Measuring and Taxing the Carbon Content of Wealth*

Yannic Rehm
Paris School of Economics

Abstract. I estimate the distribution of annual wealth-related greenhouse gas emissions in France and Germany. To that end, I develop a method to combine newly released air emission accounts, national accounts, and survey data on wealth. I make wealth holders responsible for the emissions that occur in production processes they implicitly control. For my headline results, I include in wealth-related emissions only the share of emissions required to expand and maintain the capital stock. My estimates suggest: (i) Wealth-related emissions are even more concentrated at the very top than wealth itself. (ii) Wealth-related emissions are more concentrated in Germany than in France. (iii) Inequalities largely persist if I make homeowners responsible for heating emissions and account for indirect production emissions. (iv) Wealth-related emissions of the average top 10% wealth holder exceed total emissions (including direct and indirect emissions from consumption) of the average adult in the bottom 50% in France and Germany. (v) All emissions considered, the life of the average top 10% wealth holder is 3-5 times more carbon-intensive than the average adult in the bottom 50%. Finally, I discuss a potential per-ton tax on carbon wealth. I show that because wealth-related emissions are more concentrated than wealth, such a tax is closely related to a progressive tax on net wealth.

Keywords: capital, carbon tax, emissions, inequality, national accounts, survey, taxation, wealth

JEL Codes: C83, D31, D62, E01, H21, H23, Q52, Q56

* *Master thesis submitted in July 2021 to Paris School of Economics (PSE). I thank my supervisor Lucas Chancel and referee, Thomas Piketty. I thank Campus France for supporting my studies at PSE.*

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1 Introduction

Greenhouse gas emissions need to decline rapidly if the human species wants to sustain fairly livable conditions on the planet (IPCC, 2018). At the heart of any attempt to achieve that goal lies the question of who is responsible for emissions. Different perspectives exist: Global climate treaties make *countries* responsible for the emissions released on their territory. Emission trading schemes assign responsibility to *corporations*. And the literature on global emission inequality has moved towards placing the responsibility for direct and indirect emissions in the hands of final *consumers* (Chancel and Piketty, 2015; Gore, 2020). What is missing from these perspectives is the role of *wealth holders* who own, control, shape, and financially profit from production processes that release greenhouse gases into the atmosphere.

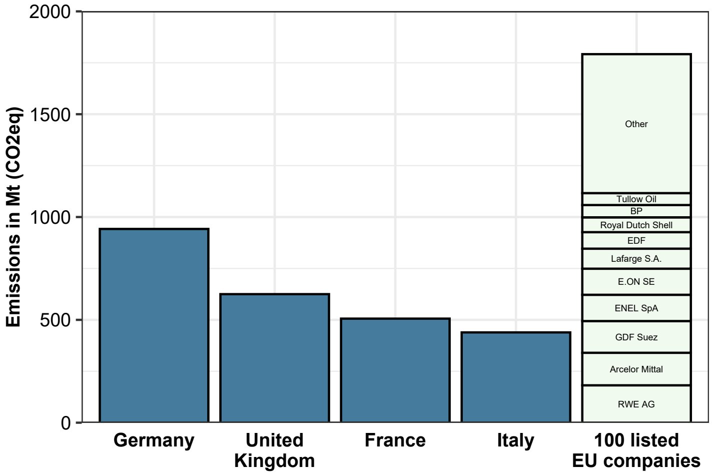
Focusing on wealth-related emissions is important for several reasons. First, these are the emissions that matter most for the wealthy. Existing studies, like the well-known publications by the advocacy group Oxfam (Gore, 2015, 2020), focus on inequality in consumption-related emissions. This is a fruitful perspective to highlight global inequalities because it manages to account for what is referred to as carbon leakage, the process of shifting carbon-intensive production abroad. However, it is less suited when it comes to within-country inequalities and the super-rich. According to my estimates, emissions linked to the production processes they control supersede the direct and indirect consumption-related emissions for top decile wealth holders. Increasingly, high-wealth individuals strive to reduce their personal consumption emissions or pay for emission compensation schemes without any meaningful impact on the living standard.[1] In that case, the decision power over production processes turns into the critical lever for policy interventions. Linking emission responsibility solely to personal consumption risks underestimating the emission responsibility of these high-wealth individuals. Policy interventions like carbon taxes – at least within countries – can turn regressive (Wier et al., 2005; Wang et al., 2016) and lose public support (Douenne and Fabre, 2020).

Considering wealth-related emissions also allows national governments to target emissions that are otherwise outside their reach but for which residents nonetheless bear some responsibility, like the carbon-intensive investment by residents abroad. The split between the geographical, group, and within-group responsibility is ultimately a matter of empirical and normative considerations. However, the control over future production and high concentration of assets at the very top provide two solid arguments for not ignoring the responsibility of those who own the capital that supports polluting production processes (see Figure 1). Finally, once a split between consumption and investment is found, including wealth-related emissions into the picture allows attributing all emissions occurring in the economy consistently and comprehensively to individuals.

To contribute to these debates, in this project, I estimate the distribution of annual wealth-related greenhouse gas emissions in France and Germany in 2017. I develop a method to combine air emission accounts, national accounts, and survey data on wealth from the latest wave of the Household Finance and Consumption Survey (HFCS). I make wealth holders responsible for

[1] Bill Gates has stated that he "will fully offset [his] family's aviation emissions in 2021." (CNBC, 14 Feb 2021)

Figure 1: Annual territorial emissions and direct emissions of 100 large EU-headquartered corporations (2013)



Note: Companies include 100 large EU-headquartered listed corporations with available emissions data in 2013. The 10 largest emitters among those are depicted separately. Scope 1 emissions refer to the direct global emissions of a corporation. The right bar can therefore be viewed as a lower bound estimate of corporate emissions. Based on data from the Carbon Disclosure Project (CDP).

the emissions that occur in production processes they implicitly control. Because I use the capital stock as a hinge between industry emissions and wealth, purely financial wealth does not come with any carbon responsibility in my presentation. First, I link annual production emissions to the industries in which they occur and determine which capital stock assets are used by each industry. Next, I relate capital stock items to institutional sectors based on national balance sheets. Wealth-related emissions of the household sector consist of emissions linked to the capital stock it (i) directly owns and (ii) indirectly controls through owning corporate equity. Finally, I merge these estimates with an enhanced wealth survey dataset, which is aligned with macroeconomic aggregates and concepts through the methods developed in the literature (Vermeulen, 2016; Blanchet et al., 2021). For my headline results, I include in wealth-related emissions only the share of emissions required to expand and maintain the capital stock by drawing upon investment shares derived from multi-regional input-output models. However, I also present a scenario in which I entirely attribute production emissions to wealth holders.

My estimates suggest: (i) Wealth-related emissions are even more concentrated at the very top than wealth itself. (ii) Wealth-related emissions are more concentrated in Germany than in France. (iii) Inequalities largely persist if I make homeowners responsible for heating emissions and account for indirect production emissions. (iv) Wealth-related emissions of the average top 10% wealth holder exceed total emissions (including direct and indirect emissions from consumption) of the average adult in the bottom 50% in France and Germany. (v) All emissions considered, the life of the average top 10% wealth holder is 3-5 times more carbon-intensive than the average adult in the bottom 50%. In the last sections, I discuss a potential per-ton tax on carbon wealth. I show that because wealth-related emissions are more concentrated than wealth, such a tax is closely related to a progressive tax on net wealth that has the potential to raise meaningful revenue.

The remainder of the project is structured as follows. Section 2.1 describes the conceptual challenges and general approach taken. Section 2.2 reviews the literature on capital-related emissions, emission inequality, and wealth inequality. In Section 2.3, I explain how I link emissions to the capital stock (2.3.1) and the household sector (2.3.2). I also expound how I proxy domestically owned foreign capital (2.3.3). Section 2.4 details the technical adjustments necessary to overcome the issues in the wealth survey, among them the comparability problem (2.4.2), the under-reporting problem (2.4.3), and the non-response problem (2.4.4). I then present and discuss my results in 2.5 under four different scenarios. Section 2.5.4 highlights the weaknesses of my approach. Finally, after a brief survey of the taxation literature, Section 3 builds on these results and presents preliminary estimates for a per-ton carbon tax on wealth. Section 4 concludes.

2 Measuring the Carbon Content of Wealth

2.1 Conceptual considerations on emissions, capital and wealth

Linking a physical phenomenon like the flow of emissions to the stock of individual wealth is not straightforward. Four conceptual questions need to be addressed before I can dive into the practicalities of how to estimate the distribution of carbon wealth: (i) how to reconcile the stock of wealth with the annual flow of emissions, (ii) whether to take a consumption or production-based perspective on emissions, (iii) the relationship between capital and wealth and (iv) which share of emissions we should assign to capital owners. The general approach taken in this project will be defined by the choices made regarding these four questions.

First, one obvious obstacle regarding emissions and wealth lies in the nature of the two concepts. Emissions are flows; wealth is a stock. To reconcile both, I will make use of the ownership linkage between emissions and the stock of wealth. Annual emissions that are not direct household emissions occur in production processes. To produce, firms require capital. Capital, in turn, is either owned by domestic households, the government, corporations, or abroad. Suppose that those who own productive capital have control over the production processes – and profit in the form of returns on their capital investment. In that case, we can attribute the annual emissions occurring in said production to the owners of the deployed capital. In other words: Owning 100% of the capital stock of a firm for one year will come with the responsibility for 100% of emissions caused by the firm's production activity in the same year.[2] Clearly, this statement calls for discussing the three remaining questions.

[2]One potential alternative would be to make capital owners responsible as a function of the actual returns on their capital investment, another flow concept. A metric could be annual emissions per euro of return on investment. However, in that case, high emissions per euro of return can stem from investment in an emission-reducing transformation (low profits) as well as from a traditional carbon-intensive business model (high emissions), making it difficult to interpret the results.

Second, my reliance on capital ownership implies that I largely take a production-driven perspective on emissions. I will link those emissions to wealth that are released through the production processes owned and controlled by the owners of the capital stock – and not the emissions necessary to satisfy final demand. I do not want to create a bias in favor of owning capital in industries that mainly produce intermediate inputs used by others. There exists a lively debate in the literature whether consumption or production-based emission accounting should prevail (Davis and Caldeira, 2010; Liu, 2015; Afionis et al., 2017). Consumption-based accounting assigns emissions to the place where products are consumed. Thereby, it manages to account for what is referred to as carbon leakage, the process of shifting carbon-intensive production abroad.[3] Numerous studies have emerged in recent years, demonstrating that territorial emissions are lower than consumption-adjusted emissions in Europe, suggesting these countries are net importers of emissions when trade is accounted for (Chancel and Piketty, 2015). Production-based accounting, on the other hand, has the advantage that it is aligned with international treaties on emission reduction targets. Both take a territorial stance on emissions, in which national emissions are determined by the production activity taking place within the country's borders. While consumption-based accounting appears to be the right tool to highlight global distributional concerns – high-income countries are outsourcing emission-heavy production to low-income countries – the same does not apply within countries.[4] When it comes to emission inequality, it would be a bad call to ignore the responsibility of firms, especially when they tend to be owned by individuals high up in the wealth hierarchy. If we merely look at consumption-related emissions, ignoring the emissions released by production processes they control, we underestimate the carbon responsibility of high-wealth individuals. Even more so because it is increasingly possible for these individuals to reduce their consumption-related footprint by means of paying for emission compensation schemes without any meaningful impact on the living standard.[5] In that case, the decision power over production processes turns into the critical lever for policy interventions.[6] On the other hand, if the responsibility for emissions becomes too closely attached to consumption, policy interventions like carbon taxes – at least within countries – are at risk of turning regressive (Wier et al., 2005; Wang et al., 2016). The production-based perspective therefore seems to be better aligned with my goal to trace out the distribution of wealth-related emissions. However, as soon as a split between consumers and capital owners is found, like the one proposed in 2.5.3, the two perspectives can complement each other. I will, for example, take a consumption-based view on all non-wealth-related emissions whenever they are included in my results. Note also that I move beyond a strict territorial perspective because I decide to proxy emissions linked to the foreign corporate capital stock owned by domestic households.

[3]Liu (2015, p.1) cautions, arguing that consumption-based accounting is "counter-productive to global emissions control if producers increase emissions due to reduced responsibility over the emissions incurred by the production of their exports."

[4]In Gore (2015), more than 50% of individuals in France and Germany are part of the global top 10%, according to Table 1 on page 7 of his technical appendix.

[5]Bill Gates has stated that he "will fully offset [his] family's aviation emissions in 2021." (CNBC, 14 Feb 2021)

[6]Emission trading schemes also take a production-based view on emissions. Who ultimately pays the tax, consumers or producers, is a matter of economic incidence. These questions are discussed when I move to the taxation of carbon wealth in Section 3.

Third, attributing emissions to capital stock owners raises the issue that wealth and capital are different concepts. Capital is a much-debated concept[7] in economics that, in its most widely shared understanding, refers to items "installed and accumulated to serve as instrumental goods for the production of the final product." (Garbellini, 2018). Wealth, however, refers to the value of financial and non-financial assets owned by an individual or the economy, a definition that follows Alvaredo et al. (2020). As they do, I include the value of land in the list of non-financial assets. It ensures that industries reliant on land are appropriately attributed to their owners, even though land is traditionally not part of the (produced) capital stock. I explain more technical issues in 2.3.1 and 2.3.2. At this point, it is important to understand that because I start from the capital stock, I only assign emissions to those assets that can be related to production activities. Owning deposits or other purely financial assets will not imply any responsibly for emissions. An exception is equity, which I use to attribute the emissions of the corporate sector to households and the government.

Forth, which share of emissions should be assigned to capital owners? In my initial results, I include all production-based emissions. This allows me to discuss the level of inequality in emissions if emissions are assigned to the owners of the productive capital stock. In a second step, I propose only to attribute a fraction of emissions to capital owners. Assigning 100% of emissions to capital owners[8] could be viewed as an extreme decision, especially when it comes to a carbon tax. Ultimately, the split needs to be guided by normative considerations or by a more detailed understanding of who is ultimately responsible and ultimately profits from the production activity – consumers or producers. However, the share of capital formation in final demand is one potential avenue to determine a split between consumers and producers in a non-arbitrary way. If production is used to expand or maintain the capital stock, the associated emissions can be allocated to capital owners. On the other hand, if production serves final consumption, these emissions can be funneled to consumers or the government. Multi-regional input-output models allow us to estimate these shares. The idea surely invited criticism. After all, investment shares are directed into the future, while my attribution concerns annual emissions today. Nonetheless, it will enable us to distribute the totality of emissions to households in 2.5.3, taking into account the stock of wealth, the approximate level of consumption, government emissions, and direct household emissions.

After expounding my choices regarding the four conceptual questions, let me briefly recapitulate the approach taken in the subsequent sections. My goal is to link household wealth to the annual emissions that occur in production, which is what I mean by the carbon content of wealth. After briefly reviewing the literature related to my project (2.2), I proceed with the following steps: First, I link annual production emissions to the industries in which they occur and determine which capital stock assets are used by each industry (2.3.1). Owning dwellings, machinery or other capital then comes with a specific average emission responsibility, defined by the production processes that heavily rely on these capital assets. Next, I relate capital stock

[7]For example, during the *Cambridge Capital Controversy* of the 1950s (Cohen and Harcourt, 2003).
[8]Except for direct household emissions.

items to institutional sectors based on national balance sheets (2.3.2). Wealth-related emissions of the household sector consist of emissions linked to the capital stock it (i) directly owns and (ii) indirectly controls through owning corporate equity. I will account for the fact that households and the government own foreign corporations and that some of the domestic corporations are foreign-owned (2.3.3). Finally, I merge these estimates with an enhanced wealth survey dataset, which is aligned with macroeconomic aggregates and concepts pertinent in national accounts (2.4.1-2.4.4). The capital stock measured in national accounts merely acts as a hinge between emissions and wealth. The extensive preparatory work allows me to then discuss the distribution of wealth-related emissions under different scenarios, like the full attribution (2.5.1) and the partial attribution (2.5.3) scenario.

2.2 Earlier attempts

Earlier attempts to estimate the distributional properties of carbon wealth in France and Germany do not exist, to the best of my knowledge. Nonetheless, what I plan to do in the first part of the project is closely connected to at least three strands of literature, which I briefly summarize in this section: the literature on (i) quantifying capital-related emissions, (ii) emission inequality and the existing work on (iii) wealth inequality.

First, my work is related to the literature on quantifying emissions linked to investment and capital. Södersten et al. (2018a) study the environmental impact of capital formation with a special focus on whether investment turns less carbon-intensive when countries develop economically. The findings suggest that, indeed, the capital stock tends to be less reliant on carbon emission in high-income countries. Methodologically, Södersten et al. (2018a) draw upon multi-regional input-output tables and allocate emissions to investment following the share of capital formation in final demand. Similarities exist to what I do in 2.5.3, when I make use of investment shares to partially attribute emissions to the owners of the capital stock. Note, however, that I take a production-driven perspective when it comes to wealth-related emissions, making wealthy individuals responsible for emissions occurring in the production processes they control. Södersten et al. (2018a), on the other hand, take a demand-driven view on capital formation and thereby focus on the emissions embodied in investment goods demanded by a given industry. I discuss the issue in more detail in 2.5.3.[9] Furthermore, Södersten et al. (2018a) restrict themselves to cross-country comparisons and do not, as I do, study the distribution of capital stock-related emissions within countries.

Ritchie and Dowlatabadi (2014) estimate what they coin the *carbon shadow* of investment on the sector level in the United States, based on input-output models. Furthermore, the authors estimate the amount of emissions embedded in the investment portfolio of a Canadian university to show that emissions from investment can easily exceed the emissions resulting from the regular operation of the university. With some resemblance to what I propose in 2.5.1 – the full attribution scenario to allocate emissions to capital stock owners –, Ritchie and Dowlatabadi (2014) define

[9] See, for example, Footnote 76.

the carbon shadow of a firm (partially) owned by an investor as the totality of emissions necessary for it to provide its services. Hence, Figure 2 in Ritchie and Dowlatabadi (2014) looks a lot like Figure 2 in 2.3.1. As is the case with my analysis, the attribution of emissions in Ritchie and Dowlatabadi (2014) reflects a snapshot of the current year. It does not take into account potential reductions in the future financed by investment decisions today.

Chen et al. (2018) try to address the aforementioned dynamic problem regarding emissions embodied in the capital stock. Not only does production today rely on potentially polluting capital formation in the past, but a fraction of current output is also used to expand the capital stock of carbon-intensive industries further. To account for the role of capital, Chen et al. (2018) endogenize it within the input-output framework.[10] Emissions related to the production of capital goods are then shifted to final consumption, based on when and where these capital goods (i) are deployed and (ii) had been produced. For that reason, Chen et al. (2018) can be understood as an evoking to better account for the role of capital formation in the process of allocating emissions to final demand. The study does not, however, allocate investment-related emissions to capital stock owners. Its core contribution is to highlight that some of the gaps between consumption-based and production-based carbon accounting are explained by the building up and maintenance of the capital stock rather than international trade.

Greenpeace (2020), a policy paper, is arguably most closely related to what I do. It presents the distribution of the annual emissions linked to financial assets in France for the year 2015 and proposes a wealth tax on the basis of these estimates. The results suggest that individuals in the top 1% of the income distribution are, on average and only through their financial assets, responsible for 189.1 tons of CO2 equivalents per year. I put these results and the assumptions made to obtain them into perspective in 2.5.4 when I discuss and compare my own estimates to what is found in the literature. Let it be noted here that several methodological differences exist. Most importantly, Greenpeace (2020) assigns emissions to assets based on carbon intensity factors that are not derived from macroeconomic statistics but compiled by the consulting firm Carbone 4. In contrast to my approach, holding financial instruments like deposits comes with some responsibility for carbon emissions, even though no direct or indirect control over production activity can be attached to these assets.

Finally, a multitude of private sector approaches and attempts exist that try to quantify the carbon footprint of investment portfolios.[11] These standards are either developed because environmental reporting is mandated by law or to address the risk investors increasingly associate with carbon-heavy investment – out of concern for their reputation or because they fear stricter environmental regulation in the future (United Nations Environment Programme, 2013). Importantly, in order

[10]See Södersten et al. (2018b) for details.

[11]Recent initiatives to introduce transparency to investment-related emissions include the Montréal Pledge (2016) and the Portfolio Decarbonization Coalition (PDC, 2017). Standard methods and practices are reviewed by the Task Force on Climate-related Financial Disclosures (2017) and in a report prepared by the United Nations Environment Programme in conjunction with the World Resources Institute and the 2 Degree Investing Initiative (2015). Unfortunately, despite the large number of reports on the topic, there appears to be a lack of coordination between the different initiatives, organizations, pledges, coalitions, and projects, which all have considerable overlap.

to quantify the portfolio footprint, an investor needs information about emissions at the firm level. If they exist, these statistics often follow the most widely used reporting standard developed in the Greenhouse Gas Protocol (GHGP, 2004).[12] Unfortunately, despite initiatives like the Carbon Disclosure Project (CDP), firm-level data on emissions is often either not collected, insufficient, or not publicly available – in particular for non-listed firms.[13] And even if firms compile and publish some data, no consensus method to quantify and attribute emissions has been found so far (Busch et al., 2020). The existing guidelines differ particularly on whether and how they (i) include indirect scope 3 emissions[14], (ii) account for plans to reduce emissions in the future, and (iii) assign emissions to assets that do come with control over firm decisions, like bank deposits or owning the minority of a firm's shares. Besides, the issue of double-counting has not been resolved. First, the indirect emissions of one firm are the direct emissions of another firm. Second, if carbon footprinting attributes all emissions to the owners of firms, to avoid double-counting, consumers would automatically be destined not to bear any responsibility (Ritchie and Dowlatabadi, 2014). On top of these questions regarding data availability and double-counting, purely bottom-up carbon footprinting is not suited to determine wealth-related emissions in a way that is consistent with macroeconomic aggregates. It is not applicable for my purposes in any case because I do not have access to the names or industries of firms to which wealth holders route their investment. Portfolio carbon footprinting methods have not yet been used to study inequalities in wealth-related emissions, to the best of my knowledge.

Second, my project has a clear connection to the literature on inequalities in carbon emissions. Recently, the distribution of consumption-based emissions has been estimated on the global level, accounting for indirect emissions embodied in final consumption (Chancel and Piketty, 2015; Gore, 2015, 2020).[15] Individuals in the global top 10% income bracket were found to be responsible for 53% of cumulative emissions between 1990 and 2015 (Gore, 2020) and for around 49% of lifestyle consumption emissions in any given year (Gore, 2015). Both publications, prepared for the non-profit organization Oxfam, (i) built upon a global income dataset prepared by Milanovic (2015), (ii) assume a unitary elasticity between income and emissions, and (iii) introduce an arbitrary emission floor at 50% of the mean emissions to circumvent unrealistically low emission

[12]If firm-level information is not available, carbon footprinting guidelines occasionally revert to using industry-level emission intensity coefficients, estimated from input-output models. See, for example, Footnote 41 on page 22 of the TCFD (2017) report. In that case, they are not more granular than what I do.

[13]Some progress has been made in recent years with the introduction of emissions trading systems (ETS), like the EU-ETS. Firm-level emissions subject to the scheme can be recovered from the European Union Transaction Log. Countries have also moved towards mandating corporations to publish quantitative estimates on emissions and energy use. One example is the *Loi Grenelle II* in France, which requires a *Bilan des émissions de gaz à effet de serre* from enterprises with more than 500 employees (*loi no 2010-788 du 12 juillet 2010*). Another example is the revised regulation applicable in the United Kingdom since 2019, which demands from quoted corporations to report on their global energy use annually (*The Companies (Directors' Report) [...] Regulations 2018*).

[14]These refer, among others, to the emissions necessary to produce intermediate inputs purchased by a firm.

[15]These studies are nested within the larger body of research that uses input-output models to reassign indirect production emissions to final consumption (Leontief, 1970; Davis and Caldeira, 2010; Chen et al., 2018). An alternative approach to determine consumption-based emissions is life-cycle analysis (LCA). It starts from the direct and indirect emissions released over the life-cycle of a product instead of working with industry averages. The data needs are demanding, though, raising similar issues as carbon footprinting on the asset level. Hence, life-cycle analysis is applied chiefly to study the emissions of individual products (Dai et al., 2019), rather than total consumption.

levels at the bottom of the global income distribution. Implicitly, the results of Gore (2015) suggest a top 10% emission share of 26.3% in France and 25.6% in Germany.[16] At 45.2-51.3%, Chancel and Piketty (2015) find similar emission shares attributed to the consumption behavior of the global top 10%.[17] In contrast to what I do, these studies on emissions inequalities[18] are based on income instead of net wealth brackets. Furthermore, they do not account separately for the emissions related to owning wealth and thereby controlling part of the capital stock. Emissions linked to investment are either removed from the analysis or distributed to final consumption. Hence, even though I will attempt to compare these results to what I obtain in 2.5.4, I develop a novel perspective not present in the existing literature on emission inequalities.

Third, my work builds on the extensive literature on wealth inequality. I make use of three types of papers in particular. First, my work is related to the efforts undertaken in recent years to build macro-consistent distributional income and wealth series, known as *Distributional National Accounts* (Piketty et al., 2018; Alvaredo et al., 2020; Chancel, 2020) because I link macroeconomic metrics on capital stocks, sectoral balance sheets, and annual emissions in a consistent way to micro data on wealth. For technical and definitional questions, I will frequently refer to these seminal contributions. Second, I need to apply a compound of techniques and methods in 2.4 to mitigate issues that come with using survey data on wealth (Cowell and Van Kerm, 2015; Eckerstorfer et al., 2016; Vermeulen, 2016; Benhabib and Bisin, 2018; Blanchet et al., 2018; Chakraborty and Waltl, 2018; Chakraborty et al., 2018; Blanchet et al., 2021). Third, I draw on the wealth inequality literature to check for the plausibility of my results and to present an alternative strategy of modeling the top tail of the wealth distribution (Alvaredo et al., 2018; Krenek and Schratzenstaller, 2018; Bach et al., 2019; Garbinti et al., 2020).

This section has shown that even though the literature has been engaged in quantifying (i) capital-related emission, (ii) emission inequality, and (iii) wealth inequality, bringing these three aspects together remains a new idea.[19] The point applies even more to the study of within-country inequalities in wealth-related emissions. In that regard, what I do complements the global or cross-country perspective frequently taken elsewhere. However, it has also become clear that everything that follows is fully reliant on the advancements made by others in recent years. In the next section, I begin my step-by-step exposition of how I link emissions to the capital stock and then to individual wealth holders in France and Germany.

[16] See Table 2 on page 10 of the technical note accompanying Gore (2015).
[17] The income-emission elasticity is either set at 0.7, 0.9 or 1.1, leading to slightly different estimates.
[18] Similar publications on the country-level exist for China (Wiedenhofer et al., 2016), India (Shoibal Chakravarty, 2011), the United States (Weber and Matthews, 2008) or the European Union (Sommer and Kratena, 2017).
[19] I provide a short survey of the literature on the taxation of wealth, externalities, and emissions in 3.1.

2.3 Prepare macro-level data on emissions

2.3.1 Link air emission accounts to the capital stock

As a first step, I explain how I link the flow of annual residence-based emissions to the national net capital stock. From hereon, capital stock refers to what economists denote as K in any production function $Y = F(K, ...)$. It includes the actual buildings, machinery, technical equipment and intellectual property necessary for the production process of output Y. This is different from the notion of wealth W, which also includes financial assets and liabilities.

Even though our goal is to link emissions to individual wealth – and not to the capital stock – it is unavoidable to start with this production-based concept of capital K because all emissions other than direct emissions by households occur in production processes. This implies that financial wealth does not have an immediate carbon content. Instead, all emissions assigned to financial wealth holders originate from domestic and foreign corporations that utilize capital K and that are directly or indirectly owned by the holders of financial assets. Think of an individual owning shares of a steel-producing company. I will use the terms capital stock and non-financial assets interchangeably.[20]

To determine the net capital stock, most statistical agencies, among them Insee in France and Destatis in Germany, rely on the perpetual inventory method (PIM) introduced by Goldsmith (1951). This method estimates the stock of capital based on the accumulated past investment flows, correcting for deprecation, the retirement of assets, and price changes. The depreciation of fixed capital is also frequently referred to as *consumption of fixed capital*, highlighting its use as an input in the production function. Consider for illustrative purposes the capital asset K_i in period t. Absent other price changes, the existing stock of capital $K_{i,t-1}$, new investment $I_{i,t}$, abnormally retired capital $R_{i,t}$ and the depreciation rate $\delta_{i,t}$ define the stock of K_i in period t:

$$K_{i,t} = (1 - \delta_{i,t})K_{i,t-1} + I_{i,t} - R_{i,t} \tag{1}$$

There are a number of known issues regarding the perpetual inventory method (PIM), which are well-summarized in the appendix to Piketty and Zucman (2014). The deprecation profiles $\delta_i(t)$ are difficult to estimate and not harmonized across countries.[21] The historical investment data underpinning $K_{i,t-1}$ is likely of poor quality. Price changes not related to deprecation (e.g., stemming from technological progress) are difficult to estimate on the asset level. Furthermore, statistical agencies do not properly observe the amount of capital $R_{i,t}$ that is not fully depreciated but permanently retired. Large one-off outflows of national importance are accounted for,[22] but

[20] The issue of land is discussed in detail at the end of this section.

[21] France and Germany use the same (linear) depreciation function, but do not estimate the average service life and retirement profiles of assets based on the same methodology (Rincon-Aznar et al., 2017; Schmalwasser and Weber, 2012).

[22] To illustrate the necessary scale, this includes (in Germany) the two major floods in 2002 and 2013 and the permanent shutdown of 8 nuclear power plants in 2011 (Gühler and Schmalwasser, 2020).

the PIM implicitly assumes that fixed assets of smaller firms going bankrupt are fully bought up by other domestic firms, as noted by Piketty and Zucman (2014) and discussed in Mayes and Young (1994).

Despite these shortcomings, I will use the capital stock as it is recorded in national accounts. First, these estimates have the advantage that they are consistent with other national account statistics, for example, those on investment and – as we shall see – those on emissions. Second, using firm-level data on non-financial capital would also entail both estimating the price changes due to technological progress and dealing with non-homogeneous deprecation schedules. This is because corporate balance sheets record physical assets based on their historical market value at the point of acquisition, net of depreciation, and not based on their current market value. Furthermore, similar to the practice of statistical agencies, firms are allowed to choose from a set of deprecation methods as per international accounting standards (like IFRS). Coming back to Section 2.2, I am also not aware of any unified and convincing database on firm-level emissions – even if only direct scope 1 emissions are of interest.

Note that for my headline estimates in Section 2.5, I do not rely on the absolute value of the corporate capital stock as recorded in national accounts, but merely on the share of different capital stock assets used in each industry. An economy-wide overvaluation or undervaluation of the corporate capital stock would not impact my results. I do, however, use the current replacement cost of the capital stock owned by households and the value of equity owned by households, the government, and the rest of the world in Section 2.4.3 to align the survey wealth with wealth recorded in national balance sheets. Note here that the non-financial wealth owned by households is dominated by housing, which – at least in aggregate terms – is believed to be estimated with less imprecision thanks to the inclusion of additional survey and census data in the estimation process of current market prices (Piketty and Zucman, 2014).

Estimates of the net capital stock by industry and asset type for the 26 members of the European Union and the United Kingdom can be obtained from Eurostat national accounts or from the EU-KLEMS project.[23] Eurostat releases estimates of the non-financial capital stock by industry for 21 industry groupings, following the sections titles of the NACE Rev.2 classification.[24] For most EU countries, the EU-KLEMS (2019) database provides more granular data, but these industry subgroups seem to be imputed based on the Eurostat groups so that they do not provide any additional information for our purposes. I therefore revert back to Eurostat data for the core of the project. Table 1 illustrates the structure of the Eurostat data on the capital stock per non-financial asset and industry. It presents the economy-wide values for France in 2017 and the values for one selected industry, namely the construction sector. I use *net* capital because it refers to the current market value, taking into account the depreciation of fixed assets. Net capital

[23]The World-KLEMS initiative hosts similar databases for Argentina, Canada, China, India, Japan, Korea, Russia and the United States. These could potentially be used to expand my analysis to more countries. KLEMS stands for capital (K), labor (L), energy (E), materials (M) and service (S).

