ACCOUNTING FOR THE CARBON FOOTPRINT OF CAPITAL OWNERSHIP ADVANCES THE UNDERSTANDING OF EMISSION INEQUALITY

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Accounting for the carbon footprint of capital ownership advances the understanding of emission inequality

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Abstract

What is the carbon footprint of capital ownership and how are these emissions distributed across the population? We develop a framework that introduces a new perspective on individual carbon footprints: rather than including in carbon footprints only emissions related to individual consumption and lifestyle choices, we also account for emissions related to the assets and firms owned by individuals. Our framework includes three complementary footprint definitions, which account for asset-ownership to varying degrees, and ensure the results can be compared to the existing carbon inequality literature. The definitions are comprehensive and exclusive, encompassing all emissions associated with economic activity while avoiding double-counting. We then apply our framework and estimate emission inequality in France, Germany and the US, yielding the following results. First, taking into account emissions linked to ownership increases the carbon footprint of the wealthiest 10% of the population by a factor of 2-2.8 as compared to consumption-only estimates, depending on the country. Second, for this group, 75-80% of emissions stem from private asset ownership, not from direct energy consumption. Third, financial assets such as equity are found to emit, on average, 75-150 tCO2e per million dollars or euros. Forth, emissions from private ownership appear to be more concentrated than total wealth, with the top 10% of the population emitting 70-85% of all emissions linked to private asset ownership. These findings suggest that policies targeting the carbon content of individuals' assets and investments, rather than focusing only on individual consumption decisions, can be critical to reduce emissions. We explore potential policy options consistent with this perspective. Our work and the methodology we propose encourage further research on ownership-based footprints that can be compared across more countries, time periods, and subgroups, thereby advancing the development of distributional environmental accounts.

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1 Introduction

Understanding how greenhouse gas (GHG) emissions are distributed across populations is key for decarbonizing the economy. While international treaties focus on country-level responsibility and others have emphasized the role of firms or final consumers (Bruckner et al., 2022; Chancel & Piketty, 2015), a critical gap exists: the role of individuals as owners of polluting assets. Individuals can own, control, shape, and financially profit from production processes (in the energy sector and beyond) that release emissions into the atmosphere, even if their personal consumption and energy use has a relatively low carbon intensity. However, little is known about how these ownership-based emissions are distributed across the population.

Previous approaches to measuring individual carbon inequality largely focused on the role of individuals as final consumers. These studies have been crucial in revealing patterns in emission inequality. For example, consumption-based footprints have the advantage that they can account for emissions induced in some parts of the world (e.g., in industrializing countries) to maintain living standards in other regions (e.g., in industrialized countries). However, these approaches typically include all production emissions into the carbon footprint of final consumers – although consumers can lack full agency, information or alternatives regarding the products they buy, and the emissions associated with them. Investigating more thoroughly the distribution of the ownership of polluting firms and associated ownership-based footprints therefore stands out as a critical complementary topic in the context of decarbonization.

The purpose of this paper is threefold. First, we outline three complementary approaches to defining individual carbon emissions that account for ownership-based emissions to varying degrees.[1] The novelty is to develop definitions that systematically incorporate the production footprint of firms into the individual carbon footprint of their owners and consumers. By doing so, we propose to widen what is commonly understood as the individual carbon footprint. The three proposed carbon footprint definitions are constructed so that the resulting estimates are consistent with macroeconomic aggregates and avoid double-counting of emissions. Second, we apply the three definitions and produce new carbon inequality estimates for France, Germany,

[1]We include all major greenhouse gas emissions in our empirical work so that our discussion of ”carbon footprints” should be understood more comprehensively as referring to greenhouse gas emissions in terms of carbon dioxide equivalent.

and the United States, using the best available data sources to our knowledge. These countries, with their relatively high per-capita emissions, provide three distinct contexts for our analysis with varied energy mixes and levels of economic inequality. Third, we derive a set of new stylized facts about emissions inequality, which we discuss in the context of environmental and tax policy.

The three carbon footprint definitions developed and implemented in this paper are the following. In the *ownership-based footprint*, emissions from production sectors (e.g. emissions from a cement factory) are attributed to the owners of firms. In the *consumption-based footprint*, emissions from production sectors are attributed to final consumers (e.g. individuals who purchase cement or goods which contain cement). In the *mixed footprint*, emissions from production sectors are attributed to consumers, except for emissions related to investment (capital formation), which are attributed to firm owners. In the three approaches, direct emissions of households (emissions from private car use, or from home heating, for instance), are attributed to the households which release those emissions. The *consumption-based footprint* corresponds to how the individual carbon footprint has been understood traditionally in the literature.

Our key findings are the following. First, we find that carbon inequalities are notable in all three definitions of the carbon footprint (*consumption-based*, *mixed* and *ownership-based*), although important differences stand out. Fully accounting for emissions from asset ownership at least doubles the emission share of the top 10% as compared to *consumption-based* accounting (see Figure 1). For example, in the *consumption-based* approach, the wealthiest 10% in the US account for nearly 24% of emissions of the country, vs. 50% in the *ownership-based* approach (and 32% in the *mixed-based* approach). The average individual carbon footprint of the top 10%, measured in tonnes of CO_2 equivalent (tCO_2e) per year, increases by a factor of 2–2.8 when we account for ownership-based emissions. Second, our estimates indicate that, in the *ownership-based* approach, the majority of emissions (i.e., 75–80%) for the wealthiest 10% of the population originate from the assets they own, rather than their direct energy consumption. Owning equity worth a million euros (in France and Germany) or dollars (in the United States) is associated with 75–150 tCO_2e, compared to the average per capita footprint which ranges from 8–20 tCO_2e in the three countries. Third, we find that emissions linked to private asset ownership appear to be even more concentrated than wealth itself, with the top 10% of the population emitting 70–85% of the emissions related to private ownership (see Figure 1). Assets predominantly owned at the very top of the distribution (such as equity or business assets) appear to have a higher average emission intensity per euro or dollar owned than the types of assets predominantly owned in the middle or the bottom of the distribution (such as deposits, housing or pension assets).[2] Fourth, leaving potential behavioral responses aside, we show that a tax of 150 euros/dollars per tCO_2e levied on the carbon content of assets has the potential to be significantly more progressive than an equivalent tax on the carbon content of consumption.

Our results contribute to the existing literature in the following ways. First, we develop a general framework to define and estimate individual carbon footprints that accounts for asset ownership, in a way that is fully consistent with satellite environmental accounts as well as distributional national accounts. Our concepts and methods complement the large body of work on the measurement of income and wealth inequality (see Blanchet et al., 2020) via the conceptualization of *distributional* environmental accounts. Second, our approach departs from a relatively large literature on individual carbon inequality which focuses on consumption-based emissions (Chancel & Piketty, 2015; Golley & Meng, 2012; Weber & Matthews, 2008). Our framework makes it possible to measure the emissions of individual consumers, but also of owners and investors; it complements a small number of recent studies which examine emissions inequality associated with investment or capital income (Chancel, 2022; Starr et al., 2023b). Third, we provide original data on the carbon content of asset classes, which are consistent with macroeconomic totals. We hereby hope to open a new area of systematic inquiry, at a time when very little information exists on the carbon content of individual asset portfolios across the wealth distribution. Finally, the datasets we build allow us to discuss the potential of novel climate policy tools, namely taxes levied on the carbon content of assets held at the individual level. Our paper contributes a new perspective to the literature on the incidence of carbon taxes (Sterner, 2012; Williams et al., 2015), which may inform future studies extending optimal taxation theory in this novel direction (Diamond & Mirrlees, 1971).

The remainder of the paper is structured as follows: Section 2 positions our work within the broader emissions and inequality research. Section 3 details our conceptual framework, data sources and methodology. Section 4 shares our aggregate findings and examines inequalities in carbon footprints between individuals based on the new approaches. Section 5 reflects on our findings and

[2] Assets that do not give raise to firm ownership rights (such as deposits) do not add to the individual carbon footprint in our *ownership-based* footprint by definition in order to comply with exclusivity principles.

discusses policy implications, and Section 6 offers concluding remarks.

– Insert Figure 1 –

2 Related literature

The concept of the *carbon footprint* goes back to the early 2000s and its presence in environmental research has grown rapidly since then.[3] It is commonly defined as the "measure of the exclusive total amount of emissions of carbon dioxide that is directly and indirectly caused by an activity or is accumulated over the life-cycle stages of a product" (IPCC, 2022; Wiedmann & Minx, 2008). Effective carbon accounting requires *comprehensiveness*, capturing both direct and indirect emissions, and *exclusivity*, avoiding double-counting. Carbon footprints have been calculated for a variety of actors, including individuals (see next paragraph), geographical regions (Asane-Otoo, 2015), multinational enterprises (Ortiz et al., 2020), industry sectors (Belkhir & Elmeligi, 2019; Griffin & Heede, 2017; Lenzen et al., 2018; Onat & Kucukvar, 2020; Z. Zhang et al., 2023), financial portfolios (Boermans & Galema, 2019; Elderson & Schnabel, 2023; Jindal et al., 2024), and specific products or processes (de Vries et al., 2022; Farzaneh & Jung, 2023). The definition provided by the IPCC does not limit the scope of entities that may be analyzed in terms of their carbon footprint.

Consumption-based accounting has emerged as the dominant method for defining individual carbon footprints. Under such an approach, an individual's footprint is comprised of the emissions released during both the production and use of goods and services consumed by the same person. The underlying assumption is that individuals express preferences through consumption choices, which signal producers what to manufacture and in what quantity, thereby guiding resource allocation in the economy. All environmental pollution is assumed to ultimately serve the final consumer. At the country-level, consumption approaches have the important advantage that they can account for "outsourced" emissions (Davis & Caldeira, 2010; Munksgaard et al., 2009; G. P. Peters, 2008; Rothman, 1998). Emissions may be released in low-income economies but ultimately serve the consumption and lifestyles of individuals in high-income countries, for example (Bruckner et al., 2023; Lenzen & Murray, 2010; Rothman, 1998). The gradual shift within the

[3] The number of scholarly articles published using the concept has grown from around 1 000 in 2010 to around 13 000 in 2022, according to Scopus, a citation database. We provide a graphical representation of this trend in SI 2, Figure S2.8.

Intergovernmental Panel on Climate Change (IPCC) towards monitoring and discussing both territorial and consumption-based emissions has garnered praise from several countries, in particular in the Global South.

A large literature has studied the distribution of carbon footprints across and within countries based on consumption-based carbon accounting methods. The methodology used most often relies on multi-regional input-output tables and the Leontief inverse (Leontief, 1970) to account for emissions that are released abroad to serve domestic consumption, which are combined with environmental pollution data to obtain emission-per-currency-unit coefficients of various economic production sectors. The coefficients are then multiplied with the individual or household expenditure on different consumption items, obtained from household budget surveys (Bruckner et al., 2022; Büchs & Schnepf, 2013; Druckman & Jackson, 2008; Irfany & Klasen, 2016; Isaksen & Narbel, 2017; Kerkhof et al., 2009; Lenzen et al., 2006; Nässén, 2014; G. Peters et al., 2006; Pottier, 2022; Sommer & Kratena, 2017; Starr et al., 2023a; Theine et al., 2022; Weber & Matthews, 2008; Wiedenhofer et al., 2017). These studies have been able to uncover large inequalities in consumption-based emission footprints within and across countries. A key finding has been that, over the last decades, inequalities in emissions *within* countries have become more important, while the role of inequalities *between* countries has declined (Chancel & Piketty, 2015).[4]

Incorporating all emissions of the production system into the individual footprint of final consumers can potentially overstate the impact individual consumption choices have on the overall functioning of the economy. It would require not only that consumers express their preferences freely on the market thanks to perfect information, but also that consumers have the power to steer producers towards producing less carbon-intensive goods and services through changing their consumption behavior in all sectors of the economy. However, individual consumers often lack information and are usually constrained by the goods offered at any given point in time, and the capital stock installed in the country where production takes place. Market failures or political economy dynamics can result in situations in which consumers do not have a choice but to purchase carbon-intensive goods, hence calling into question individual consumption-based frameworks (Lenzen & Murray, 2010).

[4] Chancel (2022) reaches similar conclusions in a framework which departs from the consumption-based approach, although not to the extent proposed in this paper.

Different approaches have been proposed to distribute emissions between firms and final consumers based on the value-added (Lenzen et al., 2007), attribution shares (Ferng, 2003), economic surplus (Jakob et al., 2021) or emission reduction pathways (Y. Zhang et al., 2023). However, to the best of our knowledge, these approaches have not been used to expand the concept of the *individual* footprint by subsequently including (some) firm emissions in the individual footprint of firm owners. It also remains challenging for investors to calculate their own footprint following these methodologies.

