduisant des solutions originales, comme la réévaluation des importations en prix de base.

Le document décrit le cadre méthodologique *SNAC simplifié*, sa mise en œuvre et les résultats obtenus, incluant des analyses de sensibilité (ex : comparaison des résultats obtenus avec les bases d'émissions EDGAR, PRIMAP-CR et PRIMAP-TP). Il aborde également des innovations en matière de présentation des résultats, comme l'évaluation des produits de la demande finale en prix d'acquisition ou la clarification du contenu en GES des importations et exportations. Ce travail vise à intégrer au mieux l'empreinte GES dans les comptes nationaux annuels de la France, en garantissant son alignement avec les résultats monétaires.

Summary

This working paper details the methodology used by INSEE and France's Ministry of the Environment to estimate the national greenhouse gas (GHG) footprint, as published in October 2025. It adopts a so-called *simplified Single-country National Accounts Consistent (s-SNAC)* approach, leveraging Eurostat's FIGARO Multi-Regional Input-Output (MRIO) tables. The paper targets two audiences: expert users seeking insights into data sources and assumptions, and international footprint compilers interested in technical innovations.

The methodology addresses key challenges in adapting global MRIOs to national contexts, including statistical consistency (reconciling national and global economic data), valuation discrepancies (aligning basic prices in MRIOs with CIF prices in national accounts), and timeliness (using nowcasting to estimate footprints for year N-1). France's approach builds on prior work but introduces novel solutions, such as revaluing imports to basic prices and extending FIGARO's coverage.

The paper outlines the *simplified SNAC* framework, data implementation and results, including sensitivity analyses (e.g., comparing the results obtained using EDGAR, PRIMAP-CR, and PRIMAP-TP emission databases). It also discusses innovations related to the presentation of the results, such as purchaser-price valuation of final demand and clarifying GHG content embedded in imports/exports. This work aims to integrate GHG footprints into France's annual national accounts, ensuring alignment with monetary results.

Estimating the French carbon footprint from 1990 to 2024 - an official statistics methodology based on FIGARO

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April 2026

About this working paper

This working paper describes the methodology used by INSEE and the Ministry of the environment to estimate the French greenhouse gases (GHG) footprint, as published in October 2025. It follows the so-called "simplified Single-country National Accounts Consistent" or "simplified SNAC" approach, based on the Multi Regional Input-Output tables FIGARO published by Eurostat.

This paper aims at presenting the methodology in detail, rather than discussing the latest results and trends in the French GHG footprint. It is therefore mainly intended for two sorts of readers. First, for expert users of the French GHG footprint results, who would like to know more about the underlying data sources and assumptions. Second, for fellow footprint compilers from other countries or international organizations, who might be interested in the technical innovations we propose to the "simplified SNAC" approach.

While most of the source data is publicly available, the code and some specific inputs are not yet in open access. The authors will be pleased to share them upon request, and answer any additional question about the methodology.

Introduction

Since Wassily Leontief's seminal article (Leontief (1970)) which laid the groundwork for calculating an environmental footprint using input-output tables, the calculation of the carbon footprint has gradually moved beyond the purely academic realm to be regularly published by National Statistical Institutes (NSIs). In France, INSEE and the SDES (the statistical office from the Ministry of the environment) first published estimates of the national CO_2 footprint in 2010 (Lenglart et al. (2010)), following in the footsteps of other pioneering NSIs (the Netherlands, Sweden, etc.).

Estimating a greenhouse gas (GHG) footprint requires the availability of two types of data. First, global input-output tables describing, for each product and each region, the inputs used in production. Second, databases of "Air Emissions Accounts", that is GHG emissions by industry and region. The use of these databases by statistical institutes is not straightforward and poses several challenges, which are described in this paper and for which solutions are proposed.

The required tables, known as "Environmentally Extended Global Multi Regional Input-Output" (EE-GMRIO) tables, aim at describing, with a global coverage, the production structures by industry and region, and the associated environmental pressures. By definition, these tables contain much information about what happens in the "rest of the world", which means that they cannot be produced entirely in-house by a given NSI. Several initiatives, academic or institutional, have led to the publication of GMRIOs in the past. Recently, Eurostat, in collaboration with the Joint Research Centre of the European Commission, has committed to the regular production of such a model, called FIGARO (Full International and Global Accounts for Research in input-Output analysis). FIGARO can be used by national statistical institutes, particularly European ones, to measure their national carbon footprint.

However, several challenges arise when NSIs try to adapt a source designed at a supranational level to a national context:

- While they do rely on input-output tables derived from the national accounts of various countries, GMRIOs also need to reconcile import and export flows between countries, which poses structural difficulties (due to differences in recording methods, concepts, imperfect data sources, etc.). This usually results in discrepancies between a country's economic information as found in the global table versus the same information as nationally published.
- The valuation method used in the GMRIO may not align with certain national practices. For example, most MRIOs value all flows at basic prices, whereas in national accounts, imports are valued "cost, insurance and freight" (CIF). This means that a specific revaluation step is needed to effectively integrate national accounts results with a GMRIO.
- Global MRIOs are very complex to construct and are therefore not immediately available. In order to fill the need for more timely information, NSIs may consider the production of provisional results, using so-called "nowcasting" statistical methods.

This working paper presents the solutions adopted by INSEE and SDES in response to these various challenges, in order to produce their own national estimate of the carbon footprint.

The first challenge relates to overall statistical consistency : what should NSIs do when the economic and environmental statistics found in EE-GMRIO models differ from the statistics they publish otherwise ?

In Edens et al. (2015), the Dutch statistical institute first proposed a methodology to develop national carbon footprint estimates consistent with (nationally published) National Accounts, giving rise to the so-called "Single-country National Accounts Consistent" (SNAC) methodology. The general idea is to start from an existing MRIO, replace the domestic information with the one from the nationally published IOT, and then re-balance the whole table to ensure that the global accounting equations are still fulfilled.

The methodology was also implemented in Hambÿe et al. (2018) for Belgium. The UK builds a "UKMRIO" model which achieves a similar result, albeit from a slightly different perspective. A dedicated global MRIO - based on EXIOBASE and FIGARO - is fully reconstructed around the national input-output table (IOT), rather than the national IOT being just embedded into an already existing MRIO, see Owen and Kilian (2025).

To avoid the need to modify and re-balance the full global MRIO (which is technically complex and prone to numerical convergence issues), a "simplified SNAC" approach has been proposed in Palm and Wood (2016) and Tukker et al. (2018a). The idea is to use national statistics to estimate the domestic component of the footprint, as well as the direct and indirect import requirements of domestic final demand in monetary terms. The MRIO is then only used to estimate a GHG content *per unit of imported products* (in kg CO_2eq / euro), which allows to compute the imported footprint. The main advantage compared to the initial SNAC approach is the ease of implementation, while the main drawback is the loss of the full consistency of the global MRIO. The method was implemented for the first time in Palm et al. (2019) to estimate the Swedish environmental footprint (not only for GHG emissions but also for land use, water and material consumption). Since then, several countries have implemented simplified SNAC methods based on EXIOBASE to estimate their national GHG footprint (among them : Denmark, Finland and Norway).

In France, between 2013 and 2023, the statistical office from the Ministry of the environment had been estimating a national carbon footprint every year, using a "single region input-output" (SRIO) methodology. This estimation was based on an environmentally extended input-output model of the French economy and 18 "exporting regions", but with each region considered in isolation. In practice, this means that goods exported to France were considered to be entirely produced in the country of last origin, with no real modeling of international value chains (which is precisely what is allowed by MRIOs).

In parallel, the French ecological transition agency (ADEME) has developed a simplified SNAC model based on EXIOBASE called MatMat (for Materials Matrices). The model is used for integrated environmental–economic analysis and long-term prospective assessments. In addition to GHG footprints, MatMat also covers other environmental extensions, such as physical energy flows and material footprints (Teixeira and Lefèvre (2025), Teixeira (2024), Teixeira et al. (2025)).

Finally, in Bourgeois et al. (2023), researchers from INSEE compared various GMRIO models (EXIOBASE, ICIO, FIGARO, EORA and WIOD) to determine the uncertainty in the French GHG footprint linked to the choice of the model, and more specifically the role of geographical and sectoral aggregation.

This working paper presents a new approach by the French statistical system to estimate the national GHG footprint, using a simplified SNAC methodology based on FIGARO. The project was conducted jointly by INSEE and the French Ministry of the environment between 2022 and 2024. All results have been published for the first time on November 5th 2024, and updated a year later on October 16th 2025 (see Annex A for links to the press releases and a list of the dissemination tables). From now on, we plan to update this publication every year in October.

The second challenge we noted above lies in the different valuation of imports between GMRIOs (basic prices) and national data (CIF prices). In this paper, we explain how, before applying the simplified SNAC methodology, we modify the valuation of imports in our national IOT, to basic prices rather than "cost, insurance and freight" (CIF), in order to make the IOT fully consistent with the MRIO valuation (section 5.1).

The third challenge NSIs face relates to timeliness. The FIGARO tables are published every year in July, up to the reference year N-2 (ex : up to the year 2023 for the July 2025 release). This is a very predictable schedule, and already quite early compared to other initiatives. However, for our national dissemination, we feel the need to go even further, up to the year N-1 (ex : year 2024 for our November 2025 release). This is because our ultimate goal is to supplement all French national accounts annual results with their "GHG equivalent", from a production and a consumption perspective. We would partly miss this objective if there was a one-year delay between the dissemination of the monetary results on final consumption and their GHG equivalent. In this paper, we therefore propose a nowcasting method to estimate the national carbon footprint up to the year N-1, when the FIGARO tables are not yet available (section 6).

After the question of "*how to estimate the GHG footprint ?*" comes the issue of "*how to present the footprint results ?*". The recent paper of Yamano et al. (2024) from the OECD explores new indicators (such as *scope 1, 2 and 3* emissions from industries) or variants of existing indicators (such as the GHG content of final demand *including distribution margins*, or the GHG content of *gross imports and exports*). Many such indicators can be built on top of the EE-MRIO framework, but they sometimes require some particular post-treatment of the EE-MRIO results. In this paper, we explain all the relevant post-treatments we have made to prepare our dissemination tables.

This working paper is organized in three parts. Part 1 presents the methodological framework we use to estimate the French carbon footprint, that is the "simplified SNAC methodology". Part 2 presents the specific data sources and implementation we have chosen to estimate the French GHG footprint using the simplified-SNAC approach, with some technical innovations compared to earlier works.

Finally part 3 presents and discusses the results of our estimation. To assess the sensitivity of our results to the data-source for global GHG emissions, we compare 3 variants of the footprint, where the Air emission accounts of non-EU countries are based respectively on EDGAR, PRIMAP-CR and PRIMAP-TP (section 8.4). A section is devoted to "presentation issues", meaning issues which do not affect the total footprint figure, but only the way results are presented to users. We propose a way to present footprint results by final use products in a *purchaser price valuation* rather than *basic price* (section 9.1). We also show how we articulate the two notions of *GHG content of gross imports and exports* vs. *net GHG imports and exports* in our dissemination tables. Finally, the last section provides a comparison between FIGARO and other footprint models, EXIOBASE and ICIO (section 10).

Contents

Part I

Methodological framework

1 Estimating a GHG footprint using an environmentally extended GMRIO

1.1 A brief description of GMRIOs and their environmental extensions

For a given reference year, a GMRIO consists in a set of data tables describing the input-output relationships of the global economy, across regions and industries.

While practical details may vary between specific GMRIOs, at least in principle a GMRIO can be seen as composed of 4 different tables : a *supply table* at basic prices, a *use table* at basic prices and two *input-output tables* : "product X product" and "industry X industry". All supply and use elements are measured in a common currency (typically dollar or euro, at current prices). The level of detail for products, industries and regions depends on the specific GMRIO.

The *supply table* presents the output by product for each industry. The *use table* at basic prices can be decomposed in two blocks:

- The "intermediate consumption table" describes intermediate consumption by product X user industry, i.e. the inputs consumed by each industry to produce its annual output;
- The "final use table" describes the final use of each product, broken down into different categories (typically: final consumption by general government, households and NPISHs, gross fixed capital formation, changes in inventories and acquisition less disposal of valuables).

Each row of the *use table* at basic prices corresponds to a product, and for each product the sum of all uses (intermediate plus final) is equal to the total supply.

The "intermediate consumption" block of the *use table* is not "symmetrical". It shows products in the rows and industries in the columns. For this reason, the Leontieff's approach to estimate GHG footprints (see next section) cannot be applied directly. Most GMRIOs databases therefore offer two *input-output tables* (IOT) derived from the use table at basic prices, which are suitable for Leontieff type modeling. A *product x product* IOT where the intermediate use table has been modified to show products in columns; and an *industry X industry* IOT where the intermediate use table shows industries in rows. Note that in this second table, the "final use" block has also been modified to show industries in rows instead of products.

The GMRIOs environmental extensions are vectors describing the environmental pressures directly linked to output, by region and industry. Each physical pressure (for example : emissions of carbon dioxide, methane, nitrous oxide, etc.) is represented by a separate vector.

1.2 Leontieff approach to estimating a GHG footprint using an EE-GMRIO

In this section and the following ones, mathematical equations will be accompanied with the dimensions *(number of rows X number of columns)* of the various vectors and matrices involved. For this, we will use the dimensions of FIGARO version 2024, with 64 different product classes and 46 regions, that is 2.944 distinct products. FIGARO version 2025 introduces 4 additional countries, but all the methodological work in this paper has been conducted at the previous aggregation level. These numbers are illustrative, and could be replaced with the dimensions of any other specific GMRIO without any loss of generality.

As explained in the previous section, a GMRIO *product x product* IOT allows us to draw a supply-use equation for the global economy.

$$\underbrace{P}_{2944\times1} = \underbrace{IC}_{2944\times2944} . \underbrace{\mathbb{1}}_{2944\times1} + \underbrace{FU}_{2944\times1}$$

Where P is the vector of output by product, IC the matrix of *product x product* intermediate consumption, $\mathbb{1}$ the summation vector and FU the vector of final use. We then define the matrix A of technical coefficients as the intermediate consumption matrix normalized by the vector of total output.

$$\underbrace{A}_{2944\times2944} = \underbrace{IC}_{2944\times2944} . \underbrace{(1/P)^t}_{1\times2944}$$

Where $1/P$ denotes the term par term inverse of the vector P and the superscript t is the transposition operator. Each column in the matrix A shows the inputs required for the production of one unit of a given product. We can now rewrite the global supply-use equation as :

$$P = A.P + FU$$

Which allows us to express global production as a function of global final use :

$$P = (I - A)^{-1}FU$$

So far, what we have done is only rewriting the global supply-use accounting equation. The Leontieff model starts from this equation and states that, for any vector of final use X, we can define the "production induced by this final use" P_X (or "the production necessary to satisfy this final use") as :

$$\underbrace{P_X}_{2944\times1} = \underbrace{(I - A)^{-1}}_{2944\times2944} \underbrace{X}_{2944\times1}$$

The crucial difference with the previous accounting equation is that now, X does not represent the full global final use, but any arbitrary subset of it, such as the final use of a given country, or the household consumption in a specific product. To make sense, this modeling implicitly assumes (i) a perfect homogeneity of products inside product groups and (ii) a proportionality of input to a given demand (constant return to scale, i.e. you need twice the input to satisfy a twice larger demand).

This basic model can then be "extended" using various external information, as far as they can reasonably be considered proportional to the output P_X. To estimate a GHG footprint, we will for example define e as the vector of GHG emissions per unit of output. The GHG footprint F_{mrio} associated to the final use vector FU is then defined as:

$$\underbrace{F_{mrio}}_{1\times1} = \underbrace{e}_{1\times2944} \underbrace{(I - A)^{-1}}_{2944\times2944} \underbrace{FU}_{2944\times1} \quad (1)$$

For an extensive introduction to input-output modeling, see for example Miller and Blair (2009).

2 The simplified-SNAC method: a variant of the EE-GMRIO approach

2.1 Principle of the simplified-SNAC methodology

As explained in the introduction, statistical institutes whishing to estimate a national carbon footprint face a consistency problem, as the economic information contained in the GMRIO is always somewhat different from their own national estimates.

Why is it so ? MRIO compilers are inevitably confronted with the following problem: the import and export statistics published by various countries are not consistent with each other. In general, what country A reports as imports from country B differs from what country B reports as exports to country A. This inconsistency forces MRIO compilers to arbitrate and apply various re-balancing procedures to ensure the consistency of global flows of goods and services. In practice, they have to modify either the imports declared by countries, or the exports, or both.

In this context, INSEE and SDES chose to apply a so-called ”simplified Single National Accounts Consistent” (s-SNAC) approach to estimate the French carbon footprint. Here, the ”single” means that we adapt the results from FIGARO to ensure their consistency with French national accounts, without trying to improve the consistency with other countries' accounts.

Our main motivation is to stay as close as possible to our nationally published results, in order to create a fully integrated information system for our national users. We consider that the “simplified SNAC” approach is a very natural option for national accountants, because in the end, compiling national accounts is all about making a consistent synthesis of several (more or less) inconsistent data sources.

As mentionned in the introduction, the full SNAC methodology was introduced in Edens et al. (2015). Starting from a given MRIO, the principle would be to replace all data corresponding to France (output by product; domestic use of domestic and imported products) by nationally published French national accounts data, and then re-balance the whole table to preserve accounting equations. The ”simplified SNAC” methodology was presented in Tukker et al. (2018a). Contrary to the full SNAC methodology, it does not require modifications to the GMRIO IOT itself. As explained in the following section, it merely consists in using the French national accounts as the data-source for certain terms in the Leontieff expression of the French carbon footprint, and the GMRIO for the other terms.

2.2 Overview of the simplified-SNAC methodological framework

To implement this approach, we first separate the French final use vector FU^{Fr} (of length 2.944) into two terms : final use of French products FU^{Fr}_{Fr} (of length 64) and final use of foreign products FU^{Fr}_{M} (of length 2.880). Please note that the ordering of countries and products in the MRIO tables is entirely arbitrary and does not affect the results. In the following equations, French products are placed in the first position purely for the convenience of the notation. We denote $\overline{FU^{Fr}_{M}}$ the vector of French final use where the demand for French products has been set to zero. $\overline{FU^{Fr}_{M}}$ is of dimension 2.944.

$$FU^{Fr} = \begin{pmatrix} FU^{Fr}_{Fr} \\ FU^{Fr}_{M} \end{pmatrix} = \overline{FU^{Fr}_{Fr}} + \overline{FU^{Fr}_{M}}$$

$$\text{where} \quad \overline{FU^{Fr}_{Fr}} = \begin{pmatrix} FU^{Fr}_{Fr} \\ 0 \end{pmatrix} \quad \text{and} \quad \overline{FU^{Fr}_{M}} = \begin{pmatrix} 0 \\ FU^{Fr}_{M} \end{pmatrix}$$

We can use the Leontieff equation 1 to decompose the GHG footprint F^{Fr}_{mrio} into three additive terms :

$$F^{Fr}_{mrio} = \underbrace{e_{Fr}}_{1\times 64}\underbrace{(I - A^{Fr}_{Fr})^{-1}}_{64\times 64}\underbrace{FU^{Fr}_{Fr}}_{64\times 1} + \underbrace{e}_{1\times 2944}\underbrace{(I - A)^{-1}}_{2944\times 2944}\underbrace{\overline{A^{Fr}_{M}}}_{2944\times 64}\underbrace{(I - A^{Fr}_{Fr})^{-1}}_{64\times 64}\underbrace{FU^{Fr}_{Fr}}_{64\times 1} + \underbrace{e}_{1\times 2944}\underbrace{(I - A)^{-1}}_{2944\times 2944}\underbrace{\overline{FU^{Fr}_{M}}}_{2944\times 1} \quad (2)$$

Where A_{Fr}^{Fr} is the matrix of technical coefficients reduced to French products used by French industries and $\overline{A_M^{Fr}}$ is the matrix of technical coefficients reduced to foreign products used by French industries. As $\overline{FU_M^{Fr}}$, $\overline{A_M^{Fr}}$ is in fact the complete matrix of French industries technical coefficients, where the demand for French products has been set to zero. Finally, e_{Fr} is just the French GHG emission intensity by industry, that is a subset of e. This decomposition is not entirely straightforward and its proof is given in Annex B.

The economic interpretation of equation 2 is that we can first take a purely domestic component of the footprint (ie. French emissions induced by the domestic final use of French products), without considering any interaction with the rest of the world (first term). We can then compute the indirect requirement of foreign products induced by this "purely domestic" footprint (through the $\overline{A_M^{Fr}}$ matrix), and estimate its global footprint (second term). The last term corresponds simply to the global footprint of the French domestic final use of foreign products.

