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« A proposal for assessing inventories of embodied emissions in trade and consumption at the country scale: an application to the French case »

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A proposal for assessing inventories of embodied emissions in trade and consumption at the country scale: an application to the French case

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Abstract

In United Nations Framework Convention on Climate Change territorial-based inventories, the CO2 emissions embodied in international trade are not assessed while they represent a lever to control carbon leakage and understand competitiveness concerns. Accounting these emissions, and therefore accounting consumption-based emissions, is not obvious. In the literature, different methods exist to evaluate alternative emissions inventories. However, methods are data-intensive and models mainly rely on existing global databases with balanced bilateral trade flows. The control of these databases and the articulation with country-scale prospective models remain difficult. This paper proposes a method based on the Input-Output analysis, at a given year, to evaluate contrasted emissions inventories for single country relying on national hybrid database in both volume and in monetary flows. Notwithstanding, it embarks exogenous information on major international partners. By applying the methodological proposal on the French case, the paper provides original insights on the key drivers of emissions. We show that consumption-based emissions are much higher than production-based emissions in France, and, we study the drivers of emissions embodied in household consumptions with sectoral distribution. We analyse the sensitivity to results of the sectoral granularity of the database. The original idea of this method is to allow an easy articulation with the IMACLIM-France CGE model to analyse how French climate policies impacts macroeconomic situation, sectoral competitiveness and emissions -regarding different scopes for inventories.

Keywords— Input-Output analysis, Emissions embodied in imports, Carbon leakage, Consumption-based inventories

1 Introduction

Environmental progress achieved by a country depends on the scope given to the greenhouse gas (GHG) emissions inventory. In United Nations Framework Convention on Climate Change (UNFCCC) territorial-based inventories, the emissions embodied in international trade are not assessed while they represent a lever to control carbon leakage and understand competitiveness concerns.

The assessment of emissions incorporated in international trade remains unpopular for stakeholders because there are uncertainties about their use in policy actions, and because they also minimise the effort done for emission reductions. Beside political consideration, these estimates are not obvious. In the literature, different methods exist to evaluate alternative emissions inventories. However, methods are data-intensive and models mainly rely on existing global databases with balanced bilateral trade flows. The control of these databases and the articulation with country-scale prospective models remain difficult.

The aim of this paper is to propose a single-region method to account for CO_2 emissions with different perspectives of inventories, moving them from a production-based to a consumption-based point of view. To do so, the method also assesses emissions embodied by its external trade while taking into consideration major specificity of partner countries. Furthermore, for each inventory, sectors that drive emissions, and thus that represent a lever for environmental efforts, are identified. The technique relies on hybrid national-scale data to then be articulated with a prospective general equilibrium model.

The procedure is applied as a study case to France (2010) which energy transition law now provides for territorial emissions reduction targets without increasing embodied emissions in its imports. The results show that the differences between French CO_2 emission inventories, taking or not into account emissions embodied in international trade, are not substantial. It also appears that if France had produced its own imports, it would have caused fewer CO_2 emissions. Finally, assessing different accounting systems of CO_2 emissions lead to different sectoral distributions although results are sensitive to the initial level of description.

The paper is structured as follows. Section 2 addresses a review of existing approaches for accounting emissions with a consumption point of view. Section 3 proposes a method for a single country relying on hybrid work and that can further be articulated with a computable general equilibrium (CGE) model developed for France. Section 4 is an application of the method on France (2010) and discusses French emissions inventories from different point of views.

2 Review of main approaches

Since UNFCCC creation, signatory countries have to establish regular national inventories of emissions which are used for the commitment to GHG reductions under Kyoto Protocol. The geographic boundary of these inventories corresponds to *"general greenhouse gas emissions and removals taking place within national territory and offshore areas over which the country has jurisdiction"* (IPCC, 2006). Thus, there are ***territorial-based inventories*** that rely on technologies used within territories to quantify the amount of emissions.

However, it appears that such inventories give biased information on the responsibility of a country in global emissions. Indeed, countries satisfy their consumptions not only thanks to their production, but also thanks to their imports. Thus, a significant share of global emissions transit through the international trade embodied in the form of products or services - 26% of CO_2 global emissions in 2008 (Peters et al., 2011). In a globalisation context, this share tends to increase, and it becomes important to take into account the role of international trade in emissions to evaluate effectiveness of environmental measures and to design global sustainable actions. Thus, alternative emissions inventories, which connect production to consumption between regions, emerge from studies and are generally identified as ***consumption-based inventories*** or ***carbon footprint***. These inventories give new opportunities to well analyse the risk of carbon leakage and competitiveness issues under unilateral climate policies, but their estimates are not straightforward. Indeed, they are no direct quantification for those emissions which involve more complex calculations than the territorial-based inventories. A large number of analyses with slightly different methods account for consumption-based emissions (Sato, 2013). They rely mainly on two types of approaches: the "top-down" approach, and the "bottom-up" approach (see Figure 1).

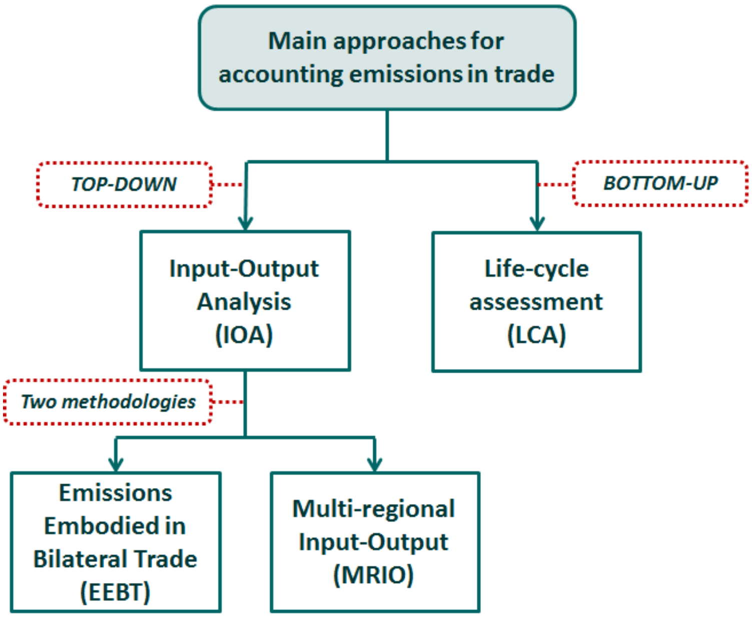

Figure 1 – Overview of the main approaches for accounting emissions in trade

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The "bottom-up" approach

It essentially corresponds to the lifecycle assessment (LCA), which estimates the environmental "footprint" of products or services by accounting the carbon emitted during their production processes, their distributions, and also their uses and their recycling or destructions (Hertwich, 2005). LCA describes a wide scale of different products, and thus it embarks very specific technologies. The counterpart of this precise description is that LCA requires a large amount of input data. Furthermore, with LCA approach, it remains difficult to link economies between each other and thus to quantify the role of international trade in emissions.

Hence, this approach is not the main focus of the review since our aim is to focus on the role of imports in emissions for a given country in a global economic framework.

The "top-down" approach

It is mainly based in Input-Ouput analysis (IOA), which no more involves a product-specific description but gives an economic-compatible description since it relies on Input-Ouput table (IOT).
As a first step, this approach requires ***production-based inventories*** consistent with System of National Accounts (SNA) description, and that provide the assessment of emissions from monetary flows. To do so, each purchase of energy is associated with a quantity of emissions. Hence, these emissions are allocated to different economic sectors corresponding to the IOT nomenclature. In national emissions inventories under the UNFCCC, the assessment is more based on direct measures or energy statistics, and its nomenclature is then origin-emission-oriented. Beyond nomenclatures differences, Peters and Hertwich (2008) emphasises that *"production-based inventory is related to, but different from the IPCC definition"*, and results in a conversion of "technological-based" inventories. Official statistic agencies have made some efforts to develop environmental extended IOTs compatible with the economic nomenclature, as for the European NAMEA accounts[1] (United Nations et al., 2003; Moll et al., 2007).
The second step of this approach consists in a reallocation of the production-based inventories to the ***consumption-based inventories*** by using the IOA technique, as illustrated in Figure 2. The consumption-based inventory is "conceptually" equivalent to the carbon footprint , since *"the consumption-based approach considers the environmental pressures arising from a product it can be considered as a generalisation of life-cycle assessment to the aggregated consumption of a country"* (Peters and Hertwich, 2008).

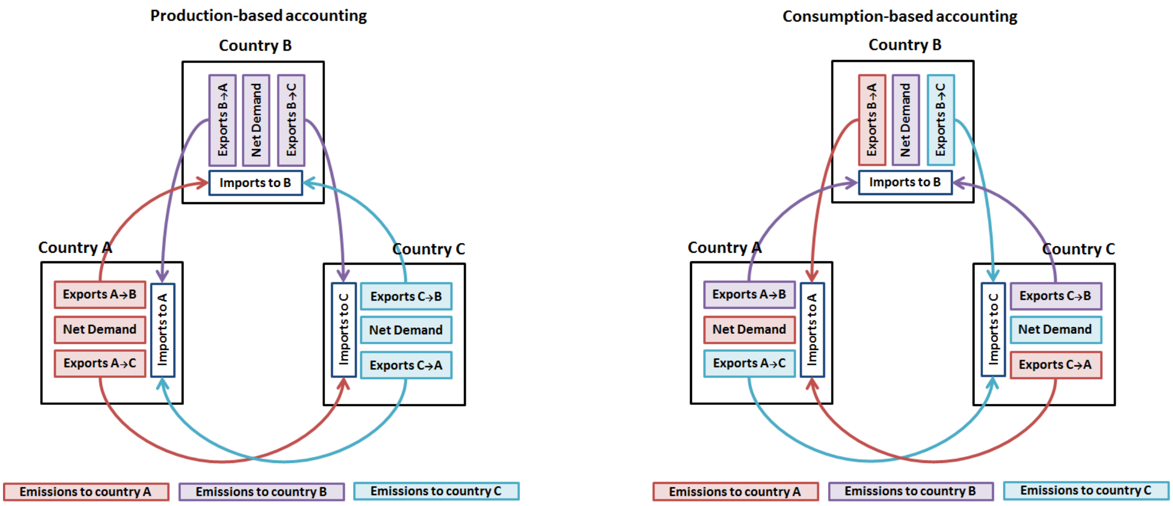


Figure 2 – Overview of the production-based and consumption-based accounting system for emissions

At this stage, the differences between methods are twofold and link by data requirements: (i) the geographical and sectoral scale used, and (i) the precise technique of IOAs conducted. Most studies are

[1]NAMEA is part of the European environmental accounting program conducted by Eurostat.

done at the global scale, and thus rely on global balanced database such as GTAP (Bureau and Mougeot, 2004), but they are limited by the sectoral level of the database used, whose granularity of industries may be inadequate depending on the purpose of the study (Caron, 2012). Regarding the technique of IOAs, there two main methodologies to assess consumption-based inventories, and so emissions embodied in trade:

- **The embodied emissions in bilateral trade (EEBT)** analysis describes all trade between each country represented within the modelling system. Distinct emission intensity factors are given to all international flows according to their origin and their specific production systems. It gives the emissions induced by the total domestic consumption (households, government, and investment), and also assesses the emissions embodied in imports and exports. The main assumption here is that international flows go directly to final consumption (households, government, and investment).
- **The multi-regional input-output (MRIO)** analysis is more complex but similar than the EEBT analysis. Indeed, in this case, international flows are split between final consumption and intermediate consumption. The international flows for intermediate consumption are then reprocessed to the production of goods wihtin another territory, and so the emissions intensity factors given to those flows are different. This approach captures all the feedback effects of imports that are re-exported - in theory (Sato, 2013).

Both of these approaches required global database well balanced for all international flows. However, for such database, control and uncertainties are difficult to assess. Weber (2008) mentioned that MRIO is a *"minefield"*. Sato (2013) discusses the lack of methodological transparency of those models.

Relying on what exists in terms of methods to set consumption-based inventories, we have to go a little beyond regarding some aspects, and relax other assumptions not necessary for our studies. Approaches described are based on historical dataset, and give descriptive analysis. Alone, they do not allow to understand the relationship between: (i) climate policy options, (ii) emission reductions depending on accounting methods, (iii) possible changes in production systems, and (iv) international trade and competitiveness issues. However each of its aspects are closely linked. Thus, next section proposes a single-region method relying on hybrid data work to embark the level of description needed for the aim of study, and then that can be articulated with prospective exercises at regional scale.

3 A method for a single region

As the study mainly focus on one region, we do not seek to quantify emissions through "closed-loop" models, like MRIO or EEBT models do. Such models require a significant amount of information harmonised at the global level. Even if global databases exist to easily build such a model, our aim is to develop a method that relies on the hybrid work of IOT, explained in Appendix A, to be consistent with the overall objectives of regional analysis and prospective studies.

