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Environmental Impacts of the French Final Consumption

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Abstract

In order to fight against climate change, ambitious targets have been set, such as decreasing carbon emissions by 75% in France compared to 1990. Yet, focusing on territorial impacts leads to overlook import-embedded impacts. As a matter of fact, French territorial greenhouse gases (henceforth GHG) emissions have slightly decreased since 1990, whereas consumption-based emissions have been shown to increase. This is why we focus in this paper on consumption-based emissions rather than territorial emissions. Moreover, our analysis is not carbon-emissions focused. Indeed, the following environmental impacts are taken into account: air acidification, photochemical oxidation and non-dangerous industrial wastes. This a first contribution. Secondly, we build a scenario of French households final consumption in 2030 aiming at decreasing its environmental impacts. Finally, a deep matrix algebra analysis gives us precious hints on the reliability of the results.

Keywords: input-output analysis, environmental externalities, scenario analysis
JEL:Q40, Q53, Q54

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1 Introduction

Following the Intergovernmental Panel on Climate Change recommendations, some countries set ambitious greenhouse gases (henceforth GHG) emissions reduction targets. In particular, France officially committed to a four-fold reduction in its territorial GHG emissions by 2050 compared to 1990 levels[1]. In this context, 2030 is an important step on the road towards a 2050 low-carbon society: emissions in 2030 will have to comply with the self-imposed target, were France to meet it. Yet, focusing on territorial impacts leads to overlook import-embedded-impacts. As a matter of fact, French territorial GHG emissions have decreased by 0.6% per year since 1990 (see CITEPA (2013)), whereas consumption-based emissions have been shown to increase by more than 0.3% per year in Pasquier (2012). Moreover, focusing on consumption-based emissions has other virtues: first, microeconomic theory teaches us that (final) consumption is what matters for individual consumers; secondly, it can be interpreted in terms of every-day-life final services. This is why we focus on consumption-based emissions rather than territorial emissions. The relevance of consumption-based analysis of environmental impacts can be appreciated by the increasing related research. To take but few examples, direct emissions (i.e., fuel burning by households) were shown to contribute no more than 25% of total consumption-based final energy consumption of French househoulds in Pourouchottamin et al. (2013). Second, at the European level, housing, transport and foods are the top-three contributors to environmental impacts, see JRC (2006). Third, imports were shown to account for about 40% of consumption-based CO_2 emissions in France in 2005 in Lenglart et al. (2010), and this weight is growing, see Pasquier (2010). Yet, these research and studies focus on carbon emissions, or more generally on greenhouse gases emissions (GHG), while there are other important environmental issues, of which air acidification (ACD), photochemical oxidation (PCO) and non-dangerous industrial wastes (NDIW). Those impacts were taken into account in a study published by Ademe[2] in 2011 (see ADEME (2011)), showing among others the extreme heterogeneity of consumption-based environmental impacts across products. One contribution of the present paper is to refine the quantification of import-embedded impacts of the latter study. In addition, it helps answer the following questions: first, to what extent environmental impacts can be decreased when current ways of living are protracted? second, to what extent is environmentally-extended input-output analysis robust?

In the following section, we describe the quantitative method. Then, we give an overview of the environmental impacts of french households final consumption and the scenarios aiming at decreasing those impacts. The fourth section presents the performed simulations. Finally, results are presented, and their reliability discussed.

2 Consumption and environmental impacts

2.1 Consumption structure

In order to make the interpretation easier, results are given according to the ”Classification of Individual Consumption according to Purpose” (henceforth COICOP), which is nothing but an aggregation of heterogeneous products (i.e., goods and services) into ”functions”, or ”final services” (e.g., ”feeding”, ”clothing”, ”moving”, etc.). It should be emphasized that even if there is much heterogeneity in the share of each function across both time and countries, France in

[1] See the 2005 Energy Policy Programming Bill (loi POPE)

[2] This study was performed by the consultancy Bio by Deloitte, the name of which was Bio Intelligence Service at the time of the study.

2007 (see table 1) was relatively close to the UE27 average in 2005 (see Eurostat's Household Budget Survey).

Table 1: COICOP and relative French effective consumption spending in 2007

Code	Label	Spending (%)
01	Food and non-alcoholic beverages (*)	11.6
02	Alcoholic beverages, tobacco and narcotics	0.4
03	Clothing and footwear	2.7
04	Housing, water, electricity, gas and other fuels (*)	30.0
05	Furnishings, household equipment and routine household maintenance (*)	4.1
06	Health	15.1
07	Transport	8.7
08	Communication	1.8
09	Recreation and culture	6.4
10	Education	7.4
11	Restaurants and hotels	4.7
12	Miscellaneous goods and services	6.9
	Total	100.0

Source: United Nations (COICOP) and INSEE (spending)

(*) Henceforth, "Food", "Housing" and "Furnishings and equipment" respectively.

2.2 How to quantify the environmental impacts of final consumption?

2.2.1 Input-output analysis basics

Following Leontief (1970), let us write that in a closed economy made up of n products, production is either consumed by final consumers (final consumption), or firms (intermediate consumption[3]):

$$\begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_n \end{bmatrix} = \begin{bmatrix} a_{1,1} & a_{1,2} & \dots & a_{1,n} \\ a_{2,1} & a_{2,2} & \dots & a_{2,n} \\ & & \ddots & \\ a_{n,1} & a_{n,2} & \dots & a_{n,n} \end{bmatrix} \times \begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_n \end{bmatrix} + \begin{bmatrix} c_1 \\ c_2 \\ \vdots \\ c_n \end{bmatrix} \tag{1}$$

Where:

- p_i stands for the output of product $i = 1, ..., n$;
- c_i stands for the final consumption of product i;
- $a_{i,j}$ stands for the quantity of product i necessary to produce one unit of product $j = 1, ..., n$.

