THE CARBON FOOTPRINT OF CAPITAL:

EVIDENCE FROM FRANCE, GERMANY AND THE US BASED ON DISTRIBUTIONAL ENVIRONMENTAL ACCOUNTS

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Abstract

What is the carbon footprint of capital and how are emissions associated with asset ownership distributed across the population? We address this question by developing a novel framework to systematically measure individual carbon footprints, taking into account both consumption and ownership-related emissions to varying degrees. Our framework is both comprehensive and exclusive, encompassing all emissions associated with economic activity, while ensuring no double-counting, thereby enhancing comparability between different countries and wealth groups. We apply the framework by constructing distributional environmental accounts for France, Germany and the US, yielding the following results. First, taking into account emissions from capital ownership increases the carbon footprint of the wealthiest 10% of the population by 2-2.8x as compared to consumption-only estimates, depending on the country. Second, for this group, 75-80% of emissions stem from asset ownership, not from direct energy consumption. Financial assets such as equity are found to emit, on average, 75-150 tonnes of carbon dioxide equivalent per million dollars or euros. Third, emissions from capital ownership appear to be more concentrated than capital itself, with the top 10% of the population emitting 70-85% of all emissions linked to capital 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 and particularly so at the top of the distribution. We explore policy options consistent with this perspective.

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1 Introduction

Understanding how greenhouse gases (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 corporations or individual 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 the production processes (in the energy sector and beyond) that release emissions into the atmosphere. However, this ownership is not distributed equally across the population.

Previous approaches to measuring carbon inequality have focused on the role of consumers. These studies have been crucial in enriching our understanding of emissions dynamics and responsibilities. In particular, consumption-based approaches are able to 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 industialized countries). However, in a given country, these approaches typically place the entire responsibility for all emissions on final consumers – although these consumers often 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 wealth-related emissions therefore stands out as a critical issue in the context of decarbonization.[1]

The purpose of this paper is threefold. First, we construct three approaches to measuring individual carbon footprints that account for ownership-related emissions to varying degrees. Our goal is to develop strategies that systematically incorporate the production footprint of firms into the individual carbon footprint of their owners and their consumers. These approaches are constructed so that the final estimates are consistent with macroeconomic aggregates and avoid double-counting of emissions. Second, we apply the three approaches to France, Germany, 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 due to their varied energy mixes and levels of economic inequality. This setting provides a diverse backdrop for examining carbon inequalities. 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 concepts mobilized in this paper are the following. In the *ownership approach*, emissions from production sectors (e.g. emissions from a cement factory) are attributed the owners of firms. In the *consumption approach*, emissions from production sectors are attributed to final consumers (e.g. individuals who purchase cement or goods which contain cement). In the *mixed approach*, 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 cars, or from home heating, for instance), are attributed to the households which release those emissions.

[1] We use the terms "ownership emissions," "capital emissions," and "wealth-related emissions" interchangeably throughout the paper. All our results refer to total greenhouse gas emissions expressed in CO2 equivalents.

We develop estimates for the three approaches using distributional environmental accounts for France, Germany, and the United States. Our methodology integrates official environmental accounts (namely air emission accounts) with national accounts (the standardized set of methods to measure the production, income and wealth of nations). In particular, we make the most of recent developments in economic accounting, which help measure inequality in the distribution of income and wealth, referred to as *distributional national accounts* (Blanchet et al., 2020; Piketty et al., 2018).

By linking production emissions to industries and then associating capital stock items with industries and institutional sectors, we identify wealth-related emissions associated with household and government sector assets. Furthermore, we account for emissions from cross-border investments and align our results with macroeconomic aggregates and concepts. Consumption-related emissions are obtained from environmentally extended input-output databases. To distribute emissions to individuals, we use the breakdown of asset ownership across the wealth distribution (as recorded in wealth surveys or distributional national accounts), in conjunction with existing estimates from the literature on the distribution of direct and consumption-related emissions.

Our key findings are as follows.

First, we find that carbon inequalities are notable in the three approaches, although important differences stand out. Fully accounting for emissions from capital ownership at least doubles the total emission share of the top 10% as compared to consumption-based emission accounting approaches (see Figure 1). For example, in our consumption approach, the wealthiest 10% in the US account for nearly 24% of emissions of the country, vs. 50% in the ownership approach (and 32% in the mixed approach).[2] The average individual carbon footprint of the top 10%, measured in tonnes of emissions per year, increases by 2-2.8x when we account for ownership emissions.

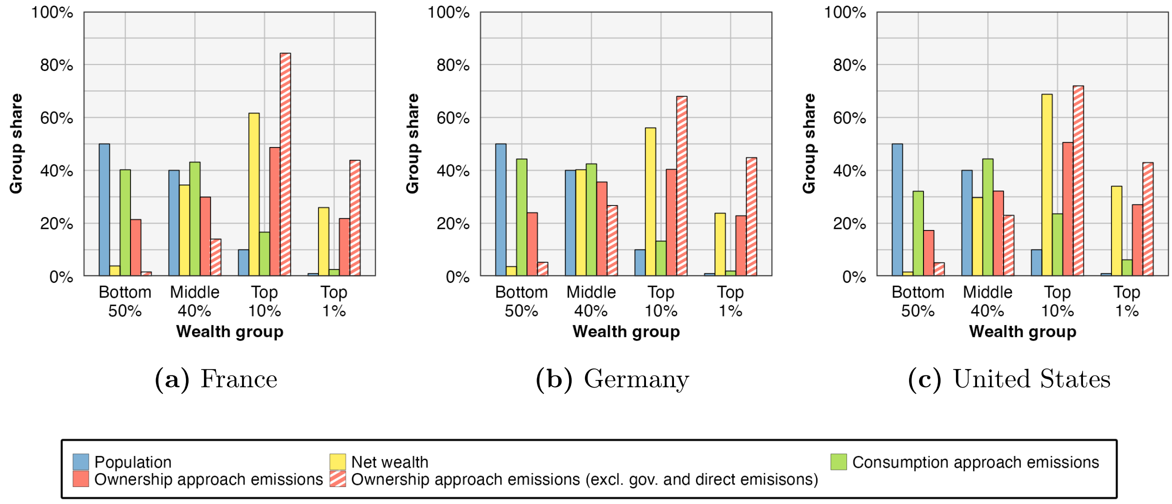
Second, our estimates indicate that in the ownership approach, the majority of emissions (i.e., 75-80%) for the wealthiest 10% of the population originate from the assets they own, rather than their direct energy consumption. Owning equity worth a million euros or dollars is associated with 75-150 tonnes of carbon dioxide equivalent (tCO2e), compared to the average per capita footprint which ranges from 8-20 tCO2e in the three countries.

Third, we find that emissions from capital ownership appear to be even more concentrated than capital itself, with the top 10% of the population emitting 70-85% of the total emissions related to capital 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 than the types of assets predominantly owned in the middle or the bottom of the distribution (such as deposits, housing or pension assets).

[2]Note the difference between *total* emission shares (i.e., including direct and government emissions) and measuring the concentration of only the subgroup of emissions linked to capital ownership. The first finding is related to the former, the second finding to the latter. Total emissions are less concentrated at the top than capital ownership emissions only. The same difference is reflected in the solid red and striped red bars in Figure 1.

Fourth, we demonstrate that a tax of 150 euros/dollars per tonne levied on the carbon content of assets would be significantly more progressive than an equivalent tax on the carbon content of consumption. A tax of 150 euros/dollars per tonne on wealth emissions would amount to an average annual wealth tax of 0.1%-0.4% for the middle 40% of the distribution, in contrast to a carbon tax on consumption, which would represent 0.7-1.2% of wealth for this group. For the top 1%, the scenario is essentially reversed: a carbon tax on wealth emissions implies a wealth tax rate of 0.5-1.1%, whereas a carbon consumption tax would equate to a tax rate of only 0.1-0.2% of wealth. Preliminary estimates suggest that a 150 euro/dollar tax on the carbon content of assets could generate revenues of up to €36 billion in France, €74 billion in Germany, and $534 billion in the US.[3]

Figure 1. Distribution of emissions and wealth by wealth group



(a) France **(b)** Germany **(c)** United States

Note: The graph presents the shares of four net wealth groups among the total population, total wealth and emissions. Emissions shares are provided for two different approaches: the consumption approach and the ownership approach. In the ownership approach, we present *total* emission shares (i.e., including emissions from asset ownership, government and direct emissions) in the solid red bars, and emission shares which are only related to asset ownership (i.e., excluding government and direct emissions) in the striped red bars. Appendix II, Figure B.1 includes the respective group shares for the mixed approach. Values refer to 2017 in France and Germany and 2019 in the United States.

Our results contribute to the existing literature the following ways.

First, we develop a general framework to measure individual carbon footprints, in a way that is fully consistent with satellite environmental accounts as well as distributional national accounts. Our concepts and methods therefore complement the large body of work on the measurement of income and wealth inequality (Blanchet et al., 2020; Piketty et al., 2018), via the conceptualization of *distributional environmental accounts*.

Second, our approach departs from a relatively large literature on carbon inequality which focuses on consumption-related emissions (Chancel & Piketty, 2015; Golley & Meng, 2012; Weber &

[3]This is obtained in a static framework with full compliance and without dynamic response to taxation.

Matthews, 2008). Our framework makes it possible to measure the emissions of individual consumers, but also of owners and investors. It can therefore be used to assess and discuss the contribution of individuals from different perspectives and account for conflicting narratives about the responsibility for emissions (e.g. firms vs. individuals). Our study complements a small number of recent studies which looked at 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 enquiry, at a time when very little information exists on the carbon content of individual asset portfolios across the wealth distribution, beyond a few industry-led initiatives (GHG Protocol, 2004; PCAF, 2022).

Finally, the datasets we build allow us to produce simplified estimates on the potential of novel climate policies tools, namely taxes levied on the emission content of assets held at the individual level. We discuss, for example, how such a carbon wealth tax compares to a tax on consumption-related emissions or to an emission-agnostic tax on net wealth. Our paper thereby contributes a new perspective to the literature on the incidence of carbon taxes (Sterner, 2012; Williams III et al., 2015), adding to the conversation about how these studies may inform theories of optimal taxation (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 data sources and methodology. Section 4 shares our aggregate findings. Section 5 examines emission inequalities among individuals based on the new approaches. Section 6 reflects on our findings and discusses policy implications, and Section 7 offers concluding remarks.

2 Related Literature

This section reviews and critiques the dominant consumption-centered approach to calculating individual carbon footprints, highlighting its limitations and discussing earlier attempts at developing alternative perspectives.

2.1 Origins of the carbon footprint concept

The concept of the *carbon footprint* goes back to the early 2000s and its presence in environmental research has grown rapidly since then.[4] 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).[5] Carbon footprint estimates should therefore ideally follow the two fundamental principles of carbon accounting: (i) comprehensiveness and (ii) exclusivity. Carbon footprints need to be

[4]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. See Appendix II, Figure F.1 for a graphical representation.
[5]IPCC (2022), Working group III, Annex I, p. 1796 drawing on Wiedmann and Minx (2008).

comprehensive in that they seek to measure not only direct, but also indirect emissions associated with the economic activity. At the same time, emissions included in the carbon footprint should be *exclusive*, i.e. there should not be any double-counting and the same tonne of carbon should not be included in more than one carbon footprint.

Carbon footprints have been calculated for a variety of actors, including individuals, geographical regions, industry sectors, and specific products or processes. The definition provided by the IPCC does not limit the scope of entities that may be analyzed in terms of their carbon footprint. The concept of individual carbon footprints—also referred to as personal or household carbon footprints—has garnered increasing attention in both public discourse and academic circles, however. It refers to the footprint associated with an individual's activities, lifestyle or choices. Shedding light on personal footprints can help individuals better understand their role in anthropogenic climate change because it can guide individuals towards identifying what can be changed at their own level. The key question is what type of emissions should be included in an individual's carbon footprint.

2.2 Consumption-centered approaches

A straightforward approach to calculate individual carbon footprints is to relate individual consumption choices to the emissions released when goods and services are produced and consumed. The underlying assumption is that individuals express their preferences through consumption choices, which signal producers what to manufacture and in what quantity, thereby guiding resource allocation in the economy. In such a view, all environmental pollution is assumed to ultimately serve consumption, because pollution is either a byproduct of production which serves consumption, or directly results from the act of consumption (literally to *waste*, in latin). The primary climate policy principle linked to consumption footprinting approaches would be the "consumer pays" principle.[6]

Consumption-centered approaches have demonstrated their relevance, especially when applied at the country level, because they accurately capture emissions which are outsourced to other countries. For example, emissions may be released in low-income economies, but ultimately serve the consumption and lifestyles of individuals in high-income home countries (Lenzen & Murray, 2010). The progressive shift in the Intergovernmental Panel on Climate Change (IPCC) negotiation framework towards monitoring and discussing both territorial and consumption emissions has garnered praise from several countries, in particular in the Global South.

Other interests may have played a role to promote the strong focus on individual consumption choices as well. British Petroleum (BP), an oil and gas company, was among the first to make reference to the concept of an individual carbon footprint in 2004. At that time, carbon footprint research and related publications were virtually non-existent. BP defined the personal carbon

[6] See the discussion of "user pays" vs. "producer pays", for example in UN (1997).

footprint as “the amount of carbon dioxide emitted due to your daily activities – from washing a load of laundry to driving a carload of kids to school” (Wiedmann & Minx, 2008).[7]

A large literature has emerged subsequently, which applies the consumption-centered notion of individual carbon footprints in the form of country-level studies. The methodology most often applied relies on multi-regional input-output tables and the Leontief inverse (Leontief, 1970) (to account for emissions released abroad to serve domestic consumption), which are combined with environmental pollution data to obtain pollution-per-currency-unit coefficients of various economic production sectors. These coefficients are then multiplied with individual or household expenditure on different consumption items, obtained from household budget surveys (Bruckner et al., 2022; Büchs & Schnepf, 2013; Chancel & Piketty, 2015; Druckman & Jackson, 2008; Gore, 2020; Kerkhof et al., 2009; Lenzen et al., 2006; Nässén, 2014; Oswald et al., 2020; G. Peters et al., 2006; Pottier, 2022; Roca & Serrano, 2007; Semieniuk & Yakovenko, 2020; Sommer & Kratena, 2017; Starr et al., 2023a; Steen-Olsen et al., 2016; Weber & Matthews, 2008; Wiedenhofer et al., 2017; Wier et al., 2001).

This body of work paved the way for a systematic understanding of the drivers and dynamics of personal carbon footprints and of emission inequality on the individual level within and between countries. A key recent finding of the stream of work 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).[8]

2.3 Critique of the consumption-centered approach

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, 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.

In fact, individual consumers are constrained by the goods and services offered at any given point in time and the infrastructure and capital stock installed in the country where production takes place. Market failures such as monopoly power, limited information or political economy dynamics can result in situations, in which consumers do not have a choice but to purchase fairly carbon-intensive goods (e.g., in a country where the production of basic necessities releases a lot of emissions). Acknowledging that certain consumers do not have the ability to change their behavior (e.g. because less carbon-intensive goods and services are sold with a mark-up) could also be a motivation to move beyond a purely consumer-centered carbon footprint.

[7] The company launched an advertising campaign asking individuals to reflect on what they could do to reduce their own footprint. It also published a carbon footprint calculator, providing information on the approximate footprints associated with individuals’ daily lives.

[8] Chancel (2022) confirms these conclusions in a framework which departs from the consumption approach.

In a more general sense, the limitations of consumer-centered approaches also appear in the works of Akerlof (1970) and Rothschild and Stiglitz (1976), for example, who highlight the role of information asymmetries. Yet another set of arguments can be found in S. J. Grossman and Hart, 1986 and Hart, 2017 who argue that, rather than only consumption, the ownership of capital itself involves residual control rights and can be a source of utility. If production is not only serving consumption, then it follows that pollution resulting from production cannot only serve consumption.

2.4 Production-centered approaches and methods of shared attribution

These limitations of a purely consumption-based view have long been recognized in the emissions literature.[9] However, the literature has mostly resorted to contrasting consumption footprints with the production footprints of firms, or to proposing mixed approaches to allocate total emissions between consumers and producers. What we propose in this paper is to develop a general framework for systematically incorporating both the consumption footprint of individuals and the production footprint of firms into individual carbon footprints.