Thereby, this section describes an IOA method around the hybrid IOT of France (see Appendix B) to estimate emissions embodied in its imports while incorporating sufficient information on the main French trading partners. The procedure is drawn from the work of Pasquier (2010) which it calls himself a "multi-regional and unilateral" Input-Ouput (IO) method (Lenglart and Pasquier, 2010). Besides domestic economic data, the method also requires extra information on technical coefficients of French partners as well as CO_2 intensity of their production. It also requires to identify the uses of imports within the French economy represented by the hybrid IOT. The large framework of the procedure and data sources are given in Figure 3. Thus, to allocate emissions to different components of the economy, we must follow some steps. First, we distinguish imported goods into uses of the hybrid IOT. We describe this in the sub-section 3.1. With the resulting input-output accounting system, we allocate national emissions to final demand. We explain this calculation in the sub-section 3.2. Finally, with assumptions on the French partners for imports, we formulate the embodied emissions in imports (sub-section 3.3).

The method proposed here is presented from a French perspective. However, as the hybridisation procedure, this method can be easily applied to other countries or regions. This is a simplified description of embodied emissions in trade or consumption but that remains sufficient in the studies we conduct.

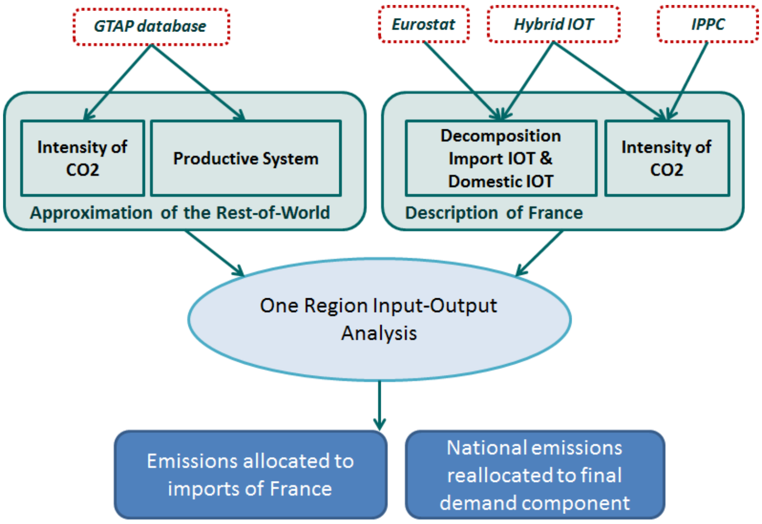


Figure 3 – General framework of the developed method

3.1 Description of the use of imports

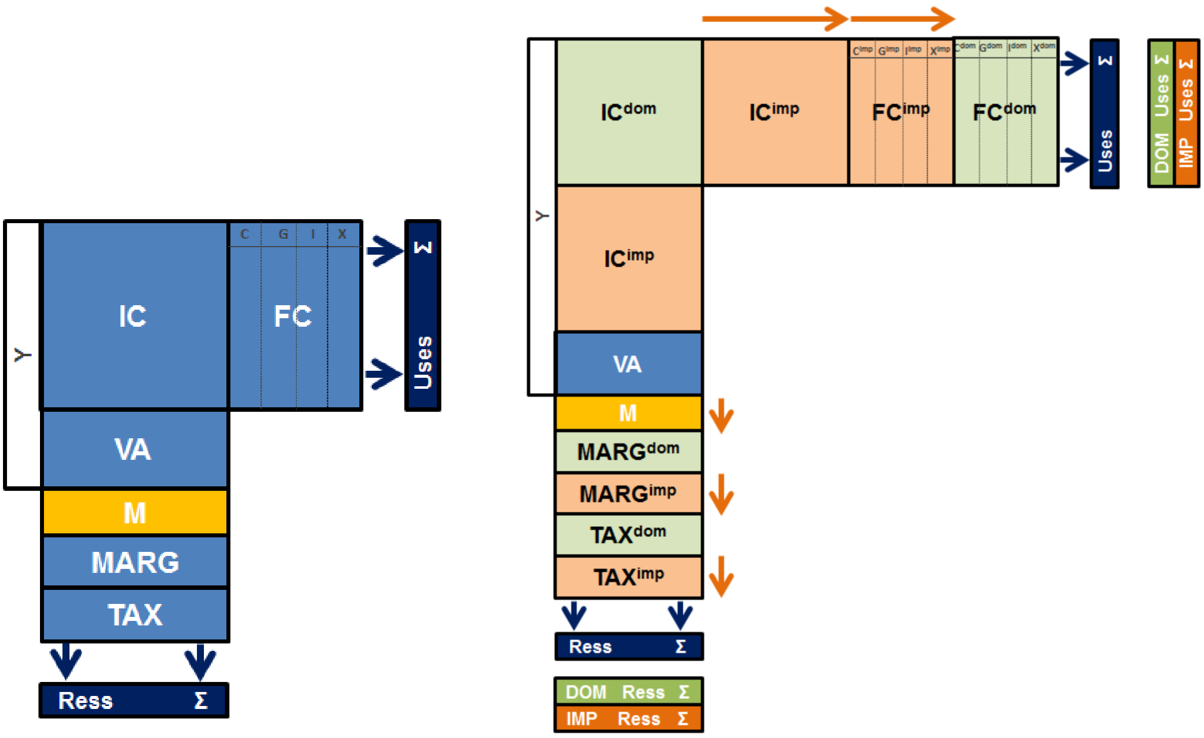
The hybrid monetary IOT can be synthesized in the form of several matrix blocks as shown in figure 4a.

IC is the square matrix of intermediate consumptions, whose size depends on the sectoral granularity describing the economy. The matrix *FC* is composed by the vectors of final consumption (households consumption *C*, government *G*, investment *I*, and exports *X*). *VA* is the matrix of the value-added components. *Y* is the outputs at basic price[2], and corresponds, for a given sector, to the sum of its intermediate consumptions and the value-added. *M* describes imports expressed in free on board (FOB) price. *MARG* is a matrix composed by the trade margins *CM* vector, and the transport margins

[2]The basic price is the amount received by the producer less the taxes on the products and plus any subsidies on the products. The purchase price is the amount paid by the purchaser, including taxes and excluding subsidies.

TM vector. The matrix *TAX* describes the fiscal revenues: from the tax on energy products T_{EnT} ($T_{EnT_{FC}}$ for the revenues from final consumption, and $T_{EnT_{IC}}$ for the revenues from intermediate consumption), the value-added tax T_{VAT}, and the excise taxes other than the energy product tax T_{OPT}. *MARG* and *TAX* are revenues either from domestic production and imports.

In this global IOT framework, *IC*, *FC*, *MARG*, and *TAX* do not distinguish the origin of the transaction: domestic or imported. The imports *M* are represented without details on their uses in the economy. Thus, the first step is to decompose the IOT between import and domestic purchases as described in Figure 4b. The *imp* exponent is given to the purchases related to imports while the *dom* exponent is related to purchases from the domestic productions.



(a) Global Input-Output table

(b) After decomposition of imports

Figure 4 – Components and notations of the Input-Output table

The decomposition process may respect two basic balances :

A) The import resources must balance the import uses.
B) Domestic and imported purchases must be consistent with the aggregated purchase given in IOT. For the sake of clarity, we sum-up this balance to a unique equation represented by the transaction *Z* which can either be *IC*, *FC*, *MARG* or *TAX*.

Thus, these balances are formulated as follows:

$$A) \quad M + MARG^{imp} + TAX^{imp} = \sum_{row} IC^{imp} + \sum_{row} FC^{imp3} \tag{1}$$

$$B) \quad Z = Z^{dom} + Z^{imp} \tag{2}$$

Decomposition of intermediate and final consumption

In order to disaggregate flows in the hybrid IOT, we use additional information from Eurostat that provides symmetric input-output tables showing the use of imports. Thanks to this database, we assess for each goods purchases the proportion of imports in each one its uses - either for intermediate consumption ($\tau^{IC^{imp}}$) or final consumption ($\tau^{FC^{imp}}$)[4].

Then, the assessment of these rates is used to define intermediate and final consumption of imported goods in the hybrid IOT as follows:

$$IC^{imp} = \tau^{IC^{imp}} \cdot IC^{5} \tag{3}$$

$$FC^{imp} = \tau^{FC^{imp}} \cdot FC \tag{4}$$

As Eurostat dataset are not available at purchase price, we do not have the information required on taxation or margins to distinguish the share related to imports. So, to disaggregate these components of the IOT, some assumptions are made.

Decomposition of margins and revenues from taxes on intermediate consumption

Regarding the margins components $MARG^{imp}$, transport and trade margins from imports (TM^{imp} and CM^{imp}) are assessed in proportion of the weight of imports within net resources (the amount of output Y and imports M). The same assumption is used to assess revenues of taxes on intermediate consumptions from imports :

$$Z^{imp} = Z \cdot [M \,/\, (M + Y)]^{6} \tag{5}$$

[3]In this paper, the operator noted as $\sum_{row}$ returns the row sum of a matrix giving as a result a row vector. Symmetrically, in the following, the operator noted as $\sum_{col}$ returns the column sum of a matrix giving as a result a column vector.

[4]The Eurostat IOT are symmetric tables in the sense that they are product-by-product tables at basic prices. The hybrid IOT developed is at purchase prices since policy analyses carried out in this thesis require the description of tax revenues.

Thus, to keep consistency, we convert domestic and imports tables from Eurostat at the purchase price (see Appendix B for more details). So, $IC_{Eurostat}$, $FC_{Eurostat}$, $IC^{imp}_{Eurostat}$ and $FC^{imp}_{Eurostat}$ are at purchase prices and are resulting from author's calculations, based on original IOT of Eurostat

[5]The operator noted as " $\cdot$ " means a multiplication, term by term, of two vectors or matrices, with at least a dimension equal.

where Z can be either TM^{imp}, CM^{imp}, $T^{imp}_{EnT_{IC}}$, or T^{imp}_{OPT}.
Implicitly, we assume that the margins rate and the intermediate consumption tax rate are the same for imported and and domestically produced goods.

Decomposition of revenues from taxes on final consumption

Regarding revenues of taxes on final consumption from imports, we suppose that they are in proportion the weight of final consumption from imports within total final consumption. So, we formulate :

$$Z^{imp} = Z \cdot [(C^{imp} + G^{imp} + I^{imp} + X^{imp}) \ / \ (C + G + I + X)] \tag{6}$$

where Z can be either T^{imp}_{VAT} or $T^{imp}_{EnT_{FC}}$.

Adjustment for imports balance

However, the previous assumptions do not ensure the total market balance for imports described in Equation 1 at first try. Because there are differences between Eurostat IOT, that we convert at purchase prices, and the hybrid IOT we developed, we need to introduce a δ parameter to restore imports balance.

The δ parameter is an adjustment variable of the share of imports in intermediate and final consumption from Eurostat as follows:

$$\hat{\tau}^{IC^{imp}} = \delta \cdot \tau^{IC^{imp}}_{Eurostat} \text{ and } \hat{\tau}^{FC^{imp}} = \delta \cdot \tau^{FC^{imp}}_{Eurostat} \text{ with } \delta \in [0,1] \, .$$

There is only a unique set of δ parameter that balances the ressources and uses of imports (Equation 1)[7]. Concretely, we adapt the information drawn from Eurostat to keep the aggregated information contained in the hybrid IOT.

Thereby, in describing all components, we get the following equality:

$$M + \underbrace{CM^{imp} + TM^{imp}}_{MARG^{imp}} + \underbrace{T^{imp}_{EnT_{IC}} + T^{imp}_{EnT_{FC}} + T^{imp}_{OPT} + T^{imp}_{VAT}}_{TAX^{imp}} = \sum_{row} IC^{imp} + \underbrace{C^{imp} + G^{imp} + I^{imp} + X^{imp}}_{FC^{imp}} \tag{7}$$

For the following, we set $\hat{M}$, the value of imports at purchase price as:

$$\hat{M} = M + CM^{imp} + TM^{imp} + T^{imp}_{EnT_{IC}} + T^{imp}_{EnT_{FC}} + T^{imp}_{OPT} + T^{imp}_{VAT}$$

Description of domestic and imports balances

Therefore, since domestic and imports uses are consistent (Equation 2), the "global" detailed balance of

[6]The operator noted as "/" means a division, term by term, of two vectors or matrices, with at least an equal dimension.

[7]The parameter δ is set at 1 at firs try. The values found for the δ parameter to balance imports are available in Appendix B.

the hybrid IOT represented in Figure 4a can be decomposed as follows :

$$Y + M + \underbrace{CM + TM}_{MARG} + \underbrace{T_{VAT} + T_{EnT_{IC}} + T_{EnT_{FC}} + T_{OPT}}_{TAX} = \sum_{row} IC + \underbrace{C + G + I + X}_{FC} \Leftrightarrow \quad (8)$$

$$\hat{Y} + \hat{M} = \sum_{row} IC^{dom} + \sum_{row} IC^{imp} + C^{dom} + C^{imp} + G^{dom} + G^{imp} + I^{dom} + I^{imp} + X^{dom} + X^{imp} \quad (9)$$

where $\hat{Y}$ is the value of outputs at purchase price :

$$\hat{Y} = CM^{dom} + TM^{dom} + T^{dom}_{VAT} + T^{dom}_{EnT_{IC}} + T^{dom}_{EnT_{FC}} + T^{dom}_{OPT}$$

Finally, the balance of IOT get in the Equation 9 can be symplified by removing import balances given by the Equation 7. To summarise, we thus obtain two market balances, for domestic and import purchases, formulated as follows:

$$\hat{Y} = \sum_{row} IC^{dom} + C^{dom} + G^{dom} + I^{dom} + X^{dom} \quad (10)$$

$$\hat{M} = \sum_{row} IC^{imp} + C^{imp} + G^{imp} + I^{imp} + X^{imp} \quad (11)$$

In the Input-Output analysis literature, studies are based on tables at basic prices. For the following, we make the assumption that developing this analysis for a single country using matrices at purchase prices does not affect results substantially.