Noticing that the production vector is in both sides of (1), we can express it as a function of the final consumption[4]:

[3] Investment is set aside in this example to focus on the fundamental input-output analysis equation

[4] $$\begin{bmatrix} l_{1,1} & l_{1,2} & \dots & l_{1,n} \\ l_{2,1} & l_{2,2} & \dots & l_{2,n} \\ & & \ddots & \\ l_{n,1} & l_{n,2} & \dots & l_{n,n} \end{bmatrix} = \begin{bmatrix} (1-a_{1,1}) & -a_{1,2} & \dots & -a_{1,n} \\ -a_{2,1} & (1-a_{2,2}) & \dots & -a_{2,n} \\ & & \ddots & \\ -a_{n,1} & -a_{n,2} & \dots & (1-a_{n,n}) \end{bmatrix}^{-1}$$

$$\begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_n \end{bmatrix} = \begin{bmatrix} l_{1,1} & l_{1,2} & \dots & l_{1,n} \\ l_{2,1} & l_{2,2} & \dots & l_{2,n} \\ & & \ddots & \\ l_{n,1} & l_{n,2} & \dots & l_{n,n} \end{bmatrix} \times \begin{bmatrix} c_1 \\ c_2 \\ \vdots \\ c_n \end{bmatrix} \tag{2}$$

Let us take two examples. First, the necessary production $p(c_1)$ needed to satisfy the final consumption of product c_1 is equal to:

$$p(c_1) = \begin{bmatrix} l_{1,1} \\ l_{2,1} \\ \vdots \\ l_{n,1} \end{bmatrix} \times c_1$$

On the other hand, the quantity of product 1 necessary to satisfy the total final consumption is:

$$p_1 = \sum_{j=1}^{n} l_{1,j} \times c_j$$

2.2.2 Extensions

Spending In addition to households final consumption, the effective consumption includes by definition government-provided private goods and services (*e.g.* health services). In our analysis, we also take households investment in dwellings construction into account[5]. From now on, any reference to "effective consumption" includes investments in dwellings. On the other hand, we exclude exports as well as government-provided public goods and services (*i.e.* national defense services). Furthermore, both domestic as well as foreign production is taken into account. As far as imported final consumption is concerned, input-output analysis is replicated on two trading-partner economies assumed to represent the set of France's trading-partners (see section 2.2.3). Concerning intermediate goods, the computations are slightly more complicated: domestic final consumption is first turned into necessary domestic production according to equation (2). Then, using the imported per-unit intermediate consumption tables, the needed quantity of intermediate products to be imported is determined. Finally, the origin of imports is assumed according to each country's share in the imports[6], and an input-output analysis is performed on each of the two countries .

Environmental impacts Thanks to the first step, we know the quantity of each of the n goods and services the domestic economy as well as the trading-partner economies have to produce in order to satisfy the domestic households effective consumption. Combining these estimates with the per-monetary-unit impacts gives us the environmental impacts of the domestic households effective consumption, to which we add the direct impacts due to fuel burning. For example, the environmental impact $k = 1, ..., K$ generated by the domestic households effective consumption (denoted e_k^c) is equal to:

$$e_k^c = e_k^p + e_k^{p*} + e_k^u$$

Where:

[5]This is not standard in the national accounts literature, but for the sake of completeness dwellings construction environmental impacts have to be taken into account. Though this strengthens the importance of "Housing" (investment in dwellings accounts for about 8% of the French effective consumption, author's estimation based on French National Accounts), it does not challenge any conclusion.

[6]The weight of each country is estimated for the n products, based on UN Comtrade database, see Annex 2

- e_k^p represents the quantity of pollutant k generated by the domestic production;
- e_k^{p*}, represents the quantity of pollutant k generated by the foreign production;
- e_k^u represents the quantity of pollutant k generated by the final user (e.g., motor fuels burning in the case of CO_2 emissions).

As an illustration, the quantity of pollutant k generated by the domestic production needed to satisfy the households effective consumption is:

$$e_k^p = \left[\ e_{k,1}, e_{k,2}, \ldots, e_{k,n}\ \right] \times \begin{bmatrix} l_{1,1} & l_{1,2} & \ldots & l_{1,n} \\ l_{2,1} & l_{2,2} & \ldots & l_{2,n} \\ & & \ddots & \\ l_{n,1} & l_{n,2} & \ldots & l_{n,n} \end{bmatrix} \times \begin{bmatrix} c_1 \\ c_2 \\ \vdots \\ c_n \end{bmatrix}$$

Where:

- $e_{k,i}$ stands for the per-unit quantity of pollutant k generated by the domestic production of product i. It is equal to the ratio of $e_k(p_i^e)$ on the one side (i.e., the quantity of pollutant k as reported in national inventories), and p_i^e on the other side (i.e., the production of product i as reported in the national accounts).

2.2.3 Our model

The input-output model we built is multi-regional. There is one core-country (France) and two trading-partner economies: Germany, assumed to represent the relatively rich countries; and Poland, assumed to represent the other countries. As imperfect as it might seem, the lack of data lead us to make such a choice. Therefore, production systems and per-unit environmental impacts heterogeneity is taken into account. To illustrate this point, let us notice that Polish power generation per-unit CO_2 emissions (2008-2010 average) are fairly close to Chinese's and 70% higher than German's: $798gCO_2/kWh$, $790gCO_2/kWh$ and $468gCO_2/kWh$ respectively, seeIEA (2012). Eurostat national accounts data (NACE 2007 rev.1) are used, in which economies are disaggregated in 59 products (*i.e.* goods and services). In addition to final consumption spending, production and intermediate consumption, some primary flows (or pollutants, then converted into environmental impacts) are available for the 59 products. This enables us to conduct a multi-regional environmentally-extended input-output analysis. The four environmental impacts[7] presented in this analysis are made up of a weighted sum of primary flows (see Table 2):

[7]Technically speaking, these are *potential* environmental impacts. Moreover, masses of wastes are not properly a potential environmental impact. However, they raise potential treatment challenges that is why they are taken into account.

