

CO₂ emissions from the economic circuit in France

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At microeconomic level, the dual labelling principle is designed to inform consumers of the CO₂ emission caused by the production, transport and distribution of the products they are buying. In an analogous manner, it is possible to associate a CO₂ content with each macroeconomic aggregate (production and imports on the supply side; consumption, investment and exports on the demand side), relying directly on the central framework of the national accounts.

In 2005, CO₂ emissions caused by economic activity on the French territory (the other greenhouse gases are excluded from the calculation) came to just over 400 million tonnes (6.7 tonnes per year per inhabitant). This is 1.3% of worldwide emissions, for a country whose economy represents 3% of world GDP and which has 1% of the world population. A third of these emissions come from the combustion of hydrocarbons (petrol, domestic fuel, gas) used by households for travel and heating. Two-thirds are emitted by the national productive system.

However, CO₂ emissions are also produced outside France due to our imports; they are actually 20% higher than the emissions from our own productive system. Conversely, foreign demand causes part of the CO₂ emitted by our productive system via exports, as well as part of the CO₂ related to our imports (since we import certain products in order to process them and, ultimately, satisfy foreign demand). Once all calculations are made, the CO₂ emissions caused by French domestic demand come to almost 550 million tonnes (9.0 tonnes per year per inhabitant), 40% of which is emitted on foreign soil. Three-quarters of these emissions are produced by household consumption expenditure, mainly on housing, transport and food; 10% are produced by general government consumer expenditure, and 15% by investment.

The quantity of CO₂ generated by household consumption clearly rises with the standard of living: the wealthiest 20% of households generate 29% of CO₂ emissions via their purchases while the most modest 20% only produce 11%. However, due to the differences in structure of their consumption baskets, the CO₂ content per euro spent is lower on average for a well-off household than for a modest one. Similarly, this content is higher for farming or blue-collar households than for executive households. Executive households nonetheless generate far more CO₂ emissions owing to their much higher consumption level. Additionally, the CO₂ content per euro spent grows with the age of the head of the family until the age of 50, and then levels off.

Bearing in mind the economies of scale in a household, the quantity of CO₂ emitted per person decreases on average with the household size. In France, one inhabitant generates an emission of 6.4 tonnes of CO₂ per year on average through his or her consumption, but this figure rises to 8.6 tonnes for people who live alone, and only comes to 4.1 tonnes for people who live in a large family.

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Integrate CO₂ emissions into the framework of the national accounts: an objective in line with the recommendations of the "Stiglitz" Commission

The national accounts were built in the middle of the last century as a conceptual framework for measuring economic phenomena and the results of their interactions. The refinement of methods and their pooling at international level have progressed constantly ever since.

And yet the central framework of the national accounts has been subjected to repeated criticism over the last few years; in particular, it has been accused of being insufficiently suited to addressing the issue of sustainable development. The Grenelle Environment Forum highlighted the need for further indicators of gross domestic product (GDP) in order to take the social and environmental dimensions into account, over and above the economic approach. Similarly, in September 2009, the Commission report on the measurement of economic performances and social progress, known as the "Stiglitz" Commission, placed the national accounts aggregates back at the heart of public debate, in order to provide a reminder of their relevance but also the limits. The authors of the report criticized the excessive focus on the GDP indicator, which measures yearly economic output on the territory, and emphasized that public debate would gain from other aggregates (some already produced by the national accounts, others which are yet to be built but which would be directly linked to their framework) being highlighted a little more.

This paper is fully in line with the Stiglitz Commission recommendations. Indeed, two of these recommendations are implemented here. On the one hand, in order to better take account of the interactions between economic activity and the environment, the Commission encourages an approach that places the emphasis on physical indicators to assess the environmental damage caused by economic activity (greenhouse gases produced in tonnes of CO₂ equivalent, for example), as opposed to a monetary measurement, considered less achievable in the short term. On the other hand, the Commission emphasizes the fact that in order to evaluate the standard of living of society, work should not be confined to producing global figures, i.e. issuing average evaluations; it insists on the need to develop new statistical information to describe - within a framework that remains consistent with the national accounts - the way macroeconomic aggregates are distributed across the population.

In France, the Observation and Statistics Department (SOeS) of the Ministry for the Ecology, Energy, Sustainable Development and the Sea, in charge of the environment satellite accounts, has undertaken a work program aiming to provide a link between the emission of a given pollution or greenhouse gas and each productive activity, with a twofold viewpoint: that of the end consumer and that of the producer. This work is conducted in conjunction with INSEE, which supplies the national accounts tables required for this task, and with the Citepa (Technical Inter-profession Centre for Studies of Atmospheric Pollution), which follows the recommendations adopted under the aegis of Eurostat and performs the physical counts of atmospheric emissions by economic activity. The first result of this program was the publication (Pasquier, 2010) of results on the one hand retracing the respective responsibilities of actors (households, businesses and general government) and activities (production, consumption) in CO₂ emissions in France, and on the other hand identifying the level of CO₂ emissions associated with French domestic demand, including those emitted abroad via French imports.

As regards the second recommendation, INSEE possesses many years' worth of thematic household surveys describing the diversity of individual situations (surveys on tax and social income, family budgets, housing, wealth, income and living conditions...). However, it is far from simple to bridge the gap between these microeconomic data - measurement of which involves a level of uncertainty because they come from sample surveys and may be affected by the response behaviour of the households surveyed - and the macroeconomic data of the national accounts. INSEE has undertaken a coherency program of this type. A first step was

completed in 2009 with the publication (Accardo et al. 2009, Fesseau et al. 2009) of the breakdown over a reference year of income and consumption, in the sense of the national accounts, into four household categories (standard of living quintile, family composition, age and socio-professional category of the reference person).

Bringing together these two recent statistical outputs, we propose to show that it is possible, basing ourselves directly on the central framework of the national accounts, to give a detailed description of the relationship between economy and environment as regards CO₂ emissions. This description can provide a response to several questions at the same time, in a consistent manner from the point of view of the accounts. Which productive activities emit CO₂ in France and in what proportion? What quantities of CO₂ emissions in the atmosphere can be linked to the various items in final demand (consumption, investment, exports)? Given that a share of the goods and services absorbed by the French economy is imported, what proportion of CO₂ emitted to satisfy French domestic demand is actually emitted abroad? Ultimately, what is the balance of CO₂ emissions linked to our foreign trade? Last, do the quantities of CO₂ emissions generated by French household consumption differ from one category of household to the next, or are they simply proportional to the weight of each category in total consumption?

France in the world: 3% of GDP, 1.3% of CO₂ emissions and 1% of the population

In 2005, CO₂ emissions linked to economic activity in the world were in the region of 32 billion tonnes (*Table 1*). Just under a quarter of emissions were from North America (including a little under a fifth from the USA), just under a quarter from Europe, Russia and the other countries of the Commonwealth of Independent States (including 13% from the 27 countries of the European Union), and slightly more than a third from Asia (including 18% from China). The rest comes in more or less equal proportions from the Middle East, Latin America and Africa.

These CO₂ emissions have constantly grown over time: in the space of 15 years they have risen by one-third (*Box 1*). This global increase has gone hand in hand with the ascension of the emerging countries, itself linked to the globalization of the economy. Between 1990 and 2005, emissions from Asia multiplied by 1.8 (2.3 for China) (*Table 1*). Those of North America increased by 20%. European emissions fell by 15%, because the moderate growth (5%) recorded in Western Europe was compensated for by a sharper fall in the countries of Central and Eastern Europe, following the restructuring of their economies. Last, the emissions from Russia and the CIS countries fell by around 30%.

In terms of both level and trend, this breakdown of CO₂ emissions linked to economic activity is clearly correlated with the gross domestic product of the countries. Expressed in purchasing power parity, the GDP of North America, that of Europe (including Russia and the other CIS countries), and that of Asia represented respectively one-quarter, one-quarter (including 20% for the European Union) and one-third (including 15% for China) of world GDP in 2005. The correlation between GDP level and CO₂ emission thus appears to be strong, although not total: it also depends on the intensity with which the economies use fossil fuels in their production processes (particularly electricity) and consumption (particularly petrol for travel, and domestic fuel and gas for heating).

In this world landscape, France, representing 1% of the world population, generates 3% of the world's GDP and 1.3% of the planet's CO₂ emissions. These figures synthetically reflect a double reality. On the one hand, France is one of the very advanced economies in terms of economic development. On the other hand, its intensity of CO₂ emission per inhabitant, whilst higher than the average across the globe, is nonetheless lower than that of many

Does a rise in standard of living necessarily imply a rise in pollutant emissions?

One of the fundamental issues in the notion of "sustainable growth" is knowing whether a rise in the standard of living necessarily leads to an increase in the degradation of our natural capital in the form of growing pollutant emissions.

1. The hypothesis of an environmental Kuznets curve

In the 1950s, economist Simon Kuznets believed that he could demonstrate a link in the shape of an inverted "U" between GDP per capita levels and inequalities in income: he believed that in the pre-industrial economies, economic progress would go hand in hand with an increase in inequalities in the standard of living, but that over and above a certain development level, the move to a post-industrial society would be accompanied by a reduction in inequalities.

Further to empirical work aiming to compare the level and trends in emissions of certain pollutants with the level of wealth of a country (cf. for example, Grossman and Kruger, 1994), a similar hypothesis, commonly referred to as the "Kuznets environmental curve" was formulated by certain economists of the environment (cf. Beckerman 1992).

This highly controversial hypothesis is based on the following reasoning. At very low income levels, the quantity and intensity of man-made environmental damage is limited to the impact of subsistence economic activities. As agriculture becomes more intensive, the population becomes more urbanised and industry takes off, the accelerated extraction of natural resources and the large-scale discharge of pollutants accentuate pressure on ecosystems. However, when material living conditions have sufficiently improved, individuals are able to devote part of

their monetary income in favour of the environment. At that stage, society has accumulated enough capital to be able to divert part of its investments into techniques aiming to diminish the impact of production processes on the environment. All in all, gains in efficiency could be great enough to reverse the direction of the relationship between economic growth and environmental degradation.

