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Summary

This article provides a panorama of greenhouse gas (GHG) emission inequalities between French households. It presents in a detailed and critical manner the methodological conventions that are used to compute "household emissions", including the related assumptions. The most common responsibility principle, the "consumer responsibility", assigns to households the emissions of the products that they consume, resulting in the carbon footprint. It focuses attention on the contributions of individuals, on their choices, and it may obscure the role of non-individual actors and also the collective component of GHG emissions, and it neglects the dimensions of responsibility that are not related to consumption choices.
We estimate the distribution of household carbon footprints based on data from the 2011 French Household Budget Survey. Household emissions tend to increase with income, but they also show a strong variability linked to geographical and technical factors that force the consumer to use fossil fuels.
Based on sectoral surveys (ENTD 2008; PHEBUS 2013), we also reconstruct household CO_2 emissions linked to housing and transport energy. For transport, emissions are proportional to the distance travelled due to the predominant use of private cars. Urban settlement patterns constrain both the length of daily commuting and access to less carbon-intensive modes of transport. For housing, while the size of the dwelling increases with income and distance from urban centres, the first factor to account for variability of emissions is the heating system: this has little to do with income but more to do with settlement patterns, which constrain access to the various energy carriers.
Finally, we discuss the difficulties, both technical and conceptual, that are involved in estimating emissions from the super-rich (the top 1 percent).

Keywords: Greenhouse Gas Emissions, Carbon Footprint, Emissions Inequality, Household Expenditure Distribution, Responsibility

JEL Classification: D12, D30, Q56, R20

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Who emits CO_2?
Landscape of ecological inequalities in France from a critical perspective*

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Abstract

This article provides a panorama of greenhouse gas (GHG) emission inequalities between French households. It presents in a detailed and critical manner the methodological conventions that are used to compute "household emissions", including the related assumptions. The most common responsibility principle, the "consumer responsibility", assigns to households the emissions of the products that they consume, resulting in the carbon footprint. It focuses attention on the contributions of individuals, on their choices, and it may obscure the role of non-individual actors and also the collective component of GHG emissions, and it neglects the dimensions of responsibility that are not related to consumption choices.

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Who is the CO_2 emitter? Landscape of ecological inequalities in France from a critical perspective

Antonin Pottier, Emmanuel Combet, Jean-Michel Cayla, Simona de Lauretis et Franck Nadaud

In the fall of 2018, the French "Yellow vest" movement highlighted the demand for social justice in the conduct of the ecological transition. For example, it was considered unfair that a wealthy household was not taxed when they flew to the other side of the world to spend their holidays, while a poor household suffered an increase in diesel taxes without the opportunity to change their vehicle. Social justice, understood in this way, would consist of a balance between the environmental damage caused by a person and the effort required of them by the public authorities. In contrast, injustice would come from the fact that "the rich are destroying the planet"(Kempf, 2007) while they reduce their emissions little, where the poor pollute little but contribute much to the mitigation effort. To appreciate the social justice of the ecological transition, it seems necessary to first understand the inequalities that we will call "ecological inequalities"[1]; in this case, inequalities in greenhouse gas (GHG) emissions.

This article provides a detailed overview of CO_2 emissions inequalities in France[2], based on original work to reconstruct household GHG emissions. This panorama is never neutral because the simple description of emissions is neither obvious nor unambiguous, even though there are standard ways of proceeding. Indeed, household emissions cannot be measured in the same way as one measures the size of a person: estimating emissions requires accounting conventions that are derived from a point of view that is partly arbitrary. We have therefore decided to detail, discuss and critically review the methodological conventions that are used to calculate "household emissions". In doing so, we wish to set out as clearly as possible the assumptions of this type of study, which is rarely done. We want to highlight the limits

[1] Following up on Emelianoff (2008), which proposed to distinguish between ecological inequalities (i.e. the inequalities of impact generated, such as how much each person contributes to air pollution) and environmental inequalities (i.e. the inequalities of impact suffered, such as how much each person is exposed to air pollution).

[2] Among studies of carbon footprints of households, Lenzen (1998), Wier et al. (2001), Roca and Serrano (2007), Weber and Matthews (2008), Golley and Meng (2012), Gough et al. (2012), Büchs and Schnepf (2013), Ummel (2014), Steen-Olsen et al. (2016), Isaksen and Narbel (2017), Wiedenhofer et al. (2017) and Gill and Moeller (2018) deal more specifically with emissions inequalities and their link with income inequalities. For France, see Lenglart et al. (2010); Malliet (2020).

of the resulting analysis and thus warn about the necessary precautions to be taken in interpreting ecological inequalities.

Three pitfalls are important to point out here. First, to establish how much a household, a company or a state "emits" CO_2, we must choose accounting rules; that is, ways to allocate to an agent the emissions generated by an activity that always involves several agents. The final result will be expressed as "this household emits $10\,tCO_{2e}$". This figure of $10\,tCO_{2e}$ emissions must always be interpreted in the light of the chosen accounting principles because what is meant by "emit" in this context is precisely defined by these principles[3]. An additional difficulty is that the expression is often understood as this household "causes" or "is responsible for" $10\,tCO_{2e}$, a shift in meaning that is often imperceptible and unavoidable. However, statistical ways of imputation often contradict moral conceptions of causality or responsibility. We are not advocating here for a specific conception of responsibility but we are highlighting this unbreakable link between accounting and conception of responsibility, including the tensions generated by this link.

Second, finding out how much greenhouse gas *each* emits is a choice of the analyst, who ignores the other, non-individual, entities involved in GHG emissions. This directs the research towards individual behavior rather than social organisation, corporate strategies or government policies. Consequently, thinking in terms of individual or household emissions focuses attention on the individual's contributions and their choices, while concealing the presence of non-individual actors and the collective component of GHG emissions, and the need to act together to reduce them. This apprehension of ecological inequalities reinforces the individualistic and moralising prism through which climate policies are viewed (Comby, 2015).

Finally, linking ecological inequalities and income inequalities is another strong trend, which risks making income the main, if not the only, factor explaining ecological impacts. If, like others, we confirm that having a higher income leads on average to "emitting" more CO_2, then we should insist on the fact that income alone does not account for ecological inequalities. At a given income, there is a high variability of emissions. Other dimensions, known as "horizontal" inequalities (as opposed to the "vertical" dimension of the income scale), come into play, such as the urban settlement patterns or the heating systems [4]. They should not be forgotten when we talk about ecological inequalities and social justice.

In this article, we will first outline the methodological difficulties to be

[3] The polysemy of the term "emit" is therefore very large. It is not uncommon for a text, whether militant or scientific, to surreptitiously move from one meaning to the other.

[4] The issues of equity according to average vertical inequalities have been highlighted since the 1990s (Pearce, 1991; Poterba, 1991); the importance of horizontal inequalities for energy and carbon was more recently highlighted (Combet et al., 2010; Dubois, 2012; Büchs and Schnepf, 2013; Douenne, 2018; Berry, 2019; Cronin et al., 2019; Stiglitz, 2019; Clément et al., 2019).

overcome and the principles to be chosen to evaluate the emissions of a household, indicating the data required in the different operations and focusing on consumption-based accounting, which is the most frequently used approach. We insist on the framing effect operated by this approach and the conception of the responsibility that it conveys. We then present our overview of emission inequalities in France. First, we deal with the carbon footprint (i.e. the direct and indirect GHG emissions linked to household consumption). We then focus on CO_2 emissions related to energy consumption in housing and private transport, for which the more detailed data that are available allow us to better discern the economic, social or technical factors of dependence on fossil fuels and inequalities between households. The carbon footprint of the very wealthy is then used as a case study to examine some problems of both estimation and attribution of CO_2 emissions. Finally, after having discussed the case of emissions from the wealthy, "the 1%", we conclude these analyses by identifying the conditions of equity of an ecological transition and designing appropriate public policies.

1 The problem of allocating emissions

A coal-fired power plant releases CO_2 to the atmosphere by burning coal to produce electricity. Who is responsible for these CO_2 emissions? The country in which the plant is located? The government that authorised its construction? The operating company that manages the plant on a day-to-day basis? the shareholders who have invested their capital? The country where the coal comes from? The mining company that mined the coal? The users of the electricity produced? The manufacturer of the (energy-guzzling) appliance that is powered by the electricity? There is no right answer here, all of them are equally possible because the emissions from the power plant are not the work of a single, well-defined actor, they are at the crossroads of several agencies, they are all entities with an intention and a capacity to act. Allocating emissions necessarily means selecting the relevant entities and determining the generating actions. This is an arbitrary operation, which proceeds from a certain point of view on who is "causing" and who is "responsible" for the emissions from the coal-fired power plant. This point of view guides the establishment of the accounting principles that allocate the emissions to the relevant entities chosen according to the generating activities that are being considered. These rules also have their internal logic and specific constraints, which make it necessary sometimes to specify and modify the initial point of view.

1.1 Production-based and consumption-based accounting

The problem of attributing GHG emissions first arose for countries. Let us look at the most common accounting principles, disregarding variations in detail.

National inventories conducted under the UNFCCC are the basic statistical source. These inventories classify GHG emissions according to the nature of the gas and the country where the emission took place. Emissions are allocated to the country if they took place on its territory. In our example, emissions would be allocated to the country in which the coal-fired power plant is located. Therefore, these inventories group the emissions according to the country of production, which is called production-based accounting (or territory-based accounting, with slight differences between the two).

While the production-based accounting is adopted by international law, consistent with the idea that States are responsible for the territories under their jurisdictions (Liu, 2015), researchers have developed other ways of allocating emissions. The most common is consumption-based accounting, also known as carbon footprinting (Peters, 2008). In this case, emissions are allocated to the location of the final consumers of the goods or services that have the GHG-generating activity. In our example, emissions are attributed to the country in which the product whose manufacturing used the electricity from the coal-fired plant was consumed. Things can become very complicated here because the product in question may not be a product intended for final consumption but may instead be an intermediate product that will be transformed: the electricity generated by coal in country A is used to produce aluminium, which is then transformed in country B into a can of soda to be consumed in country C, which will ultimately be attributed with the emissions from the power plant.

Calculating a country's emissions in the consumption approach is therefore based mainly on the environmental accounts (NAMEA) (which list how much each industry in each country emits GHGs directly) and on the input-output tables for international trade (which describe, in particular, in an aggregated manner by economic sectors, the sales of companies to other companies, whether these are located on the national territory or abroad, as well as to end users). *Input-output* analysis methods (Leontieff's inversion in particular) make it possible to reconstruct, using technical assumptions, the emissions generated throughout the production chain of a product. The carbon footprints of the countries thus obtained (Davis et al., 2010; Barrett et al., 2013) include not only direct emissions, both foreign and domestic, for the manufacture of products consumed in the country but also emissions for the manufacture of inputs, inputs of inputs, and so on, which are based on statistical and computational apparatus and not on direct observations. Their preciseness is necessarily limited by the quality of the statistical sources used (Tukker, Wood, and Schmidt, 2020), while their accuracy is limited by the quality of the assumptions made (Lenzen, 2000, p. 136-142).

These two approaches are the most common, but they are not the only ones[5]. Other methods exist, such as extraction-based accounting, which is used to identify countries or companies that are sources of fossil energy whose combustion releases carbon into the atmosphere (Davis et al., 2011; Heede, 2014); income-based accounting, which allocates emissions allowed by the supply of factors of production (capital and labour) (Marques et al., 2012); or issue-based accounting, which focuses on emissions related to a technique designed and produced by an industrial process (Rose, 2013). There are also different ways of counting emissions from organisations and companies that are geared towards action or reporting, with different scopes and accounting principles (Le Breton, 2017).

1.2 Individualising allocation

Calculating a country's emissions is not a straightforward task, while moving from country to individual adds an extra level of complexity. Emissions per capita are often considered. They are obtained simply by dividing a country's emissions, whether consumption-based or production-based, by its total population. These per capita emissions correspond to those of the "average" resident in the statistical sense of the term (Desrosières, 1993, chap. 3): they are not those of a real person, they are just another way of presenting the emissions of countries regardless of the size of their population. While this is a useful way of comparing countries, it does not allow for comparisons of the emissions of different socio-demographic groups or socio-professional categories. For example, we would like to know the emissions of a pensioner living in a rural area, or those of a couple with five years of higher education without children living in a large metropolitan area. To do this, we must first specify the accounting principle for allocating emissions to individuals.

How do we define an individual's emissions? Consumption-based accounting is the most common, if not the only, approach: the emissions of an individual are the emissions generated by all the stages of production of the final products that they consume. This includes not only the direct emissions released by the individual (e.g. by burning petrol in a car) but also the indirect (or upstream, or embodied) emissions that were necessary to produce the products and services that they consumed (e.g. to extract the oil and refine it into petrol; to heat the greenhouse that grows the tomatoes that they purchase, and to transport and package them). This approach makes it possible to attribute to households all of the emissions related to their final consumption.

How can this approach be implemented? Apart from a derived method

[5] Tukker, Pollitt, and Henkemans (2020) present five accounting principles (production-based, consumption-based, extraction-based, income-based, value-added based) with corresponding methodologies.

that will be discussed in section 4, two main methods can be used: based on either physical or monetary consumption data.

The first method deducts emissions from the physical quantities (kilogram of beef, gallon of petrol, m^3 of gas etc.) that are actually consumed by a person. The difficulties of this method concern both the conversion from quantities to emissions and the knowledge of quantities. If the conversion of a gallon of gasoline to emissions is based on a specific emission factor determined by combustion chemistry, then the emissions generated by the manufacture of a product are more complicated to estimate. They are known, for example, from the upstream part of a life cycle assessment (LCA) of the product. An LCA requires a lot of data on industrial processes, energy consumption, raw materials, and suppliers. In addition, this assessment is not systematic. Thus, the emissions contained in a given purchased product are often unknown, nor are the quantities consumed, or imperfectly, due to the lack of institutional or private systems to record them. While it is easy to reconstruct from the electricity bill the kilowatt-hours consumed, who can tell how many kilos of meat one ate and how many gallons of petrol one burned? Consequently, we often limit ourselves to the emissions that can reasonably be reconstructed from the available data. For example, with the kilometres travelled during the year (recorded by the meter) and the type of vehicle, we can deduce with a good approximation the CO_2 emitted by the use of the vehicle, where a more precise estimate would be obtained from gallons of gasoline. This method, or simplified variants of it, is used in the individual's carbon footprint that is proposed by many websites (Schlumpf et al., 1999), and in some surveys of people's behaviour (GreenInside, 2011; Sessego and Hébel, 2018).

The second method uses the amount spent to purchase each consumption item to estimate total emissions. This relies on a Household Budget Survey, which gives the annual expenditure budget, segmented into different consumption items, for each household in a representative sample. This is then combined with the emission content for each item, as reconstructed by the input-output analysis[6]. Given that this method is a refinement for individuals of the consumption-based accounting for countries, it inherits the uncertainties that have already been mentioned. It also adds specific uncertainties because the estimate is carried out on particular microentities (households) and not at the scale of large macroeconomic aggregates. While considering an average emission content for an industry can be justified as representing the emission content of the average output of the industry, this averaging is no longer relevant when considering specific expenditures: a particular individual buys a specific product of one company and not the average output of an industry.

Ultimately, these two methods allow individual consumption-based emis-

[6] Steen-Olsen et al. (2016) precisely describe the methods, its difficulties and its limits.

sions (or carbon footprint) to be calculated using a combination of activity data (quantities consumed, sums spent) and emissions factors (tCO_{2e}/ litre of petrol...) or emissions content (tCO_{2e}/ euro spent). In addition to the difficulty of collecting accurate activity data, the use of average emission contents is responsible for uncertainties in the final result: one euro has the same carbon content, whether spent on low-end or luxury clothing. In other words, the "quality effect" (as we shall call it) is not taken into account. These uncertainties can be more easily controlled for the method that relies on physical quantities because the emission factors are less uncertain. We will use the monetary method to estimate households' carbon footprints (2) and the physical method to calculate emissions from energy services in housing and private transport (3).

1.3 Assumptions behind the carbon footprint

Counting an individual's consumption-based emissions is today the most widespread allocating principle when dealing with ecological inequalities. Consequently, the presuppositions of this principle are rarely recalled, discussed or questioned, even though they are sometimes in tension with the rest of the discourse within which the carbon footprint is mobilised. However, they should be kept in mind to be aware of the framing created by invoking carbon footprints.

The principle of allocating emissions to final consumption is often justified by making consumption the *ultimate* cause of emissions[7]. This principle seems natural because it is congruent with other representations of the economy: that of national accounts for which consumption is an end; that of economics textbooks in which consumer satisfaction is the driving force of the economic system (and not, for example, the accumulation of capital); and that of neo-liberalism, which insists on individual choices to the detriment of the role of collective structures. It also resonates with the conception of conscious consumption, in a representation that depicts active consumers who can orient production conditions through their purchases (Jacobsen and Dulsrud, 2007). This is in line with the problematisation initiated in the 1990s, which makes the consumer-citizen responsible for environmental pressures (Rumpala, 2009). All of these representations are embodied in personalised emissions measurement devices, which aim to inform an individual's decisions and modify their practices (Paterson and Stripple, 2010). Through this set of correspondences, the vision of an economic system driven by consumer preferences unfolds, which makes it legitimate to reduce the consequences of

[7] Druckman and Jackson (2009, p. 2066) say it explicitly and honestly: "The premise of this study is that the responsibility for carbon dioxide emissions from economic activity lies with people's attempts to satisfy certain functional needs and desires." The justification is most often implicit, usually through the use of the word "ultimately; see for example Ummel (2014, p. 1) or Isaksen and Narbel (2017, p. 153).

economic activity, and in particular GHG emissions, to this final cause.

