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New representations of energy consumption

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Editorial

At the time of the oil shocks, industrialized economies suddenly realized that they had been negligent in taking stock of the energy that had been central to their growth models for nearly a century. To cope with the economic consequences of these shocks, these countries understood the need to be more active in terms of policies to control demand, as well as in their energy sourcing strategies, by seeking to diversify sources or develop domestic sources. To achieve such objectives, it is useful to know how to count: to understand how much energy is used for what purpose and to identify the sources used to produce our fuels, combustibles and electricity.

We have since developed and refined our knowledge to focus on the energy balance format, a format that is homogenous, internationally recognized and which distinguishes between: 1) the final energy used and paid for by industrial consumers, entrepreneurs, public authorities and households, etc.; and 2) the primary energy that is extracted from the earth, captured from nature... or imported from abroad, in order to be converted into final energy – crude oil becomes petrol and fuel, coal and wind are transformed into electricity. It is on the basis of this representation that policies for energy management have been conceived for the last 30 years: we identify the sectors that consume energy and the usages within these sectors; we consider whether new forms of organization could reduce consumption while still producing the same services (travel, heating, pumping...); and we design instruments aimed at encouraging the energy consumer to make the right decisions.

At the same time, environmental issues have appeared on the agendas of public policy makers and citizens. In terms of public policy, an approach focusing on the environment and emissions has often been favoured. In particular, in a world where the consumer occupies an increasingly important position in the collective representation of issues, as well as in potential solutions, we have attempted to measure the environmental impacts of our consumption and to derive from this some tools of awareness raising and sometimes action: thus various Life Cycle Analyses (LCA) and labelling initiatives were born (for wood, paint etc.) along with energy balance analyses related to the products and services we consume. The question of the greenhouse gas effect has not escaped this trend, and "carbon content" is now widely used as a criterion for differentiation and as a guide for action. Today, these representations are used by economists, sociologists and analysts to study the changes in society and to assess the differences between categories.

The previous issue of CLIP ("Lifestyles and carbon footprint", *Cahiers du CLIP* No. 21, February 2013) clearly demonstrated that forward-thinking on the energy needs of societies could not be limited to plans for efficiency in terms of direct consumption (low-energy vehicles, efficiently heated houses, efficient cement plants and economical aeroplanes), but should also consider the determinants of our consumption patterns and understand the link with the final energy demand. Here again, we need new tools to think about this issue, while the consumption-focused approach opens new horizons that are complementary and not designed to replace the traditional energy balance approaches. However, for energy experts, an approach based on CO_2 emissions, which has gradually become the norm, is very unsatisfactory: the differences that can be found from one consumer to another, from one country to another, from one product or service to another, are much too influenced by certain features (such as the source of electricity) to provide a robust measure of the issues that we seek to study. This indicator is not very reliable for understanding the energetic metabolism of our societies and the analyses that can be derived from it are often superficial. We have therefore tried to hybridize the two dimensions: measuring energy, but in an approach oriented towards the consumption of goods and services, i.e. on the daily activities of households. This approach invites us to focus on both the energy content of our consumption and on the social dimension of energy transition, which is currently being debated in France. This exercise is innovative, although imperfect, but the potential is significant and the initial results are exciting.

Introduction

Following France's annual environmental conference (September 2012), in November 2012 representative bodies of French society pledged to hold a national debate on energy transition. It is intended that this debate will lead to a legal act that will define government objectives for the determination of broad guidelines for French energy policy and to select the different tools that must be implemented for the achievement of its goals.

While the energy future of France has already been the subject of much national debate, the status now being attributed to energy demand and, consequently, the energy service needs of users may constitute a new element in today's discourse. This reversal of the energy issue (of supply and demand, production and consumption) places the final consumer and the citizen at the heart of the debate. However, the way in which the energy issue is currently perceived does not lend itself to such a discussion. Our collective perception of the energy system is based on national energy balances, which are broken down according to the energy produced from each energy source and also by the final energy demand of economic sectors (agriculture, industry, transport, commercial, residential). The prevailing logic is that of an energy supply to meet household and business demand. In this context, energy efficiency, i.e. the ratio between energy service needs (thermal comfort, transportation, machinery, etc...) and energy demand, is difficult to address. Beyond this, any discussion on the levels of need themselves is totally absent, since it is considered that all needs are legitimate and must therefore be met. A reversal of the representation of the energy issue to view the situation from a consumption-based perspective would enable the questioning of our patterns of consumption and production in the context of finite natural resources. It would also allow citizens to understand the energy implications of their actions.

The first question is that of the energy used to meet consumption patterns. Certainly, energy consumption induced by household demand is not limited to the energy that is accounted for by heating, electricity and fuel bills. It also includes the energy that is associated with the production of goods and services that are routinely used in every aspect of daily life: for example, the page on which this text is printed or the computer screen on which it was written. The materials that have been used to make this book and screen have been produced beyond national borders. This "invisible" energy is fully integrated into international trade: it crosses borders and industries. It goes from raw materials to finished products, from one country to another. To address the debate on energy from the perspective of consumption is equivalent to raising questions about this energy that remains unnoticed by the consumer.

For a better "view" of this physical reality, the approaches and visions of different disciplines must be combined. Energy experts alone cannot meet the proposed challenge: economists and sociologists must also be involved. However, until recently, researchers have sought mainly to advance their own interests on the subject. Energy experts have focused on the energy mix; economists have prioritized the importance of macroeconomic issues and international trade; while sociologists have placed the emphasis on microscopic issues such as the determinants of consumption and the social reality it represents.

The work presented in this report opens the door to the bringing together of these three fields of analysis: energy, "micro" and "macro".

The objective is to transform our social perception of energy through the integration of international trade, through the use of aggregate data that is consistent with national accounting and by going beyond average values. The phenomenon described here is complex: the data and analyses presented are exploratory and not definitive. The aim is to provide information on the order of magnitudes and their interpretation, to propose new ideas and to generate new research. This therefore constitutes a good example of "science in the making".[1]

This reconstruction and reorganization of the approach was initiated during the study of greenhouse gas emissions in several countries. A large literature is developing on the carbon footprints produced by individuals. The most recent research in this regard not only takes direct emissions into account, but also includes the emissions related to consumption. Carbon footprints provide a measure of the real impact of our consumption behaviours on greenhouse gas concentrations. This indicator allows us to become aware of the effort that is required to achieve emission reduction objectives. Emission studies, however, do not allow us to have a macroscopic vision of the inertia that weighs heavily on the organization of our energy system.

A focus on energy consumption, which acts upstream of the impact chain, enables the identification of drivers that influence the inertia of energetic, economic and political systems. Carbon footprints are the result of two components: practices and the carbon content of the energy system. The carbon footprint alone does not allow us to distinguish between variations resulting from different practices or the carbon efficiency of the energy mix. We therefore propose a "refocusing" on energy.

However, this new representation of energy consumption cannot be limited, as is often the case, to a line of thought based on average values. Ongoing public debates on tax justice, progressive pricing, oil and gas prices, along with the carbon tax debate three years ago in France, have shown how the issue of equity is central to the definition and implementation of public policies for energy transition. Addressing this aspect of equity in the debate on energy requires the use of appropriate orders of magnitude. The purpose is therefore to ask how energy consumption related to consumption behaviour varies according to different categories of income, and to identify the factors that explain these differences and the implications for energy transition scenarios.

The work presented in the following chapters is the result of a collaboration between EDF Research, CIRED and IDDRI, within the CLIP framework.

1 See Bruno Latour, *Laboratory life: the social construction of scientific facts*, Princeton University Press, 1986.

Part 1

Energy impact, direct energy and embodied energy

What is energy impact?

The satisfaction of household needs - food, housing, transportation, entertainment, health care, etc. - requires direct energy consumption by households (heating, electricity, fuel) but also, indirectly, energy consumption for the production and provision of goods and services necessary to meet those needs.

The consideration of energy from a consumption perspective involves the evaluation of the energy impact of households, which consists of the total energy required to meet ultimate household energy needs. Energy impact thus links household expenditure on goods and services to the entirety of the energy needs they create - also known as integrated energy consumption. The production chain of goods and services is not confined to the national territory: a proportion of the goods and services within these chains is imported. Energy impact is not therefore limited by national borders but integrates into global production processes.

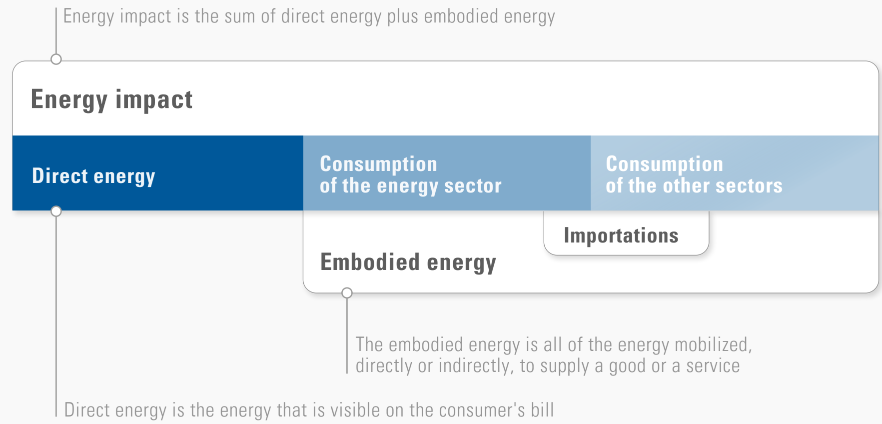
This impact is divided into two categories: direct energy and embodied energy. Direct energy means energy that is visible to consumers, it is quantified on their bills for vehicle fuels, electricity, gas and other household fuels. Direct energy therefore corresponds to the final energy consumption of households.

Embodied energy is the energy necessary for the provision of goods or services to the final consumer, prior to their usage: the energy required to manufacture equipment and food, to deliver such goods to the home, to construct the place of residence, etc. It is also known as the energy content of goods and services. Embodied energy must itself be broken down according to its use. Embodied energy of non-energy sectors thus designates that which is used by economic actors, both nationally and throughout the world, in the design, testing, production and transport of goods and services that are ultimately consumed by households. In turn, the embodied energy of direct energy is the share of energy expended upstream in the development of a final vector (i.e. the "type" of energy) from natural resources and the energy used in making this available to the consumer: extraction, conversion, transportation, construction of factories and infrastructure, etc. In this study, we firstly discuss the embodied energy of a good or service, and secondly the embodied energy of direct energy.

The embodied energy aspect of direct energy is simply the difference between the final energy and the primary energy indicators that are traditionally found in the literature, to which is added the consumption of energy of the energy "sector" itself, that is to say the energy required to build and operate facilities and infrastructure in this sector. Primary energy is the energy available in nature in a "raw" state, i.e. prior to any form of transformation by human technology. This energy is therefore located upstream of the production line before the losses inherent in the various processes of transformation and transmission. To give some examples, we refer here to crude oil from a well before its transformation into petroleum, to the chemical energy contained in fuels used in power stations and to the potential energy of a body of water behind a dam.[2] At the other end of the energy production chain, there is the final energy, which is the energy that is ready for use: a litre of petrol to put into a car or the electrical current to light a bulb. In France, for each kilowatt-hour of electricity consumed, on average another kilowatt-hour and a half was required to meet the final energy demand.[3]

Why use the term *impact* rather than *footprint*? Energy impact describes the reallocation of energy produced in a given year, according to its final usage. It does not aim to be an accurate measurement, at the

Figure 1
Embodied energy, direct energy and energy impact



Box 1
Consumption functions or units

When we talk about "consumption" without qualification, we are not referring to energy consumption, but to household expenditure on goods and services, i.e. the actual consumption of households (including social transfers).

An analysis of the means of meeting household demand goes beyond the mere study of mobilized productive sectors. A well adapted solution for economic reference databases is to use a functional classification of consumer usages. This classification is a combination of all productive activities that contribute to the satisfaction of a given need: education, defence, housing, clothing, marketing, transportation, accounting, trade, etc. An analysis according to purpose can therefore cover many activity sectors. The aim of the analysis is to see how a given need (e.g. education) is satisfied by the various activity sectors.

The analysis according to purpose is at the basis of certain specific classifications that facilitate comparisons between different databases and countries, such as the Classification of Individual Consumption According to Purpose (COICOP). The results of the INSEE study on which we base our work also gives the results in terms of COICOP (see details in Annex). However, there is no definitive grouping choice. The relevance and the decision on how to divide consumption into usages depends primarily on the needs of the analysis. We have applied the one used by the INSEE (COICOP), and simplified it: we have grouped together food products with alcohol and tobacco. But other combinations are possible. Depending on the type of consumption or energy that is to be analysed, this division may be further developed.

2 Primary energy according to the conventions of the International Energy Agency for the conversion of electricity: nuclear electricity is thus multiplied by three to calculate primary energy.
3 Note: all graphs and illustrations, where the source is not indicated, were produced by the authors.

same level as a life cycle analysis, but rather an indicator of the overall energy demand of an economic system for a year, which is allocated to the final consumption, which has caused the demand. We chose this term rather than "footprint", which may depend on past consumption.

The second part of this paper presents an energy impact evaluation method. Based on this evaluation, in France, the energy impact of the actual energy consumption of households in 2004 was 296 Mtoe. If we take this figure and express it as a unit, the kilowatt-hour,[4] that is more familiar to those who are not energy experts, and if we think in terms of per day per household,[5] the daily energy impact of a French household is 343 kWh. We will see that only 25% of the impact is used for direct energy (85.75 kWh). The remaining 75% (257.25 kWh) is incorporated into goods and services consumed by the household. Three-quarters of energy consumption is therefore not directly perceived by consumers. F1

In the next two sections we provide detailed reference levels of the direct energy consumption of French households, and present work based on a consumption approach. B1

Direct energy

Unlike embodied energy, the measurement of direct energy consumption does not require the use of a complex macroeconomic model: it is sufficient to compile household energy bills. We present here the results of a reconstruction of a household's direct energy balance. This allows the consideration of the orders of magnitude involved, but also the identification of the drivers that influence consumption.

The structure of direct energy consumption for a typical household

To make the presentation of this work more interesting, we adopt the approach used by David McKay in his book *Sustainable Energy - Without the Hot Air* (2008): the idea being to estimate the direct energy consumption for a household consisting of two people, from sunrise to sunset. For our purposes, an average two-person household (i.e. 30% of the French population) occupies 60 m^2 and is situated within a collective residence. It is equipped with household appliances that were purchased in 2005. The dwelling is insulated according to the RT 2005 standard, more details of which are given below. The data presented in this section are in kilowatt-hours.

The direct energy inventory of our household begins at the time of awakening. Consumption for a 5-minute shower equates to about 3 kWh, or 6 kWh for two people.

The typical routine of our average household continues into the kitchen, where the refrigerator/freezer requires 1 kWh each day. The household members toast bread with a toaster (0.15 kWh) and make a hot drink using a kettle (0.1 kWh). For lighting, the household uses three low energy bulbs (8 W) and three 60 watt bulbs that light up on average for three hours per day, making an average consumption of 0.6 kWh.[6]

The inhabitants of our average household then go to work by car. They own the equivalent of two mid-range cars (both of which

4 A kilowatt-hour (kWh), the unit used on the electricity meter and on bills, corresponds to the energy used by a device of 1 kW (e.g. an iron) for one hour.

5 We will see in Chapter 2 that it raises several methodological problems.

6 For information purposes, a French household has 28 light bulbs on average (Sidler, 2004), while the national average energy consumption for lighting is 0.8 kWh per day per household.

consume 7 litres per 100 km) and are the sole occupants of their vehicles. On a 12 km trip, they each consume about 8.75 kWh,[7] i.e. 17.5 kWh for the return journey. For our two people, the direct energy consumption for transport is 35 kWh per day.

Direct energy, as we have defined it, is that which appears on household bills. In this section, we do not consider energy consumption at the workplace. After work, the initial energy consumption derives from the preparation of an evening meal. The oven and electric hotplates consume between them 1 kWh on average - few households use their oven every day. The microwave oven consumes 0.2 kWh per day. To produce 20 litres of water at 60 °C, the dishwasher consumes a little less than a washing machine, i.e. 0.5 kWh. In the evening, the household watches TV for three and a half hours (0.4 kWh).[8] The computer and its LCD screen are switched on for three hours, consuming 0.5 kWh. Added to this is the printer, which consumes 0.05 kWh per day. An hour of music or radio on a compact HiFi requires 0.1 kWh and 0.1 kWh is used by a DVD player. In addition we can include the use of a vacuum cleaner (0.6 kWh), modem (0.1 kWh) and washing machine (0.7 kWh per day), which makes a total of 6 kWh per day. We have thus defined the consumption of so-called specific electricity, which includes electrical appliances and lighting.

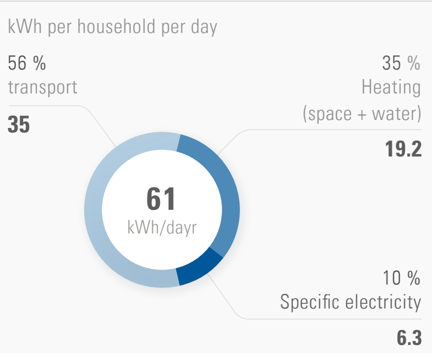
So far we have assumed that the household does not use the standby facilities on its appliances. If the contrary were true, we must add 0.5 kWh per day for these devices - this is the equivalent of the daily consumption of the dishwasher.

We have not yet considered heating: to assess the needs for thermal comfort, we should take into account the geographic area of the household, the difference between the interior and exterior temperature and the rate of energy loss of the building. We assume in this case that the housing requires 80 kWh of heat per year per m^2 (this is a new building, which is in compliance with the 2005 thermal regulations in France). Each day the household therefore consumes an average of 13.2 kWh for heating.

In summary, the highest area of consumption is transportation, which accounts for 35 kWh per day. Followed by heating and domestic hot water (DHW), which uses 19.2 kWh per day and 6.5 kWh of specific electricity per day. In comparison, the average in France is 40 kWh for transport, 39 kWh for heating, hot water and cooking and 7.6 kWh for specific electricity. Note that heat production remains a major consumption area after transport: for heating and hot water of course, but also for some household appliances (washing machine, dishwasher, oven, etc.). F2

Individual variation around this average can be considerable. Our example household is fortunate to have good insulation, unlike a majority of French dwellings. It has only two occupants, and their appliances are new and efficient, and although they each use a vehicle to get to work, their journeys are relatively short compared to the national average.

Figure 2
"Standard" equipment



Our typical household is composed of two urban dwellers living in a recently built apartment and consuming 61 kWh per day (figures rounded up to one decimal place)

7 We use stylised data here, i.e. 10 kWh per litre of oil for an average of 14 km per litre (we assume an urban/rural mixed consumption, with the urban being dominant, i.e. an average of 7 litres per 100 km). Finally, we assume an occupancy rate of one person per car, which is slightly less than the French average of 1.3 (CERTU, 2009).

8 The French average is 3.5 hours per day.

Therefore, from this we can infer that energy consumption depends on a range of factors related to technology, but also to usage behaviour.

Variation in consumption compared to the typical household

We focus here on the variations of the consumption of direct energy that explain the differences in energy balances from one household to another. These differences can be explained by several factors that must be addressed separately because they do not have the same implications for the types of policies that could be implemented to reduce consumption. The following section presents two different analysis methods to establish the impact of the technical performance of appliances and, secondly, the level of service consumed.

For the former analysis, we consider again the standard household and compare two new situations: in the first we consider a household that has highly energy efficient appliances; and in the second we look at a household with older energy-intensive devices. For the second analysis, we consider an energy intensive household. Such a high level of consumption may be a result of the lifestyle choices of household occupants, but can also be caused by a combination of economic, social and infrastructural constraints.

The impact of the technical performance of appliances

For this analysis we compared the direct energy consumption of a household equipped with energy efficient appliances, which are readily available on the market, to that of a household with the same usage requirements, but is equipped with older and more inefficient appliances. The first household corresponds to the situation of a young couple that fully equip their place of residence with new appliances (chosen from those available in early 2013) and who select only the highest rated equipment in terms of efficiency (A + + equivalent). They live in new housing (certified as "Passivhaus" or "Effinergie") which consumes 20 thermal kWh/m^2/year. It has excellent thermal insulation, superior to the RT 2012 standard. The couple has two small city cars which consume 4 litres per 100 km on average.

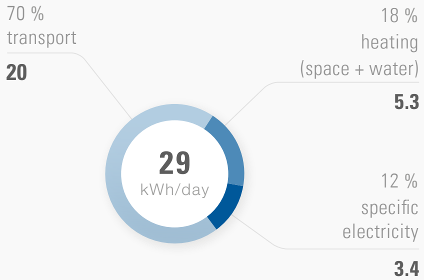
The other example household, which can be labelled as energy intensive, is equipped with end of life appliances that were purchased in the early 2000s (B/C class refrigerator, A/B class washing machine, B class oven, etc.). The housing in this case is poorly insulated, having single glazing and being situated on the top floor - we assume a heating requirement of 250 thermal kWh per m^2 per year), and they have an old family car, which consumes 10 litres per 100 km. Both households have a living space with an identical surface area, while their usage of devices is identical. Thus, we focus here solely on the characteristics of equipment.

While the household occupants in both situations get the same results from the use of their equipment, the structure and level of direct energy consumption of the "efficient" household differ dramatically from those of the "energy intensive" household. The efficient household consumes 30 kWh per day, which is considerably less than the inefficient household. This difference is essentially due to lower consumption for heating, which was three times less than the energy inefficient household, and transportation, which was two times less (both for the same level of service). The share of energy used for transport plays an important role in the energy balance of the efficient household (70%, compared to 56% for our standard household). The potential energy savings derived from the insulation of buildings are clearly much higher than the possible gains obtained from efficiency improvements to the internal combustion engine. While the construction of "zero energy" buildings may be possible, a "zero-energy" car is not currently on the agenda. We should also note that while specific electricity and heating needs are identical

in these two hypothetical situations, but there is a general trend towards an inversion of the curves for specific electricity and heating consumption (the latter tends to saturate).
The energy intensive household consumes three times more direct energy than the efficient household. Its daily balance is 104 kWh, which is dominated by the need for space heating and transportation. Specific electricity accounts for one-sixth of the balance, i.e. 14 kWh per day or fives times more than the efficient household. F3 F4
Through the total replacement of its stock of end of life appliances and vehicles with only

Figure 3
New and efficient equipment

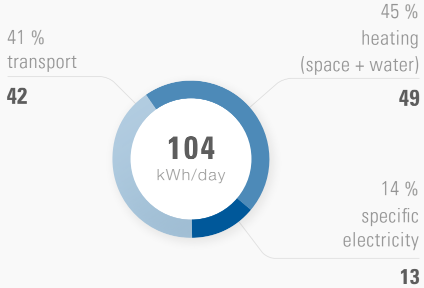
kWh per household per day



A household with appliances (and housing) that are energy efficient consumes half as much as a standard household.

Figure 4
Inefficient equipment

kWh per household per day



A household with end of life appliances and a badly insulated home consumes more than twice as much as a standard household.

the most efficient appliances, the energy intensive household could lower its consumption from 104 kWh to 80 kWh per day. To obtain further improvement in energy efficiency would require renovation of their home–a more difficult task that raises the question of funds more so than the renewal of appliances. We return to this issue of income levels at a later point in the text.

"Discretionary" usage

Let us now consider a hypothetical two-person household with occupants that lead lifestyles that are intensive in terms of so-called direct energy. Such high intensity is usually the result of three factors: a household that has energy intensive equipment, a household that has a large amount of such equipment, and one where such equipment is used extensively. A household in this category might typically own a four-wheel drive vehicle which it uses for short urban trips. This vehicle may be used for longer commuting distances than average (in this case we assume a 40 km round trip), and the dwelling type may be a poorly insulated detached house (our calculations here are based on a house such as this with 150 m^2 of living space). It has larger household appliances that consume more energy (an American refrigerator, which consumes three times more than a standard refrigerator) and it also has facilities that are entirely absent from other households (such as a swimming pool that uses 6 kWh per day, etc.).
Consumption for this household is 230 kWh per day. This high level of consumption derives primarily from transportation (98 kWh), heating and DHW (92 kWh), followed by the need for specific electricity (40 kWh). The analysis of this type of household allows us focus on cases where higher than average consumption levels are a matter of choice. This household uses a large-engined car for commuting, which is superfluous for the task. It also has a living space of 150 m^2, which is twice the size of the average home.
All studies of standard of living and direct energy show that consumption increases,

on average, with income. Households with financial means can reach very high levels of direct consumption. This is examined further below, with the analysis of impact by income level. But it is important to make a distinction between constrained direct consumption and discretionary direct consumption. This is the objective of the following analysis, where we focus on our final household type.

"Constrained" usage

In this section we analyse constrained consumption behaviour by looking at a hypothetical suburban household that is equipped with average appliances and where one of the two occupants has a 100 km per day commute. The household is a poorly insulated rented property with a living area of 60 m^2 (consuming 300 kWh/year/m^2). Apart from these differences, the behaviour of the household members and their range of equipment are identical to those of our "standard" household.

Consumption of the household (150 kWh per day) is twice that of the standard household. Heating and transportation account for over 95% of its direct energy consumption. This example highlights the constrained nature of certain types of energy expenditure and raises many questions relating to the implementation of public policies for energy conservation. This example is not, of course, merely theoretical - in reality, many such households exist. They are the focus of the debate on fuel poverty and vulnerability (see Saujot, 2012). In France for example, many young couples are unable to find affordable housing in Paris. They are restricted to housing in areas outside of the city and extending into the Ile-de-France, where property is more reasonably priced and numerous. It is these constraints that must re-examined in the light of the energy transition.