[24]NACE stands for "Nomenclature statistique des activités économiques dans la Communauté européenne." For section titles, see Eurostat (2008), p. 57.

Table 1: Capital stock and emissions in France (2017)

	National Economy	Construction
Capital stock in billion euros		
Fixed assets	7,648.6	48.4
Dwellings	4,524.6	0.0
Other buildings and structures	2,033.9	27.3
Machinery and equipment	662.4	18.2
Cultivated biological resources	22.1	0.0
Intellectual property products	405.6	2.9
Inventories	433.4	-
Valuables	141.9	-
Land	6,243.6	-
Natural resources	12.2	-
Emissions in million tons (CO2eq)		
National emissions	473.3	9.4
incl. Direct household emissions	125.2	-

Note: Excerpt of the type of data used to calculate the emissions per net capital stock asset in France (2017). The first column presents aggregate values as recorded in national balance sheets and air emission accounts. The second column presents the values for one selected industry, Construction (NACE Rev.2, Section F). As detailed in the text, I use 21 industry sectors and 9 capital stock assets. Asset subcategories (e.g., ICT equipment) are omitted from the table for better visibility. Machinery and equipment include weapon systems. Based on data from Insee and Eurostat.

also corresponds to how financial assets, for which only the market value exists, are recorded in national accounts.

These capital stocks need to be complemented with data on greenhouse gas emissions. In recent years, Eurostat has started to release annual data on industry-level emissions in the form of air emission accounts (AEA). The concepts and principles underpinning these emission accounts are fully consistent with those used in national accounts. In doing so, the emission accounts published by Eurostat form part of the larger quest to build a global *System of Environmental-Economic Accounting* (SEEA). National statistical agencies in the European Union were first mandated to submit emission accounts to Eurostat in 2013. Industry groupings in emission accounts follow the NACE Rev.2 standard. National residence-based emissions are either assigned to (i) one of 64 industry sub-groups based on the economic activity or (ii) a special column collecting direct emissions by households.

Eurostat emission accounts identify 7 distinct greenhouse gases[25] including CO2 "emitted into the atmosphere as a result of economic activity" (Eurostat, 2015). As it is common in climate accounting, the unit of measurement is *CO2 equivalents*, deduced from comparing the global warming potential of each gas to carbon dioxide. Hereafter, whenever I mention emissions,

[25] The 7 greenhouse gases in air emission accounts are carbon dioxide (CO2), Nitroux oxide (N2O), Methane (CH4), Perfluorocarbons (PFCs), Hydrofluorocarbons (HFCs), and Sulphur hexafluoride (SF6) including Nitrogen trifluoride (NF3). CO2 from biomass is included, whereas other air pollutants not directly related to global warming are excluded from my analysis.

emission intensities, or the carbon content of wealth, I refer to the sum of the 7 greenhouse gases measured in CO2 equivalents. On that matter: More than two-thirds of greenhouse gas emissions in 2017 – around 70% in France and 85% in Germany – were emissions of CO2, according to the actual emission accounts.

The consistency with national accounts implies that emission accounts follow the residence principle. The emission accounts of a given country include all emissions of its resident units, regardless of where these emissions actually occur.[26] If a company is based in France, its emissions are part of the French emission accounts. If a French tourist heats her vacation home abroad, these emissions are part of the French emission accounts. If a French airline transports a person from London to New York, these emissions are part of the French emission accounts.[27]

This might seem more problematic than it is. Remember that, according to national accounting guidelines, subsidiaries and local branches of foreign multinational corporations are considered to be *resident* institutional units (SNA 2008, 4.13/4.15 (c) and ESA 2010, 2.07). Thus, the difference between residence-based and territory-based emission accounting primarily stems from tourism and international transport. Furthermore, the bridging tables released by Eurostat indicate that the difference is small. In 2017, territory-based emissions were around 3-5% below residence-based emissions in France and Germany, implying that the emissions of French and German residents abroad superseded the emissions of foreign residents on the territory. Besides, keep in mind that the residence principle is aligned with the conceptual idea of this project as introduced in Section 2.1. Take the airline example: If we want to assign emissions to wealth holders, we want to assign the emissions of a French airline to its (resident, non-resident or governmental) owners, rather than to the country of operation or to the country where its costumers are based. The direct emissions of domestic households traveling abroad will, in any case, be captured by the separate *direct emissions by households* column in the emission accounts of their residence country.

The *direct emissions by households* column in emission accounts demands special attention, however. Direct emissions by households are those emissions that cannot be attributed to any industry because the actual release of gases into the atmosphere happens through the behavior of private households. These emissions typically include heating and road transport – but also other activities like mowing the lawn or lighting a bonfire. In this project, these emissions rightfully cannot be attributed to the owners of the capital stock because the actual emission activity occurs in the premises or the vehicle of the household. Hence, these emissions, which make up around 36% of total national emissions in France and 27% in Germany (2017), are set to remain a separate category disconnected from the distribution of wealth until the end. In Section 2.5, I include these emissions in one presentation of my results by assigning them to individuals based on the distribution of income.

[26] This distinguishes air emission accounts from air emission inventories, which are commonly used to monitor the national compliance with international climate accords. Inventories are based on a territory principle and classify economic activity according to technical processes rather than industries.

[27] See bullet point 35 on page 16 of Eurostat (2015).

Related to these reflections, it is vital to understand how housing is treated in air emission accounts. Housing wealth makes up the bulk of wealth owned by the mid-percentiles of the wealth distribution. First, both households living in their own apartment and households renting out an apartment are considered to obtain services from the *real estate services* industry.[28] In the owner-occupied case, the household owns housing capital attributed to the *real estate services* industry sector, whereas for non-owners, this capital belongs to other wealth holders. Second, emission-wise, being the owner of housing capital will be equal to owning the *cold*, unheated building (and the land beneath it, see the end of this section). It avoids an unnecessary bias resulting from owner-occupied and non-owner-occupied housing. The emissions from heating or cooling the building are attributed to the household living in the building. For one, national accounting guidelines do consider the *cold* dwelling as the output of the real estate industry (Eurostat, 2016). Furthermore, in contrast to other industry sectors with an industry-household relationship, the heating emissions occur directly through the behavior of private households, independently from the owner of the housing capital. As mentioned just above, in this project, emissions from heating will therefore not be attributed to the *cold* housing capital stock but remain a separate item[29]. Despite that, in 2.5.2, I will also present my results under the alternative assumption that allocates heating emissions to homeowners.

Table 1 provides a good starting point to understand how combining net capital stocks by industry with emission accounts allows us to allocate the flow of annual emissions to the stock of non-financial capital assets – in a way that is more informative than merely dividing all emissions by the market value of the total net capital stock. The idea is to ask, in that order: (i) In which industries is a certain type of capital used? (ii) What is the share of the given capital type in these industries? (iii) For how much of total emissions are these industries responsible? 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 is responsible for 1% of total emissions. That would make owning 100% of the IT equipment capital in the economy equivalent to being responsible for $50\% \times 1\% + 25\% \times 1\% = 0.75\%$ of national emissions.

This simple backward attribution can be done for the 9 fixed non-financial capital types[30] and 21 industries, for which data is available in national accounts and in the emission accounts. The core element needed is a matrix of capital stock by industry and asset, and a vector of annual emissions by industry. These matrices are presented in Tables A.3 and A.4 in the appendix. They allow us to compute for each asset – say machinery or dwellings – the annual emissions associated with 100% of the given capital stock item – based on the emission intensity of the industries

[28] Technically speaking, this is because the NACE Rev.2 category L includes imputed rents of owner-occupied dwellings (Eurostat, 2008, p. 80).

[29] The same applies to direct transport emissions by households. The argument is even more clear-cut, given that vehicles are excluded from the capital stock (see the paragraph at the very end of this section). If we do not want to disregard these emissions entirely, they need to be classified as *direct emissions by households*.

[30] These include: dwellings (AN.111), other buildings and structures (AN.112), transport equipment (AN.1131), ICT equipment (AN.1132), other machinery and equipment and weapon systems (AN.11O), cultivated biological resources (AN.115), research and development (AN.1171), computer software and databases (AN.1173) and other intellectual property products (AN.117-AN.1171-AN.1173).

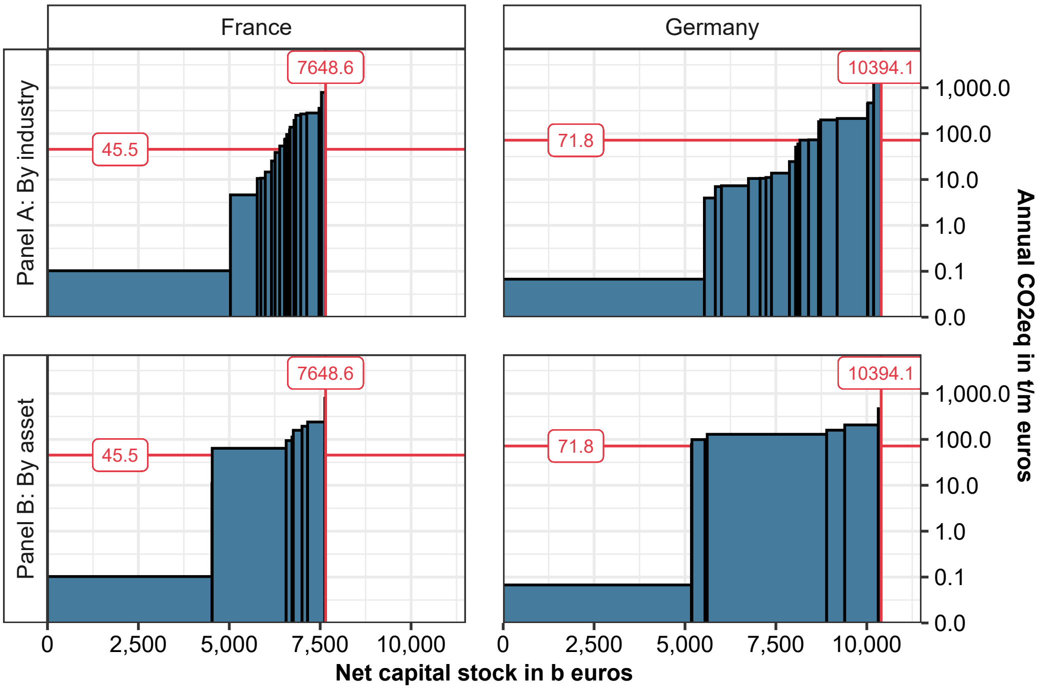
that use it. As a result, we are left with a table, see Table A.5 and Table A.6 in the appendix, that attributes all annual emissions other than direct household emissions to the 9 non-financial capital types represented in the national capital stock. As we have seen in earlier paragraphs, both emissions accounts and the capital stock are based on national accounting concepts and definitions, making it possible to combine both.

Figure 2, Panel A presents the starting point, the attribution of annual emissions to the national capital stock by industry for France and Germany in 2017. It depicts the capital stock on the x-axis and the log emission intensity in tons of annual CO2 equivalents per million euros on the y-axis. Each colored area represents one of the 21 industry sectors. Although this comes before we make any attribution of emissions to the type of capital used in each industry, the figure allows us to make three important observations. First, in 2017, the German economy is substantially more carbon-intensive than the economy in France. Owning 1 million euros of the net capital stock for one year brings with it, on average, the responsibility for 45.5 tons of greenhouse gas emissions in France and for 71.8 tons of greenhouse gas emissions in Germany. Second, in both countries, capital and emissions are concentrated in a few industries – and the industries that deploy most of the capital stock are not those with the highest emissions. More than 50% of the net capital (66% in France and 53% in Germany) can be attributed to housing, whereas the real estate industry is only responsible for a negligible fraction of greenhouse gas emissions. On the other hand, three-quarters of the emissions occur in agriculture, manufacturing, transport, and utilities. Third, the electricity and gas industry is more carbon-intensive in Germany, whereas agriculture makes up a larger share of all emissions in France. Owning 1 million of the net capital stock in the electricity sector, on average, brings with it the responsibility for 250.6 tons of emissions in France, but 1,553.3 tons of emissions in Germany.[31] Table A.1 and Table A.2 in the appendix present all numbers underpinning Figure 2, Panel A.

Figure 2, Panel B shows the results of the first step, the attribution of annual emissions from air emission accounts to the national capital stock by capital good through the respective use-tables per industry. As explained in the previous paragraphs, the average emissions associated with holding each capital stock asset for one year originate from the emissions of the industries they are used in. Two observations are warranted at this point. First, we recognize the low carbon intensity of the real estate industry from Figure 2, Panel A in the low carbon intensity of the asset category *dwellings*. This is because dwellings are primarily used in the real estate sector, which has a low carbon intensity. As we would expect, business buildings and structures have a substantially higher carbon intensity than dwellings. Second, machinery and equipment, although only representing 13% of the total capital stock in Germany and 8.7% in France, are used in industries that have high emission intensities. Owning 100% of the machinery and equipment capital stock brings with it the responsibility for 31% of greenhouse gas emissions in France and 42.2% in Germany. Table A.5 and Table A.6 in the appendix present all results underpinning

[31]This difference is well-known and can be traced back to the continued use of coal in electricity generation in Germany. Although on a declining path, 44% of electricity in Germany was generated from fossil fuels in 2020, versus 9% in France, which relies on nuclear power for 67% of its generated electricity (Redl et al., 2021).

Figure 2: Attribution of emissions to industries and capital stock assets (2017)



Note: Panel A presents the attribution of annual national emissions to 21 industry sectors in France and Germany in 2017. Panel B presents the attribution of annual national emissions to 9 capital stock assets, through their respective use in the 21 industries. The length (x-axis) of each rectangle represents the net capital stock. The height of each rectangle represents the assigned annual greenhouse gas emissions in tons per million euros of capital. The red line depicts the average emission intensity (x-axis) and the total capital stock (y-axis). The product of both is equal to total national emissions. Direct emissions by households excluded. The y-axis is log-scaled for better visibility of low-carbon rectangles. Table A.1-A.6 present the full data underpinning the figure. Based on data from Destatis, Insee, and Eurostat.

Figure 2, Panel B. Figure A.3 in the appendix demonstrates that these shares are fairly stable over time.

Thinking ahead to the structure of the wealth survey, we need to address the issue of land before we move on. Air emission accounts do no attribute any emissions to land, even though these items are part of the full list of non-financial assets in the economy. In contrast to that, housing and business assets in the household survey typically include the value of land. To make the macroeconomic and survey categories compatible, I decide to include the value of land from hereon, even though it is typically not part of the produced capital stock as understood by economists. I assign land values as available in national balance sheets proportionally to the two corresponding produced non-financial assets, *dwellings* and *other buildings and structures*.[32] The

[32] In terms of the classification used in national accounting, this corresponds to $AN.2111 \times AN.111/(AN.111 + AN.112)$ for dwellings and $AN.2111 \times (AN.112)/(AN.111 + AN.112)$ for other buildings and structures. Land not underlying buildings ($AN.211 - AN.2111$, e.g., land under cultivation) is assigned to the *other buildings and structures* line item. Similar to Piketty and Zucman (2014), I include natural resource capital where available, but it represents a small share of total non-financial assets in the two countries concerned ($< 0.1\%$ in France). As noted by Bauluz (2017), it would be correct to consistently include natural resources because its value is reflected

results are displayed in the second column of Table A.5 and Table A.6 in the appendix. The inclusion of land reduces the emission intensity of housing in terms of the annual emissions per million euros of capital stock further. However, note that this does not change the emissions assigned to 100% of the housing stock because no additional emissions are assigned to land. In terms of Figure 2, the inclusion of land reduces the height of the respective capital stock rectangles, but not the area they cover.

The comprehensive list of non-financial assets in national balance sheets also includes valuables and inventories, even though no emissions can be assigned to these items because the data is not available at the industry level. As all emissions have already been assigned, they are not able to add any additional piece of information that can be utilized. Furthermore, they are limited in size relative to the total capital stock. I will, therefore, not adjust the capital stock further and exclude valuables and inventories from the analysis.

Adjusted for the value of land, the results presented in Figure 2, Panel B form the basis for the next step of the attribution in Section 2.3.2.

2.3.2 Determine ownership of the capital stock by institutional sector

In the second step, I distribute the capital stock – and the associated annual emissions obtained in Section 2.3.1 – among the four institutional sectors of the economy: financial and non-financial corporations, the government, households and the rest of the world. In Section 2.5, I link emissions to household wealth. To do so, I need to know if capital stock assets are owned by households or by other institutional sectors.

The share of capital directly owned by the government and by households is available in national balance sheets for each of the 9 asset types used in the previous section. We can therefore easily distribute those emissions to the household and government sector. For households, it either consists of housing capital, which is reflected in the line item *dwellings*. Or it consists of self-employed, unincorporated business capital, which is reflected in the remaining capital stock items. I cannot distinguish between households and the non-profit sector in the wealth survey, which is why I combine both in what follows. The (non-financial) capital share of the non-profit sector is small, though. It adds less than 1% to the capital stock owned by households. Following the explanation in the previous section, I reassign land to the capital stock for each sector so that the added land is aligned with the capital stock deployed within *each* sector.

More effort is needed when it comes to the corporate capital stock. Even though the non-financial capital stock of the corporate sector is readily available in national balance sheets as well, these corporations are ultimately either owned by households, the government, or the rest of the world. It is important because, thinking ahead, we want to link emissions to household wealth as recorded in a wealth survey. Suppose a wealthy individual owns a corporation that emits greenhouse gases in its production process. In that case, we want to assign these emissions to the wealth

in the market value of equity of resource-intensive industries that I utilize in Section 2.3.2. I omit *purchases less sales of goodwill and marketing assets*, which are estimated by Insee for France but not by Destatis for Germany.

holder in the household sector and not to the corporate sector. Similarly, if the government owns the corporation, we want to assign these emissions to the government sector. Figure A.2 in the appendix illustrates the idea graphically. For more details on the conceptual idea behind this project, go back to Section 2.1.

To assign corporate emissions to the other sectors, I opt for an approach similar in spirit to what Piketty and Zucman (2014) do. For their measure of market value national wealth, 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. The amount of outstanding equity and equity holdings sector can be obtained from sectoral *financial* balance sheets. Financial balance sheets are published by statistical agencies in the national accounting framework and record, for each sector, the market value of financial assets and liabilities. These financial instruments include deposits, debt securities, loans, equity and investment fund shares, or private insurance and pension schemes.

Along the lines of Piketty and Zucman (2014), I use information on the outstanding amount of equity assets and liabilities in each sector. By construction, in unconsolidated balance sheets, the outstanding equity (L, Eq) of the corporate sector and the rest of the world is equal to the equity holdings of the national economy, plus the domestic equity owned by the rest of the world:[33]

$$C_{L,Eq} + RW_{L,Eq} = C_{A,Eq} + G_{A,Eq} + H_{A,Eq} + RW_{A,Eq} \tag{2}$$

With that identity in mind, the outstanding equity of corporations can be assigned to either the government, the household sector, or the rest of the world. In the wealth survey, I will not be able to distinguish between owning shares of financial and non-financial corporations. Therefore, I combine both sectors in what follows. I use unconsolidated financial balance sheets because corporations also hold corporate equity $C_{A,Eq}$, which increases the absolute amount of outstanding equity $C_{L,Eq}$. Using the consolidated net equity of the corporate sector would inflate the share of foreign-owned equity $RW_{A,Eq}/C_{Net,Eq}$. Bear in mind that the rest of the world sector is consolidated by construction. Foreign equity held abroad is not part of the national financial balance sheet. Note as well that even though corporations own corporations, at some point higher up the firm hierarchy, these corporations will be owned by one of the other sectors.

After determining the share of foreign-owned equity $RW_{A,Eq}/C_{L,Eq}$, I assign domestic corporate equity to the two remaining sectors – households and the government – based on the amount of equity assets held in each sector $G_{A,Eq}/(G_{A,Eq} + H_{A,Eq})$ and $H_{A,Eq}/(G_{A,Eq} + H_{A,Eq})$. To not impose the same share of household and government ownership in domestic and foreign equity, I use financial account tables with information on assets and liabilities per sector and counterpart sector. Table 2 presents the type and structure of the data. For France, the data is available

[33] The small amount of outstanding equity issued by the government and the household sector is not considered because it is fully owned by the same sector, see Table 2. Strictly speaking, both $GOV_{A,Eq}$ and $HH_{A,Eq}$, therefore, refer to the net equity position.

Table 2: Financial balance sheet on equity ownership in France (2017)

	Outstanding equity in billion euros				
owned by	Corporations	Government	Households	Rest of the world	Total
Corporations	6,206.9	0.0	0.0	2,219.0	8,425.9
Government	506.4	44.3	0.2	44.0	594.9
Households	1,410.4	0.0	9.5	118.3	1,538.2
Rest of the world	1,718.9	0.0	0.0	-	1,718.9
Total	9,842.6	44.3	9.7	2,381.3	12,277.9

Note: Excerpt from the counterpart data used to determine the corporate and foreign capital stock ownership among households, the government, and the rest of the world. Equity refers to the item F5 *Equity and investment fund shares* in national balance sheets. The blue rectangle represents all equity assets recorded in the balance sheet of the national economy. The red rectangle represents all equity liabilities recorded in the balance sheet of the national economy. The difference between the blue and the red rectangle is equal to the net foreign equity position (10,558.9 b euros - 9,896.6 b euros = + 662.4 b euros). Corporations include financial corporations. Households include non-profits serving households. Based on data from Eurostat.

from Eurostat. For Germany, it can be constructed based on consolidated and unconsolidated national balance sheets and financial accounts published by the Bundesbank.

The approach fully relies on the market value of corporations, represented by the total equity liability of the corporate sector. As noted by Piketty and Zucman (2014) and others, the market value does not necessarily coincide with the book value of the corporate sector, which can be defined as the difference between all (financial and non-financial) assets and non-equity liabilities. To measure national wealth, the gap between both concepts is important. If it is sufficiently large, it can visibly change the capital-income ratio of the economy. In our case, this is less of a concern, however, because we do not want to measure national wealth per se but attribute annual emissions to wealth holders or, more specifically, to holders of equity. Both national accounts and wealth surveys record equity assets and liabilities in terms of their market value. Remember that the estimated market value of non-listed shares is included in equities (ESA 2010, 7.73). Imagine stock market prices increase by 20%. The market value of equities owned by the household sector and the market value of corporations both increase by 20%. The book value of corporations does not change. Importantly, such a price change – and any other economy-wide over and undervaluation of corporations relative to their book value – does not impact the ownership structure by sector. Therefore, it suffices to rely on the market value to link corporations and their emissions to the other sectors of the economy.

Table 3 presents the resulting equity ownership shares for France and Germany in 2017. How do we interpret these results, and in which way are they helpful for the next steps of this project? In France, 60.7% of domestic corporate equity and 72.9% of foreign corporate equity is owned by the household sector. In other words: 100% of the equity owned by households can be linked to (i) 60.7% of the emissions of the domestic corporate sector as estimated in the previous section and to (ii) 72.9% of the emissions linked to foreign corporate equity owned by French residents,

Table 3: Equity ownership in France and Germany (2017)

	Outstanding equity	
owned by (in %)	Corporations	Rest of the world
France		
Government	21.8	27.1
Households	60.7	72.9
Rest of the world	17.5	-
Germany		
Government	9.4	11.5
Households	72.1	88.5
Rest of the world	18.5	-

Note: Share of equity owned by institutional sectors in France and Germany (2017). Equity refers to the item F5 *Equity and investment fund shares* in national balance sheets. Corporate equity owned by corporations is split among the government and households based on the respective share of both sectors in corporate equity assets in national balance sheets. See Table 2 for the type of data used. Counterpart tables for Germany were not available from Eurostat and were reconstructed from Bundesbank consolidated and unconsolidated national balance sheets and financial account tables. Based on data from Bundesbank and Eurostat.

as estimated in the next section. The same applies to the government and the rest of the world. 17.5% of domestic corporate equity needs to be assigned to non-resident wealth holders, for example. The information in Table 3 allows us to (i) distribute all domestic corporate emissions to the two other domestic sectors and to the rest of the world and to (ii) distribute emissions of the resident-owned foreign corporate sector between households and the government. The second point is the objective of the next section.

2.3.3 Proxy emissions of domestically-owned foreign corporations

In the third step, I deal with the direct emissions of foreign-based corporations that are owned by resident investors. The market value of these holdings can be obtained from financial balance sheets through the equity liabilities of the rest of the world sector.[34] Then, the equity can be split between the government and households.[35] Looking ahead, we need to keep in mind that wealth held abroad is part of the household-owned equity in the wealth survey. We need to find a proxy for these emissions, however, because owning equity abroad does not necessarily come with the same average emissions per euro of capital stock as holding equity of domestic corporations. Think of an investor who invests in an oil-rich country.

Precise data on equity holdings per partner country and institutional sector is unavailable. Therefore, I proxy the annual emissions associated with foreign equity in two steps: First, I use the database on investment flows and stocks per country developed by Nardo et al. (2017) to estimate the share of each destination country in outward investment. Second, I use the database

[34]The last row of column 4 in Table 2.
[35]According to column 4 in Table 2.

on country-specific emission intensities developed by Crippa et al. (2020) to determine the relative carbon intensity of economies.

The EU-Finflows database released by Nardo et al. (2017) 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. It harmonizes data on investment from a variety of sources like Foreign Direct Investment (FDI) data from the OECD, the IMF Coordinated Portfolio Investment Survey (CPIS), or Eurostat data on balance of payments (BOP). In what follows, I use the April 2020 release of the database. The EU-EDGAR dataset compiled by Crippa et al. (2020) records, among other statistics, the emissions per US Dollar of GDP for a set of 200 countries and jurisdictions. The authors use international activity data, mainly energy balance statistics from the International Energy Agency (IEA), to prepare the statistics. In what follows, I use the v5.0 (2020) release of the database.

Combining both data sources allows us to obtain a proxy for the emissions linked to outbound investment $RW_{L,Eq}$. We start from the emission level of an equivalent domestic corporate investment (first two factors in Equation 3). Then, we scale it, for each destination country i, by the country-specific emission intensity multiplier I_i/I_D (ratio of emission intensities in country i and domestic country D) and sum across all countries, each weighted by its share in total outbound investment s_i:

$$E_{RW_{L,Eq}} = E_{C_{L,Eq}} \times \frac{RW_{L,Eq}}{C_{L,Eq}} \times \sum_i s_i \frac{I_i}{I_D} \tag{3}$$

I opt for calculating the shares s_i on the basis of foreign direct investment stocks rather than portfolio investment. Both can only be viewed as an approximation for the share of equity held in a foreign country, but the advantage of using direct investment is that it comes with some form of control over the actual capital stock and the associated production processes. It is more aligned with how we distribute national emissions. In addition, outbound portfolio investment frequently involves investment in foreign entities that themselves own corporations in a third country – often for tax avoidance purposes. Given that I cannot track the investment further than from the domestic sector to the first foreign country it is invested in, direct investment seems to be the better proxy for actual physical, emission-related investment.[36]

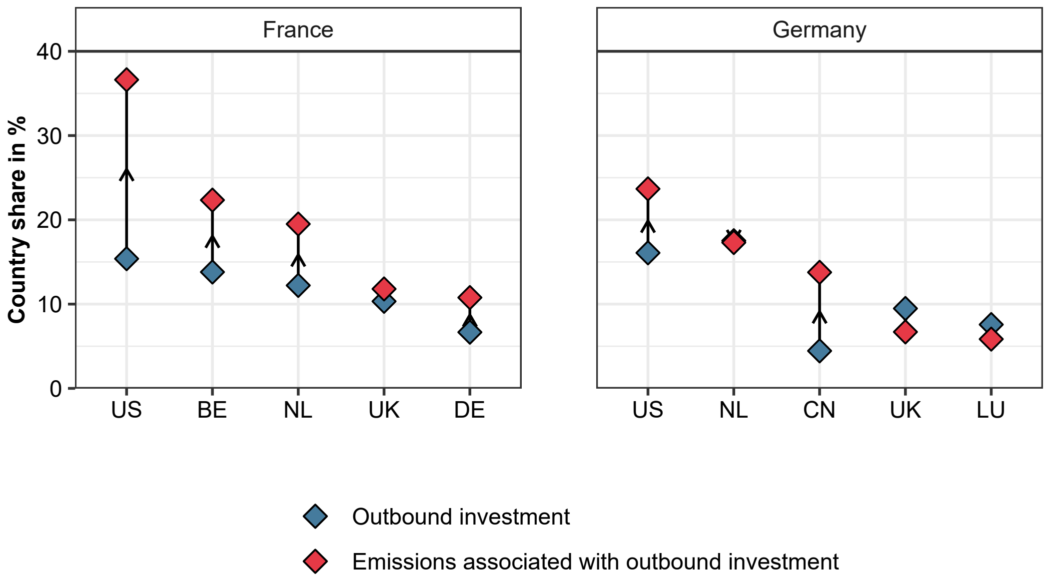
Figure 3 presents the top 5 countries based on their emission share in outbound investment. Of all the direct emissions associated with foreign equity held by resident households and the government in France[37], 36.6% occur in the United States. With 23.3%, the US also comes out at the top for Germany. We can recognize the relative importance of China with a share of

[36]The fact that Luxembourg and the Netherlands feature prominently in Figure 3 and Table A.7 suggests that using foreign direct investment does not completely alleviate the issue. This should not come as a surprise to anyone who has read Zucman (2013).

[37]Remember from Section 2.3.2 that foreign equity held by domestic corporations is included as well, but ultimately distributed to one of the two sectors.

13.7% in Germany and 8.2% in France. The size of the difference between each country's share in investment and investment-related emissions indicates whether the destination economy is more or less emission-intensive than the domestic economy. Indeed, in both France and Germany, a sizeable share of outbound investment goes to countries that are more emission-intensive than the domestic economy.

Figure 3: Emissions of outbound investment in top 5 destination countries (2017)



Note: Countries with the highest emissions associated with outbound investment in 2017. The red dots represent each country's share in the total amount of emissions linked to outbound investment. The blue dots represent the share s_i of each country in the total outbound investment. The sign of the difference between both dots indicates whether the destination country is more (upward arrow) or less emission-intensive (downward arrow) than the domestic economy ($\frac{I_i}{I_D} > 1$ or < 1). Outbound investment shares refer to the share in foreign direct investment stocks at year-end. See the main text and Equation 3 for how emissions are linked to total outstanding equity by the rest of the world sector. Based on data from Nardo et al. (2017) and Crippa et al. (2020).

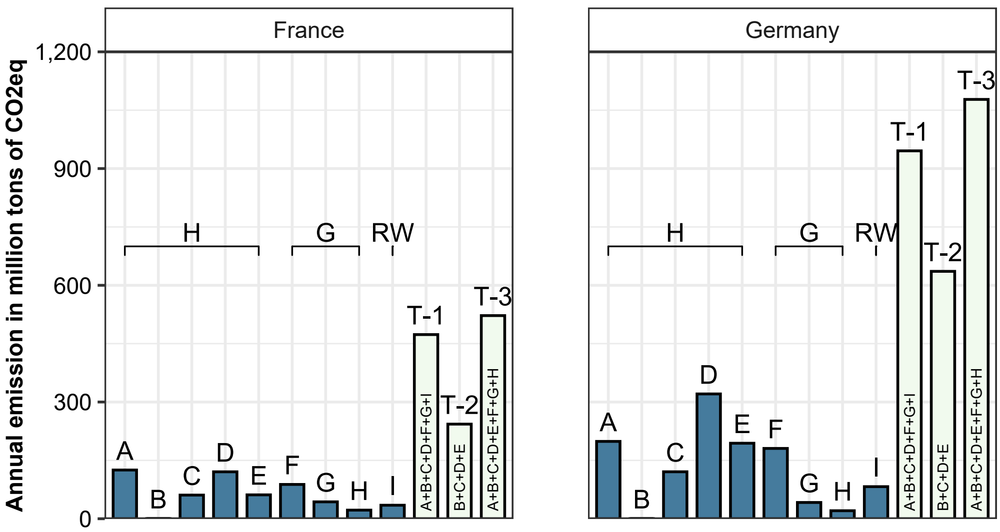
Naturally, we may use the same data sources to assign the inbound investment in France and Germany to the countries of origin.[38] Here, it suffices to use statistics compiled by Nardo et al. (2017) on the respective investment stocks by country because the emission intensity of the domestic corporate sector is already known. The shares of the leading countries are presented in Table A.7 in the appendix.