This inverted U shape is also said to be the indirect consequence of the increase in individual income: this has an effect via a modification in the demand function in favour of more environmentally-friendly products. Once a certain standard of living has been exceeded, environmental concerns are likely to become greater, with the environmental good becoming a sort of "superior good" in the consumer's utility function, meaning a good with an income elasticity greater than 1 (like health or recreation). As their preferences push them to buy "greener" products, consumers would therefore have a decisive influence on trends in the economic structures through their market power, and industries would have an incentive to improve their products in such a way that pollutant emissions are reduced.

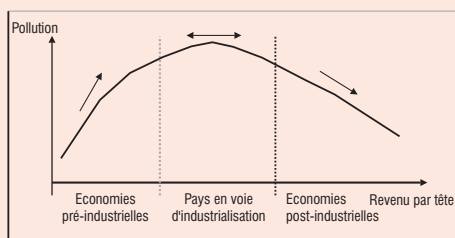
2. Empirical results from international comparisons over time

A large number of empirical studies have attempted to confirm the hypothesis of the Kuznets environmental curve. Some have concluded that such an inverted U-shape curve did exist for certain local pollutants, but others have questioned how robust these observations are from an econometric point of view (see Meunier, 2004, for a review of the literature on the subject).

However, for global pollutants such as CO₂, no such curve has been observed to date for the world economy as a whole (*graph 2*). In fact, after the post-war boom years in the industrialized countries, the world economy is now marked by the trajectory of the emerging countries, and the hypothesis therefore does not seem very credible, at least over the short to medium term.

Over the longer term, France might appear to confirm the existence of an environmental Kuznets curve, at first sight: emissions did indeed level out as of the early 1970s, and then decrease through the 1980s under the effects of the implementation of the nuclear electricity programme.

1. The hypothesis of an environmental Kuznets curve



Source : CAIT, World Resources Institute.

Box 1 ()

From the 1990s, however, CO₂ emissions increased again (moderately) as the potential for reductions in CO₂ from electricity production reached the limit of what could be achieved by switching from thermal to nuclear power plants (although there are still some possibilities for reducing the CO₂ intensity of electricity production in France by replacing coal-powered by gas-fired plants and by developing wind power). In an extended Europe including Russia, CO₂ emissions also declined over the first half of the 1990s due to the economic collapse of the former Soviet-bloc countries. They have levelled out since.

In addition, the emissions generated from a given territory only provide a partial view of any Kuznets environmental curve. In a broader vision, foreign emissions induced by domestic demand (taking account of foreign trade) should

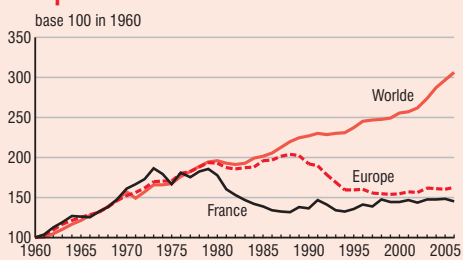
also be taken into account. Unfortunately, we do not currently have evaluations of this type over the long term.

3. Contribution and limits of this study

The present study provides a different insight into a "cross-section" of the French population at a given moment in time. In particular, it shows that in the case of CO₂, income level-related effects very clearly prevail over effects relating to the composition of the consumption basket. The quantity of CO₂ induced by the consumption of a category of household therefore grows very clearly as its consumption level increases. Although the changes to the composition of the basket of goods and services that accompany the rise in standard of living do tend to decrease the average carbon intensity of household expenditure, this effect remains weak.

To be more precise, we would also need to be able to measure, on an individual level and for a particular product (for example a fruit), the varying propensity of a household to opt for a "low-emission, ecological" product (seasonal fruit or not, imported from a remote country or not) according to their standard of living. For lack of available statistical information, the study presented here cannot address phenomena of this type (it allocates an average CO₂ content to food products without going into finer detail). It therefore cannot measure their aggregate impact on CO₂ content of the consumption of a given household category.

2. Comparison of the emissions of France, Europe and the World since 1960



Source : CAIT, World Resources Institute.

comparable developed countries (USA and other Western European countries). This is mainly due to the fact that 90% of the electricity produced in France relies on non-CO₂ emitting technologies (75% to 78% nuclear energy, 11% to 13% hydroelectric energy), while in the world overall, only one-third of electricity is produced without the use of hydrocarbons (coal, gas and oil). In France, "base" electricity production¹ is de facto of nuclear origin, placing this country in a very singular position compared with other countries (*Graph 1*).

Household heating and travel generate one-third of CO₂ emissions on the French territory, and the productive system two-thirds

In 2005, around 410 million tonnes of CO₂ emitted on the French territory were generated by economic activity². These emissions have two origins: final consumption of hydrocarbons by households, and productive activity on the territory (*Graph 2*).

1. As opposed to "peak" production required to satisfy demand during consumption peaks. "Base" production includes electric output means that operate more than 5,000 hours per year.

2. This figure only concerns CO₂ emissions. Of the six main greenhouse gases (CO₂, but also methane (CH₄), nitrogen protoxide (N₂O) and fluorinated gases), it reached 550 million tonnes of CO₂ equivalent in 2005

Table 1. CO₂ emissions, GDP and population in the world

	CO ₂ Emissions				PIB		Population	
	1990 (Mt)	2005 (Mt)	Proportion of CO ₂ linked to hydrocarbons (%)	Trend 1990-2005 (%)	2005 in share (%)	Trend 1990-2005 (%)	GDP PPP 2005 in share ¹ (%)	2005 en share (%)
North America	5 723	6 952	97,4	+ 21,5	21,7	+ 62,7	23,6	6,7
<i>including USA</i>	<i>4 934</i>	<i>5 907</i>	<i>98,6</i>	<i>+ 19,7</i>	<i>18,5</i>	<i>+ 62,6</i>	<i>19,8</i>	<i>4,6</i>
Europe, Russia and CIS excluding Russia	8 299	6 949	96,3	- 16,3	21,7	+ 38,5	27,1	13,5
<i>including UE27</i>	<i>4 266</i>	<i>4 147</i>	<i>96,0</i>	<i>- 2,8</i>	<i>13,0</i>	<i>+ 44,8</i>	<i>21,1</i>	<i>7,6</i>
<i>including Germany</i>	<i>996</i>	<i>837</i>	<i>97,4</i>	<i>- 16,0</i>	<i>2,6</i>	<i>+ 33,8</i>	<i>4,0</i>	<i>1,3</i>
including France	375	406	95,9	+ 8,1	1,3	+ 37,9	3,0	1,0
<i>including Italy</i>	<i>422</i>	<i>481</i>	<i>94,3</i>	<i>+ 14,1</i>	<i>1,5</i>	<i>+ 26,3</i>	<i>2,8</i>	<i>0,</i>
<i>including Spain</i>	<i>229</i>	<i>369</i>	<i>92,7</i>	<i>+ 61,2</i>	<i>1,2</i>	<i>+ 66,7</i>	<i>1,8</i>	<i>0,7</i>
<i>including UK</i>	<i>571</i>	<i>543</i>	<i>98,5</i>	<i>- 5,0</i>	<i>1,7</i>	<i>+ 53,5</i>	<i>3,1</i>	<i>0,9</i>
<i>including Russia</i>	<i>2 273</i>	<i>1 606</i>	<i>97,7</i>	<i>- 29,4</i>	<i>5,0</i>	<i>+ 5,3</i>	<i>2,5</i>	<i>2,2</i>
Asia	6 062	11 023	85,0	+ 81,8	34,5	+ 170,9	35,6	55,4
<i>including Japan</i>	<i>1 108</i>	<i>1 258</i>	<i>96,6</i>	<i>+ 13,5</i>	<i>3,9</i>	<i>+ 26,3</i>	<i>6,3</i>	<i>2,0</i>
<i>including China</i>	<i>2 545</i>	<i>5 843</i>	<i>87,3</i>	<i>+ 129,6</i>	<i>18,3</i>	<i>+ 416,9</i>	<i>14,6</i>	<i>20,3</i>
<i>including India</i>	<i>723</i>	<i>1 358</i>	<i>84,6</i>	<i>+ 87,9</i>	<i>4,2</i>	<i>+ 185,1</i>	<i>6,1</i>	<i>16,9</i>
Africa	1 121	2 124	42,0	+ 89,6	6,6	+ 77,0	3,8	14,2
Middle East	663	1 316	95,8	+ 98,4	4,1	+ 100,3	2,5	2,9
South America	1 555	2 218	42,9	+ 42,7	6,9	+ 76,4	6,0	7,0
Océania	287	422	97,8	+ 46,8	1,3	+ 78,9	1,3	0,4
International and air exchanges	649	959	100,0	+ 47,7	3,0	///	///	///
Total	24 359	31 962	85,4	+ 31,2	100,0	+ 84,5	100,0	100,0

Comments:

- CO₂ emissions cover energy combustion, industrial processes and "other" emissions. Energy combustion alone accounts for 85% of world emissions: more than 95% of all emissions in North America, Europe, the Middle East and Oceania, 85% of those in Asia, but only 42% of those in South America and Africa. The "other" category includes wood combustion linked to deforestation and forest fires; its contribution is large in Africa and South America. For temperate forests, the net emissions from vegetation are considered here as null.

- the growth in emissions from France over the period 1990-2005 is lower if the 6 main greenhouse gas emissions are considered: - 0.3% against + 8.1% for CO₂ only.

- GDP is expressed in purchasing power parity: this allows us to judge the production levels between countries, neutralizing in this comparison everything linked to the differences in general price level.