More closely related to our work are newer methods of *control-based* carbon accounting (López et al., 2014; Ortiz et al., 2020). These approaches account for the ownership structure of multinational firms by including the emissions of domestic and foreign subsidiaries in the footprint of the "controlling" parent company. The *ownership-based* definition we propose in this paper can be viewed as a conceptual extension of these methods as we propose to include the emissions of firms, and their subsidiaries, into the footprint of owner individuals. *Income-based* individual carbon accounting is yet another alternative strategy to distribute emissions between individuals that moves beyond a purely consumption-based carbon footprint definition (Lenzen & Murray, 2010; Pottier & Le Treut, 2023; Starr et al., 2023b). Rather than focusing on the distinction between consumers and producers, income-based carbon accounting tries to link emissions to the income streams received by individuals. The emissions released by the production system would be associated with (i) the labor income of workers or (ii) the capital income of owners according to the respective shares of the two production factors in total income. We weigh potential advantages and disadvantages of our *mixed* and *ownership-based* approaches over the *income-based* approach when we discuss our results.[5]

Our work is related to initiatives by the financial sector and the international community aimed at developing methodologies to estimate the carbon emissions linked to investment portfolios and asset classes (GHG Protocol, 2004; PCAF, 2022). However, existing approaches have important shortcomings (Janssen et al., 2022; Popescu et al., 2021), as they do not necessarily result in estimates that are consistent with economic and environmental aggregates at the macro-level (e.g., avoid double counting while also capturing all emissions) and hence fail to pass the *exclusivity*

[5] In short, we view these approaches as complementary; the three definitions for the individual carbon footprint we introduce could be extended to also include an income-based perspective.

criterion defined above.[6] Portfolio carbon accounting methods have therefore not been used to study inequalities in *ownership-based* emissions across the population, to the best of our knowledge.

Finally, we contribute with our work towards the conceptualization of *distributional* environmental accounts at the national level. Important progress has been made regarding income and wealth distributional accounting in the context of national accounts, which has been taken up by national statistical agencies to expand their statistical toolkit (Alvaredo et al., 2018; Blanchet et al., 2020; Chancel & Piketty, 2019; Garbinti et al., 2020; Piketty et al., 2018, 2019). However, the systematic study of environmental inequality within similar frameworks remains in its infancy (Chancel, 2020). This is why we follow strictly the exclusivity principle in the three carbon footprint definitions so that they can be applied at the national (or global) level and show macro-micro consistency regarding income, wealth and emissions. Such a framework can help answer questions about which income and wealth groups in the economy tend to have a more carbon-intensive consumption, savings and investment behavior. Our estimates demonstrate the potential of distributional emission accounts, but we also highlight that better (and timelier) data on firm-level emissions and individual-level asset ownership would be necessary in the three countries under study to leverage the full potential of distributional environmental accounts.

3 Data sources and methodology

3.1 Conceptual framework: three carbon footprint definitions

Our general framework encompasses three distinct definitions: ownership-based, consumption-based, and mixed footprints. Each definition consists of a strategy for allocating emissions to individuals in a comprehensive and exclusive way. The definitions are meant to demonstrate, once implemented for a country or group of individuals, how individual carbon footprints change if emissions linked to assets ownership are accounted for. The consumption-based footprint is included primarily to ensure comparability with the existing literature.[7]

[6] This stems from the different goal these initiatives are perusing, i.e. trying to capture all emissions somehow linked to an asset, rather than distributing all emissions in the economy only once to individuals. For example, firm emissions in these approaches may be distributed to an individual holding deposits in a bank that provides a loan to a polluting firm, while the same firm's emissions are also attributed to shareholders.

[7] Figures S1.2 and S1.3 in SI 1 provide schematic illustrations representing the intuition behind the three approaches visually.

Ownership-based footprint. The ownership-based footprint definition attributes so-called *scope 1* emissions of firms to the owners of these firms.[8] In other words: the definition assumes that owning 100% of a firm's capital stock for one year adds to an individual's footprint 100% of emissions directly released by the firm's production activity in the same year. It serves as the corresponding polar case to consumption-based footprints which include all emissions into the footprint of final consumers. Individuals can own a firm's capital stock either directly (e.g., self-employed businesses) or indirectly when they own the capital stock of firms through holding corporate equity. If an individual does not own the entirety of a firm, emissions are distributed according to the share of the capital stock owned by final owner individuals.[9] For most incorporated businesses, this share corresponds to the share of equity owned by the individual investor among all outstanding equity. If the capital stock or equity of a firm is owned by another firm, emissions would be traced to the ultimate owner-individuals based on the share of capital stock or equity owned at each stage of the ownership tree, in an ideal implementation of the approach. Note that ownership-based footprints deviate from a purely territorial view on emissions (as do consumption-based footprints). For example, emissions of firms that produce abroad are included in the footprint of the domestic owners of these firms.

The ownership-based footprint we propose follows a strict ownership perspective: it does not assign any emissions to holders of purely financial assets that do not give rise to the direct or indirect ownership of a firm's capital stock (such as corporate bonds, bank deposits and other fixed income assets). We do so to comply with the *exclusivity* condition, which must be respected to distribute all emissions to individuals and compare individual emission footprints without double counting. An alternative version of the ownership-based footprint could reallocate energy-related emissions to the owners of firms who use the energy as a production input. However, it would imply that these emissions do not feature in the footprint of owners of energy companies.

Some emissions are not released by firms' activities, but by households themselves (via their

[8]As per the US Environment Protection Agency's GHG Inventory Guidance: "*Scope 1* emissions are direct greenhouse (GHG) emissions that occur from sources that are controlled or owned by an organization (e.g., emissions associated with fuel combustion in boilers, furnaces, vehicles). *Scope 2* emissions are indirect GHG emissions associated with the purchase of electricity, steam, heat, or cooling. [...] *Scope 3* emissions are the result of activities from assets not owned or controlled by the reporting organization, but that the organization indirectly affects in its value chain." We refer readers to Blanchet et al. (2020) and the supplementary material (SI 1, A.5, B.1 and B.7) for more detailed definitions and explanations of the national accounting concepts used in the paper.

[9]In certain contexts, large shareholders may have more voting rights per share than small shareholders. In this case, ownership-based footprints tend to underestimate the weight of large shareholders in firms' decision-making processes.

direct transport and heating needs, the "scope 1" emissions of households). We propose to attribute these emissions to individuals, based on their actual energy consumption, in all three carbon footprint definitions, including in the ownership-based footprint. We implement the same strategy for private electricity emissions to ensure neutrality between households choosing electricity-based and fossil fuel-based vehicles or heating devices.[10] Such a treatment of private household emissions is consistent with an ownership-based footprint to the extent that individuals own the technologies associated with direct energy emissions. In reality, however, individuals (and in particular those at the bottom of the income distribution) may rent their home or the energy devices they use in their daily lives. We therefore also present results for an alternative version of the ownership-based footprint that attributes heating emissions to homeowners instead of tenants.

A certain share of the polluting production activity is fully or partially owned by the government. The ownership-based approach attributes these emissions to the government. Because we want to study the distribution of the totality of emissions at the individual level, we include these government emissions in individual footprints. Several strategies can be thought of to distribute government emissions to individuals. Two intuitive approaches are to distribute government emissions equally among the population as a lump-sum amount (flat distribution) or distribute them based on income or consumption expenditure. Our preferred approach is a combination of these two approaches, i.e. we opt for a flat distribution for government emissions linked to education and health, and for an income-based distribution in other cases. We detail the approach in the methodology section and in the supplementary material (SI 1, C.4), and we also present results under a number of alternative assignment strategies regarding government emissions (including a specification that excludes government emissions entirely from individual footprints).

When we refer to *private ownership* footprints or *private ownership* emissions, we only include emissions linked to the assets that are privately owned by individuals (i.e., we exclude government ownership emissions and direct household emissions). When we refer to *ownership-based* footprints or *ownership-based* emissions without a qualifier, government and direct household emissions are

[10] Neutrality means that our approach includes, for example, the emissions from the use of private cars in direct household emissions, regardless of whether vehicles are powered by fossil fuels or electricity (i.e., the GHG emissions released to generate electricity are part of direct household emissions for users of electric cars). We also chose this approach to anticipate the growing role of electricity-based heating and transportation over time. Choosing an alternative definition in which private electricity emissions are included in the footprint of power generation plant owners would increase top 10% ownership-based emission shares from 48.6% to 49.9% (France), 40.4% to 44.1% (Germany), 50.5% to 55.1% (US). We present detailed results under this alternative distribution method in Table S1.3 in SI 1.

included in order to distribute the totality of national emissions to individuals, which ensures comparability with the other carbon footprint definitions.

Mixed footprint. The mixed footprint attributes capital formation emissions (i.e., emissions linked to investment activity) to firm owners, and all other emissions to final consumers. The idea behind the approach can be summarized as follows: If production is used to expand or replace the capital stock, the associated emissions are allocated to capital owners. If, on the other hand, the production process serves final consumption, these emissions are attributed to final consumers. We refer to a *mixed* approach because the definition would be located between the two other definitions, which either distribute all emissions to firm owners or final consumers.[11]

The mixed footprint allocates emissions between consumers and the owners of firms using categories and concepts available in national accounts, i.e. capital formation vs. final consumption. This shared attribution method therefore explicitly recognizes the role of individuals as both consumers and asset owners. The mixed footprint is demand-centered, which sets it apart from the ownership-based footprint. Only emissions released by a firm through its own production activity are attributed to the owner in the ownership-based footprint. Emissions attributed to owners in the mixed approach include those emissions necessary to produce the investment goods *demanded* by the firm in a given year (whether they are self-produced or not and whether they are produced by other firms domestically or abroad). Likewise, if a resident consumer purchases an item that has been produced abroad, its mixed footprint includes the foreign emissions released in the production process of the item as per the demand perspective of the definition.

We suggest including gross rather than net capital formation emissions in the mixed footprint of investors.[12] National accounts distinguish gross capital formation from household final consumption; thus, conceptually, the replacement of depreciated capital is not intermediary consumption. The carbon intensity of replacing depreciated capital can vary – replacement machines can be produced with different amounts of coal, for instance – similarly to the production of new investment goods.

Implementing the mixed carbon footprint at the national level requires a multi-regional

[11]Outside the realm of this paper the approach could also be referred to as *final demand-based* footprint if compared to other methods of shared attribution.

[12]Net capital formation encompasses the construction of new buildings and machines used in production processes while gross capital formation includes, in addition to net capital formation, the replacement of existing machines and other fixed assets. For instance, in the US, net investment accounts for approximately 20-30% of gross investment.

input-output model, as we discuss in the methodology section. In such a model, the emissions linked to gross fixed capital formation can be separated from the emission linked to final household and government consumption. We propose to distribute government investment, consumption emissions, and direct household emissions (such as those from heating or private vehicles) to individuals using the same conventions as in the ownership-based footprint.

Consumption-based footprint. The consumption-based approach attributes all direct and indirect emissions to final consumers' footprints, including investment-related emissions of firms that produce goods and services for final consumption in year t+1. This approach has been followed in most of the literature to track the inequality in emission footprints at the individual level.[13] We include consumption-based footprints in our framework to compare ownership-based and mixed footprints to consumption-based footprints and to recognize the complementarity of the approaches.

The aggregate emissions of all individuals in a country will not be the same in the three carbon footprint definitions. Total emissions will be identical using the mixed or consumption-based footprint,[14] but calculations based on ownership-based footprints will result in a different emission aggregate. This is due to two reasons: First, the treatment of cross-border investment, i.e. the ownership-based approach includes the emissions of foreign firms owned by residents in their footprint while emissions of resident firms owned by foreign residents are not part of total national emissions. Second, the treatment of consumption-related emissions in case consumers are not located in the same country as producers. Both the mixed and the consumption-based approach account for the emissions released abroad to satisfy domestic consumption (and exclude emissions released domestically that serve foreign consumption). The ownership-based footprint, on the other hand, only includes the emissions directly released by firms owned by resident institutional sectors.

[13] Methods have been proposed to enhance the consumption-based approach by treating the footprint embodied in capital goods similarly to other intermediate inputs, i.e. redirecting the emissions embedded in capital goods across countries to the final consumers of the goods and services that rely on the capital input (Södersten et al., 2018). The consumption-based approach we use to benchmark our result is more simplified and implicitly assumes that investment in domestically owned firms ultimately serves domestic consumption.

[14] The way we implement the consumption-based footprint assumes that investment of domestically owned firms ultimately serves domestic consumption, which explains why total national emissions are the same using either the mixed or the consumption-based footprint. Alternatively, we could assume that all investment of resident firms (regardless of ownership) ultimately serves domestic final consumption.

3.2 Data sources

We now introduce the data sources we use to implement the three definitions in France, Germany (2017) and the United States (2019). The type of data sources and modifications we make to the data can serve as a reference for future work in other countries.[15]

Wealth data. We rely on the third wave of the Household Finance and Consumption survey (HFCS) to estimate the breakdown of assets classes owned along the wealth distribution in France and Germany. For the United States, we work with the micro-files released as part of US distributional national accounts (DINA) project (Piketty et al., 2018). These micro-files are constructed by combining tax data, survey data and national accounts data. Wealth surveys have a series of well-known disadvantages which imply they are not able to fully capture wealth dynamics, especially at the very top of the distribution, despite recent improvements and the over-sampling of the rich. There is a large literature on correcting top tails of surveys. We opt for a re-weighting approach, using the wealth distribution recorded in the World Inequality Database (WID) as a reference point for the top of the wealth distribution.[16] These wealth estimates are based on studies that combine several data sources for France (Garbinti et al., 2020), Germany (Albers et al., 2022) and the United States (Piketty et al., 2018). Because wealth is recorded at the household level in the HFCS, we individualize survey wealth using information about the composition of households available in the wealth survey. We finally match net wealth and the wealth components in the survey to national accounting concepts and re-scale the aggregate values so that total wealth in the survey matches wealth recorded in national accounts. This assumes that, within each asset category, there is a constant share of wealth under-reporting. The DINA micro-files we use for the United States do not require any additional adjustment in that regard.