In the simplified SNAC methodology, the footprint is defined as in equation 2, where we replace all the terms in red by the value they have in the French national accounts, rather than in FIGARO:

$$F_{s-snac}^{Fr} = \underbrace{e_{Fr}}_{1\times 64}\underbrace{(I-A_{Fr}^{Fr})^{-1}}_{64\times 64}\underbrace{FU_{Fr}^{Fr}}_{64\times 1} + \underbrace{e}_{1\times 2944}\underbrace{(I-A)^{-1}}_{2944\times 2944}\underbrace{\overline{A_M^{Fr}}}_{2944\times 64}\underbrace{(I-A_{Fr}^{Fr})^{-1}}_{64\times 64}\underbrace{FU_{Fr}^{Fr}}_{64\times 1} + \underbrace{e}_{1\times 2944}\underbrace{(I-A)^{-1}}_{2944\times 2944}\underbrace{\overline{FU_M^{Fr}}}_{2944\times 1} \quad (3)$$

The only term taken directly from FIGARO is therefore the vector of "unit GHG content of foreign products" $e(I-A)^{-1}$, in kg CO_2eq per euro (very often denominated as the "multiplier" vector in input-output analysis). This unit content vector is applied to the imports for intermediate use induced by the French final use of domestic products (in the second term) and to imports for final use (in the last term).

In practice, as FIGARO is very well aligned with the French national accounts regarding the use of domestic products, the terms A_{Fr}^{Fr} and FU_{Fr}^{Fr} will be very close in equations 2 and 3. They will in fact be identical, except for reasons of vintage differences in the most recent years. More important differences will show up for $\overline{A_M^{Fr}}$ and $\overline{FU_M^{Fr}}$, as explained in section 5.2.

Finally, a word about the emission intensity vector e that we will use in the simplified SNAC methodology. Generally speaking, e is equal to the vector of global emissions E divided by the vector of global output P (term by term division). As the emission vector E is independent from the economic data we use, we can use exactly the same vector in both MRIO and simplified SNAC footprint estimations. In the denominator however, when doing the simplified SNAC estimation, we will slightly modify the P vector from FIGARO into a P_{snac} vector, by replacing the French products outputs by their value in French national accounts. We then recalculate a global vector $e_{snac} = E/P_{snac}$ (term by term division). This modification is very small, and has very little impact on the final estimates (because the output of French products in FIGARO is nearly equal to its value in French national accounts). However, it allows us to keep a single, perfectly consistent, data source for the vector e_{Fr} (numerator and denominator) rather than two very slightly different versions of it, depending on wether we compute the first term of the s-SNAC footprint ("domestic footprint") or the last two terms ("imported footprint").

In practice, we apply the calculation above independently for four types of greenhouse gases : carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and an aggregate of fluorinated gases (*F-gases*). Aggregate GHG results in CO_2 equivalent (CO_2eq) are computed using the IPCC AR5 global warming potentials at a 100 years horizon.

2.3 Effect of the simplification underlying the simplified-SNAC method

The simplified SNAC methodology allows us to describe nearly all of the French emissions and economic value chain contributing to the national footprint with nationally published data, while keeping a simpler framework than the full SNAC approach.

In equation 3, a small part of the GHG emissions occurring in France and contributing to the French footprint will be embedded in the vector of unit GHG content of global products $e(I-A)^{-1}$ (in the second and third terms). Indeed, in the global value chain, a product may be manufactured in France (causing direct emissions), be exported to a partner country, used as an input to manufacture another product, and be re-imported in France under this new form. In practice in 2021, we find that only 0.9 % of the GHG content of products imported in France to satisfy the French final demand originates in France (more details in section 9.3).

This means that using a full SNAC approach rather than the simplified SNAC could only improve the consistency with national data on this 0.9 % of imported GHG content. This in turn suggests that the result we would obtain using a full SNAC would not meaningfully differ from the simplified SNAC approach. This finding is consistent with previous findings about the irrelevance of feedback impacts between exports and imports in Moran et al. (2017) and Tukker et al. (2018b).

2.4 Origin of the emissions vs. emissions embodied in final products

There are several ways to break down the footprint results for analysis. They differ only in the way we choose to keep track of the various contributions to the different scalar products in equation 3.

A first option, often referred to as the "production perspective", is to split the footprint according to the source of the emissions (country X industry of origin of the emissions). This amounts to expressing the footprint as the GHG intensity of output (in kg CO_2eq / euro) times the production induced by the French final demand (in euros). Or, in mathematical terms, not contract the scalar product between the purple and green terms :

$$F^{Fr}_{s-snac} = \underbrace{e_{Fr}}_{\substack{prod\\intensity}} \underbrace{(I-A^{Fr}_{Fr})^{-1}FU^{Fr}_{Fr}}_{\substack{induced\\production}} + \underbrace{e}_{\substack{prod\\intensity}} \underbrace{(I-A)^{-1}\overline{A^{Fr}_{M}}(I-A^{Fr}_{Fr})^{-1}FU^{Fr}_{Fr}}_{\substack{induced\\production}} + \underbrace{e}_{\substack{prod\\intensity}} \underbrace{(I-A)^{-1}\overline{FU^{Fr}_{M}}}_{\substack{induced\\production}}$$

A second possible breakdown, often referred to as the "consumption perspective", is to place oneself at the end-side of the value chain, and consider the GHG content embedded in the products destined to the final demand (households consumption or investment). This amounts to expressing the footprint as the unit GHG content of final products (in kg CO_2eq / euro) (often called the "multiplier" in the input-output literature) times the French final demand (in euros). Or, in mathematical terms, not contract the scalar product between the blue and orange terms :

$$F^{Fr}_{s-snac} = \underbrace{e_{Fr}(I-A^{Fr}_{Fr})^{-1}}_{\substack{unit\\content}} \underbrace{FU^{Fr}_{Fr}}_{\substack{final\\demand}} + \underbrace{e(I-A)^{-1}\overline{A^{Fr}_{M}}(I-A^{Fr}_{Fr})^{-1}}_{\substack{unit\\content}} \underbrace{FU^{Fr}_{Fr}}_{\substack{final\\demand}} + \underbrace{e(I-A)^{-1}}_{\substack{unit\\content}} \underbrace{\overline{FU^{Fr}_{M}}}_{\substack{final\\demand}}$$

Beyond the analysis of the GHG emissions associated with French final demand, the first two terms of this decomposition can also be used to analyze the "upstream GHG footprint" of French domestic production, providing a useful supplement to the direct emissions depicted in the Air Emission Accounts.

Section 9.4 illustrates the results we find according the "production perspective" and "consumption perspectives" for the French carbon footprint in 2023.

Finally, if we are interested specifically in analyzing the contribution of the imports for intermediate use into the French GHG footprint, there is another way to decompose the second term in equation 3, that is expressing it as the unit GHG content of final products (in kg CO_2eq / euro) times the indirect requirement of foreign products (in euros). Or, in mathematical terms, not contract the scalar product between the cyan and red terms :

$$e(I-A)^{-1}\overline{A_M^{Fr}}(I-A_{Fr}^{Fr})^{-1}FU_{Fr}^{Fr} = \underbrace{e(I-A)^{-1}}_{unit\ content}\underbrace{\overline{A_M^{Fr}}(I-A_{Fr}^{Fr})^{-1}FU_{Fr}^{Fr}}_{indirect\ requirement} \quad (4)$$

In our public dissemination tables, we mostly make use of the first and second breakdowns of the footprint. The third decomposition is more of a methodological one : it describes an intermediate step in the value chain, which is neither the initial output, nor the final use. We use it for example in section 7 to analyze the differences between our simplified SNAC estimate and the direct FIGARO estimate of the French GHG footprint.

3 Notion of a carbon content of gross imports and exports

3.1 What do we want to measure ?

The footprint estimation process naturally leads to a bridge table similar to the table 1, which articulates the source of the GHG emissions (French resident units vs. foreign resident units) and the destination of the emissions (induced by the French final demand vs. the foreign final demand).

Table 1 shows that in 2024, French resident emissions (excluding households direct emissions) amount to 305 Mt CO_2eq, of which 180 Mt are induced by the French final demand and 125 Mt by the foreign final demand. Moreover, 284 Mt CO_2eq of foreign emissions are induced by the French final demand, which gives a total French GHG footprint of 463 Mt CO_2eq.

Table 1: French resident emissions and footprint in 2024 (excl. households direct emissions, million tons CO_2eq)

Residency / final-use	**French final use**	**Foreign final use**	**All final users**
Resident in France	180	125	**305**
Resident abroad	284	-	-
All emission countries	**463**	-	-

This table is very useful to articulate the concepts of resident emissions with consumption based emissions. However, it is not sufficient to describe all GHG flows in and out of the French economy. Indeed, French imports incorporate a significant GHG content of foreign origin which will not serve *French* final demand, but *foreign* final demand, through exports. This "carbon passing through the French economy" is neutral on the national footprint.

It is therefore useful to define a notion of "carbon content of gross imports", which covers all the GHG embedded in French imports as they cross the border, irrespective of their subsequent use. Similarly, we can define a notion of "carbon content of gross exports", as they cross the French border.

This definition is also motivated by the analogy with the classical "GDP equation", which is a supply and use equation at the national level :

$$GDP + M = FU + X$$

In this equation, we can remark that GDP is a "net resource" (only value added is accounted for, not the full output value), whereas M is a "gross resource" (the full product value). If we are to build a GHG equivalent of the GDP equation, we need to describe the full carbon content of imports and exports, not only the "net imports" and "net exports" (ie. the foreign emissions contributing to the footprint / the French emissions induced by foreign final demand).

3.2 How to measure it ?

By definition, the Leontieff framework is only suitable to express the GHG emissions induced by *final demand* vectors. If we try to apply the Leontieff inverse matrix $L = (I - A)^{-1}$ to an arbitrary vector of product, we risk running into double counting issues, which will break the interpretability of the results. According to this view, the vector of unit GHG contents $e.L$ should not be applied to any arbitrary vector of products, such as "French imports" of "French exports".

While this is true, we can also hold a more "physically realistic view" of the carbon footprint, at the product level. The $e.L$ vector tells us for example that a computer produced in country X has a certain GHG content when destined to the final consumption of a French household. There is no reason to consider that the exact same computer, produced with the same technology, would have a different GHG content if destined to intermediate consumption. In other terms, the $e.L$ vector can be viewed as a general operator which gives us an estimate of the GHG embedded in any product, at any point in the value chain (intermediate or final step).

We can now consider what happens if we apply this operator to the full GDP equation :

$$e.L.GDP + e.L.M = e.L.FU + e.L.X$$

Note that, for this to make sense, the GDP equation must be written in a vectorized form, product by product, and not be aggregated into scalars. In this vectorized equation M represents the French imports by product (zero for the 64 French products, and potentially non-zero for the 2.880 foreign products); FU and X represent respectively the vectors of French final use and exports of all 2.944 products considered in our model. Finally, GDP is the vector resulting from the term by term difference between French output (non-zero only for the 64 French products, and 0 for the 2.880 imported products) and French intermediate consumption (potentially non-zero for all 2.944 products).

With this vectorized form, we can notice that $GDP = (I - A).P$ (this is the definition of the matrix A) and therefore we can simplify $e.L.GDP = e.P = E_{Fr}$ to obtain the total French resident emissions. In other terms, resident emissions are "the footprint of GDP", which makes intuitive sense. We can also notice that $e.L.FU$ is, by definition, the French GHG footprint. After rearranging the terms, this gives us the following equality :

$$F_{Fr} = E_{Fr} + e.L.M - e.L.X \tag{5}$$

The French carbon footprint is equal to the French resident emissions, plus the carbon content of gross imports (as measured by the Leontieff operator $e.L$), minus the carbon content of gross exports. We argue that this equation, despite presenting some amount of double counting of French emissions (between E_{Fr} and $e.L.M$), is a perfectly valid way of presenting the articulation between the French resident emissions and the French GHG footprint. After all, the same double counting is already present in the monetary GDP equation : a small part of the monetary value of imports can, in fact, be traced back to French value added.

The discussion we propose here is not new. Equation 5 was already highlighted for example in Palm and Wood (2016). Recent papers Wood et al. (2024) and Yamano et al. (2024) both use the term of "emissions embodied in gross exports and imports" to describe the same notion. There is also a direct link between the discussion we present here on carbon contents, and the older discussion of *trade in value added* vs. *value added in trade*, with similar considerations of "double counting".

The treatment of "re-exports" can be discussed. Re-exports occur when goods are imported by a resident unit (so that there is a real change in economic property) and then resold abroad with no transformation. They are not to be confused with transit or quasi-transit where there is no change in economic property, and therefore no entry at all in National accounts. Although re-exports are recorded in national IOTs, in a GMRIO they do not appear at all. Indeed, they are neither an intermediate nor a domestic final use of the country where the goods are bought and resold. This means that, in a pure GMRIO context, equation 5 would cover imports M and exports X *excluding re-exports*. The "carbon passing through the French economy" would cover only the GHG content of goods which are imported for intermediate use, subject to a transformation and then re-exported under a new form. On the contrary, in a s-SNAC context, it is possible to apply equation 5 to the full M and X *including re-exports*. The "carbon passing through the French economy" will be higher, and cover both goods which are transformed by the domestic industries, and goods which are bought and resold with no transformation.

Section 9.5 presents an example of a dissemination table where these different notions are articulated.

Part II

Data sources and simplified-SNAC implementation

4 Global data sources: FIGARO and its Air Emissions extension

4.1 The FIGARO global multi-regional input-output database

The FIGARO database (Full International and Global Accounts for Research in input-Output analysis) is the result of a co-operation project between Eurostat and the Joint Research Centre of the European Commission. Public dissemination started in 2021, and the database has been updated annually since.

For a given reference year, FIGARO is composed of 4 different tables : a *supply table* at basic prices, a *use table* at basic prices and two *input-output tables* : "product X product" and "industry X industry". All supply and use elements are measured in million euros, current prices, and the level of detail is as follows: 49 countries + one "Rest of the world" region X 64 activities or products, according to the NACE / CPA A64 nomenclature[1].

We chose FIGARO as the basis for our own national estimation for several reasons. The first one is its intrinsic statistical quality : FIGARO is a modern, state of the art MRIO, which is very well aligned to European national accounts and incorporates many lessons and procedures from earlier MRIO initiative, in particular the OECD's ICIO. The second one is its institutional status. FIGARO is now considered by the European Commission as "official statistics", which means that we can expect a regular update of the tables over the medium-term, every year in July. This predictability is quite unique among MRIOs, and is extremely valuable to us, as we plan to update our own footprint results yearly.

4.2 Eurostat's global Air Emission Accounts based on EDGAR

The estimation of a GHG footprint using a MRIO requires a global dataset of GHG emissions by country X industry also known as "Air Emissions Accounts" (AEAs). The AEAs are a specific form of GHG emission inventory, with two distinctive features :

- Contrary to the original IPCC inventories, AEAs follow an "economic residency" principle rather than a territorial principle.
- Emissions are not broken down by technical sources of emissions (fuel type, chemical process ...) but rather by industry (NACE codes) and "direct household emissions".

These two modifications are introduced in order to make the AEAs fully compatible with the national accounting principles of the MRIO tables, an thus enable a proper "environmentally extended input-output analysis". As an illustration, the total AEA emissions of French resident units amounted to 404 Mt CO_2eq in 2024, compared to 369 Mt CO_2eq for the IPCC territorial inventory.

The problem is that perfectly authoritative global AEAs are not readily available. European countries, as well as a few others, regularly produce such tables, but this is far from covering a majority of global emissions. Footprint practitioners are consequently obliged to "fill the gap", by estimating the missing AEAs from other sources, notably IPCC emission inventories.

For our project, we choose to rely on global AEAs estimated by Eurostat in the context of the FIGARO project. Eurostat's complete methodology is described in Eurostat Unit E.2 (2024). Countries are split in three groups:

[1] FIGARO version 2024 describes 64 different product classes and 46 regions, that is 2.944 distinct products. FIGARO version 2025 introduces 4 additional countries, but all the methodological work in this paper has been conducted at the previous aggregation level.

- For EU countries and the UK, Eurostat directly uses the AEAs published by the countries.
- For Switzerland, Norway and Turkey, Eurostat uses incomplete AEAs published by the countries and expands them to the appropriate level of detail.
- Finally, for all other countries, Eurostat builds the AEAs from the EDGAR database ("Emissions Database for Global Atmospheric Research"), developed by the European Commission (Crippa et al. (2024)). The EDGAR database contains GHG emissions in the IPCC format (territorial emissions in the "common reporting format" CRF nomenclature). An extra step is therefore needed to convert the data to the "Air Emissions Accounts" format. Eurostat's methodology to convert from IPCC to AEAs mostly consists in two things : first, allocating GHG emissions from the CRF nomenclature (in EDGAR) to the NACE nomenclature (in the AEAs); second, adjusting the perimeter to take into account "mobile sources" of emissions for maritime and air transport, which are not allocated in territorial emission inventories.

Choosing Eurostat's global AEAs offers several advantages for our project. First, Eurostat AEAs have been developed specifically to be used with FIGARO, so they are directly compiled at the appropriate level of detail (46 regions X 64 industries). Second, the compilation of these AEAs actually incorporates some monetary results of the FIGARO tables to assist in the allocation of emissions from the CRF nomenclature to the NACE nomenclature. This ensures that, by design, the NACE allocation of GHG emissions will be fairly in line with monetary output as described in FIGARO, and that the resulting emission intensities by industry will make sense.

The AEAs compiled by Eurostat have other distinctive advantages. The main one is that they use very recent and exhaustive sources on international air and maritime transport, compiled by the OECD. This means that the implementation of the residency principle for these "mobile sources" of emissions is based on the best data currently available.

To better understand this data source and also to have a more complete control of its timeliness, we have chosen to replicate Eurostat's methodology to estimate global AEAs. The resulting code is available here : `https://github.com/InseeFrLab/global-ghg-emissions`. The main benefit of this replication effort is that we can generate "FIGARO compatible" AEAs for our owns needs in our own timelines, and also explore variants of them (see section 8.4 for an example of variants based on PRIMAP).

5 Data sources and treatment for estimating France's carbon footprint from 2010 to 2023

5.1 Valuing imports in "basic prices" in the French IOT

5.1.1 Principle

In the FIGARO MRIO tables, all uses are valued in basic price, that is the amount of money actually received and kept by the producer (this can be seen as the price "out of the factory"). Potential trade and transport margins (TTM) are not part of the basic price of the goods but are recorded as if they were "consumed" separately by users, under the relevant service category (transport, trade, insurance). In the nationally published French IOT however, as in all nationally published accounts, imports are valued "CIF" (cost insurance and freight), that is the value they have when they enter the French territory.

To retrieve the basic price of French imports from the CIF price, we must substract two types of margins :

- Margins occurring in the exporter country, between the factory and the exporter's border. Those are the "domestic margins" in this country. At the exporting country's border, the goods are valued "FOB" (free on board);
- Margins occurring in international transit, between the border of the exporting country and the French border. Those are called the "CIF-FOB margins" and by definition they depend on the country of origin. They only apply to imports from countries which are not direct French neighbors, while they are zero for neighboring countries.

Let us take the example of a car built in China and sold in France in a dealership for 18.000 euros. We want to disentangle the following elements (the figures are purely illustrative) :

- Basic price (out of the factory in China) : 13.000 euros
- Trade and transport margins in China : 500 euros
- Transport and insurance margins in transit between China and France (CIF-FOB margins) : 1.500 euros
- Trade and transport margins in France : 1.000 euros
- VAT and other taxes in France : 2.000 euros
- Purchaser price for a household in France : 18 000 euros

This breakdown will allow us to make a correct estimation of the carbon footprint of the car, by applying the *unit carbon content* of Chinese car manufacturing (in kg CO_2eq / euro) only to the basic price of 13.000 euros, the appropriate *unit carbon contents* of trade and transport in various countries to 3.000 euros of margins, and a zero carbon content to the 2.000 euros of taxes.

To our knowledge, previous implementations of the "simplified SNAC" methodology in other countries did not implement this pre-treatment of the national IOT, or at least not explicitely. This could have led to some bias in their estimation of the overall footprint of imported goods.

5.1.2 Data sources used

In National Accounts, CIF-FOB margins are usually broken down only by type of service (transport and insurance), but unfortunately not by type of goods. To recover this information, we use a new data source transmitted by the French customs, which contains a breakdown of French CIF-FOB margins by {type of good X region of origin of the good X mode of transport} (land, sea and air transport). We use this data for the year 2019, and apply it as a fixed structure to break down the aggregate amount of "CIF-FOB margins" by type of service found in our national accounts for all years 2010-2023.

For TTM margins occurring in *non-EU countries* on their exports to France, we rely on a file transmitted by the FIGARO team and used internally for the compilation of the FIGARO tables. For TTM margins occurring in *EU countries*, we use the official IOT data when they are available (table T.1620 in the ESA 2010 transmission program). Unfortunately, some major exporters to France do not publish this data, among which Germany and Spain. In these cases, we impute the missing margin information by EU averages[2].

