Economics of Climate Change & Big Data BBVA Research

CO_2 Footprint of Spanish Households: Enhancing Measurement through Economic Analysis and Big Data

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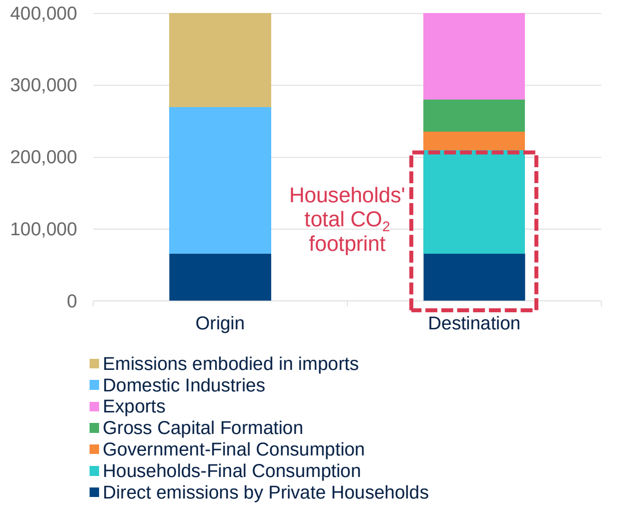
This note proposes a path to shore up the measurement of the carbon footprint of the representative household of an economy, enhancing traditional macroeconomic analysis, and with the use of Big Data in order to obtain real time outcomes and insights into the impact of the lifestyle of different households.

Takeaways

- The measurement of the carbon footprint of individual companies and households will be key to allow them to make informed decisions to reduce it. While it is still under development, calculating individual CO_2 emissions requires a holistic approach that combines data and analysis from different sources and venues.
- Spanish households emitted 66 million tons of CO_2 directly into the atmosphere in 2016, mainly due to the use of private vehicles, heating and cooking at home,[1] 24% of the country's emissions.[2] However, their total carbon footprint should also include embodied emissions from all goods and services they consume (e.g. the food that they eat or the clothes they wear), information that is not provided by official statistics.
- BBVA Research estimates[3] that these indirect emissions stood at 144 million tons in 2016 so all households' (direct and indirect) emissions summed up 210 million tons, 52% of all Spanish CO_2 emissions produced and imported (Figure 1). Among households' indirect emissions, those generated by food, shelter, mobility and manufactured goods were 88% (Figure 2). Services and clothing made the rest.
- The granular information included in Big Data allows us to go beyond the "representative" household of macroeconomic estimations and go deeper in the particular characteristics of the households in real time. This approach allows monitoring the decarbonization efforts of different households estimating the individual carbon footprint according to their different characteristics and lifestyles. Exploitation of BBVA's with Big Data techniques can help in this endeavor enhancing both update and granularity.

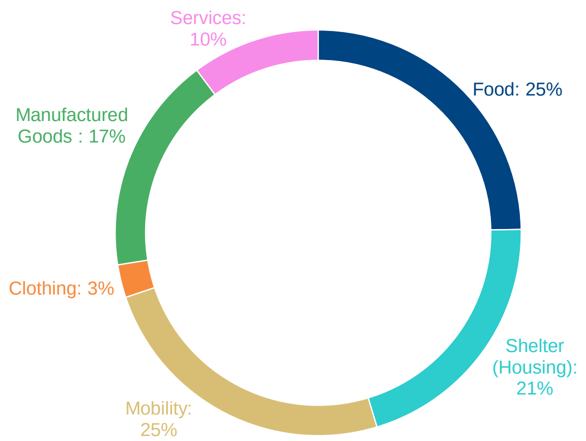
1: Direct emissions allocated to private households include: Private transport, heating/cooling including cooking and direct emissions from paints, aerosols or open fires. Reference: Eurostat, 2015. Manual for air emissions accounts.
2: CO2 emissions that are linked to economic activities and generated by resident companies and Households. Reference: INE, 2021. Environmental Accounts: Air Emissions Accounts. Standardized Methodological Report.
3: Estimations based on Input-Output Analysis applied to emissions intensity detailed by sectoral activity and products.

Figure 1. **SPAIN. CO_2 EMISSIONS BY ACTIVITY. ORIGIN & DESTINATION** (THOUSAND TONS. 2016)



Source: BBVA Research calculations with INE data

Figure 2. **INDIRECT EMISSIONS IN HOUSEHOLDS FINAL CONSUMPTION** (%)



Source: BBVA Research

Measuring CO_2 footprint: one data source is not enough

Greenhouse gas (GHG) and, in particular, CO_2 emissions contribute to global warming, the ultimate cause of climate change; and have negative effects on biodiversity and human health. That is the reason why, in line with the Paris Agreement, GHG emissions are an increasingly important policy variable, with a growing number of countries across the World pledging to reduce them in order to meet Net-Zero commitments.