Table 2: Characterization factors

Primary flows	Environmental impacts GHG	ACD	PCO	NDIW
Carbon dioxide (CO_2)	1			
Methane (CH_4)	25			
Dinitrogen monoxide (N_2O)	298			
Nitrogen monoxide & dioxide (NO_X)		0.70		
Sulfur oxides ($SO_2O\&SO_X$)		1.00		
Ammonia (NH_3)		1.88		
Non-methanic volatile organic components ($NMVOC$)			1	
Non-dangerous industrial wastes				1

Source: IPCC, and author's assumptions

Scenarios are built first by making the economy growing, and secondly by altering the following coefficients:

- final consumption, *i.e.* c_i;
- intermediate consumption, *i.e.* $a_{i,j}$;
- per-unit environmental impacts, *i.e.* $e_{k,i}$;

3 Environmental impacts: diagnosis and actions to decrease them

3.1 Environmental impacts of the French households consumption in 2007

Let us start with two important observations: first, the distribution of impacts is concentrated; second, consumption-based impacts of products are extremely heterogeneous - both in level and structure. Indeed, we confirm that food, housing and transport contribute roughly more than 2/3 of each of the four impacts considered. Yet, as shown in Table 3, the importance of the top contributor is not homogeneous across impacts:

Table 3: Top-contributors to environmental impacts, France, 2007

	GHG	ACD	PCO	NDIW
Top contributor	Housing	Food	Food	Housing
Top contributor share	28%	47%	27%	70%
Top-three contributors share	73%	72%	67%	80%

Source: Authors' s computations

The environmental impact of each function is the result of the combination of the amount spent on the one hand and its per-monetary-unit impact on the other hand. In monetary flows, the top-three contributors account for half of the effective consumption spending (see Table 1). Since their share in the different impact is greater than their share in the total spending, they also exhibit relatively high per-monetary-unit impacts. Table 4 illustrates this point:
Not surprisingly, heterogeneity is even larger among the 59 products. It ranges from $40gCO_2eq$ ("Real estate, renting and business activities, consulting") to $5,848gCO_2eq$ ("Manufacture of coke, refined petroleum products and nuclear fuel"). Even within the same function, there

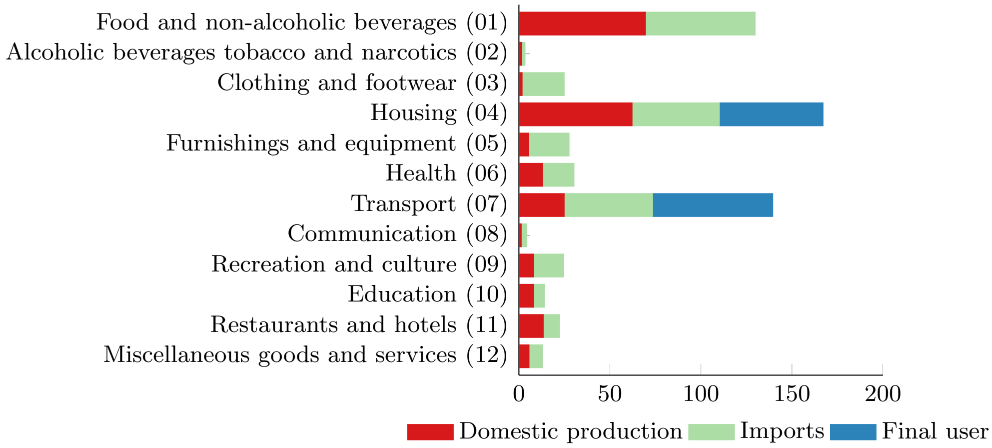
Table 4: Per-monetary-unit environmental impacts, France, 2007

		GHG (gCO_2eq)	ACD (gSO_2eq)	PCO ($gCOVNM$)	NDIW ($gndiw$)
Average		465	2	2	186
Min	Impact	126	0.5	0.15	48
	Function	Education	Miscel.	Education	Health
Max	Impact	879	8.2	1.5	431
	Function	Transport	Food	Food	Housing

Source: Authors' s computations

exists significant heterogeneity. For example, within transport services, it goes from $544gCO_2eq$ ("Water transport") to $1,539gCO_2eq$ ("Air transport"). Finally, impacts have heterogeneous origins. Considering GHG (see Figure 1), final-user emissions are significant only for housing and transport; the relative weight of import-embedded emissions is very important for "Clothing etc." and "Furnishing etc."; "Food"' is the top contributor in absolute terms to import-embedded emissions as well as domestic production-based emissions. This is all the more so interesting as France is the (European) top food products exporting country. In total, imports account for 44% of consumption-based GHG emissions.

Figure 1: French consumption-based GHG emissions in 2007, $Mt\ CO_2eq$



3.2 Reducing environmental pressures: overview of the scenarios

Two scenarios are simulated: first, the reference scenario, in which current trends are not challenged; secondly, the ambitious scenario, in which ambitious changes in consumption are simulated. The reference scenario is nothing else but a reference point, and it must not be interpreted as a "business-as-usual", or even worse, as "the most likely scenario". Indeed, some strong assumptions are made precisely to neutralize some important effects (see 3.3). Basically, apart from a larger and richer population, everything stands - relatively - equal as in 2007, the base year. Note that some progress on energy efficiency is assumed, yet not faster than current trends (about 1% per year, author's computations based on CEREN statistics). In the ambitious scenario, actions aiming at decreasing the environmental impacts of households' final effective consumption are considered. All sectors are involved to achieve a more sustainable final consumption, and actions aim at decreasing above all energy consumption and carbon emissions. Most of these assumptions come from a previous by ADEME using techno-economic energy modelling, see ADEME (2013). Here is a qualitative review of the actions *a priori* aiming at decreasing environmental impacts that have been simulated. They are summarized in Table 5.