We then proceed in two steps :

- Using the information on CIF-FOB margins by {type of good X region of origin of the good}, we first compute a FOB valuation of French imports of goods.
- The estimation of foreign TT margins is a bit more complex. Using the sources described above, we start by isolating in each country (excl. France) the domestic TTMs on exports (P6) for the year 2015. We then compute a share of those TTMs destined to France, making the assumption that it is equal to the share of exports destined to France in basic price, as found in FIGARO. This is done for each exporter country and product by product, at the A64 level. This "TTM to France" 2015 value is then divided by the French imports 2015 FOB value computed above, in order to obtain a reference "foreign TTM ratio" by {type of good X origin country}. This 2015 ratio is finally applied to the French FOB imports value by {type of good X origin country} for the whole time series 2010-2023, in order to obtain imports of goods in basic prices.

All in all, the data needed to estimate these margins is very similar to what MRIO compilers use to value all international flows in basic prices, as explained for example in United-Nations (2018) (para 17.16 and 17.44 to 17.49).

[2]Note that for future updates, we will be able to benefit from the information on Spanish export margins, which the Spanish NSI have agreed to share confidentially in early 2026.

Before applying this treatment, we need to decide what product groups in the A64 nomenclature should be considered as "goods" vs. "services" ? Given the information contained in the data-sources described above regarding CIF-FOB and foreign trade and transport margins, we choose the following split : goods are the products from A01 to C31_32, D35, E37T39, J58 and J59_60. They can be subject to TTMs. TTM services are the products G45, G46, G47 (trade), H49, H50, H51, H52 (transport) and K65 (insurance). Finally, "other services" are all the other products, which cannot be subject to TTMs.

5.1.3 Building detailed tables of trade and transport margins

From the various sources described above, we set up two tables of TTMs on French imports. The first table describes the monetary margins (in current euros) for the following crossings :

- country of origin of the *TTM service* (45 categories)
- type of *TTM service* (8 categories: G45, G46, G47, H49, H50, H51, H52, K65)
- type of margin (2 categories : foreign TTMs and CIF-FOB)

The second table describes the same margins for the following crossings :

- country of origin of the *good* (45 categories)
- type of *good* (26 categories : A64 from A01 to C32 + D, E and J)
- type of margin (2 categories : foreign TTMs and CIF-FOB)

These two tables are sufficient to proceed to the re-valuation of French imports, as described in the next section.

We also build another, more detailed table which covers only the margins on *final uses*, rather than all uses. This additional table will prove useful later, when we want to express the footprint according to the GHG content of final products in *purchaser prices* rather than *basic prices*. This step is described in section 9.1. Contrary to the previous two, this new table also covers the French domestic trade and transport margins. It describes the monetary margins for the following crossings :

- country of origin of the *TTM service* (46 categories)
- type of *TTM service* (8 categories: G45, G46, G47, H49, H50, H51, H52, K65)
- country of origin of the *good* (46 categories)
- type of *good* (26 categories : A64 from A01 to C32 + D, E and J)
- type of margin (3 categories : foreign TTMs ; CIF-FOB ; French domestic TTMs)
- type of final use (5 categories : P3_S13, P3_S14, P3_S15, P51G, P5M)

In practice, it is only for the CIF-FOB margins that we have access to a real statistical information regarding the crossings by *type of goods X type of TTM service*. For foreign TTMs but also for French domestic TTMs, due to a lack of proper information, the table is largely populated using proportionality assumptions (all goods are supposed to be transported or traded in the same way).

5.1.4 Practical modifications made to the French IOT to revalue imports in basic prices

Once we have the TTMs tables described above, we proceed to the conversion of the import valuation from CIF to basic price as shown in figure 1. It should be noted in particular that the first step (CIF $\rightarrow$ FOB conversion) does not only imply a change to the "imported IOT" but also to the "domestic IOT", where the trade and transport services provided by resident units are accounted for. Under ESA 2010, the convention is that resident CIF-FOB margins appear as a domestic supply in the relevant transport and insurance services, and as a use under the "export" category (P6). For clarity, this is the convention we have followed in figure 1, even though this is not the way the CIF-FOB margin is usually presented in French Input-Output tables.

For both steps (CIF → FOB) and (FOB → basic price), the breakdown of the margins by detailed use type (intermediate and final) is made using a proportionality assumption : the use of the TTM margin is considered to be proportional to the use of the related imported good.

Figure 1: Modifications to the French IOT to revalue imports in basic prices

	Imports CIF	Step 1 : CIF -> FOB			Step 2 : FOB -> basic price		
	Total use	Total use	*domestic*	*export*	Total use	*domestic*	*export*
Imported IOT							
Goods	Full CIF-FOB margin (resident + non-resident)	(-) Full CIF-FOB margin (resident + non-resident)	*(-) Full CIF-FOB margin (resident + non-resident)*		(-) Foreign TT margin	*(-) Foreign TT margin*	
Trade and transport services	0	(+) Non resident CIF-FOB margin	*(+) Non resident CIF-FOB margin*		(+) Foreign TT	*(+) Foreign TT*	
Total imported products	**Full CIF-FOB margin (resident + non-resident)**	**(-) Resident CIF-FOB margin**	***(-) Resident CIF-FOB margin***		**0**	***0***	***0***
Domestic IOT							
Goods	0	0			0		
Trade and transport services	Resident CIF-FOB margin	0	*(+) Resident CIF-FOB*	*(-) Resident CIF-FOB margin*	0		
Total domestic products	**Resident CIF-FOB margin**	**0**	***(+)***	***(-)***	**0**	***0***	***0***
Total							
Total products	**Double counting of resident CIF-FOB margin**	**(-) Resident CIF-FOB margin**	***0***	***(-) Resident CIF-FOB margin***	**0**	***0***	***0***
CIF-FOB correction							
Total correction	**(-) Resident CIF-FOB margin**	0			0		

5.1.5 Results

Using the above described procedure, we find that the French imports of goods basic price value is 10% lower than the CIF value (€513 bn vs. €569 bn in 2021, see table 2). Removing the CIF-FOB margins explains a -3% difference and removing the foreign TTM explains a -7% difference. Conversely, the imports of trade and transport services are more than doubled, from €34 bn to €84 bn.

The imports of road transport services (H59) are more than doubled compared to a CIF valuation (+€10 bn), whereas the imports of sea transport services (H50) are multiplied by more than six (+€4 bn). The imports of trade services are also much higher, especially for wholesale trade (G46, +€24 bn).

The uncertainty surrounding this re-valuation procedure is of course very significant. As National accountants and Balance of payment experts know all too well, agregate CIF-FOB margins are already difficult to measure. The estimates of TTM in foreign countries is, by definition, out of the reach of a given NSI, and the quality of the valuation can therefore only rely on a proper exchange of information between countries.

5.1.6 Open question : removing the taxes less subsidies on imports ?

In theory, the conversion of imports value from CIF to basic price should not only entail the removing of trade and transport margins, but also of taxes less subsidies (TLS) payable in foreign countries on exported

Table 2: French imports value depending on the valuation convention (year 2021, euro billions)

product type	**CIF value**	**FOB value**	**BP value**
Goods	569	551	513
Trade and transport services	34	46	84
G45 - Trade and repair of vehicles	0	0	3
G46 - Wholesale trade	6	6	30
G47 - Retail trade	0	0	6
H49 - Land transport	9	15	19
H50 - Water transport	1	5	5
H51 - Air transport	4	5	5
H52 - Warehousing and support	14	14	15
Other services	131	131	131
All products	**734**	**729**	**729**

goods. This is clearly stated for example in the United-Nations (2018) Handbook, para 17.44 and 17.45.

However, it is not entirely clear to us if the removal of foreign TLS is done during the compilation of FIGARO, and if yes based on what data-source. Until further investigation, we have chosen to ignore the foreign TLS on exports, and consider that the basic price revaluation only consists in the removal of TTMs.

5.2 Discrepancies between FIGARO and nationally published statistics

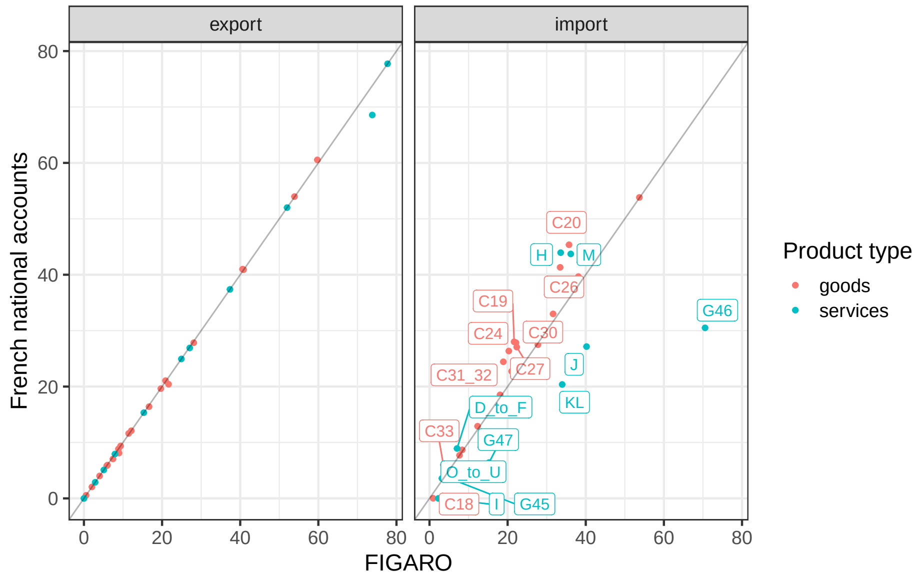
FIGARO, being compiled by the European Commission, is fairly well aligned with the National accounts published by EU countries. In particular, the main accounting aggregates (GDP, domestic output, imports and exports) are all consistent with nationally published data. Domestic output by product is also consistent with national data. Regarding imports and exports, a multi-step benchmarking procedure is applied in the FIGARO compilation process, at the end of which exports by product remain aligned with national accounts, while imports may differ from what countries publish.

In practice, we find that compared to official national accounts, French imports in FIGARO are made up of fewer goods (in red on the figure 2) and of more services (in blue). This is for example the case for chemical products (CPA C20, at €45 bn in 2021 in French national accounts vs. €36 bn in FIGARO), computers, electronic and optical products (CPA C26, at €41 bn in French national accounts vs. €33 bn in FIGARO) or refined petroleum products (C19 at €28 bn in French national accounts vs. €22 bn in FIGARO). Conversely, the imports of wholesale trade services (G46) are much lower in French national accounts than in FIGARO. This comparison is done using French National Accounts imports in "basic prices", which have been compiled using the methodology described in the previous section 5.1.

Finally, it must be noted that while FIGARO *supply and use tables* at basic prices (SUTs) are aligned with EU national statistics as explained above, the *product X product* and *industry X industry* domestic *input-output tables* (IOTs) are in fact not taken from national publications, but are recompiled by the FIGARO team directly from the SUTs, using standard symmetrization methods. A reason for this choice is that EU national accountants do not usually produce *product X product* and *industry X industry* IOTs on an annual basis, leaving many gaps to be filled by the FIGARO compilers. French national accountants for example only produce a *product X product* IOT, and no industry version, while other EU countries have the opposite practice.

In the French case, the fact that the FIGARO team makes its own symmetrization from the SUT, rather than taking the official IOT, is not a real issue. As the French supply matrix is practically diagonal (meaning that industries produce only one product), the intermediate consumption block of the IOT is practically the same than in the SUT, and consequently the specific symmetrization technique used does not really matter. This may not be the case however for other countries where the industries are more heterogeneous. This question is also touched upon in section 8.1 where we compare the results of the footprint calculation using the *product X product* vs. *industry X industry* IOTs.

Figure 2: French imports by product in basic prices, French National Accounts vs. FIGARO (year 2021, billion euros)



5.3 Disaggregating French imports by country of origin

5.3.1 Principle

The expression of the simplified SNAC footprint in equation 3 assumes that we know the terms FU_M^{Fr} (direct final demand for foreign products) and A_M^{Fr} (intermediate consumption by French industries) at a level of detail compatible with the FIGARO MRIO, that is 64 products X 45 countries (excluding France). The level of detail by product raises no problem. The French IOT is available at a 88 products level and can therefore be re-aggregated down to a 64 products level. On the contrary, the breakdown by country is problematic, as the IOT usually produced by French national accountants distinguishes only 3 origins: France, EU and non-EU.

A possible solution would be to use the geographical breakdown of French imports available from FIGARO, and apply it to our National accounts data. For reasons explained in the following section, this is what we chose to do for the imports of *services*. For the geographical origin of *goods* however, we chose to rely instead on the French customs. This offers several advantages. The first is reliability and overall consistency with other French statistical results. The second is that French customs geographical information is available in a very timely manner (as soon as February of year N+1). This allows us to apply a consistent geographical disaggregation of imports for the 2010-2023 period (simplified SNAC based on FIGARO) and for the year 2024 (now-cast described in section 6).

However, we need to keep in mind that customs data should be considered only as a proxy of the "true" geographical breakdown of French imports, because the concepts underlying the two statistics are different. Customs data represent the flows of goods crossing the French border, inwards and outwards, whereas imports and exports in National accounts represent changes in economic ownership between resident and non-resident units. Those can be different, in particular in the presence of global production arrangements such as merchanting, goods sent abroad for processing, "factoryless" goods production, etc. The first best solution for our IOT compilation would be to keep track of all geographical origins during the full correction process starting from Customs data and leading to the final National accounts aggregates. Unfortunately, this kind of detail is currently not available in French National accounts, and, at this stage, we therefore need to make the simplistic assumption that the Customs geographical breakdown is a good proxy for National accounts imports.

Note that, in the current state of the French IOT compilation, we do not have access to any information on the *specific use of products depending on their geographical origin*. In Walker et al. (2024), researchers from the Dutch NSI have shown that the precise type of use can vary for a given product depending on its origin. They propose a practical procedure to recover this information from micro-data such as trade in goods and services at trader level, and integrate it into the national imported IOT. In the French case, this level of detail does not exist yet, it is left for further research. In the meantime, we use a general proportionality assumptions in our disaggregation. This means that, for a given product at the A64 level, the use structure (in 64 industries + 5 final uses) is always the same irrespective of the geographical origin.

5.3.2 Data sources and procedure

We use three different data-sources to split the French imports into 45 regions :

- For all *goods except CPA B (products from mining and quarrying)*, we use the geographical split given by the French customs, directly in CIF value.
- For *CPA B (products from mining and quarrying)*, we start from the geographical split given by the French customs, but we correct it based on information from the French energy balance about the imports of crude oil and natural gas from the following countries : Belgium, Netherlands, Norway, Russia, Saudi Arabia and the United-States. This information is disseminated by Eurostat under "*Energy / Trade by partner country / Imports*" (code *nrg_ti*). Indeed, the French customs dataset does not seem to appropriately reflect the true origin of crude oil and natural gas, compared to the more reliable sources used in the energy balance.
- For all *services*, we use the geographical split provided in FIGARO, which is directly in basic price. This is a pragmatic choice. We believe that this information will have a very limited impact of the GHG footprint calculation, because the GHG content of services is very low compared to goods. We also know that the raw information from the French balance of payments would need very significant rework to be put to the appropriate level of CPA product detail. All in all, we consider that the task is not worth the effort, contrary to what we can do for goods.

The geographical split of imports is made jointly with the revaluation described in the previous section. More precisely : we begin by splitting the geographical origin of *goods* in the IOT in CIF value. We then proceed to the revaluation described in section 5.1 to obtain an IOT where all imports are valued in basic price. Only then we proceed to split the geographical origin of *services* (including TTM services), directly in basic prices. This two steps procedure allows us to respect the specific valuation of each source : CIF for the French customs and basic price for FIGARO.

5.3.3 Main differences between the data sources on geographical origins

We find that in the French customs source compared to FIGARO, imports of goods (excluding CPA B) come more often from the United-States (+101 % or +€14 bn in 2021), China (+37 % or +€15 bn) and Belgium (+11 % or +€3 bn), but less from Italy (-16 % or -€8 bn) and Germany (-9 % or -€7 bn, Figure 3).

For CPA B products (in monetary value, that is essentially crude oil and natural gas), using the French energy balance rather than FIGARO, imports come more often from Norway (+193 % or +€5 bn) and Russia (+119 % or +€3 bn), but less from the "Rest of the World" region (-52 % or -€10 bn).

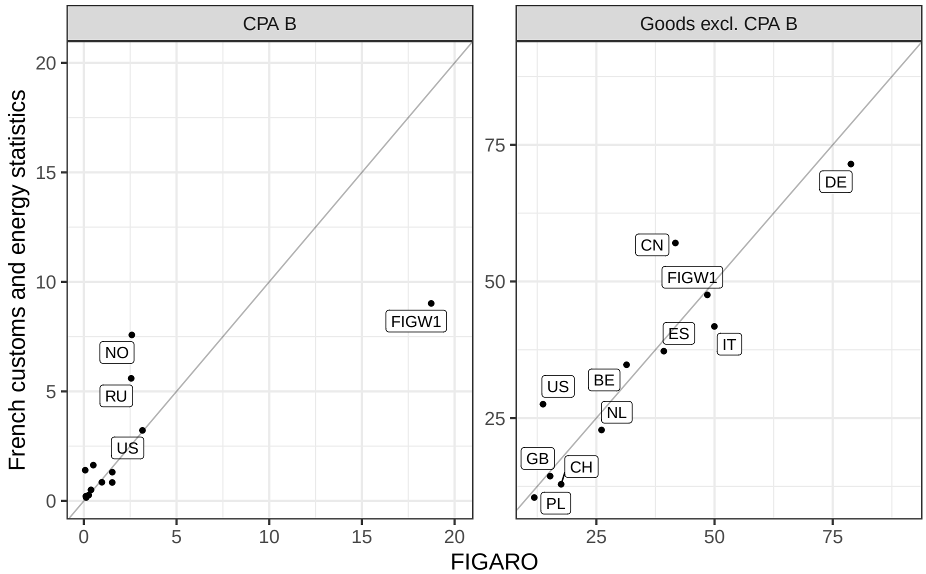
5.4 Two additional adjustments applied to FIGARO

5.4.1 Correcting some outliers in technical coefficients (FIGARO version 2024)

What was the problem ?

For our November 2024 release based on FIGARO version 2024, we noticed that the French GHG footprint (calculated directly from FIGARO or using the s-SNAC method) showed a peak in year 2011, which was not explained by a change in French monetary demand, but rather by the unit carbon content of imports. More

Figure 3: Geographical origin of French imports of goods (year 2021, euro billions)



precisely, the peak was mostly attributable to the unit content of the product C26 (computers, electronic and optical products) imported from China for intermediate and final use.

Investigating this issue, we found that, in the FIGARO product X product IOT, the year 2011 technical coefficients for the production of C26 from China were clear outliers. The sum of the technical coefficients for all inputs (total of the column "China C26" in the A matrix) was equal to 1.95 in 2011, compared to around 0.8 in 2010 and 2012. This discrepancy could not be reasonably explained by any real and sudden technological change, and was also very unrealistic from an economic perspective (total technical coefficients must be below 1 in order for the industry to generate a positive value added).

Therefore, we chose to correct this outlier value, but also to set up a more general outlier detection procedure, in order to detect if other less remarkable abnormal values exist in the FIGARO product X product IOT.

Outlier detection procedure

For the French GHG footprint calculation, we were not directly concerned about the 2944 X 2944 technical coefficients, but only about the resulting 2944 "unit carbon contents" (or "carbon multipliers") represented by the $e(I-A)^{-1}$ vector applied to French final demand.

Therefore, we set up a detection procedure directly on the "unit carbon contents" series (2880 time series, when excluding the content of French products). Each time series was composed of 12 data points, from 2010 to 2021. In each series, we considered a data point as an outlier if :

- It was greater than 3 times the 2010-2021 average value, or lower than 1/3 of the 2010-2021 average value;
- AND it was greater than 3 times the average value of its two immediate neighbors, or lower than 1/3 the average value of its two immediate neighbors.

According to this definition, data points for 2010 and 2021 (start and end of the time series) were never considered as outliers. The procedure was applied for the 4 GHG types we consider (CO_2, CH_4, N_2O and F-$gases$).

The thresholds we chose (3 and 1/3 of the series average) were quite "loose", in any case large enough to allow for any normal economic variation of the "unit carbon contents".

All in all, using FIGARO version 2024, only 35 points were considered as outliers according to this definition.

25 of those related to products from China, 13 for the year 2011 and 9 for the year 2019. In practice, as expected, the most impacting outlier related to the carbon content of product C26 for the year 2011, which was 4 times higher than the average value for 2010-2021.