Macroeconomic capital stock and balance sheet data. To link emissions first to industries and then to the capital stock owned by each institutional sector, we rely on national accounts data from Eurostat (Germany and France) and the OECD (United States). Three datasets are necessary for each country under study: (i) the stock of fixed assets by industry and year, (ii) the stock of fixed

[15]The supplementary material includes a table that specifies the exact names of the data series that are used (SI 1, Table S1.15).

[16]We adjust the survey weights so that the distribution of net wealth in the survey follows the ”traced out” distribution recorded for the same year in the WID. This assumes that the survey is able to deliver correct information about the breakdown of assets owned, but it does not correctly capture the position of the individual in the distribution. We describe the approach in more detail in the supplementary material (SI 1, A.3).

assets owned by each institutional sector (households, government, corporations, rest of the world) in a year and (iii) the stock of financial assets and liabilities by institutional sector and year. We use capital stocks at current replacement cost (net of depreciation) because it corresponds more closely to how financial assets, for which only the market value exists, are recorded in the wealth survey.

Emissions data. Greenhouse gas emissions data by industry are sourced from air emission accounts released by Eurostat for France and Germany. These accounts include the annual flow of greenhouse gas emissions, and they are consistent with national accounting concepts (e.g., they are based on the residency principle). We use the amount of total direct emissions released by each industry (scope 1). Emission accounts also include, separately, the direct emissions of the household sector (e.g., through burning fuels to drive a private car, heating the apartment etc.). For the US, we use air emission accounts published by the OECD, which record emissions by industry, although at a less granular level. We need additional data sources to single out private households' electricity consumption emissions. We use information from the national environmental economic accounts (Germany), the national energy balance (France) and the monthly energy review tables (United States). More details about these data sources are provided in the supplementary material (SI 1, B.6).

Environmentally extended input-output tables. Mixed and consumption-based footprints require calculating the emissions required to satisfy final demand in a country, some of which may be released abroad. We rely on a carbon footprint dataset released by Eurostat as part of the FIGARO (Full International and Global Accounts for Research in input-Output) project in March 2023. The dataset builds upon Eurostat inter-country supply-use and input-output tables, and a vector of the flow of emissions by industry sourced from air emission accounts.[17] It then calculates the carbon footprint linked to final demand categories (household consumption, government consumption, gross fixed capital formation) in 45 countries for the 2010-2020 period. France, Germany and the United States are included in the dataset. The emission footprints in the FIGARO dataset are the result of applying a Leontief model to the inter-country input-output tables. We detail the steps to calculate demand-related emissions using the Leontief model, input-output tables, and the vector of emissions by industry in the supplementary material (SI 1, B.10).

[17]We re-scale CO_2 emissions to GHG emissions using a country-year-industry conversion factor obtained from comparing CO_2 and GHG emissions in air emission accounts. We provide details in SI 1, B.11.

Emission inequality data from the literature. We rely on the latest country-specific estimates we are able to locate in the academic literature for the distribution of direct household emissions and consumption-related emissions (Hardadi et al., 2021; Malliet, 2020; Starr et al., 2023a). These studies use household expenditure surveys and environmentally extended input-output tables. They combine the distribution of expenditure (linked to specific product categories) with the direct and indirect emissions that were release during the production of the goods and services consumed. We present each of the three papers and the underlying data in more detail in the supplementary material (SI 1, C.3).

Cross-border investment data. We need information about the breakdown and emission intensity of cross-border investment by country to estimate the emission content of foreign investment. The EU-Finflows database records bilateral financial investment stocks and flows between 80 major countries, including European Union members, the United Kingdom, China, and the United States. We use the April 2020 release of the database, which covers the 2001-2018 time period. We also use information about the carbon intensity of 200 economies from the EU-EDGAR database (emissions released per 1 000 US dollars in GDP). The 2022 version of the database is used to calculate the relative emission intensity of countries.

3.3 Methodology

We now explain how we use the data sources to implement the three conceptual carbon footprint definitions and distribute aggregate greenhouse gas emissions to individuals. We start by preparing extended macroeconomic environmental accounts.[18] These environmental accounts record aggregate emissions of each industry, asset class and institutional sector. The novelty here is that we relate emissions to the capital stock owned by institutional sectors such as households, the government and the rest of the world. We then distribute aggregate emissions in the macroeconomic environmental accounts to individuals, using information about assets owned from the wealth survey and from distributional national accounts.

[18]Compiling macroeconomic or aggregate environmental accounts is a necessary first step to estimate the distribution of ownership-based and mixed footprints for an entire country. For one individual, the footprint could be calculated without aggregate environmental accounts if we had access to a list of assets the person owns and detailed information about each firm owned by the individual, including the emissions released, the capital stock deployed, investment activity and the structure of the supply chain. We start from aggregate environmental accounts by industry because this type of information is not available at the economy-wide level for the three countries we study.

3.3.1 Step 1: Extended aggregate environmental and economic accounts

We prepare two versions of extended environmental accounts, one that corresponds to the ownership-based footprint and one that corresponds to the mixed footprint. We start by explaining how to construct the extended environmental accounts for France, Germany and the United States in the ownership-based approach and then show how to move from ownership-based footprints to mixed footprints. Figure 2 illustrates the attribution of emissions to institutional sectors schematically.

– Insert Figure 2 –

Linking industry-level emissions to the capital stock. Annual scope 1 emissions by industry are available in air emission accounts. The only change we make is to remove emissions linked to private electricity consumption from energy sector emissions using the additional data sources introduced earlier. Other types of direct household emissions (burning of fuel to drive private cars or heat apartments) are already separated from industry emissions in air emission accounts. To assign emissions by industry from air emission accounts to capital stock assets, our procedure asks the following questions, in that order: (i) In which industries is a certain type of capital used? (ii) What is the share of the given capital type within each of these industries? (iii) How much of total emissions can be attributed to these industries? For illustrative purposes, imagine IT equipment is only used in two low-carbon industries and makes up 25% of all capital used in the first and 50% of capital used in the second industry. Each of the two industries generates 1% of total emissions. That would make owning 100% of the IT equipment capital in the economy equivalent to generating 50% x 1% + 25% x 1% = 0.75% of national emissions (in the ownership-based approach). We can make this type of attribution for 21 industries and 5 asset categories in France and Germany. In the United States, the attribution can be made, due to the lower granularity in the underlying source data, for 8 industries and 4 asset categories.[19]

Linking the capital stock to institutional sectors. We now have a table recording the total emissions associated with owning 100% of each of the capital stock components in the country. We

[19]Note that we decide to include the value of land into the total value of dwellings and other buildings. This is because the value of land is part of the value of housing and building assets in the wealth survey. We assign the values proportionally to the categories. More details are provided in the supplementary material (SI 1, A.4 and B.2). The asset categories used for each country are listed in SI 1, B.7 and SI 2, Tables S2.4-S2.6.

then determine whether these capital stock assets (and the associated emissions) are owned by the household sector, the government or corporations.[20] If the household sector owns 10% of business buildings and structures, it is assigned 10% of the emissions allocated to business buildings and structures in the previous step. The attribution exercise requires a table recording the non-financial assets owned by institutional sector. More details and tables that illustrate how we calculate the share of equity owned by each institutional sector and redistribute emissions of the corporate sector to other sectors (including to foreign investors) are provided in the supplementary material (SI 1, B.8).

Finding a proxy for emissions linked to foreign investment. What is missing from the previous exercise is a proxy for emissions linked to the foreign corporations owned by domestic households, by the government or pension and life insurance funds. Total foreign equity owned by resident investors is recorded in financial balance sheets as the equity liability of the *rest of the world* sector. Absent available data, we assume that foreign equity is distributed among the household, government and pension and life insurance sector in the same way as domestic equity.[21] We then calculate the amount of foreign equity owned by each sector and the associated emissions if foreign equity had the same carbon intensity as domestic equity (step 1). Using the relative carbon intensity of foreign economies (from EU-EDGAR) and the foreign investment stocks by country (from EU-Finflows) we then calculate the average carbon intensity of foreign equity relative to domestic equity (step 2). Finally, we adjust the estimate obtained in step 1 by the factor obtained in step 2 and use the result as a proxy for the total emissions linked to the foreign equity owned by each of the institutional sectors. More details about these calculations are provided in the supplementary material (SI 1, B.9).

Producing aggregate estimates using mixed footprints. To calculate mixed footprints by institutional sector, we have to swap the ”emission by industry” data we use. Instead of the air emission accounts (which record total scope 1 emissions by industry), we use ”emissions by

[20]The rest of the world does not own any non-financial assets by construction in national accounts. Instead, it can only own *financial* assets which can correspond to an indirect ownership of domestic capital. Note also that we cannot distinguish between households and the non-profit sector in the wealth survey, which is why we combine both. The (non-financial) capital share of the non-profit sector is small, and it adds less than 1% to the capital stock owned by the household sector.

[21]We perform robustness checks for two extreme assumptions, namely that all foreign equity is either owned by the household sector or by the government sector. Assuming all foreign equity is owned by the household sector increases the top 10% emission shares in the ownership-based approach from 48.6% to 50.8% (France), 40.4% to 47.0% (Germany) and 50.5% to 51.5% (US). We present detailed results under the two polar alternative distribution methods in SI 1, Table S1.4.

industry" data sourced from environmentally extended input-output tables. Our preferred data source, the EU-FIGARO dataset, enables us to construct a dataset recording emissions in tCO_2e linked to the investment activity of each industry. We then re-apply the procedure described for ownership-based footprints, but using these (lower) emission total. The resulting aggregate emissions by carbon footprint definition for the three countries are presented in Figure 3.

– Insert Figure 3 –

3.3.2 Step 2: Distributional environmental accounts

We now proceed and explain how we distribute the aggregate emissions by institutional sector to individuals based on wealth and ownership data.

Distributing private ownership emissions to individuals. The following four asset categories in the wealth data are relevant when it comes to distributing aggregate ownership emissions of the household sector to individuals: (i) housing, (ii) directly owned business assets, (iii) pension and life insurance assets and (iv) equity.[22] Other assets do not contribute to the carbon footprint in the definitions we use. For each asset type and individual, we calculate the share of the asset owned by the individual among all assets of the same type owned in the country. We then allocate the corresponding share of household-sector emissions avail- able in the aggregate environmental accounts to the individual. We do not have access to a more granular breakdown of assets in the wealth data (e.g., information about the precise firms owned by an individual) so that we remain restricted to working with averages by asset class. The distribution process is the same for calculating ownership-based and mixed footprints, but we use different emission aggregates as calculated in the previous step. No emissions are distributed based on asset ownership when calculating consumption-based footprints.

Distributing direct household and consumption-related emissions to individuals. To distribute these types of emissions to individuals (the national totals were calculated as part of the extended aggregate environmental accounts), we rely on the most recent country-level estimates we can find in the literature (Hardadi et al., 2021; Malliet, 2020; Starr et al., 2023a). The papers we use provide separate estimates for the distribution of direct household emissions (including electricity)

[22]See SI 1, A.4 for a detailed guide about how these concepts can be derived from the survey variables.

and of emissions linked to consumption, which we use to distribute the respective emissions among individuals. We trace out the entire distribution based on the tabulated data available in the papers using a generalized Pareto interpolation method. We combine the resulting distribution with information about incomes provided in the wealth survey and in the DINA micro-files to distribute emission totals to individuals. We use the joint income and wealth distribution from the wealth survey (for France and Germany) and the DINA micro-files (for the US) to move from the interpolated distribution of emissions by income percentile (as presented in the papers) to the distribution of emissions by wealth percentile. More details are provided in the supplementary material (SI 1, C.3).

Distributing government emissions. Government emissions include emissions related to government consumption, ownership or investment, depending on the carbon footprint definition. Distributing these emissions to individuals is a more delicate exercise because it requires additional assumptions about who controls, uses and benefits from government services.[23] Our benchmark approach tries to ensure consistency with how government activity is typically treated in distributional national accounts. As a benchmark, we assume that individuals benefit equally (i.e., in way that does not depend on their income or wealth) from the activity of the government in the areas of health and education. These emissions correspond to around 15% of total government emissions in the three countries under study. For the remaining government emissions, we assume that individuals benefit from these activities in proportion to income (see SI 1, C.4).

This ”hybrid” benchmark is certainly not the only one possible and we suspect that some readers may come to different conclusions as to what would be the appropriate benchmark. We present our headline results in Figure 4 under two alternative approaches, namely (i) excluding government emissions completely from individual footprints and (ii) distributing all government emissions as a lump-sum amount to individuals. Figure 4 shows that while the approach chosen matters, the key properties of our results do not change. We show results under six potential strategies regarding the distribution of government emissions in the supplementary material (SI 2, Tables S2.8-S2.13).