Housing (COICOP 04) 3 set of actions are simulated. First, dwellings' thermal performance is strongly increased through a massive refurbishment: 500,000 dwellings a year, to be compared with the current 150,000 [8]. The consequence is twofold: on the one hand, the final demand for "Construction" products (i.e., retrofitting activities) increases; on the other hand, both households energy consumption (and thus energy spending) and direct carbon emissions decrease. Secondly, new dwellings construction is assumed to be fixed (which corresponds to a decrease in new dwellings per capita) at about 350,000 dwellings per year. Finally, per-unit intermediate consumption of timber is assumed to increase (by 10% compared to current levels) and thus substitute non-metallic minerals.

Transport (COICOP 07) Some technological progress, organizational improvements (e.g. car-sharing) and tailored vehicles (e.g., small and light electric cars for intra-city trips) lead to a decrease in both energy consumption (and thus energy spending and direct carbon emissions) and to the number of new car registrations. Energy efficiency is also improved in the transport services. In addition, car manufacturing is assumed to (intermediately) consume a lower quantity of steel.

Food and drinks (COICOP 01 & 02) First, agricultural processes are improved: both N_2O and CH_4 per-unit emissions are assumed to decrease. Thirdly, a 25% decrease in energy consumption is achieved. Finally, a drastic reduction in food throwing away is assumed (-60% relative to current levels).

Equipment and maintenance (COICOP 03, 05, 08) 3 assumptions are simulated: first, life-cycle are increased (by 20%); secondly, energy efficiency of appliances is greatly improved though without any techological disruption. For example, refrigerators are assumed to be as energy efficient in average in 2030 as the currently most energy efficient ones. Finally, overdosing of chemical products (detergents, phytosanitary products, glues, varnish, paint, etc.) is assumed to decrease.

Others (COICOP 06, 09, 10, 11, 12) Thermal usages energy consumption in services buildings is assumed to decrease, thanks among other to refurbishments. Moreover, carbon emissions generated by power generation are decreased by two thirds. Finally, industry is globally assumed to improve its per-unit energy efficiency by 20%. More details can be found in ADEME (2013).

4 Simulations

4.1 The French economy in 2030

Households final consumption expenditure is assumed to grow along with the - exogenously determined - real GDP. Then, this increase in spending is converted into an increase in physical quantities on the one side, and an increase in value on the other side. Two forces make physical quantities increase: first, demographic growth (+11% over the period 2007-2030); second, the poorest 20% are assumed to spend their increase in income into buying more units of goods

[8]Source: ADEME (OPEN survey)

and services rather than buying higher-value goods and services, unlike the 80% other. In other words, the growth of consumption per capita is immaterial but for 20% of the population. Assuming fixed budgetary coefficients as well as fixed (after-tax) income distribution (thus only one tenth [9] of the increase in national income is "physical"), we obtain a projection of the households consumption in 2030. The direct consequence is that physical quantities increase by 14%, and the value of goods by 23%. Moreover, as budget coefficients are fixed, prices of all goods and services increase at the same rate. Though this is a very strong assumption, this was done on purpose precisely not to interfere with the actions aiming at decreasing the environmental impacts. Furthermore, we acknowledge that the assumptions on "immaterial" consumption may seem unrealistic, especially for electronic devices. However, though the manufacturing of electronic devices raises resources (e.g. rare earth) and waste treatment concerns, the former are not taken into account in our analysis while the latter is not precisely accounted for (mixed with other types of wastes). Therefore, the estimated four environmental impacts are not sensitive to the assumption on electronic devices. Moreover, some evidence supports the idea of binding physical consumption. Let us take some examples to illustrate this point. First, the number of new dwellings per capita did not increase since 1990 (though significantly variable within the period, around 0.005/year/capita[10] for both population and new residential buildings statistics). Second, since 1990 the number of new cars per capita has actually decreased: from 0.04 new car per capita to 0.03 new car per capita[11]. Third, the energy food intake is about 3,500kcal/capita/day since 1990 in France, see FAO (2012). Moreover, future budgetary coefficients are fairly uncertain and results are extremely sensitive to budgetary coefficients (see 3.3), that is why they are assumed not to vary. The comparative static analysis (see below) help appreciate the extent to which results are sensitive to assumptions on budgetary coefficients.
It is very important to notice that we are interested in potentials: we do not look for optimality or cost-effectiveness. However, this shall not be overstated. Indeed, among the simulated actions, some (e.g., reducing food wastes, car-sharing) have insignificant costs[12] while others entail additional costs that are taken into account (ex: dwellings retrofitting). Finally, some possible additional costs have not been *formally* taken into account, such as energy efficiency investment in industry and services or renewable power. However, recall that between 2007 and 2030, the value of goods -and thus their price[13]- increase, which partly takes into account the aforementioned possible additional costs. In addition, were the effect only partly taken into account, the consequences of a subsequent additional increase in prices may not challenge the orders of magnitude: either the goods are imported, and the increase in prices would incur a loss of national income and thus weaken the rebound-effect; or they are not imported, thus the increase in prices would be contrasted by an increase in income (yet the net effect is still to be determined).