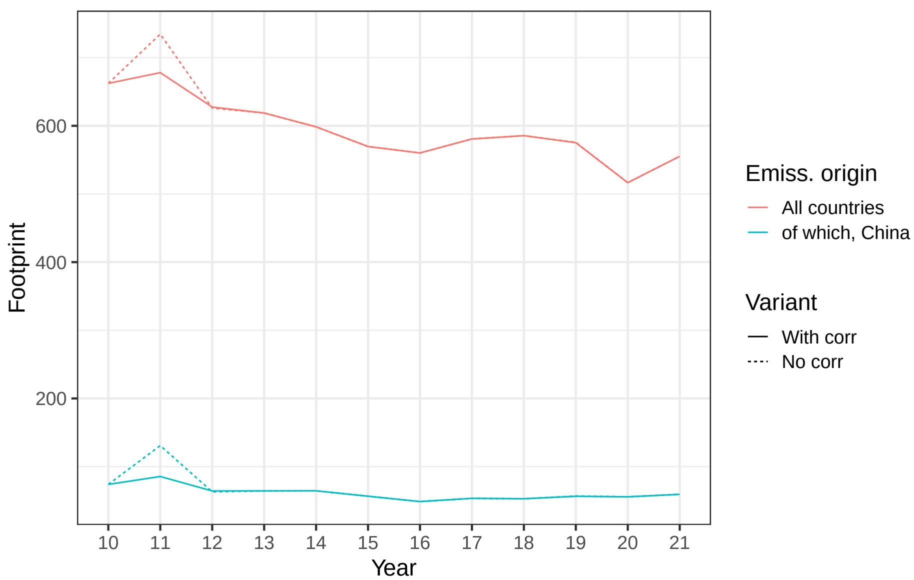
In FIGARO version 2025, most of the outliers detected in the previous vintage have been corrected. Only one remains, for the product K66 (Services auxiliary to financial and insurance services) in Romania for the year 2013. Its influence on the French GHG footprint is negligible.

Correction implemented for the November 2024 release

For our November 2024 release based on FIGARO version 2024, we implemented the following correction: we replaced the 35 outliers carbon content by the average value of their two immediate neighbors in the time series (again, we did not try to correct the A matrix coefficient directly, but rather the aggregated inverse Leontieff coefficients).

This correction brought the French carbon footprint down by 6.5 % in the year 2011 (-56 million tons in CO_2 equivalent), which was pretty significant (figure 4). The impact of the outlier correction was fairly negligible for other years (+0.2 % in 2012; -0.1 % in 2019; 0.0 % for every other years).

Figure 4: FIGARO version 2024 - Footprint before and after the correction in technical coefficient outliers (excluding households direct emissions, million tons CO_2eq)



For our October 2025 release based on FIGARO version 2025, we kept the outlier correction procedure in place, but its effect on the French GHG footprint becomes negligible.

5.4.2 Correcting the carbon content of CPA B and C19 products imported to France for years 2022 and 2023 (FIGARO version 2025)

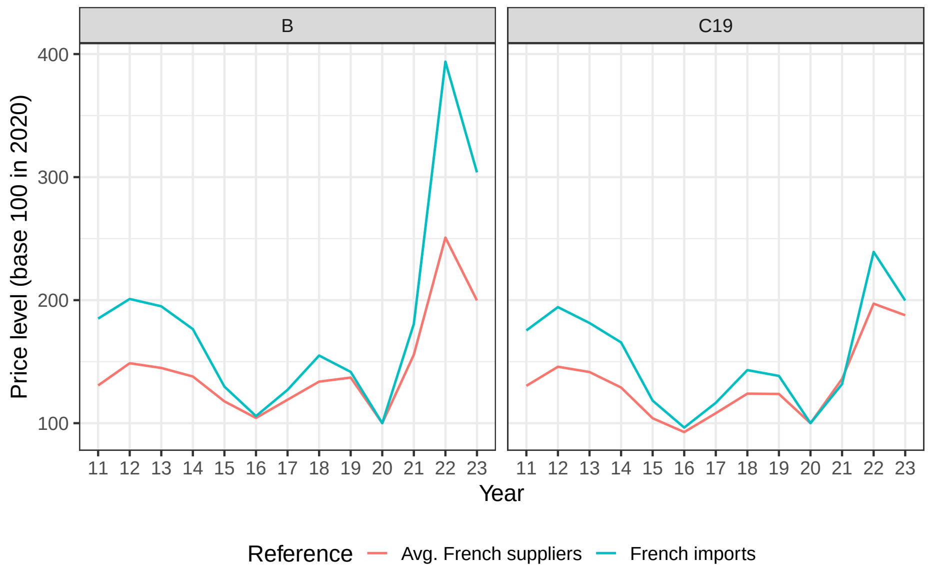
Heterogeneity in energy price developments since 2021

We combined the FIGARO tables with physical data from the International Energy Agency (IEA) on the production of crude oil, natural gas, coal and refined petroleum products, to estimate “producer price indices” for each country available in FIGARO, for both products B (which covers coal, crude oil and natural gas) and C19 (refined petroleum products). We then compared these indices with French import price indices for the same products, as known in our national accounts.

We find that price levels are very different between these two perspectives (see figure 5). With a base 100 in 2020, the price of French imports of “crude” extractive products (CPA B) reaches 394 in 2022 and 304 in

2023, compared with only 251 in 2022 and 200 in 2023 for the average producer price of France's suppliers. For refined petroleum products (CPA C19), the gap is also high in 2022 (239 vs. 197), but largely closes in 2023.

Figure 5: FIGARO version 2025 - Price levels of the CPA B and C19 products, from the point of view of the producer (source IEA/FIGARO, authors calculations) or the French importer (source French national accounts) (base 100 in 2020)



Why is that a problem ?

Putting aside the possible purely statistical causes (imperfect data sources or treatments), the price indices of French producers and imports may diverge for various economic reasons:

- The composition by end product (oil, gas, coal) of the aggregate "B" may differ between French production and imports, with different price indices for each component;
- French import prices are essentially those observed on international markets. But it is entirely possible that some producers have sold their 2022 and 2023 production at less volatile prices to certain other customers (on their regulated domestic market or to customers with long-term contracts).

Whatever these economic factors, the problem is that, with the "simplified SNAC" footprint approach based on a current price MRIO, the GHG content per euro of imported product is essentially determined by the producer's price variation. The gap with import prices in 2022 and 2023 may therefore introduce a significant overestimation of GHGs imported to France, compared with the physical underlying (quantities of oil and gas imported in tonnes or cubic meters).

Correction implemented for the October 2025 release

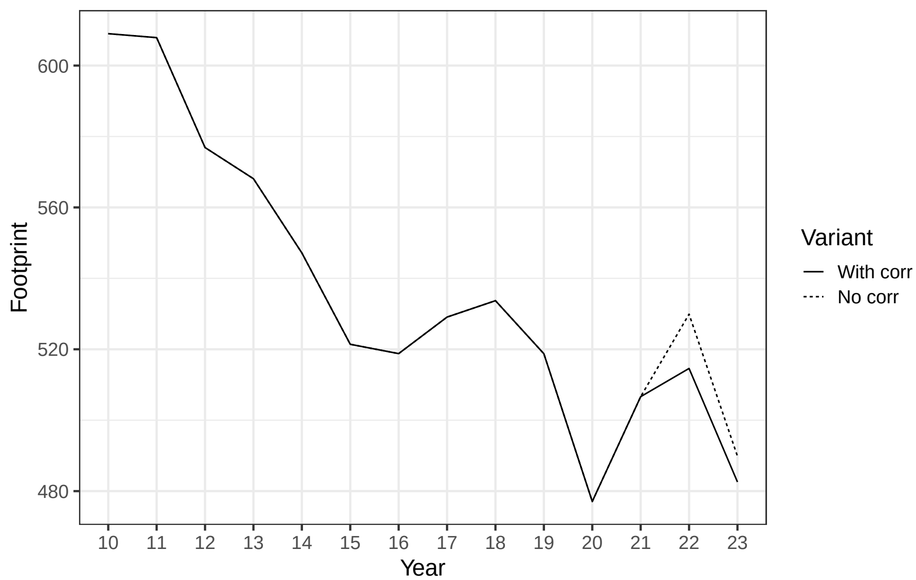
For our October 2025 release, we have therefore corrected the imported contents of products "B" and "C19" in 2022 and 2023, reducing them by the same factor as the difference observed between the import vs. producer price indices, i.e. around -25% in 2022 and 2023 for product B and around -20% in 2022 for product C19.

More precisely, we applied a country by country correction, given that the misalignment between the producer price index and the French import price index is country specific. We end up correcting the GHG content of B imports for Norway, the United-States, Russia, Saudi Arabia and the 'Rest of the world region' (FIGW1) ; and the GHG content of C19 imports for Belgium, Germany, the 'Rest of the world region' (FIGW1), India, Russia and Saudi Arabia. Only countries with significant exports of B and C19 products to France were treated.

This correction is not negligible, having an effect of around -16 Mt CO_2eq on the total footprint in 2022 and -7 Mt CO_2eq in 2023 and 2024 (see figure 6). In terms of final demand main categories, it mainly affects *transportation* (via road fuel) and *housing* (via natural gas).

It should be noted that the problem of "heterogeneous inflation" we have tackled here on B and C19 products could potentially impact other products in 2022 and 2023, which are high inflation years. This point will need to be studied in greater depth for future editions of the estimation, in cooperation with the Eurostat team responsible for compiling FIGARO. As soon as they will be available, we will also make use of the FIGARO tables in previous year's prices, which will allow us to consolidate the analysis we have presented here on B products, and also extend it to other products.

Figure 6: FIGARO version 2025 - Footprint before and after the correction in products B and C19 unit GHG content for years 2022 and 2023 (excluding households direct emissions, million tons CO_2eq)



6 Nowcasting France's carbon footprint for the year 2024

6.1 Data available for 2024 and remaining gaps

As stated in the introduction, a major objective of the project was to be able to estimate a carbon footprint for France up to year N-1 (i.e. year 2024 in the publication of October 16th, 2025). For each year, the expression of the s-SNAC footprint given in equation 3 assumes the availability of three elements : the French GHG emissions by industry, the French IOT, and the unit GHG contents of foreign products derived from FIGARO.

Prior to 2024, French GHG emissions in AEA format were estimated only up to the year N-2, on the basis of the "definitive" IPCC emissions inventory. Starting in 2024, for the purpose of the carbon footprint estimation, they are also estimated for year N-1, based on a provisional emissions inventory.

Likewise, the French IOT used to be compiled only on the basis of definitive National Accounts, i.e. for year N-3. From 2024 onwards, for the purpose of the carbon footprint estimation, the IOT is now also compiled for semi-definitive (N-2) and provisional (N-1) accounts. The revaluation of imports (section 5.1) and their geographical split (section 5.3) is also carried out for all years, up to year N-1.

All the “French” terms required for the SNAC footprint (IOT and GHG emissions) are therefore available up to year N-1 (terms in red in equation 3). On the other hand, the unit GHG content of foreign products $e(I-A)^{-1}$, taken from FIGARO, is not available. Some nowcasting is therefore required to fill the gap.

6.2 Nowcasting procedure

To now-cast the unit GHG content of foreign products $e(I-A)^{-1}$ for the year 2024, the following method was adopted:

- The projection is carried out at a very fine level of detail, that is: unit GHG content of products by *country of origin of the product (45) X product category (64) X type of GHG (4) X origin of emissions in France or abroad (2)*, i.e. a total of 23,040 series. Each of these series is available for the 2010-2023 period, and needs to be extended by 1 additional year.
- However, most of these series make an extremely small contribution to France’s carbon footprint. The GHG contents are therefore ordered by increasing contribution to the imported French footprint for a given reference year (2023 for the estimation published in October 2025), and a threshold is set to judge the relevance of the projection. All series whose cumulative contribution is less than 0.1% of the imported GHG footprint (starting from the lowest) are projected in a “naive” way for the year 2024: we simply use the value of the unit carbon content observed in year 2023.
- Only the 7,171 series above the threshold are actually now-casted. We begin by calculating the logarithmic first difference over the entire available 2010-2023 series. We then remove the (logarithmic) price variations for the relevant product, as known from French national accounts. This amounts to considering variations in unit GHG content in *volume terms* rather than in *value terms*. We then estimate a linear model of this series without explanatory variables, i.e. simply take the mean value of the series, or with an outlier for 2015 if it is deemed significant at the 5% threshold. This estimate is then used to extend the series over 1 additional year, by applying the logarithmic first difference starting from the last observed point.

6.3 Discussion

There are several motivations for this procedure.

The first question is : what variable should we try to now-cast ? We believe that nowcasting the GHG unit contents of final products (that is the $e(I-A)^{-1}$ vector) is the most natural approach, at least in the s-SNAC framework. We know the French final and intermediate demand by product in euros from our National accounts, and we ”just” have to fill the gap regarding the unit GHG content by product, in kg CO_2eq / euro.

The alternative would be to try to now-cast the complete EE-MRIO structure, that is the e vector of emission intensity of output and the A matrix of technical coefficients. We believe that this would be both very complex (because of the sheer size of the A matrix and the lack of information) and unnecessary. Indeed, we can assume that the changes in the emission intensity of output and in the technical coefficients are mostly structural in nature. Most of the short-term business cycle developments will be correctly captured by the changes in the French final and intermediate demand in monetary terms.

The second question is the level of detail at which we should make the nowcasting. Here, we choose to keep a very high level of detail, even if we know that *this does not guarantee the best nowcasting performance*. Our motivation is twofold :

- Keeping the distinction between the 45 countries of origin allows us to incorporate the changing geographical composition of imports from the French customs over the nowcasting period. For example, the continuing switch from Russian natural gas imports to United-States LNG imports in 2024 is explicitly taken into account in the now-cast.
- Distinguishing emissions originating from France vs. from abroad is not really necessary for the quality of the overall now-cast, because the French emission part in the GHG content of imported products is

very small (see section 2.3). But it allows us to properly keep track of the total of "French emissions" vs. "imported emission" in the French footprint, even for now-cast years (see section 9.3 where this is discussed). This is important for the completeness of our dissemenination tables.

- The fact that we keep the distinction between the 64 products is more open to debate. There could be a grouping of products which yields similar or better nowcasting performance. Our choice is merely practical, as this allows us to maintain a homogeneous dissemination format even for now-cast years. In particular, the allocation of the footprint to "main demand categories" described in section 9.2 requires a detail of 64 products.

The third and final question is : what explanatory variables should we include in the now-cast ? The most obvious one is the price index of each product. Indeed, the unit GHG contents given by FIGARO are in value terms (kg CO_2eq per current euro). Inflation can thus have a direct effect on the year-on-year change of these unit contents over the now-cast horizon, as well as explain the past variations of the series. There are two ways we can include the price-index into the forecast :

- Either we introduce the price index as an exogenous variable into a regression model, so that the coefficient linking the year-on-year changes of the unit GHG content and the price index is freely determined by the data ;
- Or we consider that the coefficient linking the year-on-year changes in the unit GHG content and the price index must be set ex-ante, and equal to -1. This means that, all else equal, a +1% change in the price of a product should lead to a -1% change in its unit GHG content.

We have tested both options and opted for the second one, which has the advantage of being more understandable, especially in years of very high inflation like 2022 and 2023 (see results of the various assumptions in section 8.5).

Table 3: French footprint s-SNAC method vs. direct FIGARO results (year 2021, million tons CO_2eq)

-	FIGARO	s-SNAC	diff	diff (%)
Total footprint	**587**	**620**	**33**	***5.6***
households direct emissions	113	113	0	*0.0*
Footprint excl. hholds emissions	**474**	**507**	**33**	***6.9***
by component				
domestic	190	195	4	*2.2*
imp. for intermediate use	159	190	31	*19.5*
imp. for final use	125	122	-3	*-2.1*
by gas type				
CO2	335	362	27	*8.2*
CH4	98	101	4	*3.7*
N2O	29	30	1	*3.2*
F-gases	13	13	1	*5.9*

Part III

Results and comparative analysis

7 Main result : simplified-SNAC vs. direct FIGARO estimation

7.1 Structural comparison (year 2021)

In 2021, the French GHG footprint was estimated to 620 Mt CO_2eq with our simplified SNAC methodology compared to 587 Mt using directly FIGARO, that is a +6 % difference (see Table 3). Note that the comparison is made using the same GHG emission vector for the two models. This vector is based on the AEAs compiled by Eurostat, as available in the Summer of 2025. Therefore the "FIGARO" results presented here (587 Mt CO_2eq in 2021) differ slightly from what Eurostat publishes in its own "FIGARO applications" as of January 2026 (590 Mt CO_2eq in 2021), purely for a vintage difference in the global AEA data source.

Table 3 shows a breakdown of the footprint according to the three "components" of equation 3. As expected, the domestic component is practically the same between the two variants (+2 % in the s-SNAC), because the underlying economic data is practically the same. Most of the difference lies in the GHG content of imports for intermediate consumption (+31 Mt that is +20 % of this component) and less so on the imports for final use (-3 Mt that is -2 % of this component).

Table 4 shows the contribution of individual products to the "imports for intermediate use" component of the French GHG footprint, where the breakdown by product follows the decomposition presented in equation 4. We can see that a few products, with very high unit GHG content, account for most of the difference in the GHG embedded in imports for intermediate use, notably: agriculture products (A01), chemicals (C20), refined petroleum products (C19), basic metals (C24), computers, electronic and optical products (C26) and electrical equipment (C27). For all these products, demand from France to its foreign partners is significantly higher in the SNAC than in the FIGARO source (see section 5.2) and this has a noticeable impact on the carbon footprint.

It is not possible to attribute the differences in imports by products between FIGARO and French national accounts to a single, well defined cause. As discussed in section 5.2, while FIGARO is closely based on French national accounts, the need to balance all trade flows at the global level inevitably leads to some differences. However, it seems quite clear from figure 2 (in euro billions) and table 4 (in million tons CO_2eq) that some swap is happening between the imports of "Wholesale trade services" (G46, higher in FIGARO) and the imports of goods (agricultural and manufactured, higher in French national accounts). This is most

Table 4: French footprint s-SNAC method vs. direct FIGARO results (year 2021, million tons CO_2eq) - GHG embedded in the products imported for intermediate use

product	FIGARO	s-SNAC	diff	diff (%)
All products imported for intermediate use	**159**	**190**	**31**	***19.5***
A01 - Products of agriculture, hunting and rel. services	4	9	5	*145.1*
C20 - Chemicals and chemical products	15	19	5	*30.6*
C19 - Coke and refined petroleum products	10	14	4	*39.4*
C24 - Basic metals	12	16	4	*35.7*
C26 - Computer, electronic and optical products	3	7	4	*141.2*
C27 - Electrical equipment	6	9	3	*44.8*
All other products	73	76	3	*4.3*
C10T12 - Food, beverages and tobacco products	7	9	2	*33.7*
C28 - Machinery and equipment n.e.c.	6	8	2	*25.6*
C31_32 - Furniture and other manufactured goods	3	5	2	*67.8*
C13T15 - Textiles, wearing apparel, leather and rel. products	4	5	1	*33.4*
E37T39 - Sewerage services; waste collection services	1	2	1	*201.4*
H50 - Water transport services	2	3	1	*65.6*
H51 - Air transport services	1	3	1	*87.8*
H52 - Warehousing and support services for transport	1	2	1	*144.4*
G47 - Retail trade services, ex. of vehicles and motorcycles	2	1	-2	*-72.3*
G46 - Wholesale trade services, ex. of vehicles and motorcycles	10	3	-7	*-72.3*

probably due to differences between the source data underlying our procedure to value imports in basic price, described in section 5.1, and the source data used by the compilers of FIGARO to achieve the same goal. We will try to investigate this issue in cooperation with the FIGARO team when we prepare the next releases of our estimation.

All in all, the footprint difference is essentially due to the composition of imports by *product*, which differs between FIGARO and French national accounts, while the composition by *geographical origin* is of less importance (see section 8.3 for a longer discussion of the sensitivity relative to the geographical origin of goods).

7.2 Time-series dynamics (2010-2021)

The findings presented in table 3 for 2021 are relatively stable over the available time series (see Figure 7, purple lines, solid and dotted). The difference in the total footprint (s-SNAC / FIGARO) is +8% in 2010 versus +6% in 2021. The overall dynamics thus remains unchanged: the s-SNAC footprint decreases by 17% between 2010 and 2021, versus -16% for the footprint calculated directly from FIGARO.