Before we move on, let us summarize what we have done in Section 2.3. We defined national emissions as the annual emissions released by resident units. After excluding direct emissions by households, we assigned national emissions – through information on which capital assets are used in which industry – to the capital stock. Finally, for a given year, we linked the capital stock to its ownership sector, either resident and non-resident. As a result, resident households

[38]The last column of row 4 in Table 2

are assigned the annual emissions associated with the domestic capital stock they own (housing and self-employed business wealth) and the annual emissions of the resident and non-resident corporations they own. The government is assigned the annual emissions associated with the domestic capital stock it owns (mostly buildings, structures, and land) and the annual emissions of the resident and non-resident corporations it owns. The rest of the world is assigned the annual emissions produced by the domestic corporations it owns. The detailed results of this process are available in Tables A.8 and A.9 in the appendix. The black rectangle in these tables represents the total emissions assigned to household wealth in 2017 under what I will call the *full attribution* scenario in 2.5.1, 243.2 million tons of CO2 equivalents in France and 635.8 million tons in Germany. An overview of the relevant emission categories and how they relate to the emission aggregates in France and Germany is provided in Figure 4, where the annual emissions assigned to household wealth under the full attribution scenario correspond to the *T-2* category.

Figure 4: Annual emission categories and aggregates (2017)



Note: The graph presents the annual emissions assigned to each sector in France and Germany if all production-based emissions are attributed to capital stock owners. Household emissions consist of direct emissions (A) and emissions from housing (B), self-employed business buildings wealth (C), owned domestic business (D), and owned businesses in foreign countries (E). Government emissions consist of emissions related to the directly held capital stock of the government (F), owned domestic business (G), and owned businesses in foreign countries (H). Emissions of the rest of the world consist of emissions assigned to the capital stock of domestic corporations that are owned abroad (I). These groups can be aggregated to obtain direct national emissions (T-1), emissions attributed to household wealth in the full attribution scenario (T-2, see initial results in 2.5.1) or all emissions with resident responsibility (T-3, see the right panel of the figures in 2.5.1). Based on data from Bundesbank, Crippa et al. (2020), Destatis, Eurostat, Insee, and Nardo et al. (2017).

In the following section, we prepare the wealth survey data used to link the "by-asset" emissions of the household sector obtained through the preceding steps to the actual wealth distribution. This allows us to estimate the distribution of carbon wealth in France and Germany in Section

2.5. It also enables us to make preliminary revenue estimates of a potential tax on carbon wealth in Part 3.

2.4 Prepare wealth survey data

2.4.1 Household Finance and Consumption Survey (HFCS)

To reveal the distribution of carbon wealth, we need to complement the macro-level emission statistics with information on wealth on the individual level. Three potential data sources exist. Administrative tax records on household wealth, typically a by-product of wealth taxation, would be the most reliable type of data. Where unavailable, the literature frequently relies on other tax-related administrative data sources to infer individual wealth levels. This includes utilizing estate tax records or, more recently, capitalizing income streams recorded in income tax data.[39] These secondary administrative data sources feature prominently in Saez and Zucman (2016), Garbinti et al. (2020), and in the recent efforts to build macro-consistent *Distributional National Accounts* (DINA) as expounded in Alvaredo et al. (2020). Since neither France nor Germany has in place a comprehensive personal wealth tax,[40] which would be the ideal source of data, most of the convincing literature on wealth dynamics in the two countries rests upon these secondary data source methods. Recently, Garbinti et al. (2020) were able to reconcile wealth series based on the estate multiplier and the income capitalization method in France.

Finally, information on wealth can come from wealth surveys. Because of substantial wealth under-reporting and their failure to capture the wealth at the top of the distribution, surveys are generally considered an inferior source of information. However, in the absence of access to administrative data and because my approach requires a more detailed by-asset split of wealth – rather than estimating the distribution of aggregate net wealth – I revert back to using wealth survey data from the Household Finance and Consumption Survey (HFCS). Note that the quality of wealth surveys has increased in recent years due to higher sample sizes, more harmonization across countries and a more forceful oversampling of wealthy households. Recent attempts in the literature have shown that, after some adjustments, wealth surveys can deliver meaningful results that are aligned reasonably well with inequality estimates based on administrative data (Eckerstorfer et al., 2016; Vermeulen, 2016; Bach et al., 2019). I am nonetheless aware that better-quality data on wealth would greatly improve the robustness of my results.

I use the Household Finance and Consumption Survey (HFCS), the most comprehensive survey on household wealth available for France and Germany. It is a country-representative household survey conducted in 22 EU countries. The European Central Bank (ECB) releases the micro-files,

[39] Differential mortality profiles by wealth level remain a core issue for the first method. For the latter, a major challenge is finding the correct rate of return by asset or within asset classes.

[40] The personal wealth tax in Germany was abolished in 1997. France replaced its personal wealth tax with a tax on real estate property in 2018 (Lohmüller, 2012; Rose, 2017).

Table 4: Third wave of the HFCS in France and Germany

	France	Germany
Net sample size *Number of interviews*	13,685	4,942
Response rate *in %*	68.1	31.5
Household weights *Sum in million*	29.3	40.4
Net household wealth *Mean in thousand euros*	242.0	232.8
Oversampling rate *Effective rate for top decile in %*	158.0	140.0
Oversampling criteria	Anticipated wealth based on fiscal sources	Wealthy/high income street sections
Multiple imputation	No	Yes

Note: The table presents core properties of the third wave of the Household Finance and Consumption Survey (HFCS) in France and Germany. Survey interviews conducted between 09/2017-01/2018 in France and 03/2017-10/2017 in Germany. Effective oversampling describes the percentage surplus of observations in the top wealth decile above 10% of the sample. 100 corresponds to no oversampling. Weights refer to the *HW0010* variable before the wealth of multi-adult households is individualized. Net wealth refers to the *DN3001* variable. Based on European Central Bank (2020a) and data from HFCS.

even though national statistical agencies or central banks carry out the actual data collection.[41] The goal of the HFCS is to provide a comprehensive account of household finances and balance sheets that is both (i) representative at the country level and (ii) harmonized across participating countries. Furthermore, the survey collects information on demographics, employment, income, and consumption. Three survey waves are currently available. I use the third wave (see Table 4), for which data collection in France and Germany took place in 2017.[42] Importantly, all wealth recorded in the HFCS must be understood as a self-assessment of asset values by households. Each household is assigned a weight so that the sum of survey weights is equal to the number of households in the country (European Central Bank, 2020a, p.12).

Even though harmonization is one goal of the project, some methodological differences exist between countries. In France, participation is mandatory. In Germany, it is not, which can explain the significantly lower response rates and net sample sizes in Germany. France uses two-stage stratified sampling (based on an existing master sample) to draw participant households. Germany uses three-stage stratified sampling (address clusters, street sections, resident registries). Oversampling of wealthy households relies on fiscal sources in France, whereas in Germany, wealthy street sections were identified and oversampled (European Central Bank, 2020b, p.10).

[41]The contribution of France to the HFCS is also known as the *Enquête Patrimoine* and is carried out by Insee. The German contribution to the HFCS is also known as *Private Haushalte und ihre Finanzen* (PHF) and is carried out by the Bundesbank.

[42]Interviews in France extended into January 2018.

Three well-known issues need to be addressed when linking survey wealth to national accounts. First, wealth surveys are based on different concepts and asset groupings than national accounts (comparability problem). I address the comparability problem in Section 2.4.2 by harmonizing the concepts to the best extend possible. Second, not all wealth – in particular financial wealth – tends to be reported in wealth surveys (underreporting problem), which I confront in Section 2.4.3. Third, despite oversampling, wealth surveys fail to accurately capture wealth at the top because wealthy households are more difficult to reach (non-response problem). I tackle this issue in Section 2.4.4 by adjusting the top tail of the distribution.

I profit immensely from the existing literature on linking the HFCS to national accounts, notably from Eckerstorfer et al. (2016), Vermeulen (2016), Chakraborty and Waltl (2018), Bach et al. (2019) and Ahnert et al. (2020). In Sections 2.4.3 and 2.4.4, I broadly follow the steps suggested by Vermeulen (2016) but complement them with an alternative method of adjusting the top tail, inspired by Blanchet et al. (2021).

2.4.2 Construct asset groupings consistent with national accounts

Standard asset groupings in the HFCS and national accounts are not entirely consistent. For example, in national accounts, an incorporated self-employed business is recorded as a *financial* asset while it is considered to be a *real* asset in the household survey (Ahnert et al., 2020, p. 63). It is crucial to solve this comparability problem and align the categories used in both data sources to the most granular extend possible. First, this is necessary to estimate and address the gap between national account and survey wealth in Section 2.4.3. Second, it is a prerequisite for later linking national account emissions to the survey wealth. As household emissions originate from the ownership of real assets on the one hand and the corporate sector on the other hand, it is of particular importance to align these two national account categories – the non-financial capital stock and the *equity* heading in financial accounts – with the household survey. To do so, I primarily make use of the recently released statistical report by Ahnert et al. (2020), which is a product of the EG-LMM.[43] It maintains that a "matching item with [...] high or medium comparability" has been identified for "90% of the value of households' financial and non-financial assets included in euro area National Accounts statistics."

Let us start with financial assets. According to Ahnert et al. (2020), high conceptual comparability exists between national accounts and the survey for deposits, debt securities, and loans. All three can therefore be linked to the corresponding item in the survey.[44] Note two things. First, deposits are substantially larger than both bonds and loans (owed to households) in France and Germany. Second, we did not assign emissions to either of the three financial asset types in Section 2.3.1.

[43] The "Expert Group on Linking Macro and Micro Data for the household sector" is a body within the European System of Central Banks (ESCB).

[44] Currency holdings by households (i.e., banknotes and coins) are estimated in national accounts, but are not part of the wealth survey. Typically, they account for around 1% of total financial and non-financial assets (Ahnert et al., 2020, p. 52). I do not exclude currency from the national account section AF.2 so that they are implicitly proxied in the survey when I make the adjustments in Section 2.4.3.

Similar to Alvaredo et al. (2020), I therefore combine the three into one asset category, but I keep the residual *other financial assets* (AF.7 and AF.8) separate.

For voluntary insurance and pension wealth (pension entitlements from public pension schemes are excluded both from survey wealth and national accounts), we can find a national account category that is conceptually aligned. Comparability issues exist with regard to the valuation of the pension wealth, however. In national accounts, the voluntary pension and life insurance entitlements are recorded based on their net present value, following the reserve requirement of its providers. The household survey, on the other hand, records the current value because the national questionnaires usually do not specify otherwise (Ahnert et al., 2020). In line with Alvaredo et al. (2020) and Saez and Zucman (2016), I exclude "wealth" from unfunded private pension entitlements.

Equity holdings are pivotal because we use them to link the emissions of corporations to the household sector. To obtain a group comparable to the financial balance sheet item AF.5, we need to aggregate several HFCS questions. Wealth held in the form of (i) shares, (ii) non-self-employed businesses, and (iii) mutual funds is readily available and clearly needs to be included. As indicated, we need to address the treatment of incorporated self-employed businesses.[45] These businesses are recorded as financial assets in financial balance sheets but as real assets in the survey. Hence, I add wealth from incorporated self-employed businesses to the other three survey questions to make it comparable to the financial balance sheet line AF.5.

Now we can turn to real assets. We find comparable categories for housing wealth in both the survey and national accounts. To obtain the value of dwellings, we add the real estate not used for business activities to the value of the household's main residence in the survey. Remember that, for national account wealth, the value of land has already been assigned to fixed assets in the previous section. Survey wealth already includes the value of land. Real estate used for business purposes can be linked to buildings and structures in national accounts. Finally, the remaining capital stock should be represented by business wealth in the survey, corrected for the value of incorporated self-employed businesses that we had moved to financial assets in the previous paragraph. We excluded valuables from national accounts, so we exclude them from survey wealth as well.

Liabilities play a role because I use them to derive the distribution of *net* wealth. As I do not use any further breakdown, we can match financial liabilities in national accounts to the liabilities recorded in the survey. The liabilities corresponding to unfunded private pension entitlements are not recorded in the household sector of national accounts because these pensions and life insurance schemes are managed by financial corporations. Hence, even though they were excluded from financial assets, there is no need to adjust the national account liabilities. Note that loans make up the vast majority of financial liabilities in the household sector.

[45]Self-employed businesses that are neither categorized as sole proprietorships, independent professionals or partnerships.

Table 5: Wealth underreporting in the survey in % of national account wealth

	France	Germany
Financial assets		
Deposits, bonds, and loans	59.3	54.2
Equity and investment funds	54.6	22.8
Insurance and pension schemes	69.6	57.2
Other financial assets*	90.0	-70.3
Real assets		
Housing	24.6	3.1
Business buildings	82.8	77.7
Business wealth	46.8	5.2
Liabilities	41.0	31.5
Net worth	43.4	22.1

* *The overall size of this group is small.*

Note: The table presents the share of missing wealth in the third wave of the Household Finance and Consumption Survey (HFCS), relative to national account aggregates in 2017. See the note of Tables A.8-A.9 and Table A.10 in the appendix for more details on the asset groupings. Both national accounts and the survey include the value of land. Based on data from HFCS and Eurostat.

These adjustments allow us to define total assets and net wealth – both in aggregate terms in national accounts and at the household level in the survey. To recapitulate: Total assets correspond to the sum of real assets and financial assets. Our concept of real assets includes the value of land, but excludes inventories and valuables. Real assets are split into (i) housing, (ii) business buildings, and (iii) business wealth. Financial assets are defined as the sum of (i) deposits, debt securities and loans, (ii) equity, (iii) voluntary pension and insurance schemes, and (iv) other financial assets. Net wealth equals total assets minus liabilities. As a result of the aforementioned adjustments, my definitions are not directly comparable to the standard variables available in the HFCS dataset.[46]

Table A.10 in the appendix presents the resulting correspondence table in detail.

2.4.3 Align aggregates in survey and national accounts

Aggregate household wealth in surveys tends to be substantially lower than aggregate wealth recorded in national balance sheets, even for country-representative surveys like the HFCS. The gap is believed to originate both from a broad-based underreporting of wealth and from the failure of the survey to accurately capture the top tail of the wealth distribution (Eckerstorfer et al., 2016; Blanchet et al., 2018; Chakraborty and Waltl, 2018; Chakraborty et al., 2018). Piketty et al. (2018) mention these gaps between micro-based estimates and national accounts as the prime rationale for their call to develop Distributional National Accounts (DINA).

[46] Like DN3001 for net wealth.

Table 5 presents the share of missing wealth in the third wave of the HFCS before making any adjustment to the survey. It is based on the correspondence table developed in the previous section. With more than 50% of assets missing in the survey, financial assets are considerably underestimated in both France and Germany. The gap is lower for housing but sizable for real business assets – especially in France and for buildings.

To address the issue of missing wealth in household surveys, Vermeulen (2016) proposes a three-step procedure, which I will grosso modo follow. First, the routine applies preliminary asset-specific multipliers to each observation in the survey to align aggregates in the survey with national accounts. Then, after including additional high-wealth observations from rich lists, it adjusts the top tail of the wealth distribution by estimating a Pareto tail. Finally, in an iterative process, the preliminary multipliers obtained in the first step need to be corrected to account for the newly estimated top tail of the distribution.

Applying asset-specific adjustment factors assumes that, for any given asset, each individual underestimates its wealth holding by a constant factor. As noted by Vermeulen (2016), this is not the same as assuming a constant level of underreporting *per individual* because the composition of assets varies with wealth. Suppose a given individual owns assets that are, on average, more severely underestimated. In that case, the asset-specific multipliers will increase its level of wealth by more, compared to an equally wealthy individual who owns primarily assets captured with lesser imprecision by the wealth survey.[47] Remember that the intricacy of missing wealth at the top is approached separately in the next section. The share of missing wealth presented in Table 5 implicitly defines the preliminary asset-specific multipliers.

As we start working with the actual survey data, two crucial definitional remarks are warranted. First, my reference unit is wealth per adult. Hence, I individualize the household wealth of married couples[48] in the survey and adjust the survey weights accordingly. I split the wealth of couples equally. Second, each individual is assigned wealth according to the average of the five survey implicates. These implicates are provided by the ECB to make explicit the imputation uncertainty that comes with stochastically imputing non-random missing observations based on observables. Crucially, the between-imputation variance needs to be taken into account whenever we want to obtain the variance associated with a survey estimator (European Central Bank, 2020a, p.10-12).

2.4.4 Adjust the top tail

This section addresses the failure of the HFCS to accurately capture the top of the wealth distribution – the second step in the three-step procedure proposed by Vermeulen (2016). Without any adjustments, no individual in the survey records net wealth north of 200 million euros in both France and Germany, even though we know that these individuals own a sizable share of total wealth (Garbinti et al., 2020). Besides, the actual number of unweighted observations

[47] Other assumptions implicitly made by adjustments of this sort are discussed in Blanchet et al. (2018).
[48] Based on the variable PA0100 in the personal files of the HFCS.

underpinning top wealth in the survey drops quickly with increasing wealth, despite oversampling. Within the top 0.1% wealth group, the unweighted number of observations in any 0.5 million euro band is often single-digit and eventually declines to 1. Figure A.5 reveals that this decline happens particularly early for Germany due to the smaller sample size.

The literature has developed a number of methods to adjust the top tail of survey distributions in the absence of more accurate data. Two strands can be identified. The standard approach models top wealth above a threshold by a Pareto distribution with a constant tail parameter (Eckerstorfer et al., 2016; Vermeulen, 2016; Chakraborty and Waltl, 2018; Bach et al., 2019). In most instances, authors first complement the survey by a limited number of external data points from rich lists, with the goal to better capture the very top of the distribution. Then, a Pareto parameter $\hat{\alpha}$ is estimated – either by OLS or ML – and observations in the top tail are replaced or reweighted so that their wealth level follows the simple Pareto law.

Recently, Blanchet et al. (2021) highlighted a potential issue of the standard approach. Based on administrative data in France and the United States, they show that constant tail parameters are not well-suited to characterize the top tail of actual income and wealth distributions. Instead, local Pareto coefficients $\alpha_0(p)$ tend to decrease within the top tail, which is why Blanchet et al. (2021) propose to estimate more flexible Pareto curves. They also demonstrate that a few data points from tabulated administrative data, if combined with a flexible Pareto interpolation, can deliver more accurate results than estimates from surveys with a high number of observations. In what follows, I refer to their suggestions as the alternative approach.

At first, I am largely restricted to the standard approach because I do not have access to tabulated administrative data on wealth for France and Germany in 2017. However, towards the end of this section, I do apply the insights of Blanchet et al. (2021) by calling upon the properties of the wealth distributions estimated by the World Inequality Lab (WIL). Top shares and thresholds in the WIL dataset can act as an *as-if* administrative data source, providing anchor points to estimate better the shape of the upper tail of the distribution in the survey. This allows us to move beyond constant Pareto parameters. Unfortunately, until May 2021, the WIL researchers have only compiled preliminary wealth series for the year 2017 in France and Germany.[49] In light of these limitations, I proceed on two tracks. I present my results both (i) based on a constant Pareto tail (standard approach) and (ii) based on a more flexible Pareto tail modeled after the distributional properties of the preliminary WIL wealth series (alternative approach).

Let me now briefly introduce the standard approach of adjusting the top tail in a wealth survey by means of a simple Pareto power law. If the net wealth distribution above a threshold $w > w_{min}$ follows a Pareto law with constant tail parameter α, its cumulative density function is characterized by the following survival function:

[49]Wealth series for Germany remain unavailable in the World Inequality Database (WID) to this day, even for earlier periods.

$$\overline{F}(w) = 1 - F(w) = P(W > w) = \left(\frac{w_{min}}{w}\right)^{\alpha} \quad (4)$$

The constant parameter $\alpha > 1$ is easy to interpret when it is expressed as the inverted Pareto coefficient $b = \frac{\alpha}{\alpha-1}$. If the top tail is characterized by $\alpha = 1.5$, then $b = 3$. In that case, the average wealth above any $w \geq w_{min}$ is b times larger than w.[50] Ever since Vilfredo Pareto (1897) realized that distributions of such a shape approximate the outcome of economic processes surprisingly well – from income in Augsburg in the 15th century to England in the 19th century – its properties have been relied upon in inequality economics (Atkinson and Piketty, 2007; Klass et al., 2006), but also numerous other disciplines. As different phenomena as the magnitude of earthquakes, the frequency of wars, and the diameter of moon craters have been found to exhibit properties of the Pareto distribution (Newman, 2005). For our purposes, three questions follow immediately from Equation 4: (i) How to choose w_{min}? (ii) How to improve the empirical information we have on $\overline{F}(w)$ and w within the top tail? (iii) How to estimate $\hat{\alpha}$? I address the questions in that order.

It is crucial to wisely choose the threshold w_{min} because the decision involves an important trade-off. Below w_{min}, we use survey observations without any Pareto adjustment. Above w_{min}, we adjust the wealth so that it follows the Pareto law in Equation 4. If we reduce the threshold and include more observations in the tail, we can estimate the tail parameter $\hat{\alpha}$ with more precision. However, we simultaneously increase the number of individuals whose net wealth position is likely not well-approximated by the Pareto law. No consensus approach exists to this day on how the threshold ought to be set, unfortunately. Eckerstorfer et al. (2016) develop a quantitative process to choose thresholds based on properties of the survey tail. Blanchet et al. (2018) highlight the usefulness of a secondary, administrative data source when choosing w_{min}. Practitioners tend to inspect the distributional properties of the survey tail graphically before deciding on the threshold. To test for robustness, they then present results based on a set of potential thresholds. In the absence of a secondary source of data like tax records, I cannot apply the methods recommended by Blanchet et al. (2018). Furthermore, I hesitate to make use of more complex distributional properties of the survey tail for deciding on the threshold because it is precisely its failure to capture top wealth that we need to overcome. I, therefore, follow the practice in Vermeulen (2016) and Bach et al. (2019) who introduce three tail thresholds that work well with their graphical evidence: 0.5, 1, and 2 million euros. Below, I will explain why I end up choosing a threshold of 500,000 euros for my headline results. Just like the authors, I present two alternative thresholds to discuss the robustness of my results. This also has the advantage that,

[50] To see this, first find the density function:

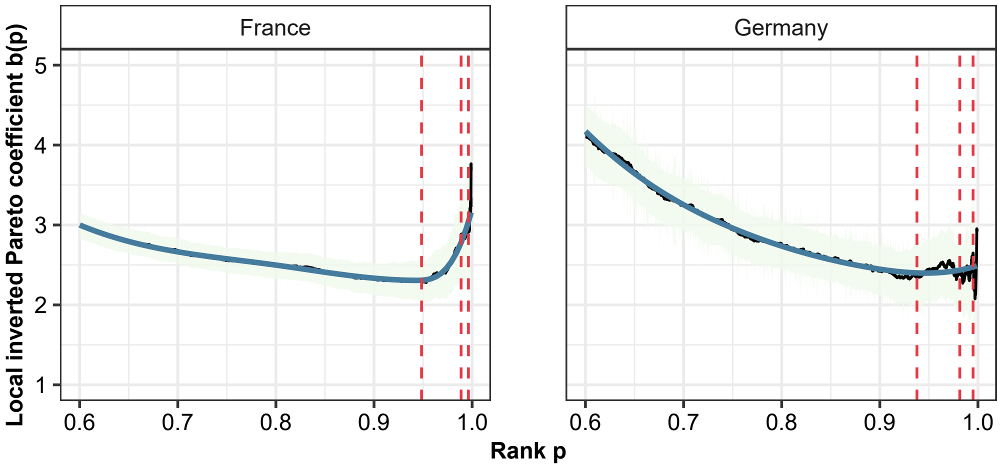
- $F(w) = 1 - \left(\frac{w_{min}}{w}\right)^{\alpha} \rightarrow f(w) = \frac{dF(w)}{dw} = -w_{min}^{\alpha}\left(-\alpha w^{-\alpha-1}\right) = \alpha\frac{w_{min}^{\alpha}}{w^{1+\alpha}}$.

Then, express average wealth above w as $\overline{w}(w)$:

- $\overline{w}(w) = \frac{\int_{w_a>w} w_a f(w_a) dw_a}{\int_{w_a>w} f(w_a) dw_a} = \frac{\alpha w_{min}^{\alpha}\int_{w_a>w}\frac{1}{w_a^{\alpha}}dw_a}{\alpha w_{min}^{\alpha}\int_{w_a>w}\frac{1}{w_a^{\alpha+1}}dw_a} = \frac{\frac{1}{1-\alpha}w^{1-\alpha}}{\frac{1}{-\alpha}w^{-\alpha}} = \frac{\alpha}{\alpha-1}w.$

Finally, write $\frac{\overline{w}(w)}{w} = \frac{\alpha}{\alpha-1} = b$

Figure 5: Local inverted Pareto coefficients in the HFCS survey (2017)



Note: The figure presets estimated local inverted Pareto coefficients $b_0(p) = \frac{\alpha_0}{\alpha_0 - 1}$ across the distribution of the third wave of the HFCS wealth survey, complemented by high wealth observations from the Forbes Billionaires list. The blue line smoothes the sequence of local coefficients (black line) using quintic splines. It corresponds to the empirical generalized Pareto curve in the survey as introduced by Blanchet et al. (2021) with $b(p) = E[W|W > Q(p)]/Q(p))$. The dashed lines represent three potential thresholds for the Pareto tail: 0.5, 1, and 2 million euros. The shaded areas depict 95% confidence intervals calculated from robust standard errors based on 1,000 replicate weights provided with the HFCS survey. Data from HFCS and Forbes.

in terms of the technique, my estimates are comparable to those in the literature.[51] In Appendix A.8, I extend the analysis and estimate Pareto coefficients for 36 potential thresholds between 0.2 and 2 million euros.

In Figure 5, to inform my decision about the threshold w_{min}, I calculate local inverted Pareto coefficients $b(p)$ for the distribution of net wealth in the survey, after adding high-wealth individuals from the Forbes Billionaires list (see following paragraphs). As noted by Blanchet et al. (2021), these local coefficients can be estimated for each observation by determining the average wealth of individuals with wealth exceeding the wealth held by the given individual. Using quintic splines, I also add a smoothed line on the sequence of local coefficients to better evaluate the trend – especially for Germany, where the tail of the survey is noisy due to the low number of observations. The dashed lines represent the three potential thresholds at 0.5, 1, and 2 million euros. If the top tail in the survey were to follow a simple Pareto power law, we would expect $b(p)$ to eventually stabilize. We see that this is neither the case for France nor Germany, confirming the concerns about simple Pareto laws raised by Blanchet et al. (2021). In both countries, $b(p)$

[51]Remember that my measure of net wealth excludes vehicles and valuables and that net wealth is individualized. If I return to the second survey wave, switch to net household wealth instead of per-adult wealth, and do not align aggregates with national accounts, I am able to reproduce the Pareto coefficients found by Bach et al. (2019) for France and Germany in 2014. Since Figure A.9 suggests that potential differences do not stem from the alignment with national accounts, they need to either originate from these definitional matters or an actual change in wealth inequality since 2014.

starts to increase around the 95th percentile. We also see that the convergence towards 1 in finite samples sets in only for the very last observations.

An alternative, more zoomed-in way of presenting the top tail are so-called log-log plots, also occasionally referred to as *Zipf* plots. These graphs present log wealth w_i on the x-axis and the log of the empirical tail distribution $\overline{F}_n(w)$ on the y-axis. If wealth in the tail follows a simple Pareto law, the plotted relationship should eventually become linear.[52] Figure A.7 presents these plots for France and Germany. A constant coefficient seems to characterize parts of the tail distribution. However, the linear relationship breaks down eventually as well. I choose the lower threshold of 0.5 million euros because it allows me to use a larger piece of the approximately linear part apparent in Figure A.7. Furthermore, the lower threshold suits the German survey data with its low number of wealthy individuals. If I were to opt for the 2 million euros thresholds, I would be left with less than 70 survey observations in Germany to estimate the Pareto coefficient.

After determining the threshold, I explain how I augment the information entailed in the top tail of the survey by including high-wealth observations from the *Forbes Billionaires* list. Since we precisely want to overcome the low representation of ultra-wealthy individuals in the survey, we cannot restrict ourselves to the empirical tail of the survey when we estimate the tail parameter $\hat{\alpha}$. Hence, it has become a custom to complement the survey by a few external data points at the very top of the distribution. In the absence of more reliable data sources, the only available information on top wealth holders can be found in rich lists published by Forbes magazine or in similar national rankings released by the *manager magazin* in Germany or by *Challenges* in France.

The methodology deployed by these outlets remains somewhat dubious, and its publishers readily admit that they are not able to publish fully accurate balance sheets.[53] However, what counts for the very top is the fact that these lists provide the correct order of magnitude, which has – in the absence of any other data source – resulted in the wide use of these lists in the literature (Eckerstorfer et al., 2016; Vermeulen, 2016; Bach et al., 2019). The Forbes dataset is also prominently used to model the upper tail in the annual *Global Wealth Report* compiled by the bank Credit Suisse (2019). In the United States, where more reliable data sources are available, the rich lists seem to track wealth inequality dynamics reasonably well (Zucman, 2019).

Rather than national rich lists, I decide to stick with the *Forbes Billionaires* list because it allows me to use a consistent source of data for both France and Germany. Furthermore, the Forbes list records net wealth based on the residence principle, just like national accounts and my survey estimates. I draw on publicly available information about marriages to individualize Forbes wealth. Finally, I convert wealth from US dollars into euros using the exchange rate on 1 March 2017 because Forbes magazine typically releases its annual rankings at the beginning of

[52]If w_i is drawn from $(\frac{w_{min}}{w})^\alpha = \overline{F}_n(w)$, then $\alpha = \frac{\log \frac{w_{min}}{w_i}}{\log \overline{F}_n(w_i)}$ should be a constant.

[53]The *Forbes World's Billionaires List* website maintains: "We don't pretend to know each billionaire's private balance sheet."

March. My final dataset contains 114 observations for Germany and 39 for France.[54] For Forbes observations, I proxy the asset composition by the average asset shares in the top tail of the survey. All of the newly added observations are assigned a weight of 1 so that they represent a single individual. The log-log plot in A.7 suggests that the distributional properties of the added Forbes observations are aligned with the eyeballed slope coefficient in the survey tail.

Finally, we need to choose a method to estimate $\hat{\alpha}$ from the totality of survey and Forbes observations in the tail of the empirical distribution. In the standard approach, two parametric methods are regularly used: OLS and Maximum-Likelihood estimators.[55] Let us briefly discuss the intuition behind the OLS estimator in the simple case and the case of a more complex survey design.

Take a simple random sample with n observations in the tail drawn from the distribution in Equation 4. Applying the logarithm and adding $\log \overline{F}_n(w_i)$ to both sides of Equation 4 generates:[56]

$$\log \overline{F}_n(w_i) = \alpha \log w_{min} - \alpha \log w_i + \left[\log \overline{F}_n(w_i) - \overline{F}(w_i)\right] \quad \text{for } i = 1, 2, ..., n \tag{5}$$

With the empirical survival function $\overline{F}_n(w_i) = \frac{1}{n}\sum_{m=1}^{i} \mathbb{1}(W_m > w_i)$. As noted by Nicolau and Rodrigues (2019), Equation 5 may be viewed as a regression with an intercept and error term. If observations w_i can be interpreted as an order statistic $W_{(i)}$, with $i = n$ for the lowest realization of $W_{(i)}$ (observations ordered from highest to lowest wealth level), then $\overline{F}_n(w_i) \approx \frac{i}{n}$ for large n. If we replace $\overline{F}_n(w_i)$ in Equation 5, $\hat{\alpha}$ can be estimated by OLS. After rearranging, the well-known structure of the problem simplifies to:

$$\log i = \underbrace{\log n + \alpha \log w_{min}}_{\text{Intercept}} - \alpha \log w_i + \varepsilon_i \tag{6}$$

In a more complex survey setup, like the one in HFCS, observations are weighted to account for unequal probabilities of entering the survey. These survey weights need to be taken into account when ranking observations to determine the empirical estimate for $\overline{F}(w_i)$. Vermeulen (2016) demonstrates that we can replace $\overline{F}_n(w_i) \approx \frac{i}{n}$ by $\overline{F}_n(w_i) \approx \frac{\sum_{m=1}^{i} \text{weight}_m}{\sum_{m=1}^{n} \text{weight}_m}$. Replacing and rearranging leads to the following regression equation, which we can estimate in the dataset:

[54] I did check an alternative setup in which I only include the top 35 Forbes observations for both France and Germany, and it did not change key outcomes of the top tail adjustment (like top 1% wealth shares). This can be explained by the low survey weight assigned to each Forbes observation.