3.2 Reallocation of national emissions to final demand

Through the decomposition of the input-output table, we now allocate national emissions to final demand components by using the Leontief input-output technique. This is equivalent to conversion of a territorial-based emissions inventory to a production-based emissions inventory.

From the matrices of intermediate consumption (IC^{dom} and IC^{imp}) and the output $\hat{Y}$, the technical coefficients A^{dom} and A^{imp} are assessed:

$$A^{dom} = IC^{dom} \;/\; \hat{Y} \;\Leftrightarrow\; \sum_{row} IC^{dom} = A^{dom} \times \hat{Y} \quad (12)$$

$$A^{imp} = IC^{imp} \;/\; \hat{Y} \;\Leftrightarrow\; \sum_{row} IC^{imp} = A^{imp} \times \hat{Y} \quad (13)$$

These matrices identify the input proportions required to produce a unit of product. Thus, they represent direct interactions between industries.

Therefore, we can rearrange the Equation 11 and the Equation 10 as follows:

$$\hat{Y} = (I - A^{dom})^{-1} \times [C^{dom} + G^{dom} + I^{dom} + X^{dom}]^{8} \quad (14)$$
$$\hat{M} = A^{imp} \times (I - A^{dom})^{-1} \times [C^{dom} + G^{dom} + I^{dom} + X^{dom}] + [C^{imp} + G^{imp} + I^{imp} + X^{imp}] \quad (15)$$

where I is the identity matrix.

The $(I - A^{dom})^{-1}$ matrix represents the domestic Leontief matrix. It represents the total direct and indirect input requirements of any industry from an additional unit of final demand (Leontief, 1970)[9].

To reallocate emissions to final demand, emissions intensity (F) of each industry are required. This corresponds to the amount of CO_2 emitted by spending one euro of final consumption. This can directly be estimated using the hybrid energy IOT in tonne of oil equivalent (toe) and emission factors given in Intergovernmental Panel on Climate Change (IPCC) report (Gómez et al., 2006). First, the direct CO_2 emissions is estimated from energy inputs of each sector $CO2^{dir}_{sec}$. Then, emissions intensities are defined as follows :

$$F = CO2^{dir}_{sec} \;/\; \hat{Y} \quad (16)$$

Finally, the reallocation of national CO_2 emissions to final demand, for each industry, are deduced from Equation 14 :

$$CO2_{FC} = F \times (I - A^{dom})^{-1} \times [\, |C^{dom} + G^{dom} + I^{dom} + X^{dom}|\,]^{10} \quad (17)$$

$CO2_{FC}$ is a vector with all sectors described within the economy.

The reallocation can be also done for each component of final demand:

$$CO2_C = F \times (I - A^{dom})^{-1} \times |C^{dom}| \quad (18)$$
$$CO2_G = F \times (I - A^{dom})^{-1} \times |G^{dom}| \quad (19)$$
$$CO2_I = F \times (I - A^{dom})^{-1} \times |I^{dom}| \quad (20)$$
$$CO2_X = F \times (I - A^{dom})^{-1} \times |X^{dom}| \quad (21)$$

We have perfect decomposition, so we have: $CO2_{FC} = CO2_C + CO2_G + CO2_I + CO2_X$.
With the aim to distinguish production-based emissions and consumption-based emissions, we also define the emissions allocated to final demand net of-exports :

$$CO2_{FC_{netX}} = CO2_C + CO2_G + CO2_I \quad (22)$$

[8] The exposant Z^{-1} designe the inversion of the matrix Z.
[9] The Leontief matrix can be developed as $(I + A + A^2 + A^3 + ... + A^{+\infty})$ to distinguish the direct and the indirect requirements.
[10] The operator noted as "|" means a diagonalisation of a vector.

3.3 Assessment of embodied emissions in imports

The previous sub-section gives domestic emissions induced by the production of one euro of domestic final demand. We now want to assess emissions embodied in imports. Those emissions should account for direct emissions in a foreign country r from energy consumption of industries, but also indirect emissions occurring in the upstream process of industries within the region r, induced by the demand of imports. Thus, this calculation requires additional information on trade partners.

At this stage, information on the rest of the world are required. For each French's trade partner r, we need the sectoral emission intensities (F_r), the technical coefficient matrix (A_r)[11], and the share of imports from region r by industry. Then, the emissions embodied in French imports can be estimated by the sum of emissions occurring in each region r to satisfy French imports :

$$CO2_M = \sum_r [(F_r \times (I - A_r)^{-1}) \times |\hat{M}_r|] \tag{23}$$

with

$$\hat{M} = \sum_r \hat{M}_r \Leftrightarrow \hat{M} = \hat{M} \cdot \sum_r \tau_{M_r} \tag{24}$$

where the vector τ_{M_r} represents the share of import from region r by industry ($\sum_r \tau_{M_r} = 1$).

So, the equation 23 can be arranged as follows:

$$CO2_M = \underbrace{\sum_r \left[(F_r \times (I - A_r)^{-1}) \times \tau_{M_r}\right]}_{COEF_{RoW}} \times |\hat{M}| \tag{25}$$

where the necessary data on the rest of the world are gathered in a global coefficient noted $COEF_{RoW}$.

Finally, by replacing the imports in Equation 25 by its expression given in Equation 15 , we asses foreign emissions induced by national demand:

$$CO2_M = COEF_{RoW} \times \left[A^{imp} \times (I - A^{dom})^{-1} \times |(C^{dom} + G^{dom} + I^{dom} + X^{dom})| + |(C^{imp} + G^{imp} + I^{imp} + X^{imp})|\right] \tag{26}$$

This equation can be decomposed in two components :

- The emissions embodied in imports used for intermediate consumptions:

$$CO2_M^{IC} = COEF_{RoW} \times \left[A^{imp} \times (I - A^{dom})^{-1} \times |(C^{dom} + G^{dom} + I^{dom} + X^{dom})|\right] \tag{27}$$

- The emissions embodied in imports for direct domestic final consumptions:

$$CO2_M^{FC} = COEF_{RoW} \times \left[|(C^{imp} + G^{imp} + I^{imp} + X^{imp})|\right] \tag{28}$$

[11] A_r is the matrix of technical coefficients for the region r without distinguishing the uses of imports.

We note that the emissions accounting in Equation 28 include emissions induced by imports that are used for exports (X^{imp}). However, these emissions are not necessary taken into account for the consumption-based inventories. They corresponds to emissions in foreign country for consumption in another foreign country. So, for not accounting these emissions, we define the emission embodied in imports, net of exports:

$$CO2_M^{FC_{netX}} = COEF_{RoW} \times \left[|(C^{imp} + G^{imp} + I^{imp})| \right] \tag{29}$$

Finally, we settle the 'avoided emissions' by imports. They are fictional CO_2 emissions that would have occurred within the territory, if imports had been produced locally. They are computed by using the domestic emissions intensities (F) and the Leontief matrix of France ($(I-A)^{-1}$) :

$$CO2_M^{av} = F \times (I-A)^{-1} \times \left[A^{imp} \times (I - A^{dom})^{-1} \times |(C^{dom} + G^{dom} + I^{dom} + X^{dom})| + |(C^{imp} + G^{imp} + I^{imp} + X^{imp})| \right] \tag{30}$$

The procedure described here for accounting embodied emissions in imports is not strictly "closed". Indeed, we only assess emissions occurring in foreign countries for satisfying intermediate and final consumption of France, but we do not assess emissions occurring for French exports, that are used for intermediate consumption in the rest of the world, and then may be re-imported in France, like MRIO models do. The box below gives more details on the implicit assumption made here.

The assumption of a "quasi-closed economy" for the rest of world

The method defined differs from methods described in section 2. It is a kind of "half way" between EEBT and MRIO models regarding what it accounts for embodied emissions in trade. Indeed, the EEBT method accounts for emissions occurring in one region A to produce trade flows to a region B (that is to say: export from region A to region B) . However, the method does not describe where the flows go within region B : if there are for intermediate or final consumption. This is not the case in the method developed. In fact, the imports from the rest of the world are decomposed between intermediate and final consumption flows inside the French economy. However, regarding French exports to the rest of the world, we do not distinguish the share that goes to intermediate consumption from the share that goes to final consumption.
The MRIO method fully describes these flows. By not making this distinction, it implicitly amounts to considering that all export flows from France to the rest of the world are used for final consumption, and therefore are never then "re-imported" into France.We assume implicitly that the world is a "nearly-closed" economy.
Analytically, compared to a MRIO model, this amounts to fix the technical coefficients of imports to almost zero for each region r we take into account : $A_r^{imp} \approx 0 \Rightarrow A_r \approx A_r^{dom}$.
This may be justified by the size of the French economy compared to the rest of the world: France is a small country. Pasquier (2010) calls this method a "unilateral multi-regional" approach: "multi-regional" because specificities of major French trading partners are taken into account, "unilateral" because specific data of a given region r which exports to France are taken into account, although the origin of the imports of this same region r is not described, and therefore its specificities either.

4 CO_2 emissions inventories : application to France (2010)

The procedure described in section 3 is applied to the hybrid IOT of France (2010).

To assess the rest of world coefficients $COEF_{RoW}$, we use the GTAP database using available specific information for the fifteen first French partner countries, and the rest of the world aggregated as one region. The fifteen countries has been identified thanks to Eurostat database and represent more than 70% of the total value of French imports in 2010. Values and ratios of French imports from those countries are given in Table 1.

Because the naming of different indicators, and scopes of emissions inventories may slightly change from one publication to another, we remind the following terms:

- **National direct emissions of CO_2**
  They correspond to the emissions from territorial fossil fuel combustion. It can be assessed by using the energy hybrid iot (see Appendix A).
  National direct emissions of CO_2 are decomposed into:
  - ***Direct emissions of households*** corresponding to final energy use, mainly for transports and residential consumptions ($CO2_{HH}^{dir}$).

2010 France	Imports in billion of Euros [a]	Ratio
Germany	79051.8	17%
China	37435.3	8%
Belgium	35933.5	8%
Italy	34801.2	8%
Spain	28314	6%
United States	26672.1	6%
UK	19841.9	4%
Netherlands	19262.2	4%
Russia	12205.7	3%
Swiss	10857.7	2%
Japan	8918.6	2%
Poland	6971.7	2%
Ireland	5886.2	1%
Sweden	5695.6	1%
Norway	4908	1%
Rest of the world	120103.2	26%
Total	456858.7	100%

[a]Source: Eurostat database

Table 1 – Major French trade partners for imports

  - ***Direct sectoral emissions*** corresponding to intermediate use of energy in production ($CO2^{dir}_{sec}$).

- **Production-based emissions of CO_2**
  The total amount of production-based emissions is equivalent to that of national direct emissions. However, sectoral distribution is not the same. Indeed, in that case, the total amount of direct sectoral emissions are reallocated to the final demand components (households, government, capital formation, and exports).
  Production-based emissions of CO_2 are decomposed into:
  - ***Direct emissions of households*** as defined above.
  - ***Emissions allocated to final demand*** correspond, for a given sector, to the emissions from the direct use of energy in proportion of its output that goes to final demand, and the 'indirect' emissions from other sectors' energy use that provide intermediate inputs ($CO2_{FC}$, Equation 17).

- **Consumption-based emissions of CO_2**
  This accounting system is decomposed into:
  - ***Direct emissions of households*** as defined above.
  - ***Emissions allocated to final demand net of exports*** correspond to emissions allocated to final demand, as define above, but without taking into account emissions allocated to exports ($CO2_{FC_{netX}}$, Equation 22).
  - ***Emissions embodied in imports*** account for emissions occurring in foreign countries to satisfy domestic demand.
    We distinguish emissions embodied in imports for intermediate uses ($CO2^{IC}_{M}$, Equation 27) and emissions embodied in imports for final demand of imports, net of exports($CO2^{FC_{netX}}_{M}$, Equation 29).

Emissions embodied in imports are compared to fictional emissions if imports have been produced locally. It is a way to estimate the gain or loss of trade for the environment. We name these emissions as the ***'avoided emissions'***($CO2^{av}_{M}$, Equation 30).

4.1 Global results

National direct emissions of CO_2

The energy IOT (29 sectors) is combined with emission factors from the IPCC report (Gómez et al., 2006) to assess national direct emissions of CO_2. The evaluation, based on energy statistics, provides sectoral and households allocations of direct emissions corresponding to the economic classification. It is therefore consistent with 'official' inventory given by NAMEA accounts.

Thus, we first compare global direct emissions of CO_2 resulting from our own calculations with the estimates from the NAMEA accounts. Results are given in Table 2.