Acting on direct energy consumption

Acting on direct energy consumption through public policy forces us to distinguish several questions:

Can we influence the usage behaviour of consumers? While some "small gestures" are possible (such as disconnecting chargers when batteries are full), such steps are individually insignificant. Some energy-intensive behaviour can be explained by lifestyle choices, social recognition or behavioural mimicry, and it is these that we may try to influence; while others result from constraints (a person finding a new job that is a long distance from their home, a house that is too big following the departure of children, a rental occupancy, etc.) that are sometimes difficult to overcome.

If we cannot change the behaviour of consumers, can we at least improve the efficiency of the production of final services (comfort, travel, leisure...) per unit of energy consumed? We have seen that efficient appliances can be a crucial issue, but we also understand that the constraints of renewal are linked both to the lifespan of equipment (very different for a light bulb compared to a building!) and to the ability of consumers to make the right choices (information, availability and finance).

Is it correct to combine all these types of consumption as we have done so here? We have seen that through the advancement of the technical characteristics of equipment, the consumption of domestic heating tends to fall sharply, while those related to specific electricity are subject to a double trend of efficiency and the proliferation of new applications. However, to generate this electricity, as we will see later in this article, much more embodied energy is necessary than to produce a kWh of gas or petrol...

Finally, the couples in our illustrative households are only aware of the energy that they are billed for directly. However, it took energy to produce their homes, vehicles and goods... and also, as soon as the occupants step outside of their homes, they use numerous services (lifts, heated and fully equipped offices, restaurants, shops, street lighting...) without knowing the cost of this energy. We now turn to the second component of the energy impact.

The importance and origin of embodied energy

The relative evolution of the embodied energy compared to direct energy and its domestic or imported origin will affect the design of public policies. For example, measures to label the carbon content of consumer goods seek to influence consumer choices to reduce the "embodied CO_2 emissions" of certain products. They thus complement more traditional measures that aim to encourage direct energy savings. Similarly, we cannot be satisfied with a decrease of final energy consumption at the national level (excluding exports) if it appears that such a decline is offset by the consumption of energy contained within imported goods and services. The evaluation of the energy impact will enable the determination of this integrated energy balance, taking into account the energy content of international trade.

We first present the overall results according to the three main components of energy impact: direct energy, embodied energy of the direct energy, and the embodied energy in goods and services as well as its origin, whether domestic or imported. The calculation method for these consumption types is complex and will be the subject of a full discussion in the second part of this document. The results of a number of studies that use a similar methodology for the calculation of carbon footprint are then presented.

The components of energy footprint

As stated in the introduction, the annual energy impact of each household is 125 MWh of primary energy (10.7 toe), i.e. an average of 343 kWh per day per household. Direct energy only represents 24% of the total impact (i.e.83 kWh/household/day). Embodied energy consumption is 259 kWh/household/day (8.1 toe per year), including 204 kWh of embodied energy contained in goods and services and 55 kWh of embodied energy that is necessary for the production of direct energy. Combining direct energy with its associated embodied energy is equivalent to 40% of our total energy consumption. The remaining 60% of energy consumed is contained within the goods and services purchased by households. F5

Out of the 204 kWh of embodied energy consumed per day per household, some of this is imported from the rest of the world (46%), either in the form of final products (the energy contained in televisions imported from South Korea, for example), or in the form of intermediate products that will be incorporated into final products in France (the energy used to make steel in India which is then imported to France to manufacture a car that is purchased in France). The remaining amount (54%) corresponds to the energy used to

Figure 5
Energy impact of an average household

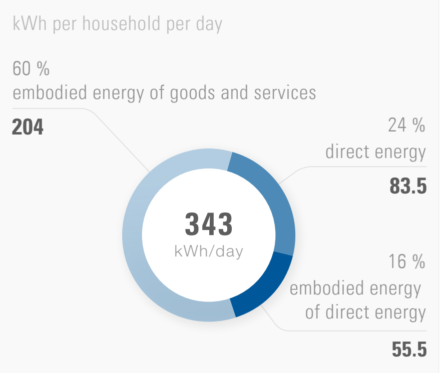
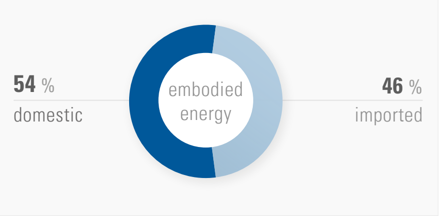
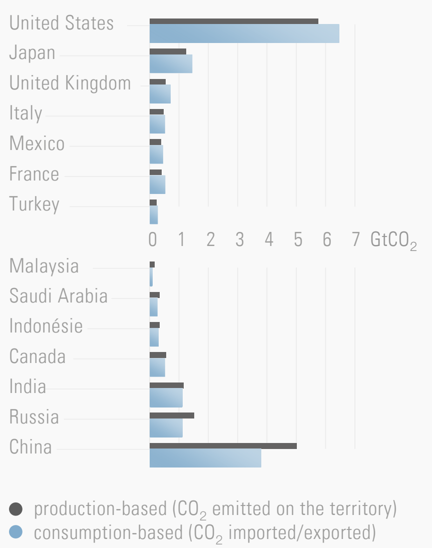


Figure 6
Imported and domestic embodied energy



produce goods and services in France that will be consumed on site. Energy consumption to produce goods in France that are consumed abroad is not included in the calculations here. F6

Figure 7
Largest net CO_2 importers and exporters - Input-Output method



Sources: IEA CO_2 Emissions from Fuel Combustion, 2010 ; OECD, Input-Output Database, May 2011

Recent similar studies

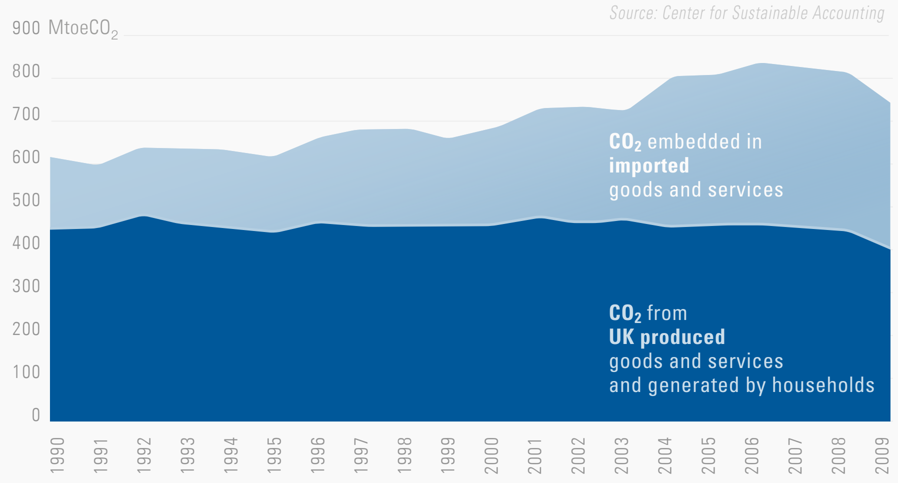
To study the environmental impact of household consumption and international trade, a number of multi-regional models that encompass the entire world have been made in recent years by many authors: Jean-Louis Pasquier in France, and internationally by Glen P. Peters, Edgar Hertwich, Tim Jackson, Christopher L. Weber, Thomas Wiedmann, Davis & Caldeira, S. Nakano *et al.*, etc. These models use input-output tables and the Leontief equation, in a similar way to the method described in the second part of this report.

The OECD and IEA have recently developed a database[9] that presents the national emissions of a territory (production base), along with the imported/exported emissions (base consumption). F7

This approach enables the better representation of the proportion of CO_2 emissions related to export activities. Thus, it clearly emerges that the United States, the country with the world's largest trade deficit, is also the world's highest CO_2 importer. In contrast, the country with the largest trade surplus, which is China, is also the world's largest CO_2 exporter.

Beyond these snapshots taken at various points, a number of recent studies have

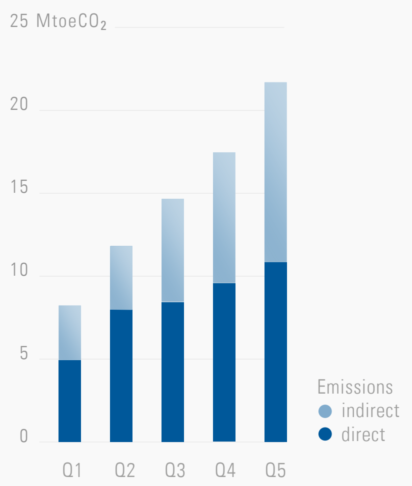
Figure 8
United Kingdom, emissions imported and produced on the territory



9 www.oecd.org/sti/inputoutput/co2

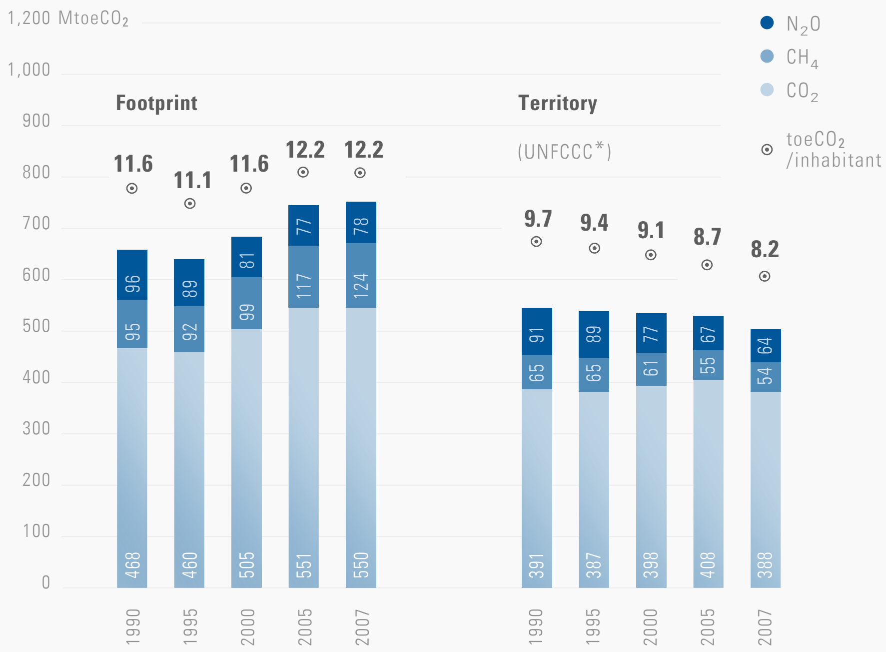
documented the evolution of imported carbon emissions over time. These studies show an increase in net emissions (net imports minus exports) in France, the United Kingdom and the United States, in the context of emission reductions for these territories. In the case of the UK, a study by the Centre for Sustainable Accounting at the University of Leeds shows a decrease in national emissions from 450 to 440 million tonnes (Mt) of CO_2 over a period of 20 years, but an overall increase of 600 to 750 Mt. F8
In France, a study by JL Pasquier for the SOeS (2009) also highlights a national emissions reduction of 15% over 17 years, but an increase in the per capita footprint of 5% over the same period (11.6 tCO_2 to 12.2 tCO_2). F9
Studies by Weber *et al.* (United States, 2009) and by Pasquier for France assessed the carbon footprint of households according to income. These studies show that

Figure 10
CO_2 footprint of French households by income quintile



Source: Pasquier et al. 2009

Figure 9
Territory emissions and imported emissions in France



* UNFCCC: United Nations Framework Convention on Climate Change (Kyoto protocol)
Version 2009 of the GHG emissions inventory for the UNFCCC

Source: J-L Pasquier, SOeS

the carbon footprint increases with income but with an elasticity (percentage change in emissions in relation to the percentage change in income) that is less than one: emissions rise as income increases, but the former is less rapid than the latter.
According to Weber *et al.* (2008), the bottom quintile (the 20% richest households) annually emits about 73 tonnes of direct and indirect CO_2 (which is analogous to direct and embodied energy), while the first quintile emits 23 tonnes. The income gap is 4.7, while the direct and indirect emission gap is 3.3. Similar trends are presented in the third part of this report.
In France, according to the same SOeS study, emissions of the bottom quintile are 22 tons per person (expressed in consumption units) compared to 8.3 tonnes for the first quintile. The emissions gap is thus 2.7, while the income gap is 3.4. This study provides additional information by presenting the proportions of direct and indirect emissions. The latter increases with income faster than direct emissions. Thus, while direct emissions reduce the appearance of the gap between rich and poor, this gap appears wider when looking at indirect emissions resulting from the purchase of goods and services. F10
These studies enable the assessment of the distributional impact of higher energy prices or the implementation of a tax. Much research in macroeconomics has focused on this issue, examining the impact of rising energy prices on unemployment and inflation.[10]

Conclusion

The embodied energy consumed by an average French household is 259 kWh each day, i.e. equivalent to the direct energy consumption of four households. This figure may surprise the non-specialist reader, but would not come as a shock to energy experts. Indeed, the embodied energy defined here corresponds to the energy balance of the energy, industrial, services and transport sectors, reallocated to the consumption behaviour of households and to which we have added the energy content of imports, and deducted that of exports. Note that, although we have only partly considered this aspect in our evaluation, we should also deduct the energy impact of foreign tourism from this balance, which is significant in France as it hosts several million tourists per month (transport, hotels, services, sports facilities...).
The transition from a representation of energy consumption that is explicitly present on consumer bills, to a representation based on the consumption of the energy that is included in consumption practices does not constitute a value judgement on the responsibility associated with the energy consumption practice. Such figures are not intended to shift the burden of energy transition onto the shoulders of householders, and to let the productive sector escape liability. It is up to all stakeholders at all stages of the production process to prioritize the most economical energy choices.
However, to go beyond the classic corporate/household dichotomy enables consumers to see the real physical and environmental impact of their lifestyles. We return later to the practical uses of this new representation. Before that, to better understand where this embodied energy comes from in the case of France, we show its origin through the complex systems of international trade and the production of goods and services - the French "economic cycle".

10 See in particular, "Oil shocks and the macroeconomy, the role of price variability", K. Lee, S. Ni, R. Ratti, The Energy Journal, 1995.

Part 2

The evaluation of energy impact

Energy is needed throughout the production chain. As noted above, to choose the most efficient public actions and policies to control consumption, we must link final energy consumption data to the energy actually used for this consumption, whether this applies to the territory of consumption or elsewhere, something that the current system of representation does not allow.

Thus, in a context where industrial production and trade are increasingly fragmented at the global level, a growing part of the overall energy that enables final consumption in a particular country does not appear in its national energy balance. A decision at the national level can have unintended, and even contrary, consequences on the global scale, through the induced externalization of problems: an apparent decrease in the energy intensity[11] of the French production system may imply an increase in process efficiency, as much as it does a delocalization of production to foreign territories.

Such a systemic perspective is singularly lacking at a time when the rational management of energy resources is increasingly needed, especially for Europe, which is one of the least endowed[12] regions in terms of energy. It is essential to give serious consideration to "sustainable" consumption policies because this would enable the analysis of the impact on the energy needs resulting from any change in the structure of consumption.

It is therefore becoming increasingly important, in the analysis of all energy-related issues, to understand how energy consumption is distributed across the economic cycle, but also to study the energy content of final consumption. Understanding these direct and indirect energy flows will enable the enrichment of the development of tools for energy consumption analysis and forecasting.

Putting the ultimate consumer back at centre of the analysis also helps us take account of the fact that any energy supply is only intended to satisfy consumer demand. This allows us to consider all of the energy that a household really needs, according to the type of need.

This approach is part of the current movement to develop new indicators, for example such as those mentioned by the Stiglitz-Sen-Fitoussi Commission (Stiglitz, Sen and Fitoussi, 2009), which recommends the use of indicators that can be interpreted as stock management tools to measure the "global demand from nature".

Today, the question is no longer about the value of this type of balance, but its feasibility given the available data, in a way that is sufficiently clear and transparent so that it can be widely shared. This is the purpose of the discussions we initiate here.

11 The energy intensity of an activity or of a geographical area is the amount of energy necessary for the creation of one unit of wealth, at the scale of one year and for a defined perimeter. This name can refer to many definitions: primary or final intensity, relative to GDP (gross domestic product) in the market exchange rate or in purchasing power parity compared with the added value.

12 See Roadmap to a resource efficient Europe and Communication on a resource-efficient Europe

In the following section, we describe the method used to calculate the impact, then present the preliminary results on a global scale, to finish with a more detailed application of household consumption in France.

The formulation of energy impact

Definition

As mentioned above, energy impact is composed of the direct final energy consumption, that we refer to as direct energy, and the energy consumption (intermediate and final) of the production systems necessary for the provision of goods and services to the final consumers, which constitute the embodied energy.

This embodied energy is itself divided into the embodied energy of products and the embodied energy of the direct energy ("the embodied component of direct energy").

In this exercise, the impact is calculated in terms of primary energy.

Many studies that adopt this new approach are still limited to considering only the domestic part of the embodied energy. This means that they do not take into account the energy consumed abroad to satisfy the needs of the national territory, or the energy consumption within the territory that is used for exported products, which is unsatisfactory in the context of increased international trade. More sophisticated approaches enable imports and exports to be taken into account. Two options are possible: either assigning imports and exports with a content that is equal to domestic content to calculate the avoided consumption, or assigning their real content. There may be significant gaps between these two methods. The approach presented below, which was developed by EDF R&D, corresponds to the second option.

Methodological approach

To develop this representation of the global energy demand linked to final consumption, we must go beyond the limits of traditional sectoral accountability, which only reflects the energy consumed in a territory rather than that induced by the final consumption of the territory's residents. As the inclusion of imports and exports is required here, the only way to achieve this is by considering the worldwide situation.

We apply here the so-called "Leontief" approach (Input-Output Model: IOM). It is based on a representation of the economic interrelations derived from national accounts. The IOM describes national and international monetary exchanges between productive sectors in the form of a matrix. It thus enables, through the application of elementary algebra, the determination of all physical consumption or pollution that are attributable, directly or indirectly, to a given economic need. Globally integrated balance sheets can be built at the "macro" level, rather than in an elementary manner. These models use the classical input-output (I-O) tables of National Accounts (NA) to allocate, through induced cash flows, a physical or environmental content to final consumption; however, clearly this means that the informal economy is not taken into account. This approach lends itself well to an overall analysis because there are a number of very comprehensive I-O tables available at the global scale, that are commonly used for economic studies. Finally, this approach allows verification by comparison with traditional annual balance sheets, which is not the case for analysis methods such as Life-Cycle Assessments (LCA), which can integrate consumption over several years. B2

This approach has been widely and successfully applied in the estimation of "GHG footprints" and for performing other types of "material assessments"; but, to our knowledge, it has rarely been applied to energy. However, energy is a prerequisite for the development of CO_2 balances or CO_2 contents. Furthermore, using this representation in a prospective way requires the modelling of the effect of choice on the changing "energy mix".

For a more precise understanding of the issues of energy and climate policies associated with the role of international trade, as well as any potential revisions to our traditional way of thinking, we present here an adaptation of the methodologies used in the studies cited above, that were developed by the EDF R&D team, in order to apply them to energy.

The methodological principle of modelling, developed in Appendix 7 (Application of the Leontief equation in a single region) is relatively simple.[13] The transition to actual calculation is more difficult, as often the real difficulty has been in making the modelling adequate for the available data, and vice versa, due to unavoidable methodological simplifications and approximations.

The differences between the scopes and subdivisions of economic and energy data systems, which were built within different statistical analysis frames, as well as the implications of the choice of representations made in the national accounts, have made this exercise particularly tricky. The hybridization of conventional economic data with the different energy balances available has led to compromises, which are sources of inaccuracies. Nevertheless, it was only by taking these first steps that we could be convinced of the value in going further. B3

"Material assessments" in France and the world today

The inclusion of an integrated physical assessment has become a priority in many countries. Linking physical and monetary data is the goal of the System of Integrated Environmental and Economic Accounting (SEEA), developed by the United Nations with a view to the standardization of national account classification.

Box 2

Input-Output tables: description and history

The methodology of the Input Output (I-O) table enables the measurement of the energy impact of households in a framework that is consistent with national accounts - this is the best way to avoid double counting. The economist Vasili Leontief developed the I-O approach in the mid-1960s, as part of his work on international trade. These tables enable every economic sector to be represented by a linear equation, allowing intersectoral monetary exchanges, both national and international, to be analysed. The simple and formal nature of its methodology attracted economists, accountants and statisticians of the time. The "Leontief matrices" have been gradually incorporated into official national accounts. It is interesting to note that the integration of this tool corresponds to the integration of a new representation of the economy in the official accounts. Vasili Leontief has thus helped define our current perception of the economy. The formal description of the methodology is presented in Appendix 7 (Application of the Leontief equation in a single region).

In the 1990s, the I-O table methodology was "enlarged" and linked to physical data. Proops (1993) used the I-O tables and combined them with data on carbon emissions: a level of CO_2 emissions is assigned to each sector, while each row of the Leontief matrix corresponds to an equation that represents the quantities of CO_2 emitted by one sector and consumed by another.

Through the application of elementary algebra it is possible to determine physical consumption or pollution that is directly or indirectly attributable to a given economic need. This opens the way for integrated and global physical balance sheets that are built at the "macroscopic" level, rather than in an elementary manner. This approach lends itself well to an overall analysis because there are a number of very comprehensive I-O tables available at the global scale, that are commonly used for economic studies.

13 The description of the methodology given here is very brief because it is clearly not the focus of this paper. Besides which, to be honest, we have not brought anything new to this issue that has not already been published in the literature. Instead, in our bibliography we refer interested readers to the various studies of the authors mentioned in the previous paragraphs, which are very well documented.

Box 3

The Life Cycle Analysis

When an integrated assessment is required, the Life Cycle Analysis (LCA) is usually the first technique to be considered. The method was developed in the 1990s and provides a precise and rigorous elementary reconstruction. It is a standardized methodology, acknowledged internationally and regulated by the ISO 14040 standard. It enables the detailed examination of the material balance of a product or industry. Unfortunately, for each product, it requires a precise knowledge of all stages of production (manufacture and distribution) at all times. It is therefore difficult to find, qualify, apply and maintain a database that covers the entirety of global consumption.

LCA methods are useful, for example, in the comparison of the energy content of a particular product compared to another, but less relevant for multi-regional macroeconomic analyses, including the flow of imports and exports, and also for multi-sectoral analyses at the global scale. LCA analysis is ill-equipped to take into account all deviations from the norm (errors of production, overconsumption due to malfunction, product diversity, economic fluctuations…) which in reality occur frequently on the global scale. Finally, they cannot deal with annual macroeconomic ramifications since the temporal scope of the analysis is not particularly limited.

LCA analysis does not therefore provide measurements, for a given period, of energy consumption at the regional, national or international scale, without the risk of duplication, double counting or possible oversights. Thus, LCA does not allow rigorous calculation of total consumption in a macroeconomic context that takes into account the flows of imports and exports or of multi-sectoral ones at the global scale, which today characterize production chains. They are therefore not suitable for the representation of energy impact.

Within the framework of the SEEA, new accounts are therefore constructed. For example, the solid waste accounts represent their movement between sectors of the economy and the environment. Another example is the material flow analysis that presents an overall picture of the physical inputs and outputs that connect a national economy to its environment. This is a new approach. Access to accurate and detailed data on these topics therefore remains limited because homogeneous databases to cover the global scale are only just beginning to be built.

In the same vein, the development of NAMEA databases (National Accounting Matrix Including Environmental Accounts) (Ifen, 2006) is underway in several countries, particularly within the European Union. Created in the late 1990s by Statistics Netherlands, NAMEA is a hybrid monetary and physical statistical system that combines national accounts and environmental accounts. Monetary information from national accounts is associated with physical supply-use tables (PSUT). The physical accounts are combined with monetary accounts in a single matrix, which is usually represented in the form of an I-O table. The first NAMEAs concern CO_2 emissions, but others are under construction for water, energy and other natural resources and raw materials. NAMEAs are formulated at the national level through a very complex process; while NAMEAs with regional or global ramifications do not yet exist, although work is underway in this area.

At the French Ministry of Environment, the Department of Observation and Statistics (SOeS) focuses on the construction of such databases for France. The first will be a NAMEA-GHG,[14] followed by a NAMEA-energy and then a NAMEA-water. Jean-Louis Pasquier, co-author of a study on CO_2 emissions of the French economic system (Pasquier, Lenglart and Lesieur, 2009) is in charge of these projects.

The EXIOPOL project, led by Eurostat and funded by the European Commission, aimed to compile I-O tables at the global scale and to link them with physical and environmental accounts. The intended result was to enable the national NAMEAs to be linked together. With 38 partners, including research centres and universities, EXIOPOL had very ambitious objectives: it aimed to facilitate the accurate calculation

14 GHG: greenhouse gas

of externalities caused by economic activities at the global scale and those that are induced by final consumption at the end of the chain. The project came to an end in late 2011, and a global database is available to purchase for the year 2000 (containing 43 countries, which cover 95% of the global economy, along with figures to take the rest of the world into account).

For the time being, to our knowledge, there are no NAMEA databases for energy. To fill this gap, EDF Research has attempted to develop a tool to reconstruct a global energy balance that is integrated with final consumption. At the world scale, two large international reference databases enable a global analysis: the OECD and the GTAP.[15]

For our study, we have used the collaborative GTAP database, developed at Purdue University (Indiana, United States). It is notably comprehensive and easy to use. We used the GTAP7 version, which includes for the year 2004, the monetary I-O tables of 113 countries, with a sectoral division into 57 sectors. This is not a conventional economic database that is annually updated, such as the OECD database. A new version (GTAP8) has been recently released, but we did not use it for this work.

This database is known for its homogenization of international data, providing overall coherence and a global loop. It is now frequently used to conduct unilateral or multilateral multi-regional studies.