[55] Often referred to as the Hill estimator following Hill (1975).

[56] I follow the notation used in Nicolau and Rodrigues (2019) in this section.

$$\log \sum_{m=1}^{i} \text{weight}_m = \underbrace{\log \sum_{m=1}^{n} \text{weight}_m + \alpha \log w_{min}}_{\text{Intercept}} - \alpha \log w_i + \varepsilon_i \tag{7}$$

I follow Gabaix and Ibragimov (2011) who strongly suggest deducting 0.5 from the rank of each observation to reduce bias in the regression. For standard errors, I use the 1,000 replicate weights provided with the HFCS dataset.

With this preparation, I apply the routine suggested by Vermeulen (2016) that I introduced in the previous section (2.4.3). First, I align survey wealth with wealth in national accounts through asset-specific preliminary adjustment factors. Then, I estimate the Pareto tail parameter $\hat{\alpha}$ above $w_{min} = 500,000$ euros through the OLS regression in Equation 7 and re-scale the wealth of each individual in the tail so that its net wealth matches the net wealth implied by the Pareto distribution. Since these revisions increase total wealth in the tail, the preliminary adjustment factors no longer align aggregate wealth by asset type in the survey and national accounts. Therefore, in the third step, the adjustment factors need to be corrected upwards or downwards, depending on the asset-specific difference between survey wealth and aggregate wealth in national accounts. It takes several iterations until the gaps in the third step converge to zero. Hence, I run the process 30 times for France and Germany. Figure A.6 in the appendix illustrates the routine schematically.

Table A.11 presents the OLS-estimated Pareto coefficients for the three potential thresholds and each step of the adjustment process: from the raw survey to the Forbes-augmented dataset with a Pareto upper tail after 30 iterations of the correction routine. The $\hat{\alpha}$ coefficient for the 500,000 euros threshold is estimated at 1.60 for France and 1.37 for Germany, pointing towards a higher wealth concentration in Germany. As expected, the standard error of these estimates increases with higher thresholds because fewer observations remain in the tail. Standard errors are always greater in Germany since its survey includes fewer observations. For any given threshold, the estimated coefficients do remain relatively stable across the adjustment process. This is also apparent in Figure A.9 and Figure A.10. Pareto coefficients tend to decline for higher thresholds w_{min}, again pointing towards a non-perfectly Pareto distributed top tail. For every threshold, the adjustment routine manages to align survey wealth and wealth in national accounts, bringing the share of missing wealth in Table 5 down to zero.

Figure A.9 in the appendix presents key parameters across the 30 iteration of the adjustment routine for France and for a Pareto threshold of $w_{min} = 0.5$ million euros. The black line indicates that the gap between survey and national account aggregates declines swiftly. At the same time, the repeated correction of adjustment factors has no impact on key distributional properties: The estimated Pareto coefficient $\hat{\alpha}$, the top 1% and top 10% wealth shares are constant across iterations. Figure A.10 in the appendix presents the corresponding graph for Germany. The behavior of the parameters is similar, though it takes longer for aggregates to converge. We also recognize the comparatively larger standard errors of $\hat{\alpha}$, the estimated Pareto coefficient.

For France, the standard approach of adjusting the top tail produces results that are well-aligned with wealth inequality estimates found elsewhere, for example, those released by the World Inequality Lab (preliminary series for 2017) or those compiled by Bach et al. (2019) (estimates for 2014 based on the previous HFCS wave). Table 6 presents key distributional properties of the wealth distribution in France. For the 0.5 million euros threshold, I estimate the net wealth shares of the bottom 50%, top 10%, and top 1% in 2017 at 4.8%, 55.9%, and 24.0%, respectively. Adjusting the top tail (Δtop 1% share $\sim +4$ppt.) and aligning the survey with macroeconomic aggregates (Δtop 1% share $\sim +$ 3ppt.) visibly increases wealth inequality relative to the original survey dataset. Compared to these differentials, in the standard approach, the choice of the tail threshold has a negligible impact on key wealth inequality indicators in France.

For Germany, the standard approach seems to overestimate wealth concentration if my results are compared to wealth inequality estimates found elsewhere. Table 7 presents key distributional properties of the wealth distribution in Germany. For the 0.5 million euros threshold, I estimate the net wealth shares of the bottom 50%, top 10%, and top 1% in 2017 at 2.4%, 65.2%, and 35.9%, respectively. Note that, compared to the preliminary series released by the World Inequality Lab (top 1% share in 2017 at 25.8%), other survey-based studies tend to converge towards higher top wealth shares in Germany as well. Bach et al. (2019) estimate the top 1% wealth share in Germany in 2014 at 33-34% on the basis of the second wave of the HFCS. The *Global Wealth Report* released by the bank Credit Suisse (2019) estimates the top 1% wealth share in Germany in 2019 at 30.2%. However, even compared to these survey-based studies, my inequality estimates for Germany appear high. The adjustment of the top tail (Δtop 1% share $\sim +18$ppt.) increases wealth inequality starkly, whereas the macro alignment does not alter the wealth distribution in a meaningful way. This, as well as the large standard errors of $\hat{\alpha}$ in Germany (see Table A.11) suggests that estimating simple Pareto parameters on the relatively small empirical top tail in Germany might a cause for concern. Fortunately, the alternative approach of adjusting the top tail more flexibly will bring my wealth inequality estimates for Germany closer to the literature. Recall also that, up to this day, the WIL has not released official top wealth shares for Germany. Uncertainties regarding top wealth shares in Germany remain generally higher than in France, where all my specifications, as well as various research publications, suggest similar levels of wealth concentration (see Table 6).

Let us know move to the alternative approach inspired by Blanchet et al. (2021). To rely on a simple Pareto law (as introduced in Equation 4) has more than one potential issue. As we have seen, particularly for the case of Germany, the limited number of observations in the empirical tail implies that the estimates of $\hat{\alpha}$ have large standard errors. Blanchet et al. (2021) raise a second, more fundamental issue: actual income and wealth tails do not seem to follow simple Pareto laws with constant tail parameters. We have found similar evidence for a U-shaped local inverted

Table 6: Net wealth distribution in France, in % of total wealth (2017)

			Pareto tail (constant)			Pareto tail (flexible)			
	HCFS	HFCS + Forbes	0.5m	1.0m	2.0m	0.5m	1.0m	2.0m	WIL
Pre macro alignment									
Bottom 50%	6.3	6.1	5.9	5.9	5.9	4.9	5.4	5.6	-
Top 10%	48.9	50.6	52.4	52.1	52.5	59.9	56.1	54.3	-
Top 1%	17.0	19.9	21.1	22.3	22.9	30.3	28.6	25.9	-
Post macro alignment									
Bottom 50%	-	-	4.8	4.7	4.7	4.9	4.8	4.8	5.1
Top 10%	-	-	55.9	56.4	56.3	55.3	55.6	55.6	57.9
Top 1%	-	-	24.0	24.0	24.5	23.3	23.3	23.2	24.2

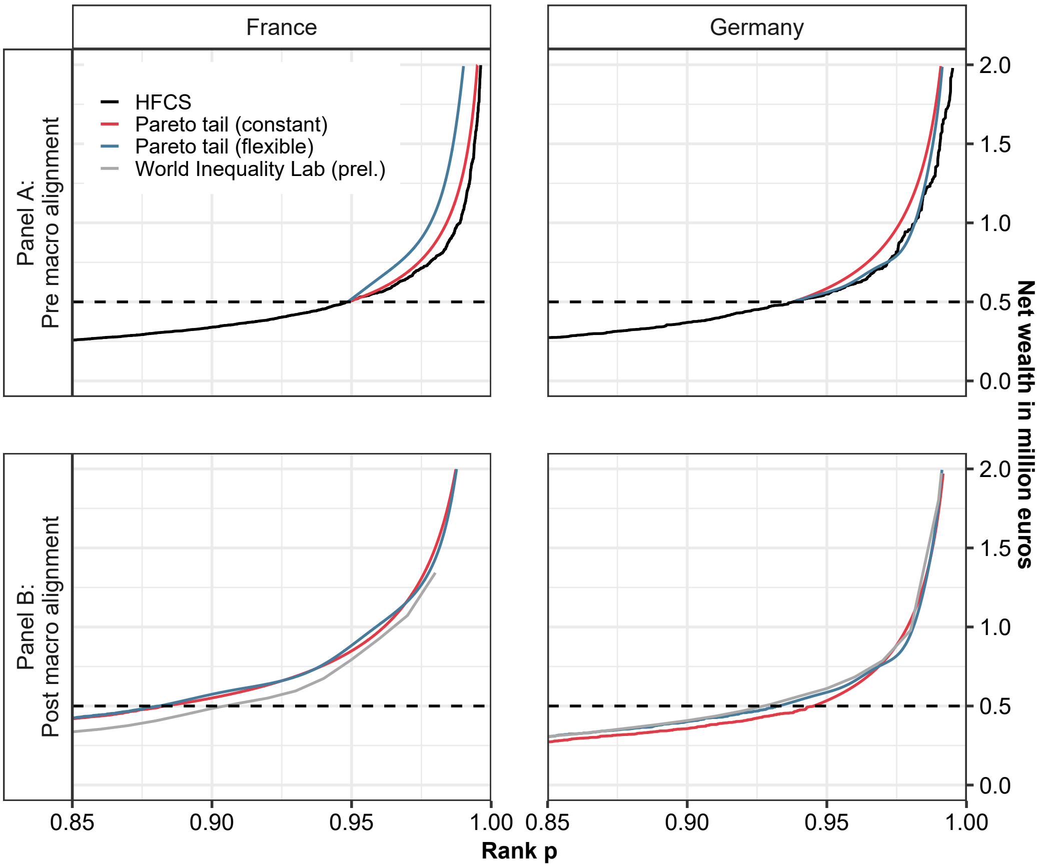
Note: The table presents key distributional properties of the net wealth distribution in France. The first two columns present group wealth shares in percent in the survey (before and after adding high-wealth observations). The constant Pareto tail columns (3-5) refer to a scenario in which the wealth tail above the threshold (0.5 million, 1.0 million, or 2.0 million) follows a Pareto power law with a constant shape parameter estimated by OLS. The flexible Pareto tail columns (6-8) refer to a scenario in which the wealth tail above the threshold follows the shape of the wealth tail recorded by the World Inequality Lab (preliminary estimates for 2017 as of May 2021). The last column presents the corresponding wealth shares released by the WIL. Macro alignment refers to the adjustment process inspired by Vermeulen (2016) that aligns survey wealth with national account aggregates. See text for more details. Based on data from Eurostat, Forbes, HFCS, and WIL.

Table 7: Net wealth distribution in Germany, in % of total wealth (2017)

			Pareto tail (constant)			Pareto tail (flexible)			
	HFCS	HFCS + Forbes	0.5m	1.0m	2.0m	0.5m	1.0m	2.0m	WIL
Pre macro alignment									
Bottom 50%	3.2	3.0	2.3	2.4	2.6	2.6	2.6	2.7	-
Top 10%	54.8	56.9	66.6	64.9	62.9	63.0	63.0	61.2	-
Top 1%	18.0	21.9	36.6	36.1	32.8	32.3	32.3	29.6	-
Post macro alignment									
Bottom 50%	-	-	2.4	2.7	2.9	2.8	2.8	3.0	3.5
Top 10%	-	-	65.2	62.7	60.2	61.1	61.4	59.5	57.4
Top 1%	-	-	35.9	34.0	29.8	30.7	30.8	28.2	25.8

Note: The table presents key distributional properties of the net wealth distribution in Germany. The first two columns present group wealth shares in percent in the survey (before and after adding high-wealth observations). The constant Pareto tail columns (3-5) refer to a scenario in which the wealth tail above the threshold (0.5 million, 1.0 million, or 2.0 million) follows a Pareto power law with a constant shape parameter estimated by OLS. The flexible Pareto tail columns (6-8) refer to a scenario in which the wealth tail above the threshold follows the shape of the wealth tail recorded by the World Inequality Lab (preliminary estimates for 2017 as of May 2021). The last column presents the corresponding wealth shares released by the WIL. Macro alignment refers to the adjustment process inspired by Vermeulen (2016) that aligns survey wealth with national account aggregates. See text for more details. Based on data from Eurostat, Forbes, HFCS, and WIL.

Figure 6: Net wealth distribution around the top tail threshold (2017)



Note: The figure presents the net wealth distribution in France and Germany around the top tail threshold for $w_{min} = 0.5$m. The constant Pareto tail refers to a scenario in which the wealth tail above w_{min} follows a Pareto power law with a constant shape parameter $\hat{\alpha}$ estimated by OLS (see Table A.11). The flexible Pareto tail refers to a scenario in which the distribution above w_{min} follows the shape of the wealth tail estimated by the World Inequality Lab (preliminary estimates for 2017 as of May 2021). The grey line depicts the distribution implied by the preliminary WIL series. Macro alignment refers to the adjustment process inspired by Vermeulen (2016) that aligns survey wealth with national account aggregates. See text for more details. Based on data from Eurostat, Forbes, HFCS, and WIL.

Pareto parameter $b_0(p)$ in the empirical top tail of the survey in Figure 5.[57] To account for these characteristics of the distribution, instead of imposing a constant parameter α (and thereby $b(p)$), Blanchet et al. (2021) recommend estimating the shape of the tail in a more flexible manner. Their preferred technique relies on tabulated data from administrative sources. Importantly, they present simulations to show that a very small number of tabulated anchor points can deliver more precise results than drawing upon randomly sampled surveys – even if the number of observations is large (e.g., above 1 million). Given the comparatively small number of observations in the HFCS, we therefore ought to prefer tabulated data when estimating the flexible shape of the tail.

[57] Atkinson (2017) metaphorically called distributions of such a shape *regal*, painting the picture of a monarch who is able to accumulate resources above and beyond other aristocrats. The antipodal case ($b_0(p)$ decreasing with p), characterized by equally well-off aristocrats at the top, was referred to as *baronial*. Atkinson (2017) presents evidence that the income distribution in the United Kingdom moved from being *baronial* to *regal* in recent times.

Unfortunately, tabulated data on top wealth in 2017 is neither available for France nor Germany from administrative sources. In its absence, I propose to use the properties of the wealth distribution estimated by the World Inequality Lab (WIL). These series are compiled by combining various data sources and are widely believed to constitute the most comprehensive and reliable data source on wealth inequality (Alvaredo et al., 2020, 2017). For France, the estimates rely on the Mixed-Income-Capitalization-Survey method (MICS) expounded in Garbinti et al. (2020), which combines capitalized income streams from fiscal sources, wealth surveys, and national accounts to trace out the distribution of wealth. For Germany, as noted earlier, the WIL has so far only compiled preliminary series on wealth, for which methodological details have yet to be published. For this project, I was granted access to the preliminary WIL wealth series for France and Germany in 2017 (as of May 2021).[58] These include 127 wealth intervals between $p = 0$ and $p = 0.99999$ with the corresponding bracket averages and shares. I now proceed *as-if* the distributional properties of these series were to originate from a tabulated administrative data source.

I start by estimating the wealth quantiles based on the average wealth within each bracket.[59] I then calculate local inverted Pareto coefficients for each of the 127 data points. As proposed by Blanchet et al. (2021), between these points, I interpolate the Pareto curve using polynomials of degree 5 (constrained quintic splines). At the very top, I extrapolate the distribution by means of a generalized Pareto law. Neither the interpolation nor the extrapolation techniques impose Pareto laws with constant shape parameters. Instead, they allow the local Pareto coefficient to vary. The result is a continuous and smooth approximation of the wealth distribution for France and Germany in 2017, which is depicted in grey in Figure 6, Panel B.[60] The properties of this distribution can then be used to adjust the tail of the wealth survey: Above the threshold w_{min}, I force the survey tail to follow the shape of the distribution obtained from the Pareto-interpolated WIL data.

The mechanics behind this adjustment are illustrated in Figure 6. For a threshold of 0.5 million euros,[61] the figure presents the net wealth distribution for the two potential adjustment techniques (standard and alternative) and both steps of the adjustment (pre and post macro alignment). Panel A confirms that the survey distribution prevails for individuals with net wealth below 500,000 euros. Above, given a flexible Pareto tail (in blue), individual wealth increases in accordance with the shape of the Pareto-interpolated WIL distribution.[62] Note that at the very top, the shape of the distribution continues to be defined by the Forbes observations. Therefore, the piece of

[58]In what follows, I refer to these estimates whenever I mention the *WIL* series.

[59]I rely on the `gpinter` package released by Blanchet et al. (2021) to implement the following steps.

[60]Surprisingly, the preliminary WIL data suggests that local inverted Pareto coefficients decline within the wealth tail in France. For Germany, the data confirm the U-shaped increase of $b(p)$ that sets in at around $p = 0.95$.

[61]One potential further extension would be to quantitatively determine the threshold w_{min} between the survey and Pareto-interpolated WIL distribution through the techniques proposed by Blanchet et al. (2018).

[62]For illustrative purposes, imagine (i) the individual with 500,000 euros net wealth has a rank of $p = 0.95$ in the survey distribution and (ii) the Pareto curves imply that wealth in the WIL dataset increases by 1 million euros between rank $p = 0.95$ and $p = 0.975$. In that case, we would adjust the wealth of an individual with rank $p = 0.975$ in the survey to be at 1.5 million euros.

the distribution that needs to be extrapolated is small.[63] Finally, I apply the Vermeulen (2016) routine (see 2.4.3) to align the survey with national accounts (i.e. to move from Panel A to Panel B in Figure 6).

Table 6 and 7 allow us to evaluate how switching from a fixed Pareto tail (standard approach) to the flexible tail based on the interpolated WIL-distribution (alternative approach) changes key wealth inequality indicators. For France, once the survey is aligned with macroeconomic aggregates, the differences between the two methods are minor. Using the alternative approach, I estimate the net wealth shares of the bottom 50%, top 10%, and top 1% in 2017 at 4.9%, 55.3%, and 23.3%, respectively. These group shares mirror closely what was found earlier and what the preliminary WIL series suggests. For Germany, the alternative approach does bring the very high top 10% and top 1% wealth shares estimated via the standard Pareto tail closer to the WIL shares. With a flexible Pareto tail, I estimate the net wealth shares of the bottom 50%, top 10%, and top 1% in Germany in 2017 at 2.8%, 61.1%, and 30.7%, respectively. Despite the convergence, my inequality estimates for Germany continue to be higher than what the preliminary WIL statistics suggest (Δtop 1% share $\sim +$ 5ppt.). As noted earlier, my estimates are in line with other survey-based studies (e.g., Bach et al., 2019); and these gaps seem to reflect the generally higher uncertainty regarding wealth inequality in Germany relative to France.

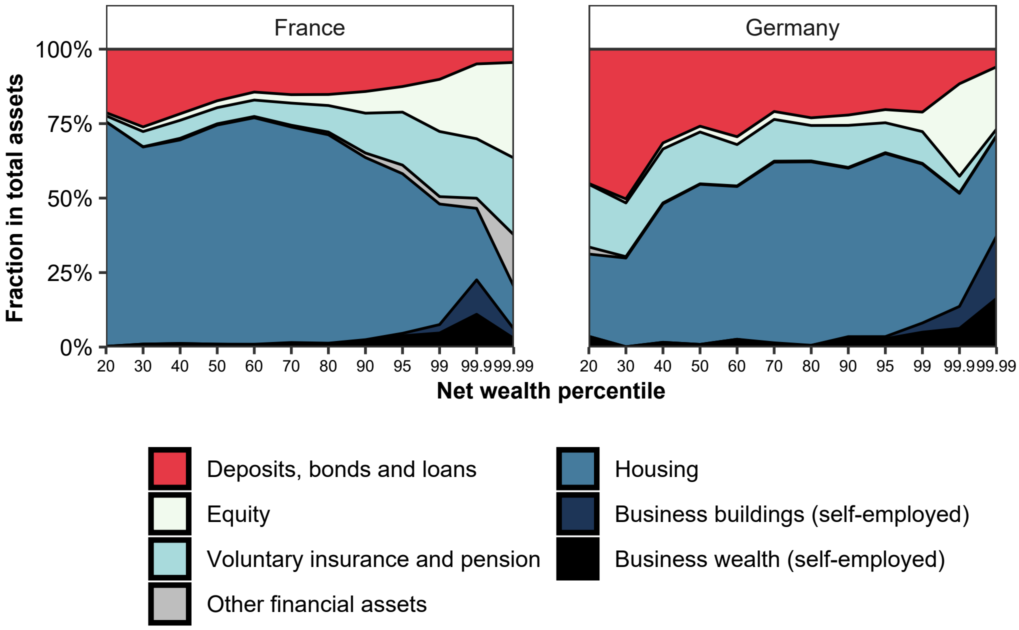
In light of these reflections, I need to decide on one preferred specification for my headline results in Section 2.5. I will use the 0.5 million euros threshold for the reasons explained above. Regarding the top tail, I will stick with the flexible, WIL-interpolated adjustment, which is motivated by (i) the fact that the alternative approach produces results that are closer to what is found in the inequality literature (Table 6-7) and (ii) the mounting evidence that empirical tails of wealth distributions do not follow simple Pareto laws (Figure 5-6).

Before we move on, in Figure 7, I take a look at the composition of wealth by asset in 2017 in both countries in the final, adjusted wealth dataset. The type of assets owned by each wealth percentile is of paramount importance because, in the following sections, annual emissions are assigned through the emission intensity of the asset owned by individuals along the wealth distribution. In both France and Germany, housing makes up the largest part of assets in the middle of the wealth distribution. Only at the very top, above the 95th percentile, do we see significant increases in the share of financial wealth – particularly if we abstract from voluntary insurance and pensions – and in the share of self-employed business wealth. The importance of deposits declines with increasing wealth levels.

Note that Figure 7 cannot be directly compared to Figure B.20 in Appendix B to Garbinti et al. (2020). Even though it also presents the asset composition by wealth in France, it records housing wealth net of debt, which reduces the share of housing at the bottom of the distribution. Think of an individual with modest net wealth who owns a house with a mortgage. In my figure, the housing wealth of said individual would appear prominently and make up a rather large share of its wealth. In Garbinti et al. (2020), the housing wealth of said individual cancels out and

[63] Between $p = 0.99999$ and the first observation coming from the Forbes list.

Figure 7: Macro-aligned asset composition by wealth level (2017)



Note: The graph shows the average asset composition by net wealth percentile in the third wave of the HFCS survey after adjusting the top tail and aligning survey and national account wealth aggregates. Net wealth above $w_{min} = 0.5$m follows the shape of the wealth tail estimated by the World Inequality Lab (preliminary estimates for 2017 as of May 2021). See text for more details. Asset classification developed in Section 2.4.2. Figure A.11 in the appendix presents the composition in the unadjusted HFCS survey. Figure A.12 presents the composition for a constant Pareto upper tail estimated from Equation 7. Figure A.13 in the appendix presents relevant asset shares by wealth group for all specifications. Based on data from Eurostat, Forbes, HFCS, and WIL.

does not appear at the bottom of the distribution. The decision to present the composition of assets differently is driven by what counts for emissions in Section 2.5. I want to assign annual emissions to the owners of assets regardless of liabilities and then present the distribution of carbon wealth for each net wealth percentile. If I were to deduct liabilities first, highly geared owners of carbon-intensive assets would not be made responsible for the emissions of the capital stock they own.

Potentially, both adjustments made in this section and in 2.4.3 can impact the asset composition by wealth. We need to distinguish them with regards to their potential effect, however. First, the preliminary adjustment factors addressed the gap between the survey and national accounts. For each asset category, they assumed a constant level of under-reporting that is independent of net wealth. Nonetheless, the macro alignment has the potential to change the composition of assets at each point of the net wealth distribution. Wealthy individuals in the HFCS tend to own assets that are more heavily under-reported (remember Table 5). On average, the correction increases their wealth (in terms of aggregate net wealth) and the share of wealth owned in the form of financial assets (in terms of percentage points) by more. In the second step, the top tail adjustment addressed the issue that surveys fail to capture the wealth at the top, independently of the fact that wealthy individuals own more heavily under-reported assets. To mitigate the problem, we re-scaled top wealth above a threshold so that it follows a simple or generalized Pareto law. Notably, the asset composition for each survey individual remained unaffected. Nonetheless, because we increased total wealth at the top, the share owned by the top wealth group increases for each asset.

Figure A.13 in the appendix presents, for each emission-relevant asset, the fraction of total assets owned by the top wealth groups. Three observations can be made. First, as expected, compared to the original survey, the share of assets owned by the top increases through the adjustments – particularly in Germany and for self-employed business assets. Second, the choice of the tail threshold w_{min} and the Pareto law (simple or generalized) has a limited impact on the fraction owned by top[64]. However, as one would expect from Table 7, the asset concentration remains somewhat lower for higher thresholds in Germany. Third, except for housing, emission-relevant assets are even more concentrated than wealth per se. For example, regardless of the specification, I estimate that more than 50% of equities are held by the top 1% of the wealth distribution in both France and Germany in 2017. These shares significantly exceeds top 1% wealth shares obtained in Tables 6-7. They will play a central role when it comes to the carbon content of wealth in the next section.

The preceding sections introduced the Household Finance and Consumption Survey (2.4.1) and then elucidated how one can address the comparability problem (2.4.2), the under-reporting problem (2.4.3) and the non-response problem (2.4.4) when it comes to linking survey wealth to national accounts. In the end, we discussed the composition of wealth by asset. The following section combines the macro-level emissions obtained in 2.3 with the adjusted wealth survey data to trace out the distribution of carbon wealth.

2.5 Combine macro-level emissions and survey wealth

2.5.1 Initial results under full attribution to capital stock owners

I now build on the preparatory work in the preceding sections and present annual emission estimates by wealth in France and Germany. In 2.3, we were able to estimate the aggregate annual emissions linked to the assets owned by each institutional sector in the economy – the government, corporations, households, and the rest of the world. Wealth-related emissions of households either stemmed from owning housing property, self-employed business wealth, or from owning parts of a resident or non-resident corporation. Through euity holdings, we shifted all direct emissions originating from corporate production to the ownership sector of the productive capital stock. In 2.4, we made several adjustments to the third wave of the Household Finance and Consumption

[64]Figure A.11 and A.12 provide an alternative way of comparing the asset composition in Figure 7 to the one in the survey and the *simple Pareto tail* specification.

Survey (HFCS) in order to obtain a comprehensive dataset on individual wealth in 2017, which takes into account the shape of the top tail and is consistent with macroeconomic aggregates.

Figure 9 and Figure 10 present my initial results, annual emissions by wealth level in France and Germany in 2017 under the full attribution scenario. Full attribution refers to the fact that all direct production emissions are shifted to the owners of the productive capital stock, either domestic or abroad. This corresponds to how we have so far attributed emissions in the preceding sections. The horizontal axis of the figures ranks adult individuals in the economy according to their net wealth level in 2017. On the vertical axis, the graphs depict the cumulative share of annual emissions in million tons of CO2 equivalents. The left panel only includes those emissions that can be linked to resident household wealth. Take the 50th percentile in France as depicted in Figure 9. Individuals with net wealth not exceeding 118,000 euros belonged to the bottom 50% of the wealth distribution. Taken together, these individuals can be made responsible for 1.9% of annual wealth-related greenhouse gas emissions. The order of magnitude is similar in Germany, where the bottom 50% of wealth holders are responsible for only 1.1% of wealth-related emissions. What do these shares imply in terms of actual per-adult emission? Table 8 and Table 9 show: the average adult in the bottom 50% of the wealth distribution is responsible for 0.2 tons of emissions per year in both France and Germany through its wealth holdings under the full attribution scenario. In contrast to that, among the wealthiest 10% of individuals, average wealth-related emissions amount to 38.7 tons per adult and year in France (31.0 per capita) 81.9 tons in Germany (67.7 per capita). Keep in mind that per capita emissions[65] in 2017 stood at 7.3 tons of CO2eq in France and 11.4 tons in Germany.

Tables 8 and 9 demonstrate that inequality in wealth-related emissions exceeds wealth inequality. The bottom 50% own 4.9% of net wealth in France and 2.8% in Germany in 2017. At the same time, their share in wealth-related emissions is estimated at only 1.1% and 1.9%. Conversely, the top 10% own 55.3% of net wealth in France and 61.1% in Germany, whereas their proportion in wealth-related emissions reaches 82.8% in France and 88.1% in Germany. For the top 1% shares, the difference between emission inequality and wealth inequality is even more pronounced.

Let me first explain the meager share in wealth-related emissions of the bottom 50%. First, the total value of assets owned by individuals in that group is low compared to individuals with higher net wealth. This is because wealth and net wealth ranks are tightly linked, especially at the top. Second, the assets owned by the bottom half of the distribution typically come with a low carbon intensity. We have seen in Figure 7 that, below the 50th percentile, individuals mostly own housing, deposits, and some voluntary insurance or pension schemes. Deposits and insurance schemes are financial assets that do not constitute a claim on the capital stock of corporations, which is why we did not assign any direct emissions to these asset types. Housing, the other dominant wealth item in the bottom 50% of the distribution (particularly so for the middle class), is of extremely low carbon intensity even though it makes up a large share of the total capital stock in both economies. Remember that we attributed emissions from heating and cooling to

[65] Total national emissions in Eurostat air emission accounts (as, for example, in Tables A.1-A.2) divided by the total population.

The box is aimed at orienting the reader as to which four perspectives on the distribution of carbon wealth are presented:

- My initial results, the full attribution scenario, attribute all direct production emissions to the owners of the productive capital stock. The distribution of emissions is presented excluding (upper and left panel) and including (bottom and right panel) emissions not related to household wealth. These include direct household emissions, assigned based on individualized annual income, and government emissions, which are flatly attributed to individuals.

  → Tables 8-9 and Figures 9-10 in Section 2.5.1

- Extension 1 starts from the initial results but shifts emissions from heating and cooling to homeowners instead of residents.

  → Tables 11-10 and Figure 11 in Section 2.5.2

- Extension 2 accounts for indirect production emissions, namely the emissions from generating electricity, by shifting these emissions to the users of electricity (industry sectors and households). It includes direct household emissions, assigned based on individualized annual income, and government emissions, which are flatly attributed to individuals.

  → Tables 11-10 and Figure 11 in Section 2.5.2

- The partial attribution scenario starts from the initial results but attributes only a fraction of production emissions to the owners of the capital stock, which is determined by the investment share in final demand in an input-output system. Again, the distribution of emissions is presented excluding (upper and left panel) and including (bottom and right panel) emissions not related to household wealth. These include (i) the direct and indirect emissions necessary to satisfy final consumption of households and the government, (ii) direct household emissions, and (iii) emissions linked to the capital stock owned by the government. Direct and household consumption emissions are attributed based on individual annual income. Government emissions are flatly assigned to individuals.

  → Tables 13-14 and Figure 12-13 in Section 2.5.3

residents rather than to homeowners.[66] On the other hand, we know from Figure A.13: more than 75% of self-employed business wealth and corporate equity is held by the wealthiest decile of adults. For these individuals, with average net wealth above around 575,000 euros in France and around 402,000 euros in Germany, we recognize a visible emission impact of owning foreign corporations in Figure 9 and Figure 10.