One stream of literature has taken the opposite strategy, attributing all emissions to institutional producers, i.e., firms, rather than attributing emissions to individuals or final consumers. These studies typically measure firm-level emissions and develop methodologies to track the carbon footprints of both upstream and downstream production processes. For example, Griffin and Heede (2017) highlight the emissions of major oil and gas companies since the industrial revolution. The study finds that 100 companies account for 71% of global industrial greenhouse gas emissions since the industrial revolution. In this view, absolutely all emissions associated with the fossil fuels extracted by these companies are attributed to the company. Such a perspective has been called the "extraction-based approach". Other studies have examined the carbon footprint of multinational corporations' supply chains beyond the fossil fuel industry.[10]

Even though producers play a key role in global emissions, it is important to note that when studies attribute emissions to firms, they cannot, at the same time, attribute the same emissions to consumers or individuals, as per the *exclusion* principle. While it might make sense to attribute (some or all of) emissions to firms, these entities are not autonomous agents operating without human intervention: they are governed by managers and belong to shareholders who hold power over strategic decisions. Put differently, individuals are behind the behavior of firms, either as consumers, regulators, owners or investors. This is why we propose to include firm emissions into

[9] In fact, at the national level, production-based accounting long preceded and dominated consumption-based carbon accounting because production-based accounting was the baseline for emissions reporting in international climate treaties. The call to consider consumption-based accounting methods at the national level was later motivated by the failure of production-based approaches to account for emissions embodied in international trade.

[10] Zhang et al. (2020), for example, find that carbon emissions embodied in the supply chains of foreign affiliates of multinational corporations reached about 6Gt CO2 in 2016, or nearly 20% of the global total. The footprint of some large multinationals in Zhang et al. (2020) can be compared to that of some countries: Coca-Cola's carbon footprint is almost equivalent to the entire food sector in China. Walmart's emissions are higher than those of the entire German retail sector.

individual carbon footprints of firm owners, rather than simply assigning (some or all of the) emissions to producers, i.e. firms.

Attempts have also been made to split total emissions between consumers and producers through methods of shared attribution. Although authors typically do not propose to redistribute production emissions to the individual owners of firms, these papers are conceptually linked to the *mixed approach* we suggest in this paper to split emissions between consumers and firm owners. For example, an earlier suggestion in the literature was to divide emissions between firms according to the share of value added at each stage of the production process and allocate the remaining emissions at the very last step to consumers (Lenzen et al., 2007).[11] A more recent contribution proposed to divide emissions between consumers and producers based the relative size of the additional economic surplus derived by consumers and producers as a consequence of the under-taxation of emissions (Jakob et al., 2021). While these approaches can be implemented on a macro-level, it remains challenging for individual investors to calculate their own emissions following these methodologies. Neither information about the value-added at each preceding step of the value chain is usually available to firm owners, nor the precise shape of supply and demand functions (which is necessary to calculate the producer and consumer surplus). In contrast, our ownership and mixed approaches would only require firm owners to know the direct emissions released by the firm, or the emissions necessary to sustain the investment of the firm.

Income-based carbon accounting is another alternative strategy to distribute emissions between economic actors (Lenzen & Murray, 2010; Pottier & Le Treut, 2023; Starr et al., 2023b). Similar to the approaches we propose, it represents a potential strategy to distribute all emissions in the economy to individuals while moving beyond a purely consumption-centered individual footprint. 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 either 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. To account for the indirect emissions enabled by the inputs provided as a worker or capital owner, the approach is typically implemented by calculating a Gosh inverse in multi-regional input-output models (rather than the Leontief inverse used in consumption-centered approaches). To our knowledge, two studies have mobilized such an approach for the countries we look at in this paper, namely Starr et al. (2023b) for the US and Pottier and Le Treut (2023) for France (although the latter study limits the analysis to the inequality of carbon emissions embedded in labour income flows).[12]

[11] Earlier papers have used fixed shares not grounded in economic reasoning to distribute emissions between consumers and producers (Ferng, 2003).

[12] We discuss potential advantages and disadvantages of our strategy over the income-based approach when we introduce the *mixed approach* in Section 3.1 and, in more detail, in Appendix I, Section C.2.

2.5 Carbon footprint of individual investment portfolios

Our work is also related to the relatively large number of private sector approaches and international initiatives that have emerged (partly in response to new disclosure requirements) which are aimed at calculating the carbon footprint of investment portfolios and other asset classes (GHG Protocol, 2004; PCAF, 2022). Similar to what we propose, these approaches try to incorporate emissions of firms into the carbon footprint of owners. Unfortunately, no consensus approach has emerged to this day. Furthermore, while useful for the individual banks, asset managers or investors, these approaches do not necessarily result in estimates that are consistent with economic and environmental aggregates on the macro-level (e.g., avoid double counting while also capturing all emissions) and hence fail to pass the *exclusivity* criterion defined above. For example, firm emissions might be distributed to an individual holding deposits in a bank that provides a loan to the polluting firm, while the same firm's emissions are also attributed to the shareholders. Portfolio carbon accounting methods have therefore not been used to study inequalities in ownership-related emissions across the population, to the best of our knowledge.

2.6 Distributional national and environmental accounts

Important progress has been made regarding income and wealth distributional accounting in the context of national accounts, but the systematic study of pollution inequality within similar frameworks remains in its infancy.[13] Encouraged by the 2008 revision of the System of National Accounts, statistical agencies have started to release aggregate air emission accounts, which provide annual emission estimates that are aligned with national accounting concepts (for example, on the industry level). While certain statistical offices produce distributional measures of pollution, these measures are not necessarily based on the combination of national accounts and emission accounts.

Distributional National Accounts (DINA) seek to reconcile the macroeconomic study of production, income, consumption, savings and wealth, with the microeconomic analysis of the distribution of economic resources between individuals (Atkinson & Harrison, 1978; Kuznets & Jenks, 1955; Piketty & Saez, 2003). Among the chief principles of this framework is the need to ensure macro-micro consistency, that is, to distribute the totality of national income (or wealth, savings, etc.) to individuals of a country (Blanchet et al., 2020).

We mobilize the DINA framework in this paper to develop a framework compatible with environmental accounting, in a way that ensures micro-macro consistency regarding both income, wealth and emissions. The DINA framework can be particularly interesting from the point of view of emission accounting: it provides building blocks for the systematic study of individual pollution

[13] In the past decade, a relatively large body of work has sought to produce Distributional National Accounts (DINA) covering both income and wealth for a large number of rich (Blanchet, Chancel & Gethin, 2022; Garbinti et al., 2020; Piketty et al., 2018; Saez & Zucman, 2016) and developing and emerging countries (Chancel & Piketty, 2019; Piketty et al., 2019) over the recent period and in the long run. The general principles underpinning this approach have been taken up by national statistical agencies to expand their statistical toolkit (André et al., 2023; Batty et al., 2019).

levels (Chancel, 2020, 2022). It can also help answer questions about which types of groups in the economy tend to have a more or less carbon-intensive consumption or savings behavior. Our estimates demonstrate the potential of distributional emission accounts, but we also highlight that better data on firm-level emissions and individual-level asset ownership would be necessary in all of the three countries under study to leverage the full potential of distributional environmental accounts.

3 Data Sources and Methodology

This section presents our conceptual framework, the main data sources used and our methodology for measuring carbon footprints. The framework makes it possible to account for emissions associated with individual consumption, investment and capital ownership to varying degrees, while being consistent with the principles of systematic and comprehensive carbon footprint accounting delineated by the IPCC (2022).

3.1 Conceptual framework: Three carbon footprint approaches

Our general framework for attributing GHG emissions to individuals encompasses three distinct methodologies: the ownership approach, the consumption approach, and the mixed approach. Each methodology consists of a unique strategy for allocating the carbon footprint of capital to a country's residents. While these approaches are not exhaustive, they provide a structure to analyze the political economy of the energy transition from three diverse and complementary viewpoints.

Ownership approach The ownership approach attributes so-called *scope 1* emissions of firms to the owners of these firms.[14] In other words: this approach assumes that owning 100% of a firm's capital stock for one year adds to that individual's footprint 100% of emissions directly released by the firm's production activity in the same year. 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 the individual. For incorporated businesses, this share corresponds to the share of equity owned by the individual investor among all outstanding equity.[15] If the capital stock or equity of a firm is owned by

[14]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."

[15]Note that large shareholders may have more voting rights per share owned than small shareholders. In this case, the ownership approach tends to underestimate the weight of large shareholders in firms' decision-making processes.

another firm, the associated 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.

The ownership linkage allows us to overcome the obstacle of combining annual emissions, a flow concept, and wealth, a stock concept. Annual emissions that are not direct household emissions occur in production processes. To produce, firms require capital. The capital stock, in turn, is either owned by domestic households, the government, corporations, or abroad. The ownership linkage between the stock of capital and the flow of annual emissions is one way to combine both concepts because those who own productive capital collectively have control over the production processes – and profit in the form of returns on their capital investment.

Our ownership approach follows a strict ownership perspective: we do 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). It also implies that we only assign a firm's *direct* emissions to the owners of the capital stock. We do so to comply with the *exclusivity* condition defined above, which must be respected to distribute all emissions to individuals and compare individual emission footprints.[16] Conceptually, if we were to apply our approach globally and aggregate each individual's emissions, total global emissions need to be equal to the actual global emissions in the same year – in line with the exclusivity and comprehensiveness conditions of carbon footprinting.

Some emissions are not released by firms' activities, but by households themselves (via their direct transport and heating needs). We propose to attribute these emissions to households, based on their actual consumption, in all three carbon footprint approaches. Direct household emissions in a narrow definition include emissions that are directly released within the sphere of the private household. The bulk of these emissions are related to the burning of fuel in private cars and to the heating of private homes. Our approaches also include in the same category the emissions necessary to satisfy private electricity consumption. In the ownership approach, these emissions could also be attributed to owners of power generation plants. However, it is relatively standard, when referring to the "direct energy" requirements of households or firms, to include this category.[17]

A certain share of the polluting production activity is fully or partially owned by the government. The ownership approach attributes these emissions to the government. Because we want to study the distribution of the totality of emissions on the individual level, we also include these government emission in individual footprints. Several potential strategies can be thought of to distribute government emissions to individuals. Two intuitive approaches are to either distribute

[16] An alternative version of the ownership approach 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.

[17] To the extent that individuals own the technologies associated with direct energy emissions, our attribution rule can be understood from the perspective of ownership. In reality, however, individuals (and in particular those at the bottom of the 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 approach that attributes heating emissions to homeowners instead tenants.

government emissions equally among the population as a lump-sum amount (flat distribution) or to distribute them using the same distribution as other emissions (neutral distribution). 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 a neutral distribution in other cases. We detail the approach further down below and in Appendix I, but we also suggest to present results under a number of alternative assignment strategies regarding government emissions (including a scenario in which government emissions are excluded entirely from individual footprints).

Note that the ownership approach deviates from a purely territorial view on emissions. For example, the ownership approach attributes emissions of firms that release emissions abroad to the domestic owners of these firms.

It is natural to ask how our ownership approach compares to emission accounting guidelines developed by the private sector, which calculate the carbon footprint linked to asset ownership held by financial institutions (GHG Protocol, 2004; PCAF, 2022). These approaches are different from our ownership approach mainly along two dimensions. First, most of these approaches also assign some emissions to the ownership of purely financial assets like corporate bonds. Second, they do not try to attribute all emissions to one ultimate owner firm or individual. Instead, they aim at reporting, for each asset owner, all emissions that are in some way linked to the asset owned. If a financial institution has provided a loan to a firm that emits carbon, these emissions would be part of the footprint of the financial institution and also of the firm itself. By doing so, these approaches do not avoid double-counting of emissions between firms because the indirect emissions of one firm are the direct emissions of another firm.

Nonetheless and maybe surprisingly, among the three approaches we present, the ownership approach remains closest to how emission accounting guidelines calculate the carbon footprint linked to asset ownership. These approaches are similar to our ownership approach in the sense that they do not attribute any emissions resulting from production processes to final consumers. If a financial institution owns a controlling stake in a polluting firm, the footprint of the financial institution includes all emissions of the polluting firm – and not only a fraction corresponding to the emissions linked to the investment of the firm (compare to our mixed approach). If the stake of the financial institution in the polluting firm is non-controlling, the firm's emissions would typically only be counted as indirect scope 3 emissions in the financial institution's footprint ("financed emissions"). Our approach is also similar to the cited emission accounting guidelines in the sense that our ownership approach calculates an attribution factor based on the ownership share to distribute emissions in case there is more than one owner.

Mixed approach The mixed approach attributes capital formation emissions to investors, and all other emissions to 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 that releases emissions serves final consumption, these emissions are attributed to final consumers.

The mixed approach proposes to split emissions between consumers and the owners of firms using categories and concepts available in national accounts, i.e. capital formation vs. final demand. This approach therefore explicitly recognizes the potential role of individuals as both consumers and owners of the capital stock. The mixed approach is demand-centered, which differentiates it from the ownership approach. In the ownership approach, emissions released by a firm through its own production activity only are attributed to the owner. In the mixed approach, emissions attributed to owners are only those necessary to satisfy the investment goods *demanded* by the firm in a given year (whether they are self-produced or not and whether they are produced domestically or abroad). This approach could therefore also be called "final demand approach" in the national accounts sense.[18]

Implementing the mixed approach on the national level requires a multi-regional 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.

All emissions occurring during the production process of firms and that are *not* related to investment (or "gross capital formation") are attributed to consumers in the mixed approach. These emissions correspond to the direct emissions (the same amount as in the ownership approach) and indirect emissions that were necessary to produce the goods and services consumed on the individual level. For example, if a resident individual purchases a clothing item that has been produced abroad, the individual would be attributed emissions released in the production process of the item. This is in contrast to the ownership approach where these emissions are included in the footprint of the owners of the firm producing the garment. Consumption emissions in the mixed approach thus also include the emissions induced abroad to satisfy domestic final consumption. There are different potential strategies to attribute emissions linked to government investment and government consumption to individuals, as we discussed in the ownership approach. We follow the same strategies regarding government emissions in the mixed approach as in the ownership approach.

Attributing only net capital formation emissions, as opposed to gross capital formation, to investors would mechanically reduce the amount of capital emissions allocated to them. For instance, in the US, net investment accounts for approximately twenty-five percent of gross investment. Net capital formation encompasses the construction of new buildings and machines used in production processes. In contrast, gross capital formation includes, in addition to net capital formation, the replacement of existing machines and other fixed assets. Our decision to attribute emissions to gross rather than net capital formation is rooted in the following considerations: First, national accounts distinguish gross capital formation from household final

[18]The ownership-related emissions in the mixed approach hence incorporate both direct and indirect emissions. If, for example, a firm invests in machinery whose production relied on carbon intensive inputs produced abroad, these emissions would be taken into account in the the footprint of the owner.

consumption; thus, conceptually, the replacement of depreciated capital is not intermediary consumption. Second, considering carbon emissions, it is prudent to treat emissions associated with gross capital formation distinctively from those originating from household final demand. This distinction is crucial as there are varying carbon intensities in replacing depreciated capital – replaced machines can be produced with differing amounts of coal, for instance – similarly to the production of new capital.

Alternative approaches to split total emissions between economic actors were presented in the literature review section of the paper. While we concluded that approaches based on the value-added or economic surplus would be difficult to implement on the individual investor level, income-based accounting would be a prime alternative and complementary strategy to our mixed approach. Income-based accounting associates emissions with labour and capital income streams in order to distribute total emissions between workers and capital income earners. By doing so, these approaches also move beyond a purely consumption-centred approach because the saving and investment behavior by individuals can impact their carbon footprint.

While we see these approaches as important contributions, we do not believe they can substitute the mixed approach we develop in this paper based on capital ownership. For example, in an income-based approach, current-year production emissions would not be part of an investor's footprint if no income streams are generated. This could be the case if investors delay the time period in which they realize capital gains or distribute firm profits (potentially indefinitely or until the carbon intensity of the firm has declined). In such a scenario, a large share of the firm's emissions would be incorporated into the carbon footprint of workers who continue to receive labour income.

Consumption approach The consumption approach allocates all direct and indirect emissions to consumers, including investment-related emissions of the firms that produce goods and services for final consumption in year $t + 1$. This approach has been followed by many studies to track the inequality in emissions between individuals. We have discussed limitations of the consumption approach in Section 2.3.

Note that the total emissions of a country will be different in the consumption and mixed approach on the one hand, and in the ownership approach on the other hand. This is due to two reasons: First, the treatment of cross-border investment, i.e. the ownership approach includes the entire direct emissions of foreign firms owned by residents in their footprint while emissions of resident firms owned by foreigners are not part of total national emissions. Second, the inclusion of indirect consumption emissions in the consumption and mixed approach. Both the mixed and the consumption approach account for the indirect emissions released abroad to satisfy domestic consumption. The ownership approach, on the other hand, only includes direct household emissions and the emissions linked to the firms owned by resident institutional sectors (see Figure 3 and also Appendix I, Section B.10).