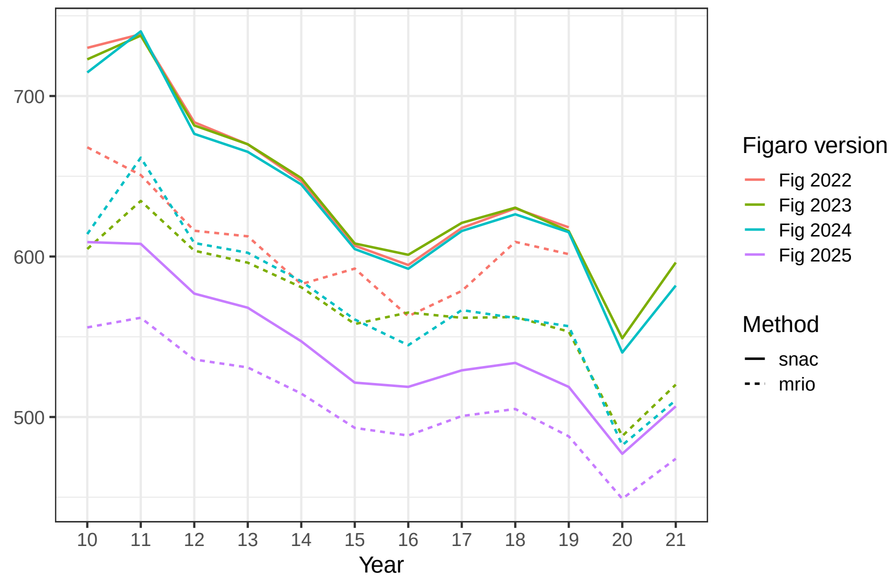
Another significant finding is that the s-SNAC methodology helps stabilizing the footprint results when using different vintages of FIGARO tables. Figure 7 shows that the revisions between the footprints using different FIGARO vintages can be quite significant (dotted lines, for the 2022, 2023 and 2024 vintages of FIGARO) while the same revisions are significantly dampened by applying the s-SNAC approach (solid lines). The revisions between the 2024 vintage (blue) and the 2025 vintage (purple) are more significant both in the s-SNAC and FIGARO version, for reasons explained in annex C.

8 Sensitivity analysis of methodological variants

8.1 Using the *product X product* IOT or the *industry X industry* IOT ?

In theory, it is possible to calculate a carbon footprint using the two input-output tables: *product X product* or *industry X industry*. There is however a trade-off to consider.

Figure 7: French footprint s-SNAC method vs. direct FIGARO results (excluding households direct emissions, million tons CO_2eq)



- The main advantage of working with the *product X product* IOT is that the final results are easier to interpret: the footprint can be broken down by *final products*, enabling a direct link with standard statistics, such as the household final consumption by product. In terms of input-output modeling, the technical coefficients of intermediate consumption are also supposed to reflect more accurately the various production technologies.
- The main advantage of the *industry X industry* IOT is its greater compatibility with environmental extensions, which are typically compiled on an industry basis. This is the case for Air emission accounts, which present GHG emissions by industry rather than by product. The disadvantage is that the resulting footprint is presented in terms of final use by "industry output", which is more difficult to interpret.

In practice however, the difference between the two approaches is very small. When using the same source for GHG emissions (ie. Air emission accounts by industry), the French footprint using the *industry X industry* IOT is very slightly lower than the one estimated with the *product X product* IOT, from -0.0% (in 2018) to -0.6% (in 2012 and 2013). There is also practically no difference by main categories of the final demand.

This is because, generally speaking, the industries in the global economy are mostly homogeneous, ie. they essentially produce the product corresponding to their main activity (CPA = NACE). This homogeneity depends on actual economic structures (size and homogeneity of companies), but also on the way national statisticians choose to define the "industry" in their country (see the European comparison discussed in Larrieu (2024)).

The homogeneity of industries is particularly marked in the French SUT, where industries are, by design, (almost) single-product. The *product X product* and *industry X industry* French domestic IOTs in FIGARO are therefore very similar.

In the end, given the very limited differences, we choose to favor the FIGARO *product X product* IOT, whose results are more easily interpretable. We therefore work with the *conceptually incorrect* mix of *industry X industry* AEA with *product X product* IOT. If we had to correct this situation, we would probably apply a technology assumption matrix to the AEA vector, in order to convert it to GHG emissions by product. But we think this would barely affect the resulting French footprint, given the very limited differences discussed above. The adjustment may however be more significant for other countries, where industries are more heterogeneous.

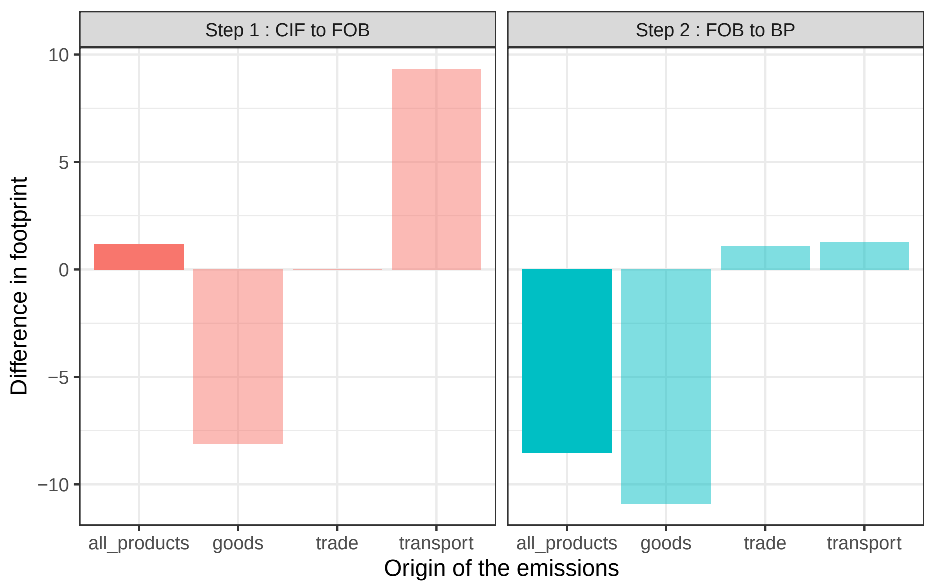
8.2 Impact of the revaluation of imports (BP instead of CIF)

We find that revaluing the French imports to basic price (as in FIGARO) instead of CIF (as in the usual French IOT), following the procedure described in section 5.1, leads to a reduction of the GHG footprint of 7 million tons CO_2eq in 2021, or - 1.2 % of the total footprint (see figure 8).

We decompose the difference in two steps (CIF to FOB) then (FOB to basic price):

- The revaluation of imports from CIF to FOB is broadly neutral on the total footprint (+ 1 million tons CO_2eq, or + 0.2 % ; red bars in the chart), because two changes compensate each other : a large reduction in the footprint originating from goods production (- 8 million tons CO_2eq, or - 3 % of this source of emission) is entirely compensated for by a significant increase in the footprint coming from transport activities (+ 9 million tons CO_2eq, or + 20 % of this source of emission).
- On the contrary, the revaluation of imports from FOB to basic price (margins in foreign countries) is not neutral on the total footprint (- 9 million tons CO_2eq, or + 1.4 % ; blue bars in the chart). The reduction in the footprint originating from goods production (- 11 million tons CO_2eq) is not compensated for by higher footprints from services. This is because the TTM margins in foreign countries are largely composed of *trade services*, whose average emission intensity in kg CO_2eq / euro is much lower than the average emission intensity of *transport services* which compose the CIF-FOB margins.

Figure 8: Impact on the French footprint of valuing imports in basic prices rather than CIF (year 2021, million tons CO_2eq)



8.3 Impact of the data source for the geographical origin of imports (French customs vs. FIGARO)

We find that using the French customs as the source to identify the geographical origin of French imports of goods (as we do in our publication, see section 5.3), rather than relying on FIGARO's geographical structure, leads to two results.

First, we find that the footprint is, overall, 9 Mt CO_2eq higher in 2021 using the French customs source, or + 1.5 % of the total footprint. This is due to the fact that, for a given good, certain geographical origins are associated with a higher unit GHG content than other. In practice, we find that most of the total difference is explained by the GHG content of computers, electronic and optical products (C26, +6.2 Mt CO_2eq, using the French Customs source rather than FIGARO).

In the French Customs source, French imports of C26 products come more often from China (CN) and FIGARO's "rest of the World" region (FIGW1), which show a unit GHG content higher than average (0.80 kg CO_2eq / euro in 2021 for China and 0.52 kg CO_2eq / euro for FIGW1 vs. an average of 0.31 kg CO_2eq / euro for all French imports), but also much less French imports come from Ireland (IE), which happen to show a unit GHG content much smaller than average (0.07 kg CO_2eq / euro) (see figure 9).

Second, we find that, overall, the geographical origin of the emissions composing the French carbon footprint is noticeably modified. The footprint using the French customs source originates more from China (+ 18 % or + 9 Mt in 2021), India (+ 3 Mt) and the US (+ 2 Mt), and less from the "Rest of the World" region of FIGARO (- 6 Mt), Russia, the UK and the EU (figure 10).

This apparent swap between China and Ireland for computers and electronic products is certainly not due to chance, but rather reflects the difference in concept between customs (cross-border flows) and national accounts (economic ownership) which was discussed in section 5.3.1. However, this poses a certain challenge for GHG footprint estimation, given the very large difference in GHG content per euro between the two countries. While this gap may partly reflect a true difference in economic substance (in electronic goods sold by Western firms established in Ireland, the share of output attributable to intellectual property may be higher and therefore the GHG content per euro lower), it also seems unlikely that the full value chain of electronic products described in FIGARO consistently follows the principles of economic ownership in all countries. Indeed, the principle of economic ownership has been stated in National Accounts since the 2008 SNA, but it is still very hard to assess the full extent of its implementation by countries, even in Europe. As a consequence, the very low GHG content per euro of product C26 coming from Ireland may also be partly a statistical artifact, coming from an inconsistent implementation of the economic ownership principle between countries.

8.4 Alternative global air emission accounts based on PRIMAP-CR and PRIMAP-TP

Tukker et al. (2018b) and Tukker et al. (2020) find that the source choice for global emissions is the first factor of discrepancy between country footprints computed from different EE-GMRIO models, before economic modeling factors.

As presented in section 4.2, our project relies on the global AEAs developed by Eurostat, which are made of three groups of countries.

- For EU countries and the UK, Eurostat directly uses the AEAs published by the countries.
- For Switzerland, Norway and Turkey, Eurostat uses incomplete AEAs published by the countries and expands them to the appropriate level of detail.
- Finally, for all other countries, Eurostat builds the AEAs from the EDGAR database.

To explore the sensitivity of the French footprint to the source choice for global emissions, we estimate two variants of the French carbon footprint where, for the third group of countries, EDGAR is replaced by PRIMAP-CR (for "country reported") or PRIMAP-TP (for "third party").

As EDGAR, those sources are available in the CRF nomenclature, on a territorial emissions basis. However, the level of detail available for the CRF codes is lower than in EDGAR. So, in order to build complete AEAs from PRIMAP, we proceed in two steps : first, we expand the level of detail of some CRF categories in PRIMAP, based on the more detailed structure found in EDGAR; then we can apply the Eurostat's methodology described in section 4.2 to convert from the CRF nomenclature to NACE. To account for international sea and air transport, we use the same sources as in the Eurostat's methodology, that is the OECD dedicated databases on CO_2 emissions from Air and Sea transport.

Figure 9: French imports of computers, electronic and optical products (C26) in 2021, share per country of origin (color bars in %) and the associated unit GHG content (black dots in kg CO_2eq / euro)

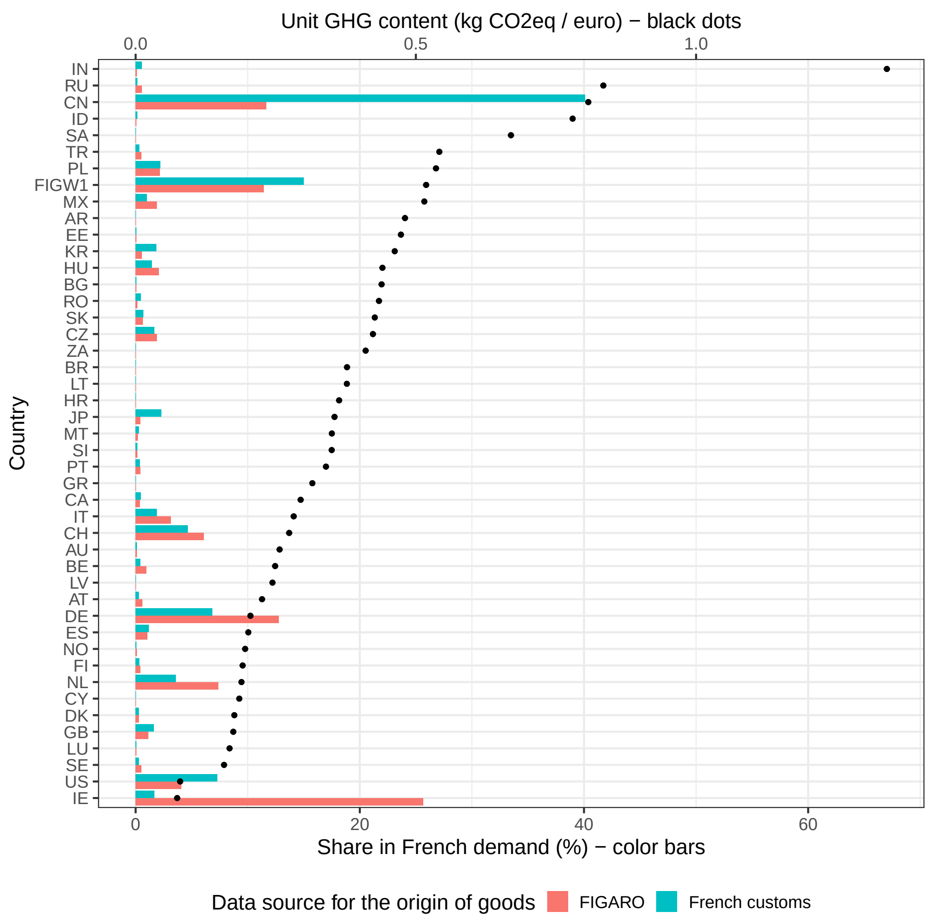
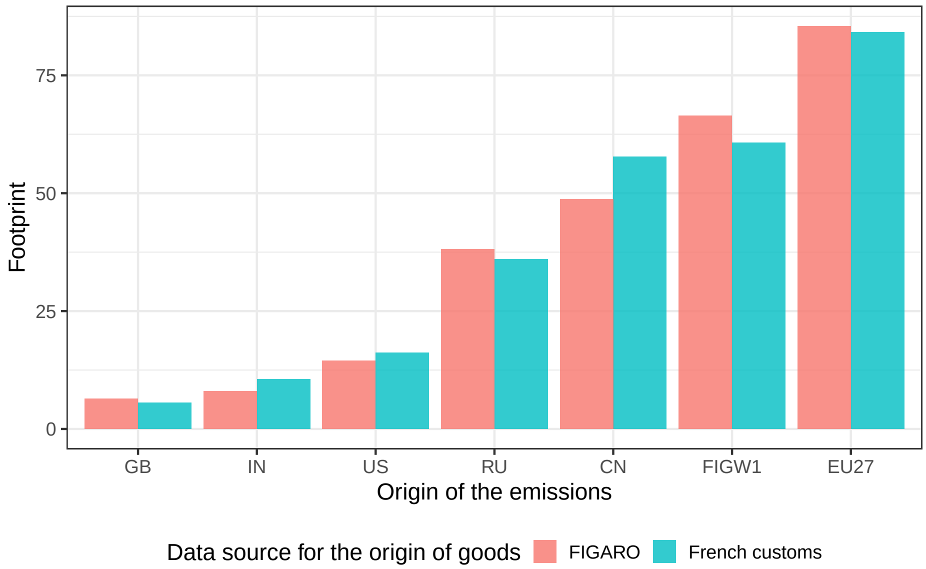


Figure 10: French footprint originating abroad, according to different data-sources for the geographical origin of the imports of goods (year 2021, million tons CO_2eq)



We end up with three sets of global AEAs, where the data for EU countries and the UK is the same (official AEAs produced by the countries), and the data for all other countries differ, being based respectively on EDGAR, PRIMAP-CR and PRIMAP-TP.

The complete procedure to create global AEAs based on PRIMAP is available in the same Github repo as for EDGAR : `https://github.com/InseeFrLab/global-ghg-emissions`.

We find that, using PRIMAP-CR as the primary source for the AEAs of non-EU countries instead of EDGAR, the French carbon footprint in 2021 would be 1.8% lower (table 5). The differences for CO_2 and *F-gases* are very limited, but they are more significant for CH_4 (-6.0% in PRIMAP-CR) and N_2O (+4.9% in PRIMAP-CR).

Using PRIMAP-TP as the primary source for global AEAs, the difference with EDGAR would be more limited, with +0.5% in total, and only significant in practice for N_2O (+4.7% in PRIMAP-CR).

In other words, the discrepancy between the three options (EDGAR, PRIMAP-CR and PRIMAP-TP) lies mostly in CH_4 emissions (where EDGAR and PRIMAP-TP broadly agree and PRIMAP-CR is lower) and in N_2O emissions (where PRIMAP-CR and PRIMAP-TP broadly agree and EDGAR is lower).

In terms of longer-term trends, the difference between sources is very limited. Global AEAs built on EDGAR and PRIMAP-TP lead to exactly the same 2010 to 2021 rate of change of the French carbon footprint (-17.5% vs. -17.4%). Using AEAs built on PRIMAP-CR, the decrease of the footprint over the period is only mildly more pronounced (-18.0%). The difference is slightly more significant for the CH_4 footprint (-15.0% for EDGAR and PRIMAP-TP vs. -18.2% with PRIMAP-CR) than for the other Greenhouse gases. The dynamics of the footprint by main demand categories is also very much the same using the three different sources.

8.5 Sensitivity tests for the nowcasting procedure (year 2024)

We simulate what would have been the results of our nowcasting procedure if it had been applied on past years. For this, we compare 7 consecutive nowcasting runs 1 year ahead, starting from the last years of observation 2017 to 2023 (figure 11). This is not a true ”real time” simulation, because we have not modified the National accounts and emissions data to reflect the past vintages and their subsequent revisions. Here,

Table 5: Footprint according to the AEA data-source for non EU countries (million tons CO_2eq)

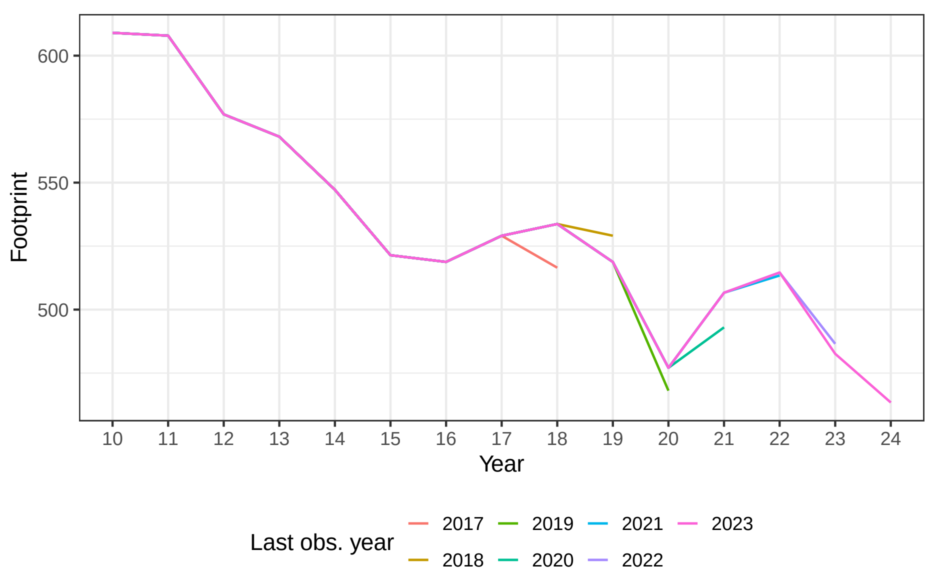
	2021 level					2010 to 2021 % change		
-	**edgar**	**primap_cr**	**primap_tp**	**diff_cr**	**diff_tp**	**edgar_chg**	**cr_chg**	**tp_chg**
Total footprint	**621.1**	**610.1**	**624.6**	***-1.8***	***0.5***	***-17.5***	***-18.0***	***-17.4***
hholds emissions (hh)	113.1	113.1	113.1	*0.0*	*0.0*	*-19.2*	*-19.2*	*-19.2*
Footprint excl. hh	**508.0**	**497.0**	**511.4**	***-2.2***	***0.7***	***-17.1***	***-17.8***	***-17.0***
by gas type								
CO2	470.4	464.3	470.8	*-1.3*	*0.1*	*-18.1*	*-18.3*	*-18.0*
CH4	104.6	98.3	106.2	*-6.0*	*1.5*	*-15.0*	*-18.2*	*-15.0*
N2O	30.9	32.4	32.4	*4.9*	*4.7*	*-8.3*	*-7.3*	*-8.7*
F-gases	15.2	15.1	15.2	*-0.7*	*-0.1*	*-30.7*	*-28.9*	*-30.7*
by demand category								
Transportation	133.8	130.4	134.7	*-2.5*	*0.7*	*-23.3*	*-24.1*	*-23.2*
Food	143.2	141.7	144.1	*-1.0*	*0.6*	*-11.1*	*-11.4*	*-11.1*
Housing	148.0	145.3	148.6	*-1.8*	*0.5*	*-17.4*	*-18.2*	*-17.4*
Public services	77.7	76.5	78.1	*-1.6*	*0.5*	*-11.0*	*-11.6*	*-11.0*
Equipements	65.5	64.3	65.7	*-1.9*	*0.3*	*-29.0*	*-29.3*	*-29.1*
Market services	53.0	52.0	53.3	*-1.9*	*0.6*	*-9.2*	*-9.9*	*-9.1*

we only change the cut-off date for the nowcasting procedure, all else being equal.