The GTAP database is supplied with software that allows the automation of sectoral or country groupings, which is a very useful facility for our particular line of research. The GTAP7 version had a slight defect regarding the reconstruction of imports, which could be corrected by the use of a rectification aggregation engine that was developed by CIRED (Hamdi-Cherif, 2011). Furthermore, from GTAP7 onwards, physical and environmental data have been used to support the monetary database. The database also contains figures for the intermediate energy consumption of each sector. This addition facilitates the calculation of energy impacts. At the national scale of France, we relied on statistical data from the INSEE.

Qualification of GTAP energy data

Primary energy consumption was allocated to different consuming entities of the GTAP database, on the basis of information from the IEA 2004 database. The comparison of raw data from these two databases showed significant differences. On a global scale, the difference between GTAP and IEA (with "bunkers")[16] exceeds 30% (3.9 = 15.1 - 11.2 Gtoe). Discussions with the designers of GTAP have ensured that this gap has been identified, enabling the pinpointing of the causes and the development of the most suitable remedial measures (see details in Annex 1: Qualification of GTAP energy data). After this initial recalibration, the gap was reduced to 3%, which is much more satisfactory. T1

However, some gaps remain, especially at the regional level (see Annex). To address these gaps we require a better

Table 1
Recalculation of the overall energy balance in GTAP 7

Energy balance	Mtoe	Gap (Mtoe)	(%)
Global IEA for 2004 (without bunkers)	10,980		
Global IEA for 2004 (with bunkers)	11,277		
Global GTAP 7 original	15,146	**3,869**	≈ 34%
Global GTAP 7 recalculated	11,664	**386**	≈ 3%

15 Global Trade Analysis of the Purdue University
16 Bunkers include the energy supply for all international maritime and aerial fleets. The allocation of these bunkers to a country is sometimes tricky.

understanding of the distribution of GTAP in bunkers, of traditional biomass and other sources of differences. Firstly, we must update calculations using the new GTAP version before holding discussions with the developers of the database.

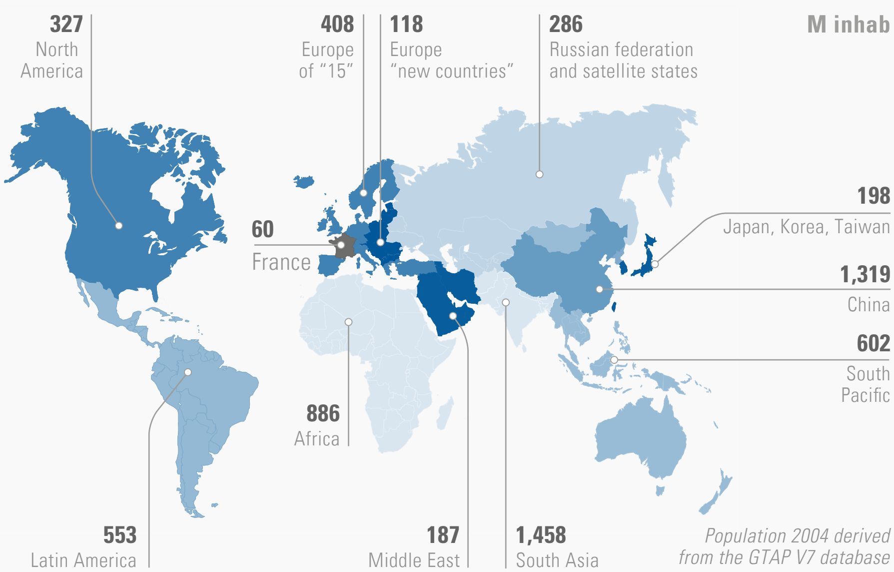
Representation of twelve regions

To establish sectoral grouping at the global scale in order to rebuild usages requires the consideration of the heterogeneity of practices around the world. Given the complexity of the task, we chose to analyse the usage consumption and the consumption of productive sectors (domestic or importers) at the global scale.

The analysis presented later for France offers a more detailed reconstruction of national practices.

Our study identifies 11 regions, which are as homogeneous as possible from an economic point of view, for the analysis of international trade (France is the subject of special treatment, see details in Annex 6: regional division). Such division, even when general, allows the rough determination of the geographic origin of imported goods. T2 F11

Figure 11
The twelve regions of the model



Population 2004 derived from the GTAP V7 database

Table 2
Selected regional division

EU 15	Countries of Europe "the 15" (France excluded) with Norway, Switzerland, Iceland and Turkey*	Ex-USSR	Other ex-"Soviet bloc" countries
EU New countries	New accession countries	Latin America	Countries from Latin America
North America	USA and Canada	Africa	African countries
Japan, Korea, Taiwan	Japan, South Korea and Taiwan	Middle East	Middle East countries
South Asia	Southern Asia (Indian subcontinent)	South Pacific	Asia-South Pacific
China	China, Hong Kong and Singapore	France	France

** These four countries were added to the group "EU 15" because the structure of their economies, and particularly their bilateral flow, was closer to this group than to the "EU New" one, whose transactions with the "Ex-USSR" group are dominant.*

Global energy impact

In this section we present the preliminary results of the global scale study and show the validity of the orders of magnitude obtained. The initial purpose is to account for the gaps between the energy impact of large regions and energy as measured conventionally. The results are not definitive and refinement is necessary, but we can still draw reliable conclusions. Unlike the data presented above, the results are presented in Gtoe, adopting the same convention applied by energy production sectors. F12

The world consumed 11.9 Gtoe of energy in 2004. An initial observation that was interesting to note was the relatively low amount of direct household energy consumption: less than 1/4 of the total when all non-commercial energy is included. Direct energy thus represents 2.9 Gtoe (or 33,000 billion "primary" kWh, i.e. one billion times the direct energy consumption of the average French household), embodied energy accounts for 9 Gtoe (or around 100,000 billion primary kWh) i.e. 3/4 of the total energy consumption. This embodied energy is divided almost equally between the productive sectors of the economy (54%) and the energy producing sectors (46%).

Structure of the impact at the regional level

The model reveals, unsurprisingly, that by "region", the respective proportion of direct energy out of the total impact decreases with the level of industrialization. The significance of the embodied energy seems naturally higher in the more developed regions. However, this observation must be balanced by the fact that everything related to the informal economy is absent from the analysis and that a part of the non-commercial energy, that is integrated to the direct energy, certainly contributes to the production. For a more meaningful analysis, it would be necessary to assess the influence of the informal economy. T3 F13

Figure 12
Energy impact at the global level in 2004

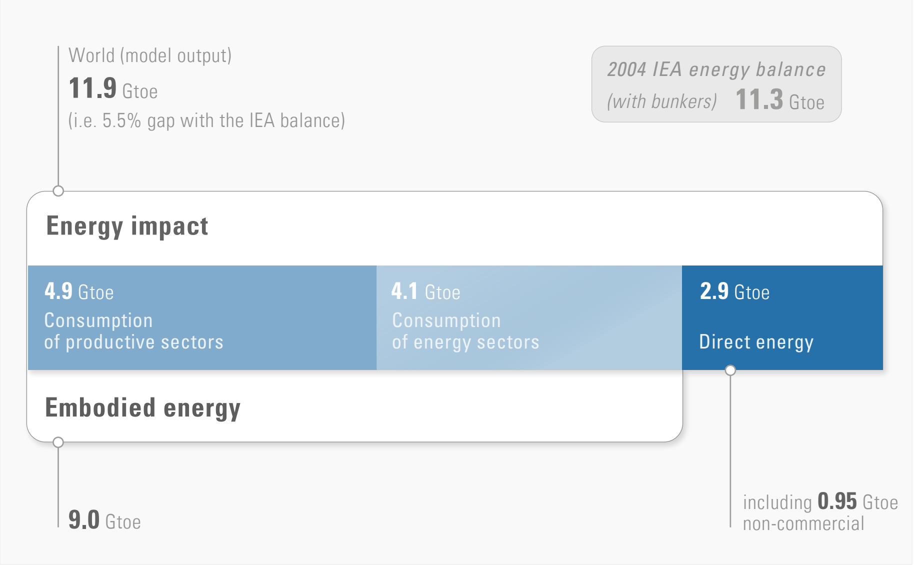


Figure 13
Breakdown of the energy impact into embodied energy and direct energy

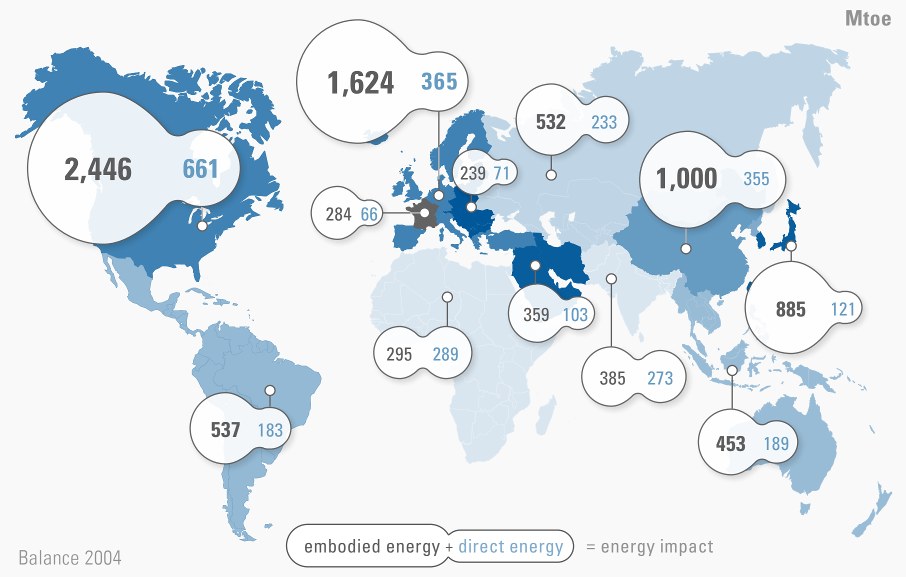


Table 3
Energy impact in world regions in 2004

Mtoe	Energy impact	Embodied energy	Direct energy	Direct / impact	non-commercial energy
EU 15	1,989	1,624	365	18%	35
France	351	284	66	19%	9
EU new countries	310	239	71	23%	13
China	1,354	1,000	355	26%	217
Japan, Korea, Taiwan	1,006	885	121	12%	2
South Asia	657	385	273	42%	202
South Pacific	643	453	189	29%	111
North America	3,057	2,446	611	20%	49
Latin America	720	537	183	25%	68
Middle East	462	359	103	22%	1
Africa	584	295	289	50%	231
Ex-USSR	764	532	233	30%	4
World	11,898	9,039	2,859	24%	942

Comparison of energy impact with the classical IEA balance

The energy impact of most economically developed regions is greater than their domestic consumption. The opposite is true for the other regions. F14

The calculation of the impact thus highlights the fact that the regions with the highest living standards externalize part of their energy needs in regions with lower income levels. F15

The export dimension of China is clear. A quarter of the energy used on its territory contributes to the satisfaction of foreign consumption demand, which generates local employment, and therefore local consumption. The situation of the former Soviet Union and the Middle East is explained by the extent of local energy resources rather than the export of manufactured goods. T4

These details allow us to see that France both imports more "energy content" and exports more than the "EU15" group as a whole. Ultimately, French consumption is thus a little less dependent on imports than the other European countries (see Figure 15). Its impact is 24% greater than its classical balance, while the difference is 33% for the "EU15" group.

The tool allows the refinement of the analysis by isolating the share of imports used for

Figure 15
Regional imbalances between energy impact and IEA balances

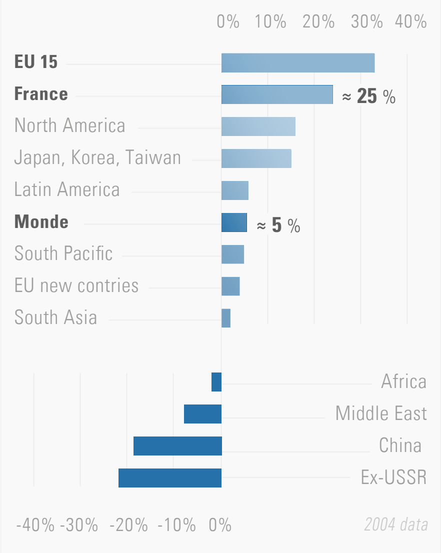
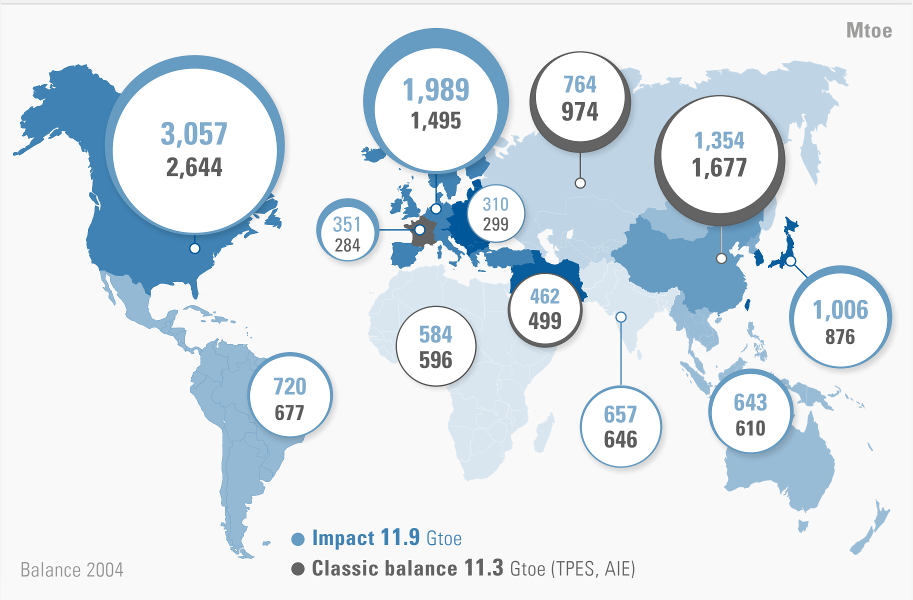


Figure 14
Comparison of impacts with the classical balances (IEA)



export. Thus we see that in China (an "assembler"), over a third of the imported "embodied" energy is used for exports. T5

This balance is not sufficient to establish the level of energy dependency because it only takes into account the location of the energy consumption and not the origin of the resources. Nevertheless, it provides a new element to add to the usual analysis of dependency ratios.

Table 4

Relative importance of imported and exported embodied energies per region

Mtoe	Energy impact	Imports Imports Dom Consumption	Imports Imports /impact	Exports "net" export	Exports Exports /impact	Import-Export "net"	Import-Export "net" /impact
EU 15	1,989	696	35%	254	13%	442	22%
France	351	134	38%	70	20%	64	18%
EU new countries	310	87	28%	85	27%	2	1%
China	1,354	167	12%	586	43%	- 419	-31%
Japan, Korea, Taiwan	1,006	286	28%	210	21%	76	8%
South Asia	657	80	12%	75	11%	5	1%
South Pacific	643	156	24%	161	25%	-6	-1%
North America	3,057	574	19%	300	10%	274	9%
Latin America	720	138	19%	161	22%	-23	-3%
Middle East	462	90	20%	217	47%	- 127	-27%
Africa	584	82	14%	110	19%	-28	-5%
Ex-USSR	764	53	7%	314	41%	- 261	-34%
World	11,898	2,543	21%	2,543	21%	0	0%

Table 5

Proportion of embodied energy imported for export per region in 2004

Mtoe	Total imported energy	Energy imported then exported	exported proportion of the imported energy
EU 15	696	38	6%
France	134	9	7%
EU new countries	87	18	21%
China	167	60	36%
Japan, Korea, Taiwan	286	49	17%
South Asia	80	5	6%
South Pacific	156	46	30%
North America	574	0	0%
Latin America	138	16	12%
Middle East	90	16	18%
Africa	82	8	10%
Ex-USSR	53	4	8%
World	2,543	258	10%

Evaluation of the bias in the applied methodology

The comparison of the model's results (11,898 Mtoe) with that of the corrected GTAP energy balance (11,664 Mtoe) shows a difference of 234 Mtoe (2.0%), which reflects the limited methodological bias.

The model allows the representation of energy production in each region that can be compared to the classic perimeter of energy balances. A regional analysis of this gap gives a measure of the bias introduced by the simplifications of bilateral trade flows, which are explained in the paragraph relating to the simplification of bilateral trade flows (see details of Leontief equation in Annex 7). We were able to verify that, even at the regional scale, the methodological bias remains low, never exceeding 4% (8.4 Mtoe for France). T6

A first step to reduce this bias would be to maintain the 56 sectors of the GTAP as discrete units, rather than group them into macro-sectors as was done for this exercise to reduce the calculation time. A precise and differentiated representation of bilateral trade flows will be considered at a later stage.

Analysis of impact per capita

At the global scale, the impact is 1.86 toe per capita per year, i.e. 21,600 primary kWh. The total impact, for a French person, is 6 toe per year on average, i.e. 70,000 kWh. Beyond these overall results, our tool also allows more refined observations. The impact per inhabitant takes into account the major demographic differences between regions. It thus enables the analysis of the impacts per usage and to envisage the differences in consumer behaviour. F16

Compared to conventional representation, the impact approach clearly emphasises the differences in consumption levels between regions. For example, the proportion of imported energy consumed per capita in wealthy regions in 2004 was of the same magnitude as the total energy required for the per capita consumption of less affluent regions, including China and Latin America!

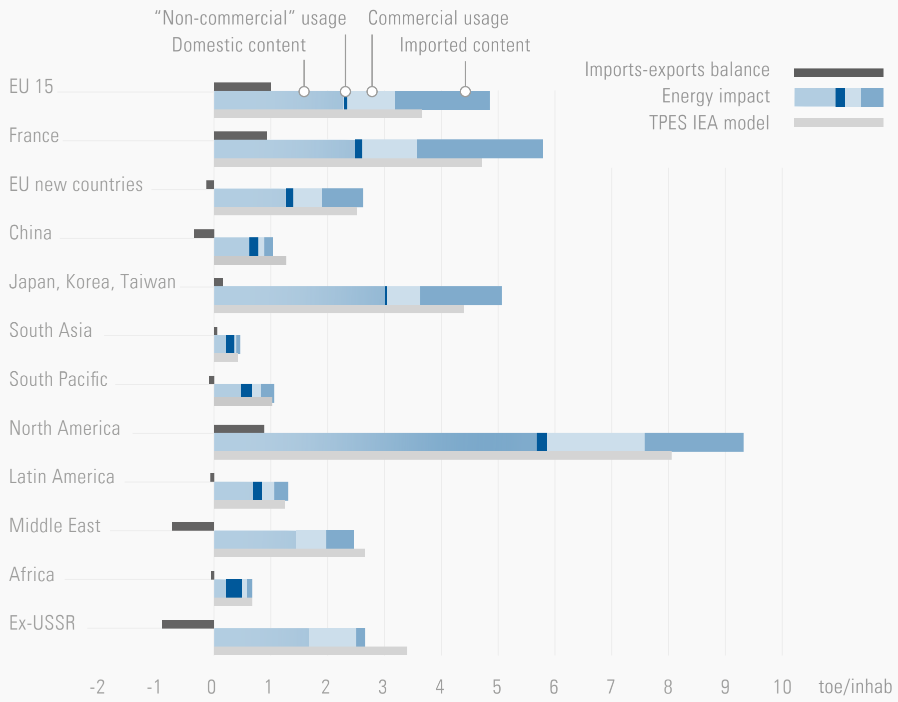
To go a stage further in our analysis, we should differentiate this impact per usage or even per population group; however, it is difficult to calculate impact at the global scale. The advantage of deepening the analysis in this way is explored in the next paragraph in the case of France.

Table 6

Gaps related to the method

Mtoe	Recalculated GTAP	Results of the model	Gap model-GTAP
EU 15	1,528	1,548	1.3%
France	278	286	3.0%
EU new countries	306	308	0.7%
China	1,711	1,773	3.6%
Japan, Korea, Taiwan	926	930	0.5%
South Asia	641	652	1.7%
South Pacific	643	648	0.8%
North America	2,725	2,783	2.1%
Latin America	731	743	1.7%
Middle East	576	588	2.2%
Africa	603	612	1.5%
Ex-USSR	995	1,025	3.0%
World	11664	11,898	2.0%

Figure 16
Regional energy impact per inhabitant versus IEA balance per inhabitant in 2004



Energy impact in France

This section provides a detailed presentation of the energy impact for overall consumption in France. We thus identify at which locations in the global production system the necessary energy to satisfy final French demand is consumed. This allows a better understanding of the energy flows of the French and global economic cycles that contribute to the energy impact of households. This focus on France should allow us to go beyond rough averages, which are not indicative of changes in behaviour, and beyond differences between population groups.

Economic data per country that are used by the applied calculation tool - the GTAP I-O tables - are global and therefore undifferentiated. To distinguish by population group and by consumption purpose, which we have done in Part 3, therefore requires the combination of this data with more individualized information, resulting from detailed household surveys.

To carry out these more detailed analyses on French consumption, we had to reconcile the structures of the GTAP database with those of INSEE. To hybridize the results with the data from French surveys, we created connections between the GTAP divisions and those of the national accounts (NES 118) from which the consumption purposes are represented.

With regard to the direct energy consumption per household, we replaced the GTAP values with those derived from national statistics because these figures were more amenable to the type of analysis that we sought to perform.[17]

By dividing the national impact by the total number of French households (27.5 million), we thus obtained an initial energy impact per household. F17

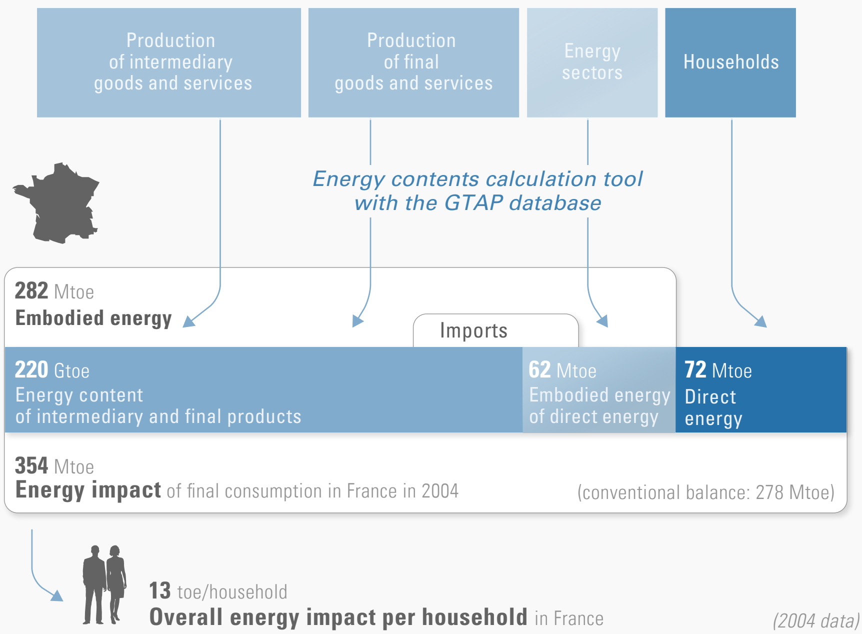
The embodied energy of French household consumption

This "overall" energy impact per household is quite difficult to analyse, firstly because there is no differentiation between household types, and secondly, because it includes some forms of consumption that are not directly attributable solely to households. We have chosen this way of representing consumers, which is a fairly common approach. Often, we use a standardized consumption unit (CU) that takes into account the scale effects of the consumption needs, depending on whether a consumer lives alone or not, or on how many children they have. It would also have been possible to do a per capita study. Of course, the values change depending on the CU chosen, but all are legitimate according to the type of analysis or the comparisons required. In future it may be necessary to devise new units for energy.

National accounts apply the following division on the French territory: the production (or "resources") on one side and the demand (or "usages") on the other.

All productive sectors are encompassed by the production grouping (agriculture, industry, energy sector companies, private and public services, etc.), including those present in the territory as well as in importer countries. The productive sector is

Figure 17
Construction of the energy impact per household in France in 2004



17 The information in the GTAP database does not allow the differentiation of fuel oil for heating from motor fuels. We therefore chose to use the statistics of the Ministry responsible for energy (SOeS) and to «hybridize» these figures with GTAP energy information. Usage energy therefore increases from 66 Mtoe to 72 Mtoe for the SOeS, which adds 6 Mtoe (6.2) to the impact.

typically differentiated according to whether its products are used directly by final consumers or by other domestic productive sectors.

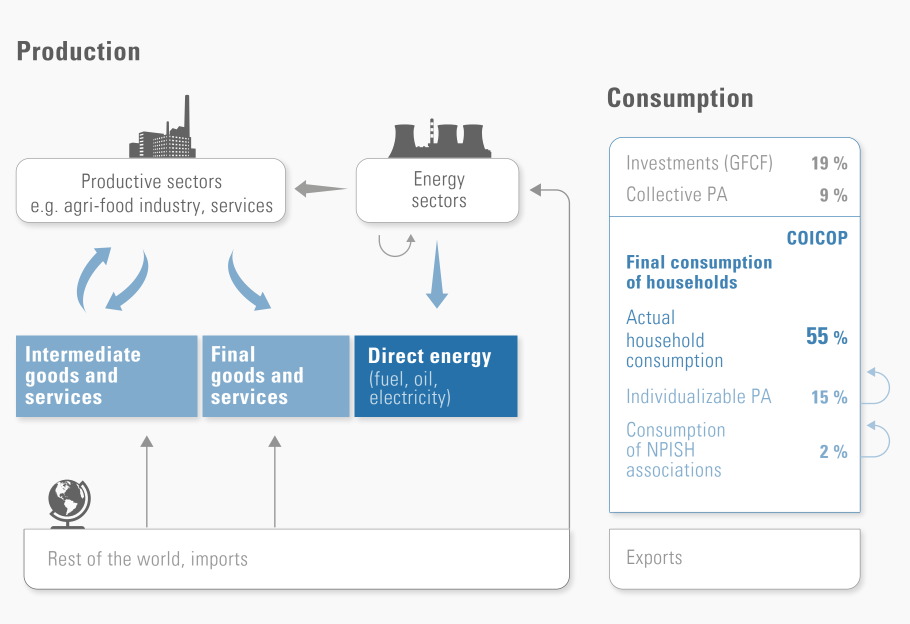
Final domestic demand is divided into four major components: household demand, public administration demand (PA), that of non-profit institutions serving households (NPISHs) and gross fixed capital formation (GFCF), which corresponds to investment. Export demand, which induces consumption in the territory, is added to this domestic demand. F18

In the national accounts, household consumption is presented by two approaches: the final consumption expenditure, if we limit ourselves to what is paid directly by households; and the actual consumption, if we add what is provided through their PA and NPISHs. Often, when talking about household consumption we only refer to that which corresponds to actual expenditure without taking transfers into account. This practice can lead to significant gaps, especially when observing the budgetary burden in relation to the income quintile.