The disadvantage of this framing is that it leaves many actors, both economic and political, who are involved in GHG emissions in the shadows. Emissions are the product of a socio-economic system of actors interacting at multiple levels. Consumers are only one category among many others, alongside companies that choose production techniques or governments that lay down the rules organising the economic space. The final consumer's *agency* is no more ultimate than that of the companies that not only respond to demand but also channel it, supervise it and even create it. In an interdependent system, singling out an actor is a matter of convention.

This convention is perfectly acceptable (as well as another one) as long as we stick to statistical attribution of emissions. The danger lies in the moral sense given to this attribution, which is perfectly expressed in a phrase like "we are each responsible for our emissions and for those that were necessary to produce the goods we decide to consume" (Gollier, 2019). Even if the calculation of carbon footprints is not done from this moral perspective, the shift from statistical to causal and then moral ascription is frequent, imperceptible and, in fact, inevitable. Rather than erecting a separation between attribution and responsibility, which the circulation of notions in the public space would soon have annihilated, it is better to recognise that the carbon footprint conveys a specific conception of responsibility, which the English-language literature sometimes explicitly qualifies as "consumer responsibility" (Munksgaard and Pedersen, 2001; Bastianoni et al., 2004; Marques et al., 2012).

Consumer responsibility, which is the moral counterpart of consumption-based accounting, is as singular a responsibility principle as it is questionable. Indeed, in moral philosophy, two conditions are often required to speak of responsibility: information and control (Oshana, 2015). If we can accept that the consumer is responsible for the act of purchasing, then is it really obvious that they are responsible for the emissions generated upstream of this act? The consumer is not, except in exceptional cases, informed of the CO_2 emissions contained in the product purchased, nor do they control those emissions—much less, in any case, than the company that runs the production lines and supply chains.

These remarks do not absolve consumers of their responsibility, nor do they suggest that consumption and lifestyle changes are unnecessary. They are simply a reminder that responsibilities are shared among all the players involved in GHG emissions. The whole question is whether and how one can estimate the share of everyone and everything, individuals or legal entities, collective structure or social groups. However, as a measure of responsibility, individual carbon footprints should not be taken too literally because underlying accounting principles are far away from standard conceptions of responsibility. Rather, inequalities according to carbon footprint are more of a stylistic exercise that would give the distribution of responsibilities if they were concentrated in the act of purchasing.

Losing sight of the fact that this is a stylistic exercise makes consumers take on a responsibility that is well beyond the limited sphere of their decisions and control. This leads to conceiving emissions mitigation primarily in terms of lifestyle changes, consumption patterns, consumer choices. The consumer's choice of equipment (e.g. internal combustion engine, hybrid or electric?) will therefore be discussed, and not an organisation of space that makes a motorised vehicle necessary or a development of infrastructure that facilitates the use of the automobile. This is the discourse of responsible consumption and the small gestures of each individual, a discourse that is quite influential in public communication (Comby, 2015). However, the reductions in emissions associated with changes in consumer behaviour and investment, while not negligible, are not sufficient and must be supplemented by structuring actions on the part of companies and public authorities (Dugast and Soyeux, 2019). Bringing ecological inequalities into the debate has the paradoxical effect of reinforcing this individualistic and moralising framing, to the detriment of highlighting collective decisions and actions to be carried out jointly (Marshall, 2017, chap. 36).

For the purposes of this exercise, we have nevertheless chosen to work within this individualistic framing; however, we wanted to retain a reminder of the integration of individuals, and their emissions, into various interlocking collective structures. Therefore, we have not calculated emissions at the individual level but instead at the immediately higher (collective) level of the household. The household is the statistical unit at which consumer spending is observed. It is also the social unit within which many consumption services, and therefore the emissions that are attributed to them, are carried out and pooled from the point of view of the individuals that make it up.

While the logic of consumption-based accounting makes it possible in theory to go down to the level of the individual, its implementation comes up against two pitfalls: the first is a practical pitfall because it would be necessary to say which member of the household benefits and in what proportion of the goods and services whose buying is observed at the household level; and the second is a conceptual pitfall because it would be necessary to define a convention for allocating pooled emissions (the heating of a dwelling benefits all its occupants). The latter is analogous at the household level to the one that we will encounter later at the national level (i.e. how to attribute emissions from pooled public consumption, e.g. national defence, to households?). These pitfalls are usually circumvented by dividing emissions by the number of household members. However, we did not want to resort to this artifice, which at all costs reduces to the individual what is partly collective.

Calculating emissions per household means that the size of the household is a (upward) factor of the variation of household emissions that we will calculate. Dividing emissions by household size to obtain emissions per capita does not eliminate this relation, only reverses it. The irreducible mutual component of emissions means that they cannot be compared regardless of household size[8]: taken at the individual level, emissions are lower for an individual belonging to a large household than for an individual belonging to a small one.

2 Carbon footprint inequalities

We now present a panorama of ecological inequalities based on the carbon footprint of French households, established for the year 2010. This panorama is congruent with the results obtained for France by an OFCE–Ademe team, independently of us and from the same data (Malliet, 2020; Malliet et al., 2020).

In 2010, the total GHG footprint[9] of the French economy amounts to 741 $MtCO_{2e}$. We have allocated to households their direct emissions, emissions embodied in their final demand (indirect emissions), as well as the emissions embodied in final demand of government[10]. The total emissions allocated correspond in the end to 615 $MtCO_{2e}$, or on average 22.1 tCO_{2e} per household (9.9 tCO_{2e} per capita), which is slightly less than the average 26.7 tCO_{2e} per households (11.4 tCO_{2e} per capita) when all the components of the national carbon footprint are taken into account.

To reconstitute the carbon footprint of households, the emissions of the final demand of households have been allocated according to current consumption expenditures, which are given by the Household Budget survey of INSEE. The principle is similar for direct emissions (see appendix B.1.2). Emissions from final demand of government were allocated according to a civic principle[11], which allocates these emissions in proportion to the number of people per household: 2 tCO_{2e} are thus allocated to a family of average size and composition (0.9 tCO_{2e} per capita).

2.1 Carbon footprint and income

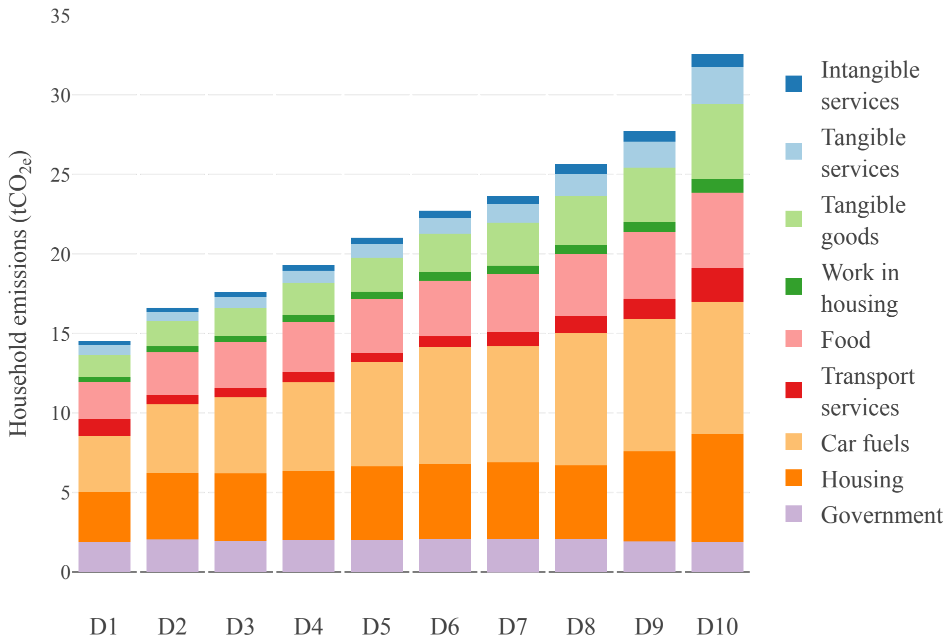
Figure 1 shows the carbon footprint, segmented by broad category of goods or services, for each decile of living standard. Households are segmented by standard of living (disposable income divided by the number of consumption

[8] See Underwood and Zahran (2015) for a discussion, as well as Gough et al. (2012, §3. 1 and §5), Büchs and Schnepf (2013, p. 118) or Weber and Matthews (2008, p. 385).

[9] In this article, GHG emissions are always expressed in tons of CO_2 equivalent (for a technical-political history of this metric, see Pottier, 2020; for the physical limits of this equivalence, see Fuglestvedt et al., 2003), although the emissions of the section 3 and 3.1 are CO_2 emissions only. On the source of the data, see annex A.

[10] For more details, on the components of national carbon footprint and on the scope of the allocated emissions, see B.1.1.

[11] See Appendix B.1.1 for a discussion of alternative choices.



Data sources : Insee, BDF 2011 ; own calculations

Figure 1 – Carbon footprint inequalities: Mean annual household emissions by equivalised disposable income decile, disaggregated by consumption categories. National average: 22.1 tCO_{2e} per household per year.

units of the household, or equivalised disposable income) and the carbon footprint is averaged for each group[12]. Two effects determine the evolution of the carbon footprint as a function of the standard of living: the volume effect (if expenditures are multiplied by two, then the carbon footprint is multiplied by two) and the structure effect (the change in the distribution of expenditure between consumption items changes the carbon footprint to the extent that the items have different emission contents).

Emissions increase with the living standards of households: a household belonging to the richest 10% (D10) emits $33\,tCO_{2e}$, on average 2.2 times more than an average household belonging to the poorest 10% (D1), which emits $15\,tCO_{2e}$. This increase is mainly explained by the increase in expenditure (volume effect) because the ratio of average annual expenditure between D10 and D1 is 2.8. It should be noted in passing that income disparities are even greater (ratio between D10 and D1 of 8.8) because the fraction allocated to current consumption falls when income increases, the rest being saved[13].

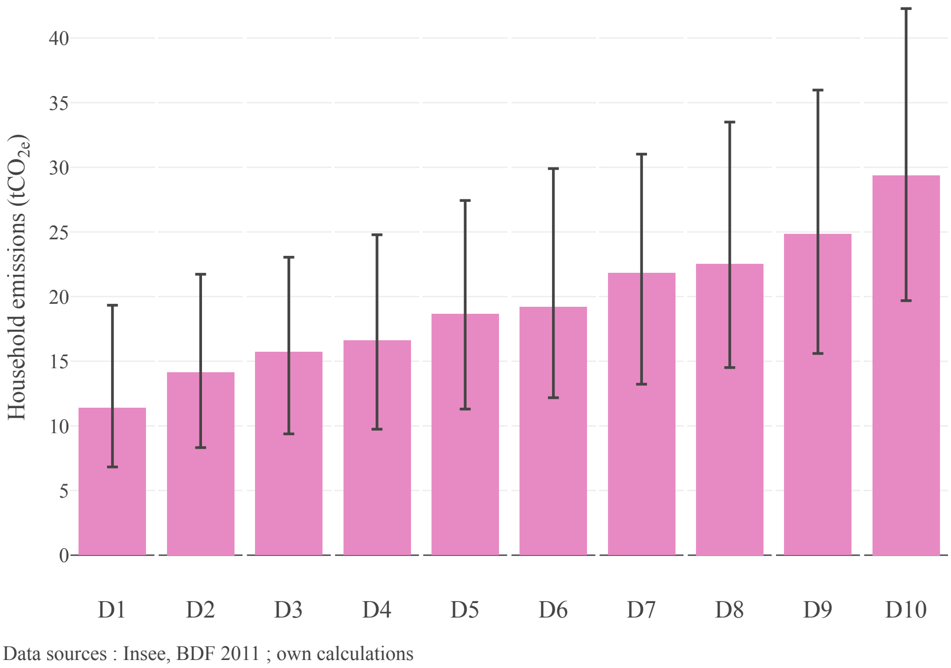
The structure effect results from the combination of different emission contents according to consumption items with a change in the structure of expenditure with the standard of living. This mainly comes from energy expenditure. On the one hand, energy expenditure has a significantly higher emissions content than other expenditure (around 3.5 kg CO_2/ € compared to 0.5 kg CO_2/ €). On the other hand, energy expenditures grow less quickly with income than other expenditures: they represent 11.4% of the mean budget of the poorest (D1) versus only 9.3% for the richest (D10). This observation, which has already made by many studies, suggests a certain saturation, on average, of energy needs. The wealthy carry over their additional budget to savings and to less emitting expenses: clothing, leisure, culture, restaurant services. As a result, the ratio of average emissions between D10 and D1 is lower than that of expenditures. Beyond energy expenditure, the impact of changing expenditure structure is negligible because the emission content of energy expenditure is an order of magnitude higher than that of other goods and services, which are fairly close to each other.

2.2 Horizontal heterogeneity

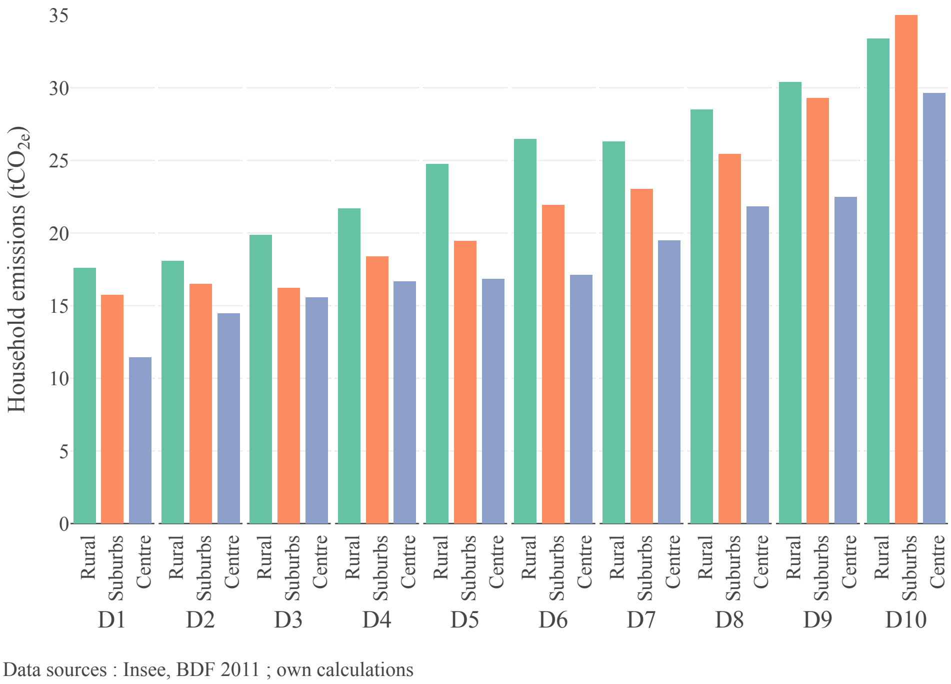
The averages of carbon footprints mask a great heterogeneity of individual situations at any income level, which is illustrated in figure 2. The graph 2a still displays a vertical segmentation of the population by income level, but

[12]See B.1.2 for the definition of the consumption categories.

[13]The question of emissions generated by savings could be raised here. However, this should not be taken into account in consumption-based accounting: although savings invested generate emissions, they are invested to produce goods; the consumers of these goods will be charged for the emissions. Meanwhile, income-based accounting considers that savings emit carbon: it accounts for the emissions enabled by the factors of production (capital in the form of invested savings, labour), but as a result there are no more emissions linked to consumption.



(a) First quartile, median and third quartile by equivalised disposable income decile



(b) Average by equivalised disposable income decile and location

Figure 2 – Carbon footprint inequalities: annual household emissions beyond average and vertical vision. National average: 22.1 tCO_{2e} per household per year; national median: 18.9 tCO_{2e} per household per year.

Quintile of carbon footprint	proportion in QU1 of income	proportion in QU2 of income	proportion in QU3 of income	proportion in QU4 of income	proportion in QU5 of income
QU1	37.4	25.8	17.6	12.2	6.9
QU2	23.5	22.7	21.7	18.2	13.8
QU3	18.5	22.6	20.7	21.0	17.2
QU4	12.7	17.5	21.2	23.6	25.0
QU5	7.8	11.3	18.7	24.9	37.2

Table 1 – Proportion of equivalised income quintiles in each quintile of carbon footprint.
Reading: In the second quintile of carbon footprint, 21.7% belongs to the third quintile of equivalised income.

instead of showing the average carbon footprints as in Figure 1 it shows the median values (as many households above as below), as well as the first and third quartile of the carbon footprints within each decile of living standards. It is clear from this figure that there is a great deal of heterogeneity[14] within each decile and that this heterogeneity is not related to income. Indeed, households in the highest emitting quarter of D1 emit more than households in the lowest emitting quarter of D10.

Another way to visualise this heterogeneity is to examine the composition in terms of income (per consumption unit) class of the 20% households that emit the more or the less (see table 1). Among the 20% households that emit the more, we find 37.2% of the households in QU5, and 19.1% in the two lowest quintiles of the income distribution. The situation is similar for the lowest emitting households: 37.4% of households in the lowest quintile of income, 19.1% in the two highest quintiles of income.

The graph 2b enables us to apprehend one of the horizontal dimensions of this heterogeneity. It divides income groups according to household location (rural, suburban, urban centre). Meanwhile, the averages by location and by income level provide a much less clear-cut picture. The carbon footprint always tends to increase with income for each location, although in a less monotonous way, but location is also a determining factor for the level of the carbon footprint. For the same decile of standard of living, living in an urban centre systematically leads to a lower average footprint than for other locations; at the top of the income distribution, suburban households tend to have the highest average footprints.