4.2 Plugging the assumptions into the model

Two different sets of hypotheses are applied to the latter projection: a set of moderate changes, corresponding to the reference scenario, and a set of deeper changes, corresponding to the main

[9] *i.e.* The share of the national after-tax income earned by the poorest 20% is 10%, see Cazenave et al. (2013)

[10] The population increased faster than new constructions did. Source: authors' computations using data from INSEE (French Office for National Statistics).

[11] Caution: the seeming 25% decrease is due to number rounding. The important fact to have in mind is simply that there is no evidence of an increase. Source: authors' computations using data from the Committee of French Car Manufacturers (authors' translation for CCFA)

[12] Switching costs are not taken into account.

[13] This increase in prices is due to an increase in the value of goods between 2007 and 2030. It must not be confused with inflation, which does not appear here since we consider only real variables.

scenario. In each scenario, assumptions are made on: the final demand, the technical coefficients - though most of them remain unchanged - and finally production per-unit environmental impacts. As far as final demand is concerned, we quantify the possible additional spending (e.g., investments to insulate homes) as well as the related economic gains (e.g., a decrease in energy spending subsequent to an increase in energy efficiency), and thus estimate the (possible) net "avoided" spending. In order to control for possible rebound-effects, we redistribute the net avoided expenditure according to the budgetary coefficients observed in 2007. The input-output analysis based on scenario-specific final demand, technical coefficients and per unit impacts gives us the total impacts of the French households final consumption. Assumptions are summarized in table 5:

Table 5: Assumptions

			Scenarios	
			Reference	Ambitious
Macro		Population	+11%	
		Income per capita	+26%	
Final consumption	Housing (04)	Energy (heating)	-13%	-42%
		Electricity (appliances)	+40%	-22%
		New dwellings	0%	
	Transport (07)	Energy (MJ/pkm)	-13%	-42%
		New cars (/pers)	0%	-19%
	Food (01 & 02)	Food waste (t/cap)	−10%	−60%
		Dining out	+40%	
	Equipment	Life-cycle	0%	+20%
		Products overdosing	+10%	-20%
Intermediate consumption	Energy (tep/unit)	Agriculture	0%	-33%
		Manufacturing industry	-5%	-20%
		Services	0%	-30%
	Steel	Car industry (t/car)	0%	-10%
	Timber	Construction (t/dwelling)	+5%	+10%
Per-unit impacts	Agriculture	CH_4 & N_2O per unit (t/t)	-5%	-15%
	Power generation	Carbon emissions (CO_2/kWh)	0%	-67%
	Foreign production (Ger.)	CO_2/ unit	0%	-29%

Source: Authors' s computations

Note that German power generation per-unit CO_2 emissions are assumed to decrease according to the 2030 the European climate target (i.e., a 40% decrease in territorial emissions in 2030 compared to 1990).

5 Results

We first present the results and secondly, we run a comparative static analysis in order to determine the hypotheses leading to the most significant environmental impact reductions. Finally, some matrix algebra gives us hints about the reliability of the results.

5.1 Scenario analysis

First, GHG emissions in the ambitious scenario are 18% lower than in the reference scenario. Compared to 2007, it is a 17% reduction (or 25% per capita). These reductions are mainly due to efforts on energy products "Coke, petroleum products and nuclear products" and "Electricity, natural gas, steam and hot water" (71% of the decrease), food products (8%), and car industry (6%). Secondly, given the importance of energy efficiency and carbon cuts in our scenarios, air acidification and photochemical oxidation decrease only by 1% and 3% respectively in the ambitious scenario compared to the reference scenario, while non-dangerous industrial wastes increase by 5%. Thirdly, as about half of the emissions are embedded in imported products, the assumptions made on technical coefficients and unitary impacts in the French production system have but limited effects, and assumptions on the final consumption and direct emissions have more tangible effects. Finally, the impacts of each product have different origins: some products exhibit high unitary impacts (e.g., motor fuels, natural gas) whereas other products account for an important share of the total spending (e.g., buildings, health, education). The main results of the simulations are summarized in the table 6:

Table 6: Simulations - Environmental impacts indexes

	Reference	Ambitious
GHG	100	82
ACD	100	99
PCO	100	97
NDIW	100	105

Source: Authors' s computations

The main conclusion to be drawn is the following one. From an environmental point-of-view, the situation is better in the ambitious scenario relative to reference one. Indeed, significant reductions are achieved in GHG emissions, slight decrease in ACD and PCO, and a 5% increase in non-dangerous industrial wastes. However, very ambitious targets such as 1.6 tCO_2/capita in 2050[14] remain far from our 2030 estimate (i.e., 6.6 tCO_2/capita) and will require important additional efforts and structural changes. This is all the more so as almost-immaterial growth scenarios were simulated. The good news is that there exists significant room for almost zero-cost actions aiming at reducing environmental impacts, such as car-sharing. The next section deals with this issue in more details.

[14] Assuming a world population of 9 billion inhabitants and a global carbon-recycling biocapacity of $15GtCO_2e$/year gives an average $1.6tCO_2e$/capita/year.

5.2 Comparative static analysis

The comparative static analysis leads us to the following conclusions. First, environmental impacts are extremely sensitive to budgetary coefficients. If overlooked by environmental policy makers, potential significant rebound-effects are to be expected. Indeed, a reduction in final consumption of a given product does not, as total spending is fixed, necessarily imply a decrease in environmental impacts. It all depends on the way spared money is then spent: according to whether households choose to spend their spared money, carbon emissions variation ranges from -1.4% (recreational services) to +6.6% (air transport services) relative to the ambitious scenario. Second, there exists some almost zero-cost actions that may help decrease environmental impacts. For example, car-sharing more intensively requires almost nothing more than some easy-to-get information and can avoid a significant amount of emissions. Finally, if per-unit environmental impacts were the same as France's, carbon emissions could be further decreased by another 10%. This latter result, given as an illustration, is yet not to be taken for granted. Indeed, international trade precisely exists because there is no such thing as a country which produces all the goods. Therefore, this estimate is clearly an upper-bound, and a deep analysis of the homogeneity of products is crucially needed.