The definition and deployment of climate policies need reliable data of emissions (who, when and how GHG are generated). This is also important for the financial system, given the role banks have to play, partnering with their customers in their transition to a low-carbon economy. Moreover, the broadening requirements of the supervisory bodies, and the stakeholders' pressures to meet climate targets also require reliable calculations of emissions footprint. However, the measurement of the carbon footprint of individual companies and households, essential for analyzing the environmental sustainability of the economy, is a work in progress, still very much under development.

In order to fill the gaps between data availability and an increasing demand to measure emissions, official statistical sources need to be complemented with private parties' additional data. The ECB Economy-wide Climate Stress Test (ECB, 2021) is a good example of this comprehensive approach to analyze climate risks, an exercise where many assumptions are made as there is a lack of granularity in the data.[4]

4: The ECB has integrated different databases to include physical and transition climate risks in their workhorse database of financial data for firms and banks. As regards the carbon footprint of companies, proxy of climate transition risk, the ECB points out that "firms not disclosing information on their carbon footprint were assigned inferred emissions data based on their NACE subsector" (ECB, 2021).

All in all, the analysis of the economy's carbon footprint requires a holistic approach that combines information from different sources and complementary analysis venues to have a complete view of the economy's carbon footprint. In this note we focus on how this approach can be used to measure the Spanish Households carbon footprint.

Measuring Spanish Households CO_2 footprint: official statistics and Input-Output analysis

What do we know directly from official data?

The Spanish Air Emissions Accounts provide data on direct CO_2 emissions generated by both resident sectoral economic activities and households as final consumers[5]. In 2020, 26% of the total CO_2 emissions were generated by households (Figure 3), 3 percentage points (pp) higher than in the period 2018-2019. However, these official statistics of household´s emissions are to some extent incomplete and only include their direct emissions[6] (Box 1); in particular:

- Transport: included only when the emissions arise from the private use of motor vehicles; emissions caused by public transport are assigned to the respective transportation industry.
- Heating/cooling (including cooking): emissions by private households that derive from the combustion of fuels for heating/cooling houses and flats as well as from the fuel combustions for cooking and producing hot water. Emissions from the production of electricity purchased by households are not allocated to private households but to electricity producers/suppliers.
- Others: emissions for other purposes than transport and heating (paints, sprays, open fires).

Box 1.
The estimation of the households' direct carbon footprint at national level can be measured using the following equation:

$$E_{direct} = Transport^{*}\, a + Heating^{*}\, b + Others\ {*}\ c$$

where Transport, Heating and Other are the three classes defined by Eurostat for households' emissions and a, b, c the CO_2 emission factors applied to each class.[7]

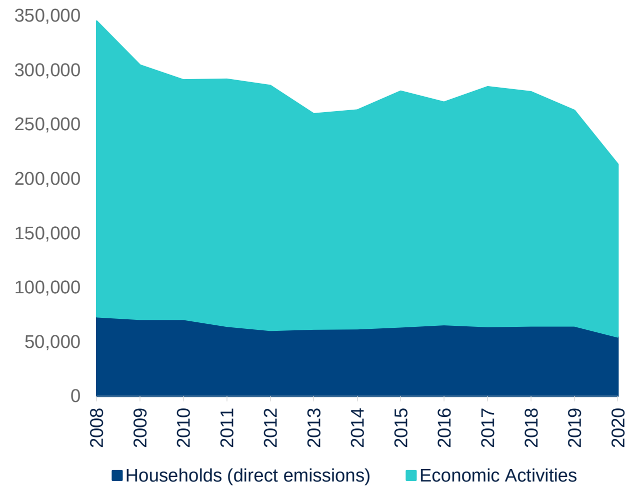
5 Air Emissions Accounts of the Spanish National Accounts System register the flows of gaseous and waste particulate matter in the air that come from the national economy. Thus, they don't include emissions from non-economic agents (nature) nor the absorption of gasses by nature (absorption of CO2). Also, they only consider national economic activities (residence principle) and the emissions of these units abroad, tourists and international transport companies that shall be included in the corresponding industry or in the households as final consumers. The emissions of non-resident units within the national border are excluded. Thus, the embodied emissions in imports of goods and services are also excluded.
For complete details of this official statistical operation see INE, 2021 and for updated data: INE, 2021b, Air Emissions Accounts. Preview 2020 and year 2019.
6 See Eurostat, 2015.
7: The Spanish Ministry for Ecological Transition has developed different tools to facilitate the calculation of an organization's carbon footprint. See here for further details.

What can we calculate by processing "other" official data sources?

To improve the measurement, an extended households' total carbon footprint should include not only their direct emissions but also those emissions embodied in the different goods and services, produced in Spain or imported, they enjoy as consumers. The emissions embodied in the production of a T-shirt, in the food eaten in a restaurant, in the home cleaning products, in the electronic products or in the manufacturing process of the car, among others, are after all the result of household consumption decisions.