2010 France, $MtCO_2$	**Hybrid IOT**	**NAMEA**	**Statistical gap**
Direct sectoral emissions	258.6	254	1.7%
Direct emissions of households	127.0	130.3	-2.5%
Total	385.6	384.5	0.3%

Table 2 – National direct emissions of CO_2

Our own estimate of total national emissions gives satisfactory results with a national quantity of CO_2 emissions close to the quantity given by NAMEA accounts. The gap is of 0.7%. The breakdown between emissions from production (direct sectoral emissions) and household's emissions is less accurate but remains acceptable. The emissions from production estimates are slightly overestimated in our account (1.7%) compared to NAMEA while direct emissions of households are underestimated (-2.5%). The difference can be mainly explained by the assumption made for the disaggregation of energy consumption in transport between transport services and households.

CO_2 emissions allocated to final demand

As described in section 3, IOA allocates direct sectoral emissions from production (258.6 $MtCO_2$) to the components of final demand. Figure 5 shows the share of each component in monetary final demand, and the share of emissions allocated to each of these components in overall direct sectoral emissions.

45% of the French final consumption corresponds to households demand. The share of emissions allocated to households consumption reaches a similar proportion (47%). With a share of 19%, exports are the third component of final demand. However, the share of emissions allocated to exports is more significant and represents 30% of the emissions from production. This may due to the fact that exports are driven by industries which are highly intensive in emissions but not so much valuable in the final demand.

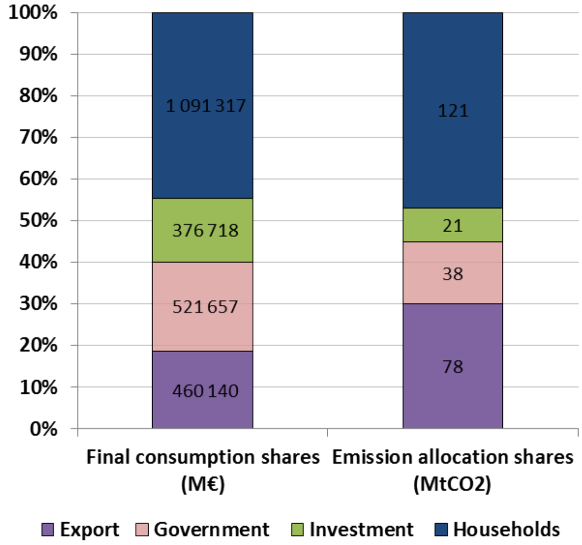


Figure 5 – Final demand and emissions shares

Production-based emissions versus consumption-based emissions of CO_2
The total amount of national direct emissions (386 $MtCO_2$) described in Table 2 are equivalent to the production-based accounting system. We compare this amount of emissions with the consumption-based emission allocations.
By applying the method described in section 3, we estimate emissions embodied in imports (net of exports) at 202 $MtCO_2$. Then, we set up the consumption-based emission attributions. Figure 6 synthesises the two emissions budgets.

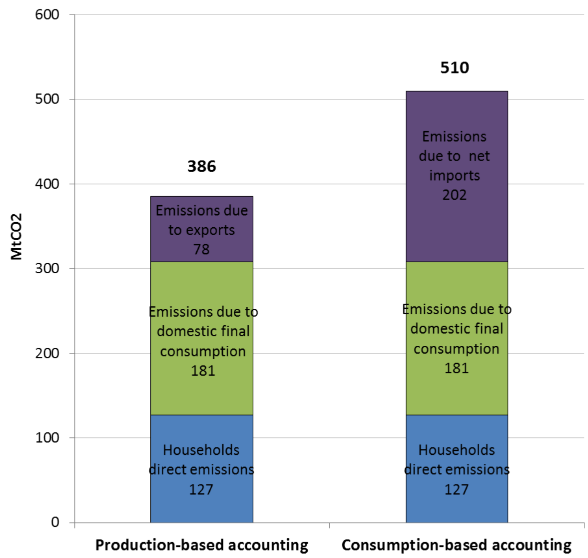


Figure 6 – Production-based vs. consumption-based emission allocations

It appears clearly that moving from the production-based inventory to the consumption-based inventory increases the French contribution to the global emissions. The total consumption-based

emissions inventory of the country amounts to 510 $MtCO_2$. Compared to the 386 $MtCO_2$ emissions of the production-based budget, the gap is not marginal, and it corresponds to an increase of 32% of the French emission inventory. This result confirms that it is important to focus not only on direct emissions from territories but also on tracking emissions embodied in imported goods.
Furthermore, if the imported products would have been produced domestically, in France , we estimate that their production would have induced the emission of 135 $MtCO_2$[12] instead of 202 $MtCO_2$ of emissions embodied in imports. We could say that globalisation has generated additional 67 $MtCO_2$ emissions.

4.2 Sectoral distribution

After estimating emissions at the macro level, we explore now the contribution of the various productive sectors to those aggregated results. Indeed, in the context of climate policy analysis, it seems crucial to have a good picture of which activities would be impacted, what drives their emissions, and if they have a key role in carbon leakage and competitiveness issues. Thus, we now analyse the sectoral distribution of previous aggregated results.

Comparison of sectoral distribution between direct emissions and emissions allocated to global final demand

We observe how emissions allocated to final demand are distributed between sectors, without distinguishing the origin of final demand (households, public administration, investment, exports).
Figure 7 gives this sectoral distribution of emissions driven by final demand and compared it to the distribution of direct sectoral emissions[13].

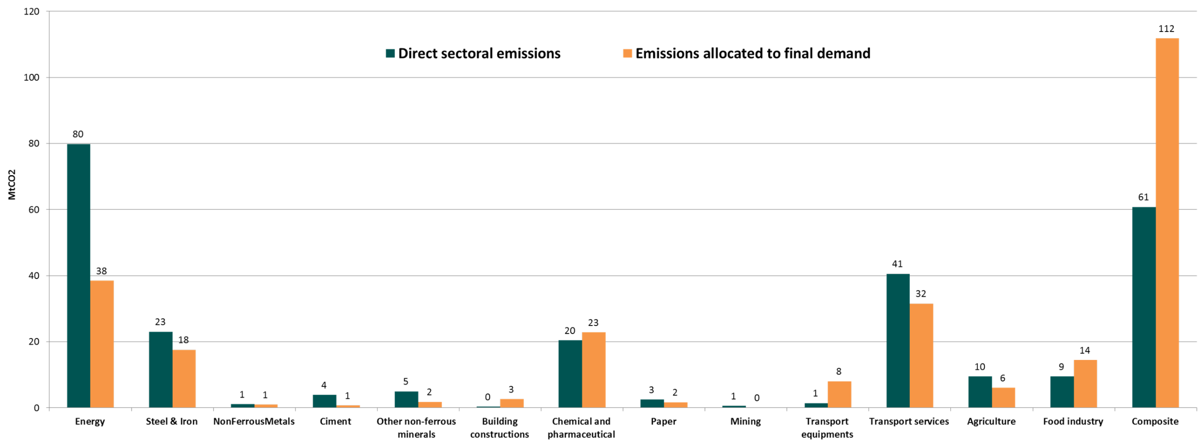


Figure 7 – Direct sectoral emissions vs. emissions allocated to final demand by sectors

The two accounting methods highlight some drastic differences in the allocation of emissions.
First, we see that for most energy-intensive and trade-exposed (EITE) sectors and the energy sector, the

[12]To assess this quantity of emission, we change in Equation 26 the $COEF_{RoW}$ by the French emission factors and the domestic Leontief matrix.

[13]The assessment provide a breakdown of the 29 sectors of the hybrid IOT. For the sake of clarity and readability, the results are aggregated to 14 sectors.

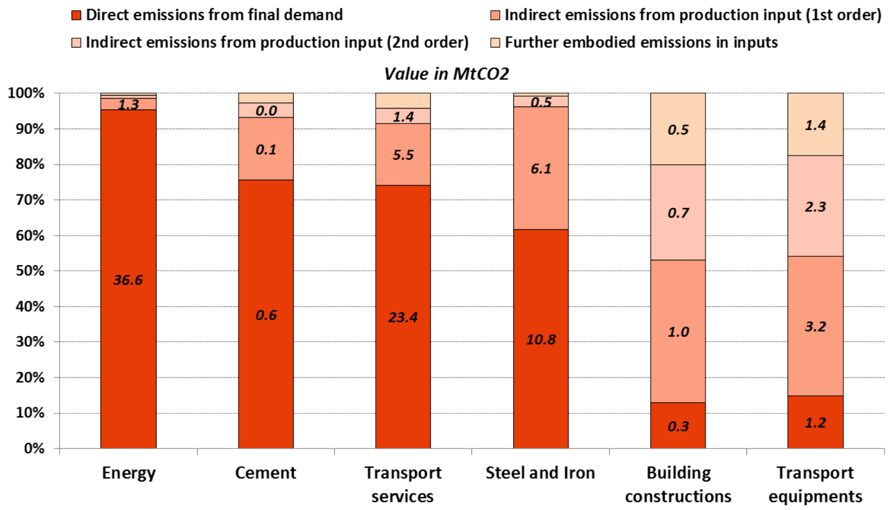


Figure 8 – Drivers of emissions allocated to final demand for some key sectors

allocation is lower for emissions induced by final demand than for direct production emissions:

- ***The energy sector:*** it emits 80 $MtCO_2$ for its production and represents 35% of total emissions from production (258$MtCO_2$). However, reallocating emissions to final demand reduces by almost half emissions from energy sector (38 $MtCO_2$). This is due to the fact that energy (including electricity) is very used as an intermediate goods. Thus, a major part of its emissions occurring during the production process are reallocated to the other sectors which use it, explaining the lower attribution observed. Among the 38 $MtCO_2$ allocated to final demand, a significant part (95%) are related to direct energy uses by final demand components, mainly households (see Figure 8). The inputs of energy sectors emitted 1.3 $MtCO_2$ to satisfy final energy demand. These *first order* indirect emissions from inputs correspond to the auto-consumption of the energy sectors.
  Similar mechanism is observed for energy-intensive sectors.
- ***The cement sector:*** its production emits 4 $MtCO_2$ from energy consumption but the emissions allocated to its final demand barely amount 1 $MtCO_2$. As shown in Figure 8, most of these 1 $MtCO_2$ (78%) are directly induced by the final uses of the sector (households and exports - in comparable proportions). The inputs required to produce final demand only amounts 18%: as for the energy sector, these emissions are mainly due to the auto-consumption in cement production.
- ***The transport services sector:*** direct emissions from transport services amount to 41 $MtCO_2$, while their emissions attributed to final demand amount to 32 $MtCO_2$. Much of this latter figure (74%) is directly attributable to final uses of the sector (households and exports). The sector's inputs account for 5 $MtCO_2$ mainly due to the use of energy in intermediate consumption.
- ***The steel and iron sector:*** it emits 23 $MtCO_2$ for its French production but by allocating emissions to final demand, the sector is "responsible" for 18 $MtCO_2$. Among these 18 $MtCO_2$, about 11 $MtCO_2$ are directly due to final uses of steel (exportation), while the inputs required steel production induced 6 $MtCO_2$ - mainly because of the intermediate consumption of coke.

The opposite mechanism occurs for sectors that use many energy-intensive inputs in their production and are mainly intended for intermediate uses :

- ***The building construction sector:*** it uses many intensive-energy goods for its production, which tends to increase its allocation of emissions to final demand up to $3\,MtCO_2$ while direct emissions from the sector are very low. Indeed, only 13% of these $3\,MtCO_2$ are due to final demand of building construction (investment), but the inputs required for the sector to reach final demand represent 40%. This is due to the consumption of steel, cement, and other minerals in the production process of building construction.
- ***The transport equipments sector:*** it emits $1\,MtCO_2$ for its French production, but reallocate emissions to final demand increases its emission balance to $8\,MtCO_2$. Only 15% of the emissions allocated to final demand directly occurs for final uses, while the required inputs for transport equipments sectors are "responsible" of almost 40%, mainly because of the intermediate use of steel in the production process. But the manufacture of this steel input itself requires energy. Thus indirect "second-order" emissions (Figure 8) account for 28% of the emissions reallocated to transport equipments final demand.

  For these sectors, the convergence towards the emissions allocated to final demand is less immediate than for previously observed sectors because of their use in the economy and their required intermediate consumption.

The following box gives deeper analytical details on the difference between direct sectoral emissions and the allocation to final demand.