Next, we can turn to those emissions that are not linked to household wealth, namely direct household emissions and the emissions attributed to the capital stock owned by the government. These emissions are taken into account in the right panel of Figures 9-10 and in the bottom panel of Tables 8-9. As explained in the previous chapters, even under a full attribution scenario, direct household emissions cannot be linked to wealth holders because the emission-causing activity – like burning fuel in private cars or heating residential buildings – is carried out by households themselves. Since this behavior is not part of any production process, it cannot be meaningfully assigned to the economy's capital stock. For different reasons, the same applies to the capital stock owned by the government. It cannot be attributed to individual wealth because the government is an entity sustained by all citizens. Nonetheless, government-linked emissions are part of the national economy. If it is the goal to present distributional properties of the totality of emissions in the economy – and not only to zoom in on wealth-related emissions – one cannot simply ignore governmental and direct household emissions. We have seen earlier that both are sizeable (see Figure 4).

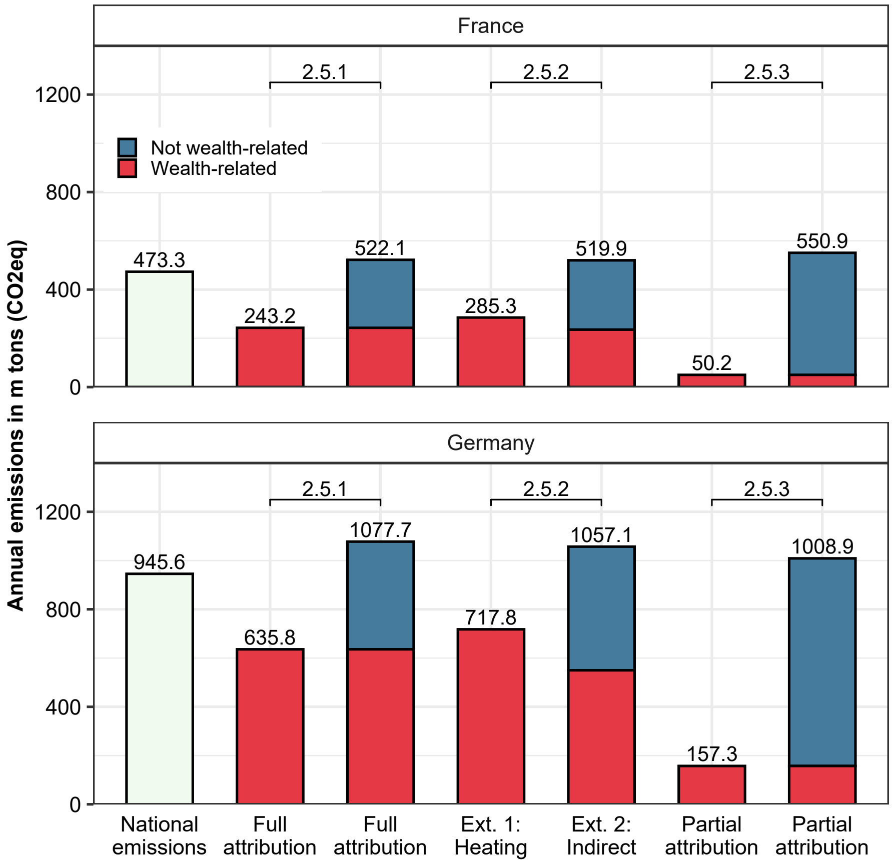
I decide to distribute direct household emissions among individuals based on individualized gross income, using income as a proxy for consumption and consumption as a proxy for direct household emissions.[67] While imperfect,[68] it appears to be the natural way to proceed, given the two other alternatives would be to either use wealth (clearly overstates inequality in direct household emissions) or to simply distribute the emissions equally among individuals (clearly understates inequality in direct household emissions). We know that, in absolute terms, wealthy individuals tend to have higher income, consume more, burn more fuel, heat larger homes, and so on (Oswald et al., 2020) – even if the marginal propensity to consume declines (Arrondel et al., 2015). Regarding the emissions linked to the government, I distribute them emissions equally among adult individuals in the economy. One could rationalize this by arguing that, similar to public debt, each individual as a citizen has the same stake in the public sector's assets.

What is noteworthy about including non-wealth-related emissions? First, inequality in total emission responsibility remains stark. The top 10% of wealth holders are now responsible for 46.3% of all emissions in France and 58% of annual emissions in Germany – despite the equality assumption regarding governmental and the income-based allocation of direct household emissions. Second, wealth-related emissions are only dominant for the very top of the wealth distribution. Even under full assignment, only about half of the emissions in the middle 40% of the distribution are related to household wealth. Out of all emissions with resident responsibility, the bottom half

[66] The first extension in Section 2.5.2 makes homeowners responsible for heating emissions.
[67] Variable *DI2000* in the survey.
[68] Chancel and Piketty (2015) suggest, for example, that direct household emissions increase less for top income earners than indirect consumption-related emissions.

of the wealth distribution now accounts for between 20-25% of emissions, compared to around 1-2% when only wealth-related emissions are regarded.[69]

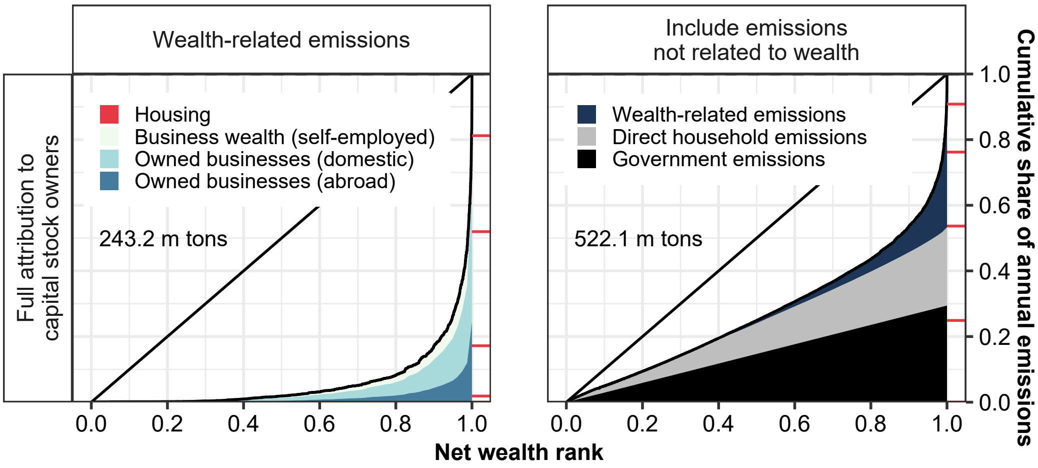
Figure 8: Aggregate emissions behind scenarios presented in this section (2017)



Note: The figure presents, for each approach discussed in this section, the aggregate level of emissions attributed to household wealth. Emissions are annual emissions in million tons of CO2 equivalents. National emissions refer to territory-based emissions as recorded in the Eurostat air emission accounts. Full attribution assigns all direct production emissions to the owners of the productive capital stock. Includes (excludes) emissions associated with domestically (foreign) owned foreign (domestic) capital stock. Extension 1 attributes emissions from heating to homeowners instead of residents. Extension 2 accounts for indirect (scope 2) production emissions. Partial attribution only attributes emissions necessary to satisfy global investment demand by industry to capital stock owners. Remaining emissions consist of direct and indirect emissions necessary to satisfy final consumption of households and the government, and direct household emissions. Based on data from Bundesbank, Corsatea et al. (2019), Crippa et al. (2020), Destatis, Eurostat, Insee, Nardo et al. (2017), and WIOD (2015).

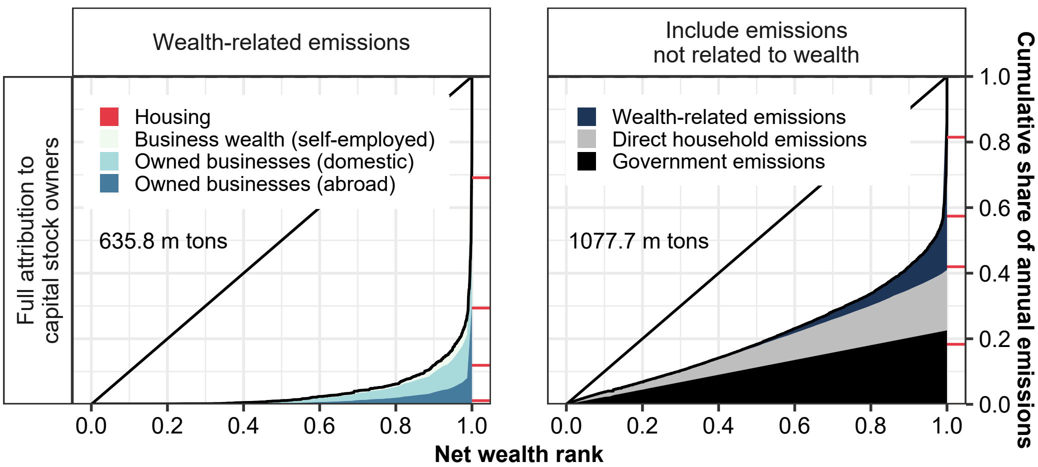
[69]To understand why total annual emissions in these figures are not equal to national emissions as recorded in air emission accounts, go back to Figure 4. We include all national emissions but add the emissions of foreign corporations owned by households and the government while removing emissions of foreign-owned domestic corporations.

Figure 9: Distribution of emissions by net wealth in France (2017)



Note: The figure presents the estimated distribution of annual emissions by net wealth rank in France under the full attribution scenario (2017). Top 0.1%, top 1%, top 10%, and bottom 50% shares can be deduced from the red lines. All direct production emissions are attributed to the owners of the productive capital stock. The left panel includes only emissions attributed to resident household wealth. The right panel includes direct household emissions and emissions linked to the capital stock owned by the government. Direct emissions are attributed based on individual annual income. Government emissions are flatly assigned to individuals. Net wealth per adult individual estimated from adjusted HFCS survey. See note below Table 8 for more definitional details. Own calculations based on data from Crippa et al. (2020), Eurostat, Forbes, HFCS, Insee, Nardo et al. (2017), and WIL.

Figure 10: Distribution of emissions by net wealth in Germany (2017)



Note: The figure presents the estimated distribution of annual emissions by net wealth rank in Germany under the full attribution scenario (2017). Top 0.1%, top 1%, top 10%, and bottom 50% shares can be deduced from the red lines. All direct production emissions are attributed to the owners of the productive capital stock. The left panel includes only emissions attributed to resident household wealth. The right panel includes direct household emissions and emissions linked to the capital stock owned by the government. Direct emissions are attributed based on individual annual income. Government emissions are flatly assigned to individuals. Net wealth per adult individual estimated from adjusted HFCS survey. See note below Table 9 for more definitional details. Own calculations based on data from Bundesbank, Crippa et al. (2020), Destatis, Eurostat, Forbes, HFCS, Nardo et al. (2017), and WIL.

Table 8: Annual emissions by net wealth group in France (2017)

	Emissions			Net wealth			
	Share *in %*	Average per adult *in tons*	Average per capita *in tons*	Share *in %*	Average per adult *in tons*	Average per capita *in euros*	Threshold per adult *in euros*
Full attribution							
Bottom 50%	1.9	0.2	0.1	4.9	21,497	17,217	-
Middle 40%	15.3	1.8	1.4	39.8	218,265	174,802	117,842
Top 10%	82.8	38.7	31.0	55.3	1,213,072	971,515	574,610
Top 1%	48.0	224.2	179.5	23.3	5,111,137	4,093,364	2,344,372
Top 0.1%	18.8	878.0	703.1	10.0	21,936,210	17,568,085	9,410,840
Total	100.0	4.7	3.7	100.0	219,362	175,681	-
Full attribution incl. emissions not related to wealth*							
Bottom 50%	24.9	5.0	4.0	4.9	21,497	17,217	-
Middle 40%	28.8	7.2	5.8	39.8	218,265	174,802	117,842
Top 10%	46.3	46.4	37.2	55.3	1,213,072	971,515	574,610
Top 1%	23.8	238.6	191.1	23.3	5,111,137	4,093,364	2,344,372
Top 0.1%	9.2	922.4	738.7	10.0	21,936,210	17,568,085	9,410,840
Total	100.0	10.0	8.0	100.0	219,362	175,681	-

* *Direct emissions attributed based on annual income/Government emissions flatly assigned to individuals.*

Note: The table presents the estimated distribution of annual emissions by net wealth group in France under the full attribution scenario (2017). All direct production emissions are attributed to the owners of the productive capital stock. Includes (excludes) emissions associated with domestically (foreign) owned foreign (domestic) capital stock. The upper panel includes only emissions attributed to resident household wealth. The bottom panel includes direct household emissions and emissions linked to the capital stock owned by the government. Direct emissions are attributed based on individual annual income. Government emissions are flatly assigned to individuals. See Figure 8, and T-2 and T-3 in Figure 4 for composition of the aggregates. Net wealth per adult individual estimated from adjusted HFCS survey. Per capita split assumes constant number of children per wealth bracket and equal wealth sharing. Own calculations based on data from Crippa et al. (2020), Eurostat, Forbes, HFCS, Insee, Nardo et al. (2017), and WIL.

Table 9: Annual emissions by net wealth group in Germany (2017)

	Emissions			Net wealth			
	Share *in %*	Average per adult *in tons*	Average per capita *in tons*	Share *in %*	Average per adult *in tons*	Average per capita *in euros*	Threshold per adult *in euros*
Full attribution							
Bottom 50%	1.1	0.2	0.2	2.8	9,420	7,786	-
Middle 40%	10.8	2.5	2.1	36.1	151,819	125,477	60,158
Top 10%	88.1	81.9	67.7	61.1	1,027,827	849,488	401,569
Top 1%	70.6	656.0	542.2	30.7	5,164,367	4,268,297	1,786,318
Top 0.1%	30.9	2,871.2	2,373.0	16.2	27,251,707	22,523,260	7,144,352
Total	100.0	9.3	7.7	100.0	168,220	139,032	-
Full attribution incl. emissions not related to wealth*							
Bottom 50%	18.3	5.8	4.8	2.8	9,420	7,786	-
Middle 40%	23.7	9.3	7.7	36.1	151,819	125,477	60,158
Top 10%	58.0	91.3	75.5	61.1	1,027,827	849,488	401,569
Top 1%	42.6	670.9	554.5	30.7	5,164,367	4,268,297	1,786,318
Top 0.1%	18.5	2,913.7	2,408.2	16.2	27,251,707	22,523,260	7,144,352
Total	100.0	15.7	13.0	100.0	168,220	139,032	-

* *Direct emissions attributed based on annual income/Government emissions flatly assigned to individuals.*

Note: The table presents the estimated distribution of annual emissions by net wealth group in Germany under the full attribution scenario (2017). All direct production emissions are attributed to the owners of the productive capital stock. Includes (excludes) emissions associated with domestically (foreign) owned foreign (domestic) capital stock. The upper panel includes only emissions attributed to resident household wealth. The bottom panel includes direct household emissions and emissions linked to the capital stock owned by the government. Direct emissions are attributed based on individual annual income. Government emissions are flatly assigned to individuals. See Figure 8, and T-2 and T-3 in Figure 4 for composition of the aggregates. Net wealth per adult individual estimated from adjusted HFCS survey. Per capita split assumes constant number of children per wealth bracket and equal wealth sharing. Own calculations based on data from Bundesbank, Crippa et al. (2020), Destatis, Eurostat, Forbes, HFCS, Nardo et al. (2017), and WIL.

2.5.2 Two extensions: heating and indirect production emissions

In this section, I present two extensions to the full attribution scenario. The first extension concerns emissions related to heating and cooling. In the previous figures, heating was part of direct household emissions and, therefore, not linked to wealth holders. While this is consistent with my approach of not assigning direct household emissions to wealth, the decision is contestable. In contrast to the air emission accounting guidelines mentioned in Section 2.3.1, one could take the view that the proper way of measuring the outcome of the real estate services industry is *livable* housing, i.e., housing units that are heated and cooled.[70]

Why is this important? For one, housing plays a dominant role in the type of assets owned at the bottom and around the center of the wealth distribution. In addition, at around 36% of all direct household emissions in France and 43% in Germany, emissions from heating are not negligible in size. One could therefore criticize my presentation in Figures 9 and 10 on the grounds that precisely those emissions that matter for the bottom and middle of the distribution are excluded from wealth-related emissions and that, as a consequence, inequalities are overstated. In the upper panel of Figure 11, I present the same distributional chart as before but assign heating emissions to the homeowners.[71] As one would expect, the first extension increases the total amount of emissions attributed to wealth. It is also visible that emission inequality indeed declines slightly. Because the housing assets owned by the bottom and center of the distribution become more carbon-intensive, the share of the bottom 50% in wealth-related emissions increases from 1.9% to 3.6% in France and from 1.1% to 1.8% in Germany. The emission share of the middle 40% increases somewhat more, by 4.7 percentage points in France and 3.1 percentage points in Germany. The bigger picture does not change, however, because housing is also owned by the wealthy. For example, the top 10% emission share declines from 82.8% to 76.4% in France and from 88.1% to 84.4% in Germany. It continues to be higher than the share of net wealth owned by these groups.

The second extension addresses the issue of indirect production emissions. It requires a more verbose explanation. So far, we have restricted the whole investigation to direct greenhouse gas emissions. These emissions are frequently referred to as *scope 1* emissions in the climate accounting literature and encompass emissions from "sources that are owned or controlled by the company" (GHGP, 2004).[72] Take the example of an energy-intensive industrial corporation. Suppose the corporation does not own its own power plants. In that case, a scope 1 perspective implies that emissions caused by the generation of electricity used as an input are not counted

[70]Interestingly, this is also currently debated in German politics. As recently as 12 May 2021, the German government announced that owners and tenants would need to split the statuary burden of the carbon tax on heating (Kersting, 2021).

[71]Technically speaking, I first assign heating emissions to the *Real estate activities industry* and then repeat my attribution steps as developed in 2.3.

[72]The scope terminology features most prominently in the Greenhouse Gas Protocol (GHGP) reporting standards, the most influential set of rules for organization-level carbon accounting in the private and public sector. For more details, see Kauffmann et al. (2012).

as emissions of the corporation. Instead, these emissions are assigned to the owners of utility companies.

Arguably, such a direct production perspective obscures who is ultimately responsible for energy-related emissions. Two otherwise identical corporations might appear to have greatly different emission records if one buys electricity and the other produces energy on its own premises. Recall also that emissions from electricity generation are non-negligible in size. According to Tables A.1 and A.2, the electricity sector is responsible for 10% of industrial emissions in France and 43% in Germany. It is hence necessary to check how the distribution of wealth-related emissions presents itself once we account for indirect *scope 2* emissions. These emissions are defined as "emissions associated with the purchase of electricity, steam, heat, or cooling" (GHGP, 2004). Just like in the technical reports of the Greenhouse Gas Protocol, for better readability, I refer to scope 2 emissions collectively as *emissions from electricity generation.*

Accounting for indirect emissions renders it necessary to deploy an additional source of data. Direct emissions of the electricity-producing industry – available in Tables A.1 and A.2 – need to be reallocated to those industries and households that use electricity. Multi-regional input-output tables present the linkages between industry sectors – foreign and domestic. Therefore, they are the natural data source to account for indirect emissions.

Input-output analysis has been famously pioneered by Wassily Leontief (1966).[73] Recently, it reappeared as a tractable tool to allocate emissions along global value chains – particularly in the context of trade between advanced and developing economies (Davis and Caldeira, 2010; Chancel and Piketty, 2015; Chen et al., 2018). The core of any input-output system is a large symmetric matrix that presents, for any given industry, its domestic intermediate inputs in one column and its output used as an intermediate input in other domestic industries in one row. This matrix is then extended by two additional matrices presenting, for each industry, imported intermediate inputs, exported output, and final demand. The symmetric nature of this system of matrices ensures that inputs equal outputs, or: the sum of (i) intermediate inputs, (ii) imports, and (iii) value-added is equal to the sum of (i) output used as intermediate input elsewhere, (ii) exports, and (iii) final demand. In our context, such a presentation allows us to determine, which industries use domestically produced electricity as an intermediate input. The residual to total output of the electricity sector can be attributed to final demand.

I use data from the World Input-Output Database (WIOD), prepared by Timmer et al. (2015). With 43 countries and 56 industry sectors, it has broad and granular coverage. Furthermore, the industry classification is aligned with how we split emissions in Section 2.3. The latest release of the database estimates industry linkages for 2014. Therefore, I need to assume that output-use shares of the electricity sector did not change between 2014 to 2017.[74]

[73]Leontief (1970) himself already suggested using the input-output framework to analyze environmental externalities.
[74]Another potential data source with a higher country coverage and a more recent release date would have been the EORA multi-region input-output tables, which were used by Chancel and Piketty (2015). However, EORA constructs its own industry classification, which is not easily compatible with what I use in Section 2.3.

Concretely, I then proceed in two steps. First, I calculate industry shares that denote, by industry, the fraction of the domestic electricity sector's output used as an intermediate input. I then use these shares to split the emissions from domestic electricity production across use industries. Consider the following example. The manufacturing industry uses 13% of the domestic electricity industry's output in France and 20% in Germany as intermediate input. Note that a certain percentage of electricity – 29% in France and 37% in Germany – is not deployed as an industrial input but directly used up by final demand. Think of the electricity consumed by households. Conceptually, I argue that these emissions fit best into the category of direct household emissions, together with emissions from heating and transport. Another fraction of domestic electricity is exported and then spent on production or final demand abroad. To avoid double-counting, the emissions associated with these exports can no longer be part of national indirect scope 2 emissions. Aggregate indirect emissions are hence strictly smaller than direct emissions after this first step. As a result of the first step, all direct scope 1 emissions of the domestic electricity sector are assigned to domestic corporations and households, or they are excluded due to the export of electricity. In a second step, we need to add the emissions originating from imported electricity. To do so, I calculate, for each domestic industry and for final demand, the share of imported electricity. Then, I add the emissions necessary to produce the imported electricity to the emissions obtained in the first step, assuming that imported electricity has the same carbon intensity as domestic electricity. After these adjustments, I reapply the steps from Section 2.3 and then link the adjusted emissions data to the wealth survey.

The bottom panel of Figure 11 presents the result of the second extension, namely annual emissions by wealth level in France and Germany in 2017, taking into account indirect production emissions. The charts also include governmental and direct household emissions, split among individuals according to the assumptions mentioned earlier. The figure hence ought to be compared to the right panel of Figures 9 and 10. The impact of re-allocating emissions from electricity generation to the use industries is small and practically non-existent for France.[75] There is a slight increase of + 0.4 ppt. in France and + 1.7 ppt. in Germany in the emission share of the bottom 50%. After all, they consume electricity while they hardly own capital stock deployed in the electricity industry. We also observe a corresponding reduction in the emission shares of the wealthy. For example, the top 1% emissions share declines from 18.5% to 16.3% in Germany. When looking at the average per adult emissions by wealth group, we do not observe major shifts.

Why does accounting for indirect production emissions has such a small impact on the distribution of emissions by wealth? The explanation brings us back to the limitations of the wealth survey. For corporate emissions, we could only attribute to equity holders the average emissions associated with holding 1 euro of equity in either France or Germany in 2017. We do not have information on the specific industry a person is invested in (see Section 2.5.4). Therefore, at least for emissions linked to the corporate capital stock, we had to assume that the industry someone is invested in does not depend on the level of wealth. One euro of equity owned by a top 10% individual has the same carbon intensity as one euro of equity owned by an individual at the bottom of

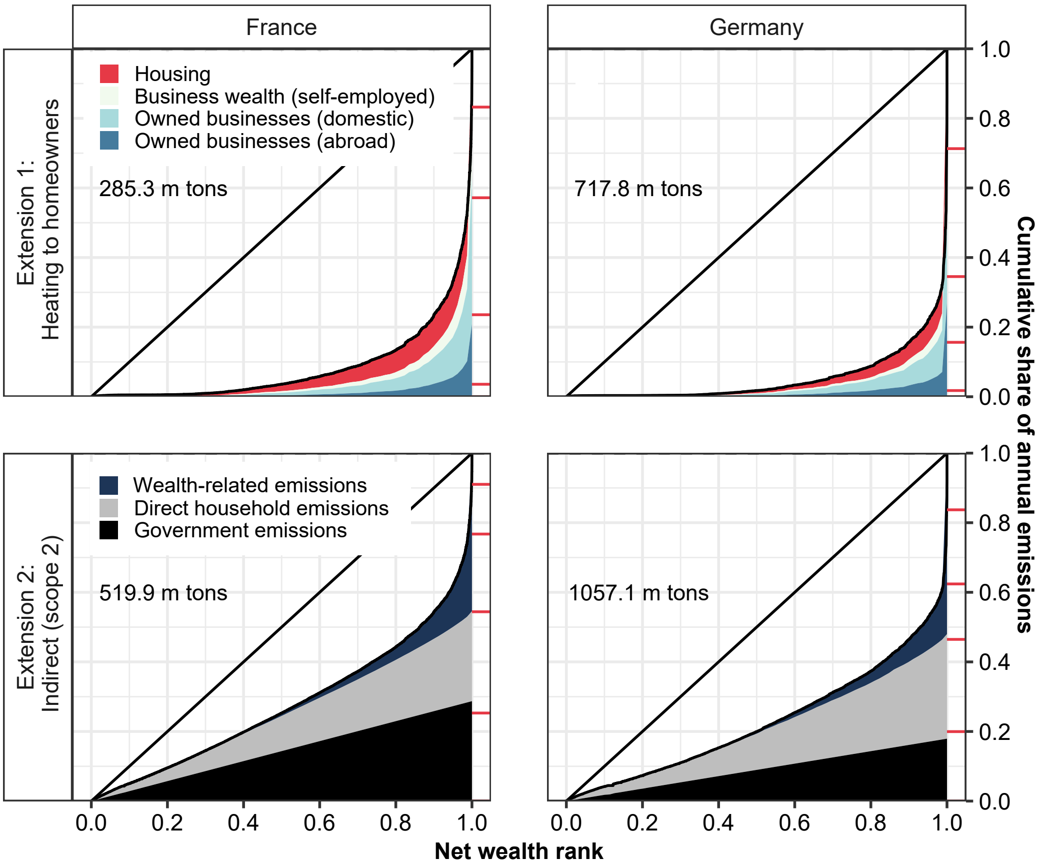
[75] Again, remember that electricity generation is less carbon-intensive in France (Redl et al., 2021).

the distribution. One can argue that the issues raised by this assumption are acceptable as most equity is owned at the top. However, they clearly are at play when we try to account for the indirect production emissions in this second extension. Apart from the export and import of electricity (which is limited in size) and the attribution of a fraction of electric emissions to households, we are merely shifting emissions from the electricity industry to other industries. The asset split in Tables A.3 and A.4, in combination with Tables A.8 and A.9, implies that the electricity sector is predominately corporate. Unsurprisingly, in this case, a reallocation between industries does not impact the share of emissions attributed to wealth groups in a major way.

Electricity-related emissions are not the only indirect emissions that one could focus on. The even broader *scope 3* perspective attempts to account for all indirect emissions associated with the production process. Notably, this includes emissions from the production of intermediate inputs other than electricity. In theory, within the input-output framework, one could reallocate some of these emissions through the same two-step procedure deployed for scope 2 emissions. For example, we could shift the transportation sector's emissions to those industries that use transportation services as an input. Two obstacles need to be remembered, however. First, if we want to avoid double-counting, an increasing fraction of emissions will be *removed* from carbon-intensive industries producing intermediate inputs and shifted to those industries producing goods for final demand. If this approach is followed through, step by step, we will move entirely from a production perspective to a consumption perspective on emission responsibility because, at some point, all production processes end up supporting the production of output used for final demand. Such a consumption-based view would, however, no longer be compatible with the capital ownership perspective on which the emission-wealth linkage developed in previous sections is grounded. From a normative perspective one could further question whether, for example, the emissions of a logistics company ought to be entirely assigned to those corporations who use its services as an input. Second, we can already tell from the experience of incorporating scope 2 emissions that, given the type of data at hand, the attempt to take into account scope 3 emissions in a full attribution scenario will be severely constrained by the fact that we can only talk about averages in the corporate sector. Third, scope 3 emissions are far from being defined in a comprehensive manner. Different organizations use different definitions and, on a macro-level, the issue of double-counting remains a challenge if one does not want to gradually move to a fully consumption/final demand-based perspective on emissions (see 2.2).

Nonetheless, I make an attempt in the next section, where I (i) move beyond the full attribution of emissions to capital stock owners and (ii) take indirect production emissions into account for those emissions that are linked to the final demand of households or the government. This approach has the potential to offer a way out of the production/consumption-based dichotomy while also addressing the issue of indirect emissions along global value chains.

Figure 11: Distribution of emissions by wealth in France and Germany (2017)



Note: The figure presents two extensions to the estimated distribution of annual emissions by net wealth rank in France and Germany (2017). Top 0.1%, top 1%, top 10%, and bottom 50% shares can be deduced from the red lines. See notes of Tables 10-11 for definitions details. Extensions (1)-(2) continue to fully attribute production emissions to the owners of the productive capital stock. Own calculations based on data from Bundesbank, Crippa et al. (2020), Destatis, Eurostat, Forbes, HFCS, Nardo et al. (2017), WIL, and WIOD (2015).

Table 10: Annual emissions by net wealth group in France (2017)

	Emissions			Net wealth			
	Share *in %*	Average per adult *in tons*	Average per capita *in tons*	Share *in %*	Average per adult *in tons*	Average per capita *in euros*	Threshold per adult *in euros*
Extension 1: Heating emissions to homeowners							
Bottom 50%	3.6	0.4	0.3	4.9	21,497	17,217	-
Middle 40%	20.0	2.7	2.2	39.8	218,265	174,802	117,842
Top 10%	76.4	41.9	33.5	55.3	1,213,072	971,515	574,610
Top 1%	42.8	234.5	187.8	23.3	5,111,137	4,093,364	2,344,372
Top 0.1%	16.8	920.3	737.1	10.0	21,936,210	17,568,085	9,410,840
Total	100.0	5.5	4.4	100.0	219,362	175,681	-
Extension 2: Account for indirect production emissions*							
Bottom 50%	25.3	5.1	4.0	4.9	21,497	17,217	-
Middle 40%	29.1	7.3	5.8	39.8	218,265	174,802	117,842
Top 10%	45.6	45.5	36.5	55.3	1,213,072	971,515	574,610
Top 1%	23.3	232.7	186.3	23.3	5,111,137	4,093,364	2,344,372
Top 0.1%	9.0	898.7	719.7	10.0	21,936,210	17,568,085	9,410,840
Total	100.0	10.0	8.0	100.0	219,362	175,681	-

* *Direct emissions attributed based on annual income. Government emissions flatly assigned to individuals.*

Note: The table presents two extensions to the estimated distribution of annual emissions by net wealth group in France (2017). Extension (1) attributes emissions from heating and cooling to homeowners instead of counting them as direct household emissions. Extension (2), in addition to government and direct household emissions, takes indirect production emissions (scope 2) into account (i.e., electricity emissions shifted to the use industry) before assigning emissions to the capital stock. Direct emissions are attributed based on individual annual income. Government emissions are flatly assigned to individuals. Extensions (1)-(2) continue to fully attribute production emissions to the owners of the productive capital stock. Net wealth per adult individual estimated from adjusted HFCS survey. Per capita split assumes constant number of children per wealth bracket and equal wealth sharing. Own calculations based on data from Crippa et al. (2020), Eurostat, Forbes, HFCS, Insee, Nardo et al. (2017), WIL, and WIOD (2015).