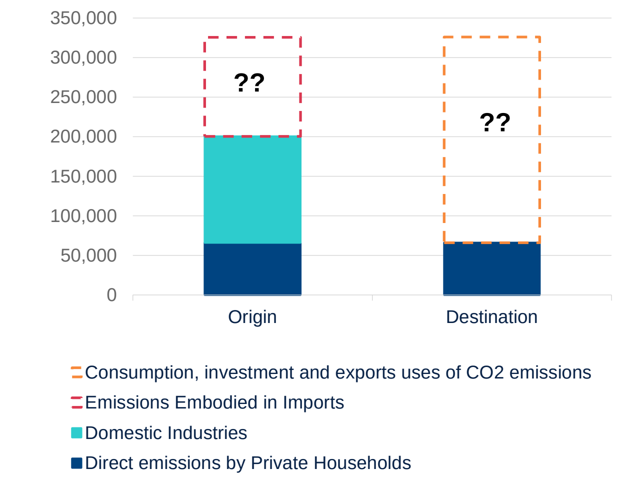
From a more general point of view, we can measure emissions both as the origin and the destination of the economic factors. The sum of the emissions generated directly by households, those produced by companies resident in Spain and those incorporated in the imports of goods and services, are the resources (the origin) that are destined to meet the different uses (destinations) which are the demand of households, companies and government: public and private consumption, investment and exports.

Figure 3. **SPAIN. CO_2 EMISSIONS LINKED TO ECONOMIC ACTIVITIES** (THOUSAND TONS)



Source: BBVA Research calculations with INE data

Figure 4. **CO_2 AND ECONOMIC ANALYSIS. ORIGIN AND DESTINATION OF EMISSIONS**



Source: BBVA Research

Box 2.

How to calculate the indirect household carbon footprint (and the rest of the uses of carbon emissions, by companies and the government)

Environmental extended input-output modeling has been increasingly used to estimate the indirect emission component of household consumption. It would capture the total emissions generated during the production process (upstream supply chain until the product is ready to be used). It is worth noting that it does not include the direct emissions of households.

For Spanish households, total indirect CO_2 emissions could be estimated using an Input-Output (IO) model based on Leontief coefficients[8]. The indirect household carbon footprint could be expressed as follows:

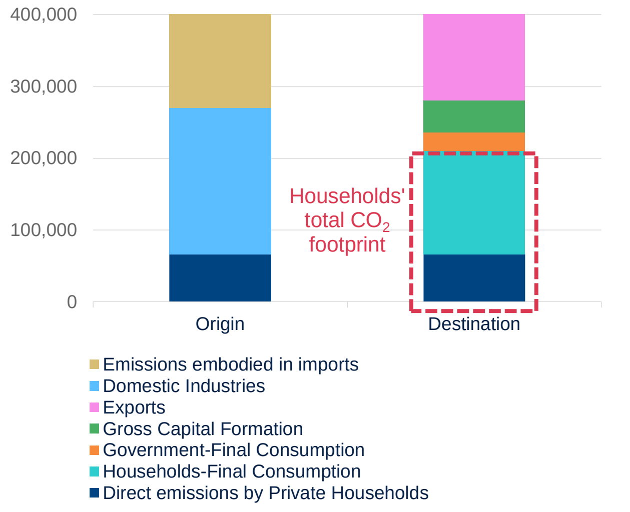
$$E_{Indirect} = EI * (I-A)^{-1} * W_{Demand}$$

where *EI* is the emission intensity vector (emissions generated per unit of output in each homogeneous sector or product)[9]; $(I-A)^{-1}$ the Leontief inverse matrix, which captures the total effects that one unit of the final demand has on the output[10]; and *W* is the vector of demand components (consumption, investment or export by product. So, the product $(I-A)^{-1} * W_{Consumption}$ gets a total output vector accounting for the inputs triggered throughout supply chains, including imports, by household's consumption**.**

As it can be seen in Figure 5, with our own calculations based on (the latest available) 2016 Input-Output Table: (i) exports of goods and services account for almost one third (31%) of total CO_2 emissions of the Spanish economy, both generated by resident economic units that export and embodied in imported goods and services from domestic agents (public consumption: 6%; gross capital formation: 11%). Regarding private consumption, 36% of total CO_2 emissions are destined to meet households' demand for consumption. These are indirect emissions associated with private consumption, however, the total CO_2 footprint of households is higher, 52% of the total emissions of the Spanish economy, as direct emissions also need to be included (16%).