It appears that only one run is significantly off-course : the 2017 now-cast (for the year 2018) shows a decrease in the carbon footprint (- 2.4 %) whereas the subsequent revised data shows a slight increase (+ 0.9 %). We also notice that the 2020 now-cast shows an increase in the 2021 footprint which is around two times lower than what appears in the revised data (+ 3.3 % vs. + 6.2 %). The other nowcasting runs appear broadly correct. In particular the footprint drop in 2020 is very correctly anticipated by the procedure, and not much revised afterwards.

In any case, the update we will make in October 2026 (footprint estimation up to 2025) will give us additional hindsight, and we will be able to adjust our nowcasting procedure if necessary.

Figure 11: Footprint now-cast 1 year ahead, last GHG unit contents of imports observed from 2017 to 2023 (excluding households direct emissions, million tons CO_2eq)

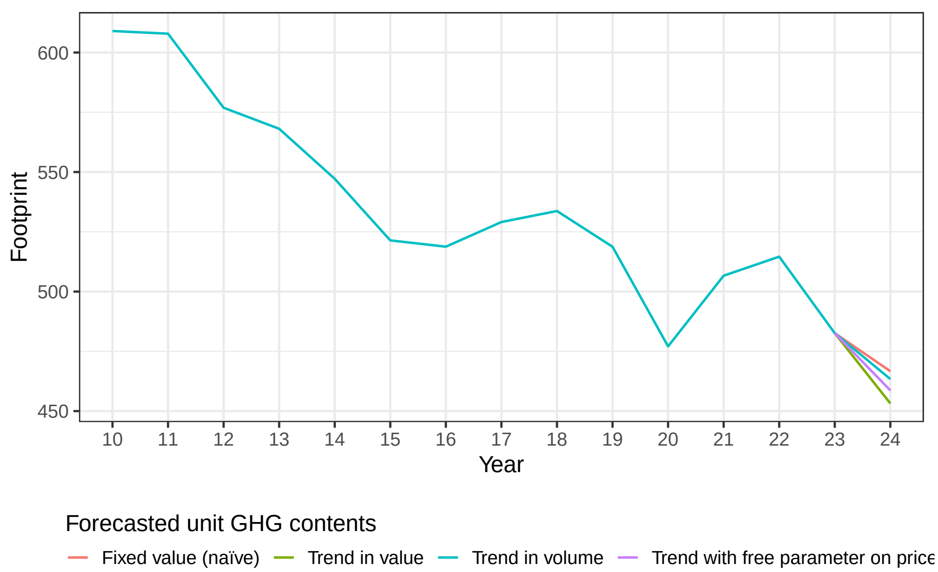


Years 2020 to 2024 are characterized by very large price fluctuations of energy products (CPA B and C19) and an overall high level of inflation on many products. This implies that the choice of nowcasting specifications regarding price indexation has a very significant impact on the overall results.

As a sensitivity test, figure 12 illustrates 4 methodological variants for the now-cast of the year 2024. The red curve corresponds to the very naive forecast where the unit GHG contents of French imports for 2024 are set equal to their value in 2023. The green curve corresponds to the case where the unit GHG contents are carried forward along their past 2010-2023 trend *in value terms*. The blue curve corresponds to the scenario where the unit GHG contents are carried forward along their 2010-2023 trend *in volume terms*. This is the scenario that has been retained for publication. Finally, the purple curve is an intermediate scenario where the relationship between the unit GHG contents and the price index of each imported product has been estimated by a linear regression on the observed 2010-2023 series.

For information, when we let the model determine the relationship between the year-on-year changes of the unit GHG content and the price index over the 2010-2023 period, we find the following results. From the 7,171 series of unit GHG content we try to model, the parameter on price variation is found significant only for 1,439 series (at a 5% threshold), that is around 1 in 5 series. The significance is more frequent for certain products : C19 (85 % of country origins display a significant relationship with price), B (65 %), C23, C20, C24 and C17 (all around 40 %). When significant, the value of the parameter is estimated to be around -0.65 for C19 (unweighted average over country origins) and -0.50 for B.

Figure 12: Footprint now-cast in 2024 depending on the price index parameter (excluding households direct emissions, million tons CO_2eq)



9 Structuring and presenting carbon footprint outcomes

9.1 Presentation by final products in purchaser prices

The carbon footprint is estimated using the French IOT and the FIGARO MRIOT, which are both in basic prices. However, to enhance the consistency with the usual monetary statistics on final use (for example households final consumption), we would like to express the GHG content of final goods and services in a format compatible with purchaser prices. In practice, this means that the carbon content of trade and transport margins should be considered as a part of the related goods, rather than being "purchased" separately by final users. Note that the methodological step described in this section is very similar to what is done in Yamano et al. (2024), where the authors estimate the "emissions associated with the distribution margins".

For this, we make use of the fully detailed table of trade and transport margins on final uses described in section 5.1.3. The conversion of footprint results from basic price to purchaser price is done in the following way :

- To each row of the table, we attribute the unit GHG content (in kg CO_2eq / euro) of the related *service type*, which we then multiply by the margin in euro. This provides us with the "GHG content" of each margin element.
- We then make two independent aggregations of the table : total GHG content by type of goods on the one hand, total GHG content by type of service on the other hand.
- Starting from the footprint results by final products in basic price, we add the GHG content "by type of goods" to the relevant goods and remove the carbon content "by type of service" to the relevant services, which gives us a purchaser prices valuation. This procedure is neutral on the total footprint, it is only a way to re-allocate some carbon content from the *TTM services* to *goods*.

Figure 13 shows the effect of this reallocation from TTM services to goods. In 2021, the footprint associated with the final use of TTM services is 60 Mtons CO_2eq in basic price, and only 21 Mtons CO_2eq in purchaser prices. For transport services, what is left corresponds only to the final use of passenger transport, rather than freight. For trade services, what is left corresponds to the final use of repair of motor vehicles and motorcycles (part of G45). There is no carbon content left on "wholesale trade" (G46) and "retail trade" (G47), which are subject to no final demand in purchaser prices. Conversely, the carbon content of goods is 286 Mtons CO_2eq in purchaser prices rather than 247 Mtons CO_2eq in basic price, that is 16 % more. As expected, the carbon content of other services is unchanged.

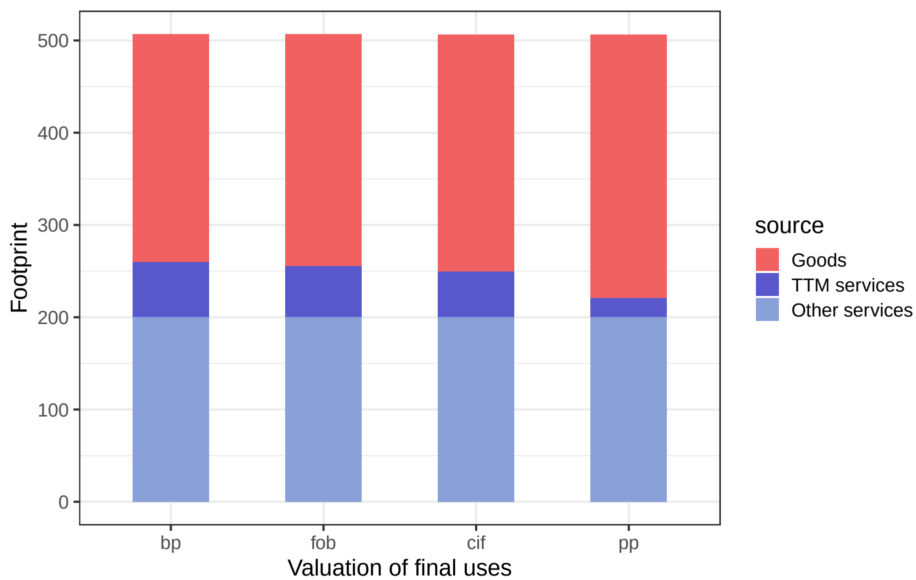
Please note that the procedure described here is very different in nature from the one described in section 5.1. The goal in 5.1 was to modify the valuation of the French IOT *before* the footprint calculation, to ensure a good compatibility between the French IOT and the MRIO. This treatment was applied to *all uses* (intermediate and final) of *imported* products and had an impact on the total footprint. Here, the goal is to modify the *final uses* valuation of *all products* (imported and domestic) *after* the footprint calculation, only for dissemination purposes. This second treatment has no effect on the total footprint.

9.2 Aggregation by main "demand categories"

To help with the communication of footprint results, we proceed to split the total footprint into 6 main "demand categories" : *food, housing, transportation, public services and health, equipments* and *market services.* This classification is loosely inspired by the classification of individual consumption by purpose (COICOP) but is actually ad-hoc (ie. in this study, we did not try to replicate exactly the CPA $\rightarrow$ COICOP allocation keys used elsewhere in French national accounts).

In Brown et al. (2021), the authors show examples of the GHG footprint associated to households final consumption for New-Zealand and Sweden, according to the COICOP. What we do here is a little different, because we do not cover only the *households final consumption* but the *total footprint* (final consumption and investment).

Figure 13: Footprint by final product type, depending on the valuation of final uses (year 2021, excluding households direct emissions, million tons CO_2eq)



For final consumption (national accounts code P3, representing around 80% of the footprint), we use a simple bridge table to allocate the carbon content from the CPA A64 nomenclature to our 6 categories. This allocation is done using GHG footprint results in *purchaser prices* (see previous section). But it is more difficult to allocate the footprint of investment (P5, 20% of the footprint) towards the main demand categories. For a given investment expense, our approach is to determine a category of final consumption that the investment will help fulfill (currently and / or in future years). We implement this in a two steps approach :

- Using French national accounts data, we first split the GFCF vector (P51G), according to the institutional sector which makes the expense : S11 (non financial corporations), S12 (financial corporations), S13 (general government), S14 (households) and S15 (NPISHs);
- We make a direct allocation for some institutional sectors : S12 (financial corporations → *market services*), S14 (households → *housing*) and S15 (NPISHs → *market services*);
- For S13 (general government), we consider that all investments in product F42 (civil engineering) contribute to the *transportation* footprint, while the investment in all other products goes to *public services*. Please note that, as our FIGARO-based footprint model does not separately identify the product F42, we use the unit carbon content of the product "F" as a proxy, and multiply it by the GFCF value in product F42 that we know from French national accounts;
- For S11 (non financial corporations), we go one step further and use the so-called "GFCF matrix" from French national accounts to split the investment according to which industry makes the expense. We then proceed to allocate the investment to main demand categories using an ad-hoc "industry → demand categories" bridge table (the product being invested plays no role here).

The overall allocation procedure is summarized in table 6.

Although imperfect, we believe that this breakdown of investment is useful to communicate the footprint results, by bringing it closer to the intuitive notion of "consumption", rather than "final demand", which is a more expert national accounting concept. In its intent, our treatment of investment can be seen as a limited attempt at "GFCF endogenization" in the footprint estimation, that is the idea of treating GFCF and the subsequent capital services as an input into production, rather than a final demand component. However, it is important to note that a more complete attempt at "GFCF endogenization", as presented

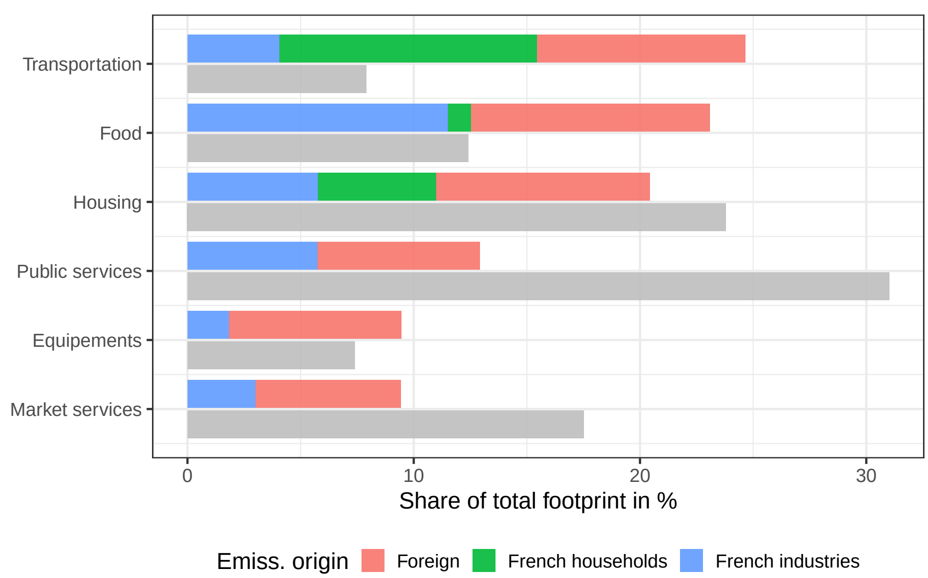
Table 6: Split of final use footprint by ”demand categories”

Final use	**Procedure to allocate the footprint to ”demand categories”**
P3_S13	bridge table from CPA to demand categories
P3_S14	bridge table from CPA to demand categories
P3_S15	bridge table from CPA to demand categories
P51G_S11	split by industry, then bridge table from industry to demand categories
P51G_S12	*market services*
P51G_S13	*transportation* for the investment in F42; *public services* for the rest
P51G_S14	*housing*
P51G_S15	*market services*
P5M	*equipment*
direct HH	bridge table from {heat, transport, other} to demand categories

for example in Södersten et al. (2018), would lead not only to a different classification of the footprint by demand categories, but also more importantly to a different *total footprint estimate*. This is because some domestic capital services would be considered to serve foreign final use, and conversely some foreign capitals services would be considered to serve domestic final use. We do not go that far in this working paper.

In 2024, we find that transportation and food are the main demand categories contributing to the French footprint (including households direct emissions), with 25 % of the footprint for transportation and 23 % for food (see color bars in Figure 14). Then follows housing at 20 %, while public services (13 %), equipments (9%), and market services (9%) have a lighter carbon content. These shares differ significantly from the shares in monetary final demand (grey bars in the figure), where public services is the most important category at 31 %, whereas transportation represents only 8 %.

Figure 14: Footprint (color bars) and monetary final demand (grey bars) by main categories (year 2024)



9.3 What exactly is considered as ”imported emissions” ?

From the expression of the GHG footprint, it is possible to separate three components : a domestic footprint, a footprint of imports for intermediate use and a footprint of imports for final use.

$$F_{Fr} = \underbrace{e_{Fr}(I - A^{Fr}_{Fr})^{-1}FU^{Fr}_{Fr}}_{\text{Domestic footprint}} + \underbrace{e(I-A)^{-1}\overline{A^{Fr}_{M}}(I - A^{Fr}_{Fr})^{-1}FU^{Fr}_{Fr}}_{\text{Imports for intermediate use}} + \underbrace{e(I-A)^{-1}\overline{FU^{Fr}_{M}}}_{\text{Imports for final use}}$$

From this, it might be tempting to define the "imported emissions" of the footprint as the sum of the last two terms. However, this would not be perfectly correct : as mentioned in section 2, the two last components of the footprint actually contain a small share of French emissions, incorporated into the carbon content of imports.

In 2021, the French emissions incorporated into the *footprint of imports for intermediate use* amounted to 1.7 Mt CO_2eq (that is 0.9 % of this component) and the French emissions incorporated into the *footprint of imports for final use* amounted to 1.2 Mt CO_2eq (1.0 % of this component).

Therefore, in our dissemination tables, we choose to consistently define the "imported emissions" as the total French emissions contributing to the footprint, including the small French shares in the *footprint of imports for intermediate use* and the *footprint of imports for final use*. The slight added complexity seems warranted, because it allows us to keep a perfectly consistent definition between all dissemination tables, be they focused on the origin of the emission, or on the GHG content of final products.

9.4 Origin of the emissions vs. emissions embodied in final products

As explained in section 2.4, footprint results can be presented according to a "production perspective", where emissions are broken down following the source of the emissions by region X industry, or a "consumption perspective", where emissions are broken down following the final product they are embodied in at the end of the value chain.

Figure 15 shows the French footprint results for 2023 (excluding households direct emissions), depending on the two perspectives. At the start of the value chain, emissions mainly originate from the primary and secondary economic sectors : agriculture (A), extraction (B), basic manufacturing (petroleum refining in C19, cement production in C23, steel production in C24), electricity generation (in D) and transportation (H). At the end of the value chain, emissions are mostly embedded in final manufactured goods ("C other"), construction (F) and "other services".

Figure 15: Footprint by product, depending on the perspective (production vs. consumption) (year 2023, excluding households direct emissions, million tons CO_2eq)

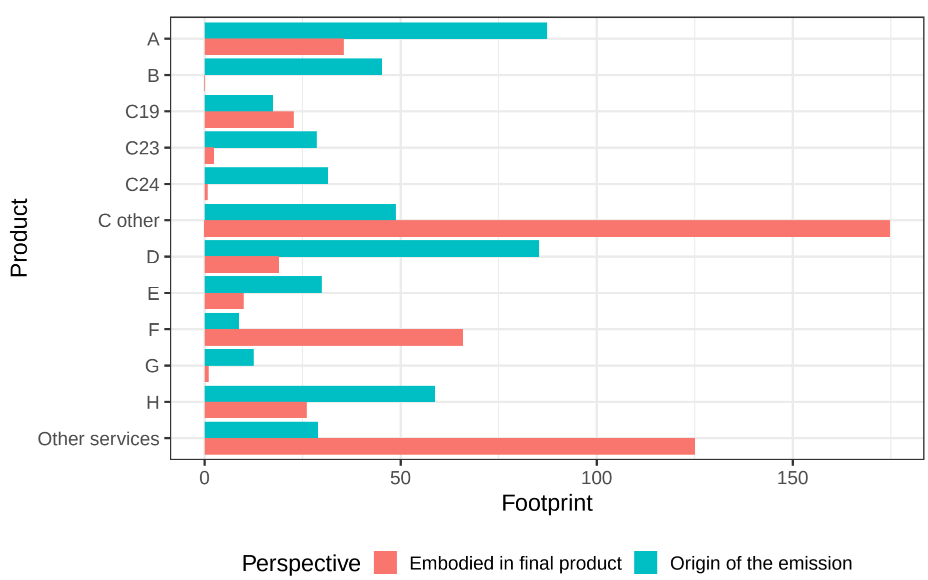


Table 7: French resident emissions and footprint (million tons CO_2eq)

	2010	...	2023	2024
Total GHG emissions (EMIS)	**548**	...	**408**	**404**
Households direct emissions	140	...	100	99
GHG emissions excluding households direct emissions	408	...	308	305
French emissions dedicated to French final demand	*254*	...	*185*	*180*
French emissions dedicated to foreign final demand	*154*	...	*123*	*125*
Gross GHG content of French imports (IMP)	**532**	...	**465**	**443**
Imported emissions dedicated to French final demand (= imported footprint)	355	...	297	284
for direct final use	*138*	...	*116*	*110*
for intermediate use in French production	*217*	...	*182*	*174*
Imported content dedicated to foreign final use (= imported and re-exported emissions)	177	...	167	160
products imported and re-exported after transformation	*145*	...	*132*	*128*
products imported and re-exported with no transformation	*33*	...	*35*	*32*
Gross GHG content of French exports (EXP)	**-331**	...	**-290**	**-285**
French emissions dedicated to foreign final demand	-154	...	-123	-125
Imported content dedicated to foreign final use (= imported and re-exported emissions)	-177	...	-167	-160
products imported and re-exported after transformation	*-145*	...	*-132*	*-128*
products imported and re-exported with no transformation	*-33*	...	*-35*	*-32*
Total GHG footprint (= EMIS + IMP – EXP)	**749**	...	**583**	**563**
Households direct emissions	140	...	100	99
GHG footprint excluding households direct emissions	609	...	483	463
French emissions dedicated to French final demand (= domestic footprint)	*254*	...	*185*	*180*
Imported emissions dedicated to French final demand (= imported footprint)	*355*	...	*297*	*284*

9.5 Articulating the notions of imported footprint vs. gross GHG content of imports

For our national dissemination, we choose to present the bridge table 7, for all years from 2010 to 2024. The level of detail allows us to illustrate the two views of international GHG flows discussed in section 3.

The main structure of the table follows the "carbon content of gross imports and exports" approach laid in equation 5 (footprint = resident emissions + gross content of imports - gross content of exports), whereas the sub-items allow the reader to identify the "net GHG imports" (ie. the foreign emissions contributing to the footprint) and "net GHG exports" (ie. the French emissions induced by foreign final demand) elements, as shown in table 1. Additional "of which" items also allow the reader to distinguish between the GHG content of products exported "after transformation" or "with no transformation", that is the "re-exports" discussed in section 3.