– Insert Figure 4 –

[23] This emission category does not include emissions linked to government transfers because these would be included in individual consumption footprints.

4 Results

4.1 The carbon footprint of capital ownership at the national level

We begin by presenting some additional observations from our compilation of extended *aggregate* environmental accounts. Table 1 shows the aggregate footprint of industries in France, Germany and the United States, as well as the carbon intensity of the physical capital stock and the value-added in these industries. The mixed scenario corresponds to emissions associated with capital formation only, while the ownership scenario takes into account all scope 1 emissions and corresponds to the industry's aggregate ownership-based footprint.

– Insert Table 1 –

Emissions by industry and institutional sector. In France and Germany, manufacturing stands out as the largest emitting sector (95 and 212 million tCO_2e, respectively), in terms of the aggregate ownership-based footprint, while in the United States, agriculture and mining is the largest emitting sector (1 637 million tCO_2e). The most carbon-intensive sector in the three countries is agriculture and mining (between 335–535 tCO_2e per million euros or dollars). The waste and water sector ranks second in Germany (289 tCO_2e per million euros) and the United States (431 tCO_2e per million dollars), while the manufacturing sector ranks second in France (230 tCO_2e per million euros). Emissions and emission intensities are lowest in the services sector (private and public services). The carbon intensity of capital in the manufacturing sector is quite close in the three countries (around 206-233 tCO_2e per million euros or dollars). This result holds to some extent when looking at emissions per value added. It could be explained by a rationalization and standardization of manufacturing processes (in cement or steel production, for instance) across the three economies, in a competitive global market.

Emission intensities can vary significantly in sectors such as the energy industry (151 tCO_2e per million euros in France compared to 289 in Germany and 431 tCO_2e per million dollars in the US). This is consistent with different national energy strategies, with nuclear power dominating electricity production in France and greater reliance on coal or gas and oil in Germany and the US. Differences are also evident in the agricultural sector (whether looking at capital or value added) and in the transport sector. In the agricultural sector, production techniques, land use and capital use differ significantly between Europe and the US. In the construction sector, emission intensities appear to differ significantly between the US and France and Germany as well, but these estimates are not directly comparable due to differences in the underlying data used.[24]

– Insert Table 2 –

Emissions by asset class. We now present emissions intensities per million euros or dollars owned by asset class for ownership-based footprints, using asset market values as the denominator (Table 2) rather than the value of the physical capital stock (Table 1).[25] The results demonstrate that differences in asset portfolio allocations can result in significant differences in ownership-based or mixed footprints for a given amount of individual wealth. The limitation of an intensity approach is that the denominator (and hence the carbon intensities) is more sensitive to changes in asset prices and affected by price movements in equity markets, even if the value of the underlying capital stock deployed does not change. We distinguish between five types of assets, namely housing assets, business assets, equities, pension assets, and fixed income assets (which include government bonds, corporate bonds, and asset-backed securities such as mortgage-backed bonds). As per the definition of the ownership-based and mixed footprints, no emissions are linked to owning fixed-income assets.

Equity is the most polluting asset class owned by the household sector in the three countries according to the total emissions associated with different asset classes. It is also a relatively highly carbon-intensive asset, emitting around 75-150 tCO_2e per million euros (France and Germany) or dollars (United States). By comparison, using a bottom-up approach, one source finds that the median carbon content of twenty of the most common investment indexes from major index providers (like MSCI, FTSE/Russell, S&P, or Morningstar) was around 140 tCO_2e per million dollars invested (FFF, 2023). Business assets rank third in terms of absolute emissions in France, Germany and the US. This asset class refers to the assets owned by unincorporated companies and their owners, including machines and intellectual property, to produce goods and services. The

[24]Real estate services (and hence housing capital) are included in the ”real estate and construction” industry grouping in France and Germany, but not in the US. If one separates real estate and construction in France and Germany, as we do in the more extended tables available in the supplementary material (SI 2, Tables S2.1-S2.2), construction still appears more carbon intensive in the US, but the differences are less extreme. Note that in the US, the physical capital of real estate is embedded in the sector ”services and other industries” due to the lower granularity of the air emission accounts data. It is hence not possible to directly compare the emission intensity of the real estate sector in Europe and the US.

[25]We present the same results for mixed footprints in Table S2.7 in SI 2.

carbon intensity per amount of business assets owned differs greatly across the three countries, with emissions at about 50 tCO_2e per million euros in France, nearly 90 tCO_2e in Germany, and exceeding 140 tCO_2e per million dollars in the United States. These differences reflect variations along three broad dimensions: differences in the relative importance of various industrial sectors, differences in the type of capital owned by each economic sector, and differences in the carbon intensity of this capital. To illustrate this, France has the lowest share of manufacturing of the three countries, as well as the lowest emissions per unit of electricity used by firms. On the contrary, US firms' electricity use is highly carbon intensive, and US firms also tend to use more electricity for space heating and cooling purposes. In addition, company cars of US businesses likely release significantly more emissions per mile than their European counterparts (see SI 1, F.).

Pensions are the third most carbon-intensive asset class in the France and the US, but this class is significantly more carbon-intensive in Germany where it is the second most carbon- intensive asset after equity assets (around 30–40 tCO_2e per million euros or dollars held in the first two countries and close to 150 tCO_2e per million euros in Germany). This finding could suggest a stronger reliance of German pension schemes on the fossil-energy sector than in the two other countries. Owning 100 000 euros of pension funds in Germany is associated with 14–15 tCO_2e emissions per year using an ownership-based footprint definition, which is slightly more than the average carbon footprint per capita in this country. Housing assets represent the largest asset class (in terms of market values) in the three countries but they are not associated with any emissions (or close to no emissions), consistent with our methodology.[26]

Foreign ownership in national emissions. Foreign equity ownership constitutes a substantial fraction of the equities held and the overall wealth of individuals in France, Germany and the US. Equity held abroad by individuals from France and the US comprises 20–25% of the total value of equities they own. This proportion rises to 40% for Germany. Equity held abroad by French and German nationals appears to be more carbon intensive than equity held at home. The reverse appears to be true for foreign equity held by US households, which has a relatively lower carbon intensity compared to domestic US equity.

[26] Higher housing emissions in the US can be explained by the fact that the real estate sector is not recorded separately in US air emission accounts. Therefore, some emissions of the services sector will be allocated to housing assets (which dominates the capital stock in the combined "services" sector). Compiling more granular air emission account would be an important task for the US.

We can only speculate about the reasons behind these observed differences given the available data. It is possible that US foreign equity is more financialized. By this, we mean that a relatively lower carbon intensity might reflect a heightened degree of intermediation between assets and their ultimate owners, with a larger proportion of asset value attributed to this intermediation rather than the physical capital itself. Alternatively, the differences observed could also indicate that the ultimate ownership of physical assets is comparatively less carbon-intensive in the US than those owned by French and Germans. It is worth noting that, in the future, emissions tied to foreign equity (foreign ownership emissions) could be an increasingly relevant category as some investors (e.g., European investors) may have to navigate more stringent decarbonization policies at home, with no direct impact on the assets they own abroad.

4.2 The distribution of carbon footprints within countries

– Insert Figure 5 –

– Insert Table 3 –

Carbon footprints rise with income and wealth regardless of the definition, but whether asset ownership is accounted for matters for the degree of inequality observed. Across all definitions, individual carbon footprints consistently exhibit a pronounced income or wealth gradient. The poorest groups emit considerably less relative to their population share, whereas the wealthier segments emit more. In France, the top 10% of the population emits on average 2x more than the poorest half of the population in the consumption-based approach, and 11x more in the ownership-based approach. In Germany, these gaps are 1.5x in the consumption-based approach and 8x in the ownership-based approach. In the USA, the gaps are found to be of 3.5x in the consumption-based approach and 14.5x in the ownership-based approach. Whether the carbon footprint definition takes into account emissions linked to asset ownership or includes only consumption-based emissions thus changes the degree of carbon inequality considerably. Within the three countries studied, consumption-based footprints show less concentration than income or wealth, mixed footprints mirror the concentration of income, and the concentration of ownership-based footprints lies between that of income and wealth. The top 1%'s share among consumption-based footprints stands at 2.5% in France, 2% in Germany, and 6.2% in the US.

However, when turning to ownership-based footprints, these values rise to 21.8%, 22.8%, and 27.0% for France, Germany, and the US, respectively. The US shows the most pronounced carbon inequality among the three approaches. When only private ownership emissions are considered (and government and direct household emissions are excluded), the level of concentration of emissions in the ownership-based approach exceeds that of wealth (see Figure 1).

In considering the specific emission magnitudes and inter-group comparisons, the following observations arise (Figure 5 and Table 3): The poorest in the United States register as significant emitters on an international scale, even when compared with high emitting industrialized countries like France and Germany. In terms of consumption-based footprints, average emissions of the bottom 50% in the US surpass or are close those of the middle 40% in both France and Germany. Notably, emission figures for the poorest half in the US mirror closely those of the top 10% of French households (16.2 tCO_2e per capita on average in France vs. 14.2 tCO_2e in the US). In terms of mixed footprints, the bottom 50% in the United States (at 12.2 tCO_2e) still emit more than the middle 40% in France (9.6 tCO_2e) on average. This is also true for ownership-based footprints where the bottom 50% in the US registers emissions of 7 tCO_2e, higher than the middle 40% in France at below 6 tCO_2e. Under a mixed footprint, emissions of the poorest half of the US population are broadly on par with the emissions of Germany's middle 40% (13.5 tCO_2e). Only when looking at ownership-based footprints does the bottom 50% in the US get clearly overtaken by the middle 40% group in Germany (who emit 11.0 tCO_2e on average). The high emission footprints of poorer groups in the United States underscore the large reliance of all US wealth groups on fossil fuels, particularly for personal transportation, home heating & cooling, and electric appliances.

In France and Germany, consumption-based footprints of the wealthiest 10% are comparable (16.2 and 17.7 tCO_2e, respectively). A similar picture emerges for mixed footprints (24.8 tCO_2e and 29.1 tCO_2e, respectively). In terms of ownership-based footprints, however, Germany's top 10% emit around 50 tCO_2e, exceeding the footprint of their French counterparts by more than 10 tonnes (37.7 tCO_2e). This result is even stronger given the French top 10% own a greater fraction of national wealth than their German peers (61.6% vs. 56.1%). Such differences in per capita emissions at the top predominantly arise from disparities in the relative carbon intensity of equity and business assets between these nations. Yet, when compared to ownership-based footprints of the top 10% in the United States, which stand at over 100 tCO_2e on average, the disparities between the top 10%

in France and Germany appear limited. The wealthiest in the US emit nearly three times more per capita than their counterparts in France and twice as much as the top 10% in Germany. These disparities exceed differences in national average emissions between the three countries and are driven by the relatively higher level of wealth inequality in the US. Examining the top 1%, average footprints in the mixed definition fluctuate between 76 tCO_2e in France, 113 tCO_2e in Germany and 274 tCO_2e in the US. In terms of ownership-based footprints, the top 1% in France, Germany and the US register at respectively 169 tCO_2e, 283 tCO_2e, and 547 tCO_2e. Ownership-based footprints of the richest 1% of the population lie 22-27x above the national average in the three countries.

– Insert Figure 6 –

The emissions intensity per dollar or euro owned increases with wealth. In the ownership-based approach, the carbon intensity per dollar or euro of assets owned by individuals increases at the very top of the distribution. In France, the ownership-based footprint of privately owned assets[27] stays below 10 tCO_2e for each million euros owned for the majority of the population. Yet, this emission intensity increases to 25 million tCO_2e (or even higher values) for the richest 5%. In Germany, for percentiles p60 to p95 (representing the upper middle 35%) of the population, the ownership-based emissions per million euros of privately owned assets averages around 20 tCO_2e. This figure jumps to more than 60 tCO_2e for the top 1%. There is a clear trend of increasing emissions intensities with wealth in the US. Ownership-based footprints per million dollars in privately owned assets hover around 20 tCO_2e from p50 to p90 and escalate steadily beyond this bracket, reaching more than 40 tCO_2e for the top 1%.

These findings suggest that beyond a certain wealth threshold, aside from the level of wealth that increases, the *composition* of asset portfolios may contribute to the increasing footprints of the wealthy. The top 0.1% of the population in the US and Germany emit, respectively, two and four times more per dollar or euro owned compared to those at percentile p95. Since ownership-based emissions per euro or dollar of privately owned assets tend to rise with wealth, it follows that private ownership-based footprints (i.e., excluding government ownership and direct household emissions from individual footprints) are even more concentrated than wealth itself. In France, the

[27]These emissions correspond to the red striped bars in Figure 1, i.e. they refer to the emissions linked to private ownership only, excluding government and direct household emissions from the individual footprint.

top 10% of wealth holders own 61% of wealth but represent around 85% of private ownership-based footprints (Figure 1). Similar patterns are observed in Germany and the US, although they are less pronounced (Figure 6).