In this study we were able to calculate the impact of actual household consumption. We must be aware that this representation is not simple,[18] even if it is particularly relevant for international comparisons. Therefore, two concepts of income are associated with these two notions of consumption: disposable income and the adjusted disposable income. The adjusted disposable income is equal to the disposable income to which we add the social transfers in kind.

Disposable income includes "imputed" income, which does not correspond to an actual expenditure but represents an "avoided" expenditure. For example, the "imputed" rents correspond to rents that owners should pay for their accommodation if they were tenants. This convention of the national accounts enables the identification of areas of consumption that do not appear directly in the cash flows.

Figure 18
Breakdown of the French economic system



18 We were apply the results of an INSEE study: "Une décomposition du compte des ménages de la comptabilité nationale par catégorie de ménage en 2003" (in Bellamy *et al.*, 2009).

Property investment, which is considered as inheritance, does not appear at the level of consumption but in the GFCF. We can thus consider that we have an "annualized" value for the price component of a good. Of course, the question remains whether the property value is representative of the cost of "manufacturing/construction", but this brings us back to the difficult issue of the fair consideration of the price effects for the evaluation of a material quantity. This difficulty is discussed in Part 3.

Within the final PA consumption there is a distinction between individualized final expenditure (that for which the actual consumer can be individually identified: e.g. health, education) and collective consumption expenditure (sovereign functions of government: justice, defence, police, etc.).

To obtain the actual consumption from the final consumption expenditure of households, we therefore had to add the individualized proportion of PA and NPISHs. This exercise is not simple, but it has already been done by the INSEE (Bellamy *et al.*, 2009). We were therefore able to use their results. B4

It is difficult to precisely link the GFCF to households. In the I-O tables of the national accounts it appears as a separate block, grouping investments according to products and not to investors (there is therefore no differentiation between households and productive sectors). This could be improved by obtaining a table showing the composition of the GFCF, which would enable a better distribution among the different sectors. For further development in this regard, we would need to check with the INSEE to see whether such a table already exists. In any case, this point requires deeper analysis to correct any double counting due to imputed rents.

In this study we adhered to the actual household consumption. The GFCF and collective part of PA (PA when there is actual consumption) were not included; but it would be possible to uniformly estimate these values for each household.

We can then breakdown the energy impact of France to establish the actual consumption, and distinguish it from other components of national consumption, such as GFCF, PA, etc. F19

We note that actual household consumption represented 84% of the French energy impact in 2004, which is divided between embodied energy (63.24%) and direct energy (20%). GFCF and PA (collective) cover the remaining 16%.

Nearly half of the embodied energy is imported. These imports are almost equally divided between intermediate consumption (IC) and direct imports ("imports in IC" = 13%, "direct imports" = 15%), while embodied domestic energy ("actual consumption") represents 36% of the national impact.

Box 4

Taking into account the difference in consumption between population groups (INSEE study)

To go from financial expenses to the physical impacts, and to assess the impacts of different categories of households, it is necessary to combine the macroeconomic approach of national accounts with the microeconomic analysis of consumption, and to harmonize the information. To achieve this, we relied on a 2009 study by INSEE: «Une décomposition du compte des ménages de la comptabilité nationale par catégorie de ménage en 2003» (Bellamy et al.*, 2009.). It presents data on final consumption, social transfers in kind and actual consumption structured according to household consumption purposes. In this study, the following data were crossed and made consistent: I-O tables, the households account of the overall Economic Table (TEE) and the following five surveys: Statistics on the Resources and Living standards of households (SRCV), Fiscal Income (ERF), Family Budget (BdF), Housing Survey (EL) and Health Survey (ES). We therefore relied on this valuable work. Household consumption data are mainly derived from the French 2005 family budget survey. To facilitate the comparison between indicators, for the most part the data are from the years 2003 to 2005. Embodied energy is calculated on the basis of 2004 data, due to the absence of more recent data.*

Regarding direct energy consumption, which is not differentiated in the INSEE study, we have applied the same differentiation that was found in the 2005 BdF survey.

We then validated the representation of the energy balance, which was made possible by the development of the impact. To do so we returned to the classic perimeter of the "production" assessment from the impact. F20

Figure 19
Breakdown of the energy impact of the total French consumption

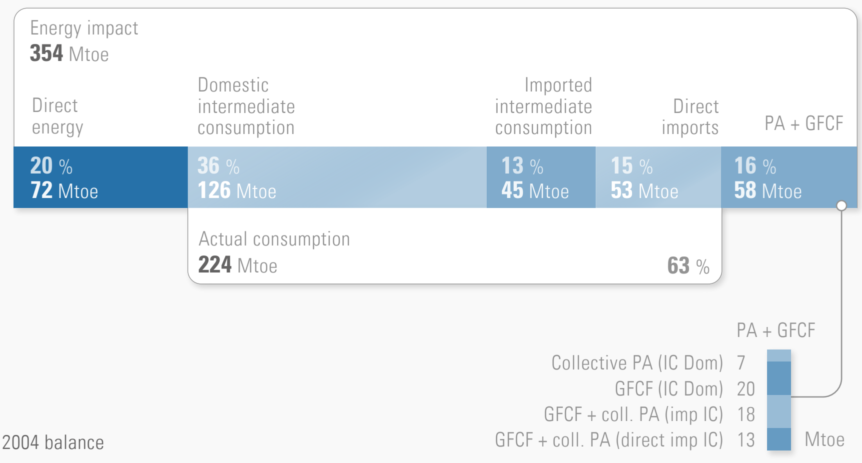
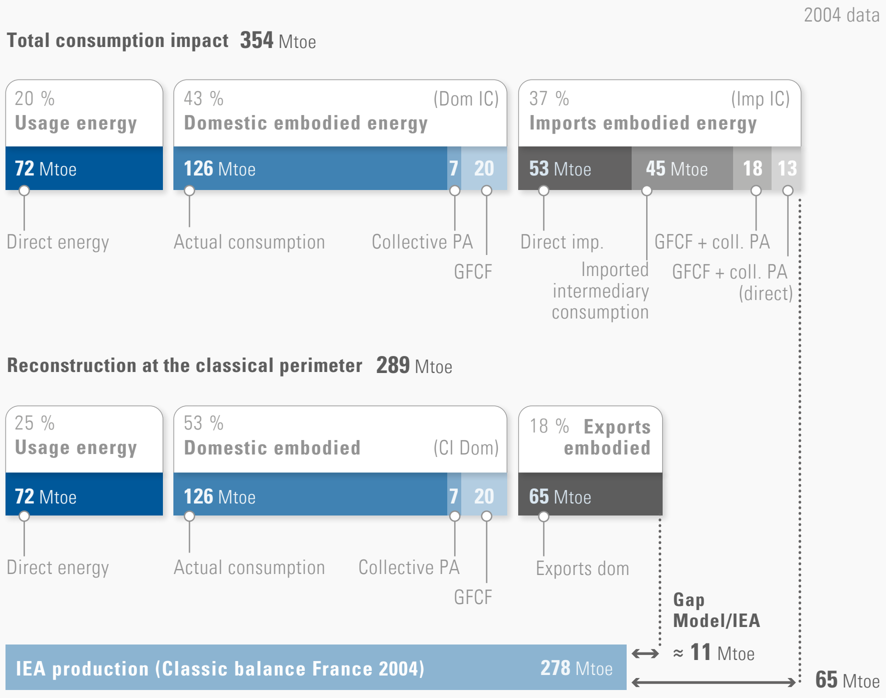


Figure 20
Validation of the construction of the French energy impact



From the latter we deducted the imported components and added the content of the exports. We thus obtained a value of 289 Mtoe, i.e. a difference of 11 Mtoe compared to the original value of the GTAP-IEA balance, which corresponds to the sum of the modelling bias of the "impact-GTAP" tool (8.4 Mtoe, see earlier section entitled - Evaluation of the bias in the applied methodology, p.30) and the change of the direct energy value (6.2 Mtoe).

We can therefore conclude that the development of the impact and the reconstitution along the lines of the INSEE format has not even slightly distorted the global energy balances.

We also notice that the proportion of "net" imports (gross imports minus exports) represents 22% (65 divided by 289) of the classic balance of the energy production on the French territory, or 18% of the impact. If we add this figure of 65 Mtoe to the "net" import of direct energy in 2004 (around 130 Mtoe), the energy dependency of France becomes greater.

Origins of the embodied energy in the final consumption of French households

Beyond the breakdown described above, it is worth trying to identify the way in which final French consumption is constituted. We can thus establish at which point along the global energy supply chain the energy was consumed to meet the demand of final consumers.

For this purpose, we divided the entire global production system into eight productive "macro-sectors". To avoid making the analysis overly complicated or spending an excessive amount of time on the calculations, we grouped together various productive sectors, described in GTAP, that we thought had relatively similar activities. T7

With the addition of a category for the direct energy consumed by households, we obtained the global distribution of energy that was used to satisfy the consumption demand of France, according to the different sectors. F21

The "energy" sector is a special case. Its consumption corresponds to the energy

Figure 21
Origin of the French energy impact in 2004 per sector

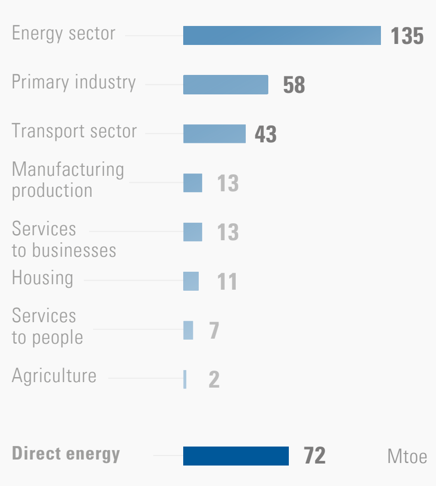
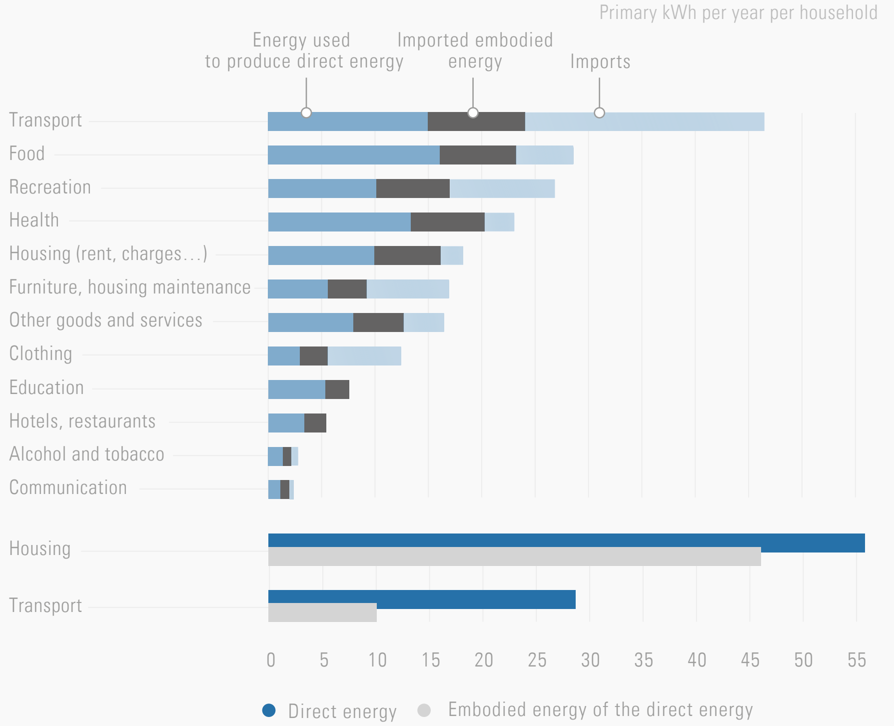


Table 7
Macro-sectors for consumption analysis

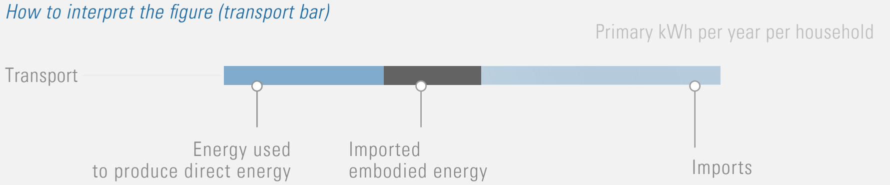
Macro-sector	Description of the grouped sectors
Energy	Energy producers and utilities (for productive sector and households)
"Transport" sector	Road, rail, sea and air transport companies
Industry	Mining, metallurgy and chemistry
Manufactured products	Appliances, electronics, transport, textiles, media products, etc.
Services to businesses	Various service companies:sales, marketing, communications, etc.
Services to people	Services/public administrations, cultural and educational services, etc.
Housing	Construction, public works, property agencies and rent ("GTAP")
Agriculture	Agriculture and food

lost during the conversion of primary resources to final vectors, to which is added the energy consumed by the sector for its construction and operation.
It was thus found that over a third (38%) of the energy needed to satisfy household consumption is used in the development, from primary resources, of energy vectors that are subsequently used by a productive sector. Direct energy covers 20% of the impact. It includes residential energy and the energy that households purchase for transport, which is primarily fuel. F22
The other two major "macro-sector" consumers are, unsurprisingly:
• the primary industry sector (16%), among which are energy intensive industries such as steel mills and chemical plants, etc.
• the transportation (of people and goods) sector (12%), which of course has a very

Figure 22
Import/export distribution of households energy impact by source of consumption



How to interpret the figure (transport bar)



Energy consumed in France in the sectors, either to operate the means of transport (electricity purchased by SNCF, oil purchased by aviation and bus companies, etc.), or to manufacture them (energy consumption of French car makers)

Energy consumed abroad to produce imports that will be used to make, in France, products used by the "transport" sector (the energy required to produce sheet metal in China, but that will be assembled in car factories in France)

Energy content of imported products used directly by the "transport" sector (vehicles or aircraft manufactured abroad) significant level of direct energy consumption. This includes, for example, SNCF, Air France and SERNAM. The energy directly consumed by households for their own transportation is not included.

The method also allows the analysis of the impacts according to the various categories of actual household consumption. Without going into detail on the analysis by category, which is the subject of the next section, we can already see how the dependency on imports is distributed according to different consumption categories. For this analysis, we do not consider household direct energy.

The French economy imports a large amount of embodied energy from the rest of the world (one third of its energy impact).

However, this proportion is not the same for all consumption categories: some import more embodied energy than the energy they use in the destination country, although this is not necessarily the case for certain sectors that may immediately spring to mind.

Indeed, the analysis of the energy impact of consumption categories enables the physical reality of a tertiary economy to be accounted for. Thus, the categories of "recreation and culture" and "health" are the third and fourth categories in terms of embodied energy consumption, after transport and food. Health and recreation are often regarded as symbols of a service economy. It would be wrong to think that these forms of expenditure are more dematerialized than others: they *activate* sectors of industrial origin and its associated embodied energy.

For the transport sector,[19] the proportion of imported embodied energy represents two thirds of the total. This result changes by orders of magnitude the classic energy balance for France, in which the proportion of direct energy for transport is usually larger than the embodied energy part. This is hardly surprising: steel imports, car components and assembled cars, for example, have a high energy content. If we add the imported fuel, the dependency of the "transport" activities of French households becomes significant.

The same observation can be made about the recreation and culture category, where imported video game consoles, cameras or printers, for example, also have a high energy content. Other categories, such as health or agriculture, have a high embodied energy content, but it comes from industries within the national territory and was not consumed abroad. Furthermore, since the production of medicinal drugs has a tendency towards delocalization, it may not be long before health expenditure uses more imported energy than embodied energy from the national territory.

It is not surprising that the importance of energy imports is much greater for clothing and recreation/culture than for food.

Origins of embodied energy per consumption category in French households

The distribution of productive sectors, which is the source of the impacts per consumption category, is also significant. F23

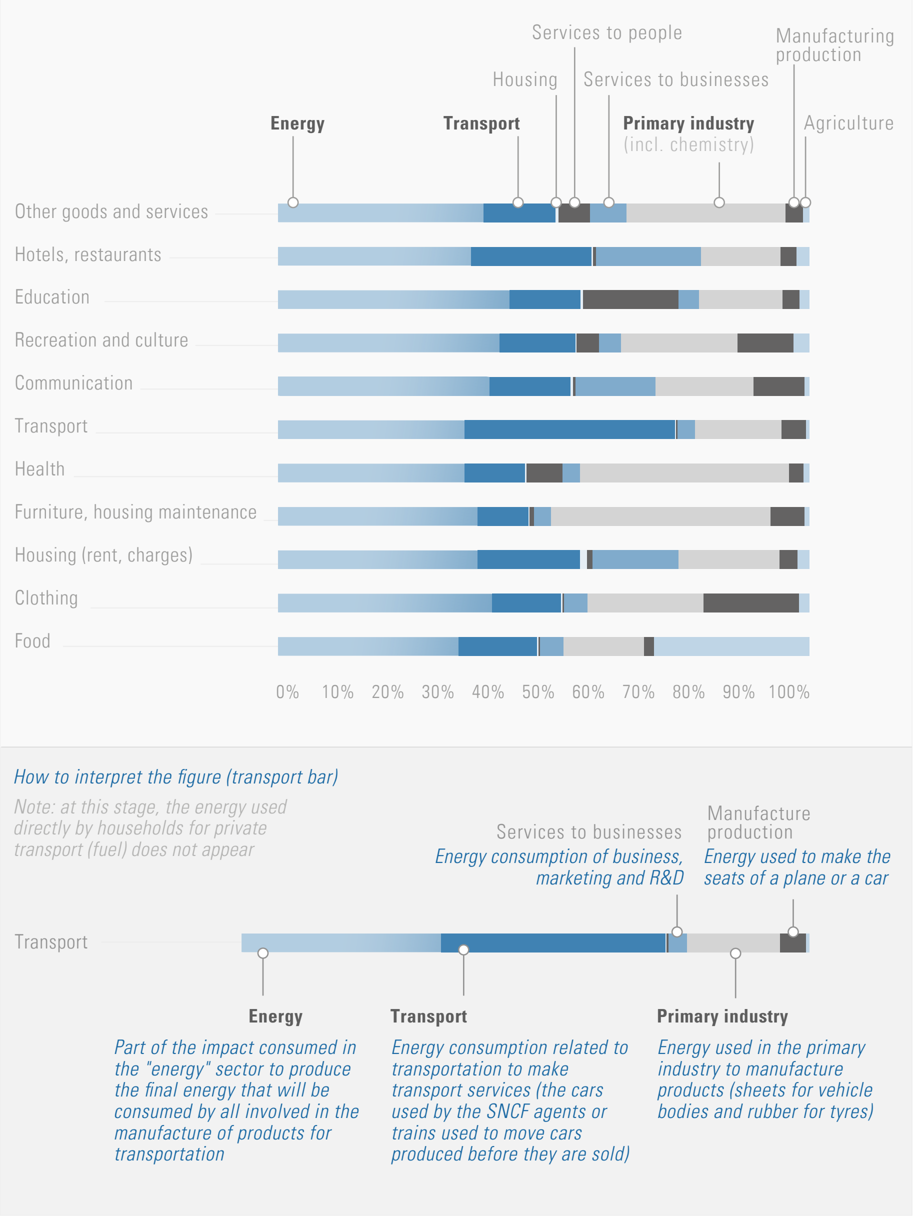
We note that the share of energy required to produce the various services consumed by households is stable for the different categories (about one third): this relative stability provides an indication of the fact that the energy consumed by the different activities derives from the same energy systems, and is therefore subject to the same constraints of efficiency and performance. Variations between categories reflect the greater or lesser use of electricity compared to other vectors.

Similarly, the share of the energy impact due to the transportation sector is relatively constant (with the exception of transportation expenditure), maintaining a figure of more than 10% (between 10% and 23%). This is indicative of the systemic role of transport in our economies; the embodied

19 Which does not take into account the energy directly consumed by households for transport.

energy associated with transportation depends more on the volume of expenditure (quantity of goods and services consumed) than it does on the type of expenditure.
This breakdown also reflects the greater significance of human services in the education or health sectors, or the relative importance of manufacturing in the clothing industry.
These are new perspectives that offer interesting avenues for further research, however, a more detailed analysis would require more time. Inter-regional comparisons would certainly be very informative too.

Figure 23
Sectors of origin of French household energy impact in 2004



Part 3

Energy impact according to the standard of living

So far we have discussed the energy impact of households through average values. However, the public debate on energy policies focuses on issues of equity and inequality between households. The carbon tax in France was rejected by the public, largely because it was perceived as a regressive tax that particularly affected rural and low-income households (Sénit, 2012). This raises the question of energy consumption linked to income distribution.

It is within this context that the INSEE has developed its activities since the 2009 Stiglitz-Sen report on the measurement of wellbeing. New indicators are being developed, taking into account different types of households and going beyond the average individual. However, in terms of the environmental impact[20] resulting from different standards of living, there is still a great lack of knowledge and data. Many studies have focused on energy consumption levels according to income, but most are limited to direct energy.

To contribute to this debate, we present here the findings from our investigation into the energy impact of French households according to their income level, basing our comments on the results of studies on financial expenditure.

Household energy impact by income quintile

The variation in energy impact according to income level and the level of household expenditure enabled us to test several hypotheses and to better understand the determinants. To further refine this analysis, we focus more precisely on the energy impact per expenditure for quintiles 1 and 5.

The representation of energy impacts per quintile show, unsurprisingly, that impact increases with income. The first quintile consumes a total of 200 primary kWh per day (6.3 toe/year) per household, compared to 504 primary kWh/day/household (15.8 toe/year) for the bottom quintile, i.e. they are separated by a factor of 2.5. F24

This gap can be compared to the difference in the income level and household expenditure. In 2003, differences in income levels between quintiles 1 and 5 were in the region of a factor of 5; consumption expenditure excluding social

20 The environmental footprint, as opposed to the term energy impact which is used specifically for this work, must be understood in a broad sense, including not only energy (carbon, matter), but other types of resources that can be calculated using various methods.

transfers differed by a factor of 3.4; and expenditure including social transfers by a factor of 2.2. F25 F26

Thus, two effects explain the observed differences: the *volume* effect (wealthier households have a higher volume of consumption) and the *structure* effect (the consumption basket of wealthier households, regardless of the volume, is more energy intensive).