In summary, while none of the three methods, on its own, provides a definitive answer to the carbon footprint of individuals, each offers a valuable and complementary perspective on emission inequalities. This multi-faceted approach is akin to understanding economic inequality: consumption distribution provides one perspective on economic inequality, yet it needs to be complemented by income or wealth distributions to properly understand economic inequality.

3.2 Data sources

We now introduce the data sources we use. We then describe in detail in the next section how we implement the three conceptual approaches for each of the three countries under study using the data sources introduced here.[19]

Wealth data. We rely on the third wave of the Household Finance and Consumption survey (HFCS) to obtain the breakdown of assets 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 several disadvantages which imply they are not able to fully capture the wealth dynamics at the very top of the distribution, despite recent improvements and the over-sampling of the rich. For example, there are no households with a net worth above one billion euros in the HFCS even though we know these households exist in reality. We therefore make a number of adjustments to the wealth survey which attempt to correct for these shortcomings. There is a large literature on correcting top tails of surveys. It ranges from the traditional approach to estimate a Pareto-shaped top tail based on external data points (often from "rich lists" such as the Forbes Billionaires list) to newer approaches based on a more flexible Pareto distribution (Blanchet, Fournier & Piketty, 2022).

Here, we opt for a re-weighting approach, using the wealth distribution recorded in the World Inequality Database (WID) as a reference point. We start by adjusting 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 and total value of assets owned, but it does not correctly capture the position in the distribution of the individual. We describe the approach in more detail in the Appendix. Because wealth is recorded on the household level in the survey, we also individualize survey wealth using the information about the composition of the household available in the 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. More detail on the matching of categories and the re-scaling

[19] Appendix I, Table E.1 lists all data sources and the precise data series used.

exercise for France and Germany is provided in Appendix I. 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 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 market value (net of depreciation) because it corresponds to how financial assets, for which only the market value exists, are recorded in the wealth survey.

Emissions data. Emissions data by industry are sourced from air emission accounts released by Eurostat for France and Germany. These accounts include the annual flow of annual greenhouse gas emissions, and they are fully consistent with national accounting concepts. Emissions recorded in air emission accounts correspond to the amount of total direct emissions released by each industry (scope 1). The emission accounts also include, separately, the direct emissions of the household sector (e.g., burning fuels to drive a private car, heating the apartment etc.). For the Unites States, we use air emission accounts published by the OECD, which record emissions by industry as well, although on a less granular level.

Household direct emissions in air emission accounts do not include emissions linked to the electricity consumption of private households (but only of fuels directly burned within the household). However, in our distributional approaches, we do want to keep emissions associated with private electricity consumption within the footprint of the household and not transfer it, for example, to the owners of electricity production plants. This is also important because private electricity will likely play a larger role in the future as a larger share of private heating systems and vehicles will operate based on electricity. We therefore use additional data sources to separate out the electricity emissions linked to private households. 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 on these data sources are provided in Appendix I, Section B.6.

Environmentally extended input-output tables. We are not only interested in direct emissions by industry. Instead, the mixed approach and the consumption approach require calculating the direct and indirect emissions necessary to satisfy final demand. For these purposes, we rely on a carbon footprint dataset released in April 2022 by Eurostat as part of the FIGARO (Full International and Global Accounts for Research in input-Output) project. 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. 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. To represent the group of countries not included in the list of 45 countries, the dataset includes a *rest of the world* category. The emission footprints in the FIGARO dataset are the result of applying a Leontief model to the inter-country input-output tables.[20] The FIGARO emissions data is available for carbon dioxide emissions only while we would like to include all greenhouse gas emissions. We therefore re-scale emissions in the FIGARO data using a country-year-industry conversion factor obtained from comparing CO2 and GHG emissions in air emission accounts, as detailed in Appendix I, Section B.10.

Emission inequality data from the literature. We rely on the latest country-specific estimates we are able to locate in the literature for the distribution of direct and consumption-related emissions. With this strategy, we can avoid imposing a constant elasticity parameter on the distribution of direct and consumption-related emissions in the mixed approach and the consumption approach. For France, we use the series published in Malliet (2020). The distribution for Germany comes from Hardadi et al. (2021) and, for the United States, we rely on the estimates produced by Starr et al. (2023a). These studies are based on 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 necessary to produce the goods and services consumed. We present each of the three papers and the underlying data in more detail in Appendix I, Section C.3.

Cross-border investment data Finally, 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 the countries of the European Union, 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 on the carbon intensity of 200 economies from the EU-EDGAR database (emissions released per 1,000 US dollars in GDP). The database is used to calculate the relative emission intensity of countries in order to quantify emissions linked to cross-border investment in countries other than the three countries covered in the paper. We use the v7.0 release of the database published in 2022.

[20]The Leontief model is a static model, which assumes a linear relationship between inputs and outputs (Leontief, 1970). Calculating the carbon footprint linked to final demand by means of a Leontief model requires an input-output table and a vector of emissions by industry. It then takes three steps: **1.** Calculate the technical coefficients. These coefficients represent the necessary inputs from sector i to produce one unit of output in sector j. To obtain the coefficients, each cell in the input-output table is divided by total industry output. The matrix of technical coefficient is usually referred to as matrix A. **2.** Calculate the Leontief inverse. The Leontief inverse is given by $L = (I - A)^{-1}$. Each element in L represents the total direct and indirect input from sector i needed to produce one unit of final output in sector j. **3.** Multiply the Leontief inverse A by the final demand vector (e.g. household final consumption) and by the emission intensity vector. The emission intensity vector includes the emissions per unit of output for each industry. See Davis and Caldeira, 2010 for an application of this procedure to aggregate consumption emissions and G. P. Peters, 2008 for a discussion of consumption-based accounting concepts. We also provide more details in Appendix I-B.9.

3.3 Methodology

We now explain how we use the data sources to implement the three conceptual approaches and distribute aggregate greenhouse gas emissions to individuals. In a first step, we prepare extended macroeconomic environmental accounts. Compiling macroeconomic environmental accounts is a necessary first step to implement the ownership and mixed approach for an entire country.[21] These extended aggregate environmental accounts record aggregate emissions of each industry, asset class and institutional sector. In a second step, we distribute the aggregate emissions in the macroeconomic environmental accounts to individuals, using information about assets owned from the wealth survey and from distributional national accounts.

3.3.1 Step 1: Extended aggregate environmental and economic accounts

The goal of extended aggregate environmental accounts is to present the carbon footprint of industries or institutional sectors as a whole. For example, aggregate environmental accounts ask: What is the carbon footprint for emissions of the manufacturing sector? What is the footprint of the household sector or the government sector? The former question is already answered by the air emission accounts that statistical offices have started to release.

The novelty here is that we relate emissions to the capital stock owned by institutional sectors, which allows us to answer questions of the latter type. We can also calculate the average annual emissions per dollar or euro owned and compare our macroeconomic estimates to the carbon footprint of investment portfolios as released by private sector institutions. To do so, we need to bring together air emission accounts with information about the type of capital deployed in each industry and information about the direct and indirect ownership of the capital stock by institutional sector. We also need to account for cross-border investment. These extended environmental accounts (by institutional sector rather than by industry) are necessary to then distribute the aggregate emissions of each sector to individuals.

We need to prepare two versions of these extended environmental accounts. One version corresponds to the ownership approach, which attributes annual emissions of firms to their owners. The other version corresponds to the mixed approach, which attributes emissions induced by the investment activity of firms to their owners. We start by explaining how to construct the extended environmental accounts for France, Germany and the United States in the ownership approach and then show how to move from the ownership to the mixed approach.

Linking industry-level emissions to the capital stock. Annual direct emissions by industry are readily available in air emission accounts. The only change we make is to remove emissions

[21]For one individual, the approaches could be implemented without macroeconomic 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. In the paper, we start from aggregate environmental accounts by industry because this type of information is not available on the economy-wide level for the three countries under study.

linked to private electricity consumption from the energy sector using the additional data sources introduced earlier. Other direct household emissions (burning of fuel to drive the private car or heat the apartment) are already separated from industry emissions in air emission accounts.

To assign the 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 $50\% \times 1\% + 25\% \times 1\% = 0.75\%$ of national emissions (in the ownership approach). The core element used for this backward attribution is a matrix of capital stock by industry and asset (from national accounts), and a vector of annual emissions by industry (from air emission accounts). 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 source data) for 8 industries and 4 asset categories.[22]

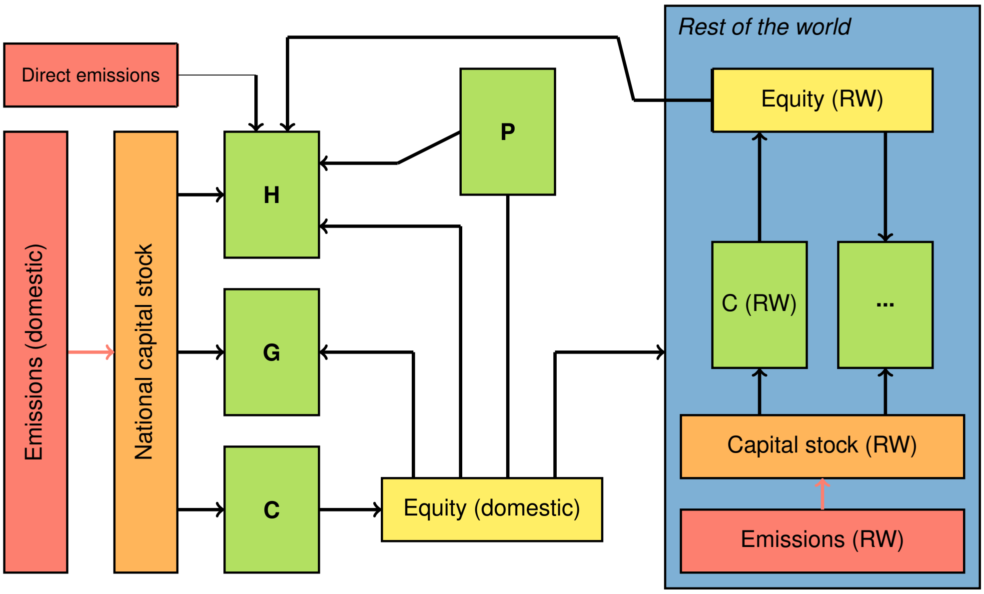
Linking the capital stock to institutional sectors. We have now obtained a table recording the total emissions associated with owning 100% of each of the capital stock components in the country. As a next step, we determine whether these capital stock assets (and the associated emissions) are owned by the household sector, the government or corporations.[23] If the household sector owns 10% of business buildings and structures, it is assigned 10% of the emissions that have been allocated to business buildings and structures in the previous step. The attribution exercises requires a table recording the non-financial assets owned by institutional sector.

The exercise is straightforward for the household and the government sector, but the emissions linked to the capital stock owned by the corporate sector require further attention. This is because corporations are ultimately owned by one of the three other institutional sectors: households, government or the rest of the world. In the ownership and mixed approaches, the emissions of the corporate sector would end-up in the emissions of these other sectors. For example, if an individual owns 5% of a polluting corporation, these emissions would enter the emission responsibility of the individual. Similarly, if the government owns a corporation, we want to assign these emissions to the government sector (and then to households based on the consumption of government services). Figure 2 illustrates the attribution of emissions to institutional sectors schematically.

[22]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 Appendix I, Section A.

[23]The rest of the world does not any 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. 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, though. It adds less than 1% to the capital stock owned by the household sector.

Figure 2. Attribution of emissions to economic sectors in the ownership approach



Note: Schematic illustration of emission attribution to the capital stock and to institutional sectors in the economy in the ownership approach. 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 are ultimately attributed to either the household sector (H), the government (G), or to foreign investors (RW). (P) refers to the equity owned by pension funds and life insurance.

To distribute the capital stock (and the associated emissions) from the corporate sector to the respective "ownership sector", we opt for an approach similar in spirit to what Piketty and Zucman (2014) do.[24] The idea is to use the ownership of domestic corporate equity in financial balance sheets to calculate the share of the total equity owned by each sector. After removing the percentage of domestic equity that is owned abroad, we distribute the remaining, domestically-owned equity (i.e., one minus the equity owned abroad) among the domestic institutional sectors according to the relative size of their respective equity holdings. We exclude inter-corporate holdings because these firms are ultimately owned by another institutional sector. Importantly, we also include a forth sector, namely the pension and life insurance sector. We do not remove the equity owned by this sector (which is part of the corporation sector) from inter-company holdings and then include the sector when calculating the share of equity owned by each sector. More details and tables that illustrate how we calculate the share of equity owned by each institutional sector are provided in Appendix I, Section B.7 and Tables B.1-B.3.

After accounting for the corporate sector (and redistributing its emissions to the ownership sectors), we obtain a table recording the total annual ownership emissions of the household, government and the rest of the world sector. The ownership emissions of the household and

[24] For their measure of national wealth at market values, they disregard corporate wealth because, in national financial balance sheets, it is already fully included in the government, household, and the rest of the world sector through the equity holdings of these sectors.

government sector are made up of the emissions linked to the *direct* ownership of the capital stock (housing and directly owned business assets), and the emissions linked to the *indirect* ownership of the capital stock through owning domestic corporate equity or pension and life insurance assets.

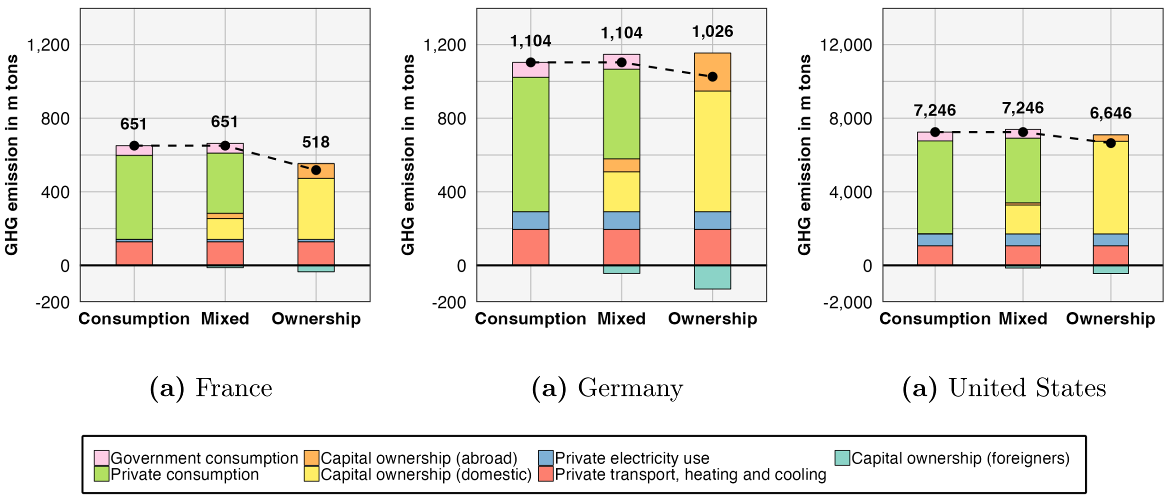
Finding a proxy for emissions linked to foreign investment. What is missing from the previous exercise is a proxy for the emissions linked to the *foreign* corporations owned by domestic households, the government or pension and life insurance funds. The total foreign equity owned by resident investors 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. 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. Using the 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. The result is a proxy for the total emissions linked to the foreign equity owned by each of the three institutional sectors. More details about these calculations are provided in Appendix I, Section B.8.

Producing estimates for the mixed approach To implement the mixed approach, we only have to swap the "emission by industry" data we use. Instead of the air emission accounts (which record total direct emissions by industry), we use the emissions by industry sourced from environmentally extended input-output tables. Our preferred data source, the EU-FIGARO dataset, enables us to obtain the direct and indirect emissions linked to the investment activity by industry. We then re-apply the procedure described in this section, using the (lower) emission totals. Remember that due to the different perspectives (final demand vs. direct production), total national emissions are different under the mixed and ownership approach (see Figure 3). Note that the remaining emissions, related to final household and government consumption will be distributed to individuals as well in the distributional environmental accounts we prepare (see next section).