In the following section, we will encounter other horizontal dimensions of

[14]These estimates of variability should be taken with caution, for more details see the discussion in the annex B.1.3.

emissions inequality when analyzing energy-related emissions from housing and transportation using databases that allow a greater diversity of technical, geographic and socio-demographic factors to be considered. The methodology followed here, which is expenditure-based and uses average emission content per euro spent, is likely to overestimate the effect of income relative to other factors of variability, particularly because it neglects the dispersion of physical factors that determine household energy emissions for housing and transport.

2.3 Elasticities of the carbon footprint

A common way to summarise the relationship between income or expenditures and carbon footprint is to compute the elasticity of carbon footprint with respect to income or expenditures. We compute here these elasticities ϵ; that is, we estimate the following equation:

$$\log CF_i = \epsilon \log X_i + u_i \tag{1}$$

where CF_i is total carbon footprint of household i, X_i is total income or total expenditures of household i, and u_i is the error term. The results are given in table 2. One can see that the progression of carbon footprint with respect to expenditure is more important than with respect to income. This is a consequence of increased savings with income. One can also see that the coefficient of determination is much larger when the regressor is expenditures than when it is income. This means that the household carbon footprint is tied more closely to their expenditures than to their income. This happens because consumption-based emissions are tightly linked to consumption, which is acquired by expenditures.

The elasticity that we have computed is the unconditional elasticity (i.e. there are no econometric controls). Conditional elasticity (i.e. elasticity with respect to expenditure or income when other factors are fixed) is generally different from unconditional elasticity because the other factors that are not controlled for in the unconditional elasticity are usually correlated with income or expenditure. To estimate the conditional elasticity, one simply introduces controls in equation (1). This is regularly done in multivariate analyses with various sets of controls (Büchs and Schnepf, 2013; Ala-Mantila et al., 2014; Nässén, 2014; Fremstad et al., 2018; Gill and Moeller, 2018; Zsuzsa Lévay et al., 2020).

One set of factors is particularly relevant as controls: the size and composition of households. Household economics has indeed revealed economies of scale in large households by pooling together equipments and resources. This is also the case for carbon footprints (Underwood and Zahran, 2015), as we have explained earlier. There are several ways to account for the dependence of carbon footprint on the size and composition of households. One way is to explicitly introduce a control for number of adults and children

independent variable	expenditures	income
elasticity	0.864	0.530
standard errors	(0.006)	(0.008)
R^2	0.640	0.312

Table 2 – Expenditure-elasticity and income-elasticity of carbon footprint, with standard errors and coefficients of determination

in (1), as in Weber and Matthews (2008). Another common way is to still estimate unconditional elasticity, but from intensive quantities (per capital or per consumption units) instead of extensive quantities, as we have done in table 2.

Here, we wish to understand how the unconditional elasticity varies when one uses extensive values or various forms of intensive values. A literature review of the estimation of elasticities of carbon footprint has indeed revealed that several forms are used concurrently in the literature (Pottier, 2021). We have therefore regressed equation (1) when CF_i can be now either total carbon footprint (as previously), carbon footprint per capita or carbon footprint per consumption unit (c.u.), and X_i can be total expenditures (as previously), or expenditures per capita, or expenditures per c.u. (also known as equivalised expenditures, and correspondingly for income). The effects of household size and composition can be accounted for differently on the two sides of equation (1), as is sometimes encountered in the literature (e.g. elasticity of carbon footprint per capita with respect to income per consumption units). This gives nine possible forms of “expenditure-elasticity of carbon footprint” (and again nine for income). Tables 3 and 4 display the result.

One can see that these choices have a strong impact on the value of elasticity reported, even when we have accounted for household size and composition consistently on both sides of the estimating equations. This highlights the necessity to be explicit about whether per capita, total, or possibly per c.u. values are used.

	expenditure	expenditure per capita	expenditure per c.u.
carbon footprint	0.864 (6.4×10^{-3})	0.403 (1.1×10^{-2})	0.747 (9.8×10^{-3})
carbon footprint per capita	0.441 (8.1×10^{-3})	0.750 (6.5×10^{-3})	0.750 (7.7×10^{-3})
carbon footprint per c.u.	0.614 (6.5×10^{-3})	0.601 (7.4×10^{-3})	0.751 (7.1×10^{-3})

Table 3 – Expenditure-elasticity of carbon footprint, depending on the use of total, per capita or per consumption units, for the independent variable and the dependent variable
Reading: Elasticity of carbon footprint per capita with respect to expenditure is 0.441. Standard errors in parenthesis.

	income	income per capita	income per c.u.
carbon footprint	0.530 (7.7×10^{-3})	0.169 (1.0×10^{-2})	0.395 (1.0×10^{-2})
carbon footprint per capita	0.158 (8.0×10^{-3})	0.401 (8.0×10^{-3})	0.337 (8.7×10^{-3})
carbon footprint per c.u.	0.308 (7.2×10^{-3})	0.298 (8.1×10^{-3})	0.359 (8.3×10^{-3})

Table 4 – Income-elasticity of carbon footprint, depending on the use of total, per capita or per consumption units, for the independent variable and the dependent variable
Reading: Elasticity of carbon footprint per c.u. with respect to income per capita is 0.298. Standard errors in parenthesis.

3 Inequalities in emissions from energy services: housing and transport

We now focus on emission[15] inequalities from two major categories of energy service: those related to transport and those related to housing. These emissions include, but are not limited to, emissions from the combustion of fossil fuels directly by households. If direct combustion could have been a coherent perimeter, then we felt it would be more relevant to reason in terms of functional unit in relation to the energy services provided to households so as not to differentiate between those who use their personal equipment and those who purchase these services. The emissions covered here thus take into account both direct household emissions (from combustion of vehicle gasoline) and those of producers of equivalent services (gasoline for buses), but not indirect emissions (emissions from the construction of the car or bus, emissions for refining gasoline). This includes more or less carbon-intensive ways of providing the same service, whether or not fossil energy combustion is operated by households.

There are two reasons to focus on emissions from private transport and housing. From a climate policy point of view, they represent two major components of French emissions and they are the focus of government action. They are also directly related to household behaviour. From a methodological point of view, surveys are available for these two items. This makes it possible to reconstruct physical data rather than amounts of expenditure. These data sources provide more precise information on the diversity of practices, physical and technical factors governing the heterogeneity of emissions.

3.1 Transport emissions

Transport emissions[16] by standard of living and their variabilities are presented in figures 3 and 4. They progress monotonously: the poorest (D1) emit on average 1.6 tCO_{2e} per household per year and the richest (D10) 5.4 tCO_{2e} (i.e. a D10/D1 ratio of 3.4 for all emissions). However, the diagnosis can be refined by distinguishing between emissions from local and long-distance mobility. Emissions from local mobility rise sharply from the lower middle classes, but peak beyond that. For the richest half of the population, they remain around 2.4 tCO_{2e} per household per year, which leads to a rather low D10/D1 ratio of 2.3. In contrast, emissions from long-distance mobility progress more slowly but more strongly in the upper deciles, and this is even more marked for aircraft-related emissions. For their long dis-

[15] This section deals only with CO_2 emissions and not other GHG, even if the unit is still tCO_{2e}.

[16] We used the INSEE (2008) National Transport and Travel Survey and a modelling of the technical characteristics of private vehicles, see the technical appendix. For another exploitation of this survey, see Longuar et al. (2010).

tance trips, D10 households emit 3.1 tCO_{2e}, including 1.7 for air travel, which corresponds to long distance emissions 1.5 times higher than those households in D9 (2.1 times for air travel), and very strongly higher than those households in D1 (5.2 times and 15 times for air travel).

The strong income-dependent growth of long-distance mobility thus contrasts sharply with the relative stagnation of local mobility. However, the determinants of these mobilities differ: local trips are largely driven by necessity (going to work, school, shopping, etc.) and are more constrained than long-distance trips, which are often associated with leisure. These leisure activities, which are more accessible to the upper classes, are also those over which households have a greater degree of choice and control.

At any level of standard of living, the differences in CO_2 emissions are very large (figure 4). Dispersion increases within each decile, with the interquartile range increasing from 2 tCO_{2e} within D1 to 7.2 tCO_{2e} within D10. Location and distance from dense urban areas immediately shows part of the variability (graph 4b): emissions vary greatly, at each level of standard of living, depending on whether one lives in a rural area (3.9 tCO_{2e}), in a suburb (3.4 tCO_{2e}) or in a city centre (2.4 tCO_{2e}). The particular situation of rural people had already been noted by previous studies (Büchs and Schnepf (2013, p. 120-121) for the United Kingdom, Gill and Moeller (2018) for Germany). But above all, 53% of urban dwellers emit less than 1% for their transport, but only 35% of rural households and 38% of suburban households. Thus, once again, we see that very different situations exist within these groups.

This variability in CO_2 emissions can be decomposed by observing differences in the energy services consumed (mobility, measured in km travelled) and differences in the modes of transport used, which determine the energy consumption required to travel these km (energy efficiency) and the CO_2 emitted (energy sources and their carbon contents).

Depending on income level, there is a clear progression in mobility (figure 5b). Wealthy households belonging to the D10 travel an average of 50,000 km per year, almost 3 times more than the poorest households in the D1 who travel 17,000 km. The accessibility of transport equipment can play a role: the proportion of households without a private car decreases continuously with the standard of living, from 47% for the poorest 10% to 8% for the richest 10%. Local mobility is increasing rapidly: from 10,700 km for the D1 to 18,500 km for the D4, it then peaks at around 21,000 km from the D5. Long-distance mobility is growing exponentially: households on the D10 travel 12 800 km by plane, those within D1 850 km.

Differences in mobility are well reflected in differences in emissions. Indeed, the modes of transport that are used today mainly function with fossil fuels (73% of journeys are made in private vehicles, and 10% by plane, see figure 5c). Active modes (cycling, walking) are limited to short-distance mobility, while rail and public transport for short and long distances are only

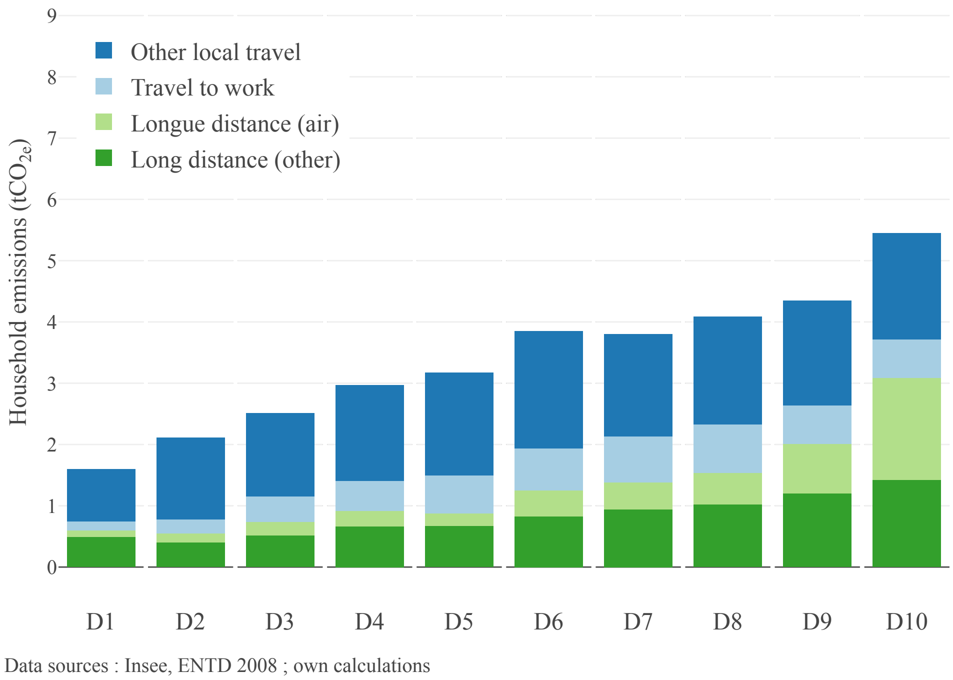
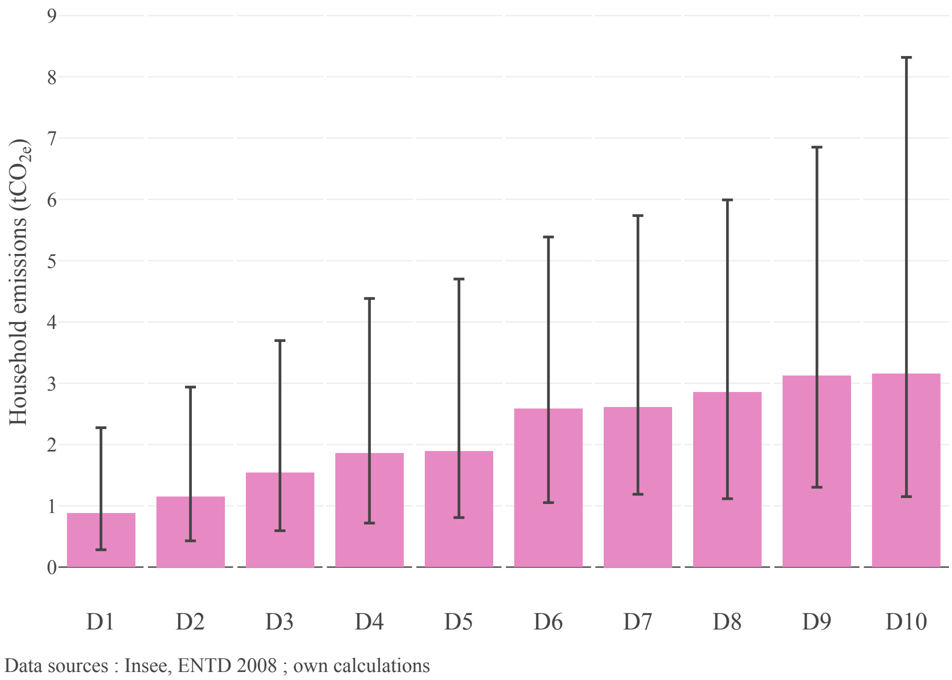
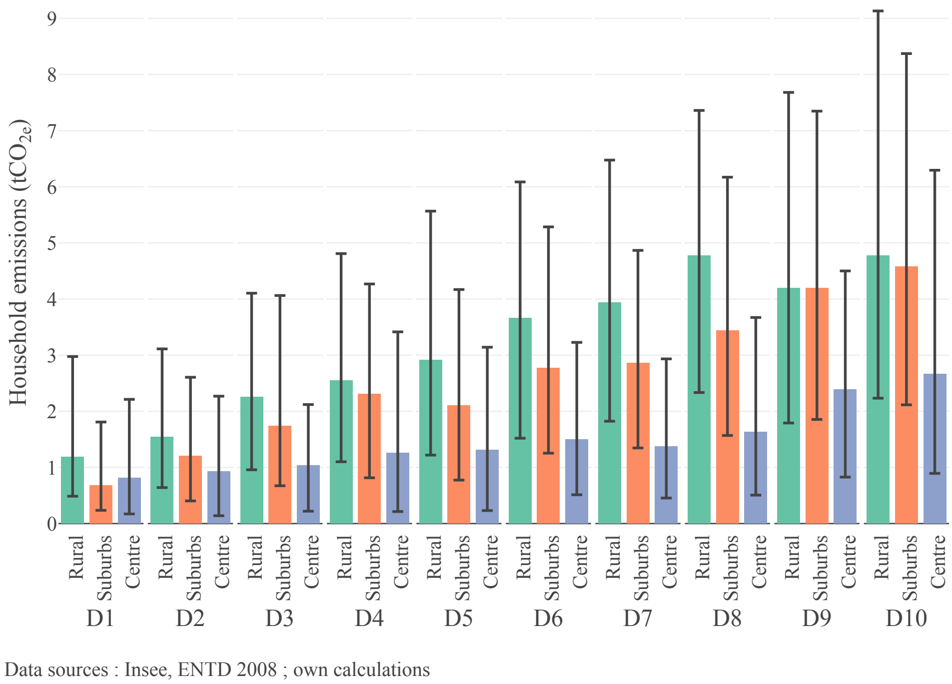


Figure 3 – Transport emission inequalities: annual average emissions by equivalised disposable income decile, disaggregated by type of mobility. National average: 3.4 tCO_{2e} per household per year.



(a) By equivalised disposable income decile



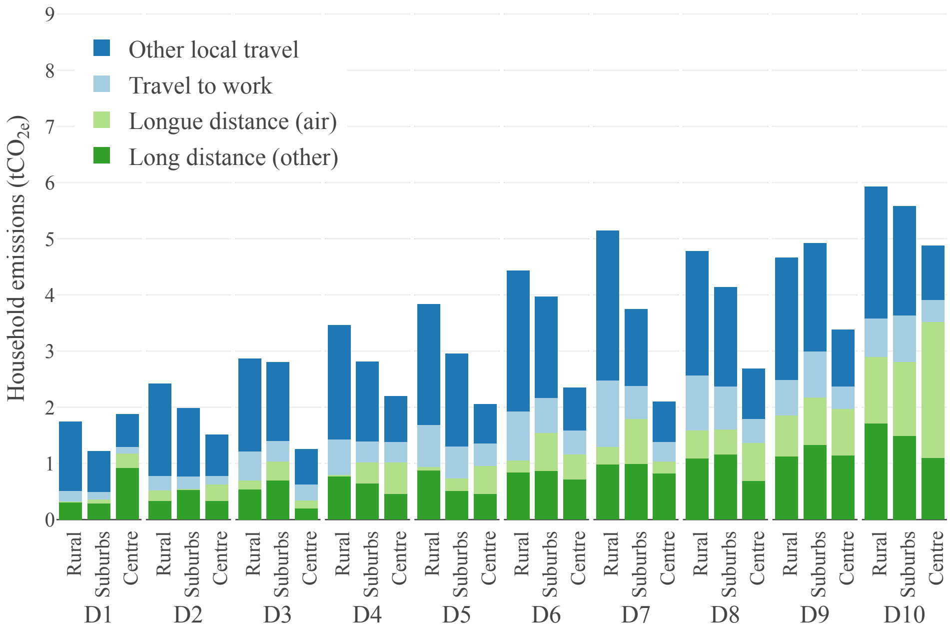
(b) By equivalised disposable income decile and location

Figure 4 – Variability of transport emissions: first quartile, median and third quartile of annual emissions. National average: 3.4 tCO_{2e} per household per year; national median: 2.5 tCO_{2e} per household per year.

used for a very limited fraction of the kilometres travelled. With regard to the consumption of fossil fuels per distance travelled, differences in energy efficiency play a small role: the order of magnitude of the consumption per 100 km is similar between airplanes and private vehicles and for the latter the carbon content of the kilometre travelled by car varies very little. The size and weight of top-of-the-range vehicles are largely offset by better fuel efficiency, so that consumption per kilometre increases little with income. Overall, emissions are today primarily correlated with distance travelled.