Analytical comparison between direct sectoral emissions ($CO2^{dir}_{sec}$) and emissions allocated to final demand ($CO2_{FC}$)

To understand the meaning of the positive or negative gaps for a given sector between its direct emissions, and the emissions allocated to its final demand, we draw analytically the differences between these two indicators. By developing the Leontief matrix (Equation 17) and introducing the definition of the emissions intensities (Equation 16), we have :

$$CO2_{FC} = \underbrace{(CO2^{dir}_{sec}/\hat{Y}) \times I \times |\sum_{col} FC^{dom}|}_{CO2^{1^{st}}_{FC}} + \underbrace{(CO2^{dir}_{sec}/\hat{Y}) \times [A + A^2 + ... + A^{+\infty}]|\sum_{col} FC^{dom}|}_{CO2^{2^{nd}}_{FC}}$$

$CO2^{1^{st}}_{FC}$ corresponds to direct sectoral emissions in proportion of its output that goes to final demand. $CO2^{2^{nd}}_{FC}$ accounts for the 'indirect' emissions from other sectors' energy use that provide intermediate inputs.
First, we compare $CO2^{dir}_{sec}$ with $CO2^{1^{st}}_{FC}$. So, we get :

$$CO2^{dir}_{sec} - CO2^{1^{st}}_{FC} = (CO2^{dir}_{sec}/\hat{Y}) \times |\sum_{col} IC^{dom}|$$

The gap corresponds to direct sectoral emissions in proportion of its output that goes to its intermediate uses. This a positive term, so this inequality is always verified :

$$CO2^{dir}_{sec} \geq CO2^{1^{st}}_{FC}$$

.
Thus, we give the following explanation to understand the sign of the difference between $CO2^{dir}_{sec}$ and $CO2_{FC}$:

- $\boldsymbol{CO2^{dir}_{sec} \geq CO2_{FC} \Leftrightarrow (CO2^{dir}_{sec}/\hat{Y}) \times |\sum_{col} IC^{dom}| \geq CO2^{2^{nd}}_{FC}}$
  Direct emissions of the sectors allocated to intermediate uses are higher than the emissions induced by the production of goods needed to produce those intermediate consumption.
- $\boldsymbol{CO2^{dir}_{sec} \leq CO2_{FC} \Leftrightarrow (CO2^{dir}_{sec}/\hat{Y}) \times |\sum_{col} IC^{dom}| \leq CO2^{2^{nd}}_{FC}}$
  Direct emissions of the sectors allocated to intermediate uses are lower than the emissions induced by the production of goods needed to produce those intermediate consumption.

Emissions allocated to each final demand components
Figure 9 provides further decomposition by distinguish final demand components[14].

As we have seen at the macro level, it is household's consumption which drives emissions in France for a number of sectors. However, export demand is largely "responsible" of the emissions allocated to

[14]The assessment provide a breakdown of the 29 sectors of the hybrid IOT. For the sake of clarity and readability, the results of energy sectors are aggregated revealing 19 sectors in the figure.

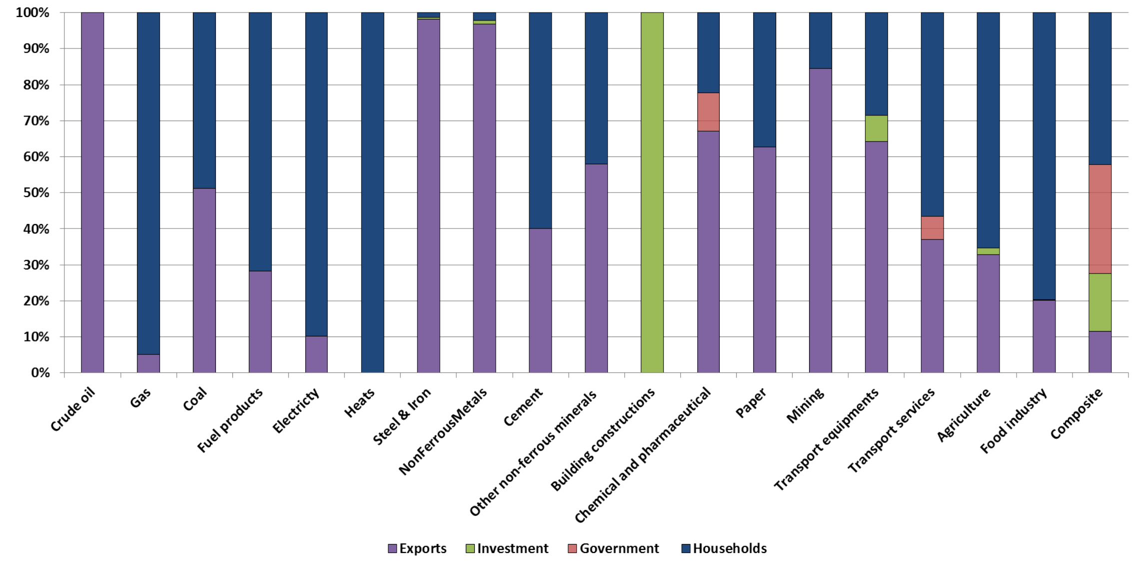


Figure 9 – Distribution between the components of final demand of allocated emissions

final demand for many sectors. These emissions will be imputed when accounting for consumption-based inventory. Furthermore, we see that final demand of energy-intensive sectors such as steel and iron, or non-ferrous-metals sectors have induced emissions mainly because of exports. This tends to reduce the footprint of France when accounting emissions with a consumption-based point of view. Cement does not have the same profile. Indeed, cement is not so much exported, because of transport costs, and the emissions allocated to final demand are mainly due to household demand. Some other sectors like the building construction sector mainly responds to investment, which then drives the allocated emissions.

Emissions embodied in international trade

Table 3 gives the sectoral emissions allocated to exports, and emissions embodied in imported goods. The net import balance of CO_2 of France is the sectoral difference between those two assessments.

We note that for many sectors, the CO_2 emissions allocated to exports offset the emissions embodied in imports. This reflects the intra-industry trade. Intra-industry trade means the import and export of similar products between countries. According to the Organisation for Economic Co-operation and Development (OECD), such trade is becoming more pronounced in developed countries mainly between members countries of the European Union[15].

However, for some sectors, there is a significant gap between emissions allocated to exports and the emissions embodied in imports that make France a net importer of CO_2 (124 $MtCO_2$):

- ***The composite sector:*** it is largely responsible of the CO_2 net importer status of France (86 $MtCO_2$). This sector aggregates industries and services in the French economy that we have not described during the hybridisation procedure. It includes all services, but also some industries such as

[15] From the book "Perspectives économiques de l'OCDE Volume 2002", Chapter 6.

2010 France, $MtCO_2$	Emissions allocated to export	Embodied emissions in net imports	Emissions "leakage"
Crude oil	0.002	0.001	-0.001
Gas	0.01	1.18	1.17
Coal	0.5	0.09	-0.42
Fuel products	4.32	14.08	9.76
Electricty	2.2	1.98	-0.23
Heats	0	0.04	0.04
Steel & Iron	17.22	2.01	-15.21
NonFerrousMetals	0.94	1.03	0.09
Cement	0.3	0.13	-0.17
Other non-ferrous minerals	1.06	1.23	0.17
Building constructions	0	2.85	2.85
Chemical and pharmaceutical	15.32	25.45	10.14
Paper	1.04	1.53	0.49
Mining	0.06	0.03	-0.02
Transport equipments	5.16	28.28	23.12
Transport services	11.67	5.47	-6.2
Agriculture	2.25	4.95	2.7
Food industry	2.76	12.43	9.68
Composite	12.93	98.9	85.98
Total	77.74	201.68	123.93

Table 3 – Emissions of CO_2 due to French international trade

2010 France	Export[a] (Millions of €)	Import[b] (Millions of €)	Trade balance (Millions of €)	Import penetration Rate[c](%)
Crude oil	13.8	28 740.3	-28 726.6	98.6
Gas	513.3	9 798.7	-9 285.3	57.0
Coal	32.1	2 148.3	-2 116.2	67.1
Fuel products	11 325.3	13 593.6	-2 268.2	42.4
Electricty	2 236.8	1 025.3	1 211.5	3.5
Heats	0.0	0.0	0.0	0.0
Steel & Iron	7 575.8	6 038.8	1 537.0	79.6
NonFerrousMetals	6 810.9	11 426.0	-4 615.1	48.0
Cement	265.3	297.3	-32.0	8.2
Other non-ferrous minerals	3 841.3	5 731.0	-1 889.7	29.9
Building constructions	0.0	0.0	0.0	0.0
Chemical and pharmaceutical	70 451.8	57 974.2	12 477.7	87.9
Paper	6 205.9	9 016.2	-2 810.3	45.1
Mining	411.1	2 355.1	-1 944.0	38.4
Transport equipments	77 281.7	62 213.4	15 068.3	62.4
Transport services	16 011.5	2 553.3	13 458.1	3.1
Agriculture	13 386.0	9 551.2	3 834.8	14.9
Food industry	24 876.0	26 736.1	-1 860.1	21.3
Composite	187 559.3	232 109.8	-44 550.5	8.6
Total	428 798.0	481 308.7	-52 510.7	14.4

[a] Domestically produced
[b] Net of re-exported imports
[c] Defined as the value of imports divided by the value of net-of-export demand

Table 4 – French international trade in value

France, tCO2/million €	Intensity Export	Intensity Import
Crude oil	111.4	0.0
Gas	22.4	120.9
Coal	15 708.3	40.7
Fuel products	381.8	1 035.9
Electricty	984.5	1 927.5
Heats	nan	nan
Steel & Iron	2 272.4	332.2
NonFerrousMetals	138.0	90.3
Cement	1 123.0	422.2
Other non-ferrous minerals	275.8	214.3
Building constructions	nan	nan
Chemical and pharmaceutical	217.4	439.0
Paper	168.3	170.1
Mining	143.7	14.7
Transport equipments	66.8	454.6
Transport services	729.1	2 143.7
Agriculture	168.2	518.7
Food industry	110.7	465.1
Composite	68.9	426.1
Total	181.3	419.0

Table 5 – Trade CO_2 intensities

textiles and electronics industry which France is a net importer, and whose production must be CO_2 intensive abroad.

- ***The transport equipment sector:*** the gap of emissions from the transport equipment sector is also striking (23 $MtCO_2$). Nevertheless, Table 4 shows that export in value for this sector are quite higher than imports in monetary value, and the corresponding CO_2 emission-intensity (see Table 5) is important for imports. We assume that the most emission-intensive part in the value chain of this sector is produced abroad, and France exports quasi-finished products that are more valuable.

In contrast, for other sectors, France is net exporter of CO_2 :

- ***The cement sector:*** exports involve more emissions than imports (−88%) but in monetary value, exports are lower (see Table 4). The differences in emissions are due to a striking difference in emission intensity which is directly due to hybridisation procedure. The cement sector is originally aggregated with the other non-metallic minerals sector. The resulting aggregate sector, the non-metallic minerals, has a lower average emission intensity. Hybridisation makes it possible to isolate these intra-sector heterogeneity. The GTAP database used to calculate emissions embodied in imports does not provide the sectoral granularity that isolates the cement sector. It is therefore an average intensity that emerges.
- ***The steel & iron sector:*** exports involves more emissions than imports (−88%). Regarding monetary value, Table 4 shows that France also exports far more steel than it imports. This is a result of the hybridisation procedure that revealed much higher exports in quantities. However, the magnitude of the balance in value (and quantities) does not explain the magnitude of balance in emissions. It is rather explained by the difference in emission intensity of this sector between

imports and exports, which is in fact a consequence of the hybridisation procedure (see 5). Indeed, we attribute a significant portion of energy as intermediate consumption of the sector, especially for coke, which is the most polluting coal products, which increases the emission intensity of exports. However, regarding imports, the calculations of emissions intensity of the rest of-world are assessed from a energy product aggregate in GTAP database, and may be underestimated because of a coal average emission intensity. At that stage, it becomes difficult to comment on figures from a database that we do not control.

We emphasise here again the interest to build our own hybrid IOT, although this remains possible only at the regional scale. Indeed, applying the method at the global scale is a too data-intensive and time-consuming exercise. Nevertheless, we need to be careful by comparing these results because differences may come from the hybridisation procedure that has only been applied for domestic flows and not for imports, which are described only in monetary terms and whose sectoral granularity do not fit studied sectors here.

4.3 The role of aggregation

Relevant theoretical literature (Morimoto, 1970; Kymn, 1990), as well as applied literature Majeau-Bettez et al. (2016); Su et al. (2010), stress the aggregation bias issue for IOAs. Majeau-Bettez et al. (2016) argue that the heterogeneous aggregation does not keep the balance of the analysis and it introduces bias. Su et al. (2010) observe that *"studies are often conducted at a specific level [...] and the choice made to a large extent is dictated by economic and energy data availability"*. The paper studies the sector aggregation effect on result and assumes that *"approximating the "ideal" situation the hybrid data treatment approach produces better results than the uniformly distributed data treatment approach"*.

We analyse here the sensitivity of the results to the aggregation level.
In our previous results, the assessments are made on the hybrid IOT at its most disaggregated level (see Table 6). We compare these results to the three higher levels of aggregation described in Table 6. The first level (*AGG_IndEner*) consists in an aggregation of main energy products. The aggregation level noted *AGG_4Sec* distinguishes primary and final energy, the aggregation of all originally described sectors in the hybrid IOT, excluding composite, and the composite sector. The last level (*AGG_EnComp*) aggregates all energies on one hand, and all the rest of the economy on the other hand.

Using the three corresponding IOTs, we run the same calculations as before. We focus on two original results which are : (i) the embodied emissions in net imports, and, (ii) the 'avoided' emissions, if imports had been produced in France. The results are shown in Table 7 and seem at first sight to strongly depend on the level of aggregation for both indicators.