– Insert Figure 7 –

Ownership-based emissions exceed direct emissions at the top. Direct emissions (from the use of person vehicles, ships, planes, appliances etc.) only represent a marginal share of top emitters' footprints in the ownership-based approach. The total ownership-based footprint includes direct emissions so that we can consistently compare the magnitude of these emissions to the emissions linked to private asset ownership. At the top of the distribution, emissions linked to private asset ownership represent the bulk of emissions, despite relatively high absolute direct emission levels (Figure 7). Within the top 10% group, after calculating the ownership-based footprint, emissions linked to private asset ownership represent 76% of total emissions in the US, or 79% and 80% in France and Germany, respectively. For the top 1%, this share increases to 85–94%. In a mixed-based approach, 35–46% of total emissions of the top 10% wealthiest come from the assets they own – a lower share because consumption emissions are now also included in their footprint. Direct emissions account for roughly 12–14% of mixed footprints within the top 10% in each country, dwindling to around 4–7% or less for the top 1% and beyond.

Although small as well, the share of direct emissions at the top is consistently higher in the US than in France and Germany. Equity and directly owned business assets represent the bulk of emissions from private asset ownership at the very top in all three countries. Pension and life insurance assets represent around 20% of emissions among the wealthiest French, but this share is marginal for wealthy Germans and Americans. These stylized facts suggest that not considering the emissions linked to asset ownership when estimating the footprint of the wealthiest can understate the emissions associated with the economic decisions made by this group.

5 Discussion

– Insert Figure 8 –

Sensitivity of the results to assumptions. Our estimates rest on a series of assumptions. Readers may be interested in how sensitive our results are to varying the assumptions made to attribute government emissions, direct household and consumption emissions, and housing-related emissions. Figure 8 displays the upper and lower bounds of top 10% emission averages (per capita) and shares, encompassing the three different carbon footprint definitions and spanning over 200 distinct combinations of assumptions per country.[28] It shows that the upper and lower bounds are relatively proximate to our benchmark estimates. For example, in the United States, the emissions share for the top 10% is 50.5% in the ownership-based approach in our benchmark series. Conversely, the upper bound hovers around 56.9%, and the lower bound is near 43.7% of the total. For Germany, these boundaries fluctuate between 37.3% and 50.0% and, in France, top 10% emission shares lie between 43.7% and 60.9%.

It is important to note that these bounds represent the most extreme combinations of assumptions in our sample. For instance, the lower bound typically corresponds to a scenario where all government emissions are attributed as a lump sum amount, while direct and consumption emissions follow a very low elasticity parameter relative to income. The supplementary material (SI 1, C.6 and SI 2, Tables S2.8-S2.13) provides a detailed list of these alternative scenarios, along with tables and figures highlighting key inequality statistics for various combinations of assumptions. These robustness checks suggest that even extreme combinations of assumptions do not alter the overall patterns identified, most notably that incorporating ownership-based emissions into individual footprints significantly increases emission inequality.

Limitations linked to data sources. We face the same limitations as other studies that rely on wealth surveys to study the distribution and breakdown of assets owned across populations. These limitations include biases related to wealth under-reporting or the self-reported nature of asset values, among other challenges. While we correct for the inability of wealth surveys to capture the distribution at the very top, we lack information about the breakdown of asset portfolios owned by these types of individuals who are not present in our survey. We discuss this in the supplementary material (SI 1, A. and E.).

Another limitation linked to the wealth survey data is that we only observe a small number of asset classes in the survey, and we cannot link individuals to the precise firms they (partly) own. As an extreme example, we cannot rule out that individuals at the very top own the most

[28] These include six scenarios regarding government emissions, four scenarios regarding non-ownership emissions and three scenarios regarding housing emissions per country, which we run for each of the three carbon footprint definitions. Each scenarios is explained in the supplementary material (SI 1, C.6).

environmentally friendly firms in each industry. However, the size of the error we can make is limited because almost all equity ownership is concentrated towards the upper parts of the wealth distribution. In forthcoming work, we estimate ownership-based footprints in countries where individual data on asset ownership is available. Nonetheless, we show in this study that revealing the broad patterns of ownership-based footprints does not depend on such data sources, which will remain unavailable in many contexts and countries. The data approach we follow in this work would benefit from improvements in the underlying macroeconomic data sources compiled and released by statistical agencies. Air emission accounts remain underdeveloped in the United States compared to countries in the European Union, for example, so that we are only able to rely on a limited number of industry groups when attributing emissions in the US. The ownership-based approach could also be implemented with higher precision if more detailed matrices of (domestic and foreign) equity holdings by institutional sector were available.

Note that consumption-based footprints suffer from data limitations as well (Hardadi et al., 2021; Malliet, 2020; Starr et al., 2023a).[29] Budget surveys are susceptible to sampling biases, particularly at the upper end of the distribution, resulting in an underestimation of both wealthy individuals' consumption and emissions. Further, the studies typically assume that the emissions per dollar spent on a particular consumption category, such as a bottle of wine, do not change across income or wealth groups. The actual emission intensities could differ for luxury products, other products sold at a high mark-up or mass-produced goods (within a product category), which could impact consumption-based footprints (SI 1, C.7). We discuss these biases, as well as additional data-related limitations in more detail in the supplementary material (SI 1, A.-C.). We provide a table summarizing all potential biases that stem from the data sources we use in the supplementary material (SI 1, Table S1.14).

Carbon footprints and individual responsibility. Broadly defined individual carbon footprint approaches cannot fully capture the actual *responsibility* each individual bears for emissions. Interpreting carbon footprints as representing responsibility would require additional assumptions about the role of individuals in economic processes and decisions. Individual responsibility has

[29] Even though we rely on these estimates for our benchmark estimates, we also present "modelled" results using a fixed elasticity parameter for these emission categories in each carbon footprint definition, i.e. these alternative results do not rely on estimates from the three cited studies. These results can be found in the supplementary material (SI 2, Tables S2.8-S2.13), and they are incorporated in the set of assumptions tested in Figure 8.

been associated in the literature with three conditions (Fahlquist, 2009; Lenzen & Murray, 2010; Paul et al., 1999): (i) agency, intentionality, and control, (ii) information and (iii) alternatives. It is not the purpose of this paper to determine to which extent each condition is fulfilled for each economic actor and each definition of the carbon footprint. Instead, we intend to show that consumption-based footprints rely on assumptions which can be inconsistent with consumer behavior, agency and information.

We briefly outline the underlying assumptions that would be consistent with interpreting carbon footprints as representing responsibility in a control-based responsibility framework. If we assume that individuals have 100% control and agency over their direct emissions and over all human-made emissions via their consumption decisions, then the consumption-based footprint would be closest to assessing responsibility inequalities (let us call this parameter α). If we assume that $\alpha < 1$, the mixed approach arguably provides a more appropriate framework, given that in this framework $\alpha \approx 0.8$.[30] If α is assumed to be 0, responsibilities would be aligned more closely with the ownership-based footprint. Note that the ownership-based footprint still assumes that individuals have 100% agency and control over their direct household emissions (we call this parameter β). In effect, the use of personal gasoline vehicles or home heating devices is often constrained, at least in the short-term. If $\alpha = 0$ and $\beta < 1$, then even the ownership-based footprint could be seen a lower bound for the true emissions responsibility.

In practice, these parameters might vary at the individual level and by sector, product and country. More work will be needed to investigate information constraints, control, agency, and the availability of alternatives. This type of work could result in more refined versions of our mixed footprint in which the distribution of emissions between consumers and investors would vary depending on the context, level of information and level of constraints, and not only depending on the investment activity of the firm.[31]

Power of owners vs. firm managers. It is possible to argue that firm managers hold (at least some) power over firms' decisions in addition to firm owners when the two do not coincide. This could be another reason why firm owners lack some agency over decisions and the polluting activities exercised within a firm. A similar argument could be made for asset managers who act as

[30] Capital formation emissions represent about 19-21% of the total in the three countries using the mixed approach.
[31] Concentration indices (such as Herfindahl indices) might be a possibility to advance our understanding of the relative agency of consumers and investors in different industries.

intermediaries and invest on behalf of their clients. We stress that, based on the data we use, we cannot determine to which extent these constraints operate on the level of managers or owners, nor of individual consumers or investors. Interpreting the ownership-based footprint as representing responsibility requires assuming that owners ultimately determine the decisions executed by firm managers.

Including investment emissions in individual footprints. Including investment emissions in owners' footprints (as suggested in our mixed approach) may be questioned on the grounds that emission-intensive investment could be required today to reduce future emissions. Emissions for certain owners might be positive in year t in their mixed footprint, but could then turn zero in $t+1$ and subsequent years for consumers, thanks to the firm's investments. The same could be said of a consumer buying an electric car (to the extent it is counted as a consumption good): the carbon footprint associated with transportation would increase significantly in year t to account for the emissions embedded in the car but will be reduced in the subsequent years. Note that this is less of a concern for consumption and ownership-based footprints because the same consumers and owners would benefit from reductions in emissions caused by the initial investment decision in the form of lower footprints in future periods.

Government footprint vs. government responsibility The government's responsibility for emissions could extend beyond those associated with its direct services. For example, the lack of public transportation in a region can limit the capacity of consumers and businesses to minimize their direct carbon footprints. In our study, we aim to allocate all emissions to consumers and investors. We account for government emissions by attributing them to individuals using various allocation rules because it is our goal to present the distribution of national footprints according to different individual carbon footprint definitions. Collective action plays a crucial role in enhancing or limiting the agency of both consumers and investors so that the government's footprint should also not be interpreted without further assumptions as representing the total responsibility for emissions of the public sector.

How our estimates compare to earlier work. Our work represents the first attempt, to our knowledge, at systematically measuring the distribution of ownership-based emissions within and across countries. A study (Greenpeace, 2020) can be compared to the ownership-based footprint we present, although important differences exist in terms of the methodology. It uses a bottom-up approach to determine emissions linked to asset ownership rather than distributing all national emissions to individuals. As a result, the authors attribute 312 million tCO_2e equivalent to wealth holders in France, significantly less than under our ownership-based approach, and significantly more than under our mixed approach. The authors also do not use a strict ownership perspective, allocating emissions also to purely financial assets. The top 1% share for ownership emissions is 17.7% for France in this study, while our benchmark estimate suggests a top 1% share in private ownership emissions of 23.1%, excluding government and direct household emissions, when individuals are ranked according to their pre-tax income (to match the ranking approach used in the study).[32]

The results of our mixed approach are fairly similar to those presented in Chancel (2022) which in effect used a simplified version of our mixed footprint definition. There are differences, however, which we discuss in the supplementary material (SI 1, C.4), for example regarding the distribution of government and direct household emissions, or the ranking of individuals by emissions rather than wealth, which limit the direct comparability. The consumption-based footprints deviate somehow from the estimates in the papers on which we rely to distribute these emissions (Hardadi et al., 2021; Malliet, 2020; Starr et al., 2023a). This can be due to different units of analysis (we use per capita emissions while the results can be presented by ”consumption unit” in these papers), different strategies regarding government emissions, and differences in the income or wealth variable used to rank individuals or households.

Emission totals and net foreign ownership emissions. Both the consumption and mixed-based footprints reproduce the well-known finding that wealthy nations import more embedded CO2 emissions from other countries than they export (in France, for example, consumption-based emissions exceed production-based emissions by 35%). We find similar patterns for France and Germany for ownership-based footprints. That is, total emissions in the ownership-based approach are larger than production-based emissions due to the net impact of cross-border firm ownership. We see much potential going forward in using the ownership-based footprint definition to investigate in more detail how ownership-based emissions compare to production-based emissions across countries and country groups.

[32]A more recent policy paper by the same advocacy group calculates the carbon footprint of billionaires in France by including in their footprint the scope 1, 2 and 3 emissions of the ”primary” firm they own (Greenpeace, 2022).

– Insert Figure 9 –

– Insert Figure 10 –

Distributional properties and revenue estimates for a tax on private ownership emissions. We now discuss what our results imply for a potential tax that could be levied on the emissions linked to assets owned by individuals. Figure 9 compares the distributional impact of a 150 euro/dollars ″per-tonne″ tax levied on private ownership emissions to a similar tax levied on direct (scope 1) household emissions (e.g., private transport or heating), and a tax levied on private consumption emissions (i.e., the emissions embodied in the goods and services consumed). Our analysis here rests on strong assumptions, i.e. we assume that a tax on direct emissions would fall entirely on consumers, while a tax on asset ownership would fall entirely on asset owners. In reality, both sides could bear a fraction of the tax incidence, and this fraction might vary depending on the tax design, type of investment and other characteristics.

Figure 9 shows that taxes on ownership-based emissions are progressive in all three countries if expressed in % of net wealth with the effective tax burden increasing for top wealth groups. This finding is linked to the increase in the carbon intensity of assets owned at the very top. In contrast, the effective tax burden of taxes levied on consumption or direct household emissions declines for individuals in top wealth groups. Taxes levied on private ownership emissions potentially share commonalities with progressive wealth taxes, at least for the average individual. A tax applied to the carbon content of assets could potentially be designed as a top-up component to a wealth tax, which would adjust the tax burden depending on the carbon content of the assets owned by the individual. This would require collecting the relevant information from asset owners and financial institutions as well as methods to externally verify the information provided, in particular regarding the ownership of firms that are not required to report annual emissions. In Figure 10 we show that, absent any behavioral change and under perfect compliance, taxes of this nature could result in meaningful tax revenues.