To summarize, in this first step of our method, we have prepared two versions of extended aggregate environmental accounts. One version corresponds to the ownership approach. It defines national emissions as the direct annual emissions of firms owned by resident units, plus direct household emissions. The second version corresponds to the mixed approach and it defines national emissions as the direct and indirect emissions necessary to sustain the final demand of resident units. Only the emissions necessary to sustain investment of firms owned by resident units are linked to capital owners. For each of the two versions, we then assign emissions to industries, industries to the capital stock and, finally, the capital stock (and the corresponding emissions) to its institutional ownership sector, either resident and non-resident. We can then divide emissions by the outstanding capital stock (for industries) or the total value of assets owned (for the household sector) to calculate average emission intensities. While the total amount of emissions assigned to capital owners varies in the ownership and mixed approach (total production emissions vs. investment emissions only), the types of capital ownership that give raise to *capital ownership-related emissions* are the same in both approaches:

- Capital ownership-related emissions are attributed to resident households through (i) the ownership of parts of the domestic capital stock (housing and directly owned business wealth) and through (ii) the ownership of resident and non-resident corporations (either through holding equity or pension or life insurance assets).
- Capital ownership-related emissions are attributed to the government through (i) the ownership of parts of the domestic capital stock (mostly buildings, structures, and land) and through (ii) the ownership of resident and non-resident corporations.
- Capital ownership-related emissions are attributed to the rest of the world (i.e. investors abroad) through the ownership of resident corporations.

Figure 3. Total national emissions in million tonnes according to the three approaches



(a) France **(a)** Germany **(a)** United States

Note: Re-scaled y-axis for the United States to ensure readability (x10). Total national emissions in 2017 (France, Germany) and the United States (2019) according to the three carbon footprint approaches. The breakdown shows which emissions are allocated to consumption and capital ownership. Direct household emissions (including emissions from private electricity use) are the same in all three approaches. Private and government consumption emissions include all domestic and foreign emissions necessary to satisfy domestic final consumption. Capital ownership includes government ownership. Emissions of domestic firms owned abroad reduce total national emissions while emissions of foreign firms owned by residents increase emissions. Tons refer to metric tons. See Appendix I, Tables B.4-B.6 for more details on the breakdown of emission aggregates.

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 the data on wealth ownership we use. It is our goal to distribute total national emissions to individuals for each of the three approaches. This enables us to estimate a comprehensive distribution of individual emissions that is consistent with macroeconomic aggregates. The thought experiment is that if we were to apply the approach to all countries globally, no emissions would be counted twice but all emissions would be counted and assigned to an individual.[25]

Assigning ownership emissions to individuals In the data sources we use on individual wealth, the following four asset categories are relevant when it comes to allocating ownership-related emissions: (i) housing, (ii) directly owned business assets, (iii) pension and life insurance assets and (iv) equity. Other types of wealth, such as purely financial wealth (bank deposits, bonds etc.) do not come with any emissions attribution in any of the three approaches we propose. Unfortunately, we do not have access to a more granular breakdown of assets in the wealth data we use so that we remain restricted to working with averages by asset type. Using the enhanced survey data (for France and Germany)[26] and the distributional national accounts micro-files (for the US), we attribute total emissions linked to each of the assets owned by the household sector to individuals. For each asset type and individual, we calculate the share of the asset owned by the individual among all assets of the same type. We then allocate the corresponding share of emissions available in the extended aggregate environmental accounts to the individual. The assignment process is the same in the mixed and ownership approach, but uses the different emission aggregates calculated in the previous step. In the consumption approach, no emissions are attributed to capital owners.

Distributing direct household and consumption emissions. We also want to distribute the emissions *not* linked to capital ownership to individuals in order to present a comprehensive distribution of individual emissions based on total national emissions. Depending on the approach chosen, these non-ownership related emissions can include only the direct households emissions (including electricity emissions) or they also include indirect emissions linked to the consumption choices of the individual. For example, in the consumption and mixed approach, the individual is attributed the direct and indirect emissions that were released when producing the goods and services purchased by the individual. In the consumption approach, these emissions also include the investment emissions of the firms that produced the goods and services.

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. The focus of this paper lies on shedding a light on the distribution of capital ownership-related emissions so that we see little value-added in reproducing these existing studies that focus on consumption-related emissions at the country level. Relying on the estimates produced in these papers also avoids imposing a constant elasticity parameter

[25] Appendix I, Figure C.2 presents a graphical illustration of the methodology and attribution procedures in the three approaches.

[26] We explain in the Section 3.2 and in Appendix I, Section A how we adjust the survey to match national accounting totals and overcome the shortcomings at the top of the distribution.

to distribute non-ownership-related emissions. Instead, we can leverage the actual distribution of these emissions as estimated in the papers. For the US, we mobilize data from Starr et al. (2023a) while data for France and Germany is sourced from Malliet (2020) and Hardadi et al. (2021). These studies combine expenditure by consumption categories derived from household expenditure surveys with information on emissions per euro or dollar spent per consumption category estimated from environmentally extended input-output models.

The papers we use provide separate estimates for the distribution of direct household emissions (including electricity) and of indirect consumption-related emissions, which we use to distribute the respective emissions. However, distributional data is only provided in tabulated form in the papers. We trace out the entire distribution using a generalized Pareto interpolation method. For the US, the data includes sufficient data points within the top decile to provide information about the shape of distributions at the very top. For France and Germany, data about the distribution at the top is more limited. For example, in France, we only know the average emissions within the top decile and do not have information about the shape of the distribution within the top decile. We hence decide to fit a constant-elasticity upper tail to the distribution in France and Germany. In other words, emissions within the top decile increase at a constant elasticity (with respect to income) of 0.2 for direct household emissions (including electricity) and 0.65 for indirect consumption emissions. These estimates are aligned with what is generally found in the literature, and they also fit well the distribution suggested by an additional data point within the top decile we have access to for Germany.

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 describe the process and the papers used for each of the three countries in more detail in Appendix I, Section C.3. To ensure robustness, we also present our results under alternative scenarios which do not rely on estimates from these three papers and instead distribute direct household and consumption emissions according to a (high or low) constant elasticity parameter for the entire distribution.

Distributing government emissions. The second major category of emissions *not* linked to individual capital ownership are the emissions linked to the consumption activity and capital ownership of the government. Distributing these emissions to individuals is a more delicate exercise because it requires additional assumptions about who uses and benefits from government services.[27] 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 benefits 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

[27]Note that these emissions do not include emissions linked to government transfers because these would be included in the individual consumption footprint.

these activities in proportion to their income. Such an approach implies that our estimates range between two more extreme assumptions, namely that (i) all government operations benefit all individuals equally or that (ii) all government operations benefit individuals in proportion to the income they earn. We describe in more detail in Appendix I, Section C.4 how we implement the approach.

The benchmark approach we chose is 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 therefore present our estimates also under a large number of alternative approaches regarding the distribution of government emissions. These robustness checks include scenarios under which total government emissions are (i) excluded completely, (ii) distributed equally (i.e. as a lump-sum amount) to individuals, (iii) distributed in proportion to individual income, (iv) distributed in proportion to consumption-related emissions, (v) distributed in proportion to all other emissions. The last scenario corresponds to a neutral scenario in which government emissions do not change the emission shares of wealth groups.

4 The Carbon Footprint of Capital

4.1 Capital emissions by industry and institutional sector

We begin by presenting some additional insights from the compilation of the extended aggregate environmental accounts. Tables 1 shows the emissions produced by different 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 the emissions associated only with capital formation, while the ownership scenario takes into account all the emissions of the industrial sector.

In France and Germany, manufacturing stands out as the largest emitting sector (95 and 212 million tonnes, respectively, in the ownership approach), while in the United States, agriculture and mining is the largest emitting sector (1,637 million tonnes in the ownership approach). The most carbon-intensive sector in the three countries is agriculture and mining (528 tonnes per million euros, 335 tonnes per million euros and 535 tonnes per million dollars, respectively). The waste and water sector ranks second in Germany (289 tonnes per million euros) and the United States (431 tonnes per million dollars), while the manufacturing sector ranks second in France (230 tonnes per million euros). As expected, emissions and emission intensities are lowest in the services sector (private and public services).

Interestingly, the carbon intensity of capital in the manufacturing sector is quite close in the three countries (around 200-230 tonnes 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 (e.g. in cement or steel production, for instance) across the three economies, in a competitive global market.

In other sectors, such as energy, emission intensities can vary significantly (151 tonnes per million euros in France compared to 289 in Germany and 431 tonnes 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. This is partly explained by the fact that 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 in Table 1. If one separates out construction in France and Germany –as we do in the more extended tables available in Appendix II– 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.

Table 1. Emission intensities by industry groups

Industry	Mixed			Ownership		
	tCO2e/ m euros capital	tCO2e/ m euros value-added	million tCO2e	tCO2e/ m euros capital	tCO2e/ m euros value-added	million tCO2e
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 in CO2 equivalents derived based from the 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 Appendix II. The granularity is lower than for France and Germany due to the less granular capital stock data. Based on data from Eurostat, BEA and EU-FIGARO.

4.2 Capital emissions by asset class

We now present the emissions intensity by asset class in the ownership approach.[28] In contrast to Section 4.1, where we used the value of the physical capital stock as the denominator, we now use asset values. This is a necessary step in attributing carbon intensity to the market value of asset held by individuals. The limitation of this approach, however, 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 here 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). Note that as per the definition of our ownership and mixed approach, no emissions are linked to owning fixed-income assets.

Equity is the most polluting asset class in the three countries according to the total emissions they are associated with. It is also a relatively highly carbon-intensive asset, emitting 75-150 tonnes per million euro or dollar. 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, and Morningstar) was around 140 tonnes per million dollar invested (FFF, 2023).

Business assets rank third in terms of absolute emissions in the France, Germany and the US. This asset class refers to the capital owned by unincorporated companies and their owners including machines and intellectual property, to produce goods and services. The carbon intensity per amount of business asset owned differs greatly across the three countries, with emissions at about 50 tonnes per million euros in France, nearly 90 tonnes in Germany, and exceeding 140 tonnes 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 a 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 release significantly more emissions per mile than their European counterparts (See Appendix I, Section 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 tonnes per million euros or dollars held in the first two countries and close to 150 tonnes per million euros in Germany). This finding is in itself quite striking and could suggest a stronger reliance of German pension schemes on the fossil-energy sector than in the two other countries. To put things in perspective, owning 100,000 euros of pension funds in Germany is associated with 14-15 tonnes emissions per year in the ownership approach, which is slightly more than the average carbon footprint per capita in this country.

[28]Appendix II, Table A.4 presents the same results for the mixed approach.

Housing assets represent the largest asset class (from the point of view of market values) in the three countries, but are not associated with any emissions (or close to no emissions), consistent with our methodology.[29]

In summary, when assessing the emissions intensity of different asset classes, clear patterns emerge. For a given amount of individual wealth, differences in asset portfolio allocation among individuals can result in significant differences in the emissions associated with that wealth. We analyze the effects on carbon emissions of observed variations in portfolio allocations across various groups of the wealth and income distributions in Section 5.

Table 2. Asset classes and emission intensity per million $/EUR owned (ownership approach)

	France (2017)			**Germany (2017)**			**USA (2019)**		
Asset class	b euros owned	million tCO2e	tCO2e/ m euros owned	b euros owned	million tCO2e	tCO2e/ m euros owned	b dollars owned	million tCO2e	tCO2e/ 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 of an individual who owns the asset for one year. The table presents household sector ownership emissions and does not include government-owned assets. Emissions attributed to assets based on the approach explained in the paper (ownership approach). The value of total assets owned is sourced from Eurostat national balance sheets (France and Germany) and from distributional national accounts released by Piketty et al. (2018) for the Unites States. Pension assets include life insurance assets.

4.3 The role of foreign capital in national emissions

We now turn the attention to the relationship between foreign capital and emissions associated with wealth ownership. It is noteworthy that 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. Foreign equity ownership therefore constitutes a substantial fraction of the equities held and the overall wealth of individuals in these nations.

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.

[29]The limited amount of emissions in the US is due to the fact that the real estate sector is not recorded separately in air emission accounts in the US. Therefore, following our approach, some emissions of the services sector will be allocated to housing capital (which dominates the capital stock in the combined "services" industry sector). Compiling more granular air emission account would be a prime task for the US.

Given the available data, we can only speculate about the reasons behind these observed differences. It is possible that US foreign equity is more financialized. By this, we mean that a 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 are comparatively less carbon-intensive in the US than those owned by French and Germans. It is worth noting that emissions tied to foreign equity could increasingly impact the wealth-related emissions of US and European nationals. This becomes especially pertinent as they navigate more stringent decarbonization policies at home, with no direct impact on the decarbonization of the assets they own abroad.

5 The Distribution of Carbon Footprints

5.1 Emissions rise with income and wealth

We now examine the distribution of carbon emissions, beginning with two foundational observations. Firstly, across all methodologies, emissions 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 approach, and 11x more in the ownership approach. In Germany, these gaps are of 1.5x in the consumption approach and 8x in the ownership approach. In the USA, the gaps are found to be of 3.5x in the consumption approach and 14x in the ownership approach.

Secondly, within the three countries studied, emissions in the consumption approach show lesser concentration than income or wealth. Mixed emissions parallel the concentration of income, and the concentration of total emissions in the ownership approach lies between that of income and wealth.[30] Given its income and wealth distributions, which are notably more unequal than in France and Germany, the US manifests the most pronounced carbon inequality among the three under all methodologies.

In considering specific emission magnitudes and inter-group comparisons, the following observations arise (Figure 4 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 the consumption approach, average emissions of the bottom 50% in the US surpass those of the middle 40% in both France and Germany. Notably, emission figures for America's poorest half closely mirror those of the top 10% of French households (16.2 tonnes per capita on average in France vs. 14.2 tonnes in the US). In the mixed approach, the bottom 50% in the United States (at 12.2 tonnes) still emit more than the middle 40% in France (9.6

[30] Note that when focusing on ownership emissions only (i.e., excluding direct household emissions or government emissions from the individual footprint), capital ownership emissions are more concentrated than capital at the top (see Figure 1).

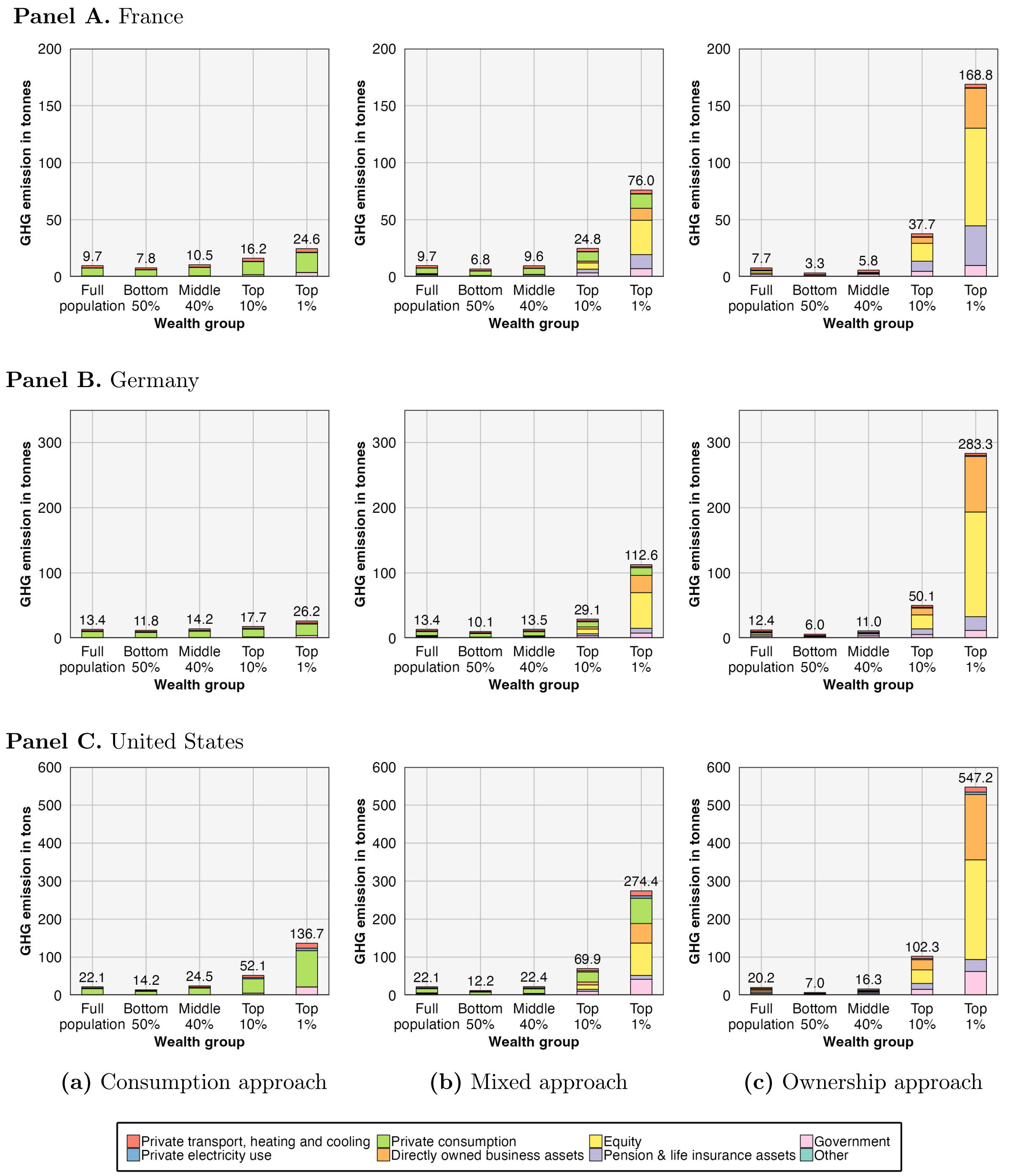
tonnes). This is also true in the ownership approach, where the bottom 50% in the US registers emissions of 7 tonnes, higher than the middle 40% in France at 5.8 tonnes. In the mixed approach, emissions of poorest half of the population in the US are broadly on par with the emissions of Germany's middle 40% (13.5 tonnes). Only in the ownership approach does the bottom 50% in the US get overtaken by the middle 40% group in Germany (who emit on average 11.0 tonnes). The elevated emissions of poorer groups in the United States underscore the reliance of all US wealth groups on fossil fuels, particularly for personal transportation, home heating, and electric appliances, as we discuss further below.