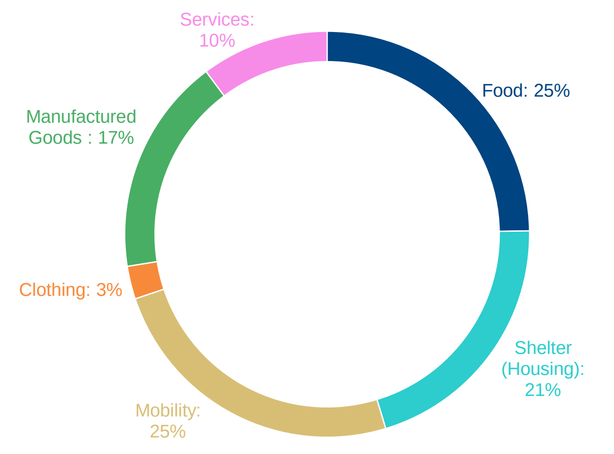
8: Kaihui S., Shen Q., Morteza T., Sai L., Ming X., 2019 Scale, distribution and variations of global greenhouse gas emissions driven by U.S. households.
9: It is worth noting that as regards economic activities, the official data provides high granularity (two-digit level NACE classification) and eases the calculation of sectoral emission intensities.
10: Miller and Blair, 2009 Miller, R., Blair, P. Input-Output Analysis Foundations and Extensions.

Figure 5. **CO_2 EMISSIONS. ESTIMATION OF ORIGIN AND DESTINATION WITH INPUT-OUTPUT ANALYSIS** (THOUSAND TONS)



Source: BBVA Research

Figure 6. **EMBODIED EMISSIONS IN HOUSEHOLDS FINAL CONSUMPTION** (%)

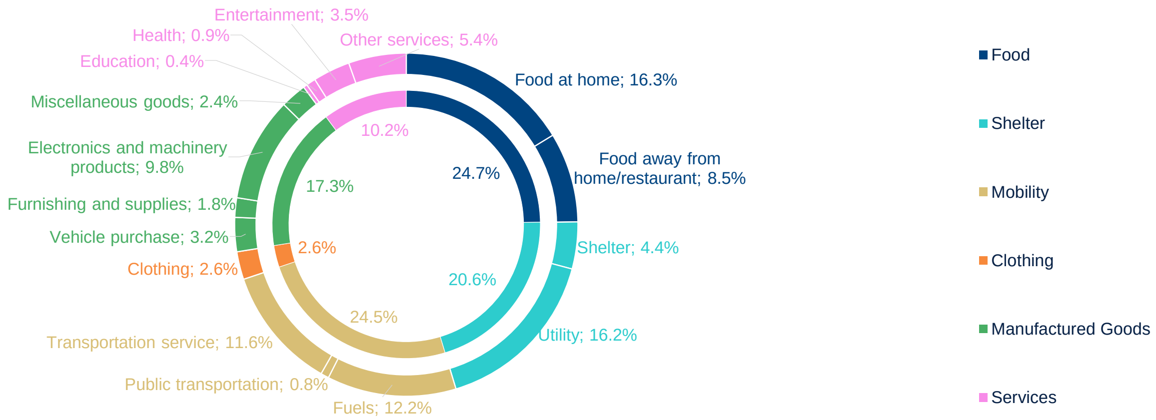


Source: BBVA Research

It is worth noting that as regards economic activities, the official data provides high granularity (two digit level NACE classification), easing the calculation of sectoral emission intensities and making possible a high definition analysis of the emissions footprint for the different goods and services destined to consumption (Figure 6 and Figure 7 for more granular detail).

The analysis reveals that in 2016, household expenditures on mobility (25%) and food (25%) account for half of the indirect carbon footprint of households. Expenditures on shelter, manufactured goods and services contributed by 21%, 17% and 10%, respectively, and clothing became the least significant component (3%). At the subcategory level (Figure 7), around two thirds of food emissions come from food at home (16.3%) and one third from eating away (8.5%). In mobility, also key in household carbon footprint, almost all of emissions are evenly distributed between fuels and transportation service. In shelter or housing, the bulk of emissions (85%) come from utilities (electricity, natural gas, water,...) and in manufactured goods more than half are generated by electronics and machinery products and the rest by vehicle, clothing and furnishing. Finally, services' emissions are distributed among entertainment, education, health, and other services.