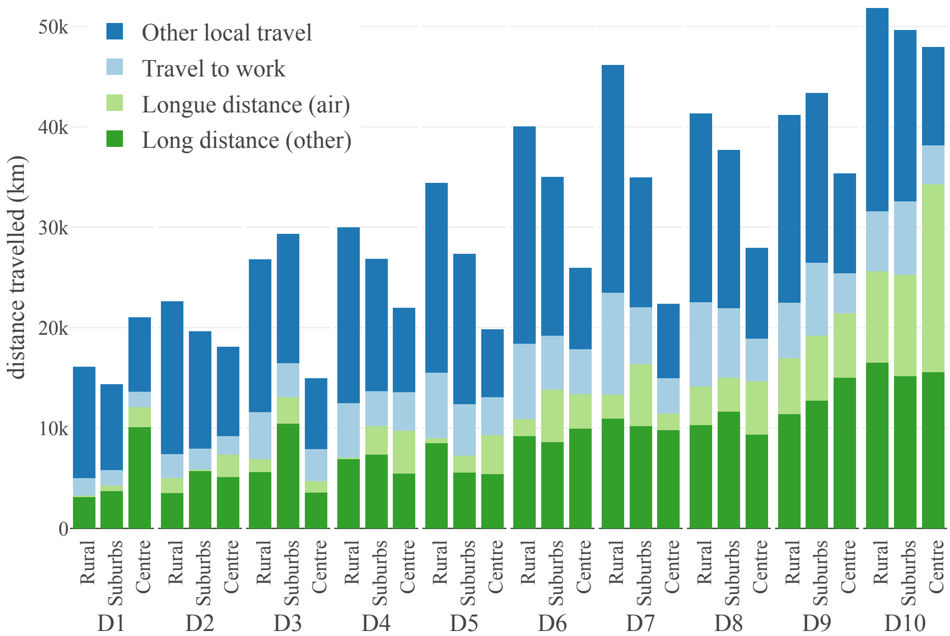
Locations and distance to dense urban areas have a strong influence on emissions because they condition both mobility (kilometres travelled, figure 5b) and the available modes of transport (figure 5c). Rural people have a higher annual mobility: a rural household travels about 35,000 km per year, a suburban household 32,000 km, an urban household 25,500 km. However, in all modes of transport, rural people emit more because they cover larger distances. It is true that urban dwellers emit more for their long-distance, more frequent journeys, because they use airplanes more often ($0.6\,\mathrm{tCO_{2e}}$ for a household in the city centre, $0.5\,\mathrm{tCO_{2e}}$ in the suburbs and $0.3\,\mathrm{tCO_{2e}}$ for a rural household, see discussion of emissions in appendix B.5).

The kilometres travelled for local mobility and the dependence on individual vehicles for these journeys (mostly thermal engines, the most emitting mode of transport per kilometre travelled) are greater for rural dwellers. In particular, 11% of rural households do not have a vehicle, compared to 17% in the suburbs and 33% in the city centre. Travel by car and two-wheeled vehicles accounts for about 84 percent of kilometres travelled, compared to 73 percent in the suburbs and 55 percent in the city centre. The use of public transport is much less frequent and possible (8% kilometres travelled, compared to 14% in the suburbs and 24% in the centres), as is active walking and cycling (2% kilometres of short-distance travel, compared to 4% in the suburbs and 8% in the city). No doubt more extensive data would make it possible to highlight more specific constraints, such as those of people from overseas territories, who can only use the plane to get to metropolitan France. Moreover, the use of airplanes is more the prerogative of households located in urban centres rather than in the countryside, with (when we look more closely) a concentration of households located in large cities and particularly in the Parisian agglomeration (Bouffard-Savary, 2010, p. 197). Infrastructure supply, access to transport technologies, distances to be travelled, and so on, are all important factors in explaining the disparity in emissions. However, these factors are very loosely correlated to income and are not directly controlled by household choices but rather by urban and land use planning policies.



Data sources : Insee, ENTD 2008 ; own calculations

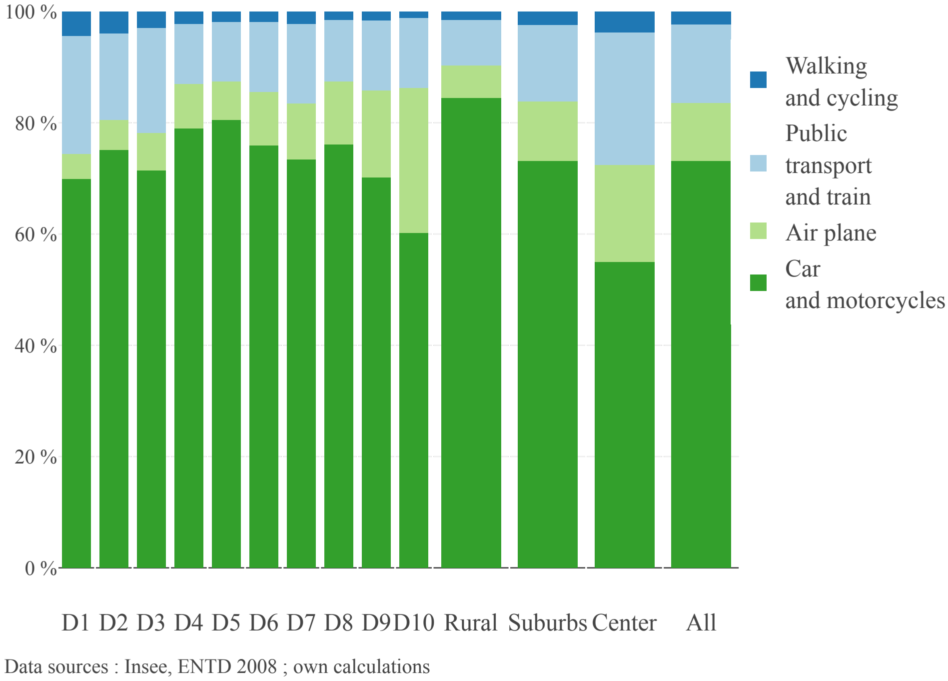
(a) Transport emissions by equivalised disposable income decile and location, disaggregated by type of mobility



Data sources : Insee, ENTD 2008 ; own calculations

(b) Kilometres travelled by equivalised disposable income decile and location, disaggregated by type of mobility

Figure 5 – Transport emissions and technical factors

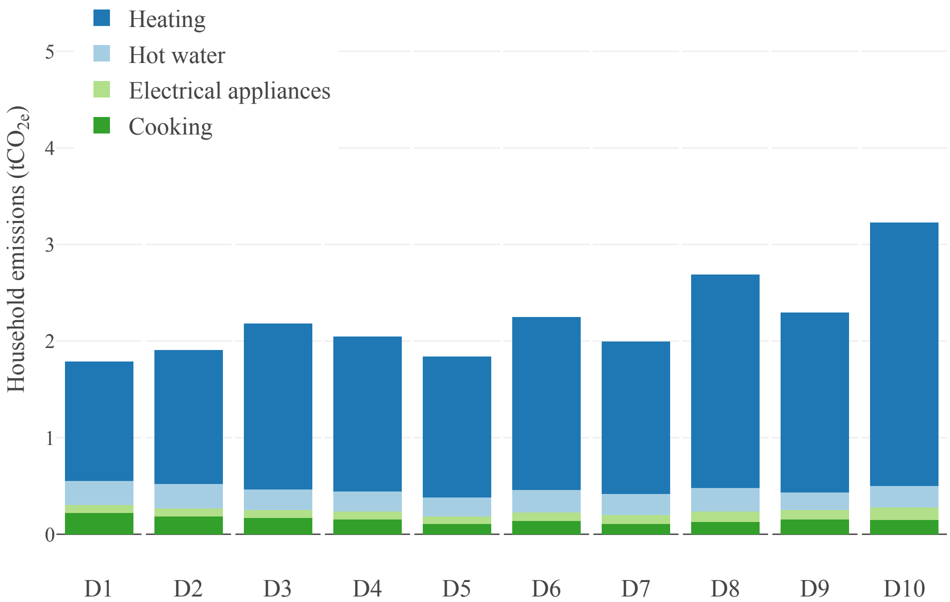


(c) Average proportion of transport modes (weighted by kilometres travelled), by equivalised disposable income decile and by location

Figure 5 – Transport emissions and technical factors

3.2 Housing emissions

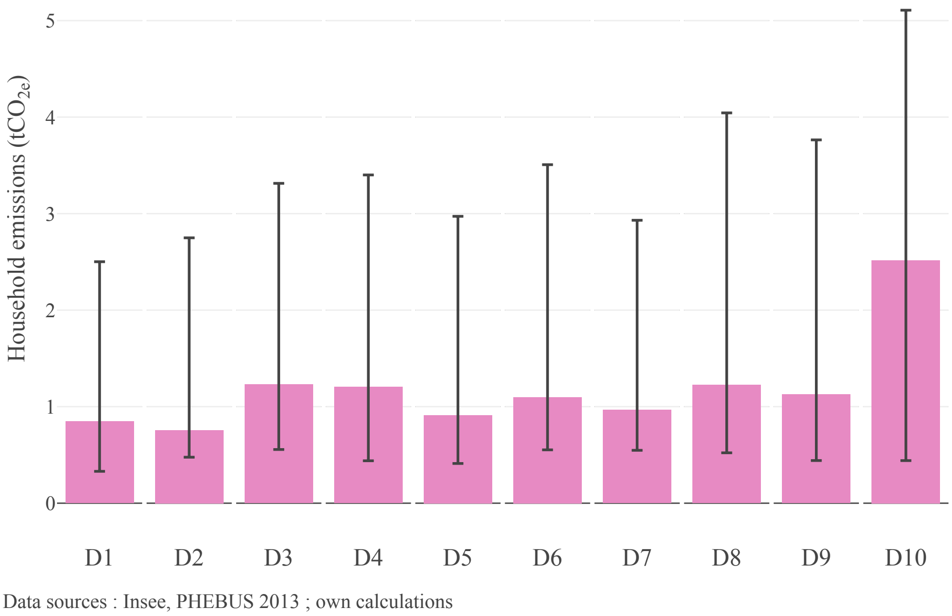
Emissions related to energy services at home[17] highlight other dynamics and further moderate the role of standard of living, which is in line with the literature. Figure 6 presents the national averages per income decile according to the different uses of energy at home (e.g. heating, cooking, hot water, and electricity for appliances). While the poorest (D1) emit less than the richest (D10) (1.8 tCO_{2e} as against 3.2 tCO_{2e} per household and per year), the progression of emissions with standard of living is rather uneven, which suggests a great variability and is confirmed by examining the variability within each decile (figure 7). Dispersion here is extreme, with no clear trend according to income. The breakdown according to geographical areas shows that the location captures a certain amount of variability. On average, an urban household emits 1.4 tCO_{2e} for housing against 2.6 tCO_{2e} in rural areas and 2.4 tCO_{2e} in the suburbs, but above all 61% of urban households emit less than 1 tCO_{2e}, while 61% of rural households and 64% of suburban households emit more than 1 tCO_{2e}.



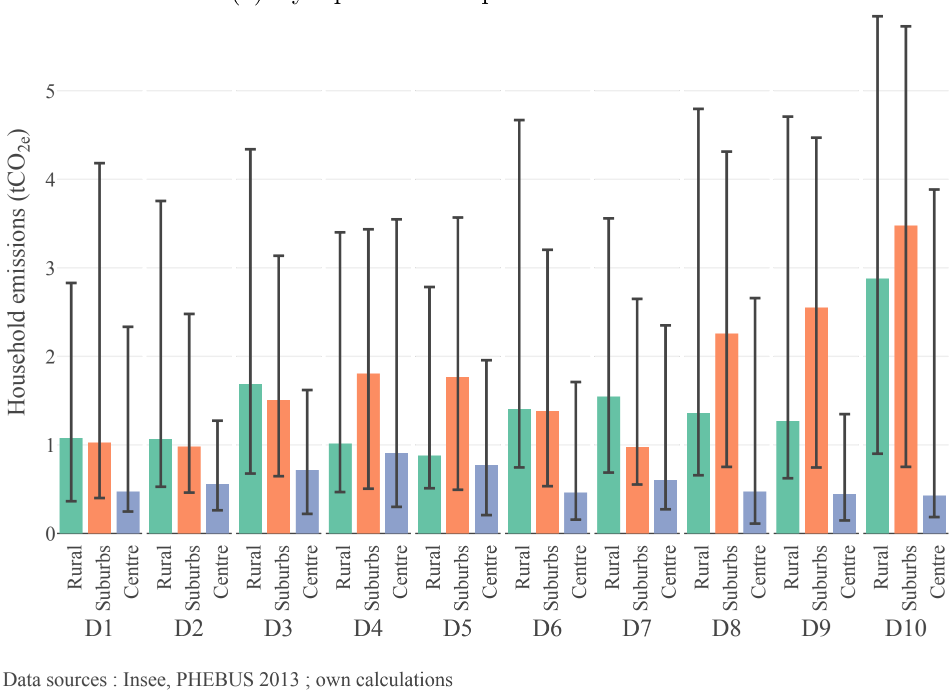
Data sources : Insee, PHEBUS 2013 ; own calculations

Figure 6 – Inequalities in energy emissions from housing: average by equivalised disposable income decile, disaggregated by use. National average: 2.3 tCO_{2e} per dwelling and per year.

[17] We used the Survey on Housing Performance, Equipment, Energy Needs and Uses (Phébus, 2013).



(a) By equivalised disposable income decile



(b) By equivalised disposable income decile and location

Figure 7 – Variability of emissions from housing energy: first quartile, median and third quartile. National average: 2.3 tCO_{2e} per dwelling and per year; national median: 1.1 tCO_{2e}.

The breakdown by use shows that emissions related to hot water or cooking display no net variation, while those related to electricity consumption (that of equipment) increase slightly with the standard of living and vary with location but in any case remain small because the carbon content of French electricity is very low (figure 8a). Note that this characteristic does not stem from a household choice but from a political (and contested) choice in favor of nuclear power. The major source of variability in emissions is therefore heating, whose emissions constitute 80% of the emissions related to energy services in housing.

This variability can be decomposed by looking at energy services (dwellings surface heated in m^2), energy efficiency (energy spent by m^2) and the carbon content of energy. The surface area of the dwellings increase with income (figure 8b), but also with the proportion of single-family houses. This variable is linked to income, geographic location and urban density. The poorest 10% occupy $75\,m^2$ on average, often in collective housing (65%), while the richest 10% have access to larger surface areas ($126\,m^2$, which does not include second homes) and they more often own single-family homes (65%). However, differences in locations and urban density are the main factors of variability: a rural household occupies on average $111\,m^2$ ($88\,m^2$ for a poor household in D1, $156\,m^2$ for a rich household in D10), $92\,m^2$ in the suburbs ($74\,m^2$ for D1, $131\,m^2$ for D10), and $70\,m^2$ in the city center ($62\,m^2$ for D1, $95\,m^2$ for D10). The proportion of single-family houses is higher in rural areas (84%) than in the suburbs (57%) and the city centers (19%). In particular, the proportion of single-family homes in the suburbs increases continuously and significantly with income (84% for D10, 26% only for D1).

As regards the annual energy consumption per unit of surface area (kWh $/m^2$ /year), the correlation with income classes is weak. The richest consume around 124 kWh $/m^2$ /year for their heating, the poorest around 139 kWh $/m^2$ /year. Meanwhile, the type of housing (e.g. individual housing or apartment building) makes a considerable difference (figure 8c). These aggregate figures hide very different situations of energy dependency. When analysing these disparities in real energy consumptions, the distinction is rarely made between differences in energy efficiency—including the heating systems (old oil-fired boiler versus new heat pump) and the building (poorly insulated versus passive building)—and differences in practices (heating at 23 °C rather than at 18 °C, even deprivation)[18] or needs (depending on the more or less harsh climate between the north and the south, the coast and the mountains) or professional occupation (the pensioner who stays at home compared to the employee who works in a company, see Gough et al., 2012, p. 16-19). For the poorest and most modest, we are dealing here with the problem of energy poverty, which is notoriously multifactorial and difficult to identify (Dubois,

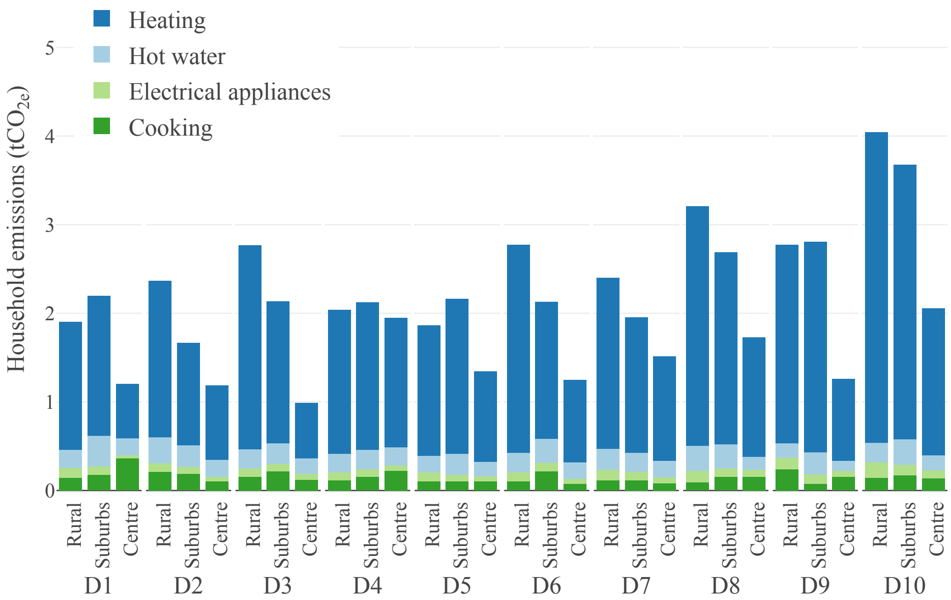
[18]For an analysis of these consumption factors without social segmentation see Cayla et al. (2019).