10 Comparisons between FIGARO, EXIOBASE and ICIO

10.1 Objectives and scope of the comparison

10.1.1 Main characteristics of the three models

This section's aim is to compare French GHG footprint estimates using the FIGARO database produced by Eurostat with other EE-GMRIO models. As we have already described the differences between our own simplified SNAC estimation and the direct FIGARO estimate in section 7, we will not repeat this analysis in detail here.

We focus on the most prominent and up-to-date models currently available for France, that is:

- Eurostat's GMRIO approach, based on the FIGARO input-output tables (Eurostat, 2019) and EDGAR-based Air emission accounts (see section 4.2). This model is particularly relevant for public policy and serves as the methodological foundation for the simplified SNAC approach developed in this paper.
- EXIOBASE GMRIO database (Stadler et al. (2018); Wood et al. (2025)), the most widely recognized in Input-Output academic research, known for its high sectoral and regional granularity and its extensive coverage of environmental pressures, including greenhouse gas emissions. In this report, we specifically compare version 3.8.2 (2021 release) and version 3.9.5 (2025 release), to highlight recent methodological improvements.
- OECD's ICIO model (Yamano et al. (2023)), a global reference frequently used for analyzing trade and global value chains, with strong policy relevance.

Other GMRIO databases were excluded from the comparison. We can cite in particular WIOD (Timmer et al. (2016)), whose last update dates back to 2016; Eora (Lenzen et al. (2013)), due to licensing restrictions and limited methodological transparency; and GLORIA (Lenzen et al. (2022)), which, although very promising and now offering carbon footprint indicators, remains under development and lacks the track record of more established databases such as EXIOBASE.

Two key critical methodological dimensions are known to significantly influence national carbon footprint estimates:

- Sectoral and regional resolution. The level of sectoral detail varies significantly across models: from 45 sectors in the OECD ICIO model, to 64 in FIGARO, and up to 200 in EXIOBASE. Similarly, EXIOBASE and FIGARO cover around 50 regions, while OECD ICIO distinguishes up to 76 regions. Previous studies (de Koning et al., 2015; Piñero et al., 2015; Steen-Olsen et al., 2014), have shown that both sectoral and regional resolution significantly affect carbon footprint results due to their influence on global value chain representation.
- Sources of input-output data and emission factors. The source and construction of IO tables and associated emission factors also affect results. As discussed in section 8.4, differences in emission factor datasets (EDGAR, PRIMAP TP, PRIMAP CR or other sources) can lead to noticeable divergences in carbon footprint estimates.

Finally, we can note that the EXIOBASE 3.9.5 release includes significant methodological and data improvements, including:

- Extended alignment with official statistics: Gross output and trade flows for each industry and product are now aligned with data from international sources (FAO, IEA, UN IRP, OECD, Eurostat, and UN ComTrade) up to 2020 or 2021, compared to 2018 in earlier releases. More recent years remain now-casted.
- Integration of Eurostat FIGARO SUTs in the balancing procedure: A major innovation is the integration of the entire Eurostat FIGARO Supply-Use Tables in the pre-scaling reconciliation process, which improves the robustness and internal consistency of the database. This integration was performed at an aggregated 42-sector level to ensure coherence between the NACE Rev. 1.1 classification used in EXIOBASE and the NACE Rev. 2 used in FIGARO.

- Improved environmental accounts: While EXIOBASE 3.8.2 included alignment with official data only up to 2015 for energy balances, 2019 for CO_2 from combustion, and 2017 for other GHGs (with nowcasting beyond these years), version 3.9.5 extends this alignment to 2020 for energy balances (IEA), 2021 for CO_2, and 2022 for other GHGs. Importantly, the new version strengthens the internal consistency between monetary, physical, and environmental flows within the energy accounts (Rasul et al. (2024)).

10.1.2 Analytical focus and comparison indicators

We assess the carbon footprint discrepancies between FIGARO, ICIO and EXIOBASE across two complementary perspectives:

- Consumption-based approach by product: assessment of GHG emissions embodied in final consumption, broken down by product.
- Production-based approach by industry of origin: assessment of upstream emissions associated with global production required to fill the domestic final demand, disaggregated by emitting industry.

To ensure consistent comparison, results for each approach are aggregated by sector following the NACE Rev. 2 classification.

Note that discrepancies between NACE Rev. 1 (used in EXIOBASE) and NACE Rev. 2 (used in FIGARO and ICIO), particularly in service and manufacturing subsectors, require harmonization assumptions when aggregating EXIOBASE to match FIGARO's classification level for the analysis of sectoral aggregation bias. For analytical consistency, both database results were first aggregated to a common 42-sector classification, where macro-level correspondence is generally reliable, as suggested in the literature (Wood et al. (2025)).

Finally, we exclude direct GHG emissions from household consumption in France (e.g., private vehicles and domestic heating), as these are uniformly covered across all models and are not relevant for our focus on embodied emissions.

10.2 Discrepancies in footprint results between the three models

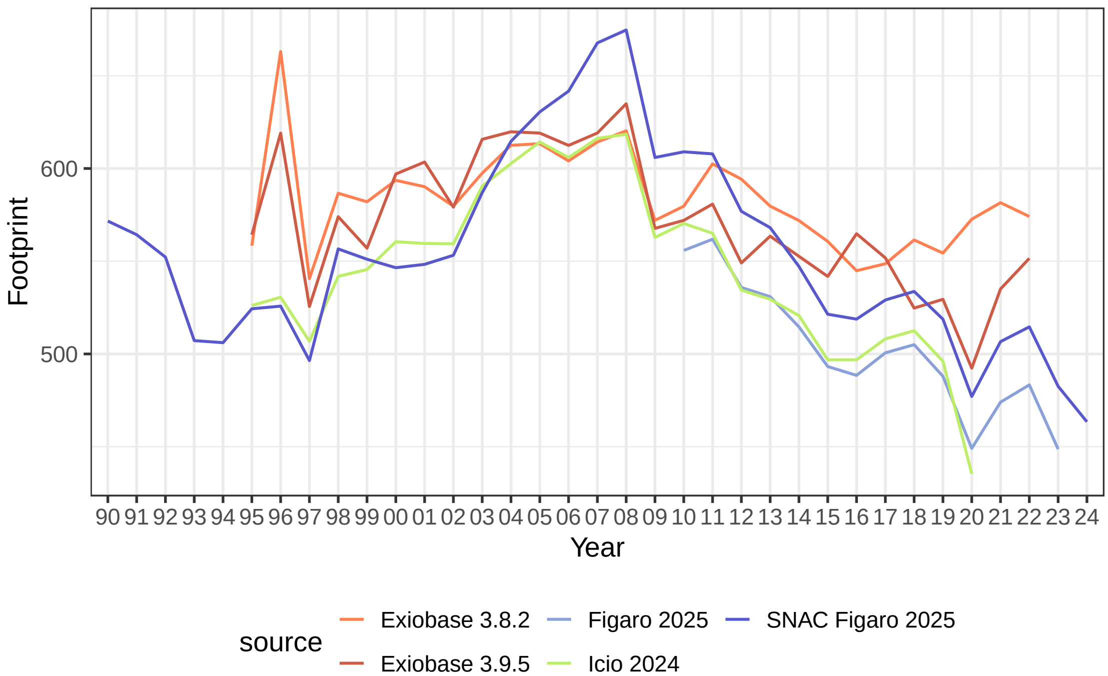
10.2.1 Discrepancies in the aggregate French GHG footprint results

Figure 16 compares the aggregate GHG footprint results (excluding households direct emissions) of 5 different models : FIGARO 2025 (direct model and SNAC), Exiobase 3.8.2, Exiobase 3.9.5 and ICIO 2024. The main conclusions are:

- The footprints resulting from ICIO 2024 and FIGARO 2025 are very similar, both in level and trends. This makes sense, because ICIO and FIGARO share a substantial part of their source data (many national IOTs for example) and methodology (some of the global trade flows balancing procedures, for example).
- As already explained in section 7, the footprint from the SNAC-FIGARO is higher than the direct application of FIGARO, but the time-series dynamics is very close.
- For recent years, EXIOBASE 3.8.2 relies on older reference data and fails to accurately reflect short-term fluctuations, such as the 2020 dip linked to the global health crisis. EXIOBASE 3.9.5 is much more up-to-date and its results appear more comparable to FIGARO and ICIO over the 2018-2021 period. For earlier years however (2010-2018 period), the downward trend in the French GHG footprint is more pronounced with ICIO and FIGARO.

Over the longer time period 1995-2021, EXIOBASE results appear to be somewhat "flatter" than ICIO, or than our own back-casting procedure based on the SNAC-FIGARO before 2010 (described in Annex D). The increase in the GHG footprint is more limited between 1995 and 2008, and the decrease afterwards is also milder.

Figure 16: Comparison of the French GHG footprint (excluding households direct emissions) for different EE-GMRIO models (million tons CO_2eq)



10.2.2 Consumption-based approach: discrepancies in the GHG content by final use product

Figure 17 shows the GHG content embedded in the French final use by product for EXIOBASE 3.9.5, FIGARO 2025 and ICIO 2024, for the year 2019.

ICIO stands out for several reasons : GHG embedded in agriculture products (A) and manufacturing products ("C other") is clearly above the other two models, while GHG embedded in trade (G) and transport services (H) is smaller. This is mostly due to a difference in presentation : in the OECD's dissemination tables, ICIO results are shown at purchaser prices (i.e. including trade and transport margins) whereas EXIOBASE and FIGARO are shown at basic prices.

EXIOBASE shows other differences. In particular, GHG embedded in agriculture products (A) is lower than in the other two models, while GHG embedded in transport services (H) is much higher.

10.2.3 Production based approach: discrepancies in the origin of the GHG emissions

When we look at the origin of the emissions by industry, FIGARO and ICIO results come very close to one another, while EXIOBASE stands out. In particular, EXIOBASE emissions originating from extractive activities (nace B), sea transport (nace H50) and air transport (nace H51) are markedly higher than in the other two models. Conversely, emissions originating from agriculture (nace A) and road transport (nace H49) are smaller.

These differences can be due to the monetary input-output model themselves, but also to the different air emission accounts used to extend them.

10.3 Impact of sectoral aggregation on carbon footprint assessments

This subsection examines how the level of sectoral aggregation influences carbon footprint estimates when comparing EXIOBASE 3.9.5 with Eurostat results. The sectoral resolution differs substantially between the two models: 64 sectors in FIGARO versus 200 sectors in EXIOBASE. It is well established in the

Figure 17: Comparison of the GHG embedded in French final use by products (excluding households direct emissions) for different EE-GMRIO models - year 2019 (million tons CO_2eq)

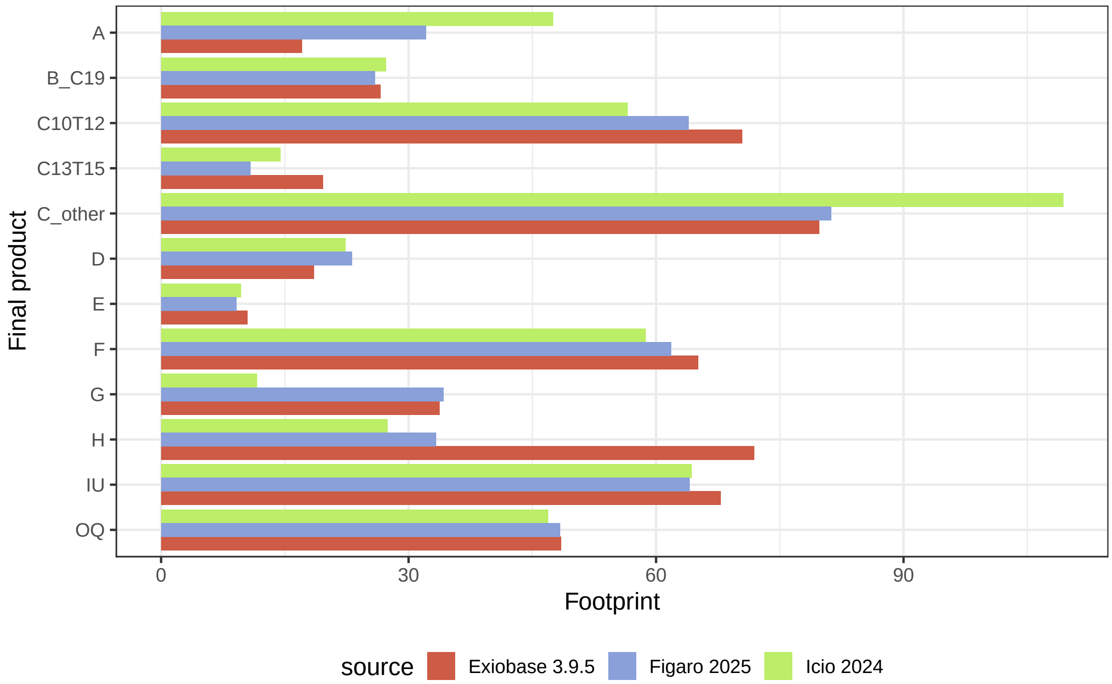
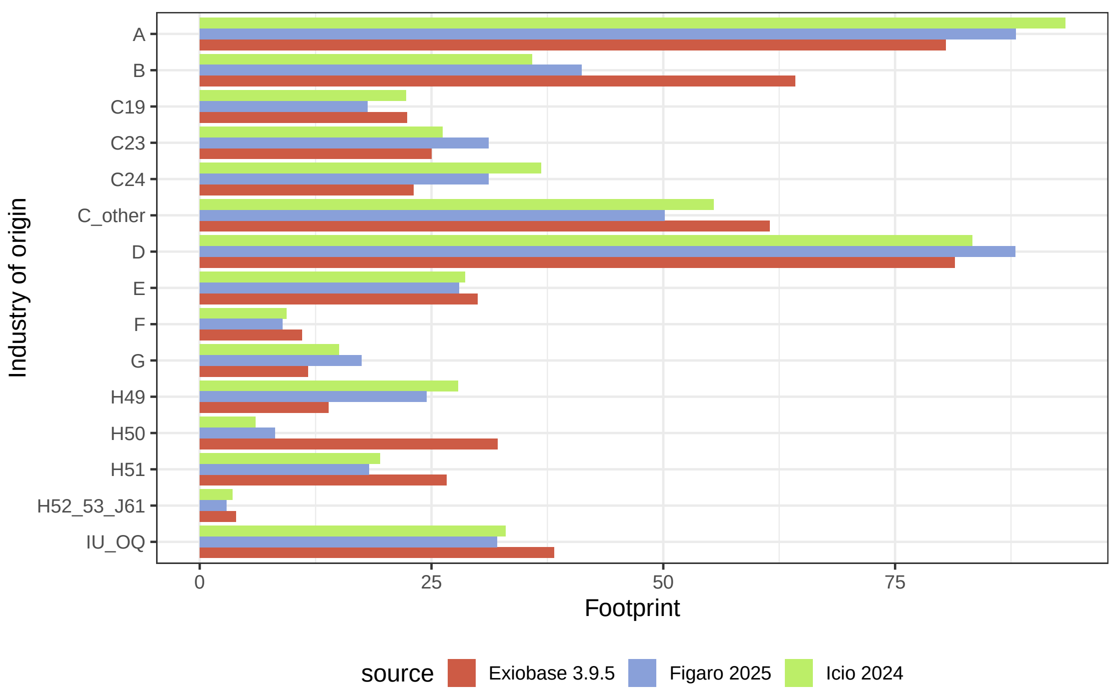


Figure 18: Comparison of the origin of the emissions in the French GHG footprint, by industry (excluding households direct emissions) for different EE-GMRIO models - year 2019 (million tons CO_2eq)



literature that coarser sectoral detail can significantly affect carbon footprint results due to its impact on the representation of global value chains, particularly in carbon-intensive sectors such as energy supply and the production of agricultural and food products.

To assess to potential scale of the sectoral aggregation effects, we build an aggregated version of EXIOBASE 3.9.5, at a level of detail of only 42 products rather than the initial 200.

Note that the Eurostat-based assessment is only marginally affected by the aggregation from 64 to 42 sectors. The conclusions drawn below from the 42-sector comparison therefore remain valid at the original level of detail.

Figure 19 shows the GHG content embedded in the French final use by product for EXIOBASE 3.9.5 and its aggregated version, as well as FIGARO 2025 for comparison.

We can see three important results :

- The total EXIOBASE footprint is higher after aggregation (557 Mt COeq vs. 529 Mt CO_2eq for the year 2019, that is + 5 %).
- The main effect is for agriculture products (cpa A), where the footprint is twice higher when products are aggregated.
- Smaller aggregation effects can be seen for the final use of refined petroleum products (C19) and energy (D).

In agriculture, from the consumption perspective, the convergence between EXIOBASE and FIGARO improves significantly after sectoral aggregation. We can therefore assume that a large part of the original difference can be attributed to the coarse sectoral resolution in Eurostat, where agriculture is represented by only three sectors, compared to 19 in Exiobase. Aligning the Eurostat model with a more detailed agricultural breakdown could lead to more accurate assessments. However, a residual gap remains, likely due to differences in emission factor sources. These discrepancies could be better understood and addressed if Eurostat provided more granular emissions data for the agricultural sector.

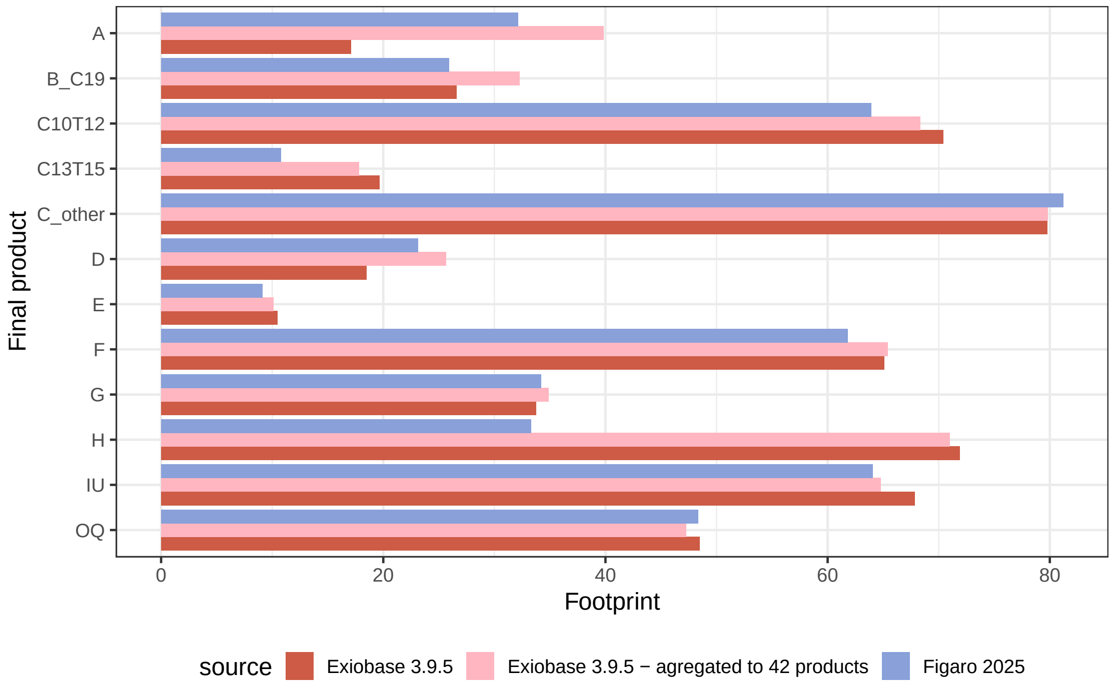
EXIOBASE also provides a much more detailed breakdown of the energy system (48 sectors, including 12 electricity supply sectors by energy source and 18 refined petroleum products), compared to just two in Eurostat (electricity and fuels). Introducing further disaggregation within the Eurostat framework would likely enhance the accuracy of footprint assessments by better capturing the complexity of global energy supply chains.

The mining sector is particularly aggregated in Eurostat, represented by a single category (nace B), whereas EXIOBASE provides a more detailed disaggregation (23 sectors including 12 fossil fuels, 8 metal ores and 3 non-metallic minerals). While improving sectoral resolution on the Eurostat side could enhance the comparability of results, it would not be sufficient on its own. As with agriculture, differences in emission factor sources likely play a significant role and should be investigated further at a finer level of detail.

Finally, for other sectors, sectoral aggregation appears to have a limited effect on footprint estimates. This suggests that aggregation biases are sector-specific and particularly relevant for high-emission, structurally diverse sectors such as agriculture and energy.

As previously noted, significant discrepancies show up for the transport sector, and they are not improved by the aggregation of EXIOBASE. From a consumption-based perspective, land transport (H50) GHG content is much higher in FIGARO, while water and air transport content is lower (figure 17). These discrepancies may result from a different approach in the allocation of international transport activities to the country of residence of shipping and aviation fleets (residence principle) rather than to the territory where emissions occur (territorial principle). The economic assessment of what part of the output is a transport margin vs. what part is dedicated to passenger transportation may also differ between models. These differences call for further analysis to clarify model assumptions and emission data sources.