Figure 7. **EMBODIED EMISSIONS IN HOUSEHOLDS FINAL CONSUMPTION (%). HIGH DEFINITION**



Source: BBVA Research

For all the additional information that can be obtained from this approach, it is worth noting some limitations of this type of detailed analysis:

- **Low frequency of the data**. GHG emissions data have a relatively low temporal (annual) frequency, which prevents their use as a high-frequency signal.
- **Lack of individual information on Households and Corporates.** The Input-Output Methodology is a Macro approach and, while providing key benchmark information of the average CO_2, cannot be used to monitor the sustainability of individual Households and Corporates. The BigData information will be key to cope with this problem.
- **Time evolution is conditioned to a given production and demand framework**. The distribution between the origin and destination of emissions is based on the input-output table, which shows the technical relationships between the productive processes of supply and the needs of demand for a given year, which must be taken into account if the temporal evolution of the results obtained is to be analyzed. In short, the outcome will always be conditioned to the production structure of a given year.
- **Domestic or multiregional input-output analysis**. It should be noted that the use of domestic or multi-regional/global input-output tables is particularly relevant. In the first case, the results involve extrapolating to the rest of the world the technical relationships existing between the sectors of the national economy. This is a relatively stringent assumption considering that in the case of emissions, there is evidence of the different embodied CO_2 emissions in imported versus domestically manufactured products.
- **Breakdown of expenditure between quantities and prices**. Updating the carbon footprint over time by maintaining the reference input-output table until a more updated one is available requires detailed information on demand expenditure, including the capability of separating its growth in volume and price evolution. For example, an increase in electricity costs due to the increase in tariffs does not imply an increase in energy consumption and with it an increase in the carbon footprint. The opposite may be true, with higher expenditure coinciding with lower actual consumption.

The road ahead: measuring carbon footprint taking advantage of Big Data

The use of input-output (IO) tables to leverage National Accounts data is a good reference to analyze the CO_2 footprint of a representative Household. However, given the identified limitations (see above) we propose to overcome them by completing this approach with high-frequency and high granular ("High Definition") data such as the one coming from Big Data sources.

What do we need to correct to improve the measure of detailed household emissions? First, the CO_2 Household footprint measurement from IO approach above corresponds to a "representative" Spanish family[11]. But "the devil is in the details" and the carbon footprint of a particular household may be very different from that of others even within a country. We need to improve this measure to get as close to the specific household as possible. Second, the information in the input-output tables is not frequently updated, a relevant caveat for having an updated picture and monitoring the progress of households in their decarbonization process. Last, but not least, most of the information available for updating is in nominal terms while CO_2 emissions should be expressed in terms of mass or volume (real variables as Kg of CO_2 emissions). In this sense, if the information coming from the IO approach or Big Data (Nominal Bills, Invoices) is not corrected from price evolutions, CO_2 emissions estimation will be biased.

Beyond these warnings, the relevance of BigData information to estimate the Households´ CO_2 footprint is straightforward and we are already observing increasing efforts in this line of work including BBVA[12]. Our habits, preferences and lifestyles can lead to a substantial dispersion around the "representative" households. The CO_2 footprint depends on variables of different nature such as economic, social, demographic, technological, geographic,cultural, seasonal. The more detailed these factors are, the more accurate the estimate of a Household CO_2 footprint would be. During the next paragraphs we describe how Big Data information can be used to improve estimations of the Scope 1 (Fuel related to Transport), Scope 1 and Scope 2 (Heating and Electricity in Housing), and Scope 3 (i.e. Food).

The CO_2 footprint coming from our mobility or transport is generated by the Households' own vehicle use or their transport expenditures. These are considered Direct Emissions (Scope 1) and the most common approach used to calculate CO_2 emissions is to use a simple formula:[13]

CO_2 Emissions: Activity Data x CO_2 Emission Factor

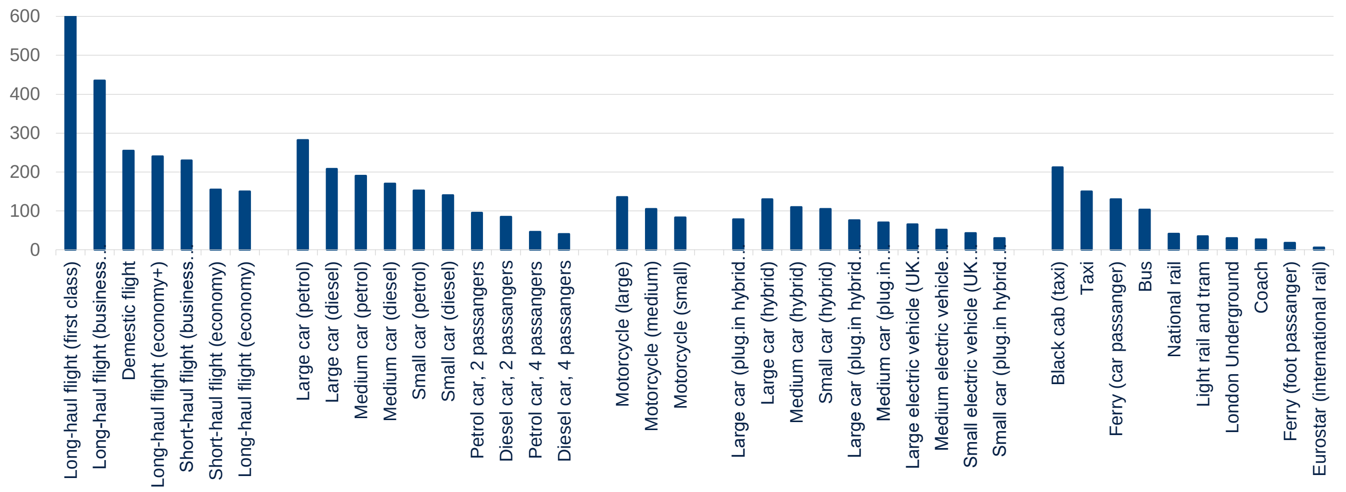
In this simple formula, Activity Data refers to the information needed to calculate CO_2 emissions from combustion and other processes. For example, this could be liters of fuel consumed by Household´s vehicles which can be obtained by the liters of fuel loaded in the car if detailed in the gas station ticket. If the amount and fuel type of litters is not indicated, we will need to convert the nominal invoices in Euros to a volume (Fuel Liters) or mass equivalent unit (KW) in the case of Hybrid or Electric Cars.