We first analyse the gaps between the different levels of aggregation for the assessment of the 'avoided' emissions. These assessments give to imports the domestic production system as well as the domestic emission factors.
By aggregating coal and fuel products from the hybrid IOT (*AGG_IndEner*), the estimate of 'avoided' emissions is drastically different (312 $MtCO_2$) and increases by 131% compared to the estimate based on the original disaggregated hybrid IOT (135 $MtCO_2$). The aggregation into four sectors (*AGG_4Sec*) gives

Hybrid IOT	AGG_IndEner	AGG_4Sec	AGG_EnComp
Crude oil	Crude oil	Primary Energy	All Energies
Natural gas	Natural gas	Primary Energy	All Energies
Coking coal	Coal	Primary Energy	All Energies
Bituminous coal	Coal	Final Energy	All Energies
Coke	Coal	Primary Energy	All Energies
Other coal	Coal	Final Energy	All Energies
Gasoline	Fuel products	Final Energy	All Energies
LPG	Fuel products	Final Energy	All Energies
Jetfuel	Fuel products	Primary Energy	All Energies
Fuel	Fuel products	Final Energy	All Energies
Fuel oil	Fuel products	Final Energy	All Energies
Heavy fuel oil	Fuel products	Final Energy	All Energies
Other fuel products	Fuel products	Final Energy	All Energies
Electricty	Electricty	Final Energy	All Energies
Heat, Geothermal & Solar Th	Heat, Geothermal & Solar Th	Final Energy	All Energies
Steel & Iron	Steel & Iron	Industries & Agriculture	Rest of sectors
Non Ferrous Metals	Non Ferrous Metals	Industries & Agriculture	Rest of sectors
Cement	Cement	Industries & Agriculture	Rest of sectors
Other Minerals	Other Minerals	Industries & Agriculture	Rest of sectors
Buildings construction	Other Industries	Industries & Agriculture	Rest of sectors
Chemical & Pharmaceutical	Other Industries	Industries & Agriculture	Rest of sectors
Paper	Other Industries	Industries & Agriculture	Rest of sectors
Mining	Other Industries	Industries & Agriculture	Rest of sectors
Transport Equipment	Other Industries	Industries & Agriculture	Rest of sectors
Transport services	Other Industries	Industries & Agriculture	Rest of sectors
Agriculture & Forestry	Agriculture	Industries & Agriculture	Rest of sectors
Fishing	Agriculture	Industries & Agriculture	Rest of sectors
Food industry	Other Industries	Industries & Agriculture	Rest of sectors
Composite	Composite	Composite	Rest of sectors

Table 6 – Aggregation levels and correspondences with original hybrid IOT

a result closer to the original case (191 $MtCO_2$) but with a gap even of 41%. By reducing the economy into two sectors (*AGG_EnComp*), the estimate of 'avoided' emissions is of the same order as the one that describes 29 sectors (135 $MtCO_2$).
At level *AGG_IndEner* of aggregation, we define an average domestic emission intensity which is very different than emission intensities of each coal types. In fact, some values of coal emission intensities are artefacts due to the production case of France. Specifically, emission intensities of coking coal and bituminous coal have been defined as zero since their French production is zero. The resulting 'avoided' emissions in France by importing coking and bituminous coal are then nil since the estimate is based on a zero domestic emission intensity factor. However, by aggregating coal products, it gives to each euro of imported coal (including thus coking and bituminous coal) a non-zero average emission intensity. This explains the higher estimate for the aggregation level *AGG_IndEner* and *AGG_4Sec*. By aggregating the economy into only two sectors, the energy sector and the rest *AGG_EnComp*, average domestic emissions intensities re-balance to give a close result of 'avoided' emissions to the result based on hybrid IOT.
At last, speaking of 'avoided' emissions can be misleading because the results strongly depend on the domestic productive structure and also the level of description of it.

We now explain the gaps observed for the results of the embodied emissions in imports. As for 'avoided' emissions results, we show a same type of aggregation bias. However, for this indicator, the gap with the hybrid IOT continually increases with the level of aggregation. With the two sector description (*AGG_EnComp*), we get 292 $MtCO_2$ of embodied emissions in imports (+45%) and with four sectors (*AGG_4Sec*), we get 268 $MtCO_2$ (+33%). Not as for 'avoided' emissions, the result is less sensitive to the only aggregation of coal and oil products (+6%).
By assessing emission intensity factors for the French partners, we rely on the GTAP database that does not give the same level of description on energy products that we have in the hybrid IOT. In particular, the database describes the coal sector and petroleum products sector without distinguishing the different products into these two sectors. We therefore estimate average emission intensities for coal and petroleum products (weighted by the French partners). Consequently, we allocate to each euro of imports of the various coal products (coking coal, bituminous coal, etc.) or petroleum products (gasoline, jetfuel, fuel oil, etc.) of the hybrid case, the same estimated average intensity. Therefore, aggregating these products does not change in a significant way the outcome for the first level of aggregation (*AGG_IndEner*). This is less the case by aggregating more and more the economy to few sectors. We then attribute to imports average intensities very different of what are initially estimated.

We observe that some results are very sensitive to the initial sectoral description of the study. However it is not the only level of description that could biased the analysis. Thus, it would be interesting to analyse if the level of French import partners embedded in the assessment of the rest of-world emission intensity ($COEF_{RoW}$) changes much these results. This could be the subject of future studies for probation of the developed method described in section 3

Finally, in a qualitative way, we observe the bahaviour of the Leontief matrix because results may also be affected by the speed at which the technical coefficients matrix raised to the n^{th} power tends to zero as n approaches infinity. Indeed, results are intimately linked to the Leontief matrix which can be analytically developed as : $I + A^{dom} + A^{dom^2} + A^{dom^3} + ...A^{dom^{+\infty}}$
So, we sum up in Table 8 these qualitative differences by stressing the highest elements of the technical coefficient matrix, for different level of aggregation, and for different power given to the matrix.

2010 France, $MtCO_2$	'Avoided' emissions	Embodied emissions in net imports
Hybrid IOT	135.2	201.7
AGG_IndEner	312	214.3
AGG_4Sec	190.9	268
AGG_EnComp	134.9	292.3

Table 7 – Allocated emissions to imports by level of aggregation

A^{dom} matrix raised to n power	A^{dom}	A^{dom^2}	A^{dom^3}	A^{dom^4}	A^{dom^5}
Hybrid IOT	0.503	0.256	0.107	0.043	0.017
AGG_IndEner	0.483	0.194	0.076	0.030	0.012
AGG_4Sec	0.343	0.131	0.056	0.022	0.009
AGG_EnComp	0.392	0.155	0.061	0.024	0.010

Table 8 – Highest coefficient of domestic A^{dom} matrix raised to n power by aggregation level

According to the level of aggregation, we see that the bahaviour of the technical coefficient matrix raised to the n^{th} power is not the same, and therefore, it must introduce a bias in the results. When the matrix is squared, the highest resulting coefficient is 50% lower than the one in the matrix A^{dom} for the disaggregated case of hybrid IOT. For all cases of aggregation, the highest resulting coefficient is 60% lower than the one in the matrix A^{dom}. At the power of 3, the gap is widening.
We can imagine that, the more quickly the coefficients resulting of the technical coefficient matrix raised to the n power, converge to zero, the less the emissions induced by the consumption of a goods by another goods are significant. This quantitative analysis could lead to an analytical calculation.

5 Conclusion

This paper proposes a method to highlight the different attributions of CO_2 emissions for a given country, and their distributions between sectors. We show that the responsibility -in terms of emissions- at national or sectoral scale, differ depending the accounting system used for inventories. The allocation is often implicitly a territorial or production-based inventory. However, we show that the diagnosis changes if we consider a consumption-based accounting system. This is a significant fact because it changes the weight of a country or sector within global emissions, and this may influence negotiations for any attempt to implement environmental policies to reduce emissions.

In explaining the method used, we show that assessing dual accounting system of emissions is very data-intensive, either for France or for the rest of-world description in order to give a good picture of emission balances at base year. As we re-built our own database for France, we rely on exogenous harmonised database for the description of the French partners. While this is saving-time, once we look at how the results are sensitive to data, it becomes difficult to control information.

In this work, we only observe the impact of the sectoral level description of the results. Still, it would be interesting to analyse the hypothesis made on the description of the rest of world. We assume that setting up the description on the first fifteen French partners covering 75% of its imports would capture largely emissions embodied in imports. Moreover, we assume that the rest of-world is equivalent to a "quasi-closed" economy to France. Thus, we neglect the export flows from France which are then re-imported into the country. The robustness of these two hypotheses might be explored by observing if any revision of these assumptions affect significantly the assessment of embodied emissions in imports.

Finally, this paper provides an overview of different emission allocation schemes without harmonising the whole world description. Beyond this "inventory" at a base year, we developed a method that we can easily articulate with the IMACLIM-S FRANCE , CGE model to analyse how any regional French policy can influence results related to international trade, in value, as well as, in emissions terms. In this context, the assumptions made previously regarding the description of the rest of the world are justified. The idea is not to develop a harmonised MRIO model, but really to focus our method on the initial description of France, which is the core of the IMACLIM-S FRANCE model.

A Technical details of the Imaclim hybridization procedure illustrated on the example of France for 2010

From a methodological point of view, the procedure can be summarised in two main steps that we explain here succinctly. More details are given on these steps in the following sub-section. First, we explain succinctly the two main steps of the method. More details are given on these in the following sub-section

The **first step** consists in reorganising the physical datasets - that are the energy balance in million tonnes of oil equivalent (Mtoe) and energy prices in euros per Mtoe (€/*Mtoe*) - into input-output formats compatible with that of national accounts. As regards consumptions, this is not only a question of reallocating the physical energy flows of the energy balance to production sectors or households, but it is rather translating the knowledge of energy flows in national account terms. This means sorting out flows which in fact correspond to an economic transaction between national accounting agents, or even combining some of them to compute such flows (e.g. directly assigning to their accounting sectors the fuel consumptions of electricity auto-producers).

The real singularities of the Imaclim procedure come up in the **second step** where the trade-offs to adjust indicators are made to guarantee the accounting balances. It starts with the reconstitution of energy expenses at the disaggregated level by the term-by-term product of volume and price tables. It then goes on with substituting this table of energy expenditures to that pre-existing in the system of national accounts in order to fully enforce energy statistics within the hybrid IOT. Other components of the system are further adjusted to maintain the accounting identities, without modifying the total value-added of domestic production. This is done : (i) for the energy sectors, by adjusting all non-energy expenses (including value-added) pro rata the adjustment induced on total energy expenses, (ii) for all producing sectors and households, by compensating the difference between the recomputed energy expenditures and the original economic statistics through an adjustment of the expenses on the most aggregated non-energy good—a composite remainder of not specifically described economic activities, usually encompassing all service activities in Energy-Economy-Environment (E3) models. The underlying logic is to focus on the flows we are interested in, and put the rest in a large sector where the error reallocation will be unimportant given the large size of the sector.

For the sake of simplicity we describe the two steps mentioned by aggregating the economy in two energy sectors: primary energy and final energy based on the case of France (2010).

Step 1: Elaborating supply-use tables in physical units for energy

Before getting dual accounting systems for some intensive industries, we begin the procedure with energy sectors. Because tables of resources and uses of energy flows and prices are not available from statistical institutes in a standardised manner, they must be built through the collection of different data sources.

Starting from IEA energy balance, statistical gaps and stock changes are first distributed between primary supply and consumptions (transformations or final consumption). Then, we isolate in marine

	2010 - Million ton oil-equivalent, Mtoe	Primary energy	Final energy	Non-valuables energies	Total
R1	Production	1	121	13	*135*
R2	Imports	68	94	0	*162*
R3	Exports	-0	-33	0	*-33*
R4	Marine & Aviation bunkers	0	0	0	*0*
R5	**Total Primary Energy Supply**	**69**	**182**	**13**	***265***
R6	Transformations	-69	-17	-0	*-86*
R7	Energy industry own use	0	-10	0	*-10*
R8	Losses	0	-4	0	*-4*
R9	**Total Final Consumption**	**0**	**151**	**13**	***164***
R10	Iron and steel	0	4	0	*4*
R11	Non ferrous metals	0	1	0	*1*
R12	Non metallic minerals	0	4	0	*4*
R13	Construction	0	1	0	*1*
R14	Chemical and petrochemical	0	6	0	*6*
R15	Paper, pulp and print	0	2	1	*2*
R16	Mining and quarrying	0	0	0	*0*
R17	Transport equipement	0	1	0	*1*
R18	Other industries	0	9	1	*11*
R19	Transport	0	48	0	*48*
R20	Residential	0	36	8	*45*
R21	Agricuture and forestry	0	4	0	*4*
R22	Fishing	0	0	0	*0*
R23	Other sectors	0	27	3	*30*
R24	Non-energy uses	0	8	0	*8*

Source : IEA, 2010

Table 9 – Simplified structure of the IEA energy balance

and aviation bunkers, the consumption corresponding to national company to return those volume of energy in the sector of transport. The amounts of remaining energy are returned to exportation. After those pre-treatments, we can identify (Table 9) domestic production (R1), international trade (R3-4), transformation processes and the distribution of final consumption across activities (R10-24).

Difficulties of the transformation from the energy balance to a supply-use format are twofold. On the one hand, the energy balance does not distinguish between intermediate consumption of productive sectors and households' final demand because it does not include information whether energy consumption serves to produce goods or directly the final consumer's needs (for mobility, heating, etc.). This question arises essentially for transport (R19) and residential (which mixes residential and tertiary-R20), and the decomposition for these two activities is dependent upon the availability of complementary datasets (e.g., transport and households' surveys). On the other hand, energy flows must be explicitly reconstituted to exclude the elements of the balance that do not correspond to commercial energy uses (e.g., non-energy uses, renewable energies, transformation by autoproduction of secondary heat or electricity).