2012; Ambrosio et al., 2013).

Our survey data allow us to disregard differences in practices and calculate (using the Energy Performance Diagnosis method) the theoretical levels of consumption, which takes into account climate-related heating needs (annual degree-hours), housing performance (energy loss per surface unit) and the energy efficiency of heating systems. This in-depth examination shows that the energy performance of heating systems and dwellings is correlated with the income of the occupants (figure 8d). This correlation is even stronger with the occupancy status of the dwelling (owner or tenant), the owners' power to act being a major factor in initiating the necessary renovation works (Bourgeois et al., 2019).

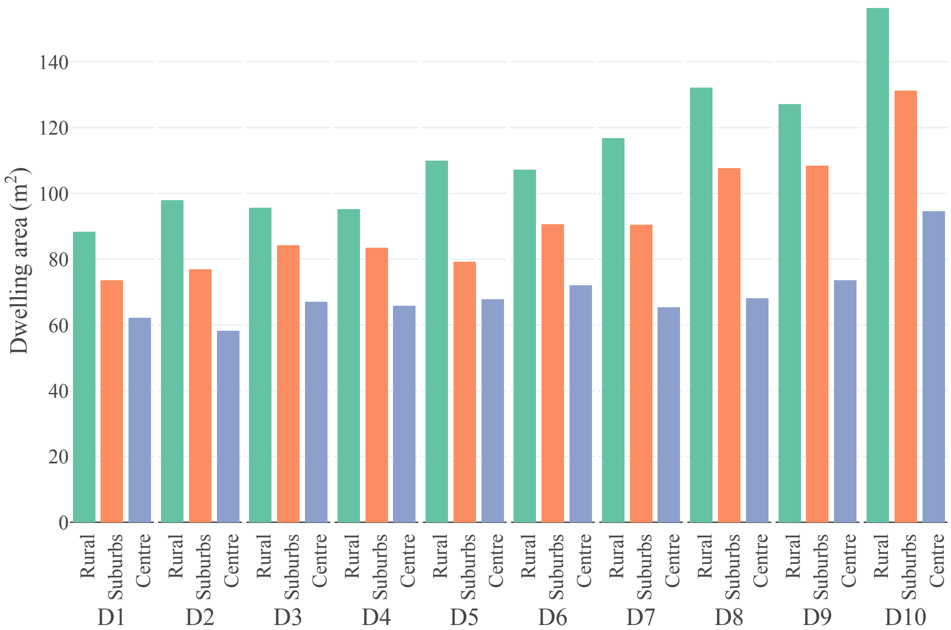
It should not be inferred from this that, in this context, the surfaces to be heated determine the emissions. In contrast to transport, energy services in housing explain to a limited extent the variability of emissions due to heterogeneous technical systems. While in transport the technology is (for the time being) relatively homogeneous, with a dominance of oil-powered private cars, the technical characteristics of dwellings and heating systems are more diverse. This diversity primarily explains the variability of housing energy emissions because the emission factor can be very different depending on the heating system (i.e. gas or oil-fired boiler, electric radiator, heat pump, wood stove, or connection to a heating network).

The distribution of these systems has little to do with the standard of living of the households, which explains why emissions from housing energy are much less correlated with income than those from transport (Figure 8e, left). About half of households are equipped with heating systems that run on fossil fuels (gas and oil). This proportion is roughly the same for each decile of living standards. However, this proportion changes strongly with geographical location and density (Figure 8e, right). It is slightly lower in rural areas (40%), to the benefit of electric and wood heating systems, which tempers the effect of larger surfaces to heat on emissions but at the expense of energy efficiency (and indoor air quality for wood). Moreover, this low share reflects more the deficit in the installation of gas boilers because the share of oil boilers is higher than in the city (20%, compared to 7% in the suburbs and only 1% in the city centre). Conversely, the share of fossil energy is higher in the suburbs because the gas network is well-developed, while urban heating networks are not very extensive (7% versus 16% in the city centre). We see here the emergence of structuring factors for the choice of housing energy, factors that households can only influence at the margin.



Data sources : Insee, PHEBUS 2013 ; own calculations

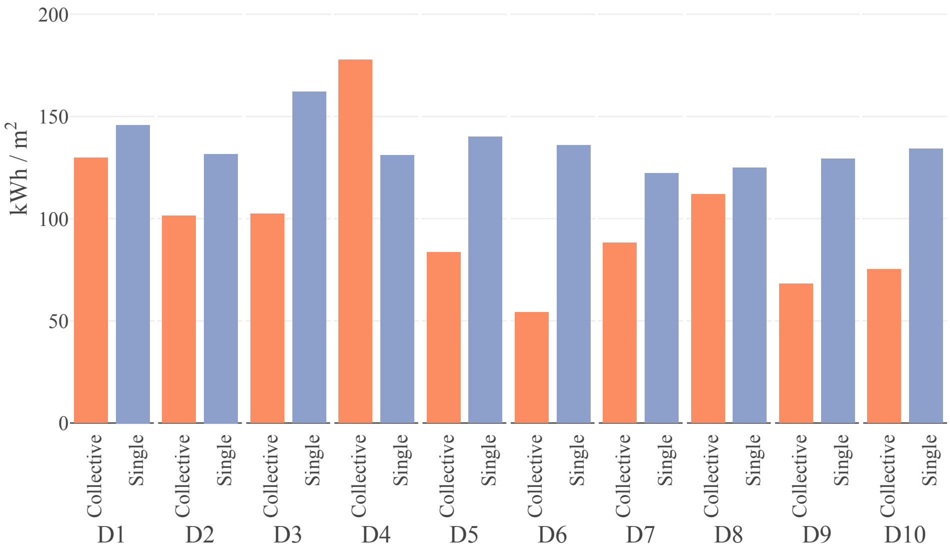
(a) Housing energy emissions by equivalised disposable income decile and location, disaggregated by use



Data sources : Insee, PHEBUS 2013 ; own calculations

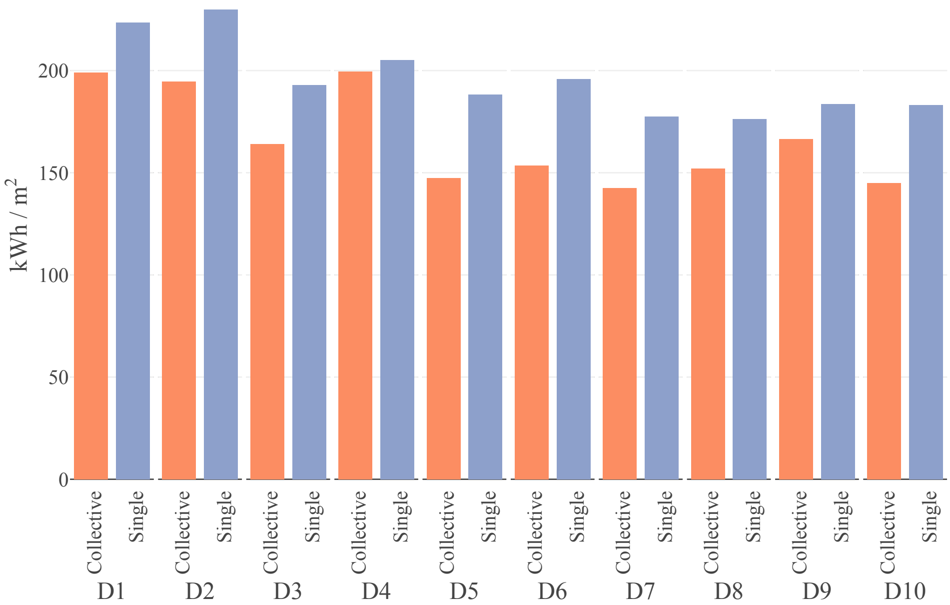
(b) Average surface area of dwellings, by equivalised disposable income decile and location

Figure 8 – Housing energy emissions and technical factors



Data sources : Insee, PHEBUS 2013 ; own calculations

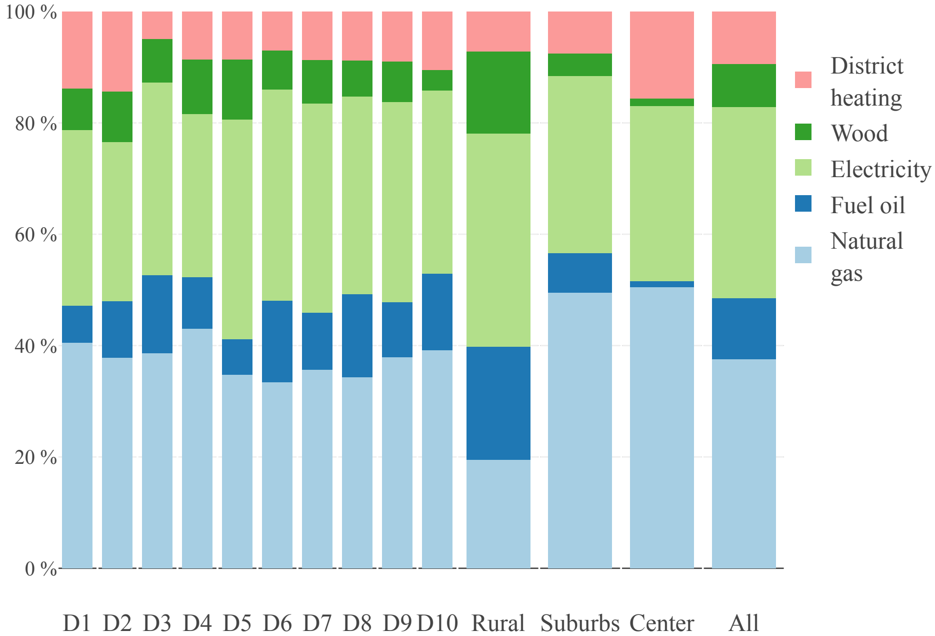
(c) Actual heating consumption (kWh /m^2 /year), by equivalised disposable income decile and type of housing



Data sources : Insee, PHEBUS 2013 ; own calculations

(d) Theoretical heating consumption (kWh /m^2 /year), by equivalised disposable income and type of dwelling

Figure 8 – Housing energy emissions and technical factors



Data sources : Insee, PHEBUS 2013 ; own calculations

(e) Proportion of energy sources used for heating, by equivalised disposable income decile and location

Figure 8 – Housing energy emissions and technical factors

4 On the links between income inequalities, ecological inequalities and responsibility

We discuss here some methodological problems related to the establishment of a link between income inequalities and ecological inequalities. We also question the relevance, in this context, of consumption-based accounting of emissions.

4.1 The quality effect

Carbon footprint increases on average with income because wealthier households spend more than poorer ones, there is also a mechanical link between the amount of expenditure and the amount of emissions (volume effect). It should be noted that this mechanical link is the result of the method that is used to calculate the carbon footprint of households from expenditures.

Indeed, by multiplying the expenditures in value (euros spent) by a constant emission content (tCO_2/ €), the method followed implicitly assumes that, within a same expenditure category, emissions are proportional to expenditures. By construction, it makes apparent that there is a linear volume effect: doubling expenditures double the carbon footprint.

One should not hastily conclude that it represents the true link between emissions and expenditures for emissions actually doubles with expenditures only when quantities consumed also double. However, if a household spends 600 € on a washing machine instead of 300 €, it is generally not to buy two machines at 300 €but to acquire a different and more expensive model. This good is more expensive not because its production required twice as much material and generated twice as much emission, but because it is of a different quality. The content of emissions per euro is then generally no longer the same and the variations in expenditure do not reflect proportional variations in emissions: this is the quality effect, which could reinforce the volume effect (if higher expenditures have a higher emission content) or temper it (if higher expenditures have a lower emission content).

It is possible that the quality effect tempers the volume effect, and thus that the method leads to an overestimation of the emissions of the better-off classes (Davison, 2016, p. 347). Indeed, luxury goods are expensive because they incorporate more labour, which does not contribute to emissions[19] (Lenzen, 1998, p. 914-915). Thus, the emissions corresponding to a meal in a café or a three-star restaurant would not be proportional to the addition. The part of the price linked to reputation or scarcity is in the same direction.

[19]In national accounts, the consumption that, one would say in Marxist terms, is related to the "reproduction of the labour force", is considered part of final consumption by the workers and is not an intermediary input of the production. Consequently, in consumption-based accounting, pure labour does not contribute to the emissions of the goods.

Between a Romané-Conti and a generic Bourgogne, the emissions should not be very different, while the price varies from one to a thousand.

Quantitative evidence supports this anecdotal evidence. For a durable consumption good such as a car, when you move up the range, the trend in emissions per euro spent is downwards: at the lower end of the range, producing a city car emits 4.6 tCO_{2e}, whereas in the middle of the range, with prices doubling, producing a MPV emits 7.2, a family car 5.4 and an SUV 5.5 [20]. In the construction sector, bio-sourced materials, which emit less, are generally more expensive (Cerema, 2017), as is low-emitting cement (Allix, 2019).

In more detail, Girod and Haan (2010) compared estimates based on monetary expenditure and physical quantities using a Swiss consumption survey that provided information on both. They conclude that there is a significant decrease in the expenditure elasticity of emissions when the quality effect is taken into account. De Lauretis (2017, p. 55-56) reproduces this calculation from detailed data taken from the diaries of the French Household Budget survey for 64 categories of food goods. The difference between the price paid by D10 and D1 varies greatly from one category to another but is positive for 57 food items, which suggests a non-negligible quality effect. The example of beef, whose production emits a lot of GHGs, is noteworthy. The richest 10% buy on average 72% more expensive their kg of meat than the poorest 10%. Assuming similar modes of production (GHGs emitted / kg of red meat produced nearby), the same amount of money spent by the richest people on beef means lower emissions.

Even if the quality effect would need to be more precisely quantified, given the existing literature, it is highly likely that the most expensive goods have a lower carbon content per euro, and therefore that the quality effect tempers the volume effect. This means that the progression of carbon footprint with income or expenditures could actually be less than what is estimated by the method.

4.2 Emissions of the "1%"

Before concluding, we should mention the emissions of the Carbon footprints of the 1% (i.e. the hundredth part of the population who earn the most), which have been the subject of public debate since an estimate of their emissions circulated in the autumn of 2018[21]. This estimate was derived from

[20]From life cycle analyses carried out by Renault for Twingo, Scénic, Mégane and Khadjar models, respectively.

[21]For France, Jean Gadrey (2018) announced a ratio of 40 between the average emissions of the poorest 10% and those of the top 1%, a figure that has since been abundantly quoted. The rest of this article should sufficiently show the reader that we are reluctant to deliver our own estimates, both because of methodological problems and because of questions of principle. However, given that "any number beats no number" (Gingras, 2014), we point out that, according to our assessment of carbon footprint disparities,

previous studies (Piketty and Chancel, 2015; Oxfam, 2015), which follows a different method than ours. In this section, we present this method and we also detail its limitations.

This so-called top-down method[22] assumes a given relationship between emissions and a predictor variable, usually income. This assumed relationship usually takes the form of a constant income-elasticity of CO_2 emissions. >From the distribution of the predictor, it allows us to estimate a distribution of emissions that is not too far from reality if the relation between emissions and the predictor is robust. Its interest is revealed when the proxy variable is known more easily than emissions. Its main weakness is that it is a derived method that is based on those already presented: it requires that previous statistical studies had established and estimated independently a robust relationship between emissions and the predictor. The top-down method then applies the relationship (estimated by a few studies – which are, moreover, heterogeneous in terms of their attribution conventions) to other contexts, in which it is not possible to test the reliability of the statistical relationship because emissions would then have to be estimated directly, which would render the method unattractive.

Three additional limitations should be noted.