In France and Germany, the emissions of the wealthiest 10% exhibit comparable figures in the consumption approach (16.2 and 17.7 tonnes, respectively). Similar parallels emerge in the mixed approach (24.8 tonnes and 29.1 tonnes, respectively). In the ownership approach, however, Germany's top 10% emit around 50 tonnes – more than 10 tonnes more than their French counterparts (37.7 tonnes). This is intriguing, given that 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. The implications of capital emissions amongst these top groups will be discussed in Section 5.3.

Yet, when compared to ownership emissions of the top 10% in the United States, which stand at over 100 tonnes on average, the disparities between the top 10% in France and Germany appear limited. The wealthiest in the US emits 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 heavily impacted by the relatively high level of wealth inequality in the US.

Examining the top 1%, emissions in the mixed approach fluctuate from 76 tonnes in France, 113 tonnes in Germany and 274 tonnes in the US. In the ownership approach, the top 1% in France, Germany and the US register at respectively 169 tonnes, 283 tonnes, and a staggering 547 tonnes. Ownership emissions of the richest 1% of the population lie 22-27x above the national average in the three countries.

Figure 4. Per capita emissions by wealth group



Note: Groups are defined in terms of net personal wealth. The graphs present the annual average per capita emissions by wealth group for the three carbon footprint concepts presented in the paper. Directly owned business assets include housing maintenance whereas heating is part of private consumption emissions. Top 1% and 0.1% consumption approach 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 section C.7 Appendix I). In effect, our consumption approach estimates 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 emissions in France and Germany. In the US, top 1% and 0.1% consumption approach estimates are slightly higher than under a constant elasticity assumption (see Tables C.4-6 in Appendix I). In the mixed and ownership approach, top 1% and 0.1% estimates are less sensitive to these specific assumptions. Estimates by income group are presented in Appendix II. 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

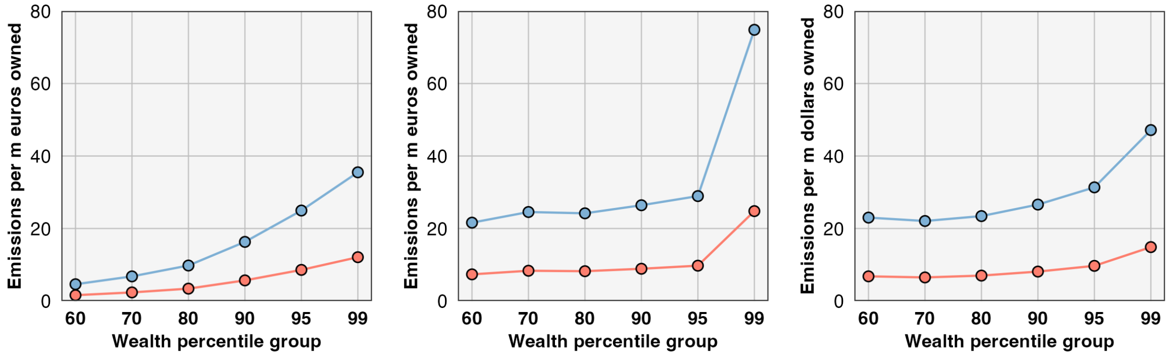
	Income	**Wealth**	**Footprint**					
			Consumption		**Mixed**		**Ownership**	
Net wealth (per capita)	Share in %	Share in %	tCO2e/ cap	Share in %	tCO2e/ cap	Share in %	tCO2e/ cap	Share in %
Panel A. France (2017)								
Bottom 50%	30.9	3.9	7.8	40.2	6.8	34.9	3.3	21.4
Middle 40%	43.5	34.5	10.5	43.1	9.6	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 the average per capita annual emissions by wealth group for the three carbon footprint concepts presented in the paper. Top 1% and 0.1% consumption approach 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 section C.7 Appendix I). In effect, our consumption approach estimates 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 emissions in France and Germany. In the US, top 1% and 0.1% consumption approach estimates are slightly higher than under a constant elasticity assumption (see Tables C.4-6 in Appendix I). In the mixed and ownership approach, top 1% and 0.1% estimates are less sensitive to these specific assumptions. Estimates by income group are presented in Appendix II. See Methodology section for more details.

5.2 Emissions intensity rises with wealth

An important discovery of our research is that the average emissions intensity tends to increase alongside wealth at the very top of the distribution across all three countries. In France, emissions in the ownership approach stay below 10 tonnes for each million euros owned for the majority of the population. Yet, this emission intensity escalates to 25 million tonnes (or even higher values) for the richest 5% of the population. In Germany, for percentiles p60 to p95 (representing the upper *middle 35%* of the population), the wealth emissions per million euros owned averages around 20 tonnes. This figure jumps to more than 60 tonnes for the top 1%. Meanwhile, in the US, there is a clear trend of increasing emissions intensity with wealth. Emissions per million euros owned hover around 20 tonnes from p50 to p90 and escalate steadily beyond this bracket, reaching more than 40 tonnes for the top 1%.

Figure 5. Average annual emissions in tonnes per million dollars or euros owned



(a) France **(b)** Germany **(c)** United States

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. Emission intensity is defined as the ratio of wealth-related emissions to gross wealth owned (i.e., 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 intensity emissions/wealth ratios show erratic trends due to low values of wealth and emissions. Excluding fixed assets from the denominator (which are associated with zero emissions by construction) would increase emission intensities. Note that the emission intensity can be impacted by changing asset values so that it needs to be interpreted in conjunction with the values of assets owned.

These findings suggest that beyond a certain wealth threshold, aside from the level of wealth that increases emissions, the composition of assets significantly augments the emissions attributed to the wealthy. The top 0.1% of Americans and Germans emit, respectively, two and four times more per euro owned compared to those at percentile p95. In France, a consistent escalation is observed from p50 to p99.5, with a moderate thereafter – which does not seem to alter the general pattern observed. The implications of this observation will be further explored in Section 6.4.

Since ownership emissions per euro or dollar owned tends to rise with wealth, it follows that ownership emissions are even more concentrated than wealth itself, as depicted in Figure 1. In France, the top 10% of wealth holders own 61% of wealth, but represent nearly 85% of ownership emissions. In Germany, the top 10% owns 56% of wealth, and contributes to 70% of ownership emissions. These values are 69% and 72%, respectively.

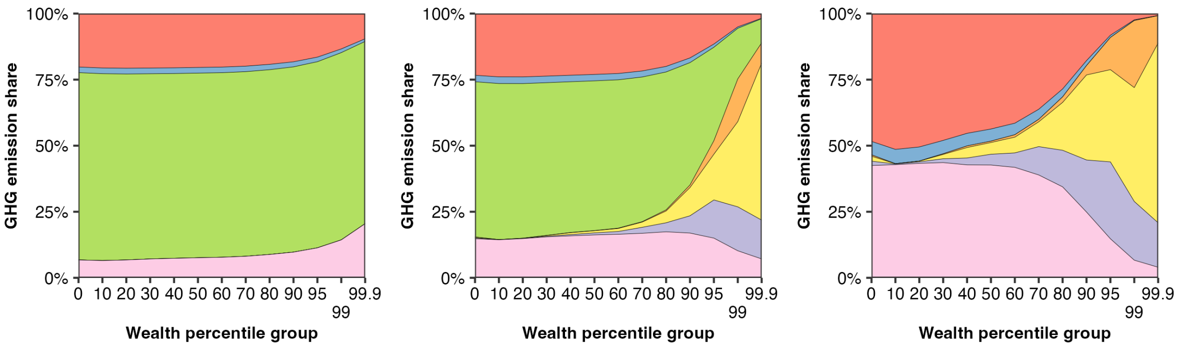
5.3 The weight of capital emissions among top groups

We proceed to analyze the role of capital emissions among total emissions within top wealth groups. By definition, capital emissions are excluded from the consumption approach. When incorporating capital emissions, as done in the ownership approach, the carbon footprint of the top 1% escalates as compared to the consumption approach: it increases by a factor of 6 in France, 11 in Germany, and 16 in the US. As another point of reference, the top 1%'s share of total emissions in the consumption approach stands at 2.5% in France, 2% in Germany, and 6.2% in the US. However, when pivoting to ownership emissions, these percentages soar to 21.5%, 22.3%, and 26.9% for France, Germany, and the US, respectively (Table 3 and Figure 1).

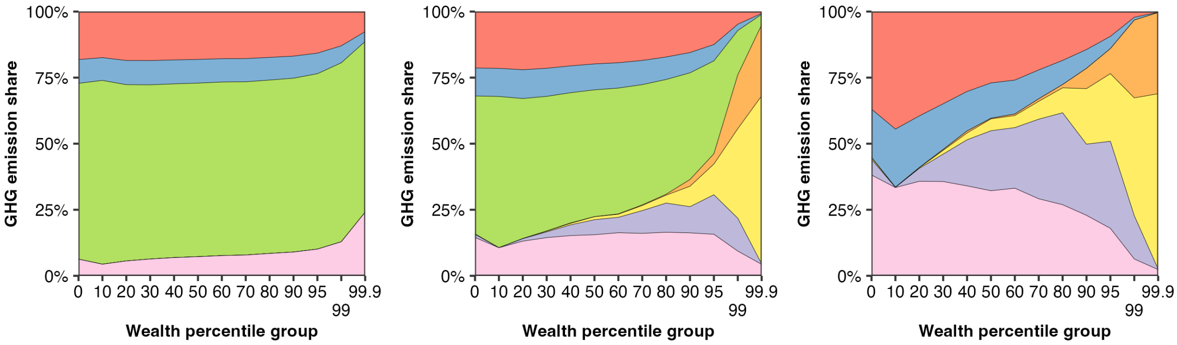
In the ownership approach, emissions resulting from the direct use of personal vehicles or household appliances ("direct emissions") are accounted for and distinctly separated from other emission categories. However, these emissions are found to represent a marginal share of top emitters' footprints in the ownership approach. Indeed, at the top of the distribution, emissions derived from asset ownership represent the bulk of emissions, despite relatively high absolute direct emission levels. Within the top 10% group, in the ownership approach, emissions linked to capital ownership represent 75.9% of total emissions in the US, or 78.8% and 79.6% in France and Germany, respectively. For the top 1%, this share increases to 85-95%. In the mixed approach, 34-44% of total emissions of the top 10% wealthiest come from the assets they own. Direct emissions account for roughly 8-9% of the aggregate within the top 10% in each country, dwindling to around 2-4% or less for the top 1% and beyond (see Figure 6). Although small as well, the share of direct emissions at the top is consistently higher in the US than in France and Germany. From this vantage point, it is quite clear that capital ownership is a paramount determinant of wealthy individuals' emissions. Equity and directly owned business assets represent the bulk of emissions from capital at the very top in all three countries. Pension and life insurance assets represent around 20% of emissions among wealthiest French, but this share is marginal for wealthy Germans and Americans.

Figure 6. Breakdown of emissions according to the three approaches

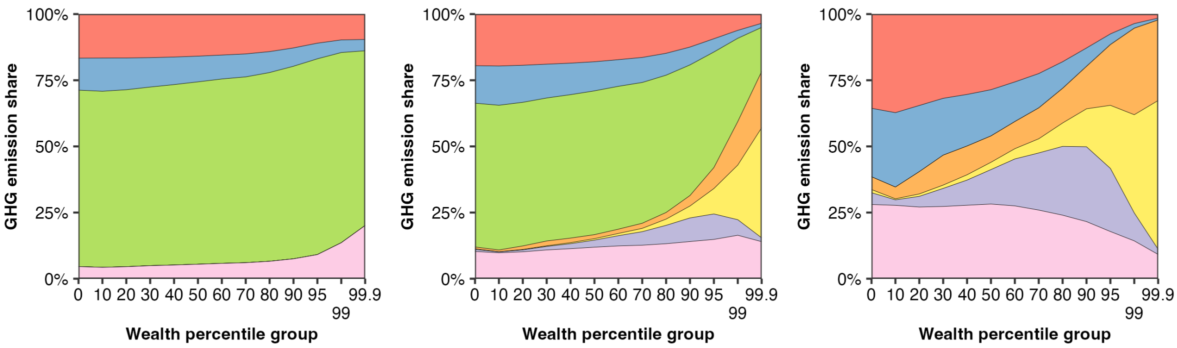
Panel A. France



Panel B. Germany



Panel C. United States



(a) Consumption approach **(b)** Mixed approach **(c)** Ownership approach

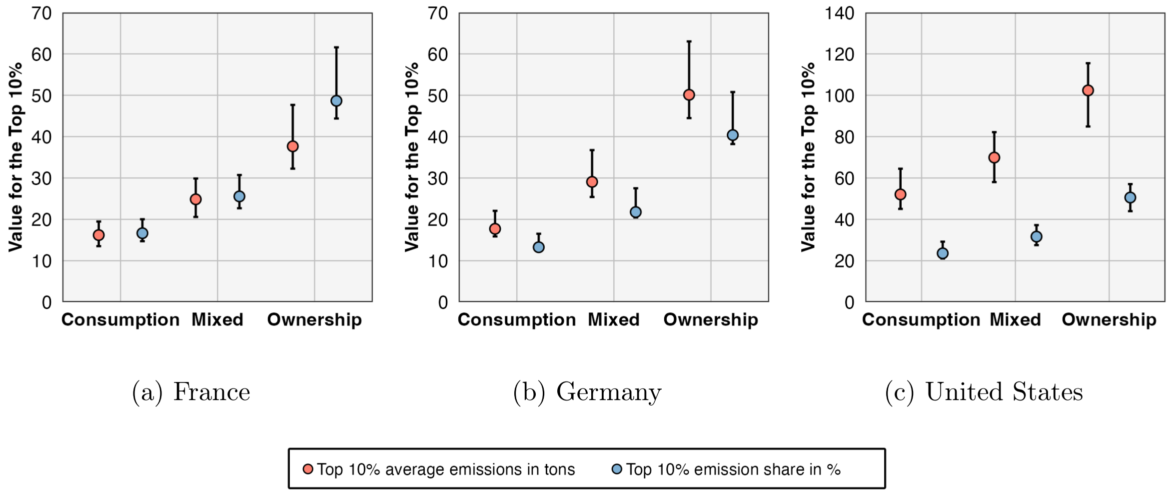
Note: Groups are defined in terms of net personal wealth. The graphs visualize the breakdown of per annual capita emissions by wealth group for the three carbon footprint concepts presented in the paper. Directly owned business assets include housing maintenance whereas heating is part of private consumption emissions. Wealth percentile group 0 refers to P0-10, group 2 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.