We stress that our dataset is not suited to make statements regarding the appropriate level or precise implementation of potential taxes applied to ownership-based emissions. Before considering such policies, a better understanding of the expected behavioral response of investors (at different levels of wealth) and how these individual responses translate into actual emission reductions at the firm level will be required.[33]

6 Conclusion

Developing and implementing carbon footprint definitions based on capital ownership further advances our understanding of emission inequality. Accounting for ownership-based emissions at least doubles the top 10%'s carbon footprint in France, Germany and the United States, increasing it by 2–2.8 times compared to consumption-based footprints or 30–65% for mixed footprints. Emissions from private ownership are more concentrated than wealth, with the top 10% responsible for 70–85% of total emissions in that category, and the majority of the 10%'s emissions (75–80%) are tied to asset ownership. Our findings highlight that defining footprints solely based on consumption choices, as it remains standard practice in research and public debate, rests on strong assumptions. Complementary approached are needed, incorporating the diverse roles individuals play within the economy and beyond, including the role of individuals as investors and firm owners.

We see this paper as the starting point for a new research agenda. Expanding the emission inequality work beyond a purely consumption-based framework for a broader set of countries is a key avenue. Future work should also replicate our approaches using more granular wealth data, assess the evolution of footprints over time, and study in more detail what an ownership-based emission perspective implies for the distribution of emissions at the global level. There is plenty of scope to study carbon inequalities across the three approaches based on characteristics that go beyond income and wealth (e.g., geography, age, gender). A deeper understanding of carbon footprints and their relationship with inequalities in agency, information, and the set of available choices is needed as well. Finally, more work is required to model the behavioral responses and tax incidence that could be expected for new climate policies based on the carbon content of assets, such as those discussed in the paper, and how they would vary depending on the actual policy design.

[33] Implementation challenges would also include concerns about the double taxation of emissions, but these could be alleviated by providing credits to individual owners in case emissions were already subject to taxation at the firm level. Taxing ownership-based emissions could in fact serve as a backstop to discourage investors who reside in countries with relatively stricter environmental policies from investing primarily in firms located in countries were such policies are absent. The logic would be similar to border adjustment mechanisms applied to traded goods.

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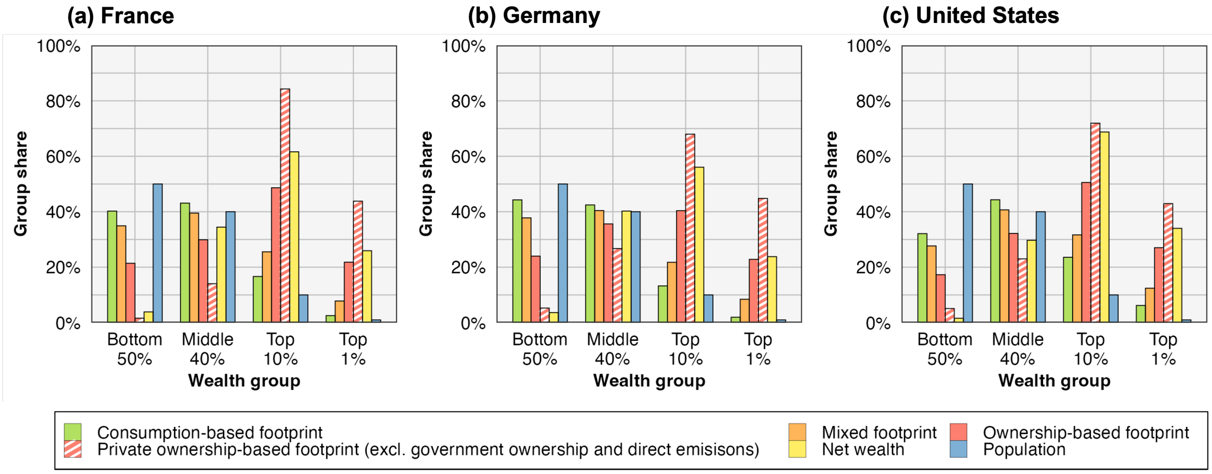
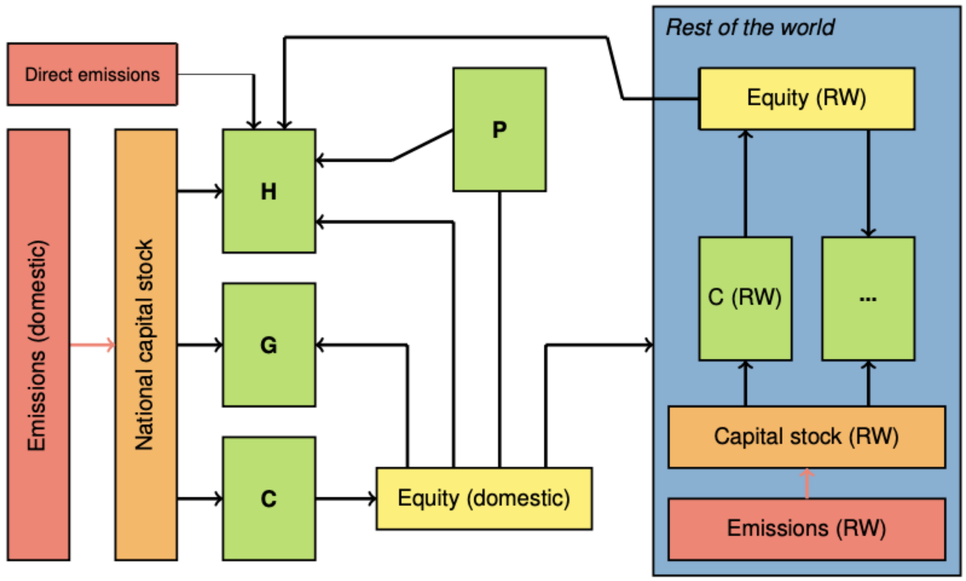
Figures and Tables

Figure 1: Distribution of emissions, wealth and population by wealth group



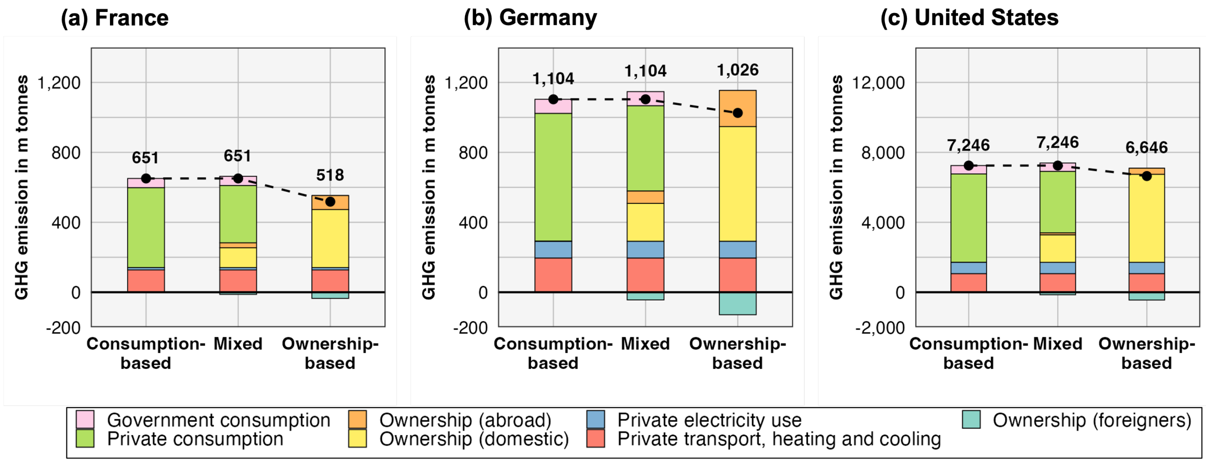
Note: The graph presents the weight of four net wealth groups among the (i) total population, (ii) total wealth and (iii) emissions. Emission shares are provided for three different carbon footprint definitions: the consumption-based footprint, the mixed, and the ownership-based footprint. For the ownership-based footprint, we present total emission shares (i.e., including emissions from private ownership, government ownership and direct emissions) in the solid red bars, and emission shares related to private ownership (i.e., excluding government and direct emissions) in the striped bars. Values refer to 2017 in France and Germany and 2019 in the United States.

Figure 2: Attribution of emissions to institutional sectors for the ownership-based carbon footprint definition



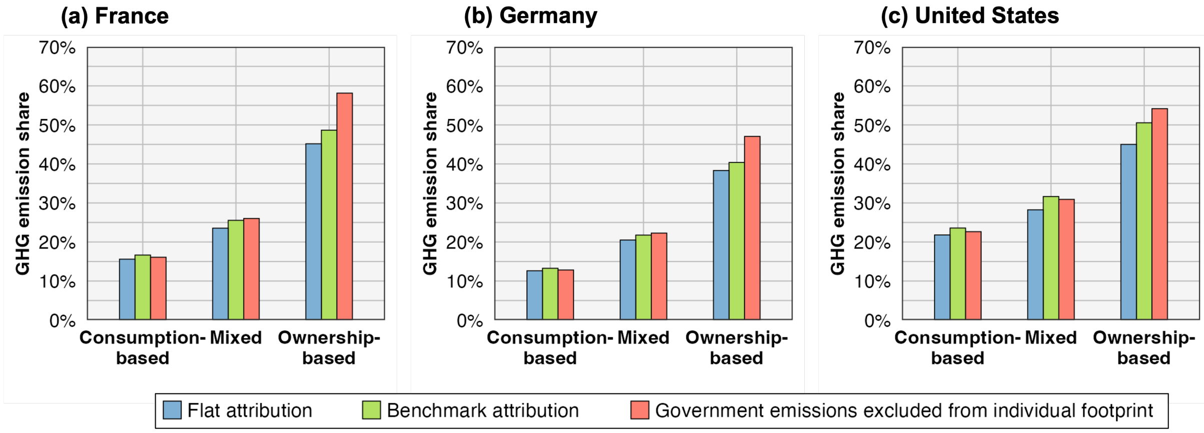
Note: Schematic illustration of emission attribution to the capital stock and to institutional sectors in the economy for the ownership-based carbon footprint definition. Black arrows depict the flow of emissions in each step of the attribution process. Red arrows represent the emissions linked to the national and foreign capital stock. The figure demonstrates how all national emissions (as available in air emission accounts) are ultimately attributed either to household sector (H), the government (G), or to foreign investors (RW). Emissions distributed to foreign investors are not part of the national footprint. (C) refers to the corporate sector and (P) refers to the equity owned by pension funds and life insurance.

Figure 3: Total national emissions in million tCO2e according to the three carbon footprint definitions



Note: Re-scaled y-axis for the United States to ensure readability (x10). Emissions in 2017 (France, Germany) and 2019 (the United States). The breakdown shows the emissions allocated to consumption and ownership. Direct household emissions (including emissions from private electricity use) are identical in the three approaches. Private and government consumption emissions include all domestic and foreign emissions released to satisfy domestic final consumption. Ownership emissions include government ownership emission in this representation. Emissions of domestic firms owned abroad (turquoise) reduce total national emissions while emissions of foreign firms owned by residents (orange) increase national emissions. The supplementary material provides a more detailed breakdown of national emissions (SI 1, Table S1.8-S1.10)

Figure 4: Top 10% emission shares depending on allocation method for government emissions



Note: The graph presents the share of emissions attributed to the group of top 10% net wealth holders for three methods to allocate government emissions to individuals. The blue bar corresponds to a flat allocation of government emissions as a lump-sum amount. The green bar corresponds to the benchmark hybrid approach elaborated in the paper. The red bar corresponds to the results if government emissions are excluded from individual footprints. SI 2, Tables S2.8-S2.10 present the detailed results, i.e, for all wealth groups and for additional allocation strategies. Values refer to 2017 in France and Germany and 2019 in the United States.