Indeed, if we compare these results to what would have been obtained with undifferentiated "consumption baskets" (where we assume that for each income quintile the distribution is identical to that of the average household) we notice an accentuation of the gaps. This indicates that the consumption baskets of poor households are made up of less energy intensive products than those of wealthier households. In other words, the energy content of household expenditure per euro spent increases with income. F27

Figure 25

Household expenditures per quintile in 2003

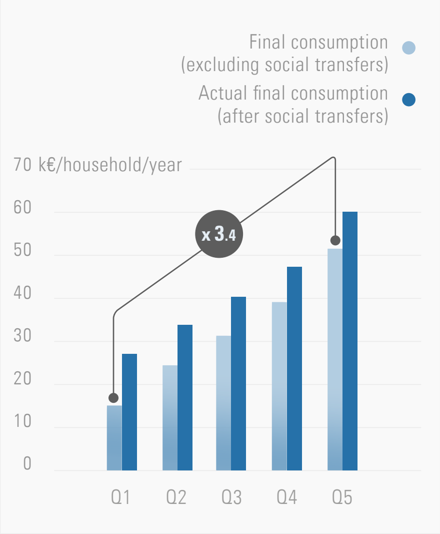


Figure 26

Revenue level per quintile in 2003

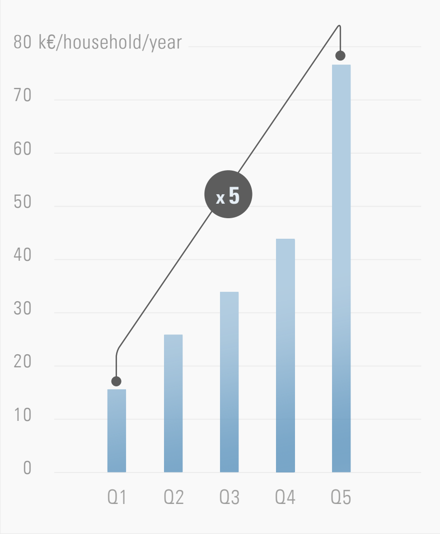
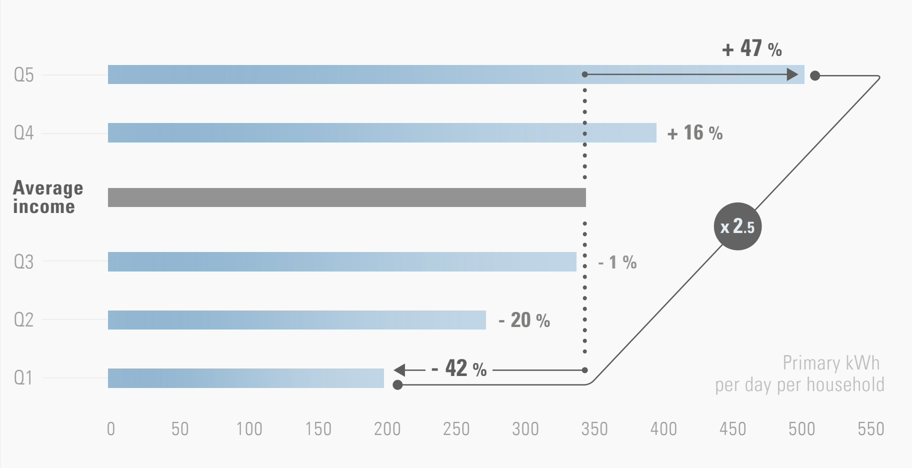


Figure 24

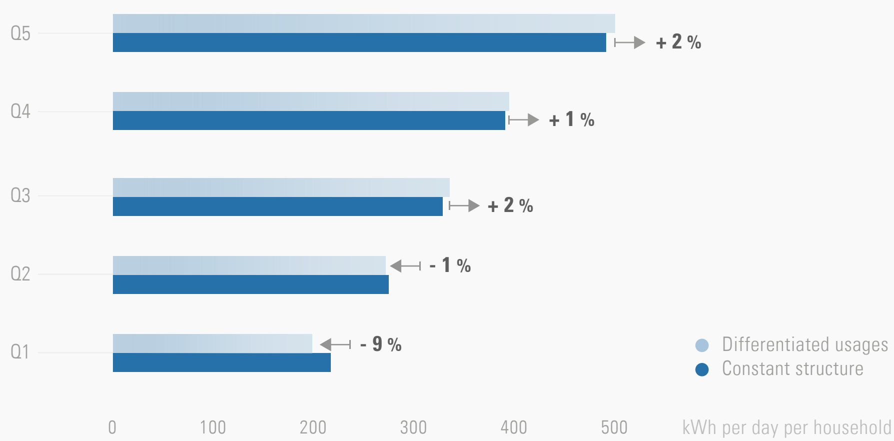
Household energy impact per income quintile: results



We can quantify the relative importance of the structure effect on the gap between the energy footprints of poor households and affluent households (Q1 and Q5) by observing the difference between households for which we assume a constant consumption structure regardless of income (dark blue bars in Figure 27) and by comparing them to households with differentiated structures (light blue bars). The structure effect of consumption accounts for 17% of the difference, while the volume effect explains the major part of the gap, i.e. 83%.[21]

An analysis by consumption category enables the understanding of the way in which consumption baskets vary between quintiles, and why this leads to a widening of the gap between the energy footprint of households in Q1 and Q5. B5

Figure 27
Effect of change in the structure of actual consumption on household energy impact



Box 5
Measurement of living standards: definitions

Living standard as defined by INSEE, is disposable income divided by the number of units of consumption.

Units of consumption is a weighting system that assigns a coefficient to each member of a household, which enables the comparison of the standards of living of households of different sizes and composition.

The available household income includes earned income, unearned income, transfers from other households and social benefits (including pensions and unemployment benefits), net of direct taxes.*

Final household consumption corresponds to the expenditure that households directly incur. It includes the share of spending on health, education and housing that has to be paid after any reimbursements. It includes imputed rents, the equivalent of the rents that owners pay to themselves.

The actual consumption of households includes all goods and services acquired by household residents in a particular country, for the satisfaction of their needs, whether these acquisitions have or have not been subject to an expense on their part. It therefore includes, in addition to the goods and services purchased themselves, those that give rise to social transfers in kind to households from government and non-profit institutions (essentially education and health expenditure, but also for culture, housing assistance, etc.).

** Three-quarters of social transfers relate to health and education, and the remaining quarter is mainly for housing and assistance for the elderly and young children.*

21 The inter-quintile ratio (Q5/Q1) is 2.7 for the quintiles with a different consumption structure, and 2.3 for quintiles with identical consumption structure.

Structure of energy impact per category and per income quintile

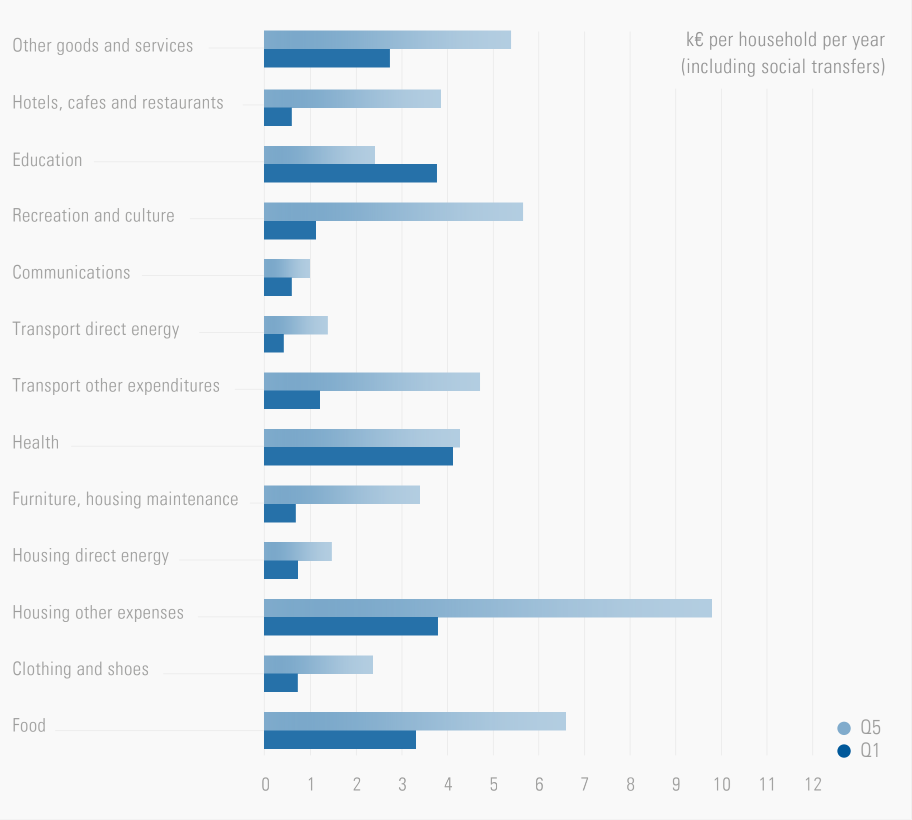
The structure of financial expenditure by category and the energy impact per euro spent for each category can explain the faster growth of household energy impact compared to household spending. These mechanisms are illustrated below using the results of the energy impact analysis per category and per quintile. This entire analysis is based on the hypothesis that the energy content of each category per euro spent is identical regardless of the level of household income. We then discuss this hypothesis and the value of further analysis to assess the energy impact gaps of one euro spent per category according to the different quintiles.

Structure of financial expenditure per category and the unitary energy impact of each category

The actual consumption of households varies from €27,000 per year per household for quintile 1, to nearly €60,000 per year for quintile 5 (in 2004). With rising income levels, the levels of expenditure per category change significantly (Figure 32). F28

Education, which essentially involves mainly social transfers, is the only expenditure item that develops inversely with income. The items for which expenditure increases in absolute value at a faster rate than income (between Q1 and Q5) are *hotels and*

Figure 28
Monetary expenditure levels per item for income quintiles 1 and 5



restaurants (by a factor of 6.9), *recreation/culture* and *furniture/home maintenance* (by a factor of 5), *transportation* and *clothing* (by factors of 3.9 and 3.5, respectively) and finally *housing* (by a factor of 2.5). Within these major categories, variation can be significant. Often purchases of durable goods increase at least as much as income, whereas the gaps between the usage expenditures are much less marked. For example, the *communication* category, consisting primarily of telephone packages and internet access, increases less rapidly than income (a factor of 1.8). In contrast, the purchase of computer equipment, TVs and other brown goods showed an increase of a factor of 3.5 between Q1 and Q5. Housing rents (actual or imputed for owners, social transfers included) differ by a factor of 4.5, while energy expenditure increased by a factor of only 1.6. Vehicle purchases increased by a factor of 6.7, while usage expenditure (repairs and fuel) only show a difference of 2.2 between quintiles 1 and 5. It is worth noting that there is no phenomenon of expenditure saturation with the increase of income for most expenditure categories, with the exception of education and health (which benefit from major social transfers) and communications. This does not mean that saturation related to price effects does not occur in terms of the matter and energy contents of these expenditures. Indeed, wealthy households can buy goods and services at higher prices (premium or luxury goods) without this necessarily being reflected by a change in the energy content. We return to this issue later.

To understand the reason why household energy impact grows faster than the increase in household expenditure between quintiles 1 and 5, the changes in the consumption basket must be analysed in regards to the unitary energy impact of each category, which is presented in table 8. The figures indicated result from the methodology presented in part two. T8

We firstly note that direct energy expenditure for housing and transport have a relatively stable proportion in quintiles 1 and 5. However, these are the two categories for which the unitary energy impact is the highest and they thus contribute to growth at the same rate as the household energy impact and that of their total expenditure.

Most expenditure items that have a proportion that decreases between quintiles 1 and 5 have a unitary energy footprint that is low compared to the average unitary impact of household expenditure, which is 2.9 kWh/euro. These categories therefore contribute to the reduction of the energy impact of Q1 households, relative to those of Q5:

• *Education* and *health* categories represent a very significant proportion of the consumption of poor households, i.e. together accounting for 34% of the actual final consumption of households in the first quintile, compared to only 13% for quintile 5. Their unitary energy impact is 0.8 and 1.6 kWh/euro, respectively.

• The share of the *food* category decreases slightly from 14% to 12.6%. Its unitary energy footprint is less than average (1.9 kWh/euro spent).

• The *communications* category is virtually unchanged; with an impact of only 0.9 kWh/euro, the effect is very limited.

Categories where the proportion increases can be classified into two groups:

• Those where the unitary energy impact is high and that contribute to significantly increasing the unitary impact of Q5 relative to that of Q1. This group mainly includes *transport other expenses*, whose unitary energy impact is 4.6 kWh/euro, which increases strongly with income. About one third (for Q1) to half (for Q5) of this category consists of vehicle purchases; the annual expenditure for vehicle purchasing increased by a factor of nine between quintiles 1 and 5. The same applies for the *furniture and household appliances* category, the proportion of which increased by 3.7% and which has a unitary energy impact that is slightly higher than the average unitary energy impact of all activities combined. We should note that the *furniture and household equipment* category contains household appliances, hence its relatively high unitary impact.

• Those with a unitary energy impact that is lower than average, and the growth of which does not therefore imply an increase in the unitary energy impact of quintile 5. The *recreation/culture* category contains, among other things, travel "packages" which include air travel and hotels, which clearly increase with income, as well as the purchase of brown goods. Similarly, there is a sharp increase between quintiles 1 and 5 for the categories of *hotels, cafes and restaurants* and *housing other expenses*, but their unitary energy impact is low (0.9 kWh/euro). We can note that the impact of the *hotels, cafes and restaurants* category is lower than that of *food* (1.9 kWh/euro). It therefore seems that it is primarily the growth in expenditure in the *transport other expenses* category and in particular the embodied energy contained in the purchase of individual vehicles, followed by the category of *furniture, household equipment and housing maintenance* which substantially increases the unitary energy impact of quintile 5 households. At the same time, the *health* and *education* categories, with a low energy content, only account for 13% of the household budget for this quintile. In contrast, the latter two categories, *health* and *education* therefore pull down the unitary impact of low-income households. Together, these phenomena explain why the expenditure basket of high-income households is more energy intensive per euro spent than that of low-income households.

Breakdown of the energy impact

The structure of the energy impact per category, on average for all households, is presented in the figure below, adjacent

Table 8
Energy impact and variation of expenditure per category

	Unitary energy impact in kWh/€	Q5/Q1 expenditure ratio
Food	1.9	-1.4%
Clothing and shoes	2.6	1.6%
Housing other expenses	0.9	2.6%
Housing direct energy*	30.1	-0.2%
Furniture, household appliances	3.0	3.7%
Health	1.6	-9.4%
Transport other expenditure	4.6	4.0%
Transport direct energy*	13.0	1.0%
Communication	0.9	-0.4%
Recreation and culture	2.6	6.1%
Education	0.8	-11.4%
Hotels, cafes and restaurants	0.9	5.0%
Other goods and services	1.3	-1.2%
Total	2.9	

* including embodied energy of direct energy

to the per category structure of financial expenditure. F29 F30

The three *housing* categories represent one third of the energy impact, i.e. 118 kWh of primary energy per day per household, corresponding to 20% of the household monetary budget.[22] This is a reflection of the effect of the major unitary energy impact of direct energy for housing. The category *housing other expenses* covers the energy content of construction, the energy consumption related to the usage of communal areas in buildings, water networks, waste management, property management and housing-related maintenance work, both large and small.

The second most important activity is *transport*, which has three components (other expenses, direct energy and the embodied component of direct energy).

Figure 29
Structure of the energy impact expenditure of households

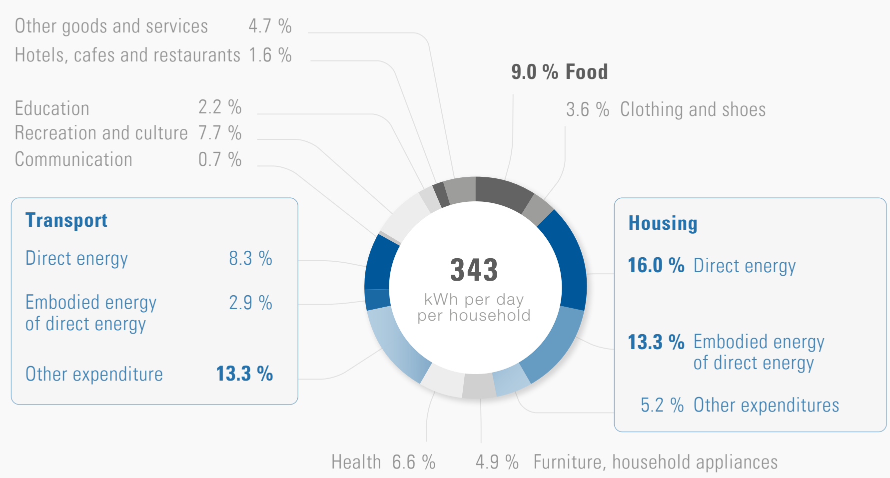
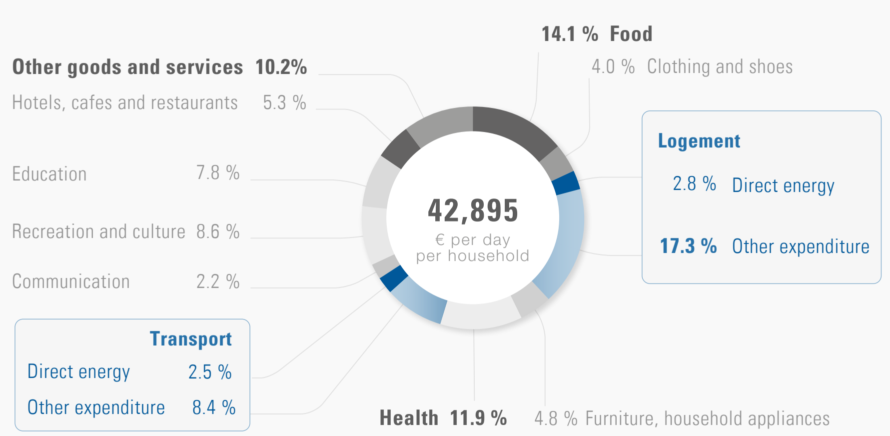


Figure 30
Structure of monetary expenditure of households



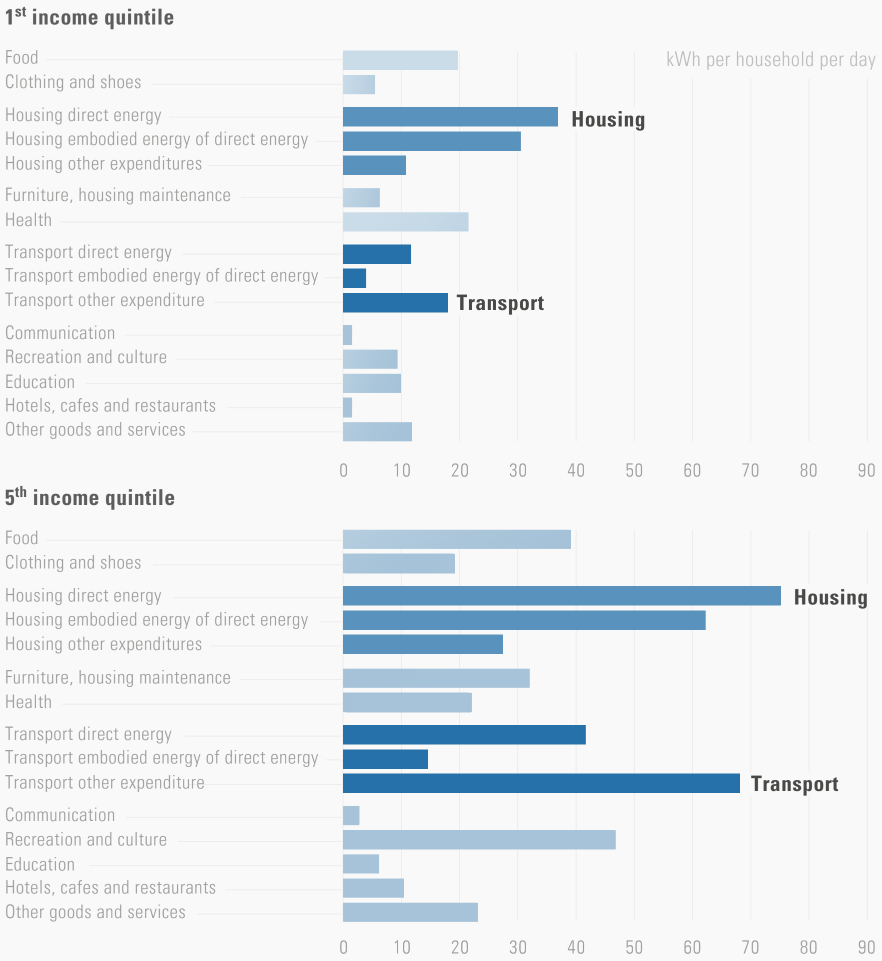
22 The housing embodied energy of direct energy is not included in monetary expenditure, since it is associated with direct energy expenditure.

It corresponds to the purchase and repair of all types of vehicle (car, motorcycle, bicycle...), expenditure on public transport (train, plane, bus... when not included as part of package tour), and the fuel and energy necessary to produce this fuel and make it available. The three components of the *transport* category thus make up 24% of the energy impact, i.e. 84 kWh per day per household, and 11% of the household budget.

The next category in terms of importance is *food*, which includes the energy content of the agri-food chain, the associated transport, the energy consumed by large retailers, etc. It represents 9% of the energy impact, or 31 kWh per day and per household and 14% of the household budget.

The *recreation and culture* category includes expenditure for travel and entertainment at home or outdoors. It represents 26 kWh per day per household. F31

Figure 31
Structure of impact according to income



These figures show the development of energy impact by category depending on income. It should be remembered that the monetary costs increase by a factor of 2.2 between quintile 1 and quintile 5. There is a strong growth, here in absolute value, in transportation, leisure/culture and hotels, cafes and restaurants.

Price effect and quantity effect

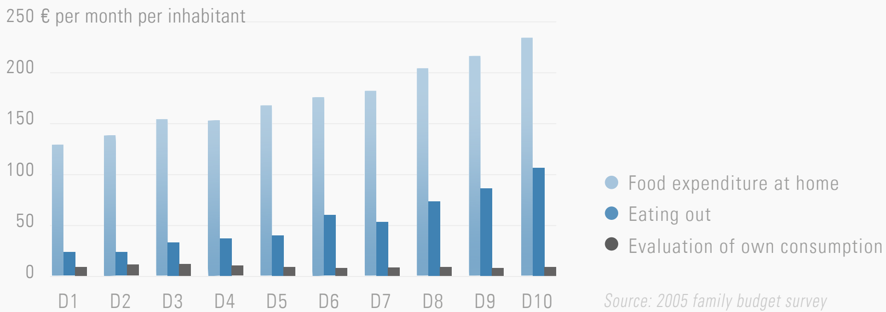
The price effect is the third factor that may have an influence on the differentiation of household energy impact according to income, that is to say, the price difference between the goods and services purchased by households of different quintiles. It is worth remembering that, in the absence of available data, the energy impact per euro spent in each category is assumed to be identical, regardless of the income level. However, wealthy households may acquire goods and services at higher prices (premium or luxury goods) without necessarily changing the energy content. However, they may also have more frequent access to activities or goods with a very high energy content (plane, yachts, exotic food, etc.), which are categories where low-income households may consume considerably less. We therefore cannot exclude significant price effects, in both directions, on most of the major aggregated categories considered here. In the case of housing, for example, the rent prices (actual or imputed) of affluent households are significantly higher per square metre than those of low-income households. However, even though housing in central Paris may be much more expensive than housing in Essonne, this does not mean that the former consumes proportionally more energy. Conversely, the homes of the wealthiest classes can be equipped with "comforts" that are highly energy intensive (swimming pools, outdoor heating, air conditioning, etc.), the impact of which on the total price of housing is secondary compared to the price of the property.

Therefore, it is necessary to isolate the price effects from the effects related to the "matter" content of household expenditure. A focus on a number of expenditure categories is presented below. While this exercise is not intended to provide an exhaustive list of answers to this question, the aim is to demonstrate the nature of the required analysis in these few examples, and their potential contribution to the issues raised in this study.

Food

The share of food expenditure in the total budget, which was close to 14% in 2003, varies little according to income. Food expenditure therefore increases as income increases at the same rate as the total household budget. Does this mean that wealthy households buy greater quantities of food, or a similar amount but more expensive foods? What are the consequences on energy impact of this category for every euro spent according to the income quintiles? F32

Figure 32
Food expenditure according to income deciles per consumption unit



Source: 2005 family budget survey

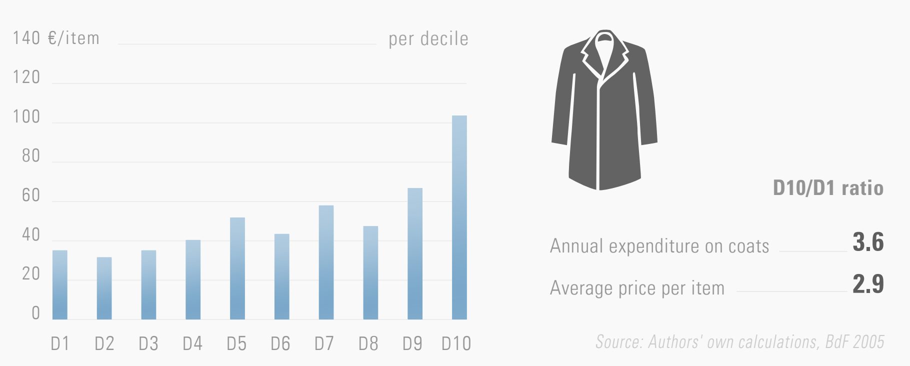
Households in the first decile are among the 10% of households with the lowest income available per consumption unit. Their food expenditure at home per person amounted to 130 €/month

The average per person food expenditure is nearly two times higher for households in the lowest decile compared to the first decile. The increase is even greater when considering expenditure on eating out (Figure 32). While the prices of purchased products account for 20% of the increase in food expenditure at home, the major part of this derives from an increase in the quantities purchased.
The structure of food consumption according to income also varies little. It is mainly the budget share for alcoholic beverages and seafood that increase with income, while the share of cereal-based products decreases. Mineral water, fruits, vegetables and pre-prepared meals are also among the products that see a rise in consumption along with increasing income.
The proportion of meat in the diet, in terms of its energy and carbon content, is critical, and yet this expenditure category remains similar from one income group to another (around 20% of the food budget). This budget can double between decile 1 and decile 10, but we are not able to determine whether this relates to the purchase of larger quantities or to prices that are twice as high. Neither can we establish at this stage if the proportions of white or red meat remain similar, or the sources of these products; and *yet all* these factors influence the energy impact per kilogram of meat purchased. All these elements require further study to reach a conclusion on the food category's energy impact according to household income.
Although it appears that the price effect is by no means the sole determining factor to account for the increase in food expenditure (which rises at the same rate as overall consumer spending) along with the increase in income, it nevertheless remains difficult to draw conclusions without further analysis regarding the difference between quintiles in terms of the energy impact per euro spent in these categories.

Clothing

The ratio between the energy impacts of quintiles 1 and 5 in the clothing category is 3.5. This figure in fact corresponds to the clothing expenditure ratio between the two groups. When we compare the prices per unit paid by the two household groups, we see that the average price per item is 2.9 times higher for the last decile than it is for the first. This probably explains much of the energy impact gap measured using the I-O table analysis.
Indeed, the quantity of items purchased by D10 is only 20% greater than the quantity of items purchased by D1.[23] The price factor plays an important role in accounting for the gap between wealthy and poor households that was measured using our methodology. F33

Figure 33
Euro spent per item (coat)



23 We use here deciles and not quintiles, but this does not alter the analysis.

Equipment and durables

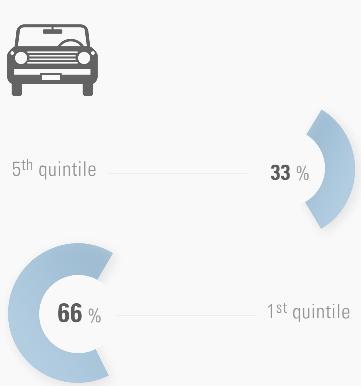
The category of *furniture and household appliances* shows similar results to clothing. Indeed, the expenditure gap between D10 and D1 for this category is greater than 150%. But in terms of the amount of goods purchased, the last decile only buy 50% more goods than the first decile. This result holds for kitchen appliances as well as for HiFi and computer equipment. T9

Table 9
Household appliances
Price gap per item between D1 and D10

	D10/D1 ratio
Expenditure on washing machines, tumble dryers and dish washerse	2.5
Prix moyen par article	1.7
Kitchen appliances	2.7

Source: Authors' own calculations, BdF 2005

Figure 34
Proportion of second-hand purchases out of total vehicle purchases, 2005



Purchase of new and second hand vehicles

In 2005, expenditure on the purchase of vehicles represented 29% of the transport budget of the first quintile (i.e. 621 euros per year) and 47% of the transport budget of the fifth quintile (i.e. 3,410 euros per year). The household motorization rate is one of the key determinants of this expenditure; while the replacement rate, the use of the second-hand market and car model quality are also relevant.