Source: SOeS, according to IEA/OECD

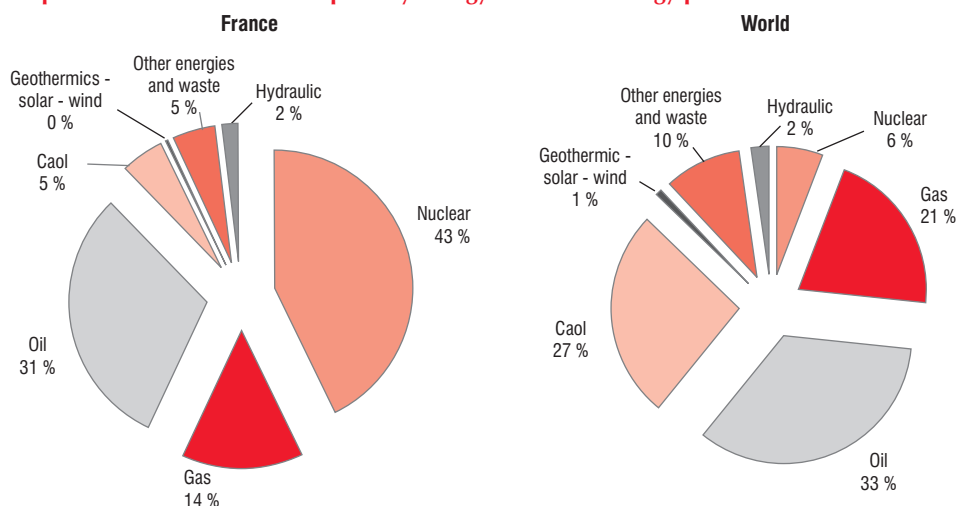
The former come to one-third of the total, that is, 130 million tonnes. Half of these emissions correspond to fuel burned by motorists, and half to the domestic fuel and gas used by households for their heating (and, far more marginally, for cooking).

The latter mainly come from fossil fuels (oil, gas, coal) used on production sites, as well as a residual proportion (less than 5%) of CO₂ emitted during specific industrial processes. This is the case, among others, in the mineral non-metallic products industries (cement, glass, tiles and bricks), for which a non-negligible proportion of CO₂ emissions comes from decarbonation (transformation, under the effect of heat, of the carbon contained in a non-energy raw material, such as lime, into CO₂). These 280 million tonnes emitted can be broken down into segment of activity by means of evaluations of emission factors on the production sites, by product. The CO₂ emissions of the primary sector (agriculture) are low: 11 million tonnes, or 4% of the total³. Those of the secondary sector (industry and construction), which only represent 20% of value-added in France, are preponderant: 180 million tonnes, which is 64% of the total. They are concentrated in the intermediate goods⁴ and energy industries (respectively 75 and 65 million tonnes). By definition, many of these activities require the intensive use of

3. Agriculture occupies a far more important position when all the greenhouse gases are counted, as it is at the origin of the majority of methane (CH₄), due to cattle rearing, and nitrogen protoxide (N₂O), resulting from the use of fertilizers.

4. Materials from mining, wood and wooden goods, paper/cardboard, chemicals, plastics, non-metallic minerals, and metals.

Graph 1. Share of the different primary energy sources in energy production



Source: IEA (2007).

fossil fuels: metallurgy, chemistry, cement manufacture, coking and refining, production of gas and heat - and of electricity in traditional plants using fossil fuels. Last, the productive activity of the tertiary sector, which generates 78% of value-added, causes the emission of 89 million tonnes of CO₂, 32% of the total. Fuel consumption by the transport service industry alone (road transport in particular) produces 38 million tonnes. The other service industries also emit (retail, services to enterprises and individuals, administrative services) because they need to heat their premises and in certain cases have company cars.

Reassign emissions by the productive system to final demand in order to calculate CO₂ contents by product

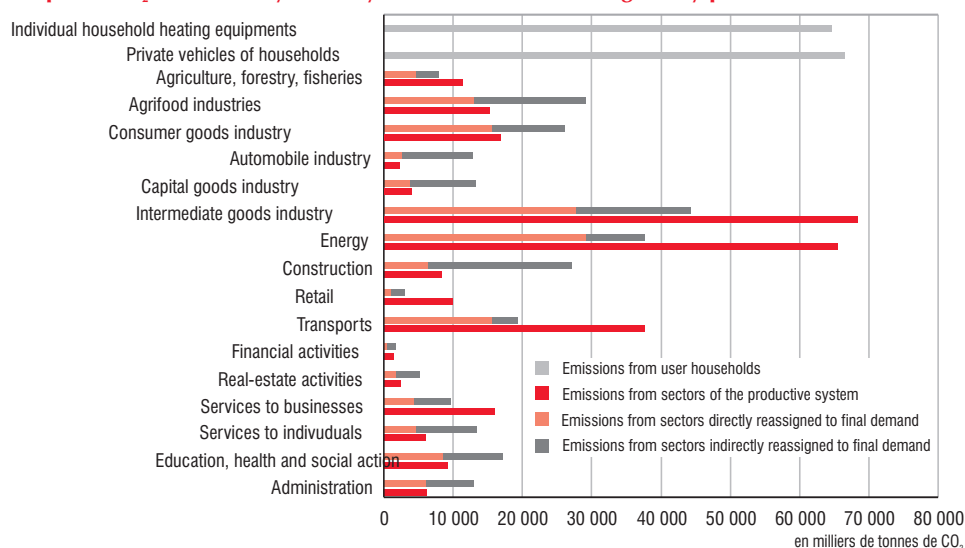
Evaluations of CO₂ emissions necessarily involve the mobilization of scientific and technical knowledge related to each manufacturing process, by type of good or service. An evaluation of their quantities by type of productive activity is thus the most natural method. However, this method alone is not sufficient to give an adequate description of the impact of economic activity on the environment via these CO₂ emissions.

Ultimately, all production meets a final demand, either directly (for example a car) or indirectly via an intermediate demand (for example the steel and glass used to make a car). This is the whole point of using the framework of the national accounts to describe the entire economic circuit of supply and demand. This accounting framework can precisely reassign the CO₂ emissions caused by productive activities to the final demand they will satisfy, either directly or indirectly (Box 2).

In practical terms, once all calculations are made, out of the 280 million tonnes emitted in 2005 by productive activity on French soil, around half corresponds to products destined for intermediate use and can therefore be reassigned to the final demand for other products. Once this reassignment is complete, we obtain the description of quantities of CO₂ emitted on the territory and generated by the final demand for each good or service.

In the first place, the three industries of activity that emit the most CO₂, those of intermediate goods, energy and transport, are precisely those for which the proportion of emissions to

Graph 2. CO₂ emissions by industry versus emissions reassigned by product (2005)



How to read the graph:

- Households emit 67 million tonnes of CO₂ by using their cars (fuel combustion); they emit 65 million tonnes by using their private heating systems (combustion of domestic fuel, gas, etc);
- the hydrocarbons burned for collective heating systems are counted here (without being isolated) in the CO₂ emissions generated by final demand for "energy";
- the construction industry generates 8.5 million tonnes of CO₂;
- final demand for construction generates 27 million tonnes of CO₂, of which 6.5 come directly from the construction industry and 20.5 from other industries in which the products are used as intermediate consumption in the production process leading to this final demand.

Sources: Service de l'observation et des statistiques (SOeS), Insee.

be reassigned is high, to the extent that final demand for their products generates (direct and indirect) emissions that are reduced by 40 to 50% (*Graph 2*). This result can easily be explained for the first two, which by definition correspond to activities (for example the manufacture of chemicals or electricity) focused on intermediate demand from other enterprises for the needs of their own production (a drug, a car). With regard to transport, this result stems from the fact that a large proportion of activity is the transport of goods, ultimately paid for by the end user of the goods transported in the form of transport margins. This reasoning also applies to retail, although it emits less (10 million tonnes, two-thirds of which are to be reassigned to goods sold by the retailer). The services to companies segment which includes, for example, legal services or telecoms services, emits 16 million tonnes, but by the same reasoning, only 10 million tonnes generated by final demand for the services it produces.

Secondly, and conversely, the CO₂ emissions caused by products mainly destined for final demand are substantially higher than the quantities of CO₂ emitted by the corresponding industries. This is - spectacularly - the case of industrial finished products (consumer goods, automobiles, capital goods and construction), for which CO₂ emissions are multiplied by factor 3 - and even 5.5 for automobiles - when the quantities of CO₂ emitted upstream on the territory to produce all the intermediate goods required for their manufacture are reassigned. To a lesser extent it is also the case for services mainly focused on final demand (services to individuals, health and education services, administrative services).

The international loop: domestic final demand also generates CO₂ emissions abroad

This reassignment of the quantities of CO₂ emitted on the national territory, from the emitting industries to the end products for which the activity of these industries is destined, is the macroeconomic analogue of the dual labelling which, at microeconomic level, informs consumers of the CO₂ emission associated with the production, transport and distribution of the product they are buying. One of the aims is to make consumers aware that the actual cost of the end products purchased goes beyond their market value, because it also includes "ecological costs" (in this case, CO₂ emissions). These ecological costs are usually hidden because the economic actors do not take them into account⁵.

However, in order to be complete, this dual labelling cannot be confined only to the quantities of CO₂ emitted on the national territory. As the French economy is open to the outside world, some of the products used in France are imported and the manufacture of these imported products has also generated CO₂ emissions, abroad this time. Counting the CO₂ emissions induced by final demand thus involves adding all these "imported" emissions of various origins to the previously mentioned domestic emissions. In the case of an imported good directly purchased by the end consumer or investor (a computer produced in Asia, for example), it is necessary to count the emissions from the corresponding industry (computer production in Asia), but also those upstream, linked to the manufacture of intermediate goods used to make the end product (electronic components) and those downstream, linked to delivery (transport, if it is also imported, i.e. transported by a foreign carrier). If an end good produced on French soil is purchased (an Airbus purchased by an airline company, for example), it is necessary to add the imported emissions to the domestic emissions generated by this purchase if the production of this good by a resident company required the upstream use of imported intermediate products (fuselage items made in Germany, in this example).