As noticed, rather than a representative car there are many options and the amount of CO_2 Emissions and the margin to decarbonize is ample depending on the energy source (Petrol, Hybrid, Electric) and the size of the vehicle. The following (UK example) graph is representative of the options we have to adapt more sustainable technologies just by using our own car. The middle groups in the Graph 8 show the CO_2 emissions in CO_2 g/Km terms according to the different type of vehicle. While the cost of running a km in a large petrol car is near 283 grams/Km the same distance can be completed with nearly 10 times less Gram/Km with a small plug in Electric

11: It is sufficient to divide the results shown, the footprint of the total number of households resident in the economy, by the number of households.
12: BBVA, primer banco en España en calcular la huella de carbono de todos sus clientes
13: Input-Output analysis might provide a more comprehensive view of mobility services including the emissions embodied in the vehicles.

Cars (29 grams/km). In general terms, a lot of margin of improvement exists when we move from large petrol cars to the small one electric ones.

Figure 8. **UK TRANSPORT: CO_2 EMISSIONS** (gCO_2e/Km)



Source: Office for National Statistics (ONS)

The rest of the transport options are quite heterogeneous. While the expenditure invoices or tickets are a good indicator of the transport expenditure it is also needed to adapt the information to the specific conditions of the trips. As observed in Graph 8, Air Transport is the least sustainable means of transport but even here there are some differences from the most contaminant Long Haul First class (as you use more space in the plane) to the short term haul economy class. As observed, using a Business Class for a short-term trip does not look like an idoneous way to combat climate change. Thus, it looks that the margin of Western countries' Middle-High Income class to improve sustainability is still very high.

The heterogeneity for the decarbonization path is also relevant on the less pollutant urban transportation. Again, this information can be inferred from tickets and invoices (once converted to real terms) but as observed in the graph there are also significant improvements from moving in taxi, in bus or by train. To give a more precise estimation of the CO_2 Emissions the analysts can obtain more precise estimations by taking into account Income levels, distance to the Downtown or Office, Mobility patterns and other variables playing an important role in the heterogeneity of Households using the urban transport.[14]

Therefore, the Big Data Information and models can be used not only to estimate the CO_2 Footprints but also to help to diagnose how Smart and Sustainable our cities are. Since Paris launched the '15-minute city' many urbanists are already working on the concept. The idea is to improve quality of life by creating cities where everything a resident needs can be reached within a quarter of an hour by foot or bike. The 15-minute city requires minimal travel among housing, offices, restaurants, parks, hospitals and cultural venues. Each neighborhood should fulfill six social functions: living, working, supplying, caring, learning and enjoying. While some European cities are closer to this concept the US cities are far from it.

14: Ibid 15.