Table 11: Annual emissions by net wealth group in Germany (2017)

	Emissions			Net wealth			
	Share *in %*	Average per adult *in tons*	Average per capita *in tons*	Share *in %*	Average per adult *in tons*	Average per capita *in euros*	Threshold per adult *in euros*
Extension 1: Heating emissions to homeowners							
Bottom 50%	1.8	0.4	0.3	2.8	9,420	7,786	-
Middle 40%	13.9	3.6	3.0	36.1	151,819	125,477	60,158
Top 10%	84.4	88.5	73.2	61.1	1,027,827	849,488	401,569
Top 1%	65.5	687.1	567.9	30.7	5,164,367	4,268,297	1,786,318
Top 0.1%	28.7	3,010.7	2,488.3	16.2	27,251,707	22,523,260	7,144,352
Total	100.0	10.5	8.7	100.0	168,220	139,032	-
Extension 2: Account for indirect production emissions*							
Bottom 50%	20.0	6.2	5.1	2.8	9,420	7,786	-
Middle 40%	26.5	10.2	8.5	36.1	151,819	125,477	60,158
Top 10%	53.5	82.7	68.3	61.1	1,027,827	849,488	401,569
Top 1%	37.6	580.9	480.1	30.7	5,164,367	4,268,297	1,786,318
Top 0.1%	16.3	2,518.2	2,081.2	16.2	27,251,707	22,523,260	7,144,352
Total	100.0	15.4	12.8	100.0	168,220	139,032	-

* *Direct emissions attributed based on annual income/Government emissions flatly assigned to individuals.*

Note: The table presents two extensions to the estimated distribution of annual emissions by net wealth group in Germany (2017). Extension (1) attributes emissions from heating and cooling to homeowners instead of counting them as direct household emissions. Extension (2), in addition to government and direct household emissions, takes indirect production emissions (scope 2) into account (i.e., electricity emissions shifted to the use industry) before assigning emissions to the capital stock. Direct emissions are attributed based on individual annual income. Government emissions are flatly assigned to individuals. Extensions (1)-(2) continue to fully attribute production emissions to the owners of the productive capital stock. Net wealth per adult individual estimated from adjusted HFCS survey. Per capita split assumes constant number of children per wealth bracket and equal wealth sharing. Own calculations based on data from Bundesbank, Crippa et al. (2020), Destatis, Eurostat, Forbes, HFCS, Nardo et al. (2017), WIL, and WIOD (2015).

2.5.3 Results under partial attribution to capital stock owners

The partial attribution scenario developed in this section addresses the concern that fully assigning production-based emissions to the owners of the capital stock was arguably a drastic decision. As the opposite pole to the current debate, which gravitates towards shifting the responsibility for emissions to final demand, the full attribution scenario was an illuminating starting point. How large are emission inequalities if we zoom in on who owns the capital that supports the productive and emission-inducing processes in the economy? The full attribution scenario in 2.5.1 allowed us to answer that question. Particularly when it comes to the practical matters of taxing carbon emissions, a less extreme split between consumers and the owners of the productive capital stock needs to be found, however.

One potential strategy to split the annual emissions in a non-arbitrary way between consumers and the owners of the capital stock would be to focus on the use of each industry's output. If production is used to expand or replace the capital stock (i.e., for investment), the associated emissions can be assigned to capital owners. Conversely, if production ends up supporting final consumption, emissions can be assigned to either households or the government. To implement the idea, I need to calculate the emissions associated with gross fixed capital formation per industry. In other words: What level of annual emissions is necessary to bring about the investment goods demanded globally from each domestic industry in a given year? To make statements about the distribution of total emissions, I also need estimates regarding emissions required to satisfy final consumption demand by households and the government. Note that for final consumption, the data I use allows me to account for all direct and indirect production emissions that occur along the global value chain. For instance, if consumers in France consume goods that require carbon-intensive inputs from abroad, these emissions are considered. For investment goods, on the other hand, I stick to the production-centered approach. This is consistent with the view held in the entire treatise that wealth holders are responsible for emissions that occur in the corporations they own. As noted earlier, it also allows me to circumvent the dilemma of either choosing a consumption or production perspective on emissions.[76]

Implementing the partial attribution scenario requires me to return to the multi-regional input-output framework introduced in the previous section. First, I estimate the emissions linked to global final demand by means of the Leontief inverse and the vector of emission by industry and country. Appendix A.4 presents the steps in more detail. The result is a matrix E with 2464 rows (44 countries[77] $\times$ 56 industries) and 220 columns (44 countries $\times$ 5 final demand categories), which allocates 100% of industry emissions to either domestic or foreign final demand. Next,

[76] A conceptually different approach would be to assign to the capital stock of a given country the emissions associated with the totality of investment goods *demanded in the country*, regardless of where they were produced – and not the emissions associated with the *globally demanded* investment goods produced by industries in the country, as we do. The first perspective appears to be the one taken by Södersten et al. (2018a). This, however, would force us to entirely switch to a consumption perspective on emissions, which is difficult to reconcile with the production(-capital stock) view taken in the previous sections. Furthermore, to the best of my knowledge, it is not possible to infer from multi-regional input-output systems to which domestic industry the domestically demanded (but foreign-produced) investment goods flow.

[77] 43 individual countries and one *rest of the world* category.

Table 12: Annual emission split based on final demand (in %, 2017)

	France	Germany
Households *Final consumption & direct emissions*	76.8	73.6
Government *Final consumption*	10.2	8.0
Capital stock owners *Gross fixed capital formation*	13.0	18.4

Note: Annual emissions split between households, the government, and capital owners based on direct and indirect emissions required to satisfy final demand. Capital owners are assigned the emissions related to globally demanded capital goods from owned industries. Total emissions change relative to those recorded in Table A.1-A.2 because indirect emissions from final consumption are included. Assignment based on the E matrix derived from the WIOD (2015) multi-regional input-output system in combination with Corsatea et al. (2019) emissions data. See Appendix A.4 and Table A.14 for more details. Based on data from Corsatea et al. (2019), Eurostat and WIOD (2015).

I extract from E, for each industry in France and Germany, the emissions associated with the globally demanded investment goods it produced. These emissions are then allocated to capital owners based on the methodology I developed earlier. Naturally, owning 100% of the capital stock now comes with a lower responsibility in terms of emissions as a large fraction of global emissions is shifted to consumers and governments.

Importantly, remember from the previous section that the last inter-industry linkages available in the World Input-Output Database (WIOD) are for 2014. I am therefore forced to assume that the structure of global production chains did not change between 2014 and 2017. Furthermore, to calculate the investment shares, I rely on the emissions data provided by Corsatea et al. (2019) because it is aligned with the 44 countries and 56 industries recorded in the WIOD database. To keep the partial attribution scenario comparable to my earlier results, I subsequently return to the Eurostat emission data from air emission accounts. I use asset-industry-country-year-specific adjustment factors to account for the changes induced by the input-output system. I also aggregate the more granular industry groupings in the input-output tables to match the 21 industries used earlier.

Table 12 presents, for France and Germany, the split between investment-related emissions (assigned to capital stock owners) and emissions linked to final consumption by households or the government. The picture looks quite similar in France and Germany. The bulk of emissions is linked to household and government consumption, 87% in France and 81.6% in Germany. Capital owners are assigned a larger share of emissions in Germany. Without considering cross-border ownership, total emissions in 2017 increase through this procedure because indirect emissions related to final household and government consumption are now taken into account.[78] For France, we observe an increase by 14.3% from 473.3 to 540.8 million tons of CO2 equivalents. In Germany, emissions increase by 3.1% from 945.6 to 975.2 million tons. Once we then account for cross-border

[78]Compare Table A.8 to Table A.12 for France and Table A.9 to Table A.13 for Germany.

ownership, we obtain the emission aggregates depicted in Figure 8. In the Appendix, Table A.14 presents the detailed investment shares by industry as well as how full attribution emissions relate to partial attribution emissions on the industry level.

We can now turn to the distribution of emissions by wealth under the partial attribution scenario. Figure 12 and Figure 13 present annual emissions by wealth level in France and Germany in 2017 when only an investment-based fraction of production emissions is attributed to capital stock owners. As we would expect, the *share* of wealth-related emissions attributed to each wealth group does not change compared to the full attribution scenario. In 2017, the bottom 50% of wealth holders continue to be responsible for 1.9% of wealth-related emissions in France and 1.1% in Germany. Similarly, the emission share of the top 1% stands at 47.9% in France and 70.2% in Germany. Attributing only a fraction of the previously determined production emissions does not impact group shares. Where we do see changes is when it comes to the actual emissions associated with these shares. As one can see in the upper panel of Table 13 and Table 14, the average annual wealth-related emissions of the bottom 50% drop to zero in both France and Germany. On the other hand, the average adult among the wealthiest 10% continues to be responsible for 8.0 tons in France and 20.2 tons in Germany per year – merely through the holding of wealth and abstracting from any consumption activity. Wealth-related emissions of the average adult among the wealthiest 0.1% reach 181.1 tons in France and 703.4 tons in Germany. These orders of magnitude remain sizeable. Remember that per capita emissions in 2017 stood at 7.3 tons of CO2eq in France and 11.4 tons in Germany.[79]

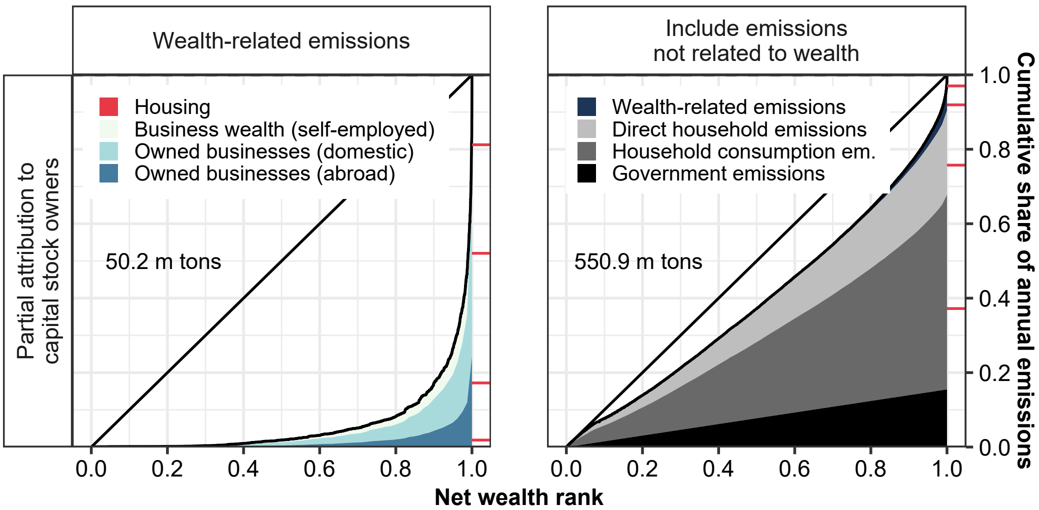
Next, let us include emissions not related to wealth. These consist of direct household emissions, emissions related to final demand of households and the government, and the emissions linked to the capital stock owned by the government. As before, I apply the same technique to split these emissions among individuals. Consumption and direct household emissions are assigned based on individualized income in 2017, as recorded in the wealth survey. Government emissions are allocated flatly to all individuals. The results are presented in the right panel of Figures 12-13 and in the bottom panel of Tables 13-14. Arguably, this is the most comprehensive of my results. It (i) takes into account all emissions, wealth-related and non-wealth-related, and (ii) makes capital stock owners only responsible for a fraction of production emissions. As the bulk of emissions is now assigned to consumers, the emission share of the bottom 50% of wealth holders increases strongly – to 37.2% in France and 31.4% in Germany. Average per capita emissions in tons of the bottom 50% are now close to the population average.

However, significant inequalities persist, driven by wealth-related emissions. With 43.8 tons per year in Germany and 24.3 tons in France, the average adult among the wealthiest 10% is responsible for 3.3 times the emissions of the average adult in the bottom 50% in France and 4.7 times in Germany. This amounts to an emission share of the top 10% of 24.3% in France and 29.7% in Germany, clearly above the population share of 10%. Note that these estimates rely on assumptions that likely produce a conservative estimate of emission inequality. There

[79]Total national emissions in Eurostat air emission accounts (as, for example, in Tables A.1-A.2) divided by the total population.

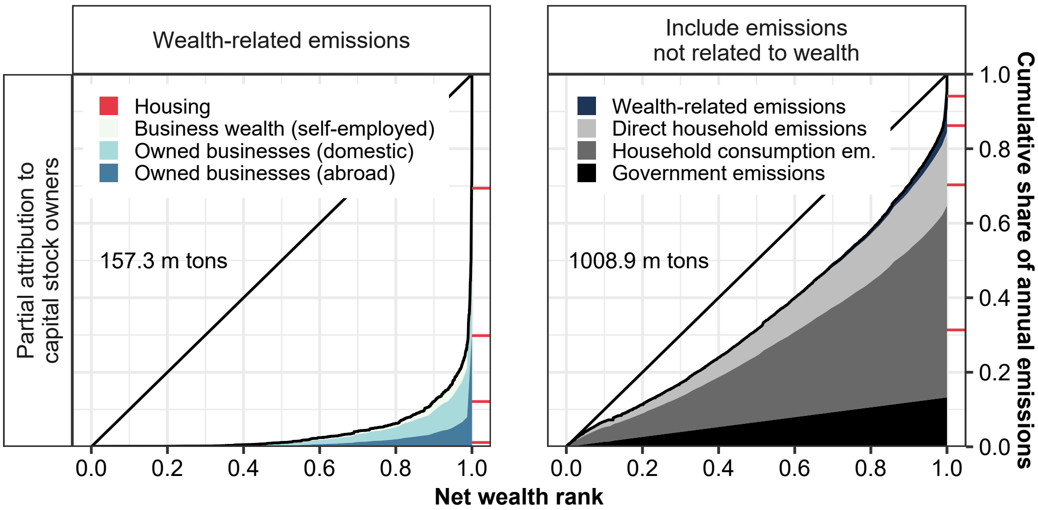
is reason to believe that the consumption of wealthier individuals is more carbon-intensive per euro spent while we split consumption-related emissions purely based on the income distribution. Nonetheless, it is clear that while wealth-related emissions are distributed more unequally than wealth itself, this can not be true for the entirety of emissions if only a fraction is attributed to capital stock owners. As can be seen in Figures 14 and 15, wealth-related emissions continue to be the dominant source of emissions for high-wealth individuals. After discussing the results and the potentially remaining methodological weaknesses in more detail in 2.5.4, I show how these properties render progressive even a per-ton tax on carbon wealth.

Figure 12: Distribution of emissions by net wealth in France (2017)



Note: The figure presents the estimated distribution of annual emissions by net wealth rank in France under the partial attribution scenario (2017). Top 0.1%, top 1%, top 10%, and bottom 50% shares can be deduced from the red lines. Partial attribution only attributes emissions necessary to satisfy global investment demand by industry to capital stock owners. The left panel includes only emissions attributed to resident household wealth. The right panel includes final household and government consumption emissions, direct household emissions, and emissions linked to the capital stock owned by the government. See note below Table 13 for more definitional details. Own calculations based on data from Crippa et al. (2020), Eurostat, Forbes, HFCS, Insee, Nardo et al. (2017), WIL, and WIOD (2015).

Figure 13: Distribution of emissions by net wealth in Germany (2017)



Note: The figure presents the estimated distribution of annual emissions by net wealth rank in Germany under the partial attribution scenario (2017). Top 0.1%, top 1%, top 10%, and bottom 50% shares can be deduced from the red lines. Partial attribution only attributes emissions necessary to satisfy global investment demand by industry to capital stock owners. The left panel includes only emissions attributed to resident household wealth. The right panel includes final household and government consumption emissions, direct household emissions, and emissions linked to the capital stock owned by the government. See note below Table 14 for more definitional details. Own calculations based on data from Crippa et al. (2020), Eurostat, Forbes, HFCS, Insee, Nardo et al. (2017), WIL, and WIOD (2015).

Table 13: Annual emissions by net wealth group in France (2017)

	Emissions			Net wealth			
	Share *in %*	Average per adult *in tons*	Average per capita *in tons*	Share *in %*	Average per adult *in tons*	Average per capita *in euros*	Threshold per adult *in euros*
Partial attribution							
Bottom 50%	1.9	0.0	0.0	4.9	21,497	17,217	-
Middle 40%	15.3	0.4	0.3	39.8	218,265	174,802	117,842
Top 10%	82.8	8.0	6.4	55.3	1,213,072	971,515	574,610
Top 1%	47.9	46.1	37.0	23.3	5,111,137	4,093,364	2,344,372
Top 0.1%	18.8	181.1	145.1	10.0	21,936,210	17,568,085	9,410,840
Total	100.0	1.0	0.8	100.0	219,362	175,681	-
Partial attribution incl. emissions not related to wealth							
Bottom 50%	37.2	7.9	6.3	4.9	21,497	17,217	-
Middle 40%	38.5	10.2	8.2	39.8	218,265	174,802	117,842
Top 10%	24.3	25.7	20.6	55.3	1,213,072	971,515	574,610
Top 1%	8.1	85.7	68.6	23.3	5,111,137	4,093,364	2,344,372
Top 0.1%	3.0	317.4	254.2	10.0	21,936,210	17,568,085	9,410,840
Total	100.0	10.6	8.5	100.0	219,362	175,681	-

Note: The table presents the estimated distribution of annual emissions by net wealth group in France under the partial attribution scenario (2017). Partial attribution only attributes emissions necessary to satisfy global investment demand by industry to capital stock owners. Includes (excludes) emissions associated with domestically (foreign) owned foreign (domestic) capital stock. The upper panel includes only emissions attributed to resident household wealth. The bottom panel includes (i) the direct and indirect emissions necessary to satisfy final consumption of households and the government, (ii) direct household emissions, and (iii) emissions linked to the capital stock owned by the government. Direct and household consumption emissions are attributed based on individual annual income. Government emissions are flatly assigned to individuals. See Figure 8 for emission aggregates. Net wealth per adult individual estimated from adjusted HFCS survey. Per capita split assumes constant number of children per wealth bracket and equal wealth sharing. Own calculations based on data from Crippa et al. (2020), Eurostat, Forbes, HFCS, Insee, Nardo et al. (2017), WIL, and WIOD (2015).

Table 14: Annual emissions by net wealth group in Germany (2017)

	Emissions			Net wealth			
	Share *in %*	Average per adult *in tons*	Average per capita *in tons*	Share *in %*	Average per adult *in tons*	Average per capita *in euros*	Threshold per adult *in euros*
Partial attribution							
Bottom 50%	1.2	0.1	0.0	2.8	9,420	7,786	-
Middle 40%	11.0	0.6	0.5	36.1	151,819	125,477	60,158
Top 10%	87.9	20.2	16.7	61.1	1,027,827	849,488	401,569
Top 1%	70.2	161.4	133.4	30.7	5,164,367	4,268,297	1,786,318
Top 0.1%	30.6	703.4	581.3	16.2	27,251,707	22,523,260	7,144,352
Total	100.0	2.3	1.9	100.0	168,220	139,032	-
Partial attribution incl. emissions not related to wealth							
Bottom 50%	31.4	9.3	7.7	2.8	9,420	7,786	-
Middle 40%	38.9	14.3	11.9	36.1	151,819	125,477	60,158
Top 10%	29.7	43.8	36.2	61.1	1,027,827	849,488	401,569
Top 1%	13.8	203.5	168.2	30.7	5,164,367	4,268,297	1,786,318
Top 0.1%	5.9	869.9	718.9	16.2	27,251,707	22,523,260	7,144,352
Total	100.0	14.7	12.2	100.0	168,220	139,032	-

Note: The table presents the estimated distribution of annual emissions by net wealth group in Germany under the partial attribution scenario (2017). Partial attribution only attributes emissions necessary to satisfy global investment demand by industry to capital stock owners. Includes (excludes) emissions associated with domestically (foreign) owned foreign (domestic) capital stock. The upper panel includes only emissions attributed to resident household wealth. The bottom panel includes (i) the direct and indirect emissions necessary to satisfy final consumption of households and the government, (ii) direct household emissions, and (iii) emissions linked to the capital stock owned by the government. Direct and household consumption emissions are attributed based on individual annual income. Government emissions are flatly assigned to individuals. See Figure 8 for emission aggregates. Net wealth per adult individual estimated from adjusted HFCS survey. Per capita split assumes constant number of children per wealth bracket and equal wealth sharing. Own calculations based on data from Bundesbank, Corsatea et al. (2019), Crippa et al. (2020), Destatis, Eurostat, Forbes, HFCS, Nardo et al. (2017), WIL, and WIOD (2015).

2.5.4 Discussion

In this section, I summarize what the different scenarios in Sections 2.5.1-2.5.3 have taught us about the distribution of carbon wealth. Then, I put my results into perspective and discuss ways to improve them further in the future.

What have we learned so far about the distribution of carbon wealth? First, if one makes wealth holders responsible for the emissions linked to the production processes they implicitly control, these wealth-related emissions are even more concentrated at the very top than wealth itself. The prime reason is that the type of assets owned by the bottom 90% – mostly housing and deposits – have a low or zero carbon intensity. Second, wealth-related emissions are more concentrated in Germany than in France because both wealth inequality and the emission intensity of the capital stock are higher in Germany. Third, the inequalities largely persist if we make homeowners responsible for heating emissions and if we account for indirect production emissions. Fourth, if we only assign to wealth holders the fraction of emissions related to the expansion and maintenance of the capital stock, the high concentration of wealth continues to make the life of an average top 10% wealth holder 3-5 times more carbon-intensive than that of an average adult in the bottom 50% of the wealth distribution. Strikingly, wealth-related emissions of the average top 10% wealth holder alone exceed the total emissions (including direct and indirect emissions from consumption) of the average low-wealth individual in the bottom 50% in both France and Germany. The last point visualized in Figure 14 and Figure 15, which present average per adult emissions by wealth group under the partial attribution scenario. Wealth-related emissions are the dominant form of emissions at the top of the wealth distribution, and these emissions are of a sizeable magnitude compared to average annual per adult emissions in the economy, represented by the dashed lines. These observations anticipate that wealth-related emissions have the potential to become a meaningful tax base – a point that is ventilated in more detail in Section 3.3.

Before moving on, let us put the results we obtained into perspective by comparing them to what can be found elsewhere in the literature. Unfortunately, estimating and studying the within-country distribution of wealth-related emissions is a rather novel topic. Existing studies about emission inequality introduced in Section 2.2 (Weber and Matthews, 2008; Kerkhof et al., 2009; Chancel and Piketty, 2015; Gore, 2015; Wiedenhofer et al., 2016; Sommer and Kratena, 2017; Chancel, 2020; Gore, 2020) can be broadly characterized by three attributes. First, most of them are concerned with consumption-related emissions and therefore do not consider wealth-related emissions separately. They redirect all emissions, including investment-related emissions, to consumers arguing that "these emissions ultimately serve households' actual final consumption." (Chancel and Piketty, 2015, p.27) As noted earlier, such a consumption perspective makes emissions of high-wealth individuals fully dependent on their consumption choices while abstracting from their control over polluting production processes. Second, distributional brackets in these studies are based on income rather than wealth. Without individual-level data on the nature of consumption choices, this strand of the literature furthermore relies on estimates regarding the elasticity between income, consumption, and emissions. Gore (2015) and Gore

Table 15: Emission-net wealth elasticity (2017)

	France	Germany
Bottom 50%	0.03	0.07
Middle 40%	1.57	1.49
Top 10%	0.78	0.63
Total	0.96	0.85

Note: The table presents the estimated elasticity of annual wealth-related emissions in tons with regard to net wealth in France and Germany in 2017, implied by the results presented in 2.5. Based on a simple log-log regression within the respective net wealth group. Net wealth per adult individual estimated from adjusted HFCS survey. Own calculations based on data from Bundesbank, Crippa et al. (2020), Destatis, Eurostat, Forbes, HFCS, Nardo et al. (2017), and WIL.

(2020) assume a globally constant unitary emission-consumption elasticity of one.[80] Chancel and Piketty (2015) presents results for three elasticities between 0.7-1.1, making reference to Chakravarty et al. (2009). To this day, reliable and fully convincing estimates of the emission elasticity are lacking. To link my analysis to these debates (Caron and Fally, 2018; Sager, 2019), I briefly present the elasticity of wealth-related emissions with regard to wealth that is implied by my results in Table 15. I obtain an elasticity of 0.95 for France and 0.85 for Germany.[81] Third, influential contributions to the literature take a global perspective (Chancel and Piketty, 2015; Gore, 2020), rather than looking at within-country inequalities. While this allows them to make statements about the emission share of the global 1%, these results are not suited to inform the national policy debate regarding the taxation of emissions. The studies that consider individual countries do not look at France and Germany but focus on China (Wiedenhofer et al., 2016), India (Shoibal Chakravarty, 2011), the United States (Weber and Matthews, 2008) or the European Union as a whole (Sommer and Kratena, 2017). This brief overview of the three characteristics was aimed at illustrating why I cannot compare the results obtained by most existing studies to my results.

The Greenpeace (2020) policy paper prepared by the environmental advocacy group in conjunction with the private consulting firm Carbone 4 is an exception and arguable the study most closely related to what I do. It presents the distribution of annual emissions related to financial assets in France for the year 2015 and proposes a wealth tax on the basis of these estimates. Unfortunately, despite the similar-sounding research question, several methodological differences make it difficult to compare my 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 simply adds up the emissions implied by multiplying gross wealth with the corresponding emission elasticities of individual financial asset classes produced by Carbone 4. As a result, the authors attribute 312 million tons of CO2 equivalents to wealth holders – significantly more than under

[80] See page 3 of the technical report accompanying Gore (2015). Note that this corresponds to how I allocate non-wealth-related emissions in my figures.

[81] Note that there is considerable variation. As we would expect, if wealth increases by 1%, the percentage increase in wealth-related emissions is low in the bottom 50%.

my partial attribution scenario and significantly less than under my full attribution scenario. Second, the authors present their distributional analysis based on brackets of household disposable income, while I use net wealth per adult. As wealth is more concentrated than income, I cannot compare their top 1% share in wealth-related emissions of 17.7%[82] to my share of 48.0%. Even if I turn to gross household income instead of net wealth per adult,[83] my method suggests a higher top 1% share in wealth-related emissions of 24.8% in France. The third major difference can explain this remaining gap. The Greenpeace (2020) paper does attribute emissions to financial wealth, independently of whether it constitutes a claim on parts of the productive capital stock. For example, keeping 1,000 euros in a checking account for one year is associated with 0.2 tons of emissions.[84] This is different from my conceptual approach that only makes wealth holders responsible for emissions that occur in the production processes they implicitly control and hence, for example, does not assign any emissions to a person holding deposits. Because we know that low and medium wealth individuals own mostly deposits and housing wealth – and we know that housing wealth has a low carbon intensity – it is not surprising that (Greenpeace, 2020) assigns a larger share of wealth-related emissions to the bottom 90%. No arguments are provided, however, why creditors of banks (i.e., holders of deposits) should be made responsible for carbon emissions. Neither do they own parts of the capital stock, nor do they have any control over the potential investment decision of the bank.

Before moving to the taxation of carbon wealth, it is warranted to mention again key weak points of my analysis that should be kept in mind. First, and maybe most importantly, the quality of the data on wealth remains limited. In the absence of other sources, I was restricted to using survey data on household wealth. Despite my pedantic attempts to correct each of its shortcomings – and my cross-checks with other data sources on wealth – both the level of wealth at the top and the composition of wealth at the top continue to be poorly measured. Even though the key properties of the asset composition by wealth appear to be robust, any replication study with access to more reliable data on wealth would be welcome. Second, to a lesser extent, the same applies to the capital stock and national balance sheets. Even though improvements have been made in recent years, I have discussed remaining measurement issues in 2.3.1. In particular, more granular data on the capital stock by assets and industries, and about the sectoral ownership of equities, would surely improve the robustness of the results. This applies equally to the correspondence of categories in wealth surveys and national accounts. Third, the reader needs to remember that I do not have information on the industry a given individual in the wealth survey is invested in. Therefore, regarding the corporate capital stock, I can only work with average carbon intensities, assuming that the industries people invest in do not change with wealth. Data on equity holdings by industry and wealth level would be a key source to improve and verify my results. Fourth, one implementable approach to perform a robustness check on my results would be to replicate the analysis for different time periods. While I restricted myself to the year 2017, for which both data on wealth and the capital stock was available to me, the same attribution procedure could be

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

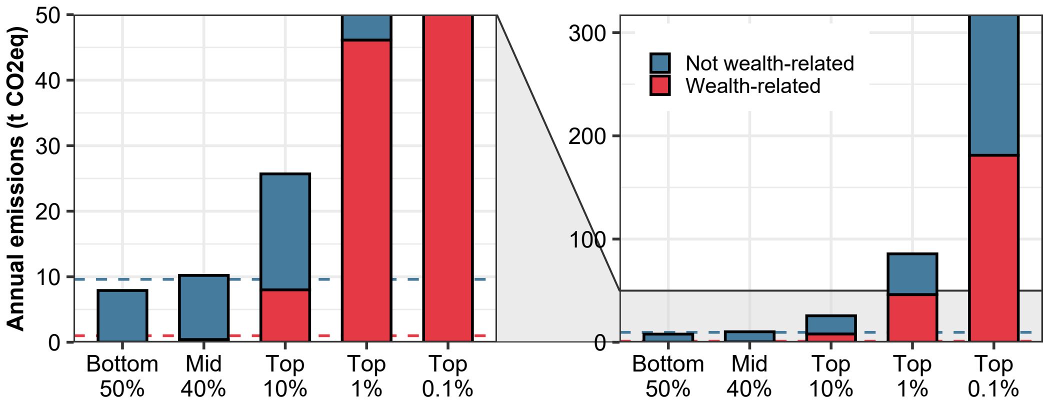
[83] Based on the DI2000 variable in the survey.

[84] See the table on page 24 of Greenpeace (2020).

repeated with earlier waves of the Household Finance and Consumption (HFCS) survey. Apart from adding to the credibility of the results, such an exercise would also allow makeing apparent the trends in the distribution of carbon wealth, which I am unable to study.

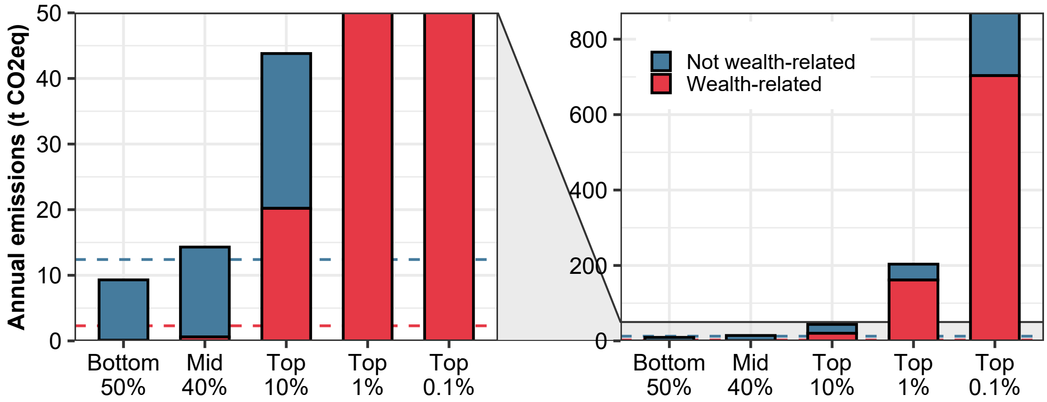
The next chapter builds upon the estimates obtained in 2.5 to present the distributional burden and potential revenue of a per-ton tax on annual wealth-related emissions in France and Germany.

Figure 14: Average per adult emissions by net wealth group in France (2017)



Note: The figure presents the estimated average annual per adult emissions by net wealth group in France (2017) under partial attribution of emissions to capital stock owners. See Table 13 for details. For comparative purposes, emissions not related to household wealth are depicted in blue. These include direct and household consumption emissions, attributed based on individual gross annual income, and government emissions (through final consumption and capital ownership), which are flatly assigned to individuals. The dashed lines represent the average level of emissions. Own calculations based on data from Corsatea et al. (2019), Crippa et al. (2020), Eurostat, Forbes, HFCS, Insee, Nardo et al. (2017), WIL, and WIOD (2015).

Figure 15: Average per adult emissions by net wealth group in Germany (2017)



Note: The figure presents the estimated average annual per adult emissions by net wealth group in Germany (2017) under partial attribution of emissions to capital stock owners. See Table 14 for details. For comparative purposes, emissions not related to household wealth are depicted in blue. These include direct and household consumption emissions, attributed based on individual gross annual income, and government emissions (through final consumption and capital ownership), which are flatly assigned to individuals. The dashed lines represent the average level of emissions. Own calculations based on data from Bundesbank, Corsatea et al. (2019), Crippa et al. (2020), Destatis, Eurostat, Forbes, HFCS, Nardo et al. (2017), WIL, and WIOD (2015).