On average, two out of three vehicle purchases are made on the secondhand market. Secondhand expenditure represents 50% of the total expenditure on vehicle purchase. However, this varies widely according to living standards. Indeed, a vast majority of the first quintile uses the secondhand market (two thirds of vehicle purchase expenditure). In contrast, wealthier households make much less use of this market (one third of purchase expenditure). F34

By taking into account vehicle depreciation, we could attribute secondhand vehicles with a low energy content per euro spent, in comparison to new purchases. This then creates a structural effect: a euro spent on a car purchase would become less intensive in terms of embodied energy for low-income households, because they buy more secondhand cars. For a more detailed analysis it would be necessary to assess the extent to which the price of secondhand vehicles properly reflects the physical depreciation of vehicles and when this is not the case, apply an additional depreciation factor. In contrast, the propensity to buy expensive vehicles increases with income, and the price effect probably also plays a role in this category.

A necessary combination of the data with sociological surveys

It would be risky to draw conclusions from these first elements regarding the respective proportions of the price effect and the quantity effect for each of these categories. In most cases, there are many intervening factors, the effects of which are often contradictory. Only quantitative sociological surveys could provide insight to enable the identification of the dominant factors. If we take the example of food, factors such as the type of meat, its origin, the production chains involved, whether products are fresh or pre-cooked, whether there is auto-consumption,[24] etc., may all have a significant impact, beyond the elements identified here. This is obviously less true for clothing and durable goods.

In conclusion, it appears that evaluations of physical footprints from surveys based on monetary data, pose methodological problems that require these statistical approaches to be combined with consumption surveys to clarify the important issues. In addition, statistical aggregates according to income classes enable a preliminary understanding of the phenomena, but of course these classes mask the diversity of very different social realities that vary according to the location (regional, rural/urban), age, household composition, level of study, etc. Conversely, some types of behaviour may be universal across different household classes.

Towards a longitudinal analysis of energy impact according to living standards

In the previous sections, we provided snapshots of household energy impacts at a given time. The study of inter-temporal dynamics linking energy consumption and income level enable the better anticipation of current trends and to act on these trends. It also allows us to put into perspective the lessons learned from other parts of this study, in order to answer the following question: how does expenditure change over time and between different social "classes"?

The study of the dynamics of consumption between different population groups is not new. The economist T. Veblen, argued in his book *The Theory of the Leisure Class* (1898), in the late nineteenth century, that the consumption habits of the entire society were shaped by the wealthier classes, which in turn influenced the others. In the United Kingdom, Tim Jackson and his team have studied the evolution of direct and indirect energy consumption in connection with income distribution from 1968 to the present time. However, to our knowledge, such studies do not exist in France.

In the absence of a historical analysis of direct and embodied energy consumption for France, we present here an analysis of monetary expenditure on direct energy for low income (decile 1) and wealthy (decile 10) households over the past 25 years. This work was based on the INSEE's household budget surveys. Where the results are not referenced, they were produced for this publication, whereas results derived from studies carried out by ADEME, the SOeS or INSEE, are explicitly referenced. The results are presented according to consumption units, to remove the effect of changes in the number of people per household over the period studied.

Direct energy expenditure

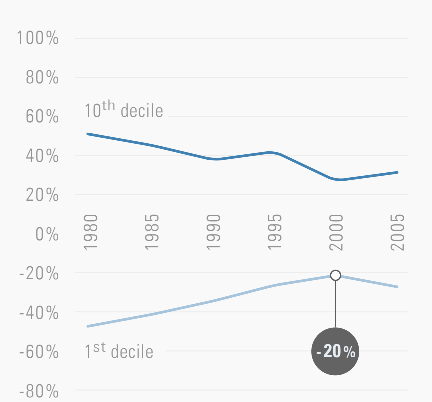
Compared to the average, there is a convergence towards the average of energy expenditure related to housing for the first decile over the period 1980 to 2000, and a divergence away from it in the final period. In 1980, this expenditure is 45% lower than the average; and 25 years later it is 22% below

24 Auto-consumption designates the consumption of goods or services produced by a household itself.

the average. In contrast, expenditure by the richest 10% was 50% higher than the average in 1980 and "only" 30% higher in 2005. F35 We do not find such marked convergence with regards to vehicle fuel expenditure (Figure 36). Thus, the level of deviation from the mean compared to the average is highly significant at around 70%. The first decile's expenditure was 80% lower than average in 1980 and 74% in 2005. Over the same period, there was a move from 75% to 61% above average for wealthy households. F36

How can we explain this inter-decile convergence of energy expenditure for housing in the approach to 2000? Multiple factors may be responsible. Firstly, this expenditure includes different usages: heating, specific electricity, domestic hot water, cooking, etc., which often have diverse energy sources. The relative evolution of the needs of these various energy services and of their price per kWh can make significant differences. A differentiated analysis of expenditure for heating and specific electricity would partly enable the developments underway, which depend on income levels, to be accounted for. One can, for example, imagine two-way trends occurring: the wealthy classes could have both improved their thermal comfort (moved to housing that was better insulated as it was either new or renovated, installed condensing boilers,[25] etc.) while also taking action to reduce expenditure in this category by multiplying their usage of other electrical equipment. At the same time, low-income households may have made only slight modifications to their "thermal" profile, while gaining access over the same period to electrical appliances that were also available to the more affluent (computer, TV, home cinema, etc.). The ownership rate of appliances and the characteristics, performance or renewal rate of such equipment also constitute factors, the evolution of which can converge or diverge depending on the example, between household categories. We should also assess the impact of structural parameters which become unfavourable, such as a decrease in the number of people living together (rising numbers of single-parent families and elderly people living alone) that may lead to the emergence of new demands.

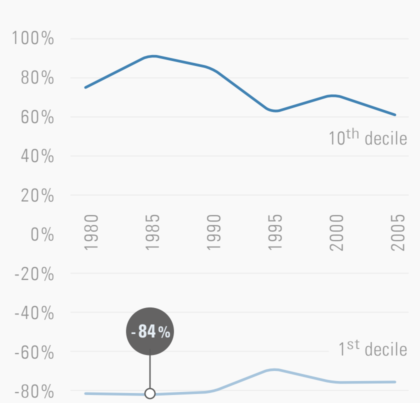
Figure 35
Deviation from the mean of direct energy expenditure for housing



In 2000, the poorest 10% spent 20% less per consumption unit than the average for gas and electricity.

Source: BdF 2005

Figure 36
Deviation from the mean of fuel expenditure



In 1985, the poorest 10% spent 84% less in fuel than the average household

Source: BdF 2005

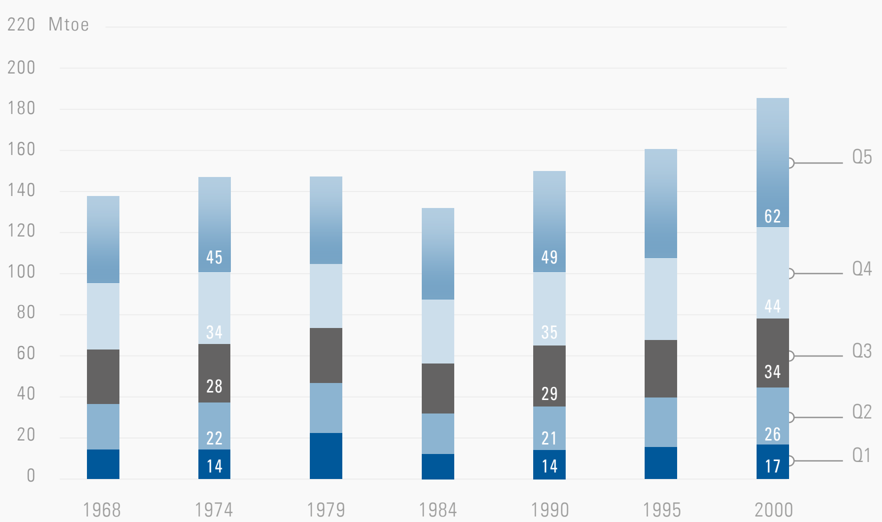
25 Over the period studied, the rate of replacement of fuel heaters by other energy sources is higher in wealthier households than among other social classes (BdF 2005). The price of fuel has increased over the period, this may help explain the decline in spending compared to the average.

While there is obvious value in a retrospective investigation into the development of household energy consumption trends according to socio-demographic characteristics, such a study however necessitates major statistical analysis work, starting with the harmonization of the Household budget surveys, the methods of which have evolved over the course of 30 years. A study such as this could not be carried out given the time available for this work. To broaden the analysis to include the household energy impact would represent an even more ambitious objective, since there are few such examples in the international literature.

What about embodied energy?

The previous sections have shown that, for the year 2004, the energy impact is positively related to income, with a gap of 1 to 2.7 between the poorest 20% and the wealthiest 20%. Embodied energy use increases even more rapidly from one quintile to another.
What development would we expect to have occurred over the last decades? One of the few studies in this area was conducted in the UK by Papathanasopoulou and Jackson (2009). It highlights a remarkable phenomenon: the more than proportional increase of the energy impact according to income, which is driven mainly by emissions from the recreation and transport categories. This increase is consistent with a shift in income distribution in favour of the wealthiest, who became richer over this period.
Furthermore, a comparison of the development of the energy impact distribution and that of the income distribution over the period shows that inequalities related to resource usage increase faster than income inequalities. In other words, wealthy households have become relatively richer and even greater energy consumers. In addition, the energy impact of all classes has increased (Figure 37). F37
Such a study has never been carried out for France. As we have indicated, to do so is a major undertaking, which in addition to the above-mentioned difficulties regarding the methodology of the I-O tables, requires the cross checking with historical statistical series which are not all homogenous.

Figure 37
Energy impact according to living standards in the United Kingdom



Source: Papathanasopoulou, E. & Jackson, T., 2009.

Conclusion

New representations of energy consumption: why and how?

Implications for public debate

This report suggests a number of considerations in the context of the debate on energy transition. It is still too early to transform the lessons of energy impact into action proposals or to produce prospective analyses. However, the presented reorganization of energy consumption offers a new perspective to the debate on energy transition that could help break some deadlocks.

Adopting a more systemic vision of consumption

Embodied energy overturns the conventional representation of energy consumption. Indeed, more than three quarters of energy consumption is not directly perceived by households. This energy consumption is included in their purchases of goods and services.

This new representation does not reveal any hitherto hidden energy. The indicator presented here, the energy impact, has enabled us to group together localized and attributable consumption, such as energy for housing, more diffuse consumption such as that used for freight, and consumption that occurred abroad to meet the needs of a particular nation. Our work therefore involved the redrawing and reorganization, at the national and international level, of energy flows and consumption to better reflect the social realities they represent.

This new approach firstly has a pedagogical function and helps to account for the systemic nature of energy in our society. It also brings together the two ends of the energy chain (producers and consumers) to better understand their interactions and their changing incentives to reduce energy consumption.

Discussion of consumption needs, levels and modes

The new representation of energy consumption that is proposed in this report is based on the principle that all goods and services produced by the productive system (the productive sector is not only comprised of factories, but also offices, hospitals, etc.) is aimed, directly or indirectly, towards consumers. A discussion of the needs, levels and modes of consumption therefore seems necessary. Until now, such a discussion had been difficult or even impossible, due to the traditional and narrow representation of energy consumption.

To put the final consumer back at the centre of the analysis raises several issues. Firstly, such a "refocusing" raises delicate questions on lifestyles and habits. It makes it clear that the targeting of efforts towards the productive system and energy efficiency is not sufficient to achieve a substantial reduction in our energy consumption. The level of household consumption is also a driver for the reduction of energy consumption. The objective here is not, however, to remove the burden of responsibility from producers and place it onto consumers instead, but to open a debate on the energy needs, their origins and their implications.

Until now, energy policy at the consumer level dealt only with direct energy consumption. To act on households, we have introduced, or attempted to create, standards, taxes or renovation plans of infrastructure (housing and transport). On the other hand, by targeting producers we would encourage the efficiency of processes and the development of new energy sources. Such approaches are necessary for unit efficiency improvements, but they are insufficient for overall improvements.

However, is it the purpose of energy policy to become involved in the field of consumption modes and to seek to address more than just household energy consumption, but all household expenditure? This is a delicate question. This line of reasoning should not be taken as a call for a labelling[26] system to indicate the embodied energy content of products, which would ultimately have little effect on overall consumption. The objective should be to encourage the consideration of global energy policy simultaneously with the planning of new policies to target the determinants of consumer choice. Social norms of consumption must also be subject to particular attention, something that must be part of a collective debate: development, urban planning, the organization of work time and professional life all have as much impact on energy consumption as the "efficiency" of consumer equipment.

A third issue has a prospective nature. How might lifestyles develop in the future and what effect will this have on energy impacts in the long-term? The involvement of sociologists in a forward-looking approach is needed to determine the drivers of social change that could have a significant impact on energy consumption.[27]

Becoming aware of outsourcing dynamics and their implications

The reorganization of energy flows highlights outsourcing dynamics: the net embodied energy of imports for France amounts to up to 20% of the country's overall impact. This outsourcing of consumption is particularly notable in the transport sector, which induces high levels of imported embodied energy for steel, but also for services to businesses. This is also the case for expenditure on recreation and culture since it includes imported equipment with a relatively high energy content (this content itself being more related to the organization of production and trade than to the manufacture of products). Conversely, other sectors such as agriculture and health import less energy from the rest of the world.

These outsourcing effects reflect the past and present dynamics of international trade, with manufacturing regions characterized by low (although growing) levels of domestic consumption, along with other areas where

26 Even if such an objective could be achieved, and the labelling could provide sufficient detail and information to be useful

27 See Cahiers du CLIP number 21 "Lifestyles and carbon footprints".

the share of industrial production in global trade is tending to decrease.

This rereading of energy consumption leads to a relativization of past improvements in terms of energy efficiency. For example, some productive sectors appear to have limited the increase in their energy consumption despite a growing final demand, but have done so through the outsourcing of certain parts of the production chains.

Taking into account the embodied energy of imports enables the reinterpretation of the concept of energy dependence, which is not only a result of direct imports. In France, for example, the importation of embodied energy from the rest of the world is almost as high as that of crude oil (about 60 Mtoe). On this point, thinking in terms of percentages can be misleading: a country that is highly energy efficient at the national level and that imports a certain amount of embodied energy from abroad would have a higher energy dependence ratio than a country that is less efficient at the national level but that imports the same amount of embodied energy from the rest of the world. The difficulty is related to the difference between the ability to take action to reduce embodied consumption at the national level, compared to that made in foreign territories.

Examining new distribution channels for goods and services

The issue of embodied energy naturally leads to the consideration of the supply chains of goods and services and their reconstruction at the international and national levels. We must examine new distribution channels (e-commerce, local food distribution cooperatives) in terms of their overall energy impact and the associated embodied energy.

Supply chains consist of all the necessary steps for the "satisfaction" of goods and services, starting from the invention of a product, through to its development, production, marketing and sales. This chain is made up of, at least, primary production, transportation and a variety of tertiary services (marketing, sales, after-sales service ...).

It raises the question of how the energy content of supermarket supply chains for food products compares to those of cooperatives associated with local farmers (AMAP - Associations for the Preservation of Peasant Farming). The objective is not only to compare the embodied energy content of an organic apple derived from an AMAP with that of an apple purchased in a supermarket, but to compare these two food chains as a whole, from the macroscopic point of view, without losing sight of the details.

Considering the social dimension of embodied energy consumption

While direct energy consumption eventually tends to stabilize with rising income[28] due to a double movement of increased equipment efficiency and the multiplication of usages, as discussed in Part 1, we observed that embodied energy consumption increases at a more rapid rate than income. The toolbox of public policy makers must therefore be adapted to these social realities. How can we reverse social norms and standards in relation to consumption that is influenced by marketing? How can we limit social mimicry which, as suggested by certain authors (Kempf, 2007), leads to a headlong rush by the whole of society towards increased embodied energy consumption?

While this work may raise more questions than it answers, solutions to all these questions are not necessarily required before a new representation of energy can be mobilized in the context of the definition of energy law and policy.

28 Chancel, L. (2013), "Agir sur les consommations directes d'énergie des ménages", Iddri, *Policy Briefs* 03/13

Follow-up

The approach presented in this report is based on a robust methodology, but one that requires further investigation on the specific issue of living standards and the adaptation of the tool towards forecasting.

Improving the methodology as a whole

The understanding of the industries and sectors where embodied energy originates requires refinement. This work would benefit from a "hybridization" of comprehensive visions (global or national) with other approaches such as individual surveys or life cycle analysis. Moreover, for a particularly valuable analysis, we must introduce more differentiation than that which is allowed through the use of the GTAP databases and the I-O tables of national accounts.

The energy impact presented here is in global in primary energy. A differentiation according to the vectors (oil, gas, electricity, heat, etc.) would enrich the analysis given the differences that exist between the production chains of these vectors.

The impact is the translation of monetary values into energy. As mentioned in part 3, it is necessary to give consideration to price/quality and price/quantity effects. A general understanding of consumption may have additional energy implications: for example, an organic fruit that requires a lower amount of inputs will cost more than its intensively farmed equivalent, and our tool will therefore attribute it with a higher energy impact, whereas this is not necessarily a reflection of the reality, especially if it was delivered via a short supply chain.

In the same vein, we have not considered investment in every sector of the economy or for each consumption category, due to a lack of available data. As mentioned in part 2, particular attention should be given to addressing property values. Finally, the implemented methodology can be applied to other factors, not only energy. Establishing the impact of other resources (water, carbon, etc.) or, for example, hours worked or wages, could further enrich the analysis at a time when we are becoming increasingly aware of the strong interpenetration of all issues.

Deepening our understanding of the social determinants

The differentiation of the impact per usage and per population group requires the collection and analysis of additional data to be combined with existing information and used in the model.

The question arises whether the definition of "usages" that was chosen for socio-economic analysis is adequate for use in an energy analysis.

Thus, for this first study, as mentioned in part 2, the energy directly consumed has not been broken down according to the consumption categories. Such a breakdown would reinforce the consistency of the approach, although to do so would be complicated. Indeed, there is currently a lack of statistical data available that would enable such work. This undertaking would require extensive expertise and exchanges between statisticians, sociologists and economists.

We chose to work on population groups differentiated by income level because we had access to such data, but it might also be interesting to observe the effects of other divisions. These divisions could be along the lines of classical categories, such as the age or "occupation or socio-occupational category" of the reference person from a household, or family composition, etc. We could also differentiate according to the geographical location of households, which has an impact on both a household's need for mobility and on the consumer products to which it has access. This research has yet to be carried out.

Developing predictive analysis tools and foresight exercises

Impact provides a snapshot of energy consumption. Beyond that, the objective is to enable energy impacts to evolve under different scenarios. To achieve this, progress is needed in a number of areas.

The tool currently provides an analysis of the situation in 2004/2005. To have an understanding of what determines the levels and distributions, and to envisage modalities to allow forward projection, a retrospective analysis of their historical and regional evolution is essential.

For this purpose we would need to obtain, or even rebuild, historical data that are sufficiently detailed to enable their integration, following adaptation, into the tool. This work is necessary at both the national and international levels. For these analyses to be of value, they also need to be based on more accurate surveys (travel surveys, family budgets, etc.). This is the objective of the ECOPA project (Evolution of consumption patterns, economic convergence and carbon footprint of development, ANR & SOC ENV 2012) for France and Brazil, coordinated by the CIRED.

While it is too early to develop prospective scenarios based on the data that we have presented here, it will be interesting to use the method for future projections. At first, the exercise can be performed on trend scenarios, based on the assumption that the structures of economies change only marginally.

However, since the reconfiguration of economies is a hot topic, the main challenge is to better understand the implications of these changes in the structure of the economy and of the above mentioned development of supply chains, according to the chosen hypothesis: GDP (de)growth, consideration of energy and environmental constraints, the global rebalancing economic influence, changing productivity (energy or work).

This involves thinking about all of the feedback mechanisms necessary to ensure global economic balance; for example, if a region shows less consumption and thus imports, we must take into account the impact of such a reduction on the growth of exporting regions.

Ultimately, substantive work to fully integrate this dimension into hybrid models such as IMACLIM may be considered.

This multiplicity of new avenues to pursue highlights the essential need to combine expertise from several disciplines, to include for example: economists, sociologists, energy specialists, statisticians and modellers, both at the national and international levels.[29] These collaborations seem all the more necessary at a time when we are becoming increasingly aware of the limitations and dangers of compartmentalizing the management of problems faced by our societies.

29 These include, among many others, at the French national level: INSEE/ACN, CITEPA, SOeS, CIRED, EDF and IDDRI; and internationally: OECD/IEA, ESRC-UK, NTNU, etc..

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Annexes

Annex 1

Direct energy consumption

Direct energy consumption according to 5 types of household

Journalière (kWh)	Efficient	Standard	Energy-intensive	Very energy intensive	Constraint
Oven	0.3	0.4	1.0	1.5	0.4
Hob	0.6	0.6	0.6	1.0	0.6
Fridge-freezer	0.3	1.0	1.8	3.3	1.0
Microwave	0.2	0.2	1.0	0.5	0.2
Electric kettle	0.1	0.1	0.5	0.5	0.1
Washing machine	0.5	0.7	1.2	1.5	0.7
Dishwasher	0.4	0.5	1.5	1.5	0.5
Vacuum cleaner	0.3	0.6	0.8	1.0	0.6
6 bulbs	0.4	0.6	0.8	4.0	0.6
Television	0.1	0.4	0.5	1.0	0.4
DVD	0.0	0.1	0.5	0.5	0.1
Hifi	0.1	0.1	0.5	0.5	0.1
Computer	0.2	0.2	0.5	0.8	0.2
LCD screen	0.0	0.2	0.4	0.8	0.2
Printer	0.0	0.0	0.4	0.6	0.0
Modem	0.1	0.1	0.4	0.4	0.1
Standby	0.0	0.5	1.0	4.0	0.5
Swimming pool	0.0	0.0	0.0	6.0	0.0
Electricity subtotal	**3.5**	**6.4**	**13.4**	**29.4**	**6.4**
Heating	3.3	13.2	41.1	82.2	49.3
Water heating	2.0	6.0	8.0	10.0	6.0
Transport	20.0	35.0	42.0	98.0	85.0
Total	**28.8**	**60.5**	**104.5**	**219.6**	**146.7**

Annex 2

Qualification des données énergétiques GTAP

The allocation of primary energy consumption to different consuming entities of the GTAP database was based on information from the IEA 2004 database. The comparison of raw data from the two databases showed significant differences.

Indeed, in the GTAP database, total consumption by businesses (13,229 Mtoe) and households (1,917 Mtoe) is 15,146 Mtoe; whereas the IEA total is 11,227 Mtoe (with "bunkers"), i.e. a difference of greater than one third (3,869 Mtoe).

Discussions with GTAP designers have confirmed the problem and enabled the causes to be identified, allowing the development of the most appropriate preliminary corrections.

This requires an understanding of the structure of the IEA database as well as the reconstruction method used by the GTAP designers.

In the IEA database, data are represented as "products" (primary or secondary) allocated to certain sectors (of the economy) which exchange "flows" (of energy). Incoming flows are considered as purchases or consumption, and allocated with a negative sign (« input »; <0). Outgoing flows are considered as sales, and allocated with a positive sign (« output »; >0); these flows are those included in the GTAP.

For each country the IEA defines a "***TPES***" (Total Primary Energy Supply) value, which represents the country's production of primary energy to which we must add the import (>0) or export (<0) flows, the stock changes and marine bunkers (<0) to have a picture of the primary energy consumed in the country. All users of this energy are divided into three groups: final consumers, the "energy" sector (providers of final energy) and the "transformation" sector (where the raw energy resource is transformed into a usable vector).

We have:

{0} $TPES = TFC - ([TS] + [ES] + \Delta)$, (with $\Delta = DL$ (Distribution Loss) + T (transferts) + SD (statistical differences)

In other words:

The entire primary production = final consumption - (energy "lost" in the transformation of energy products (< 0) + consumption in the energy sector (< 0)) + Losses (< 0) (- statistical differences - transfers (accounting reclassifications))

«Δ» represents the algebraic sum of the components of the gap

The fuel purchased by utilities (electricians and heat producers) for their resale of energy is not accounted for in the "energy" sector of the IEA databases, but is instead included in the "transformation" sector.

When the energy dimension was introduced into GTAP, the designers were faced with two problems:

- the first one, which is related to differences in sectoral divisions between the two databases, is classic and fairly easy to define - although this does not mean that the solution is easy to implement;
- the second and more difficult problem concerns energy accounting, for which the GTAP allocated an energy flow to each sectoral monetary flow. However, all energy "products" are not explicitly consumed: some simply disappear during processing (heat, etc.) without being explicitly identified as the consumption of a sector. Others are consequences of the choice of statistical conventions (for non-fossil fuels, for example). As a result, some energy flows are difficult to allocate to a monetary flow.