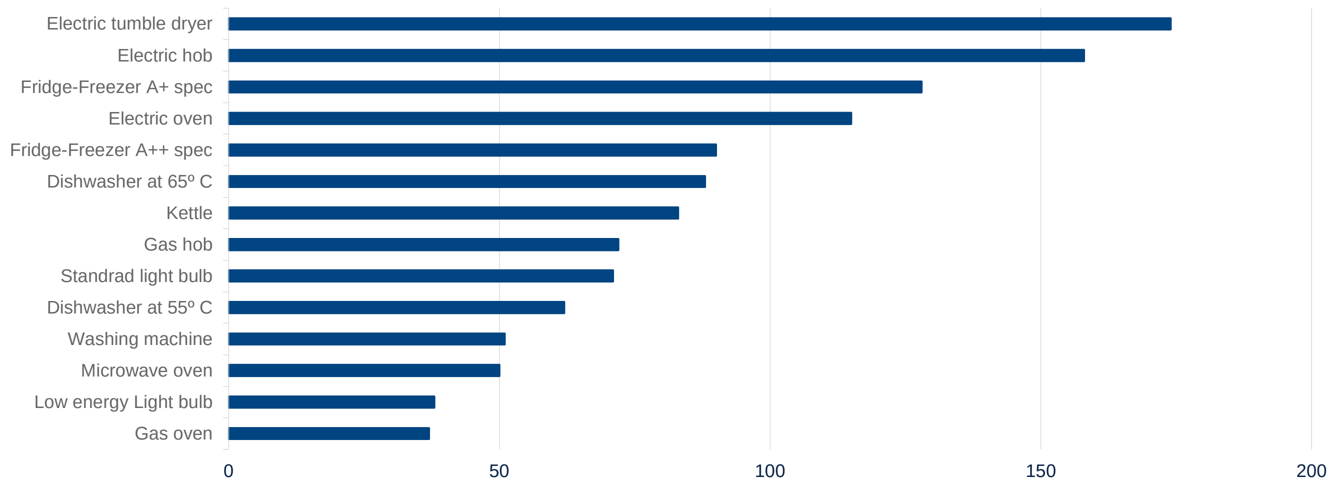
Another relevant source of **CO_2 Emissions is coming from Housing.[15] These CO_2 emissions include Scope 1 or direct emissions coming from steam, heat or cooling consumption and Scope 2 or indirect Emissions from electricity consumption.**

The accuracy of our Direct CO_2 emissions coming from steam, heat and cooling consumption will depend on how detailed are the utility invoices. Assuming one knows exactly the source of energy of let's say Heating (Electric, Natural Gas, Coal, Fuel Oil, Wood, Solar) and their prices one can estimate the CO_2 emissions coming from every heating source. The normal procedure here is to estimate individual models for different sources of energy heating. The main reason is that while the explanatory variables should be similar (floor area, urban-rural status, Household members, type of House, Age of House, heating Days) the sensitivity of every source of energy to these variables can be very different.

Focusing on the Electricity Scope 2 emissions, unless the family house is completely off the Electric grid or uses 100% renewable energy, every household house indirectly creates GHG emissions from electricity generation. However, the amount of emissions not only depends on how much energy we use, but also on how this electricity is produced and distributed from the power plant. In general terms, the more your electricity provider relies on fossil fuels (Oil, Gas, Carbon) to generate electricity, the more indirect emissions you create.

How can CO_2 emissions from electricity be calculated? Again, we can start with our electricity bills, which generally report the volume of kilowatt-hours (kWh) or multiples of kWh. Once the electricity usage in KW/h is detailed there are some possibilities to estimate the CO_2 Footprint if some additional information is provided. As in the transport case, heterogeneity is also present in electricity emissions and as observed in the graph there are substantial differences in the Kg/CO_2 per year coming from different appliances.

Figure 9. **UK HOME ELECTRIC APPLIANCES CO_2 EMISSIONS** (kg CO_2 PER YEAR)