3 Taxing the Carbon Content of Wealth

3.1 Literature on taxing carbon and wealth

I now present the properties of a potential tax to built upon the carbon wealth estimated and discussed in the preceding steps. Before doing so, I review the literature on the matter. The idea of a tax on wealth-related emissions lies at the intersection of two streams of literature: (i) the literature on carbon taxation, or more broadly, on taxing externalities, (ii) and the literature on the optimal taxation of capital and wealth.

Let us begin with carbon taxation and start by calling to mind the big picture: Why a tax on carbon?[85] Most economists continue considering some form of carbon taxation to be the key tool to address climate change. For example, more than 3,500 economists – among them 28 Nobel Laureates – declared carbon taxation "the most cost-effective lever to reduce carbon emissions" in a joint statement that appeared Wall Street Journal (WSJ) in January 2019 (Akerlof et al., 2019). Earlier but in a similar spirit, a high-level commission convened by the World Bank and chaired by Joseph Stiglitz and Nicholas Stern had called for a "strong" and "well-designed" carbon price (Stiglitz and Stern, 2017). The affection towards carbon taxation is rooted in the work of Artur Pigou. In *Economics of Welfare*, first published one century ago, Pigou introduced the distinction

[85]The fact that human-related greenhouse gas emissions contribute to the heating of the atmosphere and, therefore, need to be controlled is taken as a given and not further discussed. Instead, I focus on why carbon taxation is seen as a tool to address the issue. In 2013, the Intergovernmental Panel on Climate Change (IPCC) maintained that "Scientific evidence for warming of the climate system is unequivocal." See IPCC (2018) for more details on the scientific evidence.

between the marginal social value and the marginal private value. If the marginal private value exceeds the social value, Pigou maintains "there will be certain rates of tax, the imposition of which by the State would increase [...] economic welfare" (Pigou, 1932). To this day, it appears natural to most economists to apply this insight to the social cost of emitting greenhouse gases, which is not reflected in private prices.

The well-known Pigouvian rationale is not the only one possible, though. As I see it, economists can approach carbon taxation from three perspectives: the (i) Pigouvian, (ii) external objective, or the (iii) optimal taxation perspective. First, one can indeed defend a tax on the basis of the classical Pigouvian argument. In that case, releasing carbon into the atmosphere is believed to come with a cost that is not reflected in economic decision-making. The argument's clear-cut application would make the policymaker agnostic as to whether the tax leads to reductions in emissions or an increase in revenue or both, granted the tax per ton is set correctly where the social cost of carbon lies. Furthermore, the revenue generated by the tax is detached from the climate objectives because the price itself entirely removes the externality. In the Pigouvian perspective, determining the social cost of carbon is the key challenge.[86] For one, the damage caused by each additional unit of carbon needs to be estimated empirically. In a second step, the future welfare losses need to be arbitrated against losses in the current generation because environmental damage occurs with a delay. These social discount rates have been debated with particular contention. Existing estimates on the social cost of carbon vary widely: from 7$/tCO2e (Waldhoff et al., 2011) to 31$/tCO2e (Nordhaus, 2017) to well above 100$/tCO2e (Ricke et al., 2018).[87] Pezzey and Burke (2014) claim that, as cited by Pezzey (2019), "future climate damage is, and will very probably remain, unknowable to a high enough degree to justify valuing CO2 emissions inductively."[88] A second rationale for carbon taxation can be to meet emission reduction targets, defined outside any economic framework. If the tax aims to bring about a certain, pre-defined reduction in emissions – or a reduction path over time –, elasticities instead of the social cost of carbon move to the center of the discussion. A weak behavioral response would prescribe a high tax rate, whereas strong behavioral responses render even a lower rate sufficient. Third, environmental taxation can be conceptualized as a tool to raise revenue to finance climate transformation. In that case, the tax does not necessarily need to be tied to climate-damaging behavior. Instead, it would follow the trade-offs behind maximizing tax revenue under behavioral constraints at the heart of any optimal taxation problem, potentially taking into account distributional preferences in the form of social welfare weights. Ideally, a carbon tax manages to unite the three perspectives and (i) make explicit the social cost of carbon, (ii) lead to emission reductions, and (iii) raise revenue to equitably finance the climate transformation.

Several studies have looked at whether and how carbon taxes work from an empirical perspective. Most of them focus on energy-related taxes because fuel combustion is typically responsible for

[86] Edenhofer et al. (2021) provide an excellent review of obstacles to environmental Pigouvian taxation. Banzhaf (2020) adds an interesting historical perspective.

[87] These estimates are directly linked to the debates around social discount rates (Nordhaus, 2007; Stern, 2007).

[88] According to estimates by the IMF, the average global price on carbon stands currently at 2$ per ton (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 ton (Guivarch and Rogelj, 2017).

the overwhelming share of emissions (Marron and Toder, 2014). Andersson (2019) finds that the Swedish carbon tax on transport fuel caused transport emissions to decline by almost 11 percent.[89] Abrell et al. (2021) observe that the UK carbon tax levied on all fossil-fired power plants lowered emissions by 6.2 percent at an average cost of 18 euros per ton. The work by Gugler et al. (2020) on the same matter points in a similar direction. In Scandinavian countries, the adverse role of exemptions from taxation has been highlighted by Bruvoll and Larsen (2004) and Lin and Li (2011). Quite conclusively, the literature shows that tax and price elasticities do not necessarily coincide and that tax elasticities tend to be higher (Baranzini and Weber, 2013; Andersson, 2019). Regarding the broader economy, Metcalf and Stock (2020) do not find negative impacts of carbon taxes on employment and GDP in European countries. Yamazaki (2017) and Bernard et al. (2018) come to similar conclusions studying the carbon tax in British Columbia. These studies somehow contradict theoretical work that suggests a negative, although small, impact of carbon taxation on output and employment (Meng et al., 2013; Goulder and Hafstead, 2018; Goulder et al., 2019; Devulder and Lisack, 2020).[90]

There exists also notable work on the distributional effects of carbon taxation. To a different degree, numerous studies have found those carbon taxes that come in the form of excise taxes to be regressive (Wier et al., 2005; Kolstad and Grainger, 2010; Poterba, 2011; Andersson and Atkinson, 2020). However, the degree of regressivity depends critically on which goods the tax is applied to. Suppose it is levied on heating or electricity expenditure. In that case, it tends to be regressive, whereas the same does not apply to air travel (Zachmann et al., 2018).[91] Furthermore, the final distributional impact depends on how the revenue is used Williams et al. (2015); Klenert and Mattauch (2016); Goulder et al. (2019). Lastly, taking into account the changes in factor prices can make the overall impact of carbon taxes more progressive (Dissou and Siddiqui, 2014).[92] Recently, using the revenue as a tool to mitigate potentially regressive effects and thereby increase acceptability has become a theme in political debates (Carattini et al., 2019).[93]

These reflections lead us to the literature on optimal capital taxation and the taxation of wealth. Just like the literature on the empirics of a carbon tax, the optimal taxation framework has behavioral responses and, since recently, distributional preferences at its heart. The key trade-off is the equity-efficiency one, however, which requires the welfare optimizing policy to arbitrate negative behavioral responses (less output) against more tax revenue in the absence of full information about taxpayers (Edgeworth, 1897; Mirrlees, 1971; Saez, 2001).[94] Optimal taxation has long been applied to capital taxation. Most of the literature considers capital income and

[89] As shown in Figure A.1 in the appendix, the level of carbon taxation in Sweden continues to be among the highest in the world.

[90] See Baranzini and Carattini (2014) for a comprehensive survey of the earlier literature.

[91] As with other excise taxes, the fact that it is still difficult to estimate lifetime consumption makes it difficult to estimate the distributional impact of a comprehensive carbon tax.

[92] Work on the incidence and distributional impact of other carbon pricing tools like emission trading schemes or border adjustment taxes is mostly absent. One exception is Beznoska et al. (2012), whose results suggest a slightly regressive impact of the EU emission trading scheme.

[93] As a result of these other considerations, optimal climate policy quickly turns into a complex problem to find the second-best policy. Even more so on the global level.

[94] It is evident that, without further extensions, this perspective corresponds to the third one mentioned above. A carbon tax solely designed based on optimal taxation principles would maximize revenue, which could be spent

views capital as a homogeneous good with one homogeneous rate of return. Remember that an annual capital income tax is equivalent to a yearly tax on the stock of wealth under these assumptions. The Atkinson-Stiglitz theorem (1976) suggests that with optimal capital markets, no inheritance, and perfectly observable income streams, only labor income should be taxed. The result is the optimality of zero commodity as well as zero capital income taxation. Another important take on capital income taxation by Chamley (1986) and Judd (1985) equally points towards zero capital income taxation in the long run – this time primarily because the long-run elasticity of capital with respect to the tax is infinite.[95] Newer theoretical results come to less extreme conclusions. They find different rationales that could make the optimal capital tax non-zero. Taxing capital can implicitly tax those with higher abilities (Banks et al., 2010). It can encourage people to work more and thereby be part of the optimal social insurance policy if workers face uncertainty about earnings (Farhi and Werning, 2012). Capital taxation can furthermore mitigate borrowing constraints if capital markets are incomplete (Aiyagari, 1995). With inheritances,[96] the optimal taxation of inheritances can be expressed as a function of the total flow of bequests in the economy, the behavioral response to accumulating savings, and the average preference for inheritance (Piketty and Saez, 2013). Recently, Saez and Stantcheva (2016) developed a simple capital taxation model that nonetheless highlights the core trade-offs because it features direct utility in holding wealth and an immediate steady-state in the dynamic setting.

Besides these theoretical results, Piketty et al. (2013) mention additional arguments in favor of capital taxation. First, capital taxation allows taxing income streams comprehensively if the precise boundary between labor and capital income is ill-defined. Second, if income flows are difficult to observe for top wealth holders, do not reflect the actual economic status, or if this group of individuals generally behaves differently from the rest of the economy,[97] a separate tax on high net wealth can be desirable. Third, and finally, taxing the stock of wealth instead of the flow of capital income could increase incentives to generate a high return on capital (Chen et al., 2019). Empirical evaluations of capital taxation highlight the role of tax avoidance and evasion (Zucman, 2014).

The literature review on carbon and capital taxation has revealed at least three points that are of relevance for the following sections. First, to address climate change, carbon taxation remains the policy tool favored by economists; it works but, in its current form, it is mostly regressive or neutral from a distributional perspective. Whether people support the tax depends on its overall distributional impact, including how the revenue is used. Second, economic theory no longer agrees that zero capital taxation is optimal. In recent years, a multitude of arguments – theoretical, empirical, and anecdotal – have emerged that highlight the potentials of capital income and wealth taxation. Taken together, this suggests that more progressive and comprehensive carbon taxes – like a tax on wealth-related emissions – should be explored in order to complement

on climate transformation. I discuss the intersection between optimal taxation and the taxation of externalities further below.

[95] A key issue studied by one branch of this literature is the difference between anticipated and unanticipated reforms as well as the commitment-ability of the government.

[96] Which lets the assumption of life-cycle wealth break down.

[97] See this article published in the New York Times Magazine for anecdotal evidence.

what is currently in place. Finally, the link between the optimal taxation framework and the taxation of externalities remains understudied so that behavioral responses in the optimal taxation continue to be solely regarded as a check on the desired level of taxation.[98] The framework of capital taxation in the presence of multiple assets and heterogeneous rates of return has yet to be extended to fit the context of carbon taxation. This includes understanding better how wealth or capital elasticities translate into real economic outcomes. Studying these intersections between optimal capital taxation and the taxation of externalities theoretically could be a promising undertaking for the future, which, however, is beyond the scope of this project. Nonetheless, in Appendix A.7, I derive the optimal capital tax rate for the case of one carbon-free and one carbon-intensive asset with heterogeneous rates of returns in the spirit of (Saez and Stantcheva, 2016). This could act as a starting point for further theoretical considerations in the future.

3.2 From trade-offs to a potential tax design

I have already highlighted the need for more theoretical work on the intersection between capital and environmental taxation in the previous section and Appendix A.7. However, I want to recall the two arguments that potentially support an annual tax on wealth-related emissions, besides the distributional considerations. First, the incentive argument can explain why owning stocks of wealth rather than deriving profits should be the foundation of the tax. To modify the title of a recent working paper, either the annual emissions necessary for production are used to generate a high enough rate of return to pay the carbon tax, or capital owners lose part of their wealth (Chen et al., 2019). The tax provides an incentive to deploy carbon-intensive capital efficiently. Second, the social cost of carbon. The cost logic implies that the tax should be proportional to the damage inflicted, which is more aligned with the concept of a per-ton tax on carbon wealth than a tax that is a function of profit, revenue, or other derived variables.[99]

I limit myself to demonstrating the potential distributional impact of a per-ton tax on carbon wealth tax and to whether such a tax has the potential to raise meaningful revenue. These considerations remain fairly incomplete as I do not take into account behavioral responses, the tax incidence, and potential tax avoidance, which are crucial in the context of any wealth tax. As we have seen in the previous section, behavioral responses are one rationale to put in place the tax and, in contrast to the classical optimal taxation problem, are not merely an obstacle to raise as much revenue as possible.

Figure 17 and 18 present the relative burden per net wealth of the simplest possible tax design: a unit tax per ton of annual wealth-related emissions in CO2 equivalents. As indicated, the presentation abstracts from behavioral responses and any potential shifting of the tax on other groups. The y-axis presents the effective tax rate on net wealth implied by the per-ton tax on carbon wealth. The left panel applies the tax to the full distribution scenario, which attributes all production emissions to the owners of the capital stock. The right panel refers to the partial

[98] Exceptions include Bovenberg and Goulder (1997), Schmitt (2018), and Barrage (2019).

[99] Exponentially increasing damage functions could potentially rationalize a progressive rate even absent distributional concerns. This is another avenue that could be explored further.

attribution scenario that only assigns a fraction of emissions to capital owners, determined by the emissions necessary to sustain investment. Why do I present both scenarios even though the partial attribution one was deemed more relevant in the previous section? I do not want to predetermine whether the policy would consist of a lower tax rate applied to emissions entirely attributed to capital stock owners or a higher rate on partially attributed emissions. I use four possible prices: 30, 50, 100, and 150 euros per ton. These magnitudes are typically discussed in the context of consumption-based carbon taxation. However, in Figure 16, I also study higher prices of up to 500 euros per ton of CO2 equivalent emissions.

The two figures have one central message: Because emissions are more concentrated at the top than wealth itself, even a flat per-ton tax on wealth-related emissions places a higher effective burden on top wealth holders. Given the effective net wealth tax depicted in Figure 17 and 18 increases with the wealth rank, the per-ton tax on wealth-related emissions effectively works like a progressive tax on net wealth. For the bottom 50%, the effective tax rate on net wealth is essentially zero, regardless of the size of the per-ton levy. Figure 19 and 20 show that the absolute burden on the bottom and medium-ranked wealth holders in terms of euros per year is low as well. Under the partial attribution scenario, the tax liability per year for individuals with net wealth below 100,000 euros remains below 50 euros, even for a per-ton price on carbon wealth of 150 euros. For the average person with a net wealth of around 300,000 euros, the annual tax liability would still lie below 250 euros in Germany and 100 euros in France when faced with a carbon price of 150 euros per ton.

On the other hand, the relative burden increases progressively towards the top of the distribution. For France, a 150 per ton tax on wealth-related emissions would be equivalent to a net wealth tax of around 0.15% for the average top 1% wealth holder under the partial attribution scenario and 0.75% under the full attribution scenario. However, compared to the recently abolished French wealth tax,[100] which is represented by the dashed grey line, the burden of the per-ton tax would increase sooner and remain lower for top wealth holders. Surely, an exemption threshold could quickly alleviate this issue even though the Pigouvian logic of taxing each ton of carbon would vanish in that case. In Germany, the progressive impact of the per-ton tax is visible as well. Yet, due to the greater carbon intensity of the capital stock and higher wealth concentration, the implied burden of the tax on net wealth is higher. A 150 per-ton tax on wealth-related emissions would be equivalent to a net wealth tax of around 0.5% for the average top 1% wealth holder under the partial attribution scenario and of above 2% under the full attribution scenario.

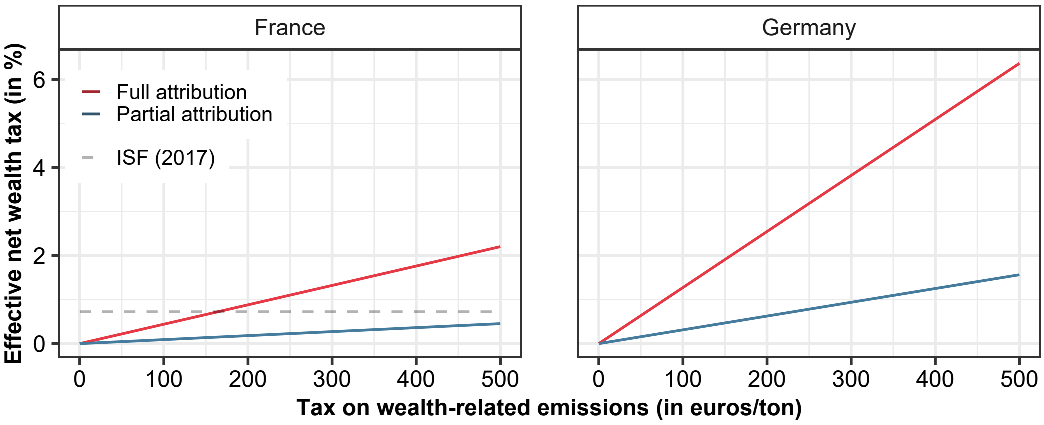
In Figure 21, I zoom in on the top 1% of wealth holders and depict the effective burden of a per-ton tax on carbon wealth for the average member of that group in France and Germany. Two observations can be made. First, for any carbon price, the effective burden is higher in Germany than in France. Second, the carbon price needs to be significantly above 150 euros per ton in the partial attribution scenario to deliver a similar burden as the abolished wealth tax in France.

[100]The *impôt de solidarité sur la fortune* (ISF) has been abolished in 2018 and replaced by a tax on real estate property. It raised around 5 billion euros per year in tax revenue in 2014-2017 (DGFiP).

Under the full attribution scenario, a tax of 200 per ton of annual wealth-related emissions would imply a similar burden as the ISF for the average top 1% wealth holder in France.

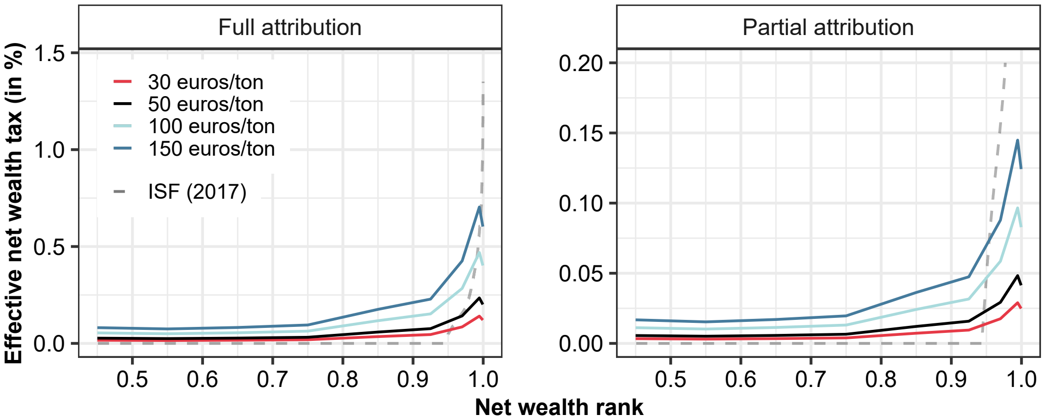
Importantly, the fact that there is some sort of equivalence between a progressive net wealth tax and a per-ton tax on carbon also applies reversely. A progressive net wealth tax would, on average, place a price on wealth-related emissions and thereby assign responsibility for emissions to the group of capital owners.

Figure 16: Implicit relative burden on the average top 1% wealth holder (2017)



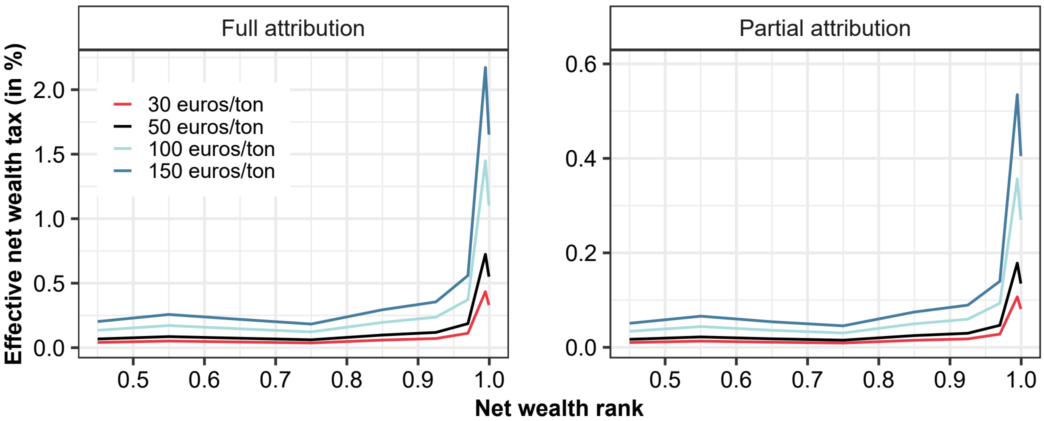
Note: The figure shows the implied effective net wealth tax for the average top 1% wealth holder, depending on the per-ton tax on wealth-related emissions, in France and Germany. For comparative purposes, the corresponding effective tax rate of the French wealth tax (ISF) in 2017 is depicted in grey. Full attribution refers to the initial results in Table 8-9 where all direct production emissions are assigned to the owners of the capital stock. Partial attribution, see Table 13-14, assigns only a fraction of production emissions to the owners of the capital stock, which is determined by the investment share in final demand in an input-output-system. Net wealth per adult individual. Own calculations based on data from Corsatea et al. (2019), Crippa et al. (2020), Destatis, Eurostat, Forbes, HFCS, Insee, Nardo et al. (2017), WIL, and WIOD (2015).

Figure 17: Relative burden of a tax on wealth-related emissions in France (2017)



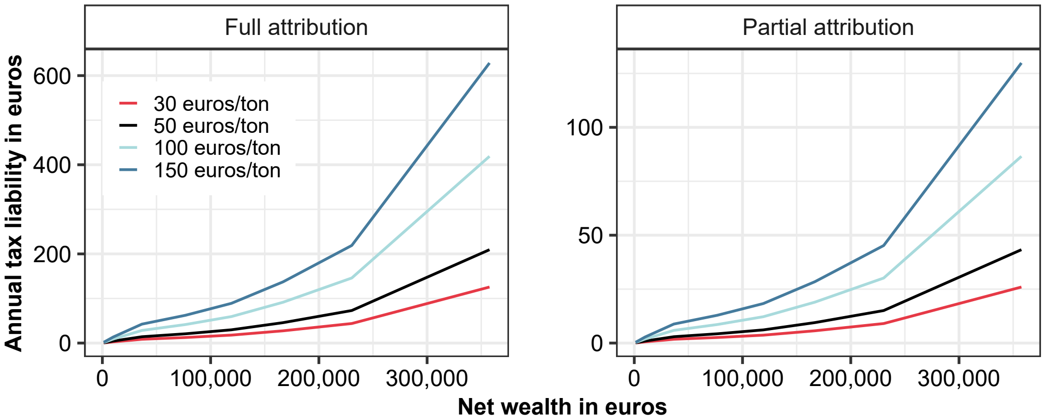
Note: The figure shows the estimated relative burden by net wealth rank of an annual per-ton tax on wealth-related emissions in France (2017). For comparative purposes, the corresponding effective tax rate of the French wealth tax (ISF) in 2017 is depicted in grey. Full attribution refers to the initial results in Table 8 where all direct production emissions are assigned to the owners of the capital stock. Partial attribution, see Table 13, assigns only a fraction of production emissions to the owners of the capital stock, which is determined by the investment share in final demand in an input-output-system. Net wealth per adult individual. Own calculations based on data from Corsatea et al. (2019), Crippa et al. (2020), Eurostat, Forbes, HFCS, Insee, Nardo et al. (2017), WIL, and WIOD (2015).

Figure 18: Relative burden of a tax on wealth-related emissions in Germany (2017)



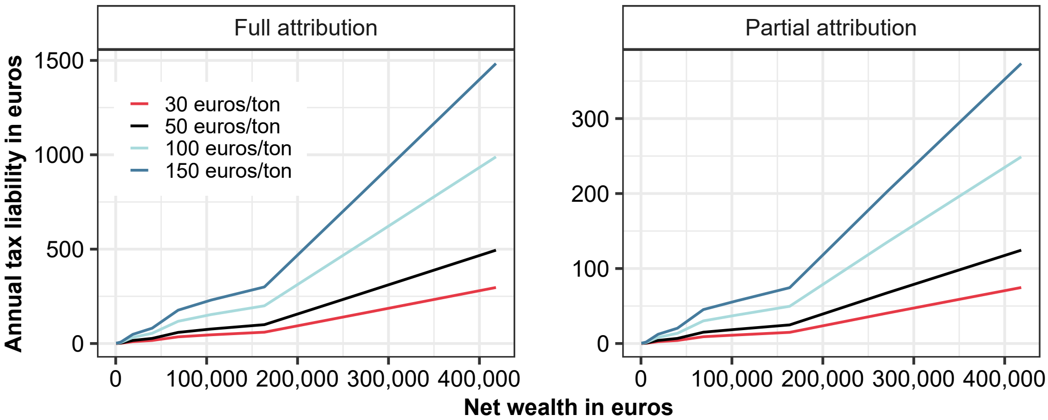
Note: The figure shows the estimated relative burden by net wealth rank of an annual per-ton tax on wealth-related emissions in Germany (2017). Full attribution refers to the initial results in Table 9 where all direct production emissions are assigned to the owners of the capital stock. Partial attribution, see Table 14, assigns only a fraction of production emissions to the owners of the capital stock, which is determined by the investment share in final demand in an input-output-system. Net wealth per adult individual. Own calculations based on data from Bundesbank, Corsatea et al. (2019), Crippa et al. (2020), Destatis, Eurostat, Forbes, HFCS, Nardo et al. (2017), WIL, and WIOD (2015).

Figure 19: Implied tax burden on medium-wealth individuals in France (2017)



Note: The figure shows the estimated absolute burden of an annual per-ton tax on wealth-related emissions on individuals with net wealth below 150,000 euros in France (2017). Full attribution refers to the initial results in Table 8 where all direct production emissions are assigned to the owners of the capital stock. Partial attribution, see Table 13, assigns only a fraction of production emissions to the owners of the capital stock, which is determined by the investment share in final demand in an input-output-system. Net wealth per adult individual. Own calculations based on data from Corsatea et al. (2019), Crippa et al. (2020), Eurostat, Forbes, HFCS, Insee, Nardo et al. (2017), WIL, and WIOD (2015).

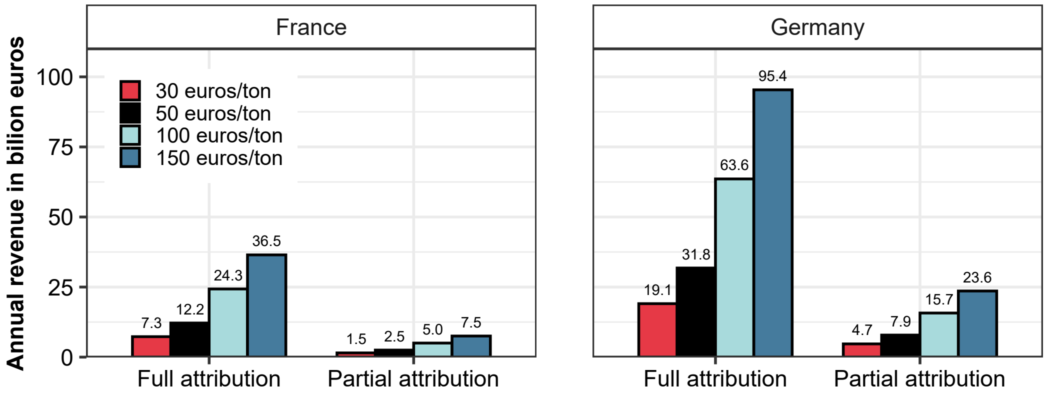
Figure 20: Implied tax burden on medium-wealth individuals in Germany (2017)



Note: The figure shows the estimated absolute burden of an annual per-ton tax on wealth-related emissions on individuals with net wealth below 150,000 euros in Germany (2017). Full attribution refers to the initial results in Table 9 where all direct production emissions are assigned to the owners of the capital stock. Partial attribution, see Table 14, assigns only a fraction of production emissions to the owners of the capital stock, which is determined by the investment share in final demand in an input-output-system. Net wealth per adult individual. Own calculations based on data from Bundesbank, Corsatea et al. (2019), Crippa et al. (2020), Destatis, Eurostat, Forbes, HFCS, Nardo et al. (2017), WIL, and WIOD (2015).

3.3 Preliminary revenue estimates

Figure 21: Revenue estimates for a tax on wealth-related emissions (2017)



Note: The figure presents simple preliminary revenue estimates for four potential per-ton taxes on wealth-related emissions in France and Germany. Full attribution refers to the initial results in Table 8-9 where all direct production emissions are assigned to the owners of the capital stock. Partial attribution, see Table 13-14, assigns only a fraction of production emissions to the owners of the capital stock, which is determined by the investment share in final demand in an input-output-system. Net wealth per adult individual. Own calculations based on data from Corsatea et al. (2019), Crippa et al. (2020), Destatis, Eurostat, Forbes, HFCS, Insee, Nardo et al. (2017), WIL, and WIOD (2015).

What would the depicted per-ton taxes on carbon wealth imply in terms of annual revenue? As we have seen, generating revenue can be one goal of environmental taxation in itself. Figure 21 presents preliminary revenue estimates for France and Germany. Under the full attribution scenario, annual revenues can reach 36.5 billion euros in France and 95.4 in Germany for a price of 150 euros per ton. A price of 30 euros per ton could generate 7.3 billion euros per year in France and 19.1 in Germany. The partial attribution scenario suggests a more modest income for the government. A 30 euros per ton price could generate 1.5 billion euros per year in France and 4.7 billion euros in Germany. On the higher end, revenues could reach 7.5 billion in France – superseding the revenue of the ISF in its last year of existence – and 23.6 in Germany for a price of 150 euros per ton of wealth-related emissions.

These very preliminary results nonetheless allow two conclusions. First, a tax on carbon wealth can generate meaningful revenue. Second, this is only the case either under the full attribution scenario or for pretty high prices per ton of emissions – at least compared to what is politically debated to this day.[101] Remember also that these revenues are an upper bound to the tax revenue. My estimates do not take into account potential behavioral responses, avoidance behavior as well as the fact that, in practice, other taxes would need to be rebated against the carbon tax to avoid double taxation.[102]

[101] Keep in mind the high uncertainty regarding prices and the estimates that project the target-compatible carbon price to reach 8300$ per ton in 2050 (Guivarch and Rogelj, 2017).

[102] These could include taxes already paid by corporations through emission trading or border adjustment schemes.

4 Conclusion

The estimates obtained in this project are insightful. They highlight the role of wealth holders when it comes to equitably targeting emissions with policy measures. I have found wealth-related emissions in France and Germany to be even more concentrated at the very top than wealth itself. The wealth-related emissions of the average top 10% wealth holder exceed total emissions (including direct and indirect emissions from consumption) of the average adult in the bottom 50% in France and Germany. All emissions considered, the life of the average top 10% wealth holder is 3-5 times more carbon-intensive than the average adult in the bottom 50%. In the sections on taxation, I presented a proposal for a per-ton tax on carbon wealth. My preliminary estimates revealed that because wealth-related emissions are more concentrated than wealth, such a tax would be closely related to a progressive tax on net wealth.

Much work remains to be done. My analysis should be repeated with better data on the by-asset distribution of wealth and extended to include more countries and time periods. Behavioral responses, incidence and the already existent carbon taxes should be taken into account before actually proposing to implement the tax on carbon wealth. And finally, the theoretical framework of optimal capital taxation needs 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.