The evaluation of the quantities of CO₂ emitted abroad because of our imports requires knowledge not only of the details of the products imported, but also of their origin by country and the structure of the productive system of each of these countries. Indeed, this structure may be more or less CO₂ intensive, depending in particular on the status of fossil fuels in it.

The result of this evaluation is spectacular: the quantity of CO₂ emissions induced abroad by our imports is 339 million tonnes, which is 20% higher than the emissions generated by productive activity on our territory (*Graph 3*). Quite logically, 95% of them are concentrated in industrial products. If this evaluation had been done on the assumption that the production structure⁶ of our partners was similar to ours, these imported emissions would be more than 40% lower - 195 million tonnes. This illustrates the fact that France is an exception, given the scale of its nuclear production: most of the time, the CO₂ content of a good or service produced in France will be lower than that of the same product from abroad, owing to the electric energy used to produce it⁷.

5. These ecological costs are measured here in physical quantities (tonnes of CO₂). If we were capable of valuing them, the final demand could then be estimated at a global cost higher than the market cost. The difference could then legitimately be interpreted as a transfer of capital from nature to the economy, since this cost reflects a concomitant deterioration of the natural capital (Vanoli, 1995).

6. This production structure is meant in the broad sense here; in particular, it includes the "energy mix", which describes the respective weight of the different primary energy sources used by the productive system of a country.

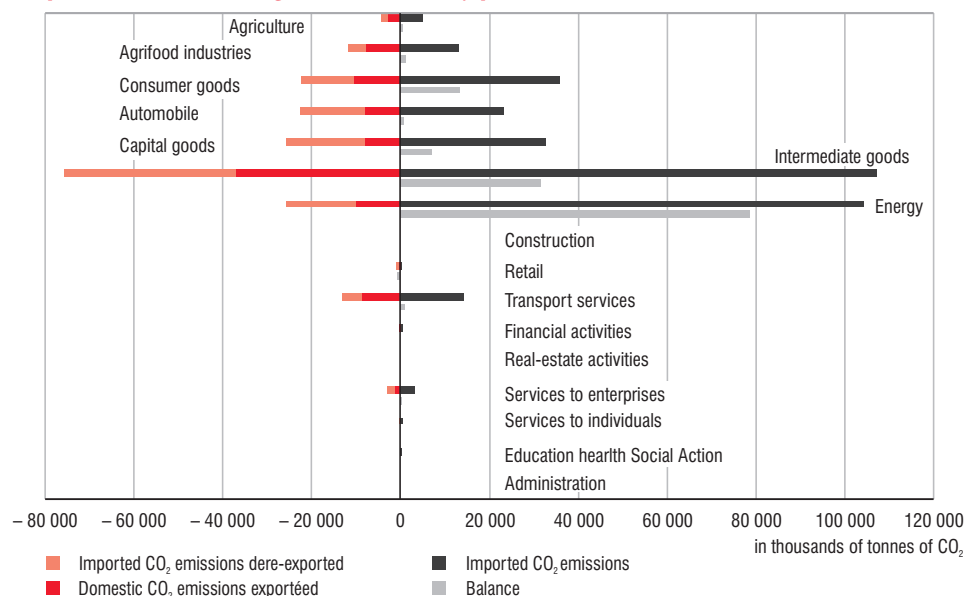
7. Bearing in mind this French singularity, i.e. the major share of nuclear energy in electricity production, it may come as a surprise that the overload of emissions linked to products imported from countries with more carbon-intensive energy mixes is not even greater. The order of magnitude of the amount of CO₂ emissions induced by our imports is, however, correct (for further details on the sources used, see box, The Leontief matrix at the service of the environment). Indeed, the majority of our imports concern industrial goods, whose CO₂ content, even in France, is much higher than that of agricultural goods and most services. Furthermore, these imports of goods assume that they are transported to France, with the transport service being a big CO₂ emitter.

While it is absolutely necessary to include the CO₂ emissions produced abroad in the calculation of CO₂ content in our final demand, it should nonetheless be remembered that this final demand includes a foreign demand. In other words, some of the CO₂ emissions - those linked to exports - must be reassigned to the non-resident economic agents: in the same way that the final demand of French households and companies located in France is at the origin of CO₂ emissions around the world, some of the emissions from our productive system are due to the demand from our partners. The quantity of CO₂ generated by French exports comes to 205 million tonnes; 95 million are emitted on the French territory and 110 million are emitted abroad (because of the content in imports of these exports) (*Graph 3*). 70% of these 205 million tonnes are linked to exports of products from the manufacturing industry, including 35% of intermediate goods.

All in all, in 2005, while 410 million tonnes of CO₂ (6.7 tonnes per year per inhabitant) were emitted on French territory owing to economic activity, domestic final demand actually generated the emission of almost 550 million tonnes of CO₂ (9.0 tonnes per year per inhabitant⁸), almost 60% in France and more than 40% abroad (*Graph 4*).

This domestic final demand covers three elements: household consumption expenditure, that is, the goods and services households buy for their own use and in so doing quit the productive circuit; general government consumption expenditure, that is, the goods and services financed by public authorities and which benefit either households taken individually (expenditure known as individualizable: public education services, medication and health financed by the social security...) or the national authorities taken together (expenditure

Graph 3. Balance of foreign trade of CO₂ by product (in thousands of tonnes, 2005)

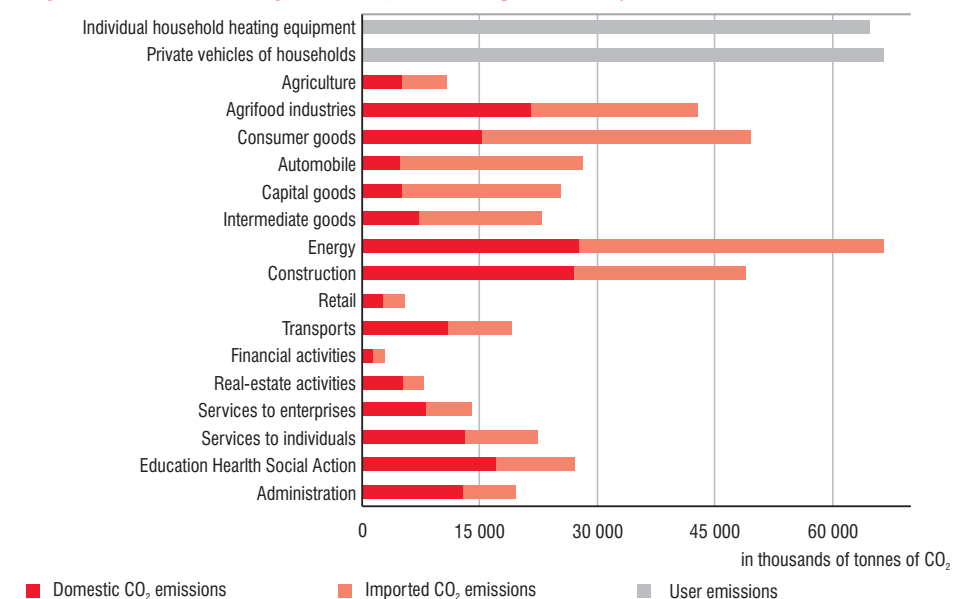


How to read the graph: the CO₂ emitted abroad because of our imports of intermediate goods comes to 107 million tonnes; the CO₂ emissions generated by our exports of intermediate goods come to 71 million tonnes, of which 37 million are emitted on the national territory and 34 million emitted abroad via the imports required to produce these intermediate goods; all in all, the CO₂ content of foreign trade in intermediate goods is a net import of 32 million tonnes of CO₂.

Sources: Service de l'observation et des statistiques (SOES), Insee.

8. This figure only takes CO₂ emissions into account. It would need to be increased by about 25% to 30% (or 11 to 12 tonnes of CO₂ equivalent per year per inhabitant) to obtain a figure for all the greenhouse gases.

Graph 4. Domestic and imported CO₂ emissions generated by domestic final demand (2005)



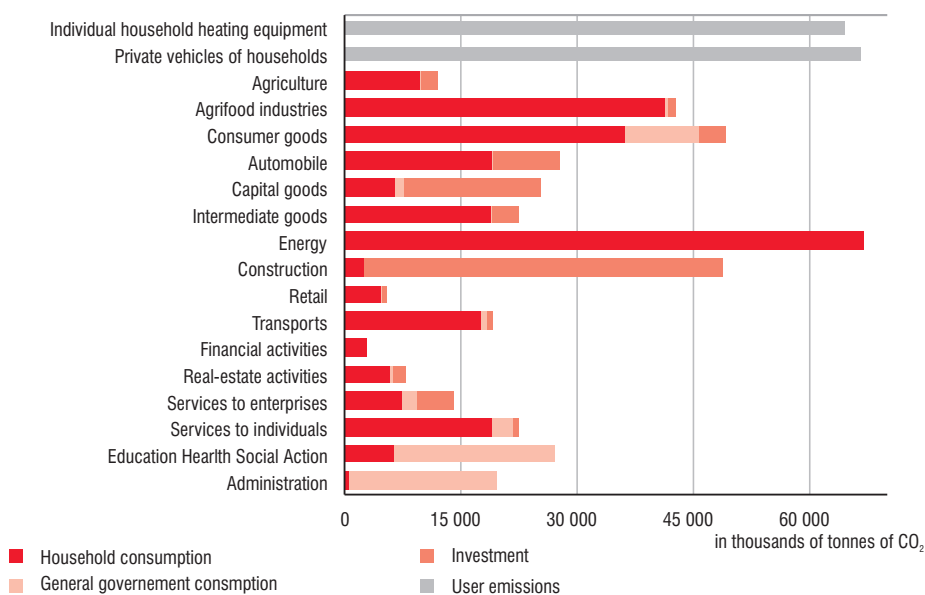
How to read the graph: the final demand for construction generates 49 million tonnes of CO₂, of which 27 million emitted by the domestic productive system and 22 million emitted abroad via the imports of products used to meet this final demand.
 Sources: Service de l'observation et des statistiques (SOeS), Insee.

known as collective: justice, security, general administrative services...); and gross capital formation, that is, the proportion of output which is invested in the productive system in order to produce other goods and services over the following periods. The CO₂ emissions generated by domestic final demand are 75% ascribable to household consumption expenditure, 10% to general government consumption expenditure, and 15% to investment, while their respective proportions in GDP are 55%, 25% and 20%.