Table 7: Alternative simulations and results relative to the "Ambitious scenario"

			Assumptions		Results (%)			
			Ambitious	Alternative	GHG	ACD	PCO	NDIW
Final consum.	Housing	Heated surface		-15%	-0.1	-0.1	-0.1	0.1
	Transport	Car load factor	1.4	2.1	-3.3	-0.3	-0.7	0.1
	Food	Food waste (t/cap)	−60%	−90%	-0.2	-0.4	-0.2	0.1
	Equipment	Life-cycle	+20%	+50%	-0.8	-0.3	-0.9	-0.2
		Overdosing	-20%	-50%	-0.1	0.0	-0.2	0.0
	Health	Spending/cap	0%	+14%	-1.1	-1.5	-1.1	-1.6
Interm. consum.	Car industry	Steel (/car)	-10%	-20%	-0.2	-0.1	-0.1	0.0
Per-unit impacts	Agriculture	CH_4 & N_2O(/unit)	-15%	-30%	-1.9	0.0	0.0	0.0
	Foreign prod.	CO_2(/unit)		Idem France	-9.7	-12.1	-25.6	-12.9
Avoided spending	Reallocation	Air transport		100%	6.6	2.7	2.4	-0.2
		Recreational activity		100%	-1.4	-1.7	-1.6	-1.7

Source: Authors' s computations

5.3 Possible biases

As already mentioned, the goal of the simulations was to give orders of magnitude of non-disturbing actions aiming at decreasing the environmental impacts. We see that such potential exists, but the orders of magnitude presented are possibly biased, for the following reasons. On the one hand, environmental impacts are likely to be underestimated because of missing data on imports. Only two countries (i.e. Germany and Poland) were considered, excluding countries such as China for example. Input-output tables for this latter country were estimated to comply with the NACE 2007 rev1.1, but we failed to estimate per-unit-of-product environmental impacts. This is a path for further research. On the other hand, environmental impacts are likely to be overestimated because the structure of the economy is almost fixed (most of intermediate coefficients are fixed) while empirically production processes improve over time. Last but not least, new forms of exchange (e.g. functionality economy, collaboration economy, barter, etc.) have hardly been taken into account and this could alter environmental impacts estimates. The alteration is ambiguous though: these new forms of exchange could help increase the efficiency of the economy, yet they may increase business opportunities. Finally, compared to detailed life-cycle analysis, the data used here are pretty much aggregated. This prevented us to simulate some possible environmental-friendly trends, such as a decrease in meat over-consumption.

5.4 On the reliability of the results

5.4.1 An example

Let us think of an economy made up of 2 goods and let be $q_1 = 10$ and $q_2 = 0.1$ the *measured* output of each of them[15]. Per-unit impacts (say, carbon emissions) are respectively $i_1 = 0.1$ and $i_2 = 10$. The total environmental impact is equal to 2, *i.e.* $q_1 \times i_1 + q_2 \times i_2 = 10 \times 0.1 + 0.1 \times 10$. Suppose now that measurement error uncertainty on *total* output is 0.1 unit, *i.e.* about 1%. For example, q_1^a and q_2^a -the *actual* outputs- can be equal to 9.9 and 0.2 respectively. In this case, the total environmental impact is equal to 2.99. We see that a 1% measurement error uncertainty on the total output *possibly* leads to a 50% uncertainty on the total environmental impact.

5.4.2 Sensitivity of the computations to the data: a first upper-bound

The objective is to find an upper-bound to the sensitivity results of the computations to the data[16]. Let us first rewrite (2) in matrix notation:

$$P = \mathbf{L}C$$

Where:

- P is the production vector;
- $\mathbf{L}$ is the Leontief matrix;
- C is the final consumption vector.

Using the euclidian norm on vectors and the induced norm on matrices[17], a first theoretical upper-bound is given by the following relation:

$$\frac{\|\Delta P\|}{\|P\|} \leq \kappa(\mathbf{L}) \frac{\|\Delta C\|}{\|C\|} \tag{3}$$

Where:

- $\frac{\|\Delta P\|}{\|P\|}$ is the relative uncertainty on the necessary production vector;
- $\frac{\|\Delta C\|}{\|C\|}$ is the relative uncertainty on the final consumption vector;
- $\kappa(\mathbf{L}) = \|\mathbf{L}\|\|\mathbf{L}^{-1}\|$, is the condition number of $\mathbf{L}$.

From Eurostat databases, one can estimate the condition number of the French economy $\mathbf{L}$ matrix to be equal to 3.11 in 2007. For a given uncertainty δ on final consumption, the uncertainty on the necessary production is at most 3.11δ. Such a large uncertainty makes the search for a lower upper-bound relevant.

[15] See Gilbert (2014)

[16] Mathematical proofs can be found in Annex 1.

[17] Let M be matrix. The induced norm of M (denoted $\|M\|$)corresponding to a norm $\| \ \|$ on vectors is defined as: $\|M\| = \max_{X \neq 0} \frac{\|MX\|}{\|X\|}$. See Annex 7.1.1 for the existence of such a maximum.