First, by using a predictor that is weakly correlated with emissions, this method reinforces the large uncertainties in final results. The predominant choice of income as a predictor is not very fortunate because carbon footprints are highly correlated with the overall amount of expenditures but less so with income. This is not surprising given the way that they are calculated, which neglects the quality effect. As we have seen in section 2.3, income elasticities are also lower than expenditure elasticities because the richest spend less as a proportion of their income (i.e. save more) than the poorest. Lenzen (1998) thus gives an income elasticity of 0.5, Büchs and Schnepf (2013) find an income elasticity of 0.6 or 0.43 when conditioning on other household characteristics (for an extensive review of the income and expenditure elasticities of household carbon footprint, see Pottier, 2021. The Oxfam study uses an income-elasticity of 1, where our own estimations from

this ratio is between 2.2 and 5.2. (between 2.4 and 5.9 if government emissions are not included, whose attribution according to the civic principle reduces the progressiveness of carbon footprints). Presented differently, the emissions of the top 10% cumulate 14.7% of emissions attributed to households, and the emissions of the 1% cumulate between 1.47% and 3.46% of the total. In these estimates, the lower bound corresponds to assuming that the emissions of the top 1% equal the emissions of the other percentiles of the last decile; while the upper bound corresponds to assuming that the emissions attributed to those other percentiles of the last decile equal the emissions of the previous decile, with the top 1% concentrating emissions above that level. If $\overline{D9}$ and $\overline{D10}$ are the mean emissions per household of D9 and D10, then the lower bound for the mean emissions per household in the top 1% is $\overline{D10}$ and the upper bound is $\overline{D9} + 10 * (\overline{D10} - \overline{D9})$.

[22] It was introduced by Chakravarty et al. (2009). Grubler and Pachauri (2009) had already criticised it by showing that the elasticity was not stable. See Weber and Matthews (2008, p. 383-384) for the test of different functional forms.

the micro-data gives something between 0.53 and 0.4. It is thus no wonder that the Oxfam study grossly overestimates the concentration of emissions with income. Applied to our data, the income elasticity of 1 would give a ratio of mean emissions of D10 to mean emissions of D1 of 8.8 (i.e. as the income ratio), where our study finds 2.2.

Second, this method is based on the problematic assumption that emissions are highly correlated with living standards (i.e. it assumes very homogeneous lifestyles at each level of standard of living). By construction, it reduces the variability of emissions and ecological inequalities to income inequalities because by methodological assumption the former mirrors the latter. Thus, the social justice issues of the ecological transition are artificially reduced to the sole issue of income redistribution. As we have seen earlier, ecological inequalities nevertheless raise questions of inequalities that are specific and not related to income.

Third, the proxy variable approach is generally fragile, and even more so when it is applied to the tail end of the income distribution (the 1%). Because there is very little observation and physical data related to the lifestyles of the very-rich, it is hardly possible to calibrate the elasticity and the use of the constant value (over the whole income distribution) is very unreliable. The relationship between emissions and income, which is already problematic in the core of the distribution, is now, at the extreme upper limit of the distribution, only an extrapolation. To overcome this lack of information, one would have to gather direct observations of the budgets and quantities consumed by the very-rich[23], whereas statistical surveys are not suited to target such a narrow segment of the population (the very top incomes). The uncertainty related to the quality effect would also have to be reduced to get a reliable estimate but (to our knowledge) no serious effort has been made in this direction. This means that the consumption of the super-rich and the associated carbon footprint will remain insufficiently characterised for a long time to come, and therefore subject of all sorts of suppositions.

4.3 Madonna's "Emissions": attribution principles and responsibility

Beyond this impenetrable statistical fog, the case of the super-rich once again raises the very question of the relevance of consumption-based accounting to identify ecological inequalities. We will look again at this issue through the lens of an example.

On 7 July 2007, the *Live Earth* concert was held around the world, which was labelled as "the concerts for a climate in crisis", a series of concerts to raise awareness of climate change. In London, Madonna performed a song specially penned for the occasion, called *Hey You.* The BBC denounced the

[23] see Otto et al. (2019) for an attempt in this direction.

hypocrisy of the pop star, a great polluter with a high carbon footprint in spite of her beautiful lyrics[24]: in one year, Madonna emitted over a thousand tons of CO_2.

What are these "emissions" from Madonna? From what we can understand[25], these emissions include the emissions generated by her real estate, her consumption, her trips around the world to give her concerts, as well as those of her team that follows her. From an attribution point of view, we aggregate here the emissions of Madonna as a consumer and the emissions of Madonna as a singer (i.e. as the producer of an "entertainment service"). In consumption-based accounting, Madonna's (final-consumer) emissions would be lower because the emissions related to her world tours would not be attributable to Madonna as a consumer but to the final consumers—those who go to her concerts and consume her entertainment service. In this approach, what the huge "carbon footprint" thus calculated[26] reveals is less Madonna's polluting lifestyle than the pollution generated by the music industry, which transports global stars across the planet to produce entertainment.

This calculation of emissions "from" Madonna raises the very question of the relevance of consumption-based accounting. Aggregating emissions that are somehow related to Madonna, and not only to her consumption, highlights the different social roles played by the "Queen of Pop". Madonna is not just a consumer who guides companies' strategies, production techniques and supply through her purchases. She is an artist at the head of a company whose activity emits CO_2. She is an influencer: her life choices, her way of being feed the dreams of millions of fans, who are otherwise consumers. She is certainly an investor who invests her fortune in companies, and as a shareholder she can influence the companies decisions.

The fact that different social roles and positions are held applies, with varying degrees, to everyone—everyone is at least a consumer and a citizen with a right to vote, often also a producer. If, as we have defended here, everyone can only have an imperfect influence on the emissions attributed to their consumption, then this also means that everyone has other channels for reducing emissions around them, through their political choices as well as through their professional decisions. This is why, for example, some artists (Cadieux, 2020) or researchers, with the Lab 1 point 5 initiative (Michaut,

[24] which were so moving and topical, such as "*Hey, you, don't you give up // It's not so bad // There's still a chance for us*" or "*Hey, you, save yourself // Don't rely on anyone else*".

[25] The work was done by the environmental auditing firm Carbon Footprint, founded by John Buckley. When contacted, he could not give us any details on the method used; we were bound to reconstruct the method according to what was published in the newspapers (BBC, 2007; Irvine, 2008).

[26] At the risk of insisting, this is not a carbon footprint in the sense that we have given to the term and that we find in the academic literature, that consumption-based accounting that attributes to each person the emissions necessary to produce their final consumption, and only those emissions.

2020), commit to emitting less in the exercise of their profession.

The super-rich and powerful have the characteristic of accumulating a large number of positions, and in each one of widening and deepening control and power far beyond what ordinary people can achieve. The social role and positions listed give Madonna a grip on a wide range of emissions, beyond the one thousand tonnes computed and publicised by the BBC, and therefore give her a share of responsibility in the collective goal to reduce these emissions[27]. In return, these social and power positions give her important levers to reduce emissions. As a result, the carbon footprint poorly reflects all of the emissions that the decisions of the super-rich could avoid (i.e. the emissions for which they are, in a sense, responsible[28]. The case of the super-rich thus puts the issue of attributions back to the centre and draws, by contrast, a vision of responsibility based on the control over emissions and the wiggle room to reduce them.

4.4 Wiggle room and power to act

Enlightened by this illustrative example, let us go back to the carbon footprint of the ordinary consumer and reason in terms of the wiggle room that they have on "their" emissions. Let us take the example of heating, which is a major component in the household footprint and a major factor in the variability of emissions. The situation implicitly taken as a reference, the one that best justifies responsibility for emissions, is that of a household owning a single-family house: as owner, the household "chooses" the insulation of the house, the heating mode, and the thermostatic control. Even in this ideal case, the wiggle room to reduce emissions from heating is not equal for all because some households may not have access to certain energies (e.g. rural households cannot heat with city gas, as we have seen), nor to credit to finance energy insulation. At the other end of the spectrum, a tenant in a social and collective housing unit has no leeway on the emissions from heating their flat. Between these two polar cases, there will be a continuum of situations, such as that of an owner dependent on a meeting of co-owners, or that of an owner connected to a district heating, whose emissions will be largely conditioned by the choices made by the district heating operator.

The same analysis could be made for home-to-work transport emissions. Attribution of these emissions to the household is justified by its choices of location and equipment, which are more or less constrained, because they

[27] Here, the responsibility does not arise from the contribution to past emissions, but from the need to act as far as possible to reduce future emissions. We are thus moving from a notion of "backward-looking" responsibility to a notion of "forward-looking" moral responsibility according to which an individual is "virtuous" and responsible if he or she takes responsibility to act actively to contribute to the common good.

[28] Much more than the consumption of the rich, Kempf (2007) denounced their control on economic and political power and the traction exerted on all social classes by their ostentatious consumption.

depend on a complex of factors and decisions (e.g. choice of business location, choice of land use planning by local authorities and the government, choice of public transport authority, choice of car manufacturers, etc.). It is not far from the truth to say that the individual action on emissions of this type may only act at the margin in comparison with other decision centers and entities with much more structuring actions.

All of these situations are very different in terms of wiggle room and each one reveals problems of collective action in addition to individual choices. However, for each, the attribution of emissions according to the consumption approach makes these emissions the responsibility of the household and of the household alone. Moreover, it makes households equally responsible, even if the "power to act" that they have over their emissions is not comparable. For example, Pautard (2017) shows that environmental sensitivity has little influence on transport use, whereas structural factors (e.g. geographical location, the type of urban area or household composition) have a strong impact, which suggests that the will of the actors in this area is less important than the constraints that they face.

This question of the wiggle room available to everyone to reduce their emissions is crucial to the perception of the justice of the ecological transition. If, to use the example with which we introduced this article, one considered it to be unfair that air travel for holidays is not taxed when diesel for private cars is, then perhaps the reason is not so much because one thought that travelling by plane emits much more GHGs than driving on diesel (although lack of knowledge of the orders of magnitude also feeds popular discontent). Probably, it is much more likely to be because we are confusedly aware that the wiggle room is not the same. For a poor household living in the country, keeping and using its old diesel car may be its only option to go to work (i.e. the household's members "have no choice"); while a rich household can always avoid taking the plane and choose like Bourvil to admire the moonlight in Maubeuge. As noted by Shue (1993), it is important, from the point of view of justice, to determine whether the emissions are a matter of necessity or luxury.

To shed light on this debate, the description and presentation of ecological inequalities in terms of emissions generated by final consumption is of limited interest. In our context of urgent ecological transition, the examination of distributional issues should be reformulated to take account of inequalities in the ability to act on what causes environmental damage.

Conclusion

To quantify ecological inequalities in France, we have adopted the most widespread convention, which attributes to households the emissions generated by the production and use of the products and services they consume (i.e. consumption-based accounting). Although the carbon footprint of households tends to increase with income, there is also a strong variability that is not linked to income but to geographical, socio-demographic and technical factors. These factors constrain dependency on fossil fuels and therefore emissions in the short term. Ecological inequalities are therefore not a copy of income inequalities.

Detailing the steps involved in quantifying a panorama of carbon footprints helps to recall and underline the fact that the carbon footprint is not a factual observation of emission sources: it is based on empirical data, but these data are processed by a calculation that attributes emissions to agents. Because emissions result from multiple and embedded individual and collective choices, decisions constrained by inherited structures, and conjunctions of actions carried out by diverse agents with heterogeneous capacities, the assumptions required to attribute these emissions to final agents will always be conventional and subject to debate. The attribution conventions determine "who emits CO_2". Our goal has not been to defend one accounting convention among all of those possible, nor a particular conception of responsibility related to GHG emissions. We wanted above all to point out that attribution conventions always convey a particular representation of responsibility, regardless of the precautions taken, and that, consequently, one cannot dissociate discussion of ways of measuring ecological inequalities from a discussion of responsibility.

Because it tends to frame the problem in terms of individual responsibility, the initial question of "who emits CO_2?" may not be the most relevant. A relevant contribution of a panorama of ecological inequalities cannot be in a quantification of the responsibility for GHG emissions of different classes of households. However detailed and precise this quantification may be, its value and relevance is always dependent on the choice of particular conventions, controversial assumptions, that have to be adopted to carry it out. Such an panorama is of interest not for the final result as such (i.e. who emits), but because it highlights the processes and the technical, economic, social, political, geographical or demographic factors that produce emissions. In short, because it answers the question of "How is CO_2emitted"?

The focus should be on describing the specific factors that both cause many emissions and are unevenly distributed in the population. In particular, identifying those factors that combine in particular situations of high dependency would be highly politically relevant. This analysis is data intensive and requires significant work to be carried out to gather and reconcile many statistical sources. This will help us to better describe the differences in wiggle room and power to act, and to identify the situations to which policies to foster a just ecological transition will have to provide solutions.

Contributions

This article was conceived and written by Emmanuel Combet and Antonin Pottier. Jean-Michel Cayla dealt with data needed to estimate emissions from private transport and housing services. The reconstruction of direct household emissions was carried out by Simona de Lauretis using the French Family Budget survey. Franck Nadaud also handled data processing of this survey.

Technical appendix

A Data Sources

The greenhouse gas footprint data for France (CO_2, CH_4, N_2O) come from the statistical service of the General Commissariat for Sustainable Development of the Ministry of Ecological Transition (SDES). These data are produced by applying an Input-Output method[29].

Data from the Enquête Budget de Famille (BDF, the French Household Budget Survey, 2011)[30] are used to attribute national carbon footprint data to a representative sample of more than 10,000 households.

The data on energy consumption, dwelling characteristics, heating equipment and energy uses in principal residences come from the Survey of Housing Performance, Equipment, Energy Needs and Uses (PHEBUS, 2013)[31].

Data on distances travelled, reasons for travel, modes of transportation and energy sources used by transport modes are taken from the Enquête nationale transport et déplacements (ENTD, 2008)[32].

B Data processing

B.1 GHG Footprint Inequalities

B.1.1 Scope of footprint

In 2010, GHG emissions (CO_2, CH_4, N_2O) produced on the national territory amounted to 481 $MtCO_{2e}$. These production-based emissions correspond to goods used for both domestic demand and exports, and do not include GHG emitted abroad and embedded in imported goods. As explained earlier, the input-output methodology allows these emissions to be reincorporated and to compute the GHG footprint of French final domestic demand. The INSEE estimates the total carbon footprint at 741 $MtCO_{2e}$, with 370 $MtCO_{2e}$ coming from domestic production (including 139 $MtCO_{2e}$ of direct household emissions), and practically the same volume coming from imported goods (371 $MtCO_{2e}$). The total GHG footprint of 741 $MtCO_{2e}$ can be decomposed according to the main aggregates of national accounts: 561 $MtCO_{2e}$ for final consumption of households (76%), 56 $MtCO_{2e}$ for final demand of govern-

[29] https://www.statistiques.developpement-durable.gouv.fr/lempreinte-carbone-note-prealable-lelaboration-du-quatrieme-rapport-gouvernemental-annuel-au-titre?rubrique=27&dossier=1286.

[30] https://www.insee.fr/fr/statistiques/2835605?sommaire=2015691

[31] https://www.statistiques.developpement-durable.gouv.fr/enquete-performance-de-lhabitat-equipements-besoins-et-usages-de-lenergie-phebus

[32] https://www.statistiques.developpement-durable.gouv.fr/enquete-nationale-transports-et-deplacements-entd-2008

ment (8%), and 118 $MtCO_{2e}$ for gross fixed capital formation (investment, 16%), neglecting some residual aggregates.

In our computation of carbon footprint of households, emissions from final demand of households have obviously been allocated to them, ss have been direct emissions, except direct emission of CH_4 and N_2O coming from sanitation. This amounts to a total of 559 $MtCO_{2e}$.

Emissions from final consumption of households are allocated according to current consumption expenditure, segmented by consumption item; the data comes from the Insee Household Budget survey (*Budget des familles*). For example, the survey reports expenditure on fuel, food, clothing, and so on in euros. The national emissions inventory data determines a carbon content for each of these expenditures (tCO_{2e}/€ of expenditure), which makes it possible to reconstitute the emissions from the consumption of each of the households surveyed.

Allocating emissions from final consumption of government or from investment, which are not part of household final consumption demand, requires us to complement the standard consumption-based accounting with other allocation conventions, specific to these emissions. For the emissions from final consumption of government, we have adopted a civic principle, which allocates these emissions in proportion to the number of persons per household. Each resident therefore takes their share of the government emissions, on an equal footing with all others, simply by virtue of her participation to the national community.

Other conventions are possible. Wier et al. (2001); Roca and Serrano (2007); Weber and Matthews (2008); Lenglart et al. (2010); Ummel (2014) only impute emissions from final consumption of households and therefore do not take these government emissions into account in the carbon footprint of households. Lenzen (1998) considers taxes as an expenditure that purchases government services. Government emissions are therefore allocated according to the amount of taxes paid, which increases the progressivity of emissions as a function of expenditure (in comparison to the absence of imputation), while on the contrary our civic vision, which is also adopted by Gill and Moeller (2018), decreases it. Gough et al. (2012) allocate these emissions according to the actual consumption of public services, which tends to further decrease progressivity with expenditures.

To illustrate this civic distribution, we have calculated that 2 tCO_{2e} accrues to a family of average size and composition by virtue of its presence on French soil. Adding this component hardly changes the distribution in average emissions across deciles because the size of the household is almost the same per decile of standard of living and per location. Note that for the same reason, presenting emissions per person instead of per household would not change the carbon footprint picture presented in this article.

For investment emissions (i.e. emissions from gross fixed capital consumption), it is even less obvious to allocate them to households. With the exception of purchases of real estate, land, and major works in housing carried out by households, these investments are largely made by organisations, companies and communities. Admittedly, because these investments enable the production of public or private goods, these emissions could in principle be allocated to future household consumption, but at the cost of additional assumptions. For the calculations that follow, we therefore leave aside investment emissions, knowing that they represent less than 16% of the total. The ECOPA project[33] has calculated the carbon footprint of households with allocation of emissions from investments made by households. This does not change the general picture, but slightly increases the progressiveness of emissions according to income.

B.1.2 Method for estimating footprint

To estimate the carbon footprint of households, a standard method (Weber and Matthews, 2008) is to use input-output analysis to obtain average GHG coefficients per euro of final consumption for each expenditure item, and then combine these coefficients with data on household spending. One of the drawbacks of this method is that the macro-aggregates may not necessarily be matched because of statistical inconsistencies between macro- and micro-data (Lenglart et al., 2010, p. 102-103). Complex data treatment to reconcile data sources and build overall consistency is needed to overcome this problem, while work in this direction is rare, such as that of Lenglart et al. (2010).