Energy products alone account for just over one-third of emissions generated by household consumption in France. More specifically, added to the 130 million tonnes directly linked to the combustion of hydrocarbons by households for heating (domestic fuel, gas), there are 65 million tonnes generated by final consumption of energy, corresponding to the emissions that take place upstream in France and abroad to produce and transport the energy consumed.

The consumption of food generates 55 million tonnes of emissions (Graph 5). 125 million tonnes are generated by industrial goods, of which 35 million for investment (most capital goods and a proportion of automobiles) and the rest by consumption. 75 million are linked to market services, of which almost 20 million to the consumption of transport services. 45 million are linked to the consumption of health services, education and administrative services, the vast majority of which are financed by the government. Last, 45 million are linked to investment in construction.

Graph 5. CO₂ emissions generated by the various elements in domestic final demand (2005)



How to read the graph: the final demand for construction causes 49 million tonnes of CO₂, of which 46 million emitted for investment and 3 million for household consumption.

Sources: Service de l'observation et des statistiques (SOeS), Insee.

The wealthiest households emit two-and-a-half times more than the most modest households

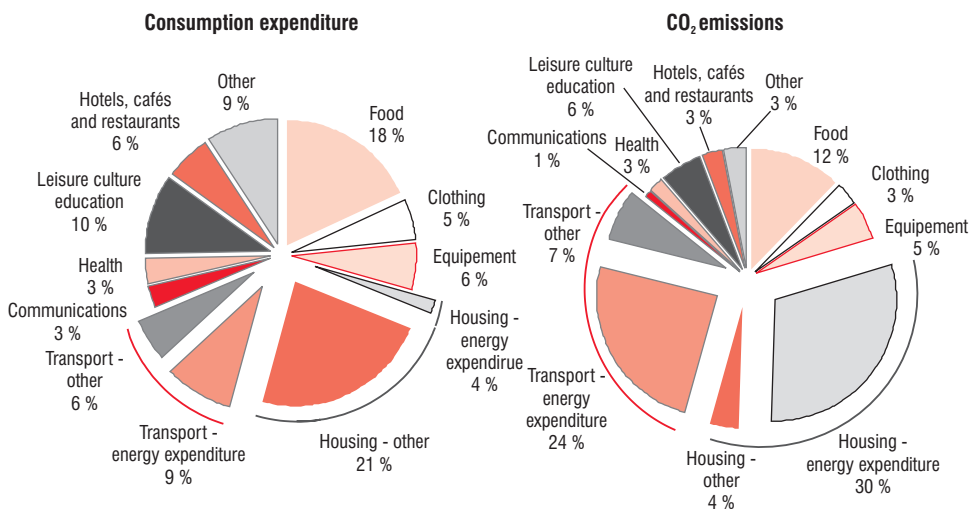
The CO₂ emissions generated by household consumption expenditure, broken down above into major types of goods and services consumed, can also be described by major consumption functions, restricted to all the ordinary households in Metropolitan France.

In monetary terms, three main consumption items share 57% of household expenditure: housing represents 25% (of which 4% for charges including heating expenses), food (at home) 18% and transports 14% (*Graph 6*). In terms of CO₂ emissions, the share of these same three items rises to 78%: housing increases to 34% (including 30% for charges alone) and transport to 31%. This result is not surprising given that households devote most of the energy they buy directly to heating (domestic fuel, gas, electricity) and travelling (fuel). Conversely, expenditure on leisure and culture, along with those on hotels, cafés and restaurants, which come to 15% of the total consumption budget, only generate 9% of CO₂ emissions.

On the basis of the recent publication by INSEE, over a reference year, of the breakdown of consumption according to four broad types of household categories (standard of living quintile, family composition, age and socio-professional group of the reference person), one more step can be made towards analysing and estimating the quantities of CO₂ induced by the purchases of each category.

The quantity of CO₂ induced by the consumption of a category of households clearly grows as the standard of living rises: the purchases of the wealthiest 20% of households induce 29% of CO₂ emissions, while the most modest households induce only 11% (*table 2*). This ratio of 1 to 2.7, however, is a little lower than the ratio of 1 to 3.4 that characterises their

Graph 6. Breakdown by major consumption item of household consumption versus related CO₂ emissions



The classification used is that of COICOP - Classification of Individual Consumption by Purpose.
Source: IFEN, INSEE.

respective consumption levels, meaning that CO₂ content per Euro spent⁹ decreases as the standard of living rises (graph 7a).

This reduction in differences between household categories when looking at the emissions generated by their expenditure can easily be explained: although the proportion of housing costs in the consumption budget remains pretty much the same whatever the standard of living (around one quarter), within this item, the share dedicated to charges, including heating expenses involving particularly high CO₂ emissions, is greater at the lower end of the range than at the higher end; it amounts to 9% of the budget for households in the first quintile, against 4% for those in the last one. Conversely, the share of expenditure dedicated to recreation and culture, and to hotels, cafés and restaurants, items with low CO₂ emissions, increases as the standard of living rises (11% for modest households, against 18% for well-off households).

When comparing on the basis of the socio-professional category of the reference person, executives give rise to the largest quantity of CO₂ emissions per household, once again due to the simple fact that they have a higher consumption level (table 3). However, the CO₂ content per euro spent for the household of a farmer or labourer is greater than that for a management-level household (respectively 32% and 18%) (Graph 7b). The other households (intermediate professions, employees, self-employed) fall somewhere in the middle. These differences can be explained by the same reasons as those behind the differences observed according to the standard of living.

The situation is more complex when it comes to the age of the reference person. Although CO₂ content per euro spent does grow moderately until the 50-59 age group (for which it is 12% higher than for the under 30s), it then levels out (Graph 7c). This particular profile is the

9. The expression "CO₂ content per euro spent" should not be over-interpreted. In this case, it refers to an average calculation of the ratio of the quantity of CO₂ emissions induced by a category of household to the amount of their aggregate consumption expenditure in euros. This calculation can therefore highlight effects relating to differences in the structure of the basket of consumption per category, with each of these structures itself only being observed as an average of all the households in a given category. It follows that a calculation of this type obviously does not mean that if one extra euro is spent by a household in a given category, then it will induce the corresponding quantity of CO.

Table 2. CO₂ emissions structure by standard of living quintile

	Q1	Q2	Q3	Q4	Q5	Total
CO2 emissions(Mt)	41,7	59,9	74,9	89,0	110,7	376,2
CO ₂ emissions (tonnes per household)	8,3	11,9	14,9	17,7	22,0	14,9
CO ₂ emissions (tonnes per household)	3,6	5,0	6,3	7,4	9,7	6,4
Share of emissions according to category %	11,1	15,9	19,9	23,7	29,3	100,0
Food and non-alcoholic drinks	12,6	12,1	11,4	10,9	10,5	11,2
Alcoholic drinks and tobacco	1,1	1,2	1,1	1,1	1,1	1,1
Clothing and footwear	2,5	2,8	2,9	3,2	3,0	3,1
Housing	43,4	37,0	34,0	32,2	31,5	34,1
<i>including electricity, gas and other fuels</i>	<i>39,2</i>	<i>33,4</i>	<i>30,4</i>	<i>28,3</i>	<i>26,8</i>	<i>30,1</i>
Furniture, cleaning items	3,5	4,2	4,5	4,9	6,5	5,0
Health	2,6	2,5	2,1	1,9	1,8	2,1
Transports	25,3	29,8	32,8	33,2	30,9	31,2
<i>including vehicle use expenditure 20,6</i>	<i>20,6</i>	<i>23,8</i>	<i>26,8</i>	<i>26,0</i>	<i>23,2</i>	<i>24,5</i>
Communications	1,0	0,9	0,8	0,8	0,7	0,8
Leisure and culture	3,9	4,6	4,9	5,4	6,2	5,3
Education	0,2	0,2	0,2	0,3	0,3	0,3
Hotels, cafés and restaurants	1,5	2,1	2,4	3,1	3,9	2,8
Other goods and services	2,3	2,6	2,7	2,9	3,6	2,9
	100,0	100,0	100,0	100,0	100,0	100,0

Sources : SOeS, Insee.

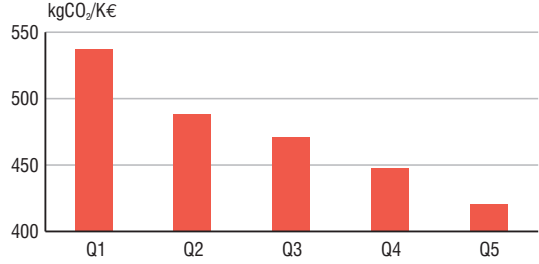
result of a twofold phenomenon. On the one hand, the weight in the household consumption budget of food and of housing-related costs (including heating expenditure) - two items with high CO₂ content - grows with age, while that of leisure and culture, and of hotels, cafés and restaurants - with low CO₂ content - decreases (*Table 4*). These items therefore contribute to increasing the average intensity of emissions over the whole lifetime. On the other hand, while households dedicate about 16% of their consumption budget to transport - an item with high CO₂ content - until around the age of fifty, this proportion diminishes distinctly thereafter, to 12.5% for the 60-69 age group and to 7.5% for the over 70s. The transport item therefore offsets the items mentioned above, with the overall outcome being that the intensity of emissions from consumption expenditure increases over the first part of our life and then levels out.