5.4.3 A lower upper-bound

The upper-bound previously estimated holds for *any* consumption vector C. For the particular consumption vector we use in our simulations, C^e, we can find a lower upper-bound. Let us define $\kappa^{'}(\mathbf{L}, C^e)$ as:

$$\kappa^{'}(\mathbf{L}, C^e) = \frac{\|\mathbf{L}\|\|C^e\|}{\|\mathbf{L}C^e\|}$$

We found that $\kappa^{'}(\mathbf{L}, C^e)$ is also an upper-bound of the amplification of the relative variations:

$$\frac{\|\Delta P\|}{\|P\|} \leq \kappa^{'}(\mathbf{L}, C^e)\frac{\|\Delta C^e\|}{\|C^e\|} \tag{4}$$

Moreover, this upper-bound is lower than the first one: $\kappa^{'}(\mathbf{L}, C^e) \leq \kappa(\mathbf{L})$. In the ambitious scenario, this bound is equal to 1.8. Moreover, we know (see Annex 7.1.1) the existence of a vector ΔC^e such that: $\frac{\|\mathbf{L}C^e\|}{\|C^e\|} = \|\mathbf{L}\|$. Multiplying both sides of the latter inequality by $\frac{\|C^e\|}{\|P\|}$, we obtain the existence of $\|C^e\| \in \mathbb{R}^n$ such that:

$$\frac{\|\Delta P\|}{\|P\|} = \kappa^{'}(\mathbf{L}, C^e)\frac{\|\Delta C^e\|}{\|C^e\|} \tag{5}$$

Therefore, the upper-bound κ' on the amplification of relative variations is a maximum, and there does not exist any lower upper-bound.[18]

5.4.4 Monte-Carlo simulations

In order to appreciate the extent to which the upper-bound is likely to be achieved or not, we ran Monte-Carlo simulations. We first randomly sample S vectors ΔC of absolute variations:

$$\Delta C = \begin{bmatrix} \delta c_1 \\ \delta c_2 \\ \vdots \\ \delta c_n \end{bmatrix}$$

Where:

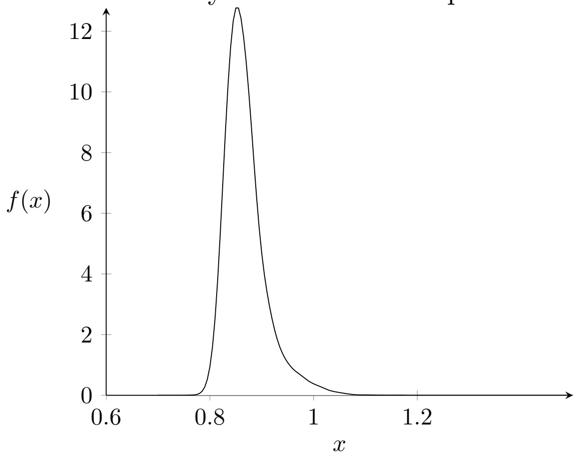
- δc_i is the absolute variation of final consumption of product i
- $\forall i \in [1, ..., n], \delta c_i \sim U[-1; 1]$
- U stands for the uniform density function
- $S = 10,000$

The kernel density estimation[19] of the distribution shows that the amplification value lies around .85 (see Figure 2). This indicates that uncertainty is reduced most of the time when simulated variations of final consumption are not necessarily of the same sign. On the other hand, if all variations are positive, that is if $\forall i \in [1, ..., n]$, $\delta c_i \sim U[0; 1]$, the amplification lies around 1.5.

[18] Since $\mathbf{L}$ is a matrix made up of positive elements, we can apply Perron-Frobenius' theorem. Thus, there exists a unique eigenvalue of $\mathbf{L}$ of greatest module, and this eigenvalue is a positive real number; equation (5) holds in the corresponding eigenspace, which is one-dimensional. Moreover, all the coefficients of any vector in this eigenspace have the same sign.

[19] The kernel is gaussian, the standard deviation of which is 0.01.

Figure 2: Kernel density estimation of amplification values



5.4.5 What conclusions to draw for our scenarios?

The analysis is a two-step analysis: first, we quantify the production variation; second, we quantify the variation in environmental impacts. As far as the first stage is concerned, the results hold for any variation, thus they are applicable to the relative variations between the two scenarios: the relative variation between production vectors is extremely likely to be smaller than the relative variation between final demand vectors. However, the second stage is not conclusive. Indeed, as there exists some negative correlation between unitary impacts and production vectors, bounds are almost uninformative.

6 Conclusion

Concerning the global-warming potential, the main scenario evaluates the impact of the French households consumption in 2030 at 6.6 tCO2e per capita. It is a significant reduction compared to 2007 (about -30%). Yet, this remains far above 1.6 tCO2e per capita, which corresponds to the average individual quota with a global 15-Gt CO_2e carbon- recycling capacity shared among 9 billion people in 2050. On the other hand, important reductions of potential impacts are to be expected from both changes in the structure of the economy (input-output analysis' main flaw), as well as new forms of exchange such as collaborative or functional economies. Both are hardly taken into account in this study. Furthermore, serious data availability issues concerning low-income trading-partner economies might lead to underestimate the impacts. Finally, in order to point at cumulative emissions effectively, trajectories issues would need to be addressed. This is a further research path.

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7 Annexes

7.1 Mathematical proofs

7.1.1 Formal construction of the induced norm

The induced norm of a matrix $\mathbf{M}$ is formally defined as:

$$\|\mathbf{M}\| = \sup_{X \neq 0} \frac{\|\mathbf{M}X\|}{\|X\|} \tag{6}$$

Let us remark that if two non-zero vectors X and Y are colinear, we have:

$$\frac{\|\mathbf{M}X\|}{\|X\|} = \frac{\|\mathbf{M}Y\|}{\|Y\|}$$

Therefore, this upper-bound can be restrained on the unit sphere, that is $\{X \in \mathbb{R}^n | \|X\| = 1\}$. Since the latter set is compact and the applied function is continuous, the upper-bound is in fact a maximum.