For GTAP, if we consider the energy flows, we get for the "processing" sector:

$[TS] = - ITS + OTS$, (transformations correspond to the difference between the absolute values that go in and out of the processing sector to be consumed/purchased by other sectors)

And for the "energy" sector:

$[ES] = -IES + OES$, (consumption of the energy sector with $OES = 0$ for the IEA)

{0} becomes:

$\{0'\}\ TPES = TFC + IES + ITS - OTS - \Delta$. (Primary consumption = Final consumption + Energy sector inputs + Processing inputs - Processing outputs - losses - transfers - statistical difference)

Where:

$\{0''\}\ TPES = TFC + IES + ITS - OTS - (\Delta)$ (Primary consumption = Final consumption + Energy sector inputs + Processing inputs - Processing outputs - the differences)

Hence:

$\{i\}\quad TFC + IES + ITS = TPES + OTS + (\Delta)$

Each time the "trigrams" (TFC, IES, ITS et OTS) are the absolute values of flows.

But in GTAP, which is based on monetary flows, the total energy balance (E_{GTAP}) is presented as the sum of the energy consumption of the productive sectors (EVF) and households (EVH), i.e.:

$E_{GTAP} = [EVF + EVH] = TFC + IES + ITS - ITSnf$, (final consumption + consumption of the "energy" sector + consumption of the "processing" sector - non-fossil inputs that do not correspond to actual energy purchases and cannot appear in the GTAP)

{i} becomes:

$TPES = E_{GTAP} - OTS - (\Delta) + ITSnf$. With $ITSnf = 1156$ Mtep and $OTS = 5581$ Mtep

The difference between the IEA and GTAP balances corresponds to the output of the "processing" sector. GTAP accounts for these twice: once at the processing sector level and once in the energy sector. Whereas, from an accounting point of view, it is often the same entity! When all of this is corrected for, the non-fossil inputs are unrecognized in GTAP. This correction allows the readjustment of the overall energy levels, but it can have an impact on the monitoring of imports/exports of energy resources; further analysis is required here.

And more precisely, by taking into account the traditional biomass (EBT= 942 Mtep) which should not appear in the TES, we obtain:

$E_{GTAP} = EVF + EVH = TFC + IES + ITS - ITSnf - EBT + \Delta$

i.e.:

$\{i\}\quad E_{GTAP} = TPES + OTS - ITSnf - EBT + (\Delta)$

Once this readjustment has been completed, the global energy balance becomes more consistent.

The following table shows that finer investigations at the regional level will also be required to fully consolidate the results, especially for the Middle East (due to oil processing), Latin America (due to the influence of the biomass resource), etc.

Readjustment of the overall energy balance in GTAP

Bilan énergétique	Mtoe	Écart (Mtoe)	(%)
Overall energy balance of the IEA for 2004 (excluding bunkers)	10,980		
Overall energy balance of the IEA for 2004 (with bunkers)	11,277		
Overall energy balance of original GTAP 7	15,146	3,869	≈ 34%
To remove from the consumption of the "processing" sector	-5,881		
To add to the primary energy equivalent of non-fossil vectors	+1,156		
To add to traditional biomass	+ 942		
Overall readjusted energy balance of GTAP 7	11,664	386	≈ 3%

A discussion with the GTAP designers is necessary to ascertain the exact distribution of bunkers and traditional biomass in GTAP, at both the global and regional levels. Such a discussion should also address the constitutive elements of «Δ» (which in 2004 amounted to -183 Mtoe for DL, +19 Mtoe for T and -21 Mtoe for SD), which are not corrected for in this study. Il faudra d'abord actualiser les résultats avec la nouvelle version de la base GTAP.

Regional breakdown of results

	① TPES	② GTAP0	*GTAP0 - IEA*	③ OTS	④ ITSnf	⑤ GTAP1	*GTAP1 - IEA*	⑥ EBt	⑦ GTAP2	*GTAP2 - IEA*
EU 15+	1,495	2,169	*-45%*	875	-200	1,494	*0%*	35	1,528	*-2%*
France	284	286	*-1%*	142	-124	269	*5%*	9	278	*2%*
EU new countries	299	409	*-37%*	148	-32	293	*2%*	13	306	*-2%*
China	1,677	2,083	*-24%*	634	-45	1,494	*11%*	217	1,711	*-2%*
Japan Korea Tw	876	1,300	*-48%*	512	-135	923	*-5%*	2	926	*-6%*
South Asia	639	629	*1%*	207	-17	440	*31%*	202	641	*0%*
South Pacific	617	718	*-16%*	230	-44	533	*14%*	111	643	*-4%*
North America	2,644	3,716	*-41%*	1,362	-323	2,676	*-1%*	49	2,725	*-3%*
Latin America	677	977	*-44%*	402	-88	663	*2%*	68	731	*-8%*
Middle East	499	897	*-80%*	323	-2	575	*-15%*	1	576	*-15%*
Africa	596	484	*19%*	170	-58	372	*38%*	231	603	*-1%*
Ex-USSR	974	1,478	*-52%*	576	-88	991	*-2%*	4	995	*-2%*
Total World	11,277	15,146	*-34%*	5,581	-1 156	10,722	*4.9%*	942	11,664	*-3.4%*

① TPES : TPES: IEA with bunker
② GTAP0 : Initial GTAP energy balance
③ OTS : Outputs of transformation sector Mtoe
④ ITSnf : Input transformation sector, non fossil
⑤ GTAP1 : GTAP0 - OTS + ITSnF
⑥ EBt : Primary solid biomass TFC
⑦ GTAP2 : GTAP1+EBT

Annex 3

Insee Study

The Insee website provides data that are organized into four household categories. The breakdown of the data according to living standard quintiles is shown below: consumption expenditure; social transfers in kind; actual final consumption of private households in metropolitan France; and the average annual amount per household and per consumption unit in 2003, depending on the scale of living standards.

							All ordinary households (metropolitan France)
P3	**Final consumption expenditure**	Q1	Q2	Q3	Q4	Q5	↓
1	Food and non-alcoholic beverages	3 021	4 115	4 825	5 452	6 253	4 733
2	Alcoholic beverages, tobacco	762	1 089	1 226	1 299	1 314	1 138
3	Clothing and footwear	770	1 224	1 612	2 079	2 696	1 676
4	Housing, water, gas, electricity and other fuels	3 719	5 630	7 666	9 828	12 919	7 953
5	Furnishings, household equipment and routine household maintenance	761	1 339	1 718	2 231	3 898	1 989
6	Health	784	1 089	1 187	1 162	1 338	1 112
7	Transport	1 737	3 366	4 664	5 827	6 935	4 506
8	Communications	621	812	919	1 089	1 117	911
9	Recreation and culture	1 093	1 993	2 702	3 591	5 336	2 943
10	Education	78	117	176	303	426	220
11	Hotels, cafes and restaurants	637	1 275	1 876	2 905	4 406	2 220
12	Other goods and services	1 260	2 043	2 650	3 328	5 077	2 872
	Consumption expenditure per household	*15 242*	*24 093*	*31 220*	*39 096*	*51 716*	*32 274*
	Consumption expenditure per consumption unit	*9 927*	*15 220*	*19 335*	*23 863*	*33 507*	*20 388*
D63	**Social transfers in kind**						
1	Food and non-alcoholic beverages						
2	Alcoholic beverages, tobacco						
3	Clothing and footwear						
4	Housing, water, gas, electricity and other fuels	1 433	462	103	27	12	408
5	Furnishings, household equipment and routine household maintenance						
6	Health	3 945	4 270	3 985	3 464	3 550	3 843
7	Transport	35	36	36	37	35	36
8	Communications						
9	Recreation and culture	182	419	615	805	1 156	636
10	Education	4 223	3 059	2 785	2 698	2 321	3 017
11	Hotels, cafes and restaurants						
12	Other goods and services	1 864	1 317	1 259	1 269	1 134	1 368
	Including: Administration	841	867	884	897	845	867
	Support for disabled	520	83	32	25	14	135
	Elderly, dependents	339	154	47	21	9	114
	Childcare, nurseries	34	103	201	239	200	155
	Child welfare	130	109	94	88	66	97
	Social transfers in kind per household	*11 681*	*9 562*	*8 784*	*8 300*	*8 208*	*9 307*
	Social transfers in kind per consumption unit	*7 607*	*6 040*	*5 440*	*5 066*	*5 318*	*5 879*
P4	**Actual final consumption**						
1	Food and non-alcoholic beverages	3 021	4 115	4 825	5 452	6 253	4 733
2	Alcoholic beverages, tobacco	762	1 089	1 226	1 299	1 314	1 138
3	Clothing and footwear	770	1 224	1 612	2 079	2 696	1 676
4	Housing, water, gas, electricity and other fuels	5 153	6 092	7 769	9 856	12 932	8 360
5	Furnishings, household equipment and routine household maintenance	761	1 339	1 718	2 231	3 898	1 989
6	Health	4 728	5 359	5 173	4 626	4 888	4 955
7	Transport	1 771	3 402	4 700	5 864	6 970	4 541
8	Communications	621	812	919	1 089	1 117	911
9	Recreation and culture	1 275	2 412	3 317	4 396	6 492	3 578
10	Education	4 301	3 176	2 961	3 001	2 747	3 237
11	Hotels, cafes and restaurants	637	1 275	1 876	2 905	4 406	2 220
12	Other goods and services	3 123	3 360	3 908	4 598	6 211	4 240
	Consumption expenditure per household after social transfers in kind	*26 923*	*33 655*	*40 004*	*47 396*	*59 923*	*41 580*
	Consumption expenditure per household after social transfers in kind per consumption unit	*17 534*	*21 261*	*24 775*	*28 928*	*38 825*	*26 267*
	Thousands of households	5 052	5 052	5 052	5 052	5 052	25 258
	Average number of consumption units	1,54	1,58	1,61	1,64	1,54	1,58

Source : http://www.insee.fr/fr/themes/theme.asp?theme=16&sous_theme=2.2

Annex 4

Analysis by consumption purpose

An analysis by purpose aims to provide a global overview of the production of a given unit. Certain production activities are not directly subject to an invoicing process and therefore are not usually registered or measured for statistical purposes. They thus avoid inclusion in analyses by activity sector or by production. The analysis by purpose focuses on the study of all activities, whether billed for or not.
In business statistics, a distinction can be made between the following functions: production, purchases, research and development, sales and marketing, administration, accounting, management, transport (internal), repairs, trade, etc. An analysis according to purpose can therefore cover many activity sectors. The objective of this analysis is to observe how a given need (for example, education) is satisfied by the different activity sectors.

An analysis by purpose provides the basis for certain specific classifications:

- the COICOP, classification of individual consumption according to purpose, which is used for household expenditures
- the COFOG, classification of the functions of government, for public administration expenditure.
- the COPNI, classification of the purposes of non-profit institutions serving households.
- the COPP, classification of outlays of producers according to purpose.

La COICOP

This is a "functional" classification of the System of National Accounts (SNA) developed by Eurostat. It is used to classify transactions between producers and the household institutional sector. It therefore provides knowledge of household expenditure on food, health, education, etc. The OECD is currently reviewing this classification to determine whether it will adopt it more broadly. This classification has, in its aggregated version, twelve "standards" plus one or two sectors covering administration expenditure (individualizable expenditure of administrations) and non-profit institutions serving households (NPISHs). These additional sectors represent transfers in kind between the institutional sector of administration and households.
There is also a finer level of disaggregation, which has 47 sub-functions of consumption divided into 12 or 14 key categories.
As part of studies on actual household consumption, positions 13 and 14 may be reallocated amongst the first 12 positions.

Here are the titles of positions at level 1

01 Food and non-alcoholic beverages
02 Alcoholic beverages, tobacco and narcotics
03 Clothing and footwear
04 Housing, water, electricity, gas and other fuels
05 Furnishings, household equipment and routine household maintenance
06 Health
07 Transports
08 Communications
09 Recreation and culture
10 Education
11 Hotels, restaurants and cafes
12 Miscellaneous goods and services
13 Individual consumption expenditure of non-profit institutions serving households
14 Individual consumption expenditure of general government serving households

Detailed classification of household consumption according to purpose (COICOP)

01 Food and non-alcoholic beverages
01.1 Food
01.2 Non-alcoholic beverages

02 Alcoholic beverages, tobacco and narcotics
02.1 Alcoholic beverages
02.2 Tobacco
02.3 Narcotics

03 Clothing and footwear
03.1 Clothing
03.2 Footwear

04 Housing, water, electricity, gas and other fuels
04.1 Actual rents for housing
04.2 Imputed rents for housing
04.3 Maintenance and repair of homes
04.4 Water supply and miscellaneous services relating to homes
04.5 Electricity, gas and other fuels

05 Furnishings, household equipment and routine household maintenance
05.1 Furniture and furnishings, carpets and other floor coverings
05.2 Household textiles
05.3 Household appliances
05.4 Glassware, tableware and household utensils
05.5 Tools and equipment for house and garden
05.6 Goods and services for routine household maintenance

06 Health
06.1 Medical products, appliances and equipment
06.2 Outpatient services
06.3 Hospital services

07 Transport
07.1 Purchase of vehicles
07.2 Operation of personal transport equipment
07.3 Transport services

08 Communication
08.1 Postal services
08.2 Telephone and telefax equipment
08.3 Telephone and telefax services

09 Recreation and culture
09.1 Audio-visual, photographic and information processing equipment
09.2 Other major durables for recreation and culture
09.3 Other recreational items and equipment, gardens and pets
09.4 Recreational and cultural services
09.5 Newspapers, books and stationery
09.6 Package holidays

10 Education
10.1 Pre-primary and primary education
10.2 Secondary education
10.3 Post-secondary non-tertiary education
10.4 Tertiary education
10.5 Education not definable by level

11 Restaurants and hotels
11.1 Catering services
11.2 Accommodation services

12 Miscellaneous goods and services
12.1 Personal care
12.2 Prostitution
12.3 Personal effects n.e.c.
12.4 Social protection
12.5 Insurance
12.6 Financial services n.e.c.
12.7 Other services n.e.c.

Consumption functions corresponding to social transfers in kind

13 Individual consumption expenditure of non-profit institutions serving households (NPISHs)
13.1 Housing
13.2 Health
13.3 Recreation and culture
13.4 Education
13.5 Social protection
13.6 Other services

14 Individual consumption expenditure of general government
13.1 Housing
13.2 Health
13.3 Recreation and culture
13.4 Education
13.5 Social protection
13.6 Other services

Disaggregated version (47 categories that provide detail of the 12 main categories).[30]

30 http://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=5

Annex 5

Comparison between NES 118 and GTAP 56

Agriculture, forestry and fishing		
A01	Agriculture, hunting and related service activities	1,2,3,4,5,6,7,8,9,10,11,12
A02	Forestry, logging and related service activities	13
A03	Fishing and aquaculture	14
Manufacture of agricultural and food products		
B01	Manufacture of meat products	19, 20
B02	Manufacture of dairy products	22
B03	Manufacture of beverages	26
B04	Manufacture of grain mill products; manufacture of animal feeds	23
B05	Manufacture of other food products	21, 24, 25
B06	Manufacture of tobacco products	26
Wearing apparel and leather products		
C11	Manufacture of wearing apparel and fur	28
C12	Manufacture of leather and related products	29
Publishing, printing and reproduction		
C20	Publishing, printing and reproduction	31
Pharmaceutical, cleaning and perfume preparations		
C31	Manufacture of pharmaceutical products	33
C32	Manufacture of soap, perfume, cleaning and polishing preparations	33
Manufacture of household equipment		
C41	Manufacture of furniture	30
C42	Manufacture of jewellery and musical instruments	42
C43	Manufacture of sports goods, games and toys and other manufacturing	42
C44	Manufacture of domestic appliances	41
C45	Manufacture of reception, recording and reproducing appliances (sound, image)	41
C46	Manufacture of optical instruments, photographic equipment, watches and clocks	41
Manufacture of motor vehicles, trailers and semi-trailers		
D01	Manufacture of motor vehicles	38
D02	Manufacture of parts and accessories for motor vehicles	38
Building of ships and boats, air and spacecraft and railway locomotives and rolling stock		
E11	Building and repairing of ships and boats	39
E12	Building of railway and tramway locomotives and rolling stock	39
E13	Manufacture of aircraft and spacecraft	39
E14	Manufacture of bicycles, motorcycles and other transport equipment n.e.c.	39
Mechanical equipment		
E21	Manufacture of metal products for construction	37
E22	Manufacture of metals, manufacture of containers of metals and boilers	35
E23	Manufacture of mechanical equipment	41
E24	Manufacture of general purpose machinery	41
E25	Manufacture of agricultural and forestry machinery	41
E26	Manufacture of machine-tools	41
E27	Manufacture of other special purpose machinery	41
E28	Manufacture of weapons and ammunition	41
Electrical and electronic equipment		
E31	Manufacture of office machinery and computers	40
E32	Manufacture of electric motors, generators and transformers	41
E33	Manufacture of broadcasting and transmitting appliances	40
E34	Manufacture of medical and surgical equipment and orthopaedic appliances	41
E35	Manufacture of appliances for measuring and controlling	41
Manufacture of mineral products		
F11	Mining of metal ores	18
F12	Other mining and quarrying	18
F13	Manufacture of glass and glass products	34
F14	Manufacture of ceramic products and other construction materials	34
Textiles		
F21	Spinning and weaving	27
F22	Manufacture of textile products	27
F23	Manufacture of fabrics and knitted articles	27
Wood and paper		
F31	Manufacture of wood and of products of wood	30
F32	Manufacture of pulp, paper and paperboard	31
F33	Manufacture of articles of paper and paperboard	31
Chemical, rubber and plastic products		
F41	Manufacture of inorganic chemicals	33
F42	Manufacture of organic chemicals	33
F43	Parachemistry	33
F44	Manufacture of man-made fibre	33
F45	Manufacture of rubber	33
F46	Manufacture of plastic products	33
Manufacture of basic metals and fabricated metal products		
F51	Manufacture of basic iron and steel and of ferro-alloys, manufacture of products of first processing of steel	35
F52	Manufacture of non-ferrous metals	36
F53	Casting of metals	35
F54	Industrial services related to metal work	35
F55	Manufacture of fabricated metal products	37
F56	Reclamation	35
Electric and electronic components		
F61	Manufacture of electrical equipment	41
F62	Manufacture of electronic components	41

Annex 6

Regional division

N°	Region	Description	Country	Name	GTAP number
1	Europe15	15 EU states - France + Turkey	AUT	Austria	46
1	Europe15	15 EU states - France + Turkey	BEL	Belgium	47
1	Europe15	15 EU states - France + Turkey	DNK	Denmark	50
1	Europe15	15 EU states - France + Turkey	FIN	Finland	52
1	Europe15	15 EU states - France + Turkey	DEU	Germany	54
1	Europe15	15 EU states - France + Turkey	GRC	Greece	55
1	Europe15	15 EU states - France + Turkey	IRL	Ireland	57
1	Europe15	15 EU states - France + Turkey	ITA	Italy	58
1	Europe15	15 EU states - France + Turkey	LUX	Luxembourg	61
1	Europe15	15 EU states - France + Turkey	NLD	Netherlands	63
1	Europe15	15 EU states - France + Turkey	PRT	Portugal	65
1	Europe15	15 EU states - France + Turkey	ESP	Spain	68
1	Europe15	15 EU states - France + Turkey	SWE	Sweden	69
1	Europe15	15 EU states - France + Turkey	GBR	United Kingdom	70
1	Europe15	15 EU states - France + Turkey	CHE	Switzerland	71
1	Europe15	15 EU states - France + Turkey	NOR	Norway	72
1	Europe15	15 EU states - France + Turkey	XEF	Rest of EFTA	73
1	Europe15	15 EU states - France + Turkey	TUR	Turkey	90
2	France	France	FRA	France	53
3	EuropeNew	New EU members	CYP	Cyprus	48
3	EuropeNew	New EU members	CZE	Czech Republic	49
3	EuropeNew	New EU members	EST	Estonia	51
3	EuropeNew	New EU members	HUN	Hungary	56
3	EuropeNew	New EU members	LVA	Latvia	59
3	EuropeNew	New EU members	LTU	Lithuania	60
3	EuropeNew	New EU members	MLT	Malta	62
3	EuropeNew	New EU members	POL	Poland	64
3	EuropeNew	New EU members	SVK	Slovakia	66
3	EuropeNew	New EU members	SVN	Slovenia	67
3	EuropeNew	New EU members	BGR	Bulgaria	75
3	EuropeNew	New EU members	ROU	Romania	78
3	EuropeNew	New EU members	XER	Rest of Europe	82
4	China	China HKG Singapore	CHN	China	4
4	China	China HKG Singapore	HKG	Hong Kong	5
4	China	China HKG Singapore	SGP	Singapore	16
5	JapanKorea	Japan, South Korea and Taiwan	JPN	Japan	6
5	JapanKorea	Japan, South Korea and Taiwan	KOR	South Korea	7
5	JapanKorea	Japan, South Korea and Taiwan	TWN	Taiwan	8
6	SouthAsia	Indian subcontinent	BGD	Bangladesh	20
6	SouthAsia	Indian subcontinent	IND	India	21
6	SouthAsia	Indian subcontinent	PAK	Pakistan	22
6	SouthAsia	Indian subcontinent	LKA	Sri Lanka	23
6	SouthAsia	Indian subcontinent	XSA	Rest of South Asia	24
7	SouthPacific	Southeast Asia	AUS	Australia	1
7	SouthPacific	Southeast Asia	NZL	New Zealand	2
7	SouthPacific	Southeast Asia	XOC	Rest of Oceania	3
7	SouthPacific	Southeast Asia	XEA	Rest of East Asia	9
7	SouthPacific	Southeast Asia	KHM	Cambodia	10
7	SouthPacific	Southeast Asia	IDN	Indonesia	11
7	SouthPacific	Southeast Asia	LAO	Laos	12
7	SouthPacific	Southeast Asia	MMR	Myanmar	13
7	SouthPacific	Southeast Asia	MYS	Malaysia	14
7	SouthPacific	Southeast Asia	PHL	Philippines	15
7	SouthPacific	Southeast Asia	THA	Thailand	17
7	SouthPacific	Southeast Asia	VNM	Vietnam	18
7	SouthPacific	Southeast Asia	XSE	Rest of Southeast Asia	19

N°	Region	Description	Country	Name	GTAP number
8	NAmerica	North America	CAN	Canada	25
8	NAmerica	North America	USA	United States of America	26
8	NAmerica	North America	XNA	Rest of North America	28
9	LatinAmer	Latin America	MEX	Mexico	27
9	LatinAmer	Latin America	ARG	Argentina	29
9	LatinAmer	Latin America	BOL	Bolivia	30
9	LatinAmer	Latin America	BRA	Brazil	31
9	LatinAmer	Latin America	CHL	Chile	32
9	LatinAmer	Latin America	COL	Columbia	33
9	LatinAmer	Latin America	ECU	Ecuador	34
9	LatinAmer	Latin America	PRY	Paraguay	35
9	LatinAmer	Latin America	PER	Peru	36
9	LatinAmer	Latin America	URY	Uruguay	37
9	LatinAmer	Latin America	VEN	Venezuela	38
9	LatinAmer	Latin America	XSM	Rest of South America	39
9	LatinAmer	Latin America	CRI	Costa Rica	40
9	LatinAmer	Latin America	GTM	Guatemala	41
9	LatinAmer	Latin America	NIC	Nicaragua	42
9	LatinAmer	Latin America	PAN	Panama	43
9	LatinAmer	Latin America	XCA	Rest of Central America	44
9	LatinAmer	Latin America	XCB	Caribbean	45
10	MiddleEast	Middle East	IRN	Iran	89
10	MiddleEast	Middle East	XWS	Rest of West Asia	91
11	Africa	Sub-Saharan Africa	EGY	Egypt	92
11	Africa	Sub-Saharan Africa	MAR	Morocco	93
11	Africa	Sub-Saharan Africa	TUN	Tunisia	94
11	Africa	Sub-Saharan Africa	XNF	Rest of North Africa	95
11	Africa	Sub-Saharan Africa	NGA	Nigeria	96
11	Africa	Sub-Saharan Africa	SEN	Senegal	97
11	Africa	Sub-Saharan Africa	XWF	Rest of West Africa	98
11	Africa	Sub-Saharan Africa	XCF	Central Africa	99
11	Africa	Sub-Saharan Africa	XAC	Southern Central Africa	100
11	Africa	Sub-Saharan Africa	ETH	Ethiopia	101
11	Africa	Sub-Saharan Africa	MDG	Madagascar	102
11	Africa	Sub-Saharan Africa	MWI	Malawi	103
11	Africa	Sub-Saharan Africa	MUS	Mauritius	104
11	Africa	Sub-Saharan Africa	MOZ	Mozambique	105
11	Africa	Sub-Saharan Africa	TZA	Tanzania	106
11	Africa	Sub-Saharan Africa	UGA	Uganda	107
11	Africa	Sub-Saharan Africa	ZMB	Zambia	108
11	Africa	Sub-Saharan Africa	ZWE	Zimbabwe	109
11	Africa	Sub-Saharan Africa	XEC	Rest of East Africa	110
11	Africa	Sub-Saharan Africa	BWA	Botswana	111
11	Africa	Sub-Saharan Africa	ZAF	South Africa	112
11	Africa	Sub-Saharan Africa	XSC	Rest of South African Customs	113
12	Ex-USSR	Former "Soviet" countries	ALB	Albania	74
12	Ex-USSR	Former "Soviet" countries	BLR	Belarus	76
12	Ex-USSR	Former "Soviet" countries	HRV	Croatia	77
12	Ex-USSR	Former "Soviet" countries	RUS	Russia	79
12	Ex-USSR	Former "Soviet" countries	UKR	Ukraine	80
12	Ex-USSR	Former "Soviet" countries	XEE	Rest of Eastern Europe	81
12	Ex-USSR	Former "Soviet" countries	KAZ	Kazakhstan	83
12	Ex-USSR	Former "Soviet" countries	KGZ	Kyrgyzstan	84
12	Ex-USSR	Former "Soviet" countries	XSU	Rest of ex-USSR	85
12	Ex-USSR	Former "Soviet" countries	ARM	Armenia	86
12	Ex-USSR	Former "Soviet" countries	AZE	Azerbaijan	87
12	Ex-USSR	Former "Soviet" countries	GEO	Georgia	88

Annex 7

Application of the Leontief equation in a single region

With a knowledge of monetary flows, the Leontief equation can be used to formalize relationships and balances between production and consumption within economies.