In practice, the elaboration of physical accounting systems can be divided in three sub-steps:

Sub-step 1.1 : disaggregating the description of certain products or uses. This step requires additional information from external statistical sources to define the split of quantities reported in an aggregate manner in the balance (in the absence of information, ad-hoc assumptions must be made). In the case of France, an important feature is, for example, to distinguish fuels used for households' mobility of those used for transport sectors. To this aim, the description of refined products in the energy balance must be complemented by more precise information on the details of uses. Table 10 illustrates the disaggregation of the transport sector (R19-20) using external sources of information.

	2010 - Million ton oil-equivalent, Mtoe	Primary energy	Final energy	Non-valuables energies	Total
R1	Production	1	121	13	*135*
R2	Imports	68	94	0	*162*
R3	Exports	-0	-33	0	*-33*
R4	Marine & Aviation bunkers	0	0	0	*0*
R5	**Total Primary Energy Supply**	**69**	**182**	**13**	***265***
R6	Transformations	-69	-17	-0	*-86*
R7	Energy industry own use	0	-10	0	*-10*
R8	Losses	0	-4	0	*-4*
R9	**Total Final Consumption**	**0**	**151**	**13**	***164***
R10	Iron and steel	0	4	0	*4*
R11	Non ferrous metals	0	1	0	*1*
R12	Non metallic minerals	0	4	0	*4*
R13	Construction	0	1	0	*1*
R14	Chemical and petrochemical	0	6	0	*6*
R15	Paper, pulp and print	0	2	1	*2*
R16	Mining and quarrying	0	0	0	*0*
R17	Transport equipement	0	1	0	*1*
R18	Other industries	0	9	1	*11*
R19	**Transport - Households**	0	24	0	*24*
R20	**Transport - Sectors**	0	24	0	*24*
R21	Residential	0	36	8	*45*
R22	Agricuture and forestry	0	4	0	*4*
R23	Fishing	0	0	0	*0*
R24	Other sectors	0	27	3	*30*
R25	Non-energy uses	1	12	0	*13*

Source : IEA; Odyssee Enerdata - 2010

Table 10 – Energy balance after sub-step 1.1

Sub-step 1.2 : delineating the domain of analysis. In practice, this comes down to isolating the crucial components of the balance for a specific study. This means suppressing the rows and columns that correspond to activities outside the core analysis without introducing disequilibria in the balance. For example, the withdrawal of renewables and wastes is not problematic because it is a rather independent production process and it is then sufficient to add the volume of electricity produced from these sources . On the contrary, suppressing non-energy uses requires an equivalent decrease of resources.

Sub-step 1.3 : aggregating and allocating quantities of the energy balance in Table 10 according to the nomenclature of the final input-output matrix. This imposes to adopt a level of aggregation compatible with the nomenclature of national accounts, which comes down to aggregating columns and rows consistently with the level of description adopted in the input-output matrix. In our illustrative example, the columns have not to be modified because they directly correspond to the level of disaggregation of energy in national accounts; but, concerning rows, the study being focused on industries and households, intermediate consumption by tertiary activities can thus be aggregated with the consumption of other sectors.

Sub-steps 1.2 and 1.3 cannot be completely systematised because they involve a number of trade-offs depending on available datasets, the context and the question under consideration. The most important choices concern:

- ***How to assign final energy use.*** When surveys on consumption per use are missing, it becomes necessary to use information from similar economies where these data exist (e.g. Odyssee, Eurostat, or Enerdata database for transport sector) or to deduct the diffracting coefficients from national accounts by adapting the Leontief technique (Moll et al., 2007).
- ***How to establish input-output description consistent with the level of aggregation.*** Volumes of energy must be allocated in accordance with the concepts of supply and use tables (Resources, Uses and Intermediate Consumption). The way to do this assignment depends on the level of aggregation used. In the example of France, only cross-sectoral exchanges associated with refining are described (disaggregated industry), other processing methods are not detailed (aggregated sector) .
- ***How to assign own use of energy.*** Most of the time, the amount of own used energy is not linked to any economic transaction, but must be recognised because it accounts for the estimation of technical coefficients, CO_2 emissions, and the opportunity cost they represent during the introduction of the carbon price (because losses and own uses reduce the net efficiency of the transformation). In particular, it seems consistent to identify own uses with distribution losses for coal, gas and electricity, and to transformation processes for refineries.
- ***How to describe the processes of co-productions.*** The relationship between co-productions is not described in the symmetrical IOTs, which conventionally postulates a separation of the conditions of goods' production. This assumption is not acceptable for some sectors (for example, in studies of agricultural production systems) and flows of co-production must then be described as well as the technical fundamentals which link the productions. In the example of France, this question remains of second order: in the circuit of commercial energies, only a small amount of refined products and industrial gases are by-products of other production processes (petrochemicals and inorganic chemistry) and we treat them as domestic resources into refined products and gas.

From sub-steps 1.1 to 1.3, we are finally able to get the IOT in physical unit, represented in Table 11. For the sake of simplicity, for next explanations, and next illustrations, non-energy sectors have been aggregated into one composite sector. However, this work has been carried out keeping all following sectors isolated from the composite sector : steel and iron, non ferrous metals, minerals, buildings construction, chemical and pharmaceutical, paper, mining, transport equipment, transport services, agri-forestry, fishing, food industry

Sub-step 1.4 : computing the energy expenses and resources of the economy in monetary values. It simply consists in multiplying on a one-to-one basis the IOTs in quantities and prices to obtain a table

2010 - Million ton oil-equivalent, Mtoe	Intermediate consumption			Final consumption			Total uses	Production	Import
	Composite	Primary energy	Final energy	Final demand	GFCF*	Export			
Primary energy	-	-	70.2	-	-	0.1	70.3	2.4	67.9
Final energy	86.6	0.04	18.9	60.0	-	32.8	198.5	109.1	89.4

* Gross fixed capital formation

Table 11 – Energy Input-output table

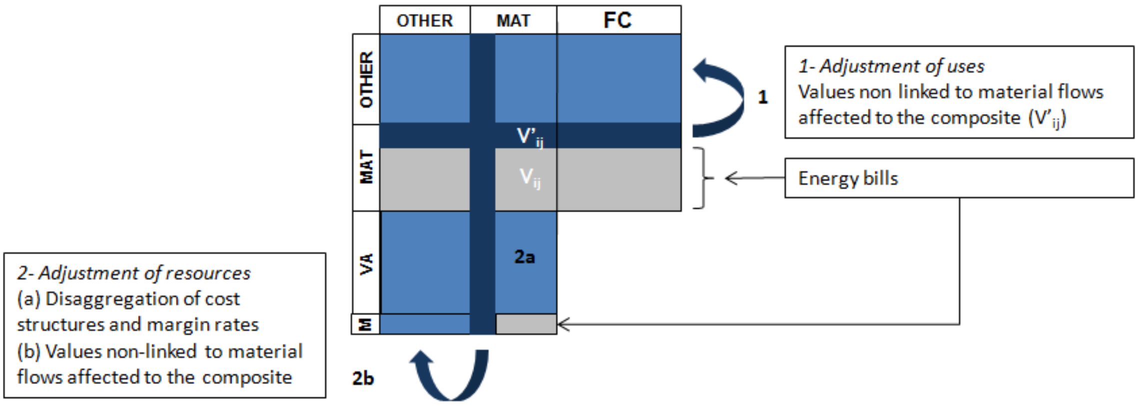


Figure 10 – Principles of alignment of material balances and monetary flows

in monetary units which corresponds to energy bills at the desired level of aggregation (Table 12). This table is fully consistent with the statistics on the diversity of prices, energy consumption, carbon content, etc.

2010 - Million of euros	Intermediate consumption			Final consumption			Total uses
	Composite	Primary energy	Final energy	Final demand	GFCF*	Export	
Primary energy	-	-	29 986.0	-	-	43.8	30 030
Final energy	59 386.9	18.9	4 224.3	72 288.6	-	16 612.1	152 531
Imports		29 535.0	28 305.8				

* Gross fixed capital formation

Table 12 – Balance of energy bills

Step 2: Aligning monetary and physical matrices

Once the IOT that describes the economic circuit of energy flows in quantity, value and price have been built, it remains to integrate it into the national accounts IOT without changing the important indicators for empirical analysis. This is the actual hybridisation step (Figure 10) that can be analysed in two stages: a set of manipulations on the rows of the table (1 - adjustment of uses) to insert the monetary sub-table resulting from step 1 and inform the energy expenses of the economy; and a set of manipulations on the columns (2 - adjustment of resources) to provide the description of the content of energy expenses: the cost structure of one litre of fuel purchased, one kWh, etc.. These columns describe the fixed and variable costs of industries that supply, process and distribute energy to consumers.

The result is a modified input-output table in which the value added of energy flows is isolated from those corresponding to non-energy products from "energy branches" aggregated in the composite sector. This rearrangement in the nomenclature maintains the total value added of the economy as well as its sub-totals (wage bill, gross operating surplus, etc.), total imports and totals of final uses (Households' consumption, exports) while specifying the description of energy circulation.

To carry out this step 2 in the case of France, we start from the IOT obtained from National Accounts (Table 13).

Millions of euros	Intermediate consumption			Final consumption			Total uses
	Composite	Primary energy	Final energy	Final demand	GFCF	Exports	
Composite	1 576 798	263	27 077	1 532 623	376 721	444 564	3 958 046
Primary energy	1 698	0	39 270	-	-	1 255	42 224
Final energy	78 302	11	49 340	80 350	-	14 334	222 338
Value added	1 710 991	264	30 160				4 222 607
Total production	*3 367 789*	*538*	*145 847*				
Imports	448 519	41 539	22 606				
Taxes	141 738	147	53 885				
Total resources	3 958 046	42 224	222 338	4 222 607			

Table 13 – Input-Output tables in National Accounts

Sub-step 2.1 : adjustments of uses. Starting from the IOT (Table 13), we replace the values of energy branches (R2, R3 in orange) by the values of reconstructed energy bills from Table 12. Differences are added to uses and imports of composite (all R1 and R6-C1, in dark blue). These operations do not affect the total value of uses, but change those of different products. Therefore, the supply-use balances are broken for individual sectors.

	Millions of euros	Intermediate consumption			Final consumption			Total uses
		Composite	Primary energy	Final energy	Final demand	GFCF	Exports	
R1	Composite	1 668 256	434	10 454	1 540 684	376 721	443 497	4 040 047
R2	Primary energy	-	-	29 986	-	-	44	30 030
R3	Final energy	59 387	19	4 224	72 289	-	16 612	152 531
R4	Value added	1 710 991	264	30 160				**4 222 607**
R5	*Total production*	*3 438 634*	*717*	*74 824*				
R6	Imports	454 823	29 535	28 306				
R7	Taxes	141 738	147	53 885				
R8	Total resources	4 035 195	30 398	157 014	4 222 607			
	Resources - Uses	-4 852	368	4 484				
		C1	*C2*	*C3*	*C4*	*C5*	*C6*	

In this example, the intermediate consumption of the composite good for the production of energy (first row, second or third column: R1-C3(2)) is estimated in order to keep the input ratio Composite/Energy for energy products given by the IOTnational accounts (R1-C3(2) / [R2-C3(2) + R3-C3(2)]). The balance of inputs is assigned to the composite consumption good for the production of composite (R1-C1).

Table 14 – Input-Output table after adjustments of uses

Sub-step 2.2 : adjustment of resources. Balances between uses and resources are restored by manipulating the cost structure of industries (columns of the IOT). Values of imports and intermediate consumption are given by the energy statistics and other cost components - value added, margins, taxes on products - are adjusted to restore equality of resources with uses (Table 15). Since, in our example, energy taxation is known (R7-C1/C2), the adjustment is made by value added (R4). Finally, in the case

	Millions of euros	Intermediate consumption			Final consumption			Total uses
		Composite	Primary energy	Final energy	Final demand	GFCF	Exports	
R1	Composite	1 668 256	434	10 454	1 540 684	376 721	443 497	4 040 047
R2	Primary energy	-	-	29 986	-	-	44	30 030
R3	Final energy	59 387	19	4 224	72 289	-	16 612	152 531
R4	Value added	1 715 843	-104	25 676				4 222 607
R5	*Total production*	*3 443 486*	*348*	*70 340*				
R6	Imports	454 823	29 535	28 306				
R7	Taxes	141 738	147	53 885				
R8	Total resources	4 040 047	30 030	152 531	4 222 607			
	Resources - Uses	0	0	0				
		C1	C2	C3	C4	C5	C6	

Table 15 – Input-Output table after adjustments of resources

of France, the margin rate is modulated according to buyers, which helps to distinguish the purchaser prices of energy products. After this last step, all accounting identities of the hybrid description are satisfied.

It is useful to keep in mind some principles to guide the choice of adjusting resources. We can offer a procedure to select the set of assumptions to be used to isolate the cost structures of two products (Figure 11) with the objective of mobilising the maximum statistical information available on intermediate consumption and unit costs of each input, labour, consumption of fixed capital and operating margin.