7.1.2 Proof of the existence of the first upper-bound

From $P = \mathbf{L}C$ and $(P + \Delta P) = \mathbf{L}(C + \Delta C)$, we know that (a) $\Delta P = \mathbf{L}\Delta C$ and (b) $C = \mathbf{L}^{-1}P$. Since by the very definition of the induced norm of a matrix, $\|\mathbf{M}X\| \leq \|\mathbf{M}\|\|X\|$, we have:

$$\|\mathbf{L}\Delta C\| \leq \|\mathbf{L}\|\|\Delta C\|$$
$$\|\mathbf{L}^{-1}P\| \leq \|\mathbf{L}^{-1}\|\|P\|$$

Using (a) and (b), we can write that:

$$\|\Delta P\| \leq \|\mathbf{L}\|\|\Delta C\|$$
$$\|C\| \leq \|\mathbf{L}^{-1}\|\|P\|$$

Multiplying the last two equations, and dividing both sides by $\|P\|\|C\|$, we obtain:

$$\frac{\|\Delta P\|\|C\|}{\|P\|\|C\|} \leq \|\mathbf{L}\|\|\mathbf{L}^{-1}\|\frac{\|\Delta C\|\|P\|}{\|P\|\|C\|} \Rightarrow \frac{\|\Delta P\|}{\|P\|} \leq \kappa(\mathbf{L})\|\frac{\|\Delta C\|}{\|C\|}$$

7.1.3 Proof of the existence of the second upper-bound

From the definition of the induced norm of a matrix, we know that $\|\Delta P\| \leq \|\mathbf{L}\|\Delta C^e\|$. Dividing both sides by $\|P\|$ and multiplying the right-hand-side by $\frac{\|\Delta C^e\|}{C^e}$, we obtain:

$$\frac{\|\Delta P\|}{\|P\|} \leq \frac{\|\mathbf{L}\|\|C^e\|}{\|P\|}\frac{\|\Delta C^e\|}{\|C^e\|} \Rightarrow \frac{\|\Delta P\|}{\|P\|} \leq \kappa'(\mathbf{L}, C^e)\frac{\|\Delta C^e\|}{\|C^e\|}$$

Now that the existence of another upper-bound has been proved that, what remains to be proved is that it is lower than the first one, i.e., $\kappa'(\mathbf{L}, C^e) \leq \kappa(\mathbf{L})$. Multiplying both sides of the inequality $\|C^e\| \leq \|\mathbf{L}^{-1}\|\|P\|$ by $\frac{\|\mathbf{L}\|}{\|P\|}$, we have:

$$\frac{\|C^e\|\|\mathbf{L}\|}{\|P\|} \leq \|\mathbf{L}^{-1}\|\|\mathbf{L}\| \Rightarrow \kappa'(\mathbf{L}, C^e) \leq \kappa(\mathbf{L})$$

7.2 Weighting import-embedded environmental impacts

In order to estimate the impact of imported products, we first had to define two clusters (i.e, ”rich countries” and ”other countries”) and then quantify, for each of the 59 products, the share of each cluster in the French imports. The cluster called ”Germany” is made of the following countries: Australia, Austria, Belgium, Canada, Denmark, Finland, Germany, Italy, Japan, Luxembourg, the Netherlands, New-Zealand, Norway, Spain, Sweden, Switzerland, the United Kingdom and the United States. The other cluster, named ”Poland”, is made up all the other countries. In order to quantify the share of each cluster, we matched the UN COMTRADE nomenclature to the Eurostat NACE rev. 1.1 nomenclature. When the matching was not possible, we simply applied the global average, that is roughly 2/3 vs 1/3 respectively. The detailed figures[20] are presented in table 8:

[20]Products which are not imported have been removed from the table in order to save on space

Table 8: Share and origins of imported goods and services (%)

Product	Share of imports		Share of cluster ”Germany”
	Final consumption	Intermediate consumption	
Products of agriculture, hunting and related services	41	7	73
Products of forestry, logging and related services	7	5	55
Fish and other fishing products; services incidental of fishing	37	43	80
Coal and lignite; peat	43	93	61
Crude petroleum and natural gas (extraction)	0	99	37
Uranium and thorium ores	0	100	99
Metal ores	0	100	30
Other mining and quarrying products	40	11	79
Food products and beverages	20	19	70
Tobacco products	75	81	92
Textiles	68	48	49
Wearing apparel; furs	69	72	29
Leather and leather products	93	99	41
Wood and products of wood and cork (except furniture); straw	58	26	52
Pulp, paper and paper products	36	40	87
Printed matter and recorded media	14	9	87
Coke, refined petroleum products and nuclear fuels	29	30	48
Chemicals, chemical products and man-made fibres	34	62	82
Rubber and plastic products	58	32	77
Other non-metallic mineral products	32	21	77
Basic metals	64	55	80
Fabricated metal products, except machinery and equipment	51	15	75
Machinery and equipment n.e.c.	60	56	85
Office machinery and computers	93	99	80
Electrical machinery and apparatus n.e.c.	61	52	60
Radio, television and communication equipment and apparatus	82	57	39
Medical, precision and optical instruments, watches and clocks	57	47	83
Motor vehicles, trailers and semi-trailers	57	49	84
Other transport equipment	69	34	84
Furniture; other manufactured goods n.e.c.	0	44	52
Electrical energy, gas, steam and hot water	1	1	100
Wholesale trade and commission trade services	0	7	67
Land transport; transport via pipeline services	3	8	67
Water transport services	23	9	67
Air transport services	37	44	67
Supporting and auxiliary transport services	1	15	67
Post and telecommunication services	5	2	67
Financial intermediation services	4	2	38
Insurance and pension funding services	1	7	67
Computer and related services	2	1	67
Research and development services	0	8	67
Other business services	1	7	67
Recreational, cultural and sporting services	4	5	67

Source: Authors’ computations