Figure 19: Comparison of the GHG embedded in French final use by products (excluding households direct emissions) for different EE-GMRIO models - year 2019 (million tons CO_2eq)



Conclusion

Using an EE-GMRIO as the foundation to estimate our national carbon footprint enables us to explicitly integrate international value chains and the domestic economy into a single consistent model. Beyond the accuracy gain offered over previous methodologies, this approach also opens up many new possibilities for economic and environmental analysis. In our specific case, choosing the FIGARO GMRIO allows us to reliably plan for future annual updates of our results in the medium and long term, benefiting from a sustained European collaborative effort.

However, the EE-GMRIO approach also comes with challenges for National Statistical Institutes, among which key examples are the consistency of results between the MRIO table and national estimates, and the need for timely estimates of the national carbon footprint.

This working paper described the solutions we provided to those challenges, following the "simplified-SNAC" approach, which is de facto the current standard for national carbon footprints published by statistical institutes.

The proposed methodology has certain limitations. Some are quite general, and apply to all EE-GMRIOs attempts to estimate GHG footprints:

- Global GHG emissions must be known precisely by country and industry. It should be noted that, under the Kyoto agreement, only those countries considered "developed" in 1995 were obliged to produce complete UNFCCC annual emissions inventories (so-called "annex I" countries). Emissions data for other countries are therefore known with less certainty. The situation should gradually improve from 2025 onwards, when the Paris Agreement regime begins to apply, making complete annual emissions inventories mandatory for all signatory countries. At the same time, international bodies such as the OECD and the IMF are actively encouraging their members, particularly those in the G20, to produce Air Emission Accounts based on these inventories.

- The GMRIO itself may be imprecise or imperfect, due to insufficient economic data in a large number of countries, particularly those outside of the OECD. Here too, global initiatives exist to improve both the availability of source data in countries with incomplete or infrequent SUTs and IOTs, and the compilation process of MRIO models (for example, the GIANT initiative).

Other methodological limitations are more specifically linked to the "simplified-SNAC" approach.

- "Environmentally extended input-output modeling" using the Leontieff formalism with a GMRIO in *current prices* relies on a strong assumption of homogeneity : irrespective of the user, the carbon emissions embedded in a given product are assumed to be proportional to the *monetary value* of this product. In other words, the product is supposed to be homogeneous in terms of *characteristics* and *price* for all users, and this at a global level. We saw that for example, in 2022 and 2023 for energy products, this strong assumption does not hold, introducing a significant bias in the French GHG footprint estimation (section 5.4.2). It is to be noted that this problem may concern all GMRIOs footprint estimates, but is more acute in the "simplified-SNAC" approach, where the national imports are taken at face value and not reconciled with other countries exports, which may mitigate the heterogeneity in price developments. There are two main ways to limit the potential biases associated with this homogeneity assumption. One is to increase the level of detail of products described in the MRIO, the other is to rely more heavily on the volumes of products rather than just their monetary value. In this regard, the upcoming availability of previous year's prices GMRIO tables (both ICIO and FIGARO are expected to publish such tables in 2026) will be an important development.
- The question of the geographical origin of imports in national accounts is not as simple as it seems. Imports and exports in National accounts represent changes in economic ownership between resident and non-resident units, which can differ from cross border flows in the presence of global production arrangements such as merchanting, goods sent abroad for processing, "factoryless" goods production, etc. However, it is currently difficult to assess to which extent this principle is actually implemented in various countries' accounts, and if detailed recordings by products and counterpart countries are, in fact, consistent between countries. As we have shown with computer and electronic products in section 8.3, this issue may have a non-negligible impact on the French carbon footprint and will deserve further study in the future.

Despite these limitations, the national carbon footprint based on macro-economic data is already a very useful indicator of a country's contribution to climate change, and enables numerous quantitative analyses. In the coming years, the French ministry of the environment and INSEE plan to continue working on the methodology for estimating the French footprint, in order to continuously integrate the best sources and methods available. Any methodological improvements will always be back-casted back to 1990, to ensure the continuity of the time-series we disseminate.

Based on the methodological findings presented in this paper, we intend to prioritize our future work on :

- The level of detail of agricultural products, where the (upwards) aggregation bias in FIGARO compared to Exiobase seems significant (see section 10);
- The level of detail and the physical quantities of energy products. In this sector, the aggregation bias in FIGARO compared to Exiobase may be more limited, but the high level of aggregation in FIGARO makes it hard to conduct meaningful volume / price decompositions, which constitutes both a structural and a short-term analysis limitation (see section 5.4.2).

Beyond aggregation biases, we will continue to work on other methodological aspects already discussed in this paper, among which the quality of global Air Emissions databases, the estimation of global trade and transport margins, the consistent application of the economic ownership principle and the footprint nowcasting methods.

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A Annex : Press release and list of the dissemination tables

The results of our simplified SNAC GHG footprint estimation based on FIGARO were first published on November 5th 2024 (1990-2023 series) and updated on October 16th 2025 (1990-2024 series).

The latest press release is available here (in French only): `https://www.insee.fr/fr/statistiques/8654458`

And the full tables are available here (in English): `https://www.insee.fr/en/statistiques/8194102`

Most of the tables provide time-series for the period 2010-2024. A few series have also been back casted to 1990 (total GHG footprint, originating from France vs. abroad).

The first set of tables provides the main results for the total French resident emissions and footprint, without any detail by industry or product.

- *GHG.100 - Greenhouse gas emissions and footprint - main aggregates*

The second set describes French resident emissions by industry and household direct emissions. Emissions are shown together with monetary output and value added by industry, in current and constant euros.

- *GHG.201 - Resident economic units greenhouse gas emissions*
- *GHG.202 - Greenhouse gas emissions and economic activity by industry*
- *GHG.203 - Households direct greenhouse gas emissions*

The third set of tables describes the bridge between resident emissions and footprint, as discussed and presented in section 3. Carbon flows are shown gross and net, with some detail by origin country and product.

- *GHG.301 - Bridge from greenhouse gas emissions to greenhouse gas footprint*
- *GHG.302 - Greenhouse gas international flows*

The following set of tables shows the footprint results, with several breakdowns : by origin of the emissions, carbon embedded in final products or "main consumption categories" as discussed in section 9.2.

- *GHG.401 - GHG footprint according to the source of the emissions*
- *GHG.411 - GHG footprint by main consumption categories*
- *GHG.412 - GHG footprint by products of the final demand*
- *GHG.413 - GHG footprint by institutional sectors*

Finally, two last Excel files provide miscellaneous results, such as a measure of the "upstream GHG content" of output by product (this is mainly intended for comparison with private sector, LCA based emission factors), and international GHG footprint comparisons based on FIGARO.

- *GHG.501 - Upstream greenhouse gas content of output by product*
- *GHG.600 - International comparisons*

B Annex : Expression of the simplified SNAC footprint in three additive components

General notations

As explained in section 1.2, the environmental footprint F for a given final demand vector X is given by the Leontieff expression :

$$F = eLX \text{ where } L = (I - A)^{-1}$$

Let us divide the global economy in two regions : France (Fr) and the rest of the World (M). The matrix A of technical coefficients can be decomposed as :

$$A = \begin{pmatrix} A_{Fr}^{Fr} & A_{Fr}^{M} \\ A_{M}^{Fr} & A_{M}^{M} \end{pmatrix}$$

where the superscript denotes the country of demand and the subscript the country of origin of the product. The inverse Leontieff matrix is :

$$L = \begin{pmatrix} I - A_{Fr}^{Fr} & -A_{Fr}^{M} \\ -A_{M}^{Fr} & I - A_{M}^{M} \end{pmatrix}^{-1}$$

What do we want to prove ?

To implement the simplified SNAC approach, we use a development of the French carbon footprint in three additive terms, given in section 2.2:

$$F = \underbrace{e_{Fr}}_{1\times 64} \underbrace{(I - A_{Fr}^{Fr})^{-1}}_{64\times 64} \underbrace{FU_{Fr}^{Fr}}_{64\times 1} + \underbrace{e}_{1\times 2944} \underbrace{(I-A)^{-1}}_{2944\times 2944} \underbrace{\overline{A_{M}^{Fr}}}_{2944\times 64} \underbrace{(I - A_{Fr}^{Fr})^{-1}}_{64\times 64} \underbrace{FU_{Fr}^{Fr}}_{64\times 1} + \underbrace{e}_{1\times 2944} \underbrace{(I-A)^{-1}}_{2944\times 2944} \underbrace{\overline{FU_{M}^{Fr}}}_{2944\times 1}$$

where the French final use vector has been decomposed in two parts : FU_{Fr}^{Fr} for the final demand of French products and $\overline{FU_{M}^{Fr}}$ for the final demand of foreign products.

We can note that the third term in the decomposition is straightforward : we just apply the classical Leontieff formula to the final demand of foreign products. The less obvious decomposition is between the first two terms, that is :

$$e(I-A)^{-1} \begin{pmatrix} FU_{Fr}^{Fr} \\ 0 \end{pmatrix} = \underbrace{e_{Fr}}_{1\times 64} \underbrace{(I - A_{Fr}^{Fr})^{-1}}_{64\times 64} \underbrace{FU_{Fr}^{Fr}}_{64\times 1} + \underbrace{e}_{1\times 2944} \underbrace{(I-A)^{-1}}_{2944\times 2944} \underbrace{\overline{A_{M}^{Fr}}}_{2944\times 64} \underbrace{(I - A_{Fr}^{Fr})^{-1}}_{64\times 64} \underbrace{FU_{Fr}^{Fr}}_{64\times 1} \quad (6)$$

This development of the footprint is pretty remarkable. Its economic interpretation is that we can first take a purely domestic component of the footprint, without considering any interaction with the rest of the world (first term), then compute the indirect requirement of foreign products induced by this domestic footprint (through the $\overline{A_{M}^{Fr}}$ matrix), and estimate its global footprint (second term). While this makes economic sense, it is not obvious that this should work. In particular, we can note that the two terms involve vectors and matrices of different dimensions, so that the mathematical equality is not trivial.

Direct proof

In this proof, we just start from the two terms decomposition above and "show it works".

The main problem in our target decomposition 6 is that the two terms on the right hand side do not involve matrices and vectors of the same dimensions. To overcome this difficulty, we rewrite equation 6 as :

$$eL \begin{pmatrix} X \\ 0 \end{pmatrix} = e \begin{pmatrix} (I - A_{Fr}^{Fr})^{-1} X \\ 0 \end{pmatrix} + eL \begin{pmatrix} 0 \\ A_M^{Fr} (I - A_{Fr}^{Fr})^{-1} X \end{pmatrix} \tag{7}$$

where X is any final demand vector of domestic products. This is the same as the above, but with all the terms now having the same dimension, which is the full dimension of the MRIO. We can check that the elements we added to complete the dimension are all zero.

The environmental extension e can directly be simplified on the left and right hand sides. We then simplify by L (i.e. left multiply by L^{-1}):

$$\Leftrightarrow \begin{pmatrix} X \\ 0 \end{pmatrix} = \begin{pmatrix} I - A_{Fr}^{Fr} & -A_{Fr}^{M} \\ -A_M^{Fr} & I - A_M^M \end{pmatrix} \begin{pmatrix} (I - A_{Fr}^{Fr})^{-1} X \\ 0 \end{pmatrix} + \begin{pmatrix} 0 \\ A_M^{Fr} (I - A_{Fr}^{Fr})^{-1} X \end{pmatrix}$$

and develop the matrix multiplication:

$$\Leftrightarrow \begin{pmatrix} X \\ 0 \end{pmatrix} = \begin{pmatrix} (I - A_{Fr}^{Fr})(I - A_{Fr}^{Fr})^{-1} X \\ -A_M^{Fr} (I - A_{Fr}^{Fr})^{-1} X \end{pmatrix} + \begin{pmatrix} 0 \\ A_M^{Fr} (I - A_{Fr}^{Fr})^{-1} X \end{pmatrix}$$

This last statement is obviously true. This proof is very direct, but tells us little about why the decomposition was possible in the first place.

More interesting proof

Now we try to see if there is a more "natural" way to obtain the previous additive decomposition. We start from the L Leontieff operator, which gives us the global production induced by any vector of final demand. What happens if we try to take first a "in-country" version of this operator, ignoring all interactions with the rest of the world ? This "in-country" footprint operator would be defined as :

$$L^* = \begin{pmatrix} (I - A_{Fr}^{Fr})^{-1} & 0 \\ 0 & (I - A_M^M)^{-1} \end{pmatrix} = \begin{pmatrix} L_{Fr}^* & 0 \\ 0 & L_M^* \end{pmatrix}$$

As this operator is bloc-diagonal, its invert can be computed directly as :

$$L^{*-1} = \begin{pmatrix} (I - A_{Fr}^{Fr}) & 0 \\ 0 & (I - A_M^M) \end{pmatrix}$$

Now, the idea of computing the "in-country" operation first for the global footprint can be expressed in a multiplicative form as :

$$L = \underbrace{L.L^{*-1}}_{\text{Unknown term}} \quad . \quad \overbrace{L^*}^{\text{In-country operator}}$$

We develop the "unknown term" :

$$L.L^{*-1} = L \begin{pmatrix} (I - A_{Fr}^{Fr}) & 0 \\ 0 & (I - A_M^M) \end{pmatrix} = L \left[I - \begin{pmatrix} A_{Fr}^{Fr} & 0 \\ 0 & A_M^M \end{pmatrix} \right]$$

$$= L\left[I - A + \begin{pmatrix} 0 & A_{Fr}^{M} \\ A_{M}^{Fr} & 0 \end{pmatrix}\right] = I + L\begin{pmatrix} 0 & A_{Fr}^{M} \\ A_{M}^{Fr} & 0 \end{pmatrix}$$

and we reinject it in our decomposition of L :

$$L = \left[I + L\begin{pmatrix} 0 & A_{Fr}^{M} \\ A_{M}^{Fr} & 0 \end{pmatrix}\right]\begin{pmatrix} L_{Fr}^{*} & 0 \\ 0 & L_{M}^{*} \end{pmatrix}$$

We finally get the following expression of the Leontieff operator :

$$\boxed{L = \begin{pmatrix} L_{Fr}^{*} & 0 \\ 0 & L_{M}^{*} \end{pmatrix} + L\begin{pmatrix} 0 & A_{Fr}^{M} \\ A_{M}^{Fr} & 0 \end{pmatrix}\begin{pmatrix} L_{Fr}^{*} & 0 \\ 0 & L_{M}^{*} \end{pmatrix}}$$

This expression is the one we were looking for. It is more general version of equation 7, but we can check that in the special case of a final demand vector X of only domestic products, we come back to equation 7.

We started by taking a "in-country" version of the Leontieff operator in a multiplicative form, but we ended up with an additive decomposition in two terms, the first being the purely "in-country" component of the footprint (ignoring all interactions with the rest of the world), the second being the global Leontieff operator applied to the indirect requirement of foreign products induced by this "in-country" footprint.

Note that this is a very general property of the Leontieff framework, and, instead of "France vs. rest of the world", it could be applied to any partition of the global economy into complementary sets of products.

C Annex : Revision between the November 2024 publication and the October 2025 Publication

France's GHG footprint for the year 2021 has been revised from 666 million tonnes CO_2eq (Mt CO_2eq) in the November 2024 publication to 620 Mt CO_2eq in the October 2025 publication, i.e. -46 Mt CO_2eq or -6.9%. The causes of the revision are as follows:

- (+ 6 Mt CO_2eq) Correction of an error in the previous publication: some data on fluorinated gas emissions in non-EU countries were missing and have been added.
- (- 7 Mt CO_2eq) Methodological improvements have been made to the French IOT used to calculate the carbon footprint. In particular, tax rates on energy products were erroneously identical for all users of the products. In real life however, households pay on average higher tax rates than businesses, and some sectors benefit from special allowances (e.g. non-road diesel for agriculture or construction). Taking into account differentiated rates for different users means that less of the carbon content of energy products is attributed to households (where they contribute 100% to France's footprint) and more to businesses (where a proportion ends up being exported abroad). The aggregate effect of this modification is therefore to reduce France's footprint.
- (+ 7 Mt CO_2eq) French Air Emission Accounts have been revised for various items, with an average increase over the entire period, which in turn causes an increase in the French footprint.
- (- 9 Mt CO_2eq) Global GHG emissions have been reviewed in the EDGAR database (non-EU countries), with an average decrease over the entire period. Emissions from EU countries (which submit full air emission accounts to Eurostat) have hardly been revised at all.
- (- 44 Mt CO_2eq) By far the biggest revision is linked to the integration of the FIGARO MRIO version 2025, replacing the version 2024. The estimate of monetary output by industry for the "rest of the world" region (code FIGW1) was incorrect in the 2024 version, with too much weight given to services and not enough to agriculture and industry. In the 2025 version, agricultural production has been revised upwards by a factor of 4. At the same time, GHG emissions from the agricultural sector in this

region are virtually unchanged, as they are taken from an independent source (EDGAR, reprocessed by Eurostat). In total, the carbon content per euro of agricultural products imported by France from this “rest of the world” region is therefore divided by around 4 between the two versions, resulting in a significant reduction in the associated footprint.

D Annex : Back-casting of the French GHG footprint since 1990

The simplified SNAC results are available from 2010 (first year in the FIGARO MRIO tables and in our own detailed national IOT). We proceed to back-cast the GHG footprint between 1990 and 2009, but only at a very aggregated level.

For this, the carbon footprint is broken down into three components:

- Direct household emissions,
- Emissions from French production, excluding emissions associated with exports,
- Emissions associated with imports.

Estimation of French Air Emissions Accounts 1990 - 2007 in NACE Rev. 2

The French national greenhouse gas (GHG) inventory is compiled by the CITEPA, a non-profit organization which is not part of the national statistical system. They produce the yearly official inventory destined to the UNFCCC, following the IPCC guidelines. The SDES, which is part of the national statistical system, is responsible for the compilation and dissemination of the yearly Air Emission Accounts (AEA), under EU regulation 691/2011. In practice, the AEA compilation is subcontracted to the CITEPA, but the methodological decisions and data validation remain the responsibility of the SDES.

CITEPA provides NACE Rev.1 AEAs for the years 1990 to 2007, while NACE Rev.2 AEAs are known from 2008 onwards. To obtain a full, continuous series in NACE Rev.2 for the whole period 1990-2008, we back-calculate the NACE Rev.2 levels by applying the annual changes of the NACE Rev.1 categories which are “as close as possible” to the new nomenclature. In practice, this involves establishing a correspondence at a 54 industries level, where the two nomenclatures correspond sufficiently well. Unfortunately, with this approach, some NACE Rev.2 categories (C33, J58, 59 and 60) have no natural equivalent in NACE Rev.1, so instead we apply to them the evolutions of other NACE Rev.2 categories, closest possible in the nomenclature.

For household’s direct emissions, CITEPA’s AEAs for the years 1990-2007 do not distinguish between the two categories “Housing” and “Other emissions” that we wish to obtain. To estimate this split, we use the so-called ”SECTEN” inventory (French specific version of the UNFCCC inventory), which provides the necessary detail.

Finally, the NACE Rev.2 emissions estimated in the previous steps are proportionally adjusted in order to keep Citepa’s NACE Rev.1 AEA total unchanged for each type of greenhouse gas and each year.

French production emissions: split between exported and domestic emissions

Emissions associated with exports in 1995, 2000 and 2005 are the result of input-output calculations based on available French IOTs and AEAs in NACE Rev.1. Emissions associated with exports in 2010 are estimated using the new methodology, simplified SNAC based on FIGARO.

The ratio between total emissions data (excluding LULUCF) from the SECTEN inventory and production data by value is used to estimate changes in the GHG intensity of production for the missing years (i.e. 1990 to 1994; 1996 to 1999; 2001 to 2004 and 2007-2008). It is assumed that trends in the average unit GHG content of exports are similar to trends in the GHG intensity of total production. This makes it possible to estimate the GHG content of exports, by gas substance, for all years.

By multiplying the unit GHG content of exports by the value of exports, we can estimate the total GHG content of French exports, for each year and each substance. The domestic emissions of the footprint are estimated by subtracting the total non-household AEA inventories from the emissions associated with exports.

Emissions associated with imports

Emissions associated with imports are estimated by multiplying the unit content of imports by the value of imports. Emissions associated with imports in 2010 are the result of the new methodology described in this working paper (simplified SNAC based on FIGARO). They enable us to estimate the unit content of imports for this reference year.

Before 2010, it is assumed that the average unit GHG content of imports evolves in line with the GHG intensity of world GDP. World GDP data in current dollars published by the World Bank are converted to euros using information on OECD currency exchange rates. The GHG content of imports, by gaseous substance, is thus estimated for all years from 1990 to 2010. Finally, we multiply the unit GHG content of imports by the value of imports to estimate the total GHG content of French imports for each year and each substance.

We might refine this methodology in future update in the time series, for example by relying more heavily on existing MRIOs to assist in the back-casting of imported emissions before 2010.