Table 1: Emission intensities per million euros or dollars owned and absolute emissions by industry groups

Industry	Mixed footprint			Ownership-based footprint		
	tCO_2e/ m euros or dollars owned	tCO_2e/ m euros or dollars value-added	million tCO_2e	tCO_2e/ m euros or dollars owned	tCO_2e/ m euros or dollars value-added	million tCO_2e
Panel A. France (2017)						
Agriculture and mining	65.5	291.9	10.9	528.4	2 354.9	87.8
Energy, water and waste	85.8	562.0	27.1	150.6	987.0	47.6
Manufacturing	120.0	212.9	49.6	230.2	408.4	95.1
Transport	38.3	103.1	9.8	163.5	440.5	41.7
Real estate and construction	0.8	20.4	7.7	1.0	24.7	9.3
Health and education	0.3	0.6	0.2	19.0	34.5	10.3
Public administration	0.1	1.1	0.2	3.2	30.6	4.9
Services	6.7	9.7	7.7	30.2	44.0	35.0
Panel B. Germany (2017)						
Agriculture and mining	84.0	568.3	18.2	335.3	2 269.7	72.8
Energy, water and waste	113.5	912.2	81.0	289.4	2 326.2	206.6
Manufacturing	96.6	131.9	87.9	232.6	317.8	211.7
Transport	24.0	116.0	14.9	161.9	783.5	100.5
Real estate and construction	0.8	15.5	7.0	1.2	23.2	10.5
Health and education	0.3	0.9	0.3	8.7	28.7	10.2
Public administration	0.3	1.8	0.3	4.9	30.7	5.5
Services	4.0	6.6	6.9	22.2	36.5	38.1
Panel C. United States (2019)						
Agriculture and mining	97.3	641.7	297.9	534.9	3 526.6	1 637.3
Energy, water and waste	146.7	1 262.1	455.3	431.4	3 710.8	1 338.6
Manufacturing	117.7	214.7	508.1	205.7	375.2	887.7
Transport	105.7	254.8	179.1	359.1	865.8	608.6
Construction	158.4	69.7	62.9	212.5	93.6	84.4
Services and other industries	0.9	4.1	65.5	6.6	30.2	477.5

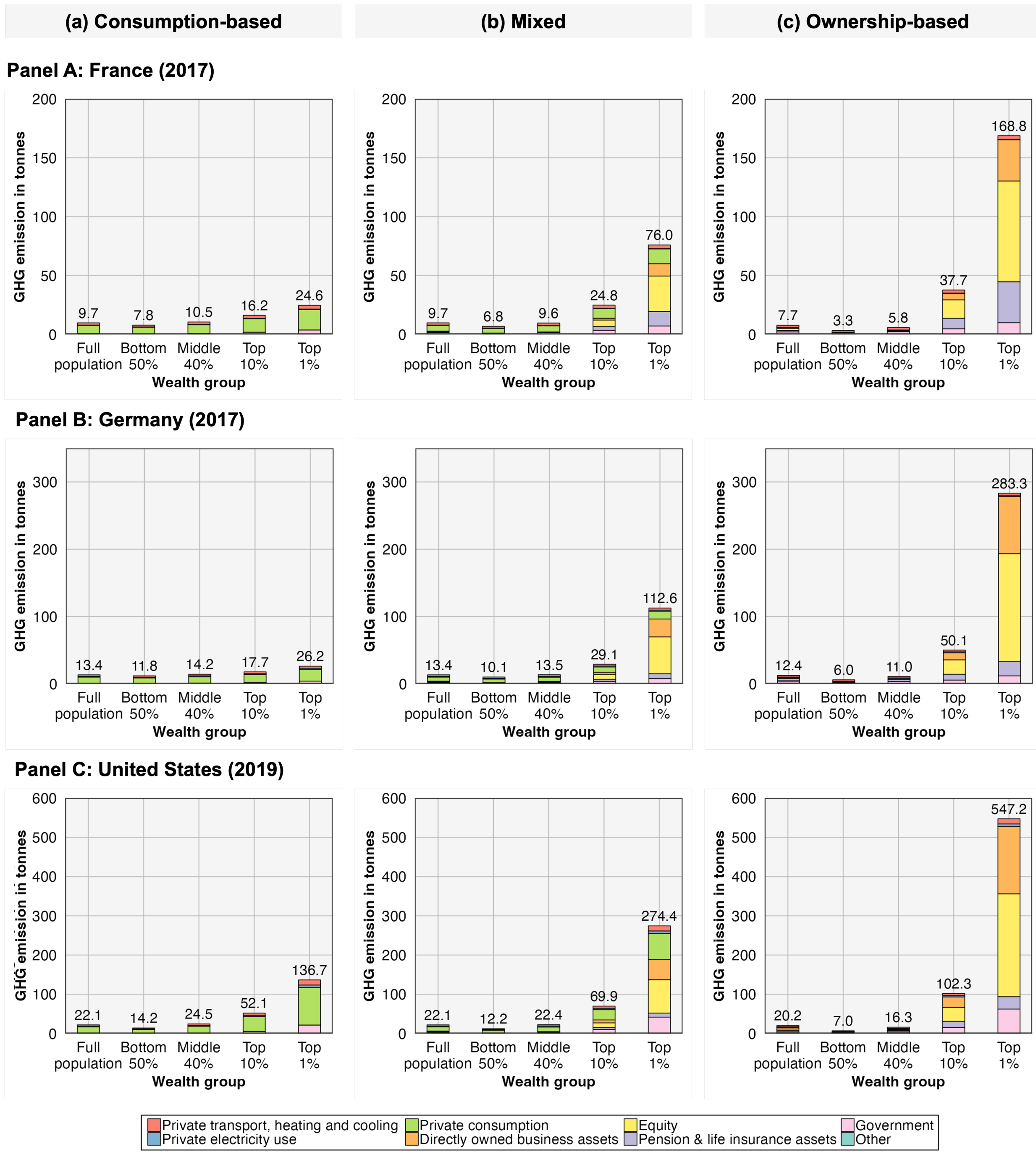
Note: Annual emissions per million euros or dollars owned in tCO_2 equivalent derived from inter-regional input output tables. Emissions of the energy sector exclude emissions linked to electricity consumed in private households. The capital stock includes the value of land. Gross value added by industry for France and Germany from Eurostat (B1G), and from BEA (Table 301) for the US. Industry groups for France and Germany are aggregated and include the following NACE codes: Agriculture and mining (A, B), Manufacturing (C), Energy, water and waste (D, E), Real estate and construction (F, L), Transport (H), Health and education (P, Q), Public administration (O), Services (G, I, J, K, M, N, R, S, T). For the US, the groups include the following NACE codes: Agriculture and mining (A, B), Manufacturing (C), Energy, water and waste (D, E), Construction (F), Transport (H), Services and other industries (the remaining industry groups). More disaggregated tables for each country are available in the supplementary material (SI 2, Tables S2.1-S2.3). The granularity for the US is lower than for France and Germany due to the less granular capital stock data. Based on data from Eurostat, BEA and EU-FIGARO.

Table 2: Assets owned, aggregate emissions and emission intensities by asset class for ownership-based footprints

	France (2017)			Germany (2017)			USA (2019)		
Asset class	b euros owned	million tCO_2e	tCO_2e/ m euros owned	b euros owned	million tCO_2e	tCO_2e/ m euros owned	b dollars owned	million tCO_2e	tCO_2e/ m dollars owned
Housing assets	6 808.5	0.3	0.1	6 901.2	0.5	0.1	36 475.5	260.8	7.2
Business assets	727.9	38.3	52.6	1 036.7	90.4	87.2	6 748.4	966.5	143.2
Equities	1 528.7	123.2	80.6	1 332.7	203.7	152.9	17 553.6	1 314.4	74.9
Domestic	*1 183.9*	*83.1*	*70.2*	*808.2*	*117.5*	*145.4*	*13 965.3*	*1 118.4*	*80.1*
Abroad	*344.8*	*40.1*	*116.4*	*524.6*	*86.2*	*164.4*	*3 588.3*	*196.0*	*54.6*
Pension assets	2 026.9	75.4	37.2	1 351.5	197.6	146.2	31 564.2	1 015.9	32.2
Fixed-income assets	1 552.8	0.0	0.0	2 579.9	0.0	0.0	17 363.7	0.0	0.0

Note: Emissions correspond to the average emissions that would be included in an individual's ownership-based footprint if the asset is owned by the person for one year. Using 2019 exchange rates, the value for owning equity in the United States would be 84 tCO_2e/m euros compared to 75 tCO_2e/m dollars owned. The table presents household sector ownership-based footprints and excludes emissions linked to government-owned assets. Emissions are attributed to assets based on the ownership-based approach as explained in the paper. The value of total assets owned is sourced from Eurostat national balance sheets (France and Germany) and from distributional national account series (Piketty et al., 2018) for the United States. Pension assets include life insurance assets

Figure 5: Per capita emissions by wealth group for the three carbon footprint definitions



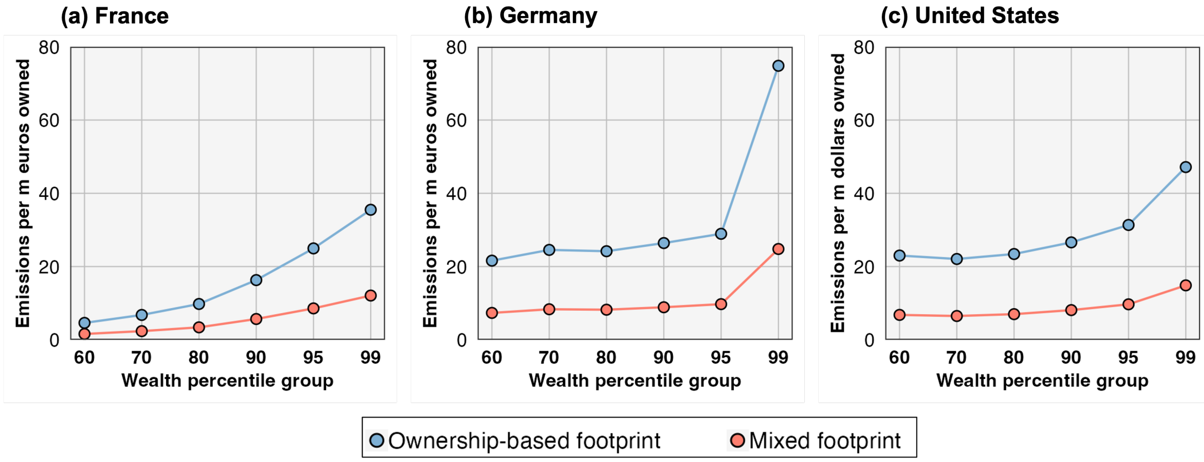
Note: Groups are defined in terms of net personal wealth. Graphs present the annual average per capita emission footprint by wealth group for the three carbon footprint definitions presented in the paper. Directly owned business assets include housing maintenance whereas private heating emissions are part of private consumption emissions in this figure. Top 1% and 0.1% consumption-based estimates are based on extrapolating the distributions from the literature and could be subject to over or underestimation (see the discussion on price-quantity effects in SI 1, C.7). Consumption-based footprints for top 1% and 0.1% groups are slightly lower than assuming a constant income-emission elasticity of 0.65 on indirect emissions, and 0.2 on direct household emissions in France and Germany. In the US, top 1% and 0.1% consumption-based footprints are slightly higher than under a constant elasticity assumption (see SI 2, Tables S2.11-S2.13). Mixed and ownership-based footprints for the top 1% and 0.1% are less sensitive to these specific assumptions. Estimates by income group (instead of wealth) are presented in the supplementary material (SI 2, D.). Values refer to 2017 in France and Germany and 2019 in the United States. See methodology section for more details.

Table 3: Key economic and environmental inequality indicators for the three carbon footprint definitions

	Income	Wealth	Footprint					
			Consumption -based		Mixed		Ownership -based	
Group	Share in %	Share in %	tCO_2e/ cap	Share in %	tCO_2e/ cap	Share in %	tCO_2e/ cap	Share in %
Panel A. France (2017)								
Bottom 50%	30.9	3.9	7.8	40.2	6.8	34.9	3.3	21.4
Middle 40%	43.5	34.5	10.5	43.1	9.6	39.5	5.8	29.9
Top 10%	25.6	61.6	16.2	16.7	24.8	25.5	37.7	48.6
incl. Top 1%	*5.5*	*25.9*	*24.6*	*2.5*	*76.0*	*7.8*	*169.0*	*21.8*
incl. Top 0.1%	*1.1*	*8.6*	*37.0*	*0.4*	*201.0*	*2.1*	*498.0*	*6.4*
Full Population	100.0	100.0	9.7	100.0	9.7	100.0	7.7	100.0
Panel B. Germany (2017)								
Bottom 50%	33.4	3.6	11.8	44.3	10.1	37.8	6.0	24.0
Middle 40%	46.2	40.2	14.2	42.4	13.5	40.4	11.0	35.6
Top 10%	20.4	56.1	17.7	13.3	29.1	21.8	50.1	40.4
incl. Top 1%	*4.6*	*23.8*	*26.2*	*2.0*	*113.0*	*8.4*	*283.0*	*22.8*
incl. Top 0.1%	*1.4*	*10.0*	*49.9*	*0.4*	*544.0*	*4.1*	*1 528.0*	*12.3*
Full Population	100.0	100.0	13.4	100.0	13.4	100.0	12.4	100.0
Panel C. United States (2019)								
Bottom 50%	18.3	1.6	14.2	32.1	12.2	27.7	7.0	17.3
Middle 40%	40.4	29.7	24.5	44.3	22.4	40.7	16.3	32.2
Top 10%	41.3	68.7	52.1	23.6	69.9	31.7	102.0	50.5
incl. Top 1%	*17.3*	*34.0*	*137.0*	*6.2*	*274.0*	*12.4*	*547.0*	*27.0*
incl. Top 0.1%	*7.9*	*17.6*	*491.0*	*2.2*	*1 355.0*	*6.1*	*3 093.0*	*15.3*
Full Population	100.0	100.0	22.1	100.0	22.1	100.0	20.2	100.0