6 Discussion

6.1 Sensitivity of the results to assumptions

We now shift our focus to robustness checks and to discussing how our results change if we deviate from the benchmark assumptions. Figure 7 displays the upper and lower bounds of top 10% emission averages and shares, encompassing the three different methodologies and spanning over 200 distinct scenarios per country. These scenarios involve varying the assumptions regarding the attribution of government emissions, non-ownership emissions, and housing-related emissions. In Appendix I, Section C.6) we present a list and detailed descriptions of each alternative scenario and robustness check, and we also included tables and figures highlighting key inequality statistics for a large number of these alternative assumptions.[31]

Figure 7. Upper and lower bound of Top 10% average emissions and emission shares



(a) France (b) Germany (c) United States

Note: The graph presents the range of the share of emissions and average emissions attributed to the top 10% net wealth holders under different assumptions. The dot represents the benchmark strategy explained in the paper. The bands correspond to the lowest and highest value obtained when calculating all potential combinations of alternative scenarios (216 scenarios per country). Alternative assumptions concern the attribution of government emissions, non-ownership emissions or housing-related emissions. Tables with average emissions and emission shares for key alternative scenarios and figures covering all wealth groups (rather than only the top 10%) are available in Appendix II, Figures C.1-C.3. Values refer to 2017 in France and Germany and 2019 in the United States.

Figure 7 indicates 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 approximately 50.3% in our benchmark series in the ownership approach. 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 highlight that these upper and lower bounds embody the most

[31]See Appendix II, Tables C.1-C.3 and Figures C.1-C.3.

extreme combinations of assumptions that would result in the lowest and highest possible emission inequality. For example, the lower bound usually corresponds to a scenario in which all government emissions are attributed as a lump-sum amount while non-ownership emissions are imposed to follow a low constant elasticity parameter, for example. This means that the upper bound of one approach should not be directly compared to the lower bound of another approach (and reversely) if one intends to keep assumptions constant across the three approaches (e.g., regarding government emissions).

The exercise highlights that the precise implementation of the three approaches will play a role for the final results, most importantly when it comes to distributing government emissions. However, the robustness checks we run also demonstrate that even extreme combinations of assumptions would not affect the general patterns we identify in the paper, notably that accounting for ownership emissions in individual emission footprints increases emission inequality considerably.

6.2 Scope and limitations of the data and footprinting approaches

We would now like to highlight key limitations of our analysis and discuss potential avenues to further develop and extend the research on capital ownership-related emissions and emission inequality in general.[32]

Limitations linked to data sources. Our study suffers from the same limitations as other papers that rely on wealth surveys to study the distribution and breakdown of assets owned across the population. These limitations include issues related to wealth under-reporting or the self-reporting 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 assets owned by these types of individuals who are not present in our survey. Implicitly, we therefore have to rely on the breakdown of assets owned by the richest individuals in the survey, which tend to own less wealth overall. While we believe that this bias operates in the direction of reducing the concentration of emissions at the top (in reality, we suspect that the share of equity assets is even larger at the very top), we cannot confirm this suspicion using the data we have. What is reassuring is that we observe similar dynamics in the United States and in France and Germany. In the United States, we do not rely on a wealth survey but use the DINA micro-files instead, which combine different tax and non-tax data sources to arrive at the asset breakdown at the very top.

A second limitation linked to wealth survey data is that we only observe a limited 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, for example, that individuals at the very top own the absolutely most environmentally friendly firms in each industry. However, the size of the error we can make is limited because equity ownership is concentrated towards the top of

[32] Appendix I-C.8 provides a summary of the various potential types of bias in each approach, and their potential impact on estimates.

the wealth distribution. This implies that the error we could make related to corporate and business emissions would take place mostly *within* the group of higher wealth individuals (as the bottom of the distribution does virtually not own any equity assets). Emissions related to housing are limited in our approaches (as heating and construction emissions are not distributed to homeowners in the benchmark approach) so that errors regarding the distribution of housing emissions cannot alter the main conclusions we draw from the results.

Ideally, we would implement the approaches we developed using individual-level data on wealth and asset holdings, linked to the precise firms owned by each individual. While we are advancing the research in that direction (for example, by implementing our approach in countries where such type of data is available), we are able to show that eliciting the broad patterns that emerge when accounting for ownership emissions does not depend on these data sources, which will remain unavailable in many contexts and countries.

There is also scope to improve the macro sources on emissions and the economy on which we rely for this study. For example, air emission accounts remain underdeveloped in the United States so that we are only able to rely on a limited number of industry groups. Another area with scope for improvement would be data on the linkage between outstanding corporate equity and the ownership institutional sectors. If more detailed matrices of (domestic and foreign) equity holdings by institutional sector were to be made available by statistical offices, for example, the approaches we propose could be implemented with higher precision.

The consumption approach suffers from data limitations which are also discussed, to some extent, in the studies on which we rely to distribute non-ownership emissions in the three countries (Hardadi et al., 2021; Malliet, 2020; Starr et al., 2023a). *Firstly*, budget surveys utilized in these studies are susceptible to sampling biases, particularly at the upper end of the distribution, resulting in underestimation of both wealthy individuals' consumption and the emissions connected to it. *Secondly*, these studies assume that emissions per dollar spent for a particular consumption category, such as a bottle of wine, are equal across different income or wealth groups. However, in reality, the intensity of these emissions could differ throughout the population. In particular, for certain luxury products benefiting from brand recognition, differences in prices may reduce the carbon intensity of the product, which may result in overestimating the footprints of top groups. This effect is likely to operate in the opposite direction than the first type of potential bias (see section C.7 Appendix I). *Thirdly*, consumption-based footprints are constrained by the quality of multi-regional input-output datasets, which combine international trade, industrial, and environmental data from multiple countries. National average emissions for a specific country can vary across different databases, for example, but the EU-FIGARO we use is consistent with Eurostat air emission accounts. Limitations of these input-output datasets are discussed in Tarne et al., 2018 and Owen et al., 2014. Even though we rely on estimates from the three country-specific papers for our benchmark estimates, we also present results using a fixed elasticity parameters, i.e. results that do not rely on estimates from these studies. These results can be found in Appendix II.

Estimates of the mixed approach share the limitations of the consumption approach (both in terms of underlying input-output databases and of the socioeconomic databases used to attribute these emissions to consumers) and some of the limitations of the wealth approach (in particular those associated with the underestimation of top-end wealth inequality).[33] In the future, it would be key to implement the mixed approach for a limited number of firms to evaluate how estimates compare to those derived from the macro sources we use (which rely on the carbon content of investment by industry sector).

Carbon footprints and individual responsibility. A challenge in interpreting our results lies in the fact that no broadly-defined individual footprinting approach can fully capture the actual *responsibility* individual bears for emissions. Attributing emissions to individuals under one of the three approaches, and then interpreting the carbon footprint as representing the responsibility for emissions, requires assumptions about the role of the individual in economic processes and decisions. In the literature, individual responsibility has been associated with one or more of the following conditions (Fahlquist, 2009; Lenzen & Murray, 2010; Paul et al., 1999):[34]

- **Agency, intentionality, and control.** Individuals should have the ability to make choices with a specific purpose in mind and be able to act accordingly. In other words, the act that causes pollution (such as investing in a carbon-intensive asset or buying red meat) should be voluntary.
- **Information.** Individuals should have knowledge about the specific impact of their actions on pollution, for example through carbon scores or information on the carbon footprint of pension funds.
- **Alternatives.** Individuals should be able to choose between different options (e.g. more or less carbon intensive meat options, or more or less carbon intensive financial products or companies to invest in).

When consumers or investors make a decision, these conditions are simultaneously satisfied only in rare instances and it is not the purpose of this paper to determine to which extent each condition is fulfilled for each economic actor. This indeed calls for caution in interpreting the individual carbon footprints we estimate, regardless of the approach chosen, as representing the all-encompassing *responsibility* an individual bears for emissions.

In some instances, the consumers or investors, for example, will not be aware of the carbon content of products they purchase or the investments they make, and which contribute to their individual footprint. Additionally, even when households possess knowledge about the carbon implications of their choices, many may see little alternatives to using a specific, carbon-intensive technology. A prime example can be found in the "yellow vests" protests in France during 2018-19

[33]The mixed approach relies both on consumption data, and wealth data (see Section 3.3).

[34]An alternative, more empirically minded approach could be to link emission responsibility to the change in aggregate emissions that would occur if an individual were to change its behavior, as we plan to do in further work.

when many demonstrators argued that the lack of viable alternatives forced them to rely on their carbon-emitting cars to maintain a basic standard of living, encompassing work and access to essential services.[35]

Focusing on criteria such as agency, information, and alternatives, one could argue that carbon footprints might be more easily interpreted as representing individual responsibilities in the ownership approach than in the consumption approach. Wealthier owners often possess greater autonomy over their investments and the ownership of firms and assets usually comes with at least some form of control over the production processes. This may not be as applicable for less affluent consumers. In addition, an individual consumer decision to not, say, board a plane, will not physically be associated with less emissions released from that plane. This choice may (or may not) be associated with lower plane emissions in the future, if supply adapts to demand. On this matter, the history of oil production, for instance, is filled with instances when supply does not react to demand-side forces, because of deliberate supply-side decisions (see Mitchell, 2009 for instance). In the specific case of the flight, reduction in airline operations will ultimately be made by the firm's managers and owners, whose decisions would have actual, physical effects on emissions. Viewed in this light, the ownership paradigm is potentially more aligned with the stated conditions of agency, information and alternatives than the consumption-only framework.

It is possible to argue that it is firm managers who hold (at least some) power over investment decisions, rather than firms' owners, when the two are distinct. In this case, owners would also lack agency. We stress that, based on the data we use in the paper, we cannot determine to which extent these constraints ultimately operate on the level of the manager or owners – nor, for that matter on individual consumer or investor. This means we cannot conclude with certainty which of the footprinting approaches (or which combinations of approaches) best represents individual responsibilities for the emissions released.

The discussion over carbon footprints takes a more complex turn in the case of emissions released today, to serve emissions reduction tomorrow. In fact, even in cases where agency, information and absence of alternatives can be unambiguously determined, certain emissions associated with an investment (or a consumption act) could potentially be required to reduce emissions in the future. Think about capital owners who invest in a machine in year t to decarbonize production in year $t + 1$. While the emissions of these owners might be positive in year t in the mixed approach, they could turn to zero in $t + 1$ and subsequent years for consumers, thanks to the investments made by the firm's owner. The same could be said of a consumer buying an electric car (to the extent it is counted as a consumption good): their carbon footprint associated with transportation would increase significantly to account for emissions embedded in the car, and will be reduced in the subsequent years.

[35] Another example would be emissions linked to basic technologies, such as refrigerators, which are integral to daily life even for the bottom 50% (in the three countries under study), but contribute to carbon emissions during their manufacturing process. Given the absence of decent alternative technologies, does this imply that individual buyers should not be considered less responsible for the emissions released during the production process?

Such considerations are important, but their impact on the interpretation of our estimates at the level of statistical groups, such as the top 10%, 1%, or even 0.1%, is likely limited. It should be noted that statistical groups consist of individuals with varying investment habits, including both green and polluting sectors. Our study depicts the average emissions of all individuals belonging to each group. At present, there is no indication that differences exist in green versus brown investments between the groups, regarding the particular asset type studied. Further work based on more granular data will help us better understand this dynamics.

In summary, if we assume that individuals have 100% control and agency over their direct emissions and over all emissions embedded in their consumption, then the consumption approach is indeed a powerful framework for assessing responsibility inequalities. However, if we assume that the rate of control over the *indirect* emissions embedded in individual consumption (let us call this parameter α) is less than 100%, the mixed approach arguably provides a more appropriate framework. In this framework, $\alpha \approx 80\%$ [36]. If α is assumed to be 0, then the ownership approach appears as a more appropriate framework for assessing emissions responsibilities. Note here that the ownership framework assumes that individuals have 100% agency and control over their direct emissions (we call this parameter β). However, in practice, the use of personal gasoline vehicles or home heating devices is often constrained. This is especially true at the bottom of the distribution due to location, housing type and/or income constraints. If $\alpha = 0$ and $\beta < 1$, the ownership approach should be seen as a lower bound on emissions inequality. Of course, in practice, the α and β parameters might vary at the individual level.

More targeted studies will be needed to better investigate information, agency, and the availability of alternatives, and reveal in which contexts (by industry, market structure, type of product etc.) responsibility falls on the consumer or owner side. This type of work could also result to more refined versions of our "mixed" approach in which the distribution of emissions between consumers and investors varies depending on the context, level of information and level of constraint, and not only depending on the investment activity of the firm.[37]

Another key aspect of our discussion, which we have only partially and imperfectly addressed, is the government's role in decarbonization. In our study, we aim to allocate all emissions to consumers and investors. We also explore the government's role by attributing government emissions to individuals using various allocation rules (detailed in Appendix One, section C.4). In reality, 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 carbon footprints. In essence, collective action plays a crucial role in enhancing, or limiting, the agency of both consumers and investors.

To summarize, our research presents a comprehensive framework that integrates consumer and investors perspectives at varying degrees. We show that attributing carbon footprints and individual emissions responsibility solely to consumer behavior is based on overly simplistic

[36] Capital formation emissions represent about 19-21% of the total in the three countries studied.

[37] Concentration indices (such as Herfindahl indices) for investment vs. consumption might be a possibility to advance our understanding of the relative agency of consumers and investors.

assumptions and our results demonstrate the feasibility of developing systematic approaches that overcome these limitations. Our methodology is in line with the IPCC's criteria for both exclusion and comprehensiveness, and enable a more nuanced understanding of unequal contributions to climate change.

6.3 How our estimates compare to earlier work

Our study represents the first attempt, to our knowledge, at measuring emissions inequality associated with owning wealth in the three countries.[38] However, a small number of studies with similar research questions exist to which readers might be drawn to compare our results. We will briefly discuss how our results compare to these studies and highlight important ways in which these studies differ from what we do, often making direct comparisons difficult.

One policy paper released by Greenpeace in France is arguably the existing study that is most closely related to our ownership approach (Greenpeace, 2020). It estimates the distribution of annual emissions related to financial assets in France for the year 2015. Unfortunately, despite the similar-sounding research question, several methodological differences make it difficult to compare our results to those obtained by Greenpeace (2020). *First*, the study does not seem to determine the total amount of emissions linked to wealth from macro sources. Instead, it adds up the individual-level emissions calculated through multiplying gross wealth with the corresponding emission intensity of financial asset classes. As a result, the authors attribute 312 million tCO2e equivalents to wealth holders – significantly less than under our ownership approach (and significantly more than under our mixed approach). *Second*, the authors present their distributional analysis based on brackets of household disposable income only while our benchmark estimates are presented by net wealth group. Their top 1% share of wealth-related emissions is 17.7%.[39] Our benchmark estimate suggests a top 1% share in ownership emissions of 23.1% in France (excluding government and direct household emissions), when individuals are ranked according to the per-capita pre-tax income distribution.[40]

The results of our mixed approach are closely aligned with those presented in Chancel (2022) because a simplified version of our mixed method serves as the benchmark approach in that study. Nevertheless, there are some differences between the studies. *First*, in estimating total national emissions, we rely on sources that are arguably more accurate. Chancel (2022) uses data from EORA and the Global Carbon Project, which requires a series of imputations to arrive at carbon dioxide equivalent emissions of various institutional sectors, as described in Burq and Chancel (2021). Here, we mobilize FIGARO data from Eurostat, with more granular economic sector (e.g. mining, agriculture, etc.), and institutional level sector (e.g. households, government, GFCF)

[38] We presented a preliminary version of these results in a Working Paper entitled "Measuring the Carbon Content of Wealth" drawing on the Master's thesis of (Rehm, 2021). However, for this paper, we have further developed the methodology along multiple dimensions, incorporated higher quality data sources, and added the United States as a third country under study.

[39] This share is implied by what Greenpeace (2020) presents in the table on page 16: $\frac{189.1\times 1}{10.7\times 100} \approx 0.17$

[40] 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).

data. Our estimations of GHG emissions from CO2 emissions is also more accurate, as it is based on more granular economic sector-level multipliers. *Second*, a limitation of the previous study is the limited availability of data on the joint distribution of individual income and wealth. In the present study, we use raw data sources that inform on the joint distribution of income and wealth at the household level, which does not require to impute this joint distribution. *Third*, we allow for a broader set of possible ways through which government emissions are distributed across the population, departing from the strict egalitarian approach followed in the previous study.