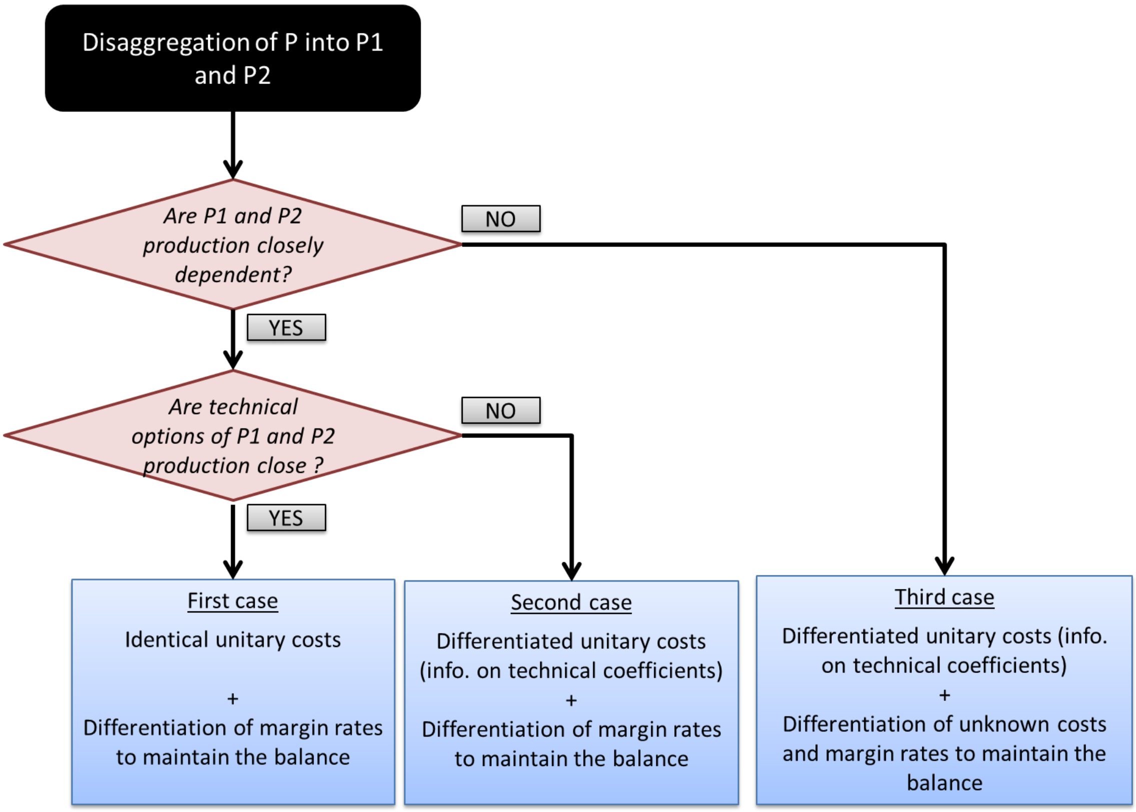


Figure 11 – Methodology for disaggregating cost structures and margin rates

We can then guide the search for information by discussing the conditions of production:

1 ***Productions P1 and P2 are the result of separate units.*** Therefore, the level of dependence is low. It is then likely that the information on one or the other of the structures of this cost is available. This is the case of industries specialised and concentrated, like the nuclear industry that can be isolated from other energy industries.

2 ***Productions P1 and P2 are products within the same units but with different processes.*** Information on technical coefficients (the unit quantities of inputs, capital, and labour) can be used to distinguish costs. This is the case, for example, for refined petroleum products which are derived from a combination of different methods of physico-chemical separation implemented in refineries.

3 ***The production unit and the processes are similar.*** Therefore, it is justified to retain the assumption of the same cost structure. Information is used either on unit costs or on the technical coefficients, but for both productions. Associated with the assumption of returns to scale and / or factor prices, this information can help reconstructing a structure of unitary costs for aggregates (since the total quantities produced are known). This case corresponds, for example, to the distinction between diesel and heating oil, two products actually identical in physical term but used either for transportation or for heating.

B Hybrid input-output table for France

B.1 Data sources

Economic information
INSEE - National accounts database
INSEE – EACEI Survey 2010 (Enquête sur les consommations d'énergie dans l'industrie)
INSEE – ESANE Survey 2010

Price information
SOeS - Pégase Database (Pétrole, Électricité, Gaz et Autres Statistiques de l'Énergie)
ENERDATA - Global Energy & CO2 Data
IAE - Prices and Taxes Database
ADEME – AMORCE Survey 2010 (Enquête sur les conditions d'accueil des professionnels dans les déchèteries publiques)

Physical information
Union Française des industries pétrolières (UFIP) – Database 2010
Comité professionnel du pétrole 2010
ODYSSEE Energy Efficiency Database
Bulletin statistique - Transport aérien commercial – Direction générale de l'aviation civile
IPCC - Guidelines for National Greenhouse Gas Inventories, Volume 2 : Energy - Chapter 2 (2006)
ADEME – Emission Factor Documentation – Carbon Database (2014)
Syndicat Français de l'Industrie Cimentière (SFIC)
World Steel Association

B.2 Input-Output tables for France

The database has been published on Mendeley Data (Le Treut and Ghersi, 2018). All tables are freely available under the following reference:
Le Treut, Gaëlle; Ghersi, Frédéric (2018), "Hybrid Input-Output tables for France at year 2010", Mendeley Data, v1, http://dx.doi.org/10.17632/gyv6hxcwt3.1

B.3 Details on the disaggregation between domestic and imports tables

	δ
Crude oil	1.1
Natural gas	-
Coking coal	3.0
Bituminous coal	64.3
Coke oven coke	1.0
Other coal products	0.2
Gasoline / biogasoline	0.5
LPG	2.0
Jet Fuel	2.1
Diesel and biofuel	1.6
Heating fuel	1.3
Heavy fuel oil	2.0
Other petroleum products	1.4
Electricity	5.2
Heat, Geothermal, Solar Th	0.0
Iron and steel	0.9
Non ferrous metals	0.9
Cement and clinker	0.4
Other non-metallic minerals	1.3
Construction	0.0
Chemical and petrochemical	1.4
Paper, pulp and print	1.2
Mining and quarrying	0.8
Transport equipement	1.2
Transport - Sectors	2.7
Agricuture and forestry	1.0
Fishing	1.8
Agri-food industry	1.6
Composite	0.9

Table 16 – Adjustment parameter for import balance

\hat\tau	Crude oil	Natural gas	Coking coal	Bituminous coal	Coke oven coke	Other coal products	Gasoline / biogasoline	LPG	Jet Fuel	Diesel and biofuel	Heating fuel	Heavy fuel oil	Other petroleum products	Electricity	Heat, Geothermal, Solar Th	Iron and steel	Non ferrous metals	Cement and clinker	Other non-metallic minerals	Construction	Chemical and petrochemical	Paper, pulp and print	Mining and quarrying	Transport equipement	Transport - Sectors	Agricuture and forestry	Fishing	Agri-food industry	Composite	C	G	I	X
Crude oil	26%	82%	26%	26%	99%	73%	99%	99%	99%	99%	99%	99%	99%	82%	82%	73%	73%	24%	24%	24%	61%	27%	26%	22%	21%	20%	20%	22%	27%	1%	0%	0%	43%
Natural gas	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	8%	0%	0%	0%
Coking coal	72%	100%	72%	72%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	67%	67%	67%	100%	75%	72%	62%	59%	56%	56%	63%	76%	4%	0%	0%	100%
Bituminous coal	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	84%	0%	0%	100%
Coke oven coke	27%	22%	27%	27%	28%	31%	28%	28%	28%	28%	28%	28%	28%	22%	22%	31%	31%	27%	27%	27%	28%	26%	27%	27%	24%	26%	23%	25%	24%	20%	0%	0%	0%
Other coal products	13%	7%	13%	13%	11%	10%	11%	11%	11%	11%	11%	11%	11%	7%	7%	10%	10%	8%	8%	8%	10%	1%	13%	6%	8%	6%	0%	11%	8%	7%	0%	5%	2%
Gasoline / biogasoline	12%	10%	12%	12%	13%	14%	13%	13%	13%	13%	13%	13%	13%	10%	10%	14%	14%	12%	12%	12%	13%	12%	12%	12%	11%	12%	10%	12%	11%	9%	0%	0%	0%
LPG	54%	43%	54%	54%	57%	61%	57%	57%	57%	57%	57%	57%	57%	43%	43%	61%	61%	53%	53%	53%	56%	53%	54%	54%	47%	51%	45%	51%	47%	41%	0%	0%	0%
Jet Fuel	55%	44%	55%	55%	58%	62%	58%	58%	58%	58%	58%	58%	58%	44%	44%	62%	62%	54%	54%	55%	57%	54%	55%	55%	49%	52%	46%	52%	48%	41%	0%	0%	41%
Diesel and biofuel	44%	35%	44%	44%	46%	49%	46%	46%	46%	46%	46%	46%	46%	35%	35%	49%	49%	43%	43%	43%	45%	43%	44%	44%	38%	41%	37%	41%	38%	33%	0%	0%	0%
Heating fuel	34%	27%	34%	34%	36%	38%	36%	36%	36%	36%	36%	36%	36%	27%	27%	38%	38%	33%	33%	34%	35%	33%	34%	34%	30%	32%	28%	32%	30%	26%	0%	0%	0%
Heavy fuel oil	53%	43%	53%	53%	56%	60%	56%	56%	56%	56%	56%	56%	56%	43%	43%	60%	60%	52%	52%	53%	55%	52%	53%	53%	47%	50%	45%	50%	46%	40%	0%	0%	40%
Other petroleum products	37%	29%	37%	37%	39%	42%	39%	39%	39%	39%	39%	39%	39%	29%	29%	42%	42%	36%	36%	37%	38%	36%	37%	37%	33%	35%	31%	35%	32%	28%	0%	0%	0%
Electricity	8%	6%	8%	8%	9%	8%	9%	9%	9%	9%	9%	9%	9%	6%	6%	8%	8%	6%	6%	9%	6%	7%	8%	7%	7%	6%	7%	7%	6%	0%	0%	0%	0%
Heat, Geothermal, Solar Th	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Iron and steel	67%	37%	67%	67%	57%	54%	57%	57%	57%	57%	57%	57%	57%	37%	37%	54%	54%	45%	45%	43%	54%	3%	67%	31%	40%	33%	0%	60%	44%	39%	0%	26%	39%
Non ferrous metals	65%	36%	65%	65%	55%	52%	55%	55%	55%	55%	55%	55%	55%	36%	36%	52%	52%	44%	44%	41%	52%	3%	65%	30%	39%	32%	0%	58%	43%	38%	0%	25%	13%
Cement and clinker	6%	5%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	5%	5%	6%	6%	6%	6%	6%	10%	9%	6%	11%	6%	12%	11%	13%	9%	7%	0%	0%	4%
Other non-metallic minerals	20%	15%	20%	20%	19%	20%	19%	19%	19%	19%	19%	19%	19%	15%	15%	20%	20%	21%	21%	20%	33%	29%	20%	35%	18%	37%	35%	42%	27%	22%	0%	0%	14%
Construction	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Chemical and petrochemical	90%	75%	90%	90%	97%	93%	97%	97%	97%	97%	97%	97%	97%	75%	75%	93%	93%	86%	86%	84%	82%	88%	90%	82%	81%	81%	72%	81%	80%	31%	56%	0%	5%
Paper, pulp and print	52%	46%	52%	52%	53%	53%	53%	53%	53%	53%	53%	53%	53%	46%	46%	53%	53%	49%	49%	45%	45%	56%	52%	44%	48%	23%	23%	39%	43%	24%	0%	0%	3%
Mining and quarrying	21%	66%	21%	21%	79%	58%	79%	79%	79%	79%	79%	79%	79%	66%	66%	58%	58%	19%	19%	19%	49%	21%	21%	18%	17%	16%	16%	18%	22%	1%	0%	0%	34%
Transport equipement	60%	58%	60%	60%	78%	45%	78%	78%	78%	78%	78%	78%	78%	58%	58%	45%	45%	52%	52%	45%	49%	46%	60%	57%	49%	56%	78%	46%	38%	47%	55%	66%	5%
Transport - Sectors	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
Agricuture and forestry	16%	7%	16%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	7%	7%	0%	0%	0%	0%	5%	8%	5%	16%	0%	7%	8%	0%	9%	7%	19%	0%	42%	0%
Fishing	0%	56%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	56%	56%	0%	0%	0%	0%	67%	69%	0%	0%	0%	0%	50%	57%	64%	62%	29%	0%	0%	0%
Agri-food industry	36%	28%	36%	36%	30%	30%	30%	30%	30%	30%	30%	30%	30%	28%	28%	30%	30%	30%	30%	34%	26%	24%	36%	18%	18%	13%	33%	26%	22%	18%	19%	0%	0%
Composite	21%	11%	21%	21%	13%	14%	13%	13%	13%	13%	13%	13%	13%	11%	11%	14%	14%	12%	12%	18%	12%	20%	21%	26%	-8%	15%	14%	9%	10%	7%	0%	15%	7%

Table 17 – Import ratio of hybrid Input-Output table

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