This trend in the intensity of consumption-related CO₂ emissions according to the age of the head of the family must be interpreted with caution. In this case, we are making a comparison between the consumption behaviour of different generations at the same date, without being able to differentiate between age and generation-specific effects. For example, the tendency of the elderly to emit less CO₂ on account of the transport item could be explained by less of a taste for, and less of a need to travel after a certain age, or to a less pronounced travel habit among generations born prior to the 1930s.

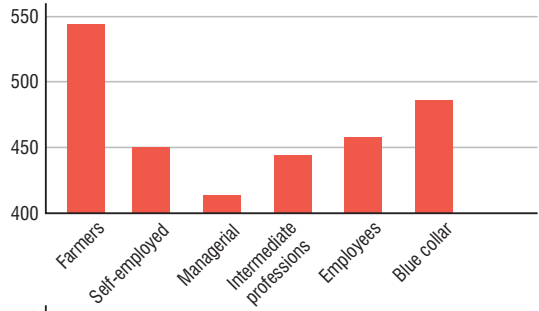
Finally, no significant difference is observed in CO₂ content per euro spent between different types of families (*Graph 7d*). On examination, one-person households, single-parent families and couples without children all devote a larger proportion of their budget to housing costs (including heating expenditure) than couples with children, but the situation is reversed for transport expenditure. These two differences tend to offset each other. Ultimately, the quantities of CO₂ emitted are therefore roughly proportional to the consumption expenditure of each type of family. Given the economies of scale that exist on a large number of consumption items within a household, and notably on the heating and travel items, this means that the quantity of CO₂ emitted per person decreases on average as the size of the household in question increases. For example, while consumption induces emissions of 6.4 tonnes of CO₂ per person for the resident population as a whole, the figure rises to 8.6 tonnes per person living alone, but comes to 4.1 tonnes per person living in a large family (couples with three children or more) (*Table 5*). ■

Graph 7. Propensity to emit CO₂ (ratio of CO₂ emissions to consumption expenditure) by household category

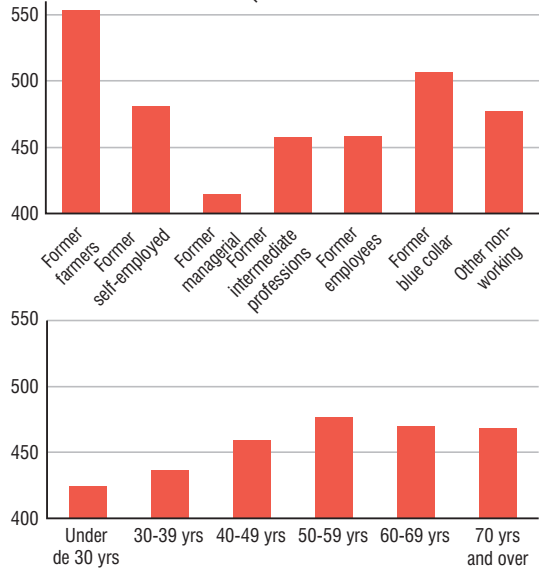
7a. By standard of living quintile



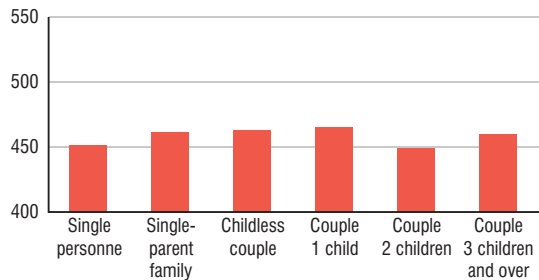
7d. 7b. By socio-professional category



7c. By age of the reference person



7d. By type of family structure



Sources : Service de l'observation et des statistiques (SOeS), Insee.

Table 3. CO₂ emissions structure by socio-professional group

	Farmers	Self-employed	Managerial	Intermediate professions	Employees	Blue collar	All working people	
CO₂ emissions (Mt)	7,2	28,8	54,4	65,9	35,5	67,9	259,6	
CO ₂ emissions (tonnes per household)	18,3	21,4	22,3	18,1	13,4	14,8	17,2	
Émissions de CO ₂ (tonnes per household)	5,8	7,3	8,1	6,9	5,7	5,0	6,3	
Share of emissions according to catégorie %	1,9	7,7	14,5	17,5	9,4	18,0	69,0	
Food and non-alcoholic drinks	11,9	10,3	9,5	10,3	11,2	11,2	10,5	
Alcoholic drinks and tobacco	0,7	1,0	1,0	1,1	1,2	1,2	1,1	
Clothing and footwear	2,6	3,5	3,9	3,5	3,1	3,1	3,4	
Logement	40,2	35,2	27,8	29,9	32,3	33,3	31,5	
<i>including electricity, gas and other fuels</i>	<i>37,8</i>	<i>31,3</i>	<i>23,3</i>	<i>26,0</i>	<i>28,2</i>	<i>29,8</i>	<i>27,7</i>	
Furniture, cleaning items	4,2	5,2	6,2	5,1	4,9	4,4	5,1	
Health	1,2	1,4	1,6	1,7	1,8	1,9	1,7	
Transports	29,6	30,3	33,9	35,3	33,7	34,3	33,8	
<i>including vehicle use expenditure</i>	<i>24,1</i>	<i>21,8</i>	<i>25,0</i>	<i>27,5</i>	<i>27,5</i>	<i>28,1</i>	<i>26,4</i>	
Communications	0,6	0,7	0,8	0,9	1,0	0,9	0,9	
Leisure and culture	4,2	5,4	6,7	5,6	4,9	4,8	5,4	
Education	0,3	0,6	0,4	0,3	0,3	0,2	0,3	
Hotels, cafés and restaurants	1,9	3,3	4,7	3,4	2,8	2,4	3,3	
Other goods and services	2,6	3,1	3,6	2,9	2,8	2,4	2,9	
	100,0	100,0	100,0	100,0	100,0	100,0	100,0	
	Former farmers	Former self-employed	Former managerial	Former intermédiaire professions	Former employees	Former blue collar	Other non-working peoples	All non-working people
CO₂ emissions (Mt)	6,8	11,5	15,6	19,7	15,7	24,9	22,5	116,6
CO ₂ emissions (tonnes per household)	10,2	14,0	18,6	14,7	9,5	10,7	9,0	11,5
CO ₂ emissions (tonnes per household)	6,0	8,3	10,2	8,4	6,8	5,9	4,6	6,6
Share of emissions according to catégorie %	1,8	3,1	4,2	5,2	4,2	6,6	6,0	31,0
Food and non-alcoholic drinks	13,6	12,0	12,4	12,4	13,5	13,8	12,2	12,8
Alcoholic drinks and tobacco	0,9	1,1	1,4	1,2	1,1	1,2	1,0	1,2
Clothing and footwear	1,6	1,7	2,3	2,2	2,2	1,6	3,3	2,2
Housing	47,3	42,4	33,5	36,6	44,3	42,8	38,1	40,0
<i>including electricity, gas and other fuels</i>	<i>44,5</i>	<i>38,3</i>	<i>28,1</i>	<i>32,1</i>	<i>39,0</i>	<i>39,1</i>	<i>33,9</i>	<i>35,7</i>
Furniture, cleaning items	3,4	4,9	6,9	5,2	4,5	4,6	4,3	4,9
Health	3,0	3,0	2,6	2,8	3,2	3,4	2,4	2,9
Transports	22,3	24,6	27,3	28,4	20,9	23,9	26,9	25,3
<i>including vehicle use expenditure</i>	<i>19,5</i>	<i>19,3</i>	<i>19,7</i>	<i>22,4</i>	<i>16,9</i>	<i>20,1</i>	<i>20,9</i>	<i>20,1</i>
Communications	0,5	0,6	0,7	0,6	0,8	0,6	1,1	0,7
Leisure and culture	3,9	4,7	6,4	5,6	4,7	4,0	5,1	5,0
Education	0,0	0,0	0,1	0,1	0,0	0,0	0,6	0,2
Hoels, cafés and restaurants	0,8	2,0	2,9	2,1	1,6	1,3	2,3	1,9
Other goods and services	2,7	3,0	3,6	2,6	3,3	2,8	2,7	2,9
	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0

Sources : Service de l'observation et des statistiques (SOeS), Insee.

Table 4. CO₂ emissions structure by age group

	Under de 30 yrs	30-39 yrs	40-49 yrs	50-59 yrs	60-69 yrs	70 yrs or over	Total
CO₂ emissions (Mt)	28,0	75,1	89,7	84,7	46,6	52,1	376,2
CO ₂ emissions (tonnes per household)	10,8	16,0	18,3	18,1	14,5	10,2	14,9
CO ₂ emissions (tonnes per household)	10,8	6,2	9,2	6,1	3,7	1,9	6,4
Share of emissions according to catégorie %	7,4	20,0	23,8	22,5	12,4	13,9	100,0
Foods and non-alcoholic drinks	9,3	10,4	10,7	10,8	12,8	13,7	11,2
Acoholic drinks and tobacco	1,1	1,0	1,1	1,2	1,2	1,2	1,1
Clothing and footwear	4,1	3,8	3,4	2,9	2,0	1,6	3,1
Housing <i>including electricity, gas and other fuels</i>	27,5 23,5	31,1 26,9	31,6 28,0	33,1 29,4	38,5 34,3	44,6 39,7	34,1 30,1
Furniture, cleaning items	5,3	5,3	4,7	5,2	5,1	4,8	5,0
Health	1,5	1,6	1,7	1,9	2,6	3,6	2,1
Transports <i>including vehicle use expenditure</i>	35,9 27,4	33,3 25,8	34,1 26,7	33,4 26,1	27,0 21,4	20,4 16,8	31,2 24,5
Communications	1,4	0,9	0,8	0,8	0,6	0,6	0,8
Leisure and culture	6,4	5,7	5,4	5,1	5,0	4,6	5,3
Education	0,5	0,2	0,5	0,3	0,1	0,0	0,3
Hotels, cafés and restaurants	3,9	3,4	3,3	2,7	2,1	1,7	2,8
Other goods and services	3,2	3,3	2,6	2,7	3,0	3,1	2,9
	100,0	100,0	100,0	100,0	100,0	100,0	100,0

Sources : Service de l'observation et des statistiques (SOeS), Insee.