Despite these differences, and while Chancel (2022) primarily focuses on analyzing global trends rather than detailed country and percentile-level estimates, the findings appear to be largely consistent between the two studies. For example, Chancel (2022) reports an average emission level of 25tCO2e for the top 10% in France in 2019, which is comparable to our finding of 24.8tCO2e for 2017 (when individuals are ranked by pre-tax income per capita, see Appendix II, Table D.1 for comparability). In our study, the bottom 50% in France emit 6.2tCO2e per capita in 2017 (also ranking by pre-tax income), compared to around 5tCO2e reported in the previous study. It is noteworthy that the average emissions for the full population in France are about 20% lower in the previous study than in our current one. Overall, we regard the results of the present study as more accurate for the reasons outlined earlier.

In this paper, we mobilize data from three earlier studies to distribute emissions from productive sectors to consumers in the consumption approach (see Methodology section). We note that their overall results are not necessarily directly comparable with ours. *First*, the unit of analysis is not necessarily the same across studies. For instance, Malliet (2020) presents results by household or by "consumption unit", while ours are presented per capita. Emission levels will then differ between studies, even if group shares might be consistent. *Second*, the benchmark strategy followed to distribute government-related emissions might vary between the studies. *Third*, the income or wealth variable used to rank individuals (or household units) might vary across studies as well (e.g. either net wealth or pre-tax or post-tax income per capita).[41]

Focusing on emission totals by country, we observe that both the consumption and mixed approach are able to reproduce important findings from the literature. In particular, wealthy nations import more embedded CO2 emissions from other countries than they export (in France, for example, consumption-based emissions exceed territorial emissions by 35%). Interestingly, we have found similar results for France and Germany when using the ownership approach. That is, total emissions in the ownership approach are larger than territorial emissions. However, the discrepancy between territorial and ownership emissions is less pronounced in the ownership approach, than in the consumption approach. In the US, territorial emissions are slightly higher than ownership emissions, which appears to be consistent with the negative net foreign asset position of the country.

[41]Note that we also present results up to the top 1% (and top 0.1% in some cases) while the underlying studies do not necessarily do so, either because they lack granularity or for other reasons. Our estimates for these smaller groups (in particular in France) are obtained via generalized Pareto interpolation and should be treated with care (see Blanchet, Fournier and Piketty, 2022) and the dedicated section in Appendix I-A.

6.4 The impact of redistribution on carbon emissions

We now turn to the discussion of redistribution and its potential impact on aggregate emissions. We start by summarizing three key findings of this study on inequality and carbon emissions.

Stylized facts *First,* across the three methodologies, we consistently identify a pronounced economic gradient linked to emissions. This observed pattern challenges the existence of an "Environmental Kuznets curve" theorized by a part of the literature, and according to which emissions decline after a certain income level (M. Grossman & Krueger, 1995; Mills & Waite, 2009). Instead, what we observe is that although the top 10% or top 1% of individuals possess greater means to transition to low-carbon consumption (and possibly to low-carbon investments) compared to other economic groups, recent emissions data contradict the idea that they emit less than other groups. We note however that there can be significant variance in emissions within each wealth or income group, in particular when looking at direct emissions from transport or heating as highlighted by the literature (Büchs & Schnepf, 2013; Jones & Kammen, 2011).

Second, consumption emissions are less concentrated than income and wealth. The reason is simple: wealthier individuals consume a smaller fraction of their income (and wealth) than less well-off individuals. Moreover, as income and wealth increase, individuals can purchase relatively more products that are less carbon-intensive. This does not mean that their consumption emissions are lower than those of the poor, but that the carbon content of a euro/dollar spent is, on average, higher at the bottom of the distribution than at the top. It follows that consumption emissions are also typically found to be less unequally distributed than overall consumption in most countries instances (Chancel, 2022; Pottier, 2022).

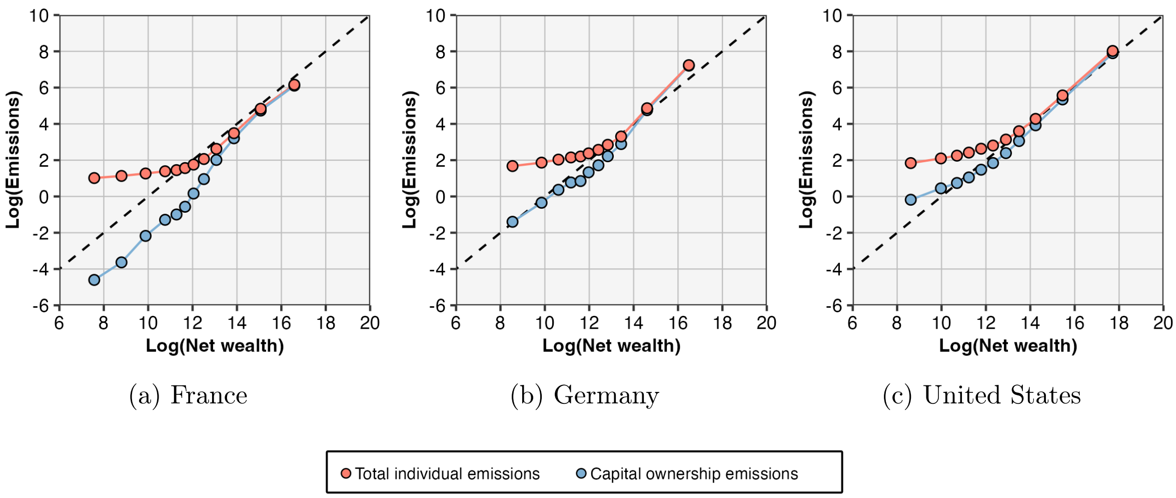
Third, the opposite appears to be true when focusing on wealth emissions, which are found to be more concentrated than wealth itself. The main reason for this is that the type of assets owned by the bottom 90% - mostly housing and deposits - have low or zero carbon intensity. In contrast, assets that are relatively abundant at the very top (equity and directly owned business assets), are found to be relatively carbon-intensive. Pension assets, which are relatively important among the upper middle segment of the distribution, appear to be less carbon intensive than equity, and less intensive than business assets in France and the USA. This further reinforces the difference in total wealth related emissions between the very top of the distribution and the upper middle.

Elasticity and redistribution The argument is sometimes made that, ceteris paribus, lower economic inequality would result in higher aggregate emissions. The logic behind this argument is relatively simple: if the poor spend a larger fraction of their income and if the expenditure-to-emissions elasticity[42] is lower than unity, redistributing an amount from the rich to the poor could increase aggregate emissions in a theoretical setting. One implicit assumption made in this type of reasoning is that saving and owning assets does not come with any associated emissions. A rich individual who accumulating savings and wealth would have a low carbon footprint if their private consumption expenditure remained low.

[42]That is, the marginal change in emissions associated with a marginal change in expenditure.

Our general framework can be used to illustrate how this claim no longer holds when wealth ownership and savings are taken into account. The key insight here is that the relationship between wealth and emissions does not follow a simple power law with a constant elasticity parameter across the entire distribution. Instead, in the ownership approach, the relationship between emissions and wealth changes as the level of wealth increases – and ownership emissions ultimately represent the dominant source of emissions for the individual. Figure 8 shows the logarithm of the average net wealth and the logarithm of average emissions for different wealth groups and for two types of emissions: total individual emissions (in red) and ownership-related emissions only (in blue). If emissions followed simple power law with a constant elasticity parameter, a log-log plot of the two variables would show a straight line (and the slope would be equal to the elasticity parameter). However, Figure 8 shows that the implied elasticity between wealth and emissions increases as ownership emissions start to dominate. Eventually, the elasticity approaches (and surpasses in some scenarios) unity, implying that individuals whose wealth is 1% higher than the wealth of the given individual on average record an emission footprint that is at least 1% higher.

Figure 8. Relationship between wealth and emissions in the ownership approach



(a) France (b) Germany (c) United States

Note: The graph presents the logarithm of net wealth and the logarithm of average emissions for different net wealth groups. Each first eight dots from the left to the right correspond to the decile average from P0-10 until P80-90. The first decile in France and Germany and the first two deciles in the United States are not displayed because average net wealth is negative. The remaining dots represent P90-95, P95-99 and P99-99.9 and P99.9-100. The dashed line represents a line with slope one. Capital ownership emissions include emissions linked to the individual wealth. Total emissions also include government emissions, private electricity and direct household emissions as distributed in the benchmark scenario. Values refer to 2017 in France and Germany and 2019 in the United States.

We use the relationship between log wealth and log emissions in our data to conduct a simple thought experiment to illustrate that point more clearly. Imagine a given amount of wealth is redistributed from a high-wealth individual to an individual with lower wealth. What impact would such a transfer have on total emissions? The type of data we constructed can (of course) not capture the types of complex dynamic responses that may be induced by such a transfer (such as political economy effects). Instead, let us assume that, after the transfer is made from the higher wealth to the lower wealth individual, the emissions of the two individuals are equal to the average emissions at the new wealth level. We fit a cubic polynomial regression to the log-log relationship between total emissions and wealth observed in our data for the ownership approach (using all data points).[43] We then simulate the emissions responsibility of the two individuals before and after the wealth transfer, using the estimated equation and the new levels of wealth.[44]

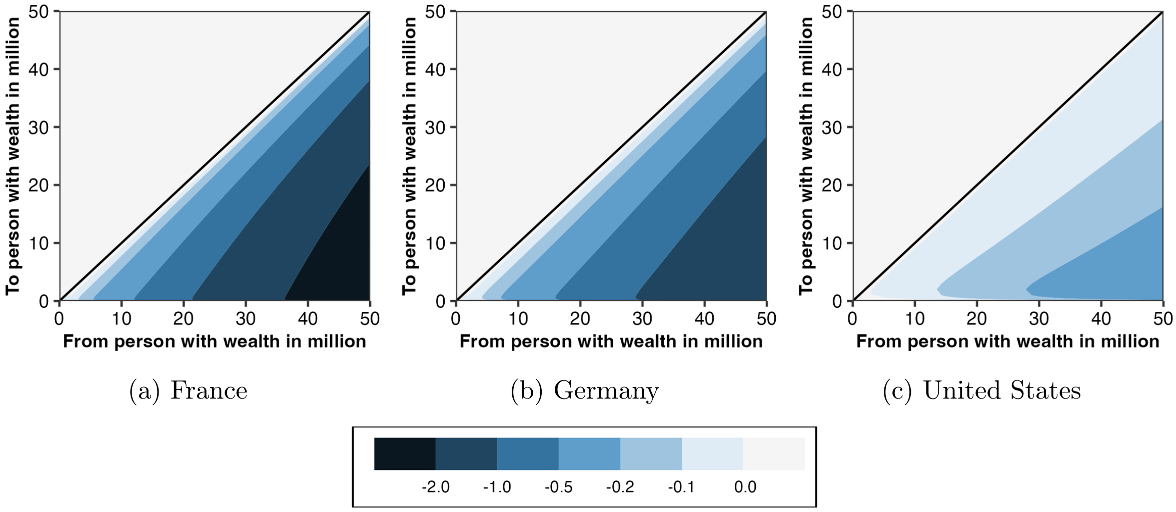
Figure 9 shows the net impact on total emissions suggested by our thought experiment for a hypothetical transfers of 10,000 euros/dollars between individuals with high levels of wealth prior to the transfer. Due to the relationship between total assets and wealth identified earlier, total emissions tend to decline if a transfer is made from higher to lower wealth individuals (values below the 45 degree line in the figure). At these high levels of wealth, the dynamics between wealth and ownership emissions dominate the relationship between wealth and total emissions. The reduction in emissions would thus be driven by a change in the average carbon intensity of assets owned. However, our data suggests that reductions in total emissions would also occur for transfers of wealth from wealthy individuals to the bottom or middle of the wealth distribution. Although, the results are more complex in such a setting (and the increase in – mostly direct – emissions occasionally dominates the reduction in ownership emissions), we find plenty of scenarios in which aggregate emissions decline.

Our point here is not to claim that accounting for ownership emissions automatically implies that any wealth transfer will reduce aggregate emissions, even in the simplified setting used here. The actual expected impact of a wealth transfer on emissions needs to be determined in studies that track individuals and their investments over time, using more fine-grained data than we use in this study. What we do show, however, is that accounting for the emissions associated with wealth ownership will nuance some of the stylized facts established in the literature. Focusing on consumption elasticities continues to be useful for those interested in purchasing responses to shocks to income and wealth. However, it misses the variation in emissions due to individual savings and wealth. The ownership approach attempts to address this concern, but it omits indirect emissions from consumption. The mixed approach arguably combines some of the strengths of both frameworks, but lacks the conceptual simplicity of the other two. We emphasize that there is no perfect approach to study inequality, emissions, and redistribution, but there is a need for researchers to clarify which conceptual framework they are referring to when conducting work on the individual emissions, and to carefully analyze its strengths, limitations and implications for the analyses conducted in their work.

[43]Cubic models are well suited to reproduce relationships that are characterized by an inflection point – such as the one observable in the relationship between wealth and total emissions at the point when ownership emissions start dominating the aggregate emission footprint of an individual.

[44]Scatter plots showing all observations (rather than groups as in Figure 8) and the fitted cubic model are presented in Appendix I, Section D.

Figure 9. Net emission impact of redistributing 10,000 euros/dollars in the ownership approach



(a) France (b) Germany (c) United States

Note: The graph presents the simulated net emission impact in tonnes of transferring 10,000 euros/dollars from the average individual with net wealth denoted on the x-axis to the average individual with net wealth denoted on the y-axis. Red colors correspond to net emissions increases and blue colors to net emission reductions. Emission impact simulated based on a cubic model fitted to the log-log relationship between wealth and emissions. Redistribution scenarios from lower wealth to higher wealth individuals are not represented (i.e., scenarios above the 45 degree line). Values refer to 2017 in France and Germany and 2019 in the United States.

Table 4. Net emission impact of redistributing 10,000 euros/dollars in the ownership approach

Redistribution from a person with net wealth of (in euros/dollars)	**Redistribution to person with net wealth (in thousand euros/dollars)**									
	10	20	30	40	50	60	70	80	90	100
Panel A. France (2017)										
1 Million	+	+	+	+	+	+	+	+	+	+
10 Million	-	-	-	-	-	-	-	-	-	-
100 Million	-	-	-	-	-	-	-	-	-	-
Panel B. Germany (2017)										
1 Million	+	+	+	+	+	+	+	+	+	+
10 Million	-	-	-	-	-	-	-	-	-	-
100 Million	-	-	-	-	-	-	-	-	-	-
Panel C. United States (2019)										
1 Million	+	+	+	+	+	+	+	+	+	+
10 Million	+	+	+	+	+	+	+	+	+	+
100 Million	+	-	-	-	-	-	-	-	-	-

Note: The table presents the simulated net emission impact in tonnes of transferring 10,000 euros/dollars from the average individual with net wealth denoted on the rows to the average individual with net wealth denoted on the column. Red colors correspond to net emissions increases and blue colors to net emission reductions. Emission impact simulated based on a cubic model fitted to the log-log relationship between wealth and emissions. Values refer to 2017 in France and Germany and 2019 in the United States.

6.5 Distributional properties and revenue estimates for a carbon wealth tax

We now discuss what our results imply for a potential tax levied on the emissions linked to assets owned by individuals. Similar to the inequality literature, carbon taxes that target individual behavior have so far predominantly centered on emissions linked to individual consumption and lifestyle choices. For example, many countries levy specific taxes on carbon-intensive transportation choices (fuel, air travel etc.) and in some countries the taxes have been designed as explicit carbon taxes.[45] However, these types of taxes suffer from similar disadvantages to those that we discussed in the context of inequality studies, which narrowly focus on consumption footprints. Importantly, the distributional impact of these taxes can be regressive and welfare losses are likely concentrated on groups that (i) have a limited ability to change their behavior, or groups for which (ii) behavioral change comes with a large relative loss in welfare.[46]

Other common types of carbon pricing are applied at the firm level, with policies such as emission trading schemes, or carbon taxes levied on firm's energy use. Finally, some countries have started implementing carbon border taxes that aim at the carbon content of internationally traded goods in order to counterbalance different levels of environmental taxation or regulation globally. By focusing on these sets of policies (applied either at the firm or the individual consumer level), climate tax policy mirrors the approaches taken in the climate inequality literature, which have underemphasized the role of individuals as owners of firms.

Figure 10 compares the distributional impact of a 150 euro/dollars "per-tonne" tax on the carbon content of wealth to a similar tax levied on direct household emissions (e.g., private transport or heating), and to a tax levied on indirect private consumption emissions (i.e., the emissions embodied in the goods and services consumed).[47] The figure also includes estimates for a potential tax that would only apply to wealth-related emissions determined through the mixed approach we propose. This scenario corresponds to taxing the emissions linked to the investment of firms owned by the individual. The graph demonstrates that taxes on capital ownership emissions are progressive in all three countries under study because the effective tax burden (expressed in % of net wealth) increases with wealth. This finding is directly 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 individual in the top net wealth groups.