The relationship between economic sectors within a region can be described as follows:

For i producing sectors of goods and services in an economy $(i=1, \;\, , n)$, with an x_i production (or resource) by sector i that satisfies a final demand (*consumption or employment*) y_i in products of the i sector and intermediate demands (x_{ij}) in other sectors j $(j=1, \ldots, n)$ in other i sector, we can write:

Employment = CI + Y = Ressources / Productions

On the employment side, we must add the GFCF, the stock variations (SV) and exports

$$x_{11} + x_{12} + x_{13} + \ldots + x_{1n} + y_1 = X_1$$
$$x_{21} + x_{22} + x_{23} + \ldots + x_{2n} + y_2 = X_2$$
$$\ldots$$
$$x_{n1} + x_{n2} + x_{n3} + \ldots + x_{nn} + y_n = X_n$$

On the resources side (dom+imports), we must add the margins of trade and transport, and taxes (-subsidies)

and with:

$X = (x_i)$ the production vector of the region r with x_i = output of sector i in region r.

$Y = (y_i)$ the final consumption vector of the region by sector i;

y_i = final demand of products from sector i, which includes the domestic final consumption (including imports) of households and public administration, with stock variations and gross fixed capital formation.

$A = [a_{ij}]$ the matrix $(n \times n)$ of technical coefficients of intermediate inputs;

$a_{ij} = x_{ij} / x_j = x_{ij} / (\Sigma_i \, x_{ji} + y_j)$ quantity of products of sector i used by sector j per unit of its production.

We obtain:

$X = A\,X + Y \rightarrow X = (I - A)^{-1}\,Y$ (Leontief equation)

The equation can be generalized for an "arbitrary" demand (production induced in each sector by the increase of consumption of a given product), as follows: $\Delta X = (I - A)^{-1} \Delta Y$

For R regions (multi-regional approach)

If we divide the world into R regions, for each region r $(r = 1, \ldots, R)$, the equation becomes, with the following notations:

$X_r = (x^r_i)$	Domestic production of region r, by sector i, with x^r_i = production of sector i in region r.
$Y_{rr} = (y^r_i)$	Domestic final demand in region r, by sector i, with y^r_i = final demand of products from sector i, in region r.
$Y_{zr} = (y^{zr}_i)$	Flow of products coming from the region z and consumed in region r
$A_{rr} = [a^{rr}_{ij}]$	Domestic intermediate matrix of region r, with a^{rr}_{ij} = amount of household products i (from sector i) used by sector j in region r for its production per unit of output of sector j; i and j varying from 1 to n.
$A_{zr} = [a^{zr}_{ij}]$	Intermediate matrix, with a^{zr}_{ij} = quantity of products from sector i of region z used by sector j in region r for its production per unit of production.

We can represent all necessary production in the world for the "arbitrary" demand of a single region r, with R equations, with m (m =1,…, R), with:

For the region r; $X_r = A_{rr}\, X_r + Y_{rr} + \sum_{z\neq m}^{R} (A_{rz}\ \ X_z + Y_{rz})$ ← Exports

For regions $m \neq r$; $X_m = A_{mm}\, X_m + Y_{mm} + \sum_{z \neq m}^{R} (A_{mz}\ \ X_z + Y_{mz})$ ← Exports

With $Y_{mm} = 0$ for $m \neq r$, the equation can be generalized as follows:

$$X_m = A_{mm}\, X_m + Y_{mm} + \sum_{z \neq m}^{R} (A_{mz}\ \ X_z + Y_{mz})$$

The set of equations in matrix form becomes for the case r=1:

$$\underbrace{\begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ . \\ . \\ . \\ X_R \end{bmatrix}}_{X_1} = \underbrace{\begin{bmatrix} A_{11} & A_{12} & A_{13} & & A_{1R} \\ A_{21} & A_{22} & A_{23} & \ldots\ldots\ldots & A_{2R} \\ A_{31} & A_{32} & A_{33} & \ldots\ldots\ldots & A_{3R} \\ . & . & . & \ldots\ldots\ldots & . \\ . & . & . & \ldots\ldots\ldots & . \\ . & . & . & \ldots\ldots\ldots & . \\ A_{R1} & A_{R2} & A_{R3} & \ldots\ldots\ldots & A_{RR} \end{bmatrix}}_{A_1} \underbrace{\begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ . \\ . \\ . \\ X_R \end{bmatrix}}_{X_1} + \underbrace{\begin{bmatrix} Y_{11} + \sum_{z\neq 1}^{R} Y_{1z} \\ Y_{22} + \sum_{z\neq 2}^{R} Y_{2z} \\ Y_{33} + \sum_{z\neq 3}^{R} Y_{3z} \\ . \\ Y_{mm} + \sum_{z\neq m}^{R} Y_{mz} \\ . \\ Y_{RR} + \sum_{z\neq R}^{R} Y_{Rz} \end{bmatrix}}_{Y_1}$$

Finally, more generally for a region r, a "meta-equation" of Leontief is obtained:

$(X_r) = [\,A_r\,]\,(\,X_r\,) + (\,Y_r\,) \rightarrow (\,X_r\,) = (\,I - [\,A_r\,])^{-1}\,(Y_r)$

By adding the "meta-equations" related to the needs arising from the consumption of all regions, we obtain the needs for the total consumption of the world.

The algebraic expression of the decomposed matrix equation enables the use of a formula that identifies the different productive sectors that contribute to the manufacture of products (X_r); i.e., for each region:

$(X_r) = {}^t({}^t(1) \times [I-A_r]^{-1} \times [\mathrm{diag}(Y_r)])$;

with $[\mathrm{diag}(Y_r)] = [y_{rii}]$ the diagonalized matrix of (Y_r) with $y_{ii} = y_i$ and (1) the unit vector.

Application to energy

It is then possible to assign to each final product the energy that has been necessary at each stage, by sector i and region r, of its development by multiplying the monetary value of each step by the unit energy consumption of the production step in question.

Embodied energy by sectors

We can then calculate the embodied energy, energy content of the final output of each sector:

$(\,E^{Cr}\,) = (\,e^{Cr}{}_i\,) = {}^t({}^t(e^r{}_i) \times [I-A_r]^{-1} \times [\mathrm{diag}(Y_r)])$;

with $(e^r{}_i)$ column vector:

$e^r{}_i$ = (Energy consumption of sector i in region r) / (monetary value of all production of sector i in region r)

Embodied energy per "usage"

Once this energy content, or embodied energy, per sector has been calculated, it is possible to establish a content per usage U, provided that it is known how to aggregate the sectors involved, i.e.:

per usage U: $E^{CU}{}_r = \sum^{uf}_{j=u0} e^{Cr}{}_j$;

with $\{u_0\ ;\ uf\}$ = the products necessary to satisfy the usage U.

Energy impact per "usage"

It is possible, then, to add to the embodied energy (E^{CUr}) of the usage U, the energy consumed at the moment of the usage U satisfaction (usage energy) in region r (E^{DUr}), to obtain the energy impact of a usage U in the region r (E^{Ur}), i.e.:

per usage U: $E^{Ur} = \sum^{uf}_{j=u0} e^{r}_{j} + E^{DUr}$

with $\{u_0 ; u_f\}$ = the products necessary to satisfy the usage U.

Energy impact of consumption in each region

The energy impact of the total consumption of each region then becomes:

$Er = \sum^{T}_{u=1} E^{Ur}$

with T = All of the usages U in the region r

Simplification of bilateral trade flows

Matrices $[A_{mr}]$ and vectors (Y_{mr}) which provide for each sector the origin of the imports, from region m to region r, differentiated both by sectors and by regions of origin are rarely available in global databases of TES. In general, the databases provide instead:

- the matrix $[A^{IMr}] = \sum_{m\neq r}^{R} [A_{mr}]$, which is the sum, by sector, in all regions, of all imports coming from the same sector in the region r. A^{IMr} gives, by sector, all imports of intermediate consumption by sector of origin, but without the distribution by region of origin of these imports.
- The vector $(Y^{I}_{r}(= \sum_{m\neq r}^{R} (Y_{mr})$, which is the sum, by sector and for all regions, of all imports coming into the region r. (Y^{I}_{r}) gives, by sector, all of the direct imports differentiated by sector of origin, but without the distribution by region of origin of these imports.
- And the matrix $[P^{Ir}] = [p^{Ir}_{im}]$ (total) matrix of distribution per region m (m) of all the imports (direct + intermediate consumption) in each sector i with p^{I}_{iz} accounting for the sector i of the country r, the share of all its imports, regardless of the origin sectors, coming from the region m.

We chose to make the assumption that the regional distribution of sources of imports of each product is the same:

- for each sector: each sector of region r imports the same proportion of its total imports of products of all sectors of the region m. This means, for example, that if 70% of the overall energy imported by France comes from the Middle East, 70% of the energy imported by the steel industry comes from the Middle East, although in reality this area mainly imports coal and therefore very little energy from the Middle East: in this case, we would increase the proportion of exports from the Middle East!
- for imports consumed directly (direct imports) and for intermediate consumption (CI).

Of course, this is not the reality, but the information available makes this an unavoidable approximation at this stage of the process in order to carry out the "real" calculation. This approximation explains the gap between the total energy balance of the model and the expected value (cf §).

A_{mr} and Y_{mr} matrices can then be "approximated", by adjusting the coefficients of the A^{IMr} matrix and of the Y^{I}_{r} vector, according to the relative shares of total imports for each region derived from $P^{T}r_{m}$. We obtain:

$[A_{mr}] = [P^{Ir}_{m}]\times[A^{IMr}]$ et $(Y_{mr}) = [P^{Ir}_{m}]\times(Y^{I}_{r})$

with $[P^{Ir}_{m}] = [\mathrm{Diag}(p^{I}_{im})]$ the diagonalized matrix of the vector (p^{I}_{im}) = the column m of the matrix $[P^{Ir}]$ which represents the share of all imports for the n sectors "i" of the region r coming from the region m

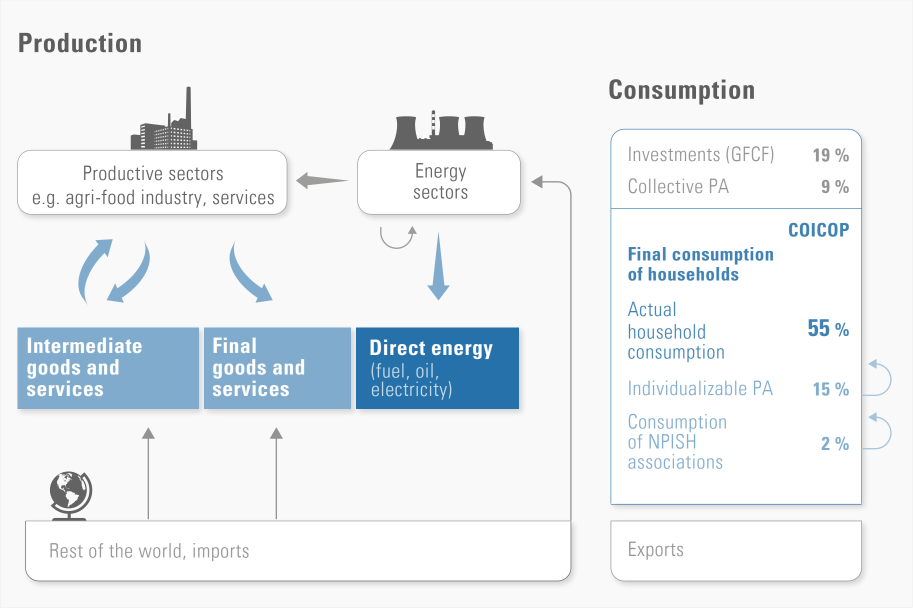
Since $[A_{mm}]$, $[P^{Ir}]$, $[A^{IMr}]$, (Y_{r}), (Y_{mr}), are accessible data, the numerical application can be done.

Annex 8

The ten key stages of the approach

To summarise the approach, we have:

1. taken the COICOP of consumption per quintile of the INSEE study on metropolitan France and calculated these values for the whole of France in € 2004 => $€_{2004}$/COICOP(Q_F),
2. taken the energy contents in millions of 2004 dollars of production of GTAP sectors derived from the calculation tool and calculated the content in millions of 2004 euros, which varied according to domestic or imported intermediate consumption, direct imports and exports => toe/$M€_{2004}$ (S_{GTAP}, ImpD, CIDom, CIImp, Exp),
3. used the I-O table 2004 in NES118 to reconstruct the entire final consumption ("employment") in 2004 by adding the collective PA components, NPISHs, GFCF and exports to the actual consumption described in the INSEE study,
4. used the transition matrix NES118-COICOP to obtain the importance of the NES118 sectors in each COICOP,
5. used the I-O_{NACE60} table information to identify the share of final consumption of the I-O_{NES118} table derived directly from imports and translated, using (4) and (3), this information in the results of (1) hence => $€_{2004}$/COICOP(Q_F,ImpD, CIDom, CIImp),
6. built a correlation table between sectors in NES118 and those in GTAP,
7. used (6) and (4) to obtain the importance of the GTAP sectors in each COICOP
8. used (7) and (2) to obtain the unit energy contents per COICOP => toe/$M€_{2004}$ (COICOP, ImpD, CIDom, CIImp, Exp)
9. used the 2004 energy balance of the SOeS and the detailed valuesof energy consumption expenditure per quintile of the INSEE to evaluate the energy used directly by each quintile in each COICOP => toe/$M€_{2004}$ (COICOP, Q, NRJ_{uti})
10. applied (8) and (9) to (1) to obtain for each quintile, Q, the energy impact per COICOP of the final consum



Annex 9

Ten key points to clarify certain details of the approach

Population groups

The INSEE study provides differentiated data according to living standards, socio-professional category or the age of the reference person and household composition.

We present the application of the calculation of the energy impact of households according to their living standards, because this differentiation is the easiest for the interpretation of energy levels.

National consumption

Since we wanted to analyse the entirety of French consumption in order to verify the accuracy of the energy calibration compared to the national balance, we could not only use household consumption, but needed to integrate the remaining component of employment, mainly the collective PA and the gross fixed capital formation (GFCF).

We have chosen to distribute these components evenly between each household; this is not necessarily correct but we have not found a better alternative.

Regarding the GFCF, one improvement would be to obtain the table of formation of this GFCF, which would allow us to better distribute it between the different sectors. We will discuss with INSEE whether such a table exists.

Year and geographical scope of work

The INSEE study (Bellamy *et al.*, 2009) was fixed to 2003, while the global data were from 2004. The easiest thing to do was to "roughly" bring back the study to the year 2004 by globally increasing the results of the increase in GDP in France between 2003 to 2004. In making this assumption, we supposed that the structure of consumption remained unchanged, which is not true. However, we estimated that the error was not significant in terms of our research.

The study was limited to the area of metropolitan France, whereas global and energy data correspond to the whole of the French territory. We have integrated the populations of overseas departments, assuming that they have the same consumption patterns as in metropolitan France. This is, of course, not true, because the demographic structure of populations and social transfers are very different, but here again we considered that this error remained low, compared to the orders of magnitude that we wanted to identify.

We confirmed these choices following a discussion with one of the authors of the study, Maryse FESSEAU.

Reconstruction of usages

The issue of the transition from productive sectors to usages that are more representative of household consumption is not new. A solution that is well adapted to economic reference databases is to use a functional classification of consumption usages, such as the classification of individual consumption by purpose (COICOP). The results of the INSEE study, on which we base our work, give the results in terms of COICOP (see Annex 3).

In any case, there is no definitive choice for grouping. The relevance and the choice of the division of consumption per usage, according to the possibilities offered by the GTAP database, depend primarily on analytical needs. The one presented below was dictated by the best possible match to a reconstruction of the consumption by purpose (COICOP) used by INSEE. It may be necessary to change this, depending on the type of consumption or energy that is to be analysed.

Transition from INSEE data to COICOP

The I-O tables that we must use to develop the impact are in the NES 118[31] classification of the national accounts. To switch to the COICOP format, we have used a matrix to complete the transition from the NES 118 classification to the INSEE disaggregated version of the functional COICOP classification, which was very kindly sent to us by Fabrice Lenglart.

In the context of our study, we did not use the matrix in its disaggregated version (47 categories that provide detail on the 12 main categories).[32] We reduced the allocation percentages to 12 major consumption functions. Indeed, the consumption data of the decomposition of household accounts for 2003 conducted by INSEE (Bellamy *et al.* 2009) are only accessible to the public in the format of 12 main categories of the COICOP. The data exist for the 47 categories, but they are not published by INSEE.

Transition from the GTAP 57 format to the INSEE NES 118

A first step was to go from 57 GTAP sectors to the NES 118 format. We did not find an ad-hoc transition matrix and therefore manually rebuilt the transition based on the known definitions of the two databases. The correlation table obtained is presented in the annex (Annex 5: comparison between NES 118 and GTAP 56).

The second step has enabled, through the use of the NES118-COICOP matrix, the evaluation of the respective weights of GTAP sectors in each COICOP.

This work was very difficult and it remains one of the major weak points of the method, as there was of course no exact match and we were forced to make many simplifications.[33]

Here is an example, in this case for nuclear materials, of the problems encountered during the construction of the correlation:

- Sector 32 of the GTAP contains the following products: "Coke, propane, butane, hydrocarbon gases and liquids, petroleum bitumen". It corresponds to the sectors NES G14 and G15 which correspond respectively to the "production of coking coal, coke oven gas, tar and nuclear materials" (but not mining, which is in G11, G12 and G13!) and to "petroleum refining and fuel production".
- In GTAP, the production of nuclear materials is assigned to sector 33 (chemicals and plastics) and therefore a gap in the correlation occurs. It would be useful to analyse this more closely because it introduces a disparity in the allocation of energy contents!

The construction of the activity sectors in the GTAP database is based on two classifications: CPC[34] and $ISIC_{\text{rév3}}$.[35] Therefore, there are precise correlations between the CPC, $ISIC_{\text{rév3}}$ and

31 Nomenclature économique de synthèse : nomenclature d'activités économiques et de produits en 16, 36 et 114 ou 118 positions utilisée par l'Insee entre 1994 et 2007 : *http://www.insee.fr/fr/methodes/default.asp?page=nomenclatures/nes2003/nes2003.htm*

32 *http://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=5*

33 Des coefficients de recalage ont été utilisés pour lisser les écarts dus aux différences de périmètre des secteurs productifs et consommateurs dans GTAP et les TES Insee

34 Central Product Classification est la nomenclature exhaustive des produits des Nations Unies *http://www.insee.fr/fr/methodes/default.asp?page=definitions/clas-centr-produits-nat-unies.htm*

35 International Standard Industrial Classification of All Economic Activities des Nations Unies *http://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=2*

GTAP sectors. CPC and ISIC are classifications that are used on an international scale, it should therefore be possible to obtain a correlation between these classifications and the NES 118 - perhaps from the INSEE. This aspect has not been explored in detail in this study and would benefit from further research. Through the automation of the correlations it should be possible to reconstruct the NES 118 - GTAP correlation in a more systematic way.
However, this study does not extend to include such a calculation as the NES 118 classification has not been used since 2007. An update must therefore be carried out in order to work with the new NACE classification.

Development of "embodied energies" for each COICOP category
To calculate the "embodied energies" of COICOP categories, given that the actual consumption expenditure was known, we needed to obtain the unitary energy contents for each COICOP category.
Based on the calculation tool, we had the unitary contents (domestic and imported) for each GTAP sector. Since we knew the respective weight of each GTAP sector in the COICOP, we were able to rebuild the unitary energy content for each COICOP category.

Treatment of direct energy
Direct energy is the final energy consumed by households; the details of this expenditure (second level of the COICOP) is available per quintile on the INSEE website.
The information in the GTAP database does not allow differentiation between automotive fuels and domestic fuel oils. We therefore chose to use statistics from the Ministry responsible for energy, thus hybridizing the GTAP energy information with national data (SOeS). GTAP introduces a breakdown into imported and domestic energy use, which is not the case in national statistics: we go from 66 Mtoe of energy use to 72 Mtoe in the SOeS, which adds 6 Mtoe (6.2) to the balance that results from the calculation compared to the real balance.
In our study, we considered that all direct energy was domestic.
We allocated all fuel expenditure to the COICOP transport category and all residential energy to the COICOP housing category, in proportion to specific expenditure.
Ultimately, the residential energy should be divided between the "food", "communication", "recreational" and "clothing" categories, and not simply classified as "domestic". However, such an operation would be too delicate at the current time. Indeed, there is currently no statistical data available to enable this task. This work of differentiation per use of final consumption is far from obvious and requires considerable expertise. It is the subject for another study.

Consideration of imports
The differentiation between domestic and imported embodied energy is automatically provided by the development tool for the GTAP, since all GTAP data are differentiated as being domestic or not. This is one of the major benefits of this approach.
By contrast, regarding the final consumption of products that are consumed directly, the INSEE study does not specify the origin of the goods consumed. Indeed, these data derive from surveys and since consumers are unable to identify the origin of all products, this information is not obtained.
We therefore had to rebuild the "imported" and "domestic" proportions of the COICOP categories.
To the different consumption expenditures in COICOP, we decided to apply the average distribution of the final demand in NES 118. This represents a major assumption because there is no reason why the purchase of imported products should be the same for all population groups, but there were no other elements that enabled us to opt for a better solution. We therefore

introduced a smoothing factor to address the gaps that must be corrected for at a later date. Since these details on imports were not available in the I-O tables in NES118, we reconstructed them from a more aggregated I-O table in NACE60.[36]

Distribution in the COICOP of domestic and (directly) imported production

COICOP	Domestic	Imported
Food 1	79%	21%
Alcohol - tobacco 2	52%	48%
Clothes - shoes 3	36%	64%
Housing 4	98%	2%
House equipement 5	61%	39%
Health 6	90%	10%
Transport 7	69%	31%
Communication 8	92%	8%
Recreation - culture 9	78%	22%
Education 10	100%	0%
Restaurants - hotels 11	100%	0%
Other services 12	86%	14%

36 This operation required adjustments as the distinction between households and PA does not appear in the NACE60, and we did not have a matrix for the NACE60-COICOP transfer.

Annex 10

Details on international energy impacts in 2004

Table A10-1

Details on international energy impacts in 2004

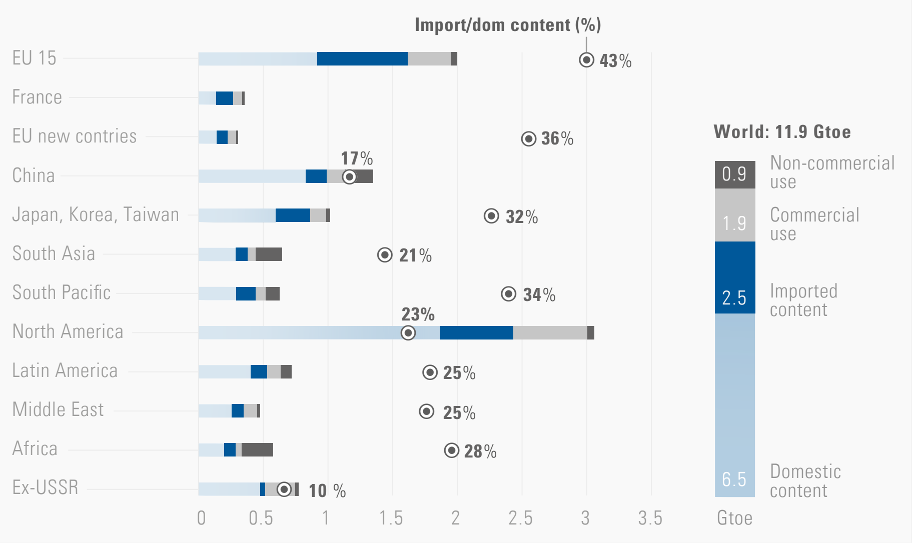
Mtoe	Energy impact	Embodied energy	Direct energy	Direct energy / impact	Non-commercial energy	Non-com / impact
EU 15	1,989	1,624	365	18%	35	2%
France	351	284	66	19%	9	3%
EU new countries	310	239	71	23%	13	4%
China	1,354	1,000	355	26%	217	16%
Japan Korea Tw	1,006	885	121	12%	2	0%
South Asia	657	385	273	42%	202	31%
South Pacific	643	453	189	29%	111	17%
North Am.	3,057	2,446	611	20%	49	2%
Latina Am.	720	537	183	25%	68	9%
Middle East	462	359	103	22%	1	0%
Africa	584	295	289	50%	231	40%
Ex-USSR	764	532	233	30%	4	1%
World	11,898	9,039	2,859	24.0%	942	7.9%

Table A10-2

Energy impact according to the regions in 2004

Mtoe	IEA (with bunkers)	Energy impact	Gap model-IEA
EU 15	1,495	1,989	33%
France	284	351	24%
EU new countries	299	310	4%
China	1,677	1,354	-19%
Japon Corée Tw	876	1,006	15%
South Asia	646	657	2%
South Pacific	610	643	5%
Am. du Nord	2,644	3,057	16%
Am. Latine	677	720	6%
Middle East	499	462	-8%
Africa	596	584	-2%
Ex-USSR	974	764	-22%
World	11,277	11,898	5.5%

Figure A10-1
Energy impact of consumption per region



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