For this study, we chose a simpler method (Gough et al., 2012), which takes the emissions aggregates established at the macro-level and allocates them to household observations on a pro-rata basis for each item. This means that the difference between the total of the micro-economic expenditure of a product category and its macro-economic estimate is absorbed in the emissions content of that category (tCO_2/€).

More specifically, the attribution of the carbon footprint of all French households to the observations of the Family Budget Survey (BDF) distinguishes between the attribution of direct emissions (energy consumption by households) and the attribution of indirect emissions (resulting from the production of the goods and services consumed).

The data from SDES on national direct GHG emissions were attributed to BDF micro-observations using an estimate of household CO_2 emissions from the BDF survey, distinguishing between energy combustion for housing services and fuel combustion for transportation. Indirect emissions from the production of electricity and district heat, and also from the refining, conversion and distribution of fossil fuels are accounted for in the national indirect emissions of the SDES data and imputed like other indirect emissions using

[33]Supported by the French National Research Agency ANR (https://anr.fr/Projet-ANR-12-SENV-0006)

COICOP Code	Description
4500	Electricity + gas bill (not separable)
4511	Electricity bill, main residence, other dwelling, garage, outbuilding
4521	Gas bill, main residence, other dwelling
4522	Purchases of butane, propane, main residence, other accommodation
4531	Liquid fuels, the main residence: fuel oil, heating oil, petroleum
4541	Solid fuel, main residence
4551	District heating (steam)

Table A – Distribution of household energy expenditure by COICOP category in BDF

the BDF expenditure, here the expenditures by energy source (electricity, gas, butane-propane, fuel oil and other liquid fuels, district heat, wood and other solid fuels for housing, fuels for private vehicles).

Direct emissions from the combustion of fossil fuels by households were estimated by applying emission coefficients to the quantities of energy (kWh) imputed to the micro-observation of BDF by de Lauretis (2017). These quantities were deduced by dividing the expenditure data from the BDF survey (see table A) for each energy source by the average energy prices (€ per MWh) estimated for different categories of households (see below).

Expenditures on "electricity plus gas (inseparable)" have been allocated to the two energy sources as a proportion of the electricity and gas expenditures that are separable for households using the same home heating system. De Lauretis (2017) estimates energy prices for 2010 for each energy source (Table 2.9, p.46). For gas and electricity, prices are distinguished from the PHEBUS survey (2013) according to 60 groups of households defined by crossing the quintile of standard of living to which the household belongs, 6 modalities of household type (according to size, composition and age) and two modalities of housing type (individual house or collective housing).

The energy prices obtained for 2013 have been retropolated for 2010 using the "Pégase" base of energy prices. An average car fuel price is also estimated for each of the 60 household groups. Indeed, BDF's fuel expenditure includes all types of fuel, which can have very different selling prices. For each group of households, the breakdown of consumption between petrol and diesel (the two fuels that account for the vast majority of household consumption) is calculated from the ENTD transport survey (2008). The average price of the two fuels in 2010 is based on the consumer prices in €/l provided by the 2010 transport accounts (SDES), which are then transformed into €/MWh on the basis of the lower calorific value of the fuels. Finally, a weighted average makes it possible to estimate the average car fuel price for each group of households.

The Pégase database also provides average prices for fuel oil, LPG and wood, which are assumed to be the same for all households due to a lack of information on the heterogeneity of tariffs. The price of district heat, which is also unique, is given by the AMORCE/ADEME survey (2012).

The CO_2 emissions for housing services of households used to allocate the corresponding national direct emissions from the SDES data are calculated by summing the emissions of gas, butane-propane, fuel oil and other liquid fuels, wood and other solid fuels for each of the micro-observations of BDF.

Direct emissions of CH_4 and N_2O from households (non-centralised) sanitation are marginal (1.5% of the direct households' emissions, 3.5 ‰ of total emissions attributed by our study) and have not been assigned.

The volumes of national indirect emissions of CO_2, CH_4 and N_2O, resulting from the households' consumptions of products and services were attributed to the BDF survey observations using the expenditure data for the 37 aggregates of products and services corresponding to level 2 of the COICOP 1998 nomenclature of consumption functions[34].

The Institut national de la statistique et des études économiques (INSEE) made available the coefficients for bridging these expenditure nomenclatures.

Preliminary work is indeed necessary to establish a bridge with the 88 products of the input-output nomenclature (activities-products), at level 2 of the international CPA nomenclature[35].

The emission data by household observation and by product item were then aggregated to produce the graphs.

Our own emission categories group the emissions of the following COICOP categories:

- housing energy: c045
- car fuels: c072
- transport services: c073, c074
- food: c011, c012, c013, c021, c022, c023, c024
- major works in housing: c043, c044
- tangible goods: c031, c032, c033, c051, c052, c053, c054, c055, c056, c057, c06, c071, c08121, c08131, c08141, c091, c092, c093, c094, c095
- tangible services: c111, c112, c121, c123

[34] https://www.insee.fr/fr/information/2408172

[35] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Statistical_classification_of_products_by_activity_(CPA)/en

- intangible services: c041, rev801, c046, c08111, c096, c097, c101, c124, c125, c126, c127

B.1.3 Variability of reconstructed carbon footprints

We used the carbon footprints thus reconstructed for each of the households surveyed to estimate not only the average carbon footprint, which is standard, but also the variability of the carbon footprint, which is less frequent.

Estimating carbon footprint variability from BDF expenditure data poses a number of difficulties. The first are related to the emissions reconstruction method, which assumes constant emission content per euro spent by expenditure category. On the one hand, this method neglects the quality effect (see main text), which leads, if this effect is significant, to overestimating the proportionality relation of emissions to expenditure, and thus overestimating variability. On the other hand, the use of constant emission content coefficients neglects the variability linked to different techniques, which leads to an underestimation of the variability. For the most emitting items (transport and energy expenditures for housing services), precision can be gained by matching BDF data with specific databases providing information on these technical characteristics.

The last difficulty is related to the methodology of the BDF survey. This methodology extrapolates annual expenditure from the information gathered in diaries that record the household's purchases during one week and interviews on certain expenditure items. The interaction between the survey methodology and the occasional purchase of goods produces discrepancies between the expenditure reconstructed by the survey and the actual expenditure of a household during the year. For example, car fuel expenditure is estimated from purchase records. A household that fills up their car during the survey week will therefore have much higher reconstituted expenditures than a household that does not purchase gasoline during this particular week. In another example, gas expenditures are sometimes reconstructed from the last bill. For a household heating with gas, more significant expenditures (and thus emissions) will be attributed depending on whether the household is surveyed in winter or summer.

Because of these effects, for a given household, the survey is not representative of its total annual expenditures. Once a sufficiently large set of households is considered, the average estimates are nevertheless correct, as these biases at the individual observation level cancel each other out. Thus, for example, the total annual expenditures of all households, the average annual expenditures, the average annual expenditures within a decile, and so on are correctly estimated. Meanwhile, apart from the mean, the distributions of expenditures revealed by the survey are not representative of the distributions of real expenditures; that is the statistical moments greater than 2 (and in particular the variance) of these two distributions will not coincide.

For emissions, this means that if average emissions are correctly estimated, the variability of emissions is certainly biased. It is generally considered that the methodology followed leads to over-estimating the variability of emissions (Büchs and Schnepf, 2013, p. 116-117).

Finally, it should be noted that the precision of the estimates for the measures of variability given in this paper (the emission quartiles within a decile) is less than the precision of the average emissions of this decile because the sample size is smaller. The measures of variability given in the paper should therefore be understood more as plausible orders of magnitude than as true statistical estimates.

B.2 Emission inequalities from energy services

The PHEBUS survey collects from about 3,000 households the characteristics of the dwelling, the equipment, the inhabitants and the energy bills. In the second part, the survey provides data relating to the diagnosis of energy performance (DPE) of the dwelling, carried out by an approved organisation.

The data relating to monetary energy expenditure collected in the PHEBUS survey are translated into physical consumption on the basis of subscribed tariffs, as well as energy prices data from the Pégase database[36]. Certain data relating to physical electricity consumption from the PHEBUS survey were then imputed by the SDES (Denjean, 2014), in case of partial or total non-response. Some aberrant data were also corrected afterwards when there was no consistency between the equipment, uses and energy consumption variables.

For households with collective heating or domestic hot water (e.g. collective boiler, heating network, etc.) it was not possible to access individual physical energy consumptions. These consumptions were reconstituted on the basis of the specific housing charges for heating and hot water paid by the households, when this information was available, and it was estimated for the others, from the data of the (CEREN, 2013b) and on the basis of the surface area and the year of construction of the dwelling in particular.

Once these total physical consumptions in kWh for each household and for the different energy vectors (e.g. electricity, gas, etc.) have been reconstituted, they have to be attributed to the different energy uses: heating, domestic hot water, cooking and specific electricity. In some cases, an energy vector is used for a single use (e.g. wood for heating), while in other cases it serves several uses (e.g. gas for heating and cooking). A rule for the breakdown of energy consumption over the different energy uses was therefore necessary. This is carried out on the basis of regressions from studies by the Centre d'Etudes et de Recherche Economique sur l'Energie (CEREN, 2007, 2013a), which are based on the equipment owned by the household as

[36] https://www.statistiques.developpement-durable.gouv.fr/donnees-mensuelles-de-lenergie?rubrique=22&dossier=188

well as the surface area of the dwelling and the characteristics of the inhabitants. This work of decomposition thus makes it possible to reconstitute the energy consumption by energy vector for heating, domestic hot water, cooking and specific electricity.

Finally, an emission factor is applied to each energy vector to reconstitute the CO_2 emissions of each household, by energy vector and by use. The data are taken from the ADEME carbon database (ADEME, French Environment and Energy Management Agency) which in particular consider a breakdown by use for electricity consumptions to take into account the seasonal variability of use and the carbon content of the associated electricity mix. It is then possible, from all these data, to determine the CO_2 emissions for each of the households responding to the survey, by energy vector and by energy use.

A comparison of each household's heating consumption data with a theoretical consumption threshold is then carried out. These theoretical heating consumption values are calculated according to the standard of the Energy Performance Diagnostic (DPE), calculation carried out for each of the households surveyed. The calculation method used is the 3CL-DPE method[37].

B.3 Emissions inequalities from transport

The Enquête nationale transport et déplacements (ENTD) survey asks about 20,000 households about their socio-demographic characteristics and the vehicles they own. It also collects, from an individual over 6 years of age, randomly selected in each household, his or her mobility practices on a typical working day and during the weekend for the past week, as well as his or her long-distance trips over the last 13 weeks: distance, mode of transport, reason, duration, and so on.

The local mobility data by mode and by purpose are taken from the "local travels" section of the ENTD survey, which asks a randomly selected household member aged 6 years and over about his or her mobility practices on a typical working day and during a weekend for the past week.

The long-distance mobility data by mode and by reason are taken from the "long-distance journeys" section of the ENTD survey, which interviews one person randomly selected in each household on his or her trips made in the last 13 weeks. To obtain annualised data on kilometres travelled, we extrapolate this partial observation of households' trips.

To infer energy consumptions in kWh from kilometres travelled, the unitary consumption per kilometre of the different modes of transport other than the private car is taken from the SDES transport accounts data[38]. To

[37] https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000026601023&categorieLien=id

[38] https://www.statistiques.developpement-durable.gouv.fr/les-comptes-des-transports-en-2008

determine the unitary consumption per kilometre for private vehicles, a regression model is used from the individual data from the "Ownership of private vehicles" section of the ENTD survey: age of first entry into service of the vehicle, type of fuel used, fiscal power of the vehicle and total unladen weight (Cayla, 2011).

Finally, emission factors for the different energy vectors, taken from the ADEME carbon base, are applied to the different energy consumptions previously calculated in order to reconstitute CO_2emissions. It is then possible, using all these data, to determine the CO_2 emissions by energy vector and by energy use for different household groups by aggregating the individual weighted consumptions. Indeed, in the case of the national transport and travel survey database, only a limited part of mobility practices was surveyed and for only one individual within each household. It is therefore very difficult to trace total annual energy consumption and CO_2 emissions for the households of the database.

B.4 Definition of modalities of urban settlement patterns

The variable of urban settlement pattern is based on the categorisation used in the IMMOVE model, which was developed by EDF. Two geographical factors were used: the size of the urban area to which the commune belongs, and its distance from the center of the said urban area (see also Raillard (2017) for a description of the zoning).

More precisely, the first dimension is based on the size of the municipality that constitutes the center of the urban area to which the municipality belongs:

- Municipality outside the urban area or size strictly less than 2,000 inhabitants (1st line of table B);
- Size between 2,000 and 100,000 inhabitants (2nd row);
- Size strictly greater than 100,000 inhabitants, excluding the Paris conurbation (3rd row);
- Parisian agglomeration (4th row).

The second dimension describes the position of the commune in the urban area:

- If the commune is outside urban areas or multipolarised, it is a so-called rural commune (1st column in the table B);
- When the commune belongs to an urban area:
  - If it belongs to the peripheral ring, it is said to be polarised (2nd column);

Size of center of urban area	Rural municipality	Polarised municipality	Municipality of the urban center	City center of the urban center
$<$ 2 000 inhab.	Rural	Rural	–	–
2 000–100 000 inhab.	Rural	Rural	Suburbs	Suburbs
$>$ 100 000 hab.	–	Suburbs	Suburbs	Centre
Parisian agglo.	–	Suburbs	Centre	Centre

Table B – Modalities of urban settlement patterns defined by two dimensions

- If not, it belongs to the urban center and a distinction is made between belonging to the urban center (column 3) and the city center of the urban center (column 4).

The table B presents the zoning retained from these two dimensions. The relevance of the zoning thus described is validated by various studies (Bigot et al., 2009; Tregouët, 2010).

The distance to the center variable is available in the PHEBUS survey, but not in the Family Budget survey. For reasons of individual data protection, we asked the INSEE statistical service to provide us with the urban settlement patterns modality for the BDF observations, based on a correspondence table that we provided them with between the commune code (2006 classification) and the adopted classification.

B.5 Emissions from air travel

Given that air transport emissions are regularly decried in the media, we feel that it is important to discuss a few methodological points in relation to the figures used in our analysis of the ENTD survey (2008).

Emissions for air travel, which amount at most, for D10 households, to 1.7 tCO_{2e} per household and per year, may seem low compared to the orders of magnitude that can be found in the press, for example 2.5 tCO_{2e} tonnes per passenger (Monod, 2019).

There are two reasons for this low average figure:

- First, the emissions accounted for in our study are only the CO_2 emissions linked to the combustion of aircraft fuel, in line with the choices made for other modes of transport. Therefore, the volume of emissions do not include grey emissions (aircraft construction) or emissions from associated services (e.g. on-board power, or airport). Above all, they do not include emissions related to condensation trails and the formation of altitude clouds, which would double the GHG count of the aviation sector. With this emission perimeter, and using our method, a round trip from Paris to New York and back for one passenger emits: 5,775 km x 115 kg CO_2 / pkm x 2 (A/R) = 1.32 tCO_{2e}.

- Second, and more importantly, air travels are less frequent than might be expected. For all ages, the average number of trips in 2008, the survey year, was 0.37 per person. Being between the ages of 20 and 40, having a higher income, or coming from a large urban area increase the chances of having travelled by air, relative to the rest of the population (Bouffard-Savary, 2010). The perception of more frequent air travel than one every three years may come from a subjective estimate made on a population with these characteristics, this bias is exacerbated by the trend increase in air traffic between 2008 and 2019.

With an average household size of 2.2 people in France and an average trip estimated at 2,255 km like Istanbul in Turkey, one of the favourite destinations for the French, a round trip generates about 0.72 tCO_{2e} per passenger, which leads to 2.2 * 0.37 * 0.72 = 0.59 tCO_{2e} per year and per household, a figure of the same order of magnitude as our average estimate of 0.48 tCO_{2e} for annual air transport emissions for one average household.

We can compare our estimates with others and see that the orders of magnitude are the right ones. To estimate the emissions of an air trip, we make assumptions about aircraft occupancy rates and specific unit consumption for short, medium and long haul flights from (Enerdata, 2004). This leads us to an average of 130gCO_2/km for all the trips in the survey. Based on the same survey, Longuar et al. (2010, p.168) estimate unitary emissions at 128gCO_2/km, this figure is consistent with ours. If the passenger-kilometres of the French are correctly evaluated by ENTD 2008, then our emission estimates should be of the right order of magnitude, taking into account the perimeter chosen.

References

ALA-MANTILA, Sanna, Jukka HEINONEN, and Seppo JUNNILA (2014, August) — Relationship between urbanization, direct and indirect greenhouse gas emissions, and expenditures: A multivariate analysis, *Ecological Economics* ***104***, pp. 129–139.

ALLIX, Grégoire (2019, January 26) — À la poursuite du béton vert, *Le Monde*, pp. 2.

AMBROSIO, Giulia, Fateh BELAID, Sabrine BAIR, and Olivier TERSSIER (2013, October) — Analyse de la précarité énergétique à la lumière de l'enquête PHEBUS, Technical Report CASE-152, CSTB and Observatoire de la précarité énergétique.

BARRETT, John, Glen PETERS, Thomas WIEDMANN, Kate SCOTT, Manfred LENZEN, Katy ROELICH, et al. (2013, July) — Consumption-based GHG emission accounting: a UK case study, *Climate Policy* ***13***(4), pp. 451–470.