Taxes levied on capital ownership emissions therefore share commonalities with progressive wealth taxes, at least for the average individual. Figure 11 presents more details on the average tax burden (in % of net wealth) implied by taxes levied at different levels per tonne of capital ownership emissions. These graphs show that a tax of 150 euros/dollar per tonne would be, on average, similar to a 0.5%-1.1% tax on net wealth per year for a top 1% wealth holder. A lower

[45] Whether all existing fuel excise taxes should qualify as implicit carbon taxes remains a contested question because these taxes have often been introduced out of a revenue raising motive (e.g. to finance road construction).

[46] Think as an example of a lower income individual who, as a result of higher travel costs, is forced to reduce the number of flights from one to zero vs. a higher income individual who decides to pay the higher price or reduce the number of flights from ten to nine.

[47] We explain in the note of Figure 10 why we exclude the bottom 50% from the graphs in this section.

emission price of 50 euros/dollar per tonne of ownership emissions would be similar to a 0.2-0.4% tax on net wealth. Note that these estimates are for the ownership approach, i.e. for an approach that attributes all firm emissions to firm owners. To provide some perspective, Figure 11 also includes the approximate tax burden of the French wealth tax schedule before it was abolished in 2017. It shows that per-tonne taxes on capital ownership emissions can result in tax burdens that are of a similar magnitude as existing or proposed wealth taxes.[48] Note that one advantage of a tax on capital ownership emissions would be precisely that higher wealth individuals whose assets have a lower emission intensity than the average observed in their wealth group would pay a lower amount of tax.

Figure 12 zooms in on the tax burden for the average top 1% individual (by net wealth) for a larger range of potential tax rates. The figure reveals, for example, that taxing capital ownership emissions at 300 euros/tonne in France, 150 euros/tonne in Germany or 200 dollars/tonne in the United States would on average result in a tax burden similar to a net wealth tax of 1% for top 1% individuals.[49] In Figure 13 we show that, absent any behavioral change and under perfect compliance, the taxes could result in meaningful tax revenues.

Our data does not allow us to make a concrete proposals regarding the appropriate level and precise implementation of a tax applied to capital ownership emissions. Instead, our results are intended to show that there is a potential to broaden the policy mix in the area of carbon taxation. How to best determine the appropriate level of carbon taxation remains contested. Linking the level of tax to the "social cost of carbon" comes with a large number of normative and measurement challenges, for example. As a result, estimates of the social cost of carbon range from from 7$/tCO2e (Waldhoff et al., 2014) to 31$/tCO2e (Nordhaus, 2017) to well above 100$/tCO2e (Ricke et al., 2018).[50] Departing from a purely Pigouvian perspective, carbon taxes could also be rationalized as a policy tool to achieve an externally defined behavioral change with the most limited harm to social welfare. Finally, carbon taxes can be motivated as a tool to raise revenue. These alternative rationales highlight in particular the importance of the induced behavioral responses that can be expected after implementation, whether the tax is applied to consumption, firms or firm owners. Answering these questions will require a better understanding of the the behavioral response of investors (at different levels of wealth) to climate policies and how these individual responses translate into actual emission reductions at the firm level.

Concerns about double taxation could be a second objection to taxes applied to ownership emissions at the individual level. To answer those, it would be possible to allow owners to

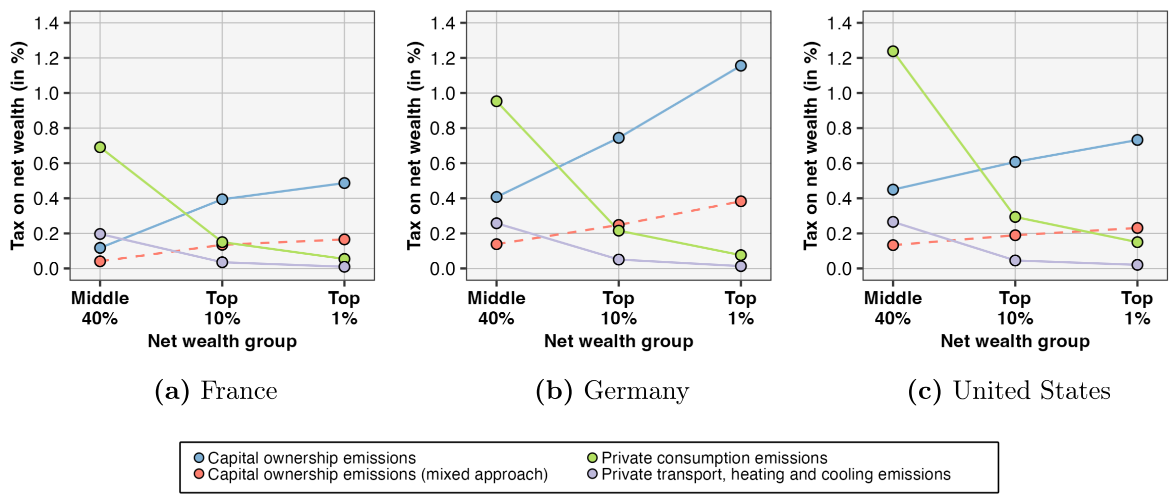
[48] Note that the actual effective tax burden of the French wealth tax was much lower, for example as a result of deductions available in the tax code and tax avoidance behavior. Here, we simply apply the rate schedule to the net wealth observed in our dataset to show that taxes on capital ownership emissions, even in the ownership approach, can be designed such that the effective tax burden would be similar to wealth taxes that have already been implemented in the past.

[49] Note that the tax burden of any real-world net wealth tax of 1% would critically depend on the deductions available and the amount of wealth that is exempt from tax.

[50] These estimates are directly linked to the debates around social discount rates (Nordhaus, 2007; Stern, 2007). According to estimates by the IMF, the average global price on carbon stands currently at 2$ per tonne (Parry et al., 2019). Estimates on the global carbon price for 2050 that would be in line with a 2-degree climate target lie between 140 and 8300$ per tonne (Guivarch & Rogelj, 2017).

credit any tax on emissions paid at the firm level against the tax levied at the individual level. Through such a strategy, an ownership tax could be a way to price emissions that otherwise escape domestic climate policies (such as the emissions of foreign firms producing for foreign markets, but owned by resident investors). However, if climate policies are rationalized as policies with the primary goal to bring about behavioral change, some form of double taxation might be desirable. Depending on the incidence of different types of carbon taxes – a topic on which future work is needed as well – policymakers might want to ensure that each economic actor is confronted with a personal incentive to change their behaviors (whether as a consumer, as a firm manager or as a firm owner). Finally, other taxes also intervene at different stages of the same (circular) economic process with many countries levying, for example, consumption taxes, corporate income taxes and taxes on distributed profits on the individual owner level.

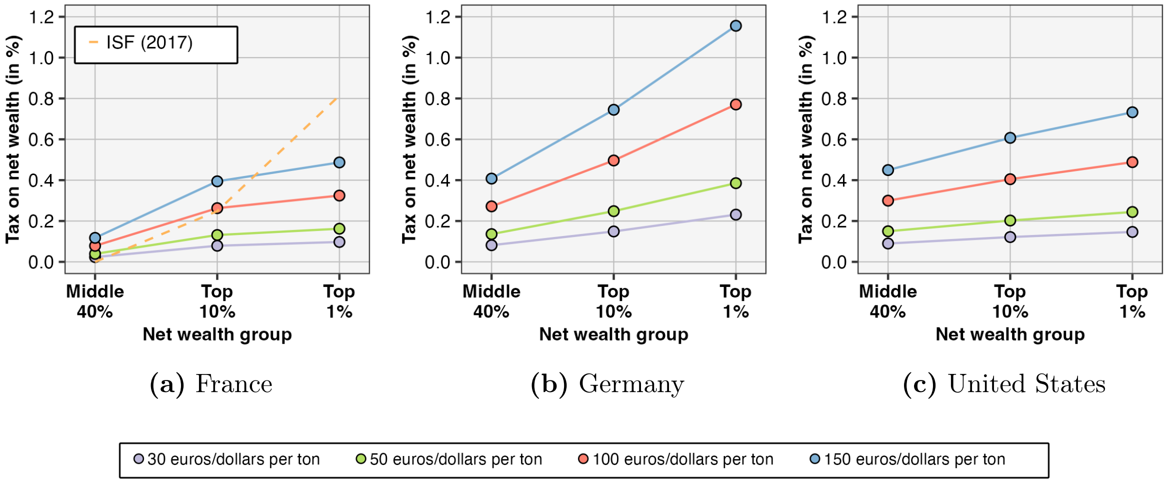
Figure 10. Progressivity of a 150 euros/dollars per-tonne tax on different types of emissions



(a) France **(b)** Germany **(c)** United States

Note: The graphs present the static distributional impact of a tax levied annually per tonne of emissions on different types of emissions. For tax simulations, emissions are distributed to adult individuals instead of the total population. We omit the bottom 50% from the graphs in the figure because the ratio between emissions and net wealth is heavily impacted by the small denominator. If individuals are ranked by *net* wealth, the average individual in the bottom 50% owns relatively little net wealth (due to the impact of liabilities) but somewhat higher gross wealth (which determines ownership emissions). Total wealth-related emissions remain very small in the bottom 50%. Our estimates suggest ownership-related emissions of 1.47t (US), 0.15t (France) and 0.76t (Germany) for the average adult in bottom 50%. The tax carbon wealth tax payment would hence amount to 2-18 euros/dollars per month. In practise, a tax on wealth-related 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.

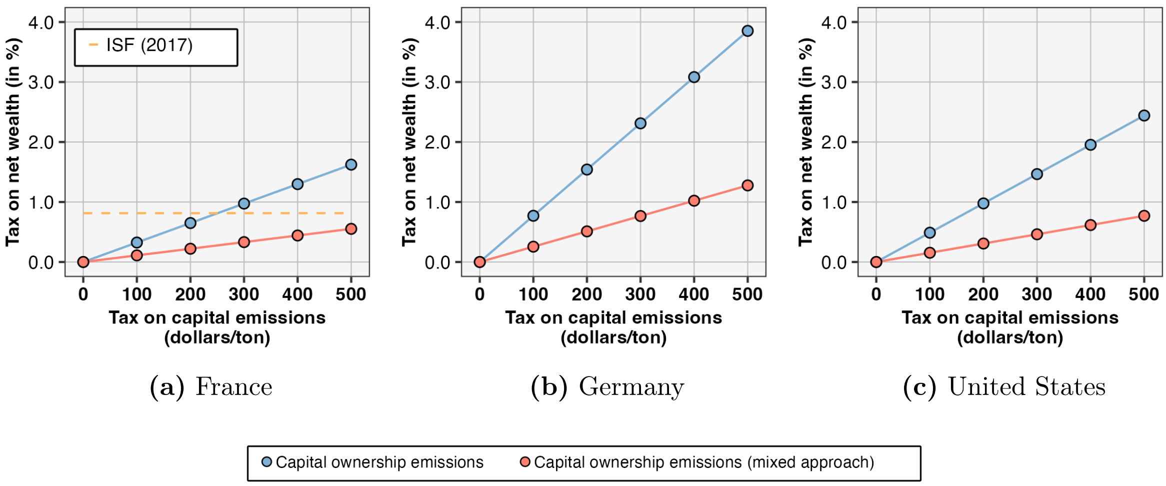
Figure 11. Progressivity of taxes levied on ownership emissions (ownership approach)



(a) France **(b)** Germany **(c)** United States

Note: The graphs present the static distributional impact of a potential tax levied on capital ownership emissions at different levels per tonne. For tax simulations, emissions are distributed to adult individuals instead of the total population. Capital ownership emissions correspond to the wealth-related emissions under the ownership approach. Figures that reproduces the estimates for the mixed approach are available in Figure E.1 in Appendix II. For comparative purposes, we included the tax burden implied by the French wealth tax (ISF) schedule prior to its abolition if the tax had been applied to personal net wealth without deductions or non-compliance. See the note of Figure 10 for why we exclude the bottom 50%. Values refer to 2017 in France and Germany and 2019 in the United States. Tons refer to metric tons.

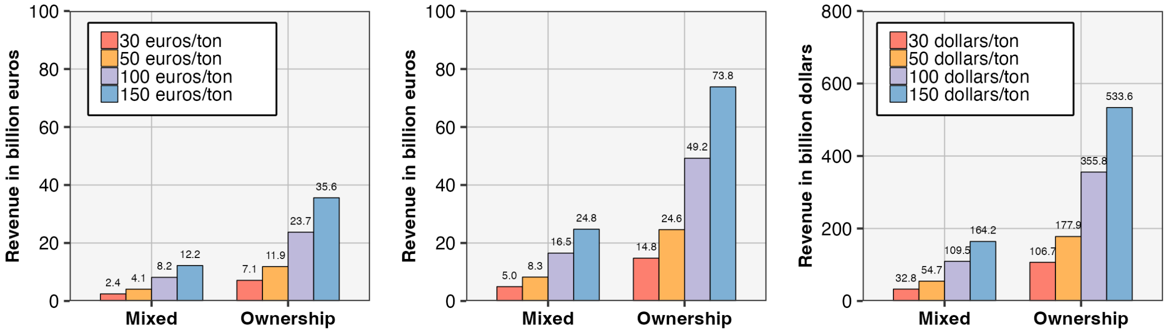
Figure 12. Tax burden for average top 1% wealth holder of taxes levied on ownership emissions



(a) France **(b)** Germany **(c)** United States

Note: The graphs present the static distributional impact of a potential tax levied on capital ownership emissions for the average top 1% wealth holder at different levels of tax per ton. For tax simulations, emissions are distributed to adult individuals instead of the total population. For comparative purposes, we included the tax burden implied by the French wealth tax (ISF) schedule prior to its abolition if the tax had been applied to personal net wealth without deductions or non-compliance. Values refer to 2017 in France and Germany and 2019 in the United States. Tons refer to metric tons

Figure 13. Simple static revenue estimates for a per-tonne tax on capital ownership emissions



(a) France (b) Germany (c) United States

Note: The graph presents static revenue estimates without behavioral responses and with perfect compliance for a per-tonne tax on wealth-related emissions. Values refer to 2017 in France and Germany and 2019 in the United States. Tons refer to metric tons

7 Conclusion

The approaches developed and the estimates produced in this paper are insightful in several ways. Most importantly, they highlight potential strategies to enlarge the perspective on individual carbon footprints by accounting for the role of wealth holders. These new perspectives are of high relevance when it comes to equitably targeting emissions with policy measures. We have found that accounting for capital ownership emissions more than doubles the carbon footprint of the top 10%, increasing it by 2-2.8 times compared to consumption-based estimates (or by 30-65% in the mixed approach). Our results have also shown that emissions from capital ownership alone are more concentrated than capital itself, with the top 10% accounting for 70-85% of total emissions, and that 75-80% of the top 10% emissions come from their owned assets. In the final sections of the paper, we have discussed policy implications and presented some analysis regarding a potential per-tonne tax on carbon wealth. The preliminary estimates revealed: because wealth-related emissions are more concentrated than wealth, such a tax could be closely related to a progressive tax on net wealth for the *average* wealth holder at the top of the distribution, while a emissions-based wealth tax would offer a reduced tax payment to individual investors investing in low-carbon assets.

Much work remains to be done. Our findings suggest that augmenting existing country-level studies on climate inequality with the new approaches developed in this paper (rather than the consumption-perspective only) would be a fruitful research agenda for the coming years. Ideally, however, the analysis should be repeated with much more granular data on the by-asset distribution of wealth. A better understanding of the relationship between carbon footprints, and inequalities in agency, information and available alternatives is required. Behavioral responses, incidence and the already existent carbon taxes should be analysed in more detail before a tax on carbon wealth is actually implemented. There is also a need for the theoretical framework of optimal capital taxation to be extended to include the mechanisms and trade-offs relevant for taxing wealth-related emissions. Most importantly, this includes understanding better the channels through which investor behavior translates into real-world changes in the carbon intensity of the production processes.

At the outset, let us emphasize that achieving decarbonization represents a challenge that will require contributions from all social groups, regardless of their wealth and other socio-economic characteristics. The aim of this paper has been to develop a comprehensive framework for conceptualizing and measuring individual carbon emissions inequalities, thereby enhancing our understanding of the various potential distributional conflicts in the context of the energy transition, in view of better addressing them.

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Appendix

- Link to Appendix I: Methodology
- Link to Appendix II: Additional Figures and Tables