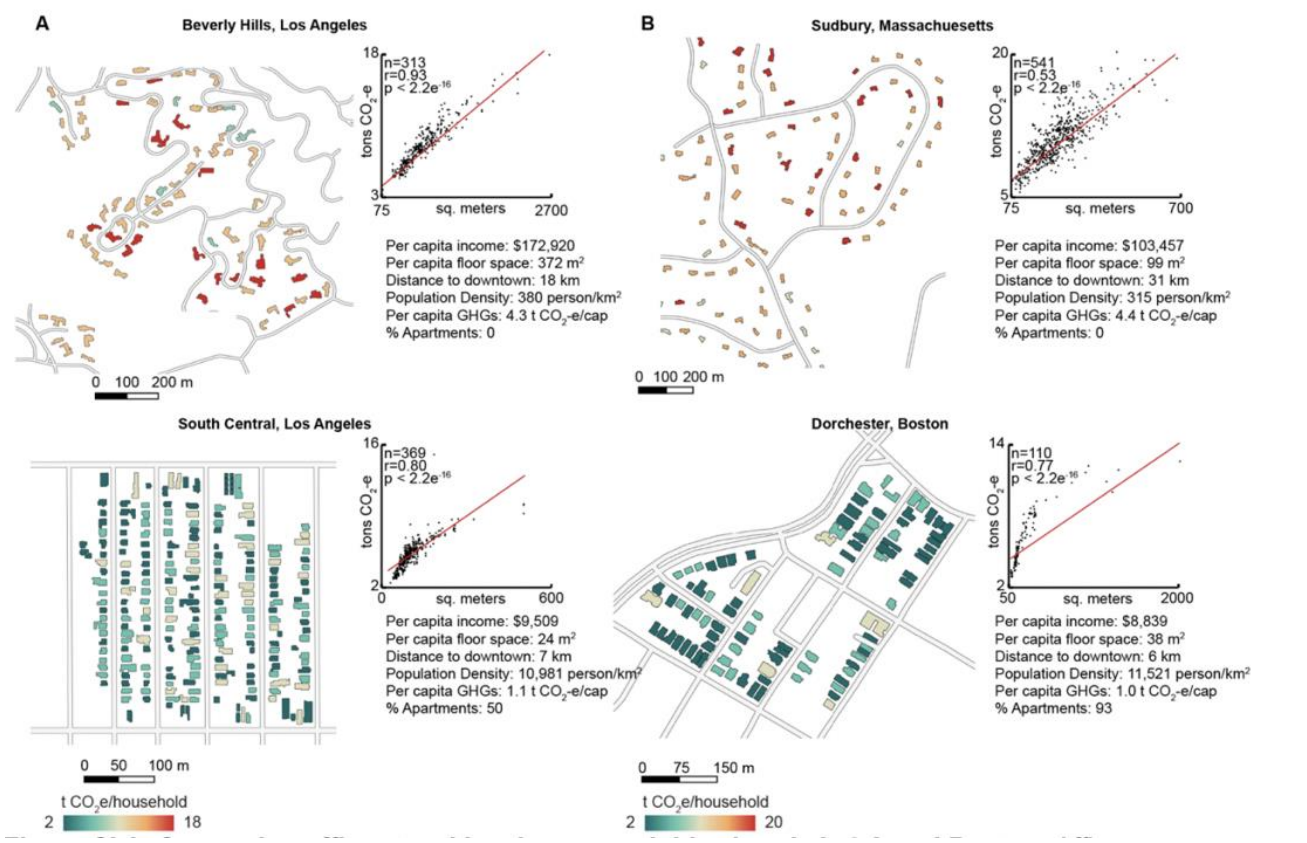


Source: Office for National Statistics (ONS)

15: Housing refers to the use of shelter service that a house provides. The carbon footprint of its construction should be allocated not to household consumption demand, but to the demand for investment in residential housing.

Rather than compute the different appliances one by one, CO_2 emissions can be estimated depending on a reduced number of variables such as per capita Income, per capita floor space, distance to downtown, population density and number of apartments (see Goldstein et al 2020 for the US case). According to this analysis, the CO_2 Emissions of residential areas in Boston and LA can be more than 4 times that of a family living in low-income neighborhoods of the same cities.

Figure 10. **COMPARING AFFLUENT AND LOW-INCOME NEIGHBORHOODS IN LA AND BOSTON**



Affluent neighborhoods (top) and low-income neighborhoods (bottom) in Los Angeles (A) and Boston (B). Scatterplots show relationship between household floor area and household GHGs.
Source: Poore and Nemecek (2018)

The latest example is coming from another important source of Emissions: **The Household CO_2 Emissions coming from Food consumption**. The Food Component is indirect Scope 3 emissions and depends on the characteristics of the production process of the food products (supply side) but also on the consumer habits (demand side).

According to the most exhaustive study to date on Food CO_2 emissions (Poore and Nemecek, 2018), these can change substantially depending on the characteristics of their different phases of the value chain of the product (land use, farm, animal feed, processing, transport, retail and packaging). For most foods, most GHG emissions result from land use change and processes at the farm stage (application of fertilizers.). Combined, land use and farm-stage emissions account for more than 80% of the footprint for most foods in the US. Transport is a small contributor to emissions (accounting for less than 10%) and most processes in the supply chain after the food leaves the farm – processing, transport, retail and packaging – mostly account for a small share of emissions.

For example, while we can find some stylized facts for different products (i.e establish an average of Kg CO_2/Kg of food), the changes in the value chain of processing of the same product can alter the estimates of the CO_2 Emissions among producers of the same product (near 50 times if they are substantial), creating substantial mitigation opportunities. On the demand side some factors can also influence the diet of households including culture, economic level, demographic, geographical, urban configuration and even the seasonality of the diet.

While it is very difficult to account for Supply factors, the estimations can be improved by introducing some of the demand relevant variables in the models. Thus, rather than simply convert (real terms) Household food Bills to some representative (usually by the National Food Expenditure Survey) basket, it can be inferred some of the heterogeneity in the diet of individuals. Introducing some key variables in the models such as level of income, household size, age, regions, season… will help to estimate more accurately different food baskets and, once applied the emission factors, their CO_2 emissions.

Summing Up, the Big Data information can be extremely useful to improve estimation of direct and indirect sources of CO_2 Emissions as Transport, Housing and Food. Sustainability "accounting" is in continuous development but if one thing is clear is that in measuring the CO_2 Emissions the "Devil is in the details'. In this sense, the high granularity of Big Data will improve the estimations and open the door to more accurate and personalized advice for each particular household about how to decarbonize its consumption.

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