BASTIANONI, Simone, Federico Maria PULSELLI, and Enzo TIEZZI (2004, July) — The problem of assigning responsibility for greenhouse gas emissions, *Ecological Economics* ***49***(3), pp. 253–257.

BBC (2007, July 03) — How green is the Material Girl?

BERRY, Audrey (2019, January) — The distributional effects of a carbon tax and its impact on fuel poverty: A microsimulation study in the French context, *Energy Policy* ***124***, pp. 81–94.

BIGOT, Régis, Patricia CROUTTE, and Catherine DUFLOS (2009, December) — Les différences de modes de vie selon le lieu de résidence, Cahier de recherche 259, Crédoc.

BOUFFARD-SAVARY, Elisabeth (2010, December) — L'avion: des voyages toujours plus nombreux et plus lointains, See Tregouët (2010), pp. 151–162.

BOURGEOIS, Cyril, Louis-Gaëtan GIRAUDET, and Philippe QUIRION (2019) — Social-environmental-economic trade-offs associated with carbon-tax revenue recycling, in *Proceedings of the ECEEE 2019 Summer Study*, p. 1365–1372.

BÜCHS, Milena and Sylke V. SCHNEPF (2013, June) — Who emits most? Associations between socio-economic factors and UK households' home energy, transport, indirect and total CO2 emissions, *Ecological Economics* ***90***, pp. 114–123.

CADIEUX, Axel (2020, February 1-2) — Quand les DJ tentent de mixer écologie et tournées, *Libération*, pp. 38–39.

CAYLA, Jean-Michel (2011) — *Les ménages sous la contrainte carbone. Exercice de modélisation prospective des secteurs résidentiel et transports avec TIMES*, Ph. D. thesis, Ecole des Mines de Paris.

CAYLA, Jean-Michel, Laurent GRIGNON-MASSÉ, and Jean-Pierre HAUET (2019) — Comment atteindre la neutralité carbone dans le secteur résidentiel?, *Revue de l'électricité et de l'électronique* (3), pp. 69–79.

CEREMA (2017, June) — Le coût des matériaux biosourcés dans la construction: état de la connaissance – 2016, Technical report, Cerema.

CEREN (2007) — Estimation des consommations de gaz à usage eau chaude sanitaire et cuisson, Étude 7107, Centre d'Etudes et de Recherche Economique sur l'Énergie.

CEREN (2013a) — Ré-estimation en 2010 de la consommation d'électricité par usage fin, Étude 2104, Centre d'Etudes et de Recherche Economique sur l'Énergie.

CEREN (2013b) — Suivi du parc et des consommations d'énergie. Consommations en 2012, Volume 2, Étude 3102, Centre d'Etudes et de Recherche Economique sur l'Énergie.

Chakravarty, Shoibal, Ananth Chikkatur, Heleen de Coninck, Stephen Pacala, Robert Socolow, and Massimo Tavoni (2009) — Sharing global CO2 emission reductions among one billion high emitters, *Proceedings of the National Academy of Sciences* ***106***(29), pp. 11884–11888.

Clément, Mathilde, Alexandre Godzinski, and Isabelle Vincent (2019) — Les effets économiques de la fiscalité environnementale sur les ménages et les entreprises, Technical report, Conseil des Prélevements Obligatoires, 5e rapport particulier, *La fiscalité environnementale au défi de l'urgence climatique.*

Combet, Emmanuel, Frédéric Ghersi, Jean-Charles Hourcade, and Camille Thubin (2010) — La fiscalité carbone au risque des enjeux d'équité, *Revue française d'économie* ***25***(2), pp. 59–91.

Comby, Jean-Baptiste (2015) — *La question climatique: genèse et dépolitisation d'un problème public*, Paris: Raisons d'agir.

Cronin, Julie Anne, Don Fullerton, and Steven Sexton (2019, March) — Vertical and Horizontal Redistributions from a Carbon Tax and Rebate, *Journal of the Association of Environmental and Resource Economists* ***6***(S1), pp. S169–S208.

Davis, Steven J., Ken Caldeira, and H. Damon Matthews (2010) — Future CO_2 Emissions and Climate Change from Existing Energy Infrastructure, *Science* ***329***, pp. 1330–1333.

Davis, Steven J., Glen P. Peters, and Ken Caldeira (2011) — The supply chain of CO2 emissions, *Proceedings of the National Academy of Sciences* ***108***(45), pp. 18554–18559.

Davison, Aidan (2016) — The luxury of nature: the environmental consequences of super-rich lives, in I. Hay and J. V. Beaverstock (Eds.), *Handbook on Wealth and the Super-Rich*, pp. 339–359. Cheltenham, Northampton, MA: Edward Elgar Publishing.

de Lauretis, Simona (2017) — *Modélisation des impacts énergie/carbone de changements de modes de vie. Une prospective macro-micro fondée sur les emplois du temps*, Ph. D. thesis, Université Paris-Saclay.

Denjean, Mathias (2014) — Enquête sur la performance de l'habitat, équipements, besoins et usages de l'énergie. De la base de sondage aux données exploitables, Master's thesis, Université de Rennes 1.

Desrosières, Alain (1993) — *La politique des grands nombres: histoire de la raison statistique*, Paris: Editions La Découverte.

Douenne, Thomas (2018) — The vertical and horizontal distributive effects of energy taxes: A case study of a French policy, Technical Report 2018.10, FAERE Working Papers.

Druckman, Angela and Tim Jackson (2009, May) — The carbon footprint of UK households 1990-2004: A socio-economically disaggregated, quasi-multi-regional input-output model, *Ecological Economics* ***68***(7), pp. 2066–2077.

Dubois, Ute (2012, October) — From targeting to implementation: The role of identification of fuel poor households, *Energy Policy* ***49***, pp. 107–115.

Dugast, César and Alexia Soyeux (2019, June) — Faire sa part? pouvoir et responsabilité des individus, des entreprises et de l'État face à l'urgence climatique, Technical report, Carbone 4.

Emelianoff, Cyria (2008) — La problématique des inégalités écologiques, un nouveau paysage conceptuel, *Ecologie & politique* (35), pp. 19–31.

Enerdata (2004) — Efficacité énergétique des modes de transport.

Fremstad, Anders, Anthony Underwood, and Sammy Zahran (2018, March) — The Environmental Impact of Sharing: Household and Urban Economies in CO2 Emissions, *Ecological Economics* ***145***, pp. 137–147.

Fuglestvedt, Jan S., Terje K. Berntsen, Odd Godal, Robert Sausen, Keith P. Shine, and Tora Skodvin (2003, June) — Metrics of Climate Change: Assessing Radiative Forcing and Emission Indices, *Climatic Change* ***58***(3), pp. 267–331.

Gadrey, Jean (2018, November 20) — En France, les très riches émettent 40 fois plus de carbone que les pauvres, mais les pauvres paient plus de 4 fois plus de taxe carbone en % de leurs revenus !, *Debout! le blog de Jean Gadrey, alternatives-economiques.fr*.

Gill, Bernhard and Simon Moeller (2018, March) — GHG Emissions and the Rural-Urban Divide. A Carbon Footprint Analysis Based on the German Official Income and Expenditure Survey, *Ecological Economics* ***145***, pp. 160–169.

Gingras, Yves (2014) — *Les dérives de l'évaluation de la recherche: du bon usage de la bibliométrie*, Paris: Raisons d'agir éditions.

GIROD, Bastien and Peter De HAAN (2010) — More or Better? A Model for Changes in Household Greenhouse Gas Emissions due to Higher Income, *Journal of Industrial Ecology* ***14***(1), pp. 31–49.

GOLLEY, Jane and Xin MENG (2012, November) — Income inequality and carbon dioxide emissions: The case of Chinese urban households, *Energy Economics* ***34***(6), pp. 1864–1872.

GOLLIER, Christian (2019, September 27) — Une politique climatique « fondée sur un prix universel du carbone », *Le Monde.fr*.

GOUGH, Ian, Saamah ABDALLAH, Victoria JOHNSON, Josh RYAN-COLLINS, and Cindy SMITH (2012, March) — The Distribution of Total Greenhouse Gas Emissions by Households in the UK, and Some Implications for Social Policy, Working Paper CASE/152, London School of Economics, London.

GREENINSIDE (2011, March) — Observatoire du bilan carbone des ménages, Technical report, Green Inside.

GRUBLER, A. and S. PACHAURI (2009, October) — Problems with burden-sharing proposal among one billion high emitters, *Proceedings of the National Academy of Sciences* ***106***(43), pp. E122–E123.

HEEDE, Richard (2014, January) — Tracing anthropogenic carbon dioxide and methane emissions to fossil fuel and cement producers, 1854–2010, *Climatic Change* ***122***(1-2), pp. 229–241.

IRVINE, Chris (2008, August 23) — Madonna's carbon footprint under scrutiny.

ISAKSEN, Elisabeth T. and Patrick A. NARBEL (2017, January) — A carbon footprint proportional to expenditure - A case for Norway?, *Ecological Economics* ***131***, pp. 152–165.

JACOBSEN, Eivind and Arne DULSRUD (2007, August) — Will Consumers Save The World? The Framing of Political Consumerism, *Journal of Agricultural and Environmental Ethics* ***20***(5), pp. 469–482.

KEMPF, Hervé (2007) — *Comment les riches détruisent la planète*, Paris: Éditions du Seuil.

LE BRETON, Morgane (2017, April) — La volonté de compter : carbone, conventions de calcul et référentiels de comptabilisation, *Entreprises et histoire* ***86***, pp. 86–104.

LENGLART, Fabrice, Christophe LESIEUR, and Jean-Louis PASQUIER (2010) — Les émissions de CO2 du circuit économique en France, in *L'économie française, comptes et dossiers, édition 201*. INSEE.

Lenzen, Manfred (1998, June) — Energy and greenhouse gas cost of living for Australia during 1993/94, *Energy* ***23***(6), pp. 497–516.

Lenzen, Manfred (2000) — Errors in Conventional and Input-Output–based Life–Cycle Inventories, *Journal of Industrial Ecology* ***4***(4), pp. 127–148.

Liu, Lee (2015) — A critical examination of the consumption-based accounting approach: has the blaming of consumers gone too far?, *WIREs Climate Change* ***6***(1), pp. 1–8.

Longuar, Zahia, Jean-Pierre Nicolas, and Damien Verry (2010, December) — Chaque Français émet en moyenne deux tonnes de CO2 par an pour effectuer ses déplacements, See Tregouët (2010), pp. 163–176.

Malliet, Paul (2020, January) — L'empreinte carbone des ménages français et les effets redistributifs d'une fiscalité carbone aux frontières, OFCE policy brief 62, OFCE, Paris.

Malliet, Paul, Ruben Haalebos, and Emeric Nicolas (2020, January) — La fiscalité carbone aux frontières et ses effets redistributifs, Technical report, Ademe, Paris.

Marques, Alexandra, João Rodrigues, Manfred Lenzen, and Tiago Domingos (2012, December) — Income-based environmental responsibility, *Ecological Economics* ***84***, pp. 57–65.

Marshall, George (2017) — *Le syndrome de l'autruche: pourquoi notre cerveau veut ignorer le changement climatique*, Arles: Actes Sud.

Michaut, Cécile (2020, March 11) — La recherche veut réduire ses émissions de CO_2, *Le Monde* ***Supplément Science & Médecine***, pp. 5.

Monod, Olivier (2019, February 13) — Est-ce qu'un aller-retour en avion à Bali émet autant de CO_2 qu'une année de vie en France?, *Libération / Checknews.fr*.

Munksgaard, Jesper and Klaus Alsted Pedersen (2001, March) — CO2 accounts for open economies: producer or consumer responsibility?, *Energy Policy* ***29***(4), pp. 327–334.

Nässén, Jonas (2014, March) — Determinants of greenhouse gas emissions from Swedish private consumption: Time-series and cross-sectional analyses, *Energy* ***66***, pp. 98–106.

Oshana, Marina A.L. (2015) — Responsibility: Philosophical Aspects, in *International Encyclopedia of the Social & Behavioral Sciences*, pp. 587–591. Elsevier.

OTTO, Ilona M., Kyoung Mi KIM, Nika DUBROVSKY, and Wolfgang LUCHT (2019, February) — Shift the focus from the super-poor to the super-rich, *Nature Climate Change* ***9***(2), pp. 82–84.

OXFAM (2015, December) — Inégalités extrêmes et émissions de CO_2, Technical report, Oxfam.

PATERSON, Matthew and Johannes STRIPPLE (2010, April) — My Space: Governing Individuals' Carbon Emissions, *Environment and Planning D: Society and Space* ***28***(2), pp. 341–362.

PAUTARD, Eric (2017) — L'inégale capacité des ménages à agir en faveur de l'environnement, in *Les acteurs économiques et l'environnement*, pp. 57–71. INSEE.

PEARCE, David (1991) — The Role of Carbon Taxes in Adjusting to Global Warming, *The Economic Journal* ***101***(407), pp. 938–948.

PETERS, Glen P. (2008, March) — From production-based to consumption-based national emission inventories, *Ecological Economics* ***65***(1), pp. 13–23.

PIKETTY, Thomas and Lucas CHANCEL (2015, November) — Carbon and inequality: from Kyoto to Paris Trends in the global inegality of carbon emissions (1998-2013) & prospects for an equitable adaptation fund.

POTERBA, James M. (1991) — Tax Policy to Combat Global Warming: On Designing a Carbon Tax, in R. DORNBUSCH AND J. M. POTERBA (Eds.), *Global warming: economic policy responses*, pp. 71–98. Cambridge, Mass: MIT Press.

POTTIER, Antonin (2020) — L'équivalence entre gaz, de Montréal à Kyoto, in E. CHIAPELLO, A. MISSEMER, AND A. POTTIER (Eds.), *Faire l'économie de l'environnement*, pp. 121–139. Paris: Presses de l'École des Mines de Paris.

POTTIER, Antonin (2021) — Expenditure-elasticity and income-elasticity of GHG emissions: a survey of literature on household carbon footprint, FAERE Working Paper, 2021.01.

RAILLARD, Nicolas (2017, August) — Décarboner la mobilité dans les zones de moyenne densité: moins de carbone, plus de lien – note méthodologique, Technical report, The Shift project.

ROCA, Jordi and Monica SERRANO (2007, June) — Income growth and atmospheric pollution in Spain: An input-output approach, *Ecological Economics* ***63***(1), pp. 230–242.

Rose, Antoine (2013) — La comptabilité des émissions de carbone par enjeux: définition, justification et comparaison avec les modèles existants, Cahiers de la Chaire 60, Chaire Finance et Développement durable, Paris.

Rumpala, Yannick (2009) — La «consommation durable» comme nouvelle phase d'une gouvernementalisation de la consommation, *Revue francaise de science politique* ***Vol. 59***(5), pp. 967–996.

Schlumpf, C., J. Behringer, G. Dürrenberger, and C. Pahl-Wostl (1999, January) — The personal CO2 calculator: A modeling tool for Participatory Integrated Assessment methods, *Environmental Modeling & Assessment* ***4***(1), pp. 1–12.

Sessego, Victoire and Pascale Hébel (2018, December) — Consommer durable est-il un acte de distinction ? Représentations, pratiques et impacts écologiques réels au regard des dynamiques sociales, *Cahier de recherche* ***344***.

Shue, Henry (1993) — Subsistence Emissions and Luxury Emissions Symposium: Above the Boundaries: Ozone Depletion, Equity, and Climate Change, *Law & Policy* ***15***(1), pp. 39–60.

Steen-Olsen, Kjartan, Richard Wood, and Edgar G. Hertwich (2016) — The Carbon Footprint of Norwegian Household Consumption 1999-2012, *Journal of Industrial Ecology* ***20***(3), pp. 582–592.

Stiglitz, Joseph E. (2019) — Addressing climate change through price and non-price interventions, *European Economic Review* ***119***, pp. 594–612.

Tregouët, Bruno (Ed.) (2010, December) — *La mobilité des Français: Panorama issu de l'enquête nationale transports et déplacements 2008*, Paris: Revue du CGDD.

Tukker, Arnold, Hector Pollitt, and Maurits Henkemans (2020, April) — Consumption-based carbon accounting: sense and sensibility, *Climate Policy* ***20***(sup1), pp. S1–S13.

Tukker, Arnold, Richard Wood, and Sarah Schmidt (2020, April) — Towards accepted procedures for calculating international consumption-based carbon accounts, *Climate Policy* ***20***(sup1), pp. S90–S106.

Ummel, Kevin (2014, October) — Who Pollutes? A Household-Level Database of America's Greenhouse Gas Footprint, Working Paper 381, Center for Global Development, Rochester, NY.

Underwood, Anthony and Sammy Zahran (2015, August) — The carbon implications of declining household scale economies, *Ecological Economics* ***116***, pp. 182–190.

WEBER, Christopher L. and H. Scott MATTHEWS (2008, June) — Quantifying the global and distributional aspects of American household carbon footprint, *Ecological Economics* ***66***(2), pp. 379–391.

WIEDENHOFER, Dominik, Dabo GUAN, Zhu LIU, Jing MENG, Ning ZHANG, and Yi-Ming WEI (2017, January) — Unequal household carbon footprints in China, *Nature Climate Change* ***7***(1), pp. 75–80.

WIER, Mette, Manfred LENZEN, Jesper MUNKSGAARD, and Sinne SMED (2001, September) — Effects of Household Consumption Patterns on CO2 Requirements, *Economic Systems Research* ***13***(3), pp. 259–274.

ZSUZSA LÉVAY, Petra, Josefine VANHILLE, Tim GOEDEMÉ, and Gerlinde VERBIST (2020, April) — The association between the carbon footprint and the socio-economic characteristics of Belgian households, Working paper 20.05, Universiteit Antwerpen, Herman Deleeck Centre for Social Policy, Antwerp.

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