Table 5. CO₂ emissions structure by family structure

	Single person	Single-parent family	Childless couple	Couple 1 child	Couple 2 children	Couples 3 children +	Total
CO₂ emissions (Mt)	64,7	24,6	116,9	65,3	69,5	35,3	376,2
CO ₂ emissions (tonnes per household)	8,6	12,3	15,8	19,5	21,2	21,6	14,9
CO ₂ emissions (tonnes per household)	8,6	4,8	7,9	6,5	5,4	4,1	6,4
Share of emissions according to catégorie %	17,2	6,6	31,1	17,3	18,4	9,4	100,0
Foods and non-alcoholic drinks	10,4	11,5	11,8	10,9	11,3	11,3	11,2
Acoholic drinks and tobacco	1,1	1,0	1,3	1,1	1,0	1,0	1,1
Clothing and footwear	2,4	4,0	2,5	3,3	3,3	3,6	3,1
Housing <i>including electricity, gas and other fuels</i>	39,1 33,9	36,8 32,2	34,7 30,8	31,6 28,0	31,9 28,3	31,6 28,0	34,1 30,1
Furniture, cleaning items	5,0	4,4	5,5	4,9	4,7	4,9	5,0
Health	2,3	1,7	2,4	1,9	1,7	1,8	2,1
Transports <i>including vehicle use expenditure</i>	27,5 21,8	28,1 22,7	30,1 23,5	34,2 27,3	33,2 25,6	33,3 25,5	31,2 24,5
Communications	0,9	1,1	0,7	0,8	0,8	0,9	0,8
Leisure and culture	5,5	5,2	5,4	5,2	5,1	5,3	5,3
Education	0,2	0,4	0,1	0,3	0,5	0,5	0,3
Hotels, cafés and restaurants	2,7	2,8	2,5	2,7	3,5	3,2	2,8
Other goods and services	3,0	3,0	2,9	3,0	3,0	2,7	2,9
	100,0	100,0	100,0	100,0	100,0	100,0	100,0

Sources : Service de l'observation et des statistiques (SOeS), Insee.

La matrice de Leontief au service de l'environnement

The approach consisting in defining physical accounts broken down by economic activity and then combining them with the input-output tables from the national accounts is known as NAMEA (National Accounting Matrix Including Environmental Accounts), also referred to as "hybrid accounts" in the guide to integrated economic and environmental accounting (SEEA, 2003).

In proposing NAMEA in the 1990s, the Dutch statistical office (Keuning et al. 1999) focused attention on the extension of input-output analysis to the environment (Moll et al. 2007). This form of analysis draws its inspiration from the work of Leontief (cf. Leontief et al. 1972), who conceived the use of input-output tables in economics. As part of the European environmental accounting programme, Eurostat is encouraging this approach to be applied to various environmental fields. For the moment, the most advanced field is that of atmospheric emission accounts, for which Eurostat has prepared a methodological guide (Eurostat, 2009).

A. Method

1. From the central framework IOT to the symmetric, domestic and imported IOTs

The input-output table of the central framework of the national accounts describes both the balance of supply and demand and the production accounts by sector.

An open economy is reduced to three products: two goods and one commercial service activity¹. The IOT is then schematically written as follows:

$$\begin{bmatrix} P_1 \\ P_2 \\ P_{com} \end{bmatrix} + \begin{bmatrix} TM_1 \\ TM_2 \\ -TM_1 \quad -TM_2 \end{bmatrix} + \begin{bmatrix} T_1 \\ T_2 \\ 0 \end{bmatrix} + \begin{bmatrix} M_1 \\ M_2 \\ 0 \end{bmatrix} = \begin{bmatrix} IC_{11} & IC_{12} & IC_{1com} \\ IC_{21} & IC_{22} & IC_{2com} \\ 0 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} + \begin{bmatrix} FD_1 \\ FD_2 \\ 0 \end{bmatrix} \quad (1)$$

The first line of this table describes the equality at purchase price between supply of and demand for product type 1:

production at basic price of product 1	(P_1)
+ trade margin on product 1	(TM_1)
+ taxes (net of subsidies) on product 1	(T_1)
+ imports of product 1	(M_1)

=

intermediate consumption of product 1 by the industryproducing product 1	(IC_{11})
+ intermediate consumption of product 1 by the industryproducing product 2	(IC_{12})
+ intermediate consumption of product 1 by the trade sector	(IC_{1com})
+ final demand for product 1	(FD_1)

The last line of this table, which describes the supply-demand balance of the commercial service, is specific: it translates the fact that production of the commercial service is equal to the sum of the commercial margins by product.

Additionally, the production account defines the value-added of each industry as the difference between production and the sum of the sector's intermediate consumptions:

$$\begin{bmatrix} P_1 \\ P_2 \\ P_{com} \end{bmatrix} - \begin{bmatrix} IC_{11} & IC_{21} & 0 \\ IC_{12} & IC_{22} & 0 \\ IC_{1com} & IC_{2com} & 0 \end{bmatrix} \cdot \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} = \begin{bmatrix} VA_1 \\ VA_2 \\ VA_{com} \end{bmatrix} \quad (2)$$

1. For the sake of clarity, here we do not explain the case of how the transport service activity is treated in the IOT, even though it too is specific. Indeed, it is a mixed case: schematically, the production of goods transport service is treated in the margin of transports on the other products (accounting treatment analogous to that of trade) and the production of the transport of passengers service directly feeds the elements of demand for transport (accounting treatment analogous to that of "standard" products).

Box 2 ()

By adding together the lines of equation (1) and by capitalizing on the fact that the sum of intermediate consumptions across all products is equal to the sum of intermediate consumptions across all industries, we get:

$$\underbrace{(P - IC)}_{GDP} + T + M = FD \quad (3)$$

GDP, defined as the sum of all the added values by industry and the taxes on products, added to imports, is equal to the sum of the elements in final demand (consumption, investment and exports), corrected for inventory change.

To calculate the CO₂ content, the central framework IOT first has to be converted into a so-called "symmetric" IOT; then this symmetric IOT needs to be broken down into two IOTs, one domestic and the other imported.

The switch from IOT to symmetric IOT is a matter of expressing the supply and demand balance at basic price, that is, excluding taxes and margin, rather than at the final demand price. The result is the following table:

$$\begin{bmatrix} P_1 \\ P_2 \\ P_{com} \end{bmatrix} + \begin{bmatrix} M_1 \\ M_2 \\ 0 \end{bmatrix} = \begin{bmatrix} \tilde{IC}_{11} & \tilde{IC}_{12} & \tilde{IC}_{1com} \\ \tilde{IC}_{21} & \tilde{IC}_{22} & \tilde{IC}_{2com} \\ \tilde{IC}_{com1} & \tilde{IC}_{com2} & \tilde{IC}_{comcom} \end{bmatrix} \cdot \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} = \begin{bmatrix} \tilde{FD}_1 \\ \tilde{FD}_2 \\ \tilde{FD}_{com} \end{bmatrix} \quad (4)$$

where intermediate consumption \tilde{IC}_i and final demand \tilde{FD}_i for product i ($i = 1$ or 2) are this time net of taxes on products and net of commercial margins. The commercial margins on intermediate consumption and on final demand for products 1 and 2 are reassigned as intermediate consumption \tilde{IC}_{com} and final demand \tilde{FD}_{com} on the "commercial service" product line (last line in the table).

The IOT is known as symmetric because it now makes all the products and all the industries play a perfectly symmetric role. It could thus be written summarily in matrix form:

$$P + M = \tilde{IC} \cdot e + \tilde{FD} \quad (5)$$

where $e = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$ in the simplified framework (in general cases, it will be the column unit vector size n ,

where n designates the number of products and industries under consideration).

The symmetric IOT is then broken down into a domestic IOT and an imported IOT, distinguishing the proportion produced on the national territory from that which is imported in each item of demand. In matrix form

$$P = \tilde{IC}^d \cdot e + \tilde{FD}^d \quad (6)$$

$$M = \tilde{IC}^m \cdot e + \tilde{FD}^m \quad (7)$$

2. CO₂ emissions generated by final demand

For an industry j , the technical coefficients A_{ij} represent the unit intermediate consumptions of products i , that is, the quantity of products required to produce a unit of product of industry j . The domestic and imported technical coefficient matrices can thus be established:

$$A^d = (A_{ij}^d) = \left(\frac{\tilde{IC}_{ij}^d}{P_j} \right) \text{ et } A^m = (A_{ij}^m) = \left(\frac{\tilde{IC}_{ij}^m}{P_j} \right)$$

Under these conditions, equations (6) and (7) can be rewritten:

$$P = (I - A^d) \cdot \tilde{FD}^d \quad (8)$$

Box 2 ()

$$M = A^m \cdot (I - A^d)^{-1} \cdot \langle \tilde{F}^d \rangle + \langle \tilde{F}^m \rangle \quad (9)$$

The above equalities describe the production of each product induced by final demand as a whole. Without any further hypothesis, they cannot assign to a given final demand sub-item (for example household consumption of health services, or corporate investment in automobiles) the corresponding production, let alone the associated CO₂ emissions. This crucial hypothesis consists in considering that these technical coefficient matrices are structural coefficient matrices, describing both the production technologies by industry and the degree of openness of the economy for each product, independently of the final use under consideration.

Under these conditions, for a unit amount produced by industry *j* on the national territory, irrespective of its use, the technical coefficient matrices set the quantity of product *i* used as intermediate consumption, as well as the respective shares of product *i* which will be imported and produced on the national territory to do so. For example, we assume that the quantity of intermediate consumption of plastic induced by the production of an automobile is the same, whether this automobile is a private vehicle for a household or a delivery vehicle for a company; similarly, the shares imported and produced in France of this quantity of plastic required for the production of an automobile are the same, irrespective of the vehicle.