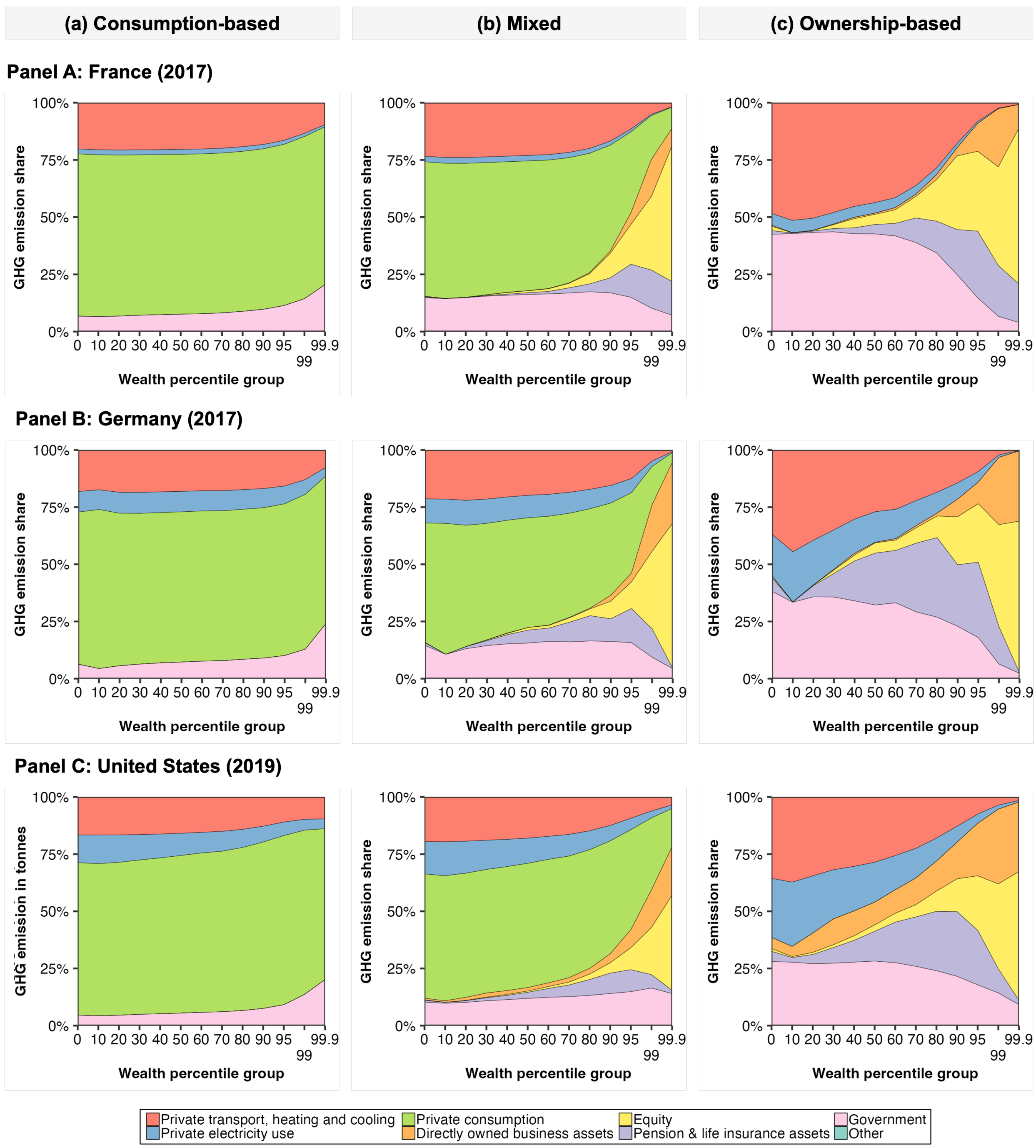
Note: Groups are defined in terms of net personal wealth. The table presents average per capita annual emissions by wealth group for the three carbon footprint definitions presented in the paper. Top 1% and 0.1% consumption-based estimates are based on extrapolating the distributions from the literature and could be subject to over or underestimation (see the discussion on price-quantity effects in SI 1, C.7). Consumption-based footprints for top 1% and 0.1% groups are slightly lower than assuming a constant income-emission elasticity of 0.65 on indirect emissions, and 0.2 on direct household emissions in France and Germany. In the US, top 1% and 0.1% consumption-based footprints are slightly higher than under a constant elasticity assumption (see SI 2, Tables S2.8-S2.13). Mixed and ownership-based footprints for the top 1% and 0.1% are less sensitive to these specific assumptions. Estimates by income group (instead of wealth) are presented in the supplementary material (SI 2, D.). See methodology section for more details.

Figure 6: Average annual emissions in tCO2e per million dollars or euros owned



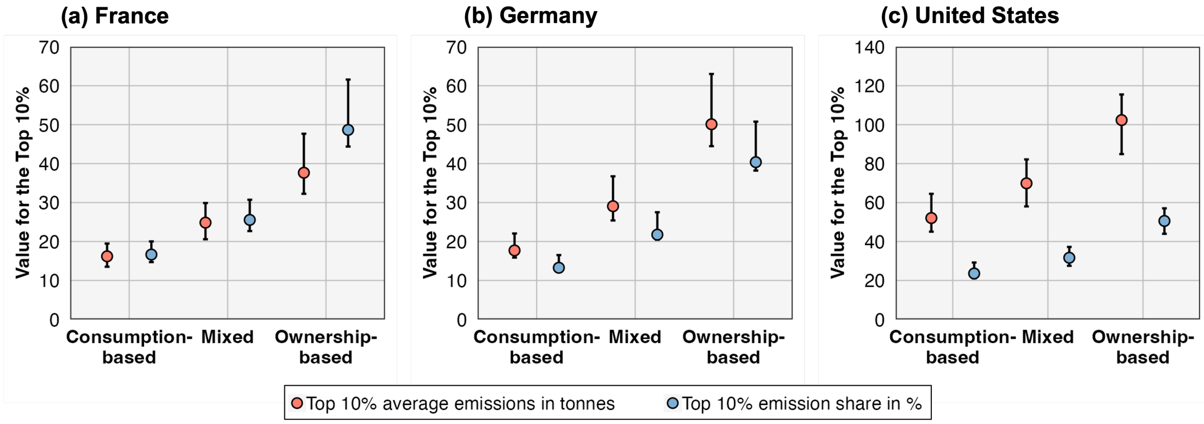
Note: The graph presents the average emission intensity per million dollars or euros owned in France, Germany (2017) and the United States (2019) by net wealth groups. The emission intensity is defined as the ratio of private ownership emissions to gross wealth owned (i.e., the wealth that can potentially be associated with emissions). P60 refers to the p60-p70 group, p95 to the p95-p99 group, p99 to the p99-p100 group, etc. Bottom wealth groups excluded because the emissions-wealth ratios show erratic trends due to the very low values of wealth and private ownership emissions. Excluding fixed assets from the denominator (which are associated with zero emissions in our definition by construction) would further increase emission intensities. The emission intensity can be impacted by changing asset values over time so that it needs to be interpreted in conjunction with the values and types of assets owned.

Figure 7: Breakdown of per capita emissions by wealth group in the three carbon footprint definitions



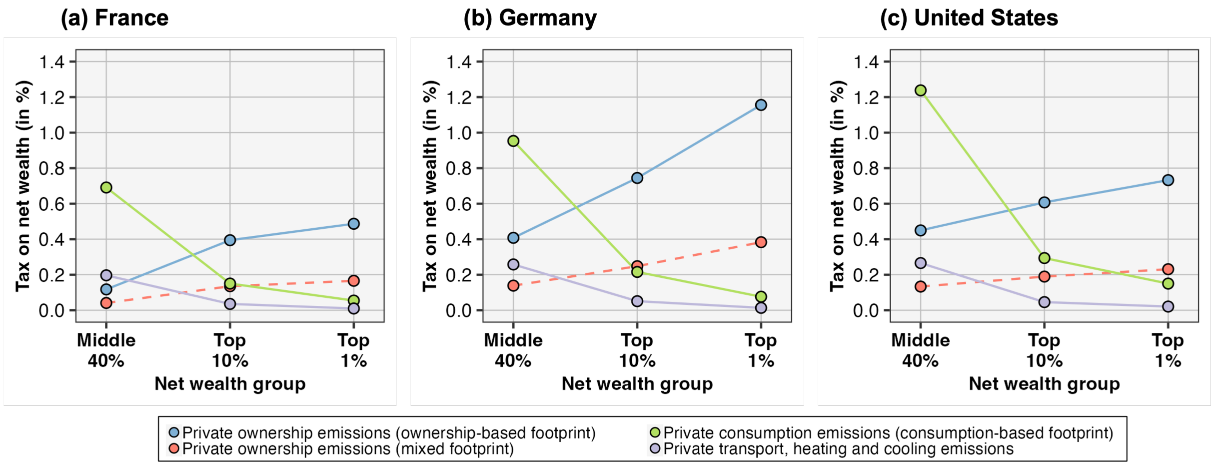
Note: Groups are defined in terms of net personal wealth. Graphs visualize the breakdown of per annual capita emissions by wealth group for the three carbon footprint definitions presented in the paper. Directly owned business assets include housing maintenance whereas private heating emissions are part of private transport, heating and cooling emissions in this figure. Wealth percentile group 0 refers to P0-10, group 10 to P10-20 etc. The final group represents the top 0.1% wealth group. Values refer to 2017 in France and Germany and 2019 in the United States.

Figure 8: Upper and lower bound of top 10% emissions in tonnes and emission shares



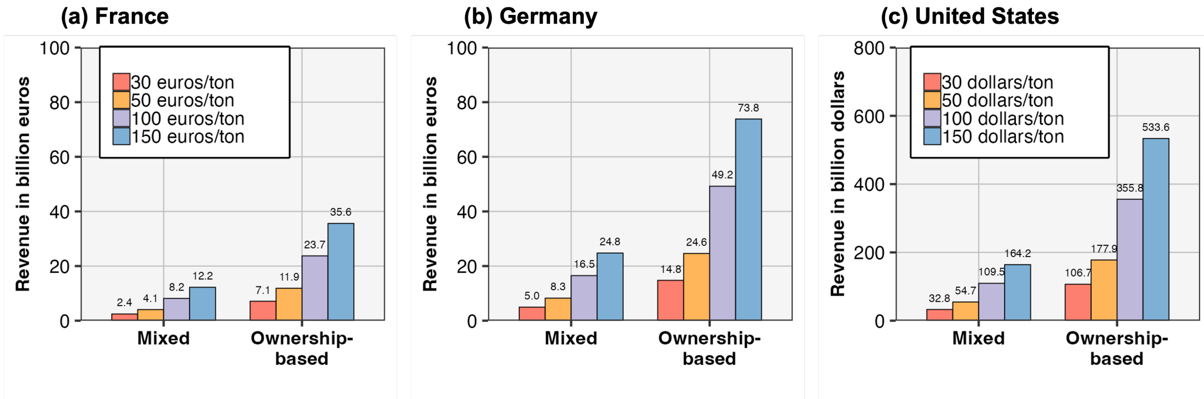
Note: The graph presents the range of average per capita emissions and group emission shares for the top 10% wealth group under different assumptions for each of the three carbon footprint definitions. The dot represents the benchmark strategy as explained in the paper. Bands correspond to the lowest and highest value obtained when calculating all potential combinations of alternative assumptions (216 scenarios per country). Alternative assumptions concern the attribution of (i) government emissions, (ii) consumption-related and direct household emissions or (iii) housing-related emissions. Tables with results for key alternative assumptions and similar figures presenting all wealth groups (rather than only the top 10%) are available in SI 2, Tables S2.8-S2.13 and Figures S2.2-S2.4. Values refer to 2017 in France and Germany and 2019 in the United States.

Figure 9: Progressivity of a 150 euros/dollars per-tonne tax levied on different types of individual emissions



Note: The graphs present the static distributional impact of a tax levied annually per tonne of individual emissions. Emissions are distributed to adult individuals instead of the total population for tax simulations. We omit the bottom 50% from the graph because the ratio between emissions and net wealth is heavily impacted by the small denominator and low ownership-based emissions. If individuals are ranked by net wealth, the average individual in the bottom 50% owns relatively little net wealth (due to liabilities) but somewhat higher gross wealth (which determines ownership-based footprints). Total private ownership emissions remain very small in the bottom 50%. Our estimates suggest private ownership emissions of 1.47t (US), 0.15t (France) and 0.76t (Germany) for the average adult in bottom 50% in the ownership-based footprint. The tax payment would hence amount to 2–18 euros/dollars per month for this group. An actual tax levied on private ownership emissions would likely feature an exemption threshold below which emissions would not be subject to taxation. Values refer to 2017 in France and Germany and 2019 in the United States.

Figure 10: Simplified static revenue estimates for per-tonne taxes on private ownership emissions



Note: The graph presents static revenue estimates without behavioral responses and with perfect compliance for per-tonne taxes on private ownership emissions in the mixed-based and ownership-based approach (i.e., no tax is applied to government or direct household emissions). While taxes applied to government ownership emissions could change the incentives and influence government behavior, these taxes would not result in a net revenue gain. Values refer to 2017 in France and Germany and 2019 in the United-States.

Supplementary Information

- Supplementary Information 1 (Methods)
- Supplementary Information 2 (Results)