On this assumption, we can use the previous equalities to calculate the column vectors of productions and imports required to satisfy final demand for each product considered separately, then join together all these production column vectors on the one hand and import column vectors on the other hand, to obtain two matrices P^{FD} and M^{FD} summarizing the content in productions and imports of final demand, product by product. By denoting as $\langle \rangle$ the operator that transforms a column vector into a diagonal square matrix, this can be written:

$$P^{FD} = (I - A^d)^{-1} \langle \tilde{F}^d \rangle \quad (10)$$

$$M^{FD} = A^m \cdot (I - A^d)^{-1} \langle \tilde{F}^d \rangle + \langle \tilde{F}^m \rangle \quad (11)$$

Now we assume that we have the CO₂ emissions on the national territory by industry $EM^d = (EM_j^d)$ and that the emission linked to industry *j* is once again structurally proportional to quantity P_j that it produces. The direct CO₂ content coefficient column matrix by industry (or intensity of CO₂ of production by industry):

$$CO_2^d = (CO_{2j}^d) = \left(\frac{EM_j^d}{P_j} \right) = \langle P \rangle^{-1} EM^d$$

The reassignment of CO₂ emissions on the territory to final demand, product by product, is deduced from (10):

$$\tilde{E}M^{FD,d} = \langle \tilde{F}^d \rangle (I - A^{d'})^{-1} CO_2^d \quad (12)$$

where $A^{d'}$ designates the transposed form of matrix A^d .

Additionally, taking account of the CO₂ emissions abroad generated by the import of a product *i* implies counting not only the foreign emissions linked to the corresponding industry *i*, but also the supplementary emissions emitted upstream by all the intermediate goods used by this industry. In other words, we need not only the direct CO₂ content coefficient column matrix by industry of the rest of the world, CO_2^{d*} , but also the structure of the productive system of the rest of the world (summarized by the technical coefficient matrix A^{d*})².

2. Strictly speaking, the model should be completed: in the calculation of the CO₂ content of imports, we should take account not only of the emissions produced abroad, but also of those emitted in France as the share of French exports used by the rest of the world as intermediate consumptions to produce the goods imported into France. Implicitly, we suppose that in the case of a small economy (such as that of France on the world scale), this effect can be neglected because the rest of the world can then be considered as an almost closed economy (*i. e.* $A^{m*} \approx 0$).

Box 2

Under these conditions, the emissions generated by French imports are none other than the emissions generated by French final demand for product from the rest of the world; and can thus be written:

$$\tilde{E}M^m = \langle M \rangle (I - A^{d^*})^{-1} CO_2^{d^*} \quad (13)$$

To finish, the CO₂ emissions generated abroad by French final demand, product by product, are deduced by calculating the import content of each element in this final demand (cf. (11)):

$$\tilde{E}M^{FD,m} = M^{FD'} (I - A^{d^*})^{-1} CO_2^{d^*} = \left(\langle \tilde{F}D^d \rangle (I - A^{d'})^{-1} \cdot A^{m'} + \langle \tilde{F}D^m \rangle \right) (I - A^{d^*})^{-1} CO_2^{d^*} \quad (14)$$

In this equation the two components contributing to imported CO₂ emissions are found once again: those linked to imports of products consumed as intermediate goods by the national productive system to satisfy domestic final demand, and those linked to the products imported to meet this final demand directly.

3. Breakdown by household category of CO₂ emissions induced by final consumption

The CO₂ emissions generated by final demand ($\tilde{E}M^{FD,d}$ et $\tilde{E}M^{FD,m}$) were evaluated on the basis of the final demand of the symmetric IOT. For example, the CO₂ emissions generated by final demand for the commercial service product actually correspond to the emissions generated by commercial margins. These margins therefore have to be reassigned to the products paid for by the end user - the products to which these margins are attributed. This reassignment is performed in due proportion to the commercial margin amounts; it ultimately results in vectors $EM^{FD,d}$ and $EM^{FD,m}$ of CO₂ emissions generated by the final demand of the central framework IOT (that is, the IOT evaluated at purchase price).

As we also have the breakdown of consumer expenditure, product by product from the central framework, into four types of household category (standard of living quintile, family composition, age and socio-professional category of the reference person), we can deduce by proportion the CO₂ emissions linked to the consumer expenditure of each household category.

B. The sources used

The calculation of CO₂ emissions for France is estimated over the year 2005, using the central framework IOT along with the domestic and imported symmetric IOTs elaborated by the National Accounts Department at level G (118 product items) of the French composite economic classification (NES) of activities and products. The symmetric tables are converted into the European nomenclature with 60 products (NACE 60) via a nomenclature conversion table.

These IOTS are then coupled with the direct CO₂ emissions by industry, evaluated for 2005 in NACE 60 by the Citepa (Technical Inter-profession Centre for Studies of Atmospheric Pollution).

As regards the evaluation of CO₂ emissions abroad generated by French imports, we used a number of statistical data (symmetric IOTs, direct CO₂ emissions by industry) from countries from which France imports (see below). In practice, the coefficient matrix of direct and indirect CO₂ content from the rest of the world was approximated as follows:

$$(I - A^{d^*})^{-1} CO_2^{d^*} = \sum_{country} \langle \pi_{country} \rangle (I - A^{country'})^{-1} CO_2^{d',country}$$

where $\pi_{country}$ designates the column vector of the share of French imports from a given country, product by product: $\sum_{country} \langle \pi_{country} \rangle = I$

$$\text{and where : } A^{country} = \left(A_{ij}^{country} \right) = \left(\frac{\tilde{C}_{ij}^{d, country} + \tilde{C}_{ij}^{m, country}}{P_j^{country}} \right)$$

Box 2

With the "unilateral" multi-region approach we use here, a large proportion of the specificities of France's trading partners are taken into account. For example, we use the German coefficients for French imports from Germany, including the CO₂ associated with its imports, but we do not take account of the specificities of German imports by country of origin. A number of studies underway are aiming for a "multilateral" multi-region modelling which would allow us to complete international trade data on the world scale. However, it seems that the unilateral approach covers most of the difference between the calculations based only on importing country data (the hypothesis whereby the structure of the productive system of the rest of the world is analogous to the French structure) and the multilateral multi-region approach.

Full data relating to five European Union countries were used here (Germany, Belgium, Spain, the UK and Italy), from which almost half of French imports in value came in 2005 (*source: Eurostat, national accounts for the symmetric IOTs in 60 industries/products, and environmental accounts for CO₂ emissions by economic activity*). The direct and indirect CO₂ coefficient vector obtained for Germany was applied to the proportion of imports from the other European countries excluding Russia. Since we did not have the symmetric IOTs from the other regions of the world (which in 2005 collectively represented 25% of French imports in value), we combined the direct CO₂ contents by industry (*source: Rømse P., Olsen T., Hansen D., 2009*) of countries considered as representative with the technical coefficient matrices from European IOTs, in the following manner:

- North America: CO₂ content by industry of the USA combined with the German IOT
- South America: CO₂ content by industry of Brazil combined with the German IOT
- Asia excluding Japan: CO₂ content by industry of China combined with the German IOT
- Japan: CO₂ content by industry of Japan combined with the French IOT
- Oceania: CO₂ content by industry of the USA (adjusted to take into account the CO₂ content of electricity produced; *source: International Energy Agency*) combined with the German IOT
- Russia: CO₂ content by industry of Russia combined with the German IOT
- Africa and Middle East: CO₂ content by industry of Germany (adjusted to take into account the CO₂ content of electricity produced; *source: International Energy Agency*) combined with the German IOT.

Additionally, the direct and indirect CO₂ content coefficient obtained for hydrocarbons (crude oil and gas) for Russia was applied to all imports of hydrocarbons, irrespective of the country of provenance (Russia, but also the Gulf countries, Algeria, etc.).

The CO₂ content of our trade balance obtained with this approximation results in a rise of around 35% in the CO₂ emissions generated by the French economic circuit when we switch from a domestic output approach to a domestic final demand approach³. As a comparison, a recent OECD study (Nakano et al. 2009) evaluated the country by country trade balances of CO₂ using data from all the world's geographic zones (although this data was *a priori* less homogenous in terms of statistical content than the data collected by Eurostat on European countries). This study also estimates a rise of the order of 35% for France for the year 2000. Even more recently, an American study based on a multi-lateral multi-region approach estimates this adjustment at 40% for France in 2004 (Davis, Caldeira, 2010).

For the requirements of this study, the CO₂ contents of final demand at basic price were modified and expressed according to final demand at purchase price (return from the symmetric IOT to the central framework IOT), then expressed in NES and in COICOP (Classification of Individual Consumption by Purpose) via nomenclature conversion tables.

To finish, we use the households by category account elaborated by INSEE for the year 2003. This account is built using national accounting data, several household surveys ('SILC' statistics on income and living conditions of 2004, tax incomes of 2003, family budget of 2006, housing of 2002 and health of 2003), and the socio-demographic data from the Employment survey and the satellite account for housing in 2003 (for further details, see Bellamy et al. 2009).

3. At the national conference on sustainable development indicators of 20 January 2010, the indicator resulting from this approach was presented with the name carbon footprint of national final demand. The estimate proposed (Pasquier, 2010) was lower than that provided here because the inclusion of foreign data has been completed since then, notably as regards countries outside the European Union.

Box 2 (

Because the microeconomic data from household surveys only concern the field of ordinary households (i.e. excluding households living in communities) in mainland France, the breakdown of the households by category account is only available on this sub-field (which represents 95% of total household consumer expenditure). The CO₂ content of consumer expenditure on this sub-field was evaluated item by item in due proportion. The breakdown thus obtained is based on the approximation that the consumption structure of households in 2005 is equal to that observed in 2003. This approximation is theoretically acceptable, because the consumption structures are relatively stable over time.

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