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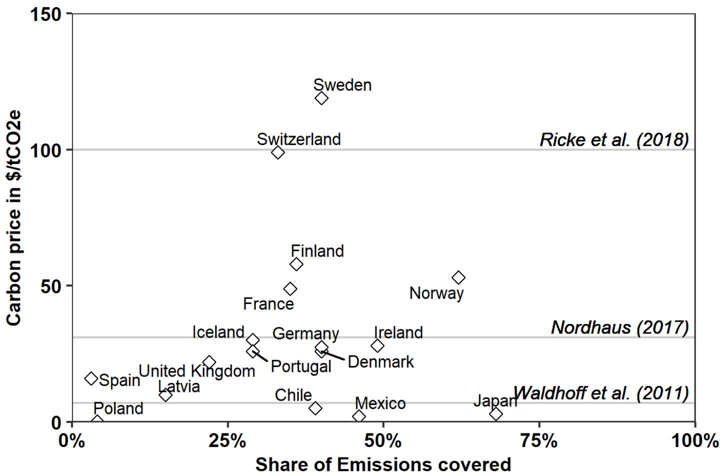
A Appendix

A.1 Carbon taxation in practice

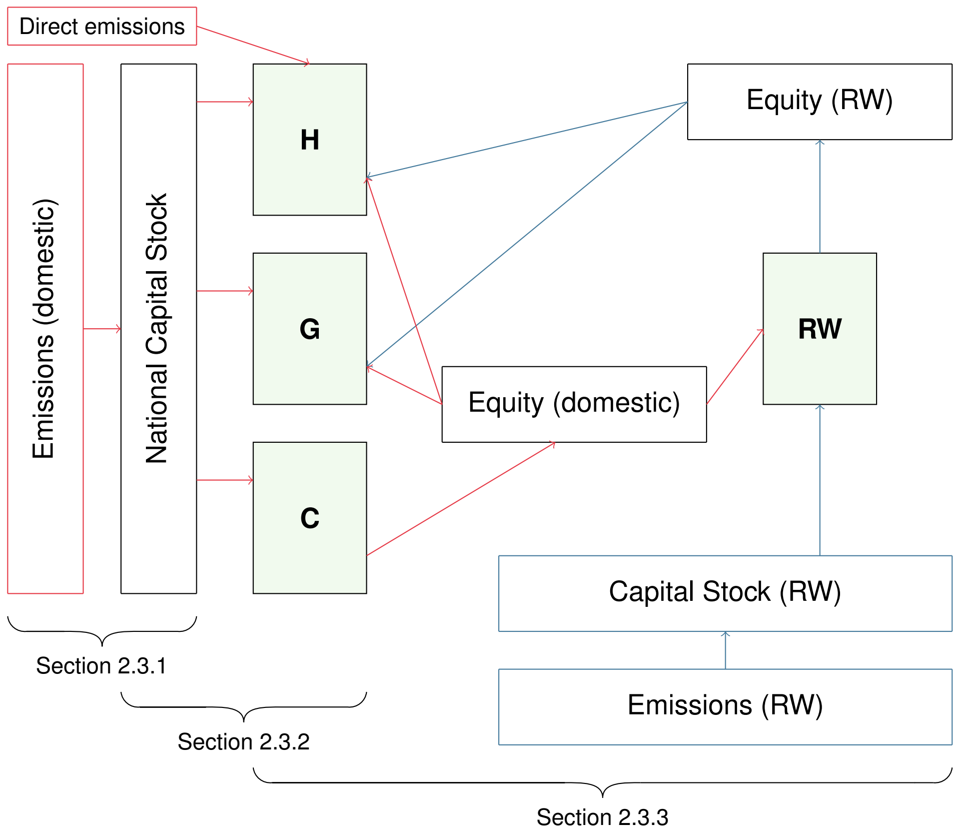
Figure A.1: Selected national carbon prices and their scope compared to recent estimates of the social cost of carbon



Note: Includes nationwide carbon taxes with data availability on prices in 2021. The y-axis depicts the implied price per ton of CO2 equivalent greenhouse (GHG) emissions. The x-axis shows the share of emissions covered by the tax. For the United Kingdom, the figure refers to the cap of the carbon price floor. For Germany, the tax refers to the newly introduced emission trading scheme, which takes the form of a fixed carbon price until 2025. Data Sources: Waldhoff et al. (2011), Nordhaus (2017), Ricke et al. (2018), World Bank (2020).

A.2 Additional material on macro-level emissions

Figure A.2: Attribution of emissions to economic sectors



Note: Schematic illustration of emissions attribution to the capital stock and to sectors in the economy. Arrows depict the flow of emissions in each step of the attribution process. The figure demonstrates how all emissions are ultimately attributed to either the household sector (H), the government (G), or to foreign investors (RW). Equity held by domestic corporations (C) in the corporate sector or abroad is omitted from the figure. See the discussion in Section 2.3 for details.

Table A.1: Capital stock and annual emissions in France (2017) – by industry

	Capital stock		Emissions		Intensity
	b euros	% of total	m tons	% of total	t/m euros
Industry activities	7,648.6	100.0	348.1	100.0	45.5
Agriculture, forestry and fishing	113.4	1.5	89.4	25.7	789.0
Mining and quarrying	15.0	0.2	1.1	0.3	73.8
Manufacturing	336.8	4.4	94.6	27.2	280.9
Electricity, gas, steam and air conditioning supply	136.5	1.8	34.2	9.8	250.6
Water supply; sewerage, waste management and remediation activities	67.3	0.9	24.0	6.9	356.4
Construction	48.4	0.6	9.4	2.7	194.1
Wholesale and retail trade; repair of motor vehicles and motorcycles	109.9	1.4	15.1	4.4	137.8
Transportation and storage	165.7	2.2	44.4	12.8	267.8
Accommodation and food service activities	42.4	0.6	3.2	0.9	76.2
Information and communication	121.2	1.6	1.3	0.4	10.7
Financial and insurance activities	99.3	1.3	1.0	0.3	10.5
Real estate activities	5,031.9	65.8	0.5	0.1	0.1
Professional, scientific and technical activities	172.1	2.3	2.5	0.7	14.6
Administrative and support service activities	78.0	1.0	7.5	2.1	95.7
Public administration and defence; compulsory social security	737.1	9.6	3.4	1.0	4.6
Education	128.6	1.7	5.0	1.4	38.8
Human health and social work activities	134.0	1.8	7.2	2.1	53.6
Arts, entertainment and recreation	96.9	1.3	2.5	0.7	25.3
Other service activities	14.1	0.2	1.7	0.5	119.8
Direct household activities	-	-	125.2	100.0	-
incl. Heating	-	-	45.6	36.4	-
incl. Transport	-	-	73.5	58.7	-
incl. Other household activities	-	-	6.1	4.8	-

Note: Annual greenhouse gas emissions in CO2 equivalents as recorded in air emission accounts. No emissions assigned to (i) the activities of households as employers and to (ii) the activities of international organizations because the non-financial capital stock of these two industries is zero. Capital stock refers to the aggregate net capital stock by year-end as recorded in national accounts. Capital stock excludes land, which is added in Table A.5. Data from Eurostat and Insee.

Table A.2: Capital stock and annual emissions in Germany (2017) – by industry

	Capital stock		Emissions		Intensity
	b euros	% of total	m tons	% of total	t/m euros
Industry activities	10,394.1	100.0	746.8	100.0	71.8
Agriculture, forestry and fishing	157.1	1.5	73.3	9.8	466.6
Mining and quarrying	13.1	0.1	5.8	0.8	440.5
Manufacturing	832.9	8.0	178.0	23.8	213.8
Electricity, gas, steam and air conditioning supply	205.6	2.0	319.3	42.8	1,553.3
Water supply; sewerage, waste management and remediation activities	274.5	2.6	20.1	2.7	73.1
Construction	56.7	0.5	10.3	1.4	182.4
Wholesale and retail trade; repair of motor vehicles and motorcycles	240.5	2.3	17.3	2.3	72.1
Transportation and storage	454.2	4.4	90.2	12.1	198.7
Accommodation and food service activities	56.7	0.5	3.4	0.5	59.6
Information and communication	153.1	1.5	1.7	0.2	11.1
Financial and insurance activities	159.7	1.5	1.7	0.2	10.6
Real estate activities	5,533.0	53.2	0.4	0.0	0.1
Professional, scientific and technical activities	171.1	1.6	4.2	0.6	24.6
Administrative and support service activities	301.1	2.9	1.2	0.2	4.0
Public administration and defence; compulsory social security	743.3	7.2	5.4	0.7	7.3
Education	321.1	3.1	3.4	0.5	10.5
Human health and social work activities	492.9	4.7	6.8	0.9	13.8
Arts, entertainment and recreation	167.9	1.6	1.2	0.2	7.0
Other service activities	59.7	0.6	3.0	0.4	50.7
Direct household activities	-	-	198.8	100.0	-
incl. Heating	-	-	85.1	42.8	-
incl. Transport	-	-	111.1	55.9	-
incl. Other household activities	-	-	2.6	1.3	-

Note: Annual greenhouse gas emissions in CO2 equivalents as recorded in air emission accounts. No emissions assigned to (i) the activities of households as employers and to (ii) the activities of international organizations because the non-financial capital stock of these two industries is zero. Capital stock refers to the aggregate net capital stock by year end as recorded in national accounts. Capital stock excludes land, which is added in Table A.6. Data from Destatis and Eurostat.

Table A.3: Capital stock and annual emissions in France (2017) – by industry and asset type

	Capital stock *in b euros*						Emissions *in m tons*
	Fixed Assets (total)	Dwellings	Other buildings and structures	Machinery and equipment	Cultivated biological resources	Intellectual property products	
Industry activities (total)	7648.6	4524.6	2033.9	662.4	22.1	405.6	348.1
Agriculture, forestry and fishing	113.4	0.0	37.2	51.7	22.1	2.4	89.4
Mining and quarrying	15.0	0.0	9.8	3.8	0.0	1.4	1.1
Manufacturing	336.8	0.0	61.7	124.2	0.0	150.9	94.6
Electricity, gas, steam and air conditioning supply	136.5	0.0	45.3	86.3	0.0	5.0	34.2
Water supply; sewerage, waste management and remediation activities	67.3	0.0	45.1	21.2	0.0	1.0	24.0
Construction	48.4	0.0	27.3	18.2	0.0	2.9	9.4
Wholesale and retail trade; repair of motor vehicles and motorcycles	109.9	0.0	64.8	36.5	0.0	8.6	15.1
Transportation and storage	165.7	0.0	72.2	88.3	0.0	5.2	44.4
Accommodation and food service activities	42.4	0.0	33.3	8.6	0.0	0.5	3.2
Information and communication	121.2	0.0	22.7	32.2	0.0	66.2	1.3
Financial and insurance activities	99.3	0.0	68.4	15.3	0.0	15.6	1.0
Real estate activities	5031.9	4524.6	499.8	6.6	0.0	0.9	0.5
Professional, scientific and technical activities	172.1	0.0	49.5	21.6	0.0	101.1	2.5
Administrative and support service activities	78.0	0.0	8.5	63.2	0.0	6.3	7.5
Public administration and defence; compulsory social security	737.1	0.0	664.1	47.8	0.0	25.1	3.4
Education	128.6	0.0	118.8	6.3	0.0	3.4	5.0
Human health and social work activities	134.0	0.0	107.3	22.8	0.0	3.9	7.2
Arts, entertainment and recreation	96.9	0.0	89.8	5.6	0.0	1.5	2.5
Other service activities	14.1	0.0	8.1	2.3	0.0	3.7	1.7

Note: Matrix used to calculate average asset-specific carbon intensities for France (2017) as presented in Table A.5. Annual greenhouse gas emissions in CO2 equivalents as recorded in air emission accounts. No emissions assigned to (i) the activities of households as employers and to (ii) the activities of international organizations because the non-financial capital stock of these two industries is zero. Capital stock refers to the net capital stock at year-end by asset type in each industry as recorded in national accounts. Capital stock excludes land, which is added in Table A.5. Sub-categories for machinery and intellectual property omitted for better visibility. Based on data from Eurostat and Insee.

Table A.4: Capital stock and annual emissions in Germany (2017) – by industry and asset type

	Capital stock *in b euros*						Emissions *in m tons*
	Fixed Assets (total)	Dwellings	Other buildings and structures	Machinery and equipment	Cultivated biological resources	Intellectual property products	
Industry activities (total)	10394.1	5177.4	3285.2	1351.3	9.8	570.5	746.8
Agriculture, forestry and fishing	157.1	0.0	96.1	49.6	9.8	1.6	73.3
Mining and quarrying	13.1	0.0	2.8	8.1	0.0	2.3	5.8
Manufacturing	832.9	0.0	133.2	351.5	0.0	348.2	178.0
Electricity, gas, steam and air conditioning supply	205.6	0.0	151.3	51.0	0.0	3.3	319.3
Water supply; sewerage, waste management and remediation activities	274.5	0.0	254.0	20.2	0.0	0.3	20.1
Construction	56.7	0.0	25.7	29.5	0.0	1.4	10.3
Wholesale and retail trade; repair of motor vehicles and motorcycles	240.5	0.0	153.5	74.3	0.0	12.7	17.3
Transportation and storage	454.2	0.0	290.8	161.4	0.0	2.0	90.2
Accommodation and food service activities	56.7	0.0	42.3	13.9	0.0	0.5	3.4
Information and communication	153.1	0.0	58.1	52.4	0.0	42.6	1.7
Financial and insurance activities	159.7	0.0	138.1	16.9	0.0	4.7	1.7
Real estate activities	5533.0	5177.4	344.1	11.2	0.0	0.3	0.4
Professional, scientific and technical activities	171.1	0.0	72.5	34.4	0.0	64.2	4.2
Administrative and support service activities	301.1	0.0	41.1	257.8	0.0	2.1	1.2
Public administration and defence; compulsory social security	743.3	0.0	653.9	77.5	0.0	11.9	5.4
Education	321.1	0.0	253.8	20.6	0.0	46.7	3.4
Human health and social work activities	492.9	0.0	376.6	95.9	0.0	20.4	6.8
Arts, entertainment and recreation	167.9	0.0	150.9	12.7	0.0	4.3	1.2
Other service activities	59.7	0.0	46.5	12.3	0.0	0.9	3.0

Note: Matrix used to calculate average asset-specific carbon intensities for Germany (2017) as presented in Table A.6. Annual greenhouse gas emissions in CO2 equivalents as recorded in air emission accounts. No emissions assigned to (i) the activities of households as employers and to (ii) the activities of international organizations because the non-financial capital stock of these two industries is zero. Capital stock refers to the net capital stock at year-end by asset type in each industry as recorded in national accounts. Capital stock excludes land, which is added in Table A.6. Sub-categories for machinery and intellectual property omitted for better visibility. Based on data from Destatis and Eurostat.

Table A.5: Capital stock and annual emissions in France (2017) – by asset type

	Capital stock		Capital stock *incl. land*		Emissions		Intensity
	b euros	% of total	b euros	% of total	m tons	% of total	t/m euros
Fixed Assets	7,648.6	100.0	13,904.4	100.0	348.1	100.0	45.5
Dwellings	4,524.6	59.2	8,271.6	59.5	0.5	0.1	0.1
Other buildings and structures	2,033.9	26.6	4,542.7	32.7	130.2	37.4	64.0
Machinery and equipment	662.4	8.7	662.4	4.8	147.0	42.2	221.9
Transport equipment	154.3	2.0	154.3	1.1	29.8	8.6	193.4
ICT equipment	36.1	0.5	36.1	0.3	4.1	1.2	112.9
Other machinery and equipment	472.0	6.2	472.0	3.4	113.1	32.5	239.5
Cultivated biological resources	22.1	0.3	22.1	0.2	17.4	5.0	789.0
Intellectual property products	405.6	5.3	405.6	2.9	53.0	15.2	130.8
Research and development	240.2	3.1	240.2	1.7	37.9	10.9	157.9
Computer software and databases	159.8	2.1	159.8	1.1	15.1	4.3	94.2
Other intellectual property products	5.7	0.1	5.7	0.0	0.1	0.0	11.0

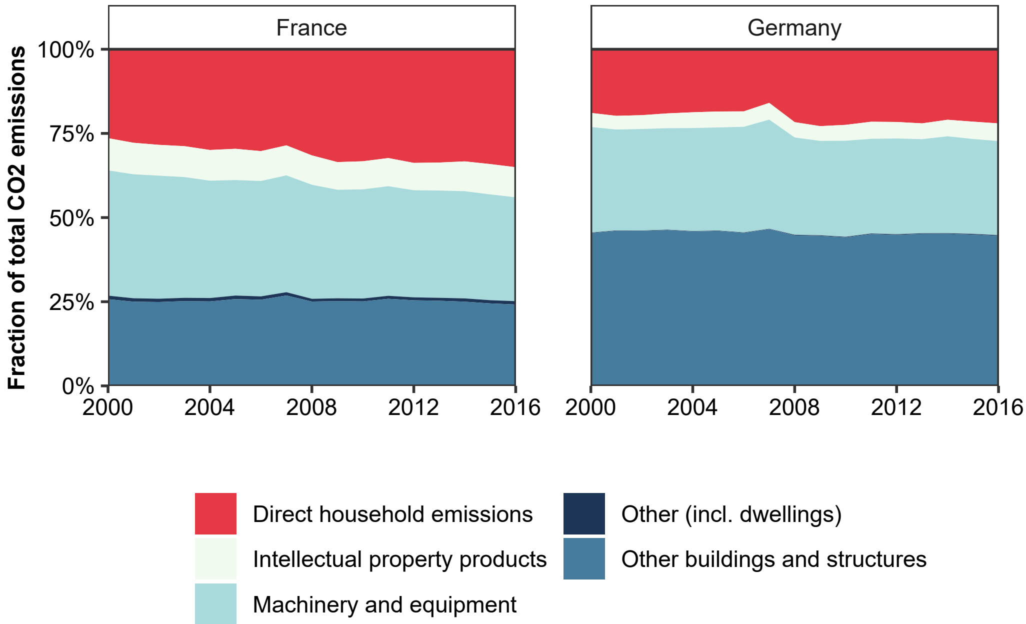
Note: Annual greenhouse gas emissions in CO2 equivalents as recorded in air emission accounts. Emissions assigned through the use of each asset type per industry, based on a more granular version of Table A.3. Emissions exclude direct emissions by households. Capital stock refers to the aggregate net capital stock by year-end as recorded in national accounts. Machinery and equipment includes weapon systems. The intensity column excludes land. Based on data from Eurostat and Insee.

Table A.6: Capital stock and annual emissions in Germany (2017) – by asset type

	Capital stock		Capital stock *incl. land*		Emissions		Intensity
	b euros	% of total	b euros	% of total	m tons	% of total	t/m euros
Fixed Assets	10,394.1	100.0	14,976.1	100.0	746.8	100.0	71.8
Dwellings	5,177.4	49.8	7,868.4	52.5	0.3	0.0	0.1
Other buildings and structures	3,285.2	31.6	5,176.3	34.6	424.3	56.8	129.2
Machinery and equipment	1,351.3	13.0	1,351.3	9.0	231.6	31.0	171.4
Transport equipment	360.1	3.5	360.1	2.4	35.6	4.8	98.9
ICT equipment	68.8	0.7	68.8	0.5	-	-	-
Other machinery and equipment	922.5	8.9	922.5	6.2	190.7	25.5	206.8
Cultivated biological resources	9.8	0.1	9.8	0.1	4.6	0.6	466.6
Intellectual property products	570.5	5.5	570.5	3.8	85.9	11.5	150.6
Research and development	496.3	4.8	496.3	3.3	78.8	10.6	158.8
Computer software and databases	61.1	0.6	61.1	0.4	6.1	0.8	99.4
Other intellectual property products	13.1	0.1	13.1	0.1	1.0	0.1	78.0

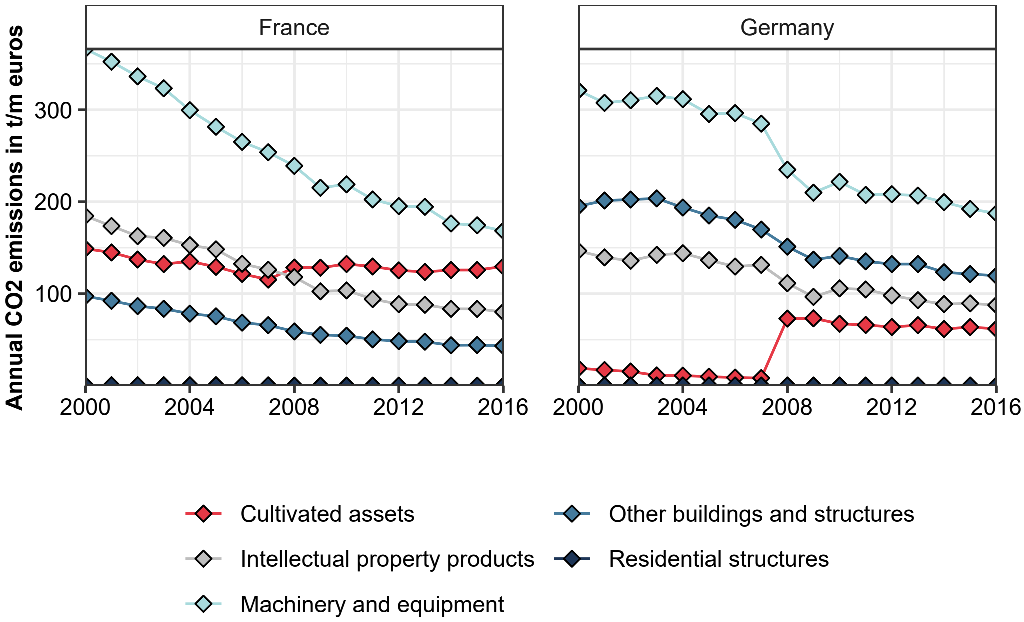
Note: Annual greenhouse gas emissions in CO2 equivalents as recorded in air emission accounts. Emissions assigned through the use of each asset type per industry, based on a more granular version of Table A.4. Emissions exclude direct emissions by households. Capital stock refers to the aggregate net capital stock by year-end as recorded in national accounts. Data on ICT equipment per industry unavailable for Germany. Machinery and equipment includes weapon systems. The intensity column excludes land. Based on data from Destatis and Eurostat.

Figure A.3: CO2 emissions attributed to the capital stock over time (2000-2016)



Note: Includes only CO2 emissions. EU-KLEMS uses slightly different asset and industry categories than those used in the main text. Does not include the value of land. Full attribution of direct production emissions to capital stock owners, see 2.5.1. For an explanation on how emissions were assigned, see Section 2.3.1. Based on capital stock data from EU-KLEMS (2019) and corresponding emission data from Corsatea et al. (2019).

Figure A.4: Emission intensity of capital stock assets over time (2000-2016)



Note: Includes only CO2 emissions. EU-KLEMS uses slightly different asset and industry categories than those used in the main text. Does not include the value of land. Full attribution of direct production emissions to capital stock owners, see 2.5.1. For an explanation on how emissions were assigned, see Section 2.3.1. Based on capital stock data from EU-KLEMS (2019) and corresponding emission data from Corsatea et al. (2019).

Table A.7: Country shares in total inbound investment (2017)

Origin of investment	Share in total investment in %
France	
Luxembourg	18.5
Netherlands	13.5
United Kingdom	11.9
Belgium	11.0
Switzerland and Liechtenstein	9.3
Germany	
Netherlands	30.2
Luxembourg	11.8
United States	9.4
United Kingdom	7.6
France	6.9

Note: The table presents the 5 countries with the highest inbound investment position in France and Germany in 2017. Investment shares refer to the share in foreign direct investment stocks at year-end. France includes Monaco. Based on data from Nardo et al. (2017).

Table A.8: Emissions attributed to capital-owning sectors in France (2017)

Sector/asset type	Direct ownership	Indirect ownership*	
		Resident corporations	Non-resident corporations
Households			
Business buildings and land	11.2	35.6	-
Business capital	49.6	85.0	61.4
Housing	0.4	0.0	-
Government			
Business buildings and land	60.4	12.8	-
Business capital	27.7	30.6	22.1
Housing	0.0	0.0	-
Corporations			
Business buildings and land	58.6	-	-
Business capital	140.1	-	-
Housing	0.1	-	-
Rest of the world			
Business buildings and land	-	10.2	-
Business capital	-	24.5	-
Housing	-	0.0	-
Total	348.1	198.8	83.5
+ Direct household emissions	125.2	-	-

* *Through the ownership of resident and non-resident corporations.*

Note: Annual emissions in million tons of CO2 equivalents. The table presents the result of the three attribution steps detailed in Section 2.3 under the full attribution scenario. Sectors either own parts of the capital stock directly or indirectly through the ownership of corporate equity. The black rectangle represents the emissions allocated to resident wealth-holding households. The red rectangle represents total national residence-based emissions recorded in air emission accounts, excluding direct emissions by households. Each blue rectangle represents the total emissions of resident corporations. Business buildings and land (AN.112), business capital (AN.113-7), and housing (AN.111) aggregated after emission assignment. Housing includes land. Based on data from Crippa et al. (2020), Eurostat, Insee and Nardo et al. (2017).

Table A.9: Emissions attributed to capital-owning sectors in Germany (2017)

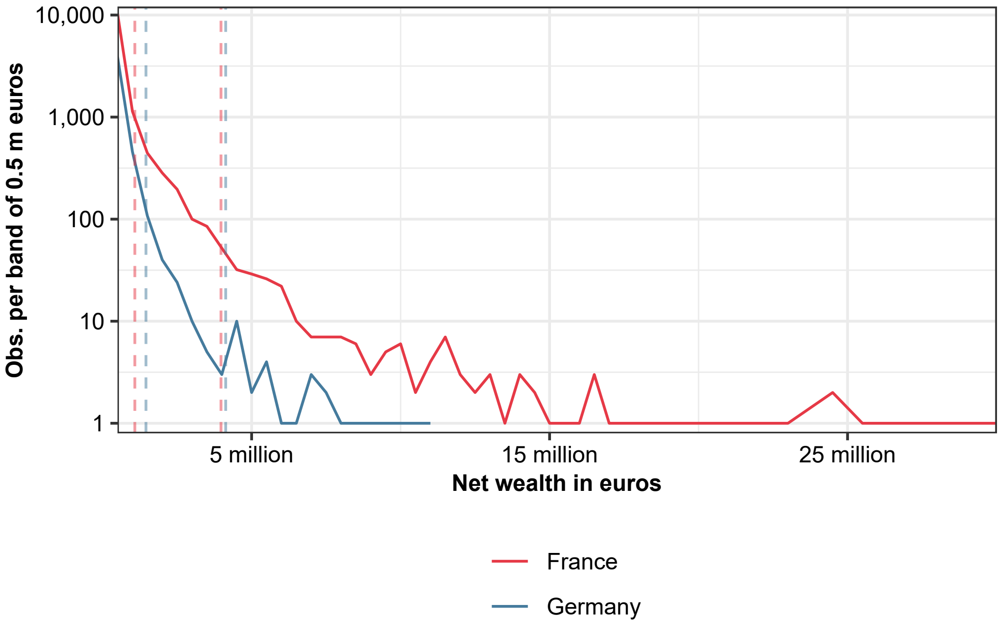
Sector/asset type	Direct ownership	Indirect ownership*	
		Resident corporations	Non-resident corporations
Households			
Business buildings and land	50.0	161.2	-
Business capital	70.7	159.6	194.0
Housing	0.3	0.0	-
Government			
Business buildings and land	150.8	21.0	-
Business capital	30.0	20.8	20.6
Housing	0.0	0.0	-
Corporations			
Business buildings and land	223.6	-	-
Business capital	221.4	-	-
Housing	0.0	-	-
Rest of the world			
Business buildings and land	-	41.4	-
Business capital	-	41.0	-
Housing	-	0.0	-
Total	746.8	445.0	214.6
+ Direct household emissions	198.8	-	-

* *Through the ownership of resident and non-resident corporations.*

Note: Annual emissions in million tons of CO2 equivalents. The table presents the result of the three attribution steps detailed in Section 2.3 under the full attribution scenario. Sectors either own parts of the capital stock directly or indirectly through the ownership of corporate equity. The black rectangle represents the emissions allocated to resident wealth-holding households. The red rectangle represents total national residence-based emissions as recorded in air emission accounts, excluding direct emissions by households. Each blue rectangle represents the total emissions of resident corporations. Business buildings and land (AN.112), business capital (AN.113-7), and housing (AN.111) aggregated after emission assignment. Housing includes land. Based on data from Bundesbank, Crippa et al. (2020), Destatis, Eurostat and Nardo et al. (2017).

A.3 Additional material on household survey wealth

Figure A.5: Decline in observations with increasing wealth level in HFCS



Note: The figure shows the number of unweighted observations in the third wave of the HFCS survey per band of 0.5 million euros in France and Germany. Dashed lines correspond to the 99th and 99.9th percentile of individualized net wealth in the survey. The y-axis is log scaled for better visibility. Based on data from HFCS.

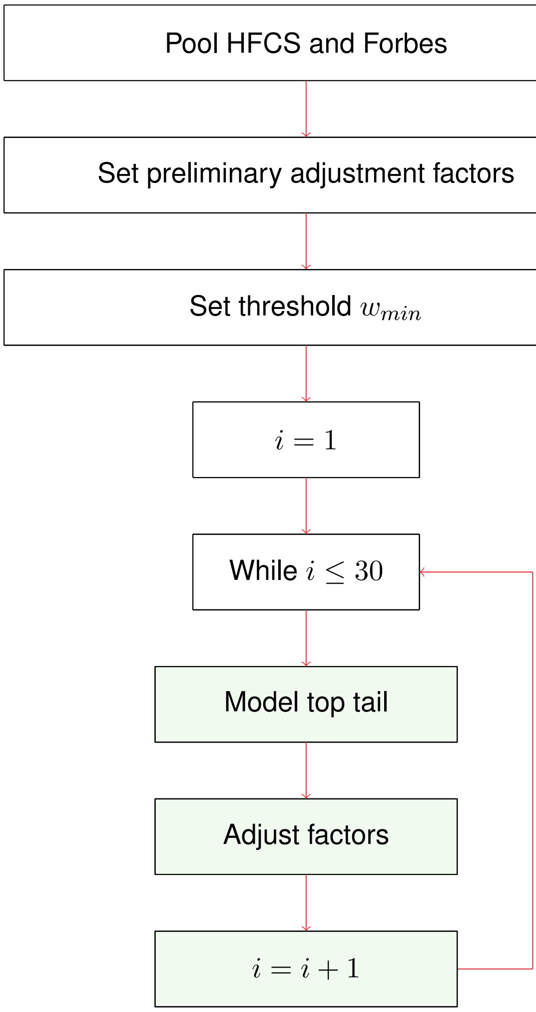
Table A.10: Correspondence of variables in national accounts and the wealth survey

	Corresponding variables	
	National accounts	HFCS
Financial Assets		
Currency and deposits	AF.2	DA2101
Debt securities	AF.3	DA2103
Loans	AF.4	DA2107
Equity and investment funds	AF.5	DA2102 + DA2104 + DA2105 + HD080 if HD040 ≠ (1 OR 2)
Insurance and pension schemes	AF.61 + AF.62	DA2109
Other financial assets	AF.1 + AF.7 + AF.8	DA2106 + DA2108
Real assets/capital stock		
Housing	AN.111*	DA1110 + DA1122 + HB2900
Self-employed business buildings	AN.112*	DA1121
Self-employed business wealth	AN.113 + AN.114 + AN.115 + AN.116 + AN.117	DA1140 - HD080 if HD040 ≠ (1 OR 2)
Liabilities		
Financial liabilities	PF.0	DL1000
Net wealth	B.90 - AN.12 - AN.13 - AN.23 - (AF.6 - AF.61 - AF.62)	DN3001 - DA1130 - DA1131

* *Includes the value of land.*

Note: Correspondence table between variables in national accounts and in the Household Finance and Consumption Survey (HFCS). See Section 2.4.2 further explanations, Eurostat (2013) for a description of each national account variable, and European Central Bank (2020a) for a description of each HFCS variable. The value of land is included in national accounts according to Footnote 32.

Figure A.6: Iterative process to align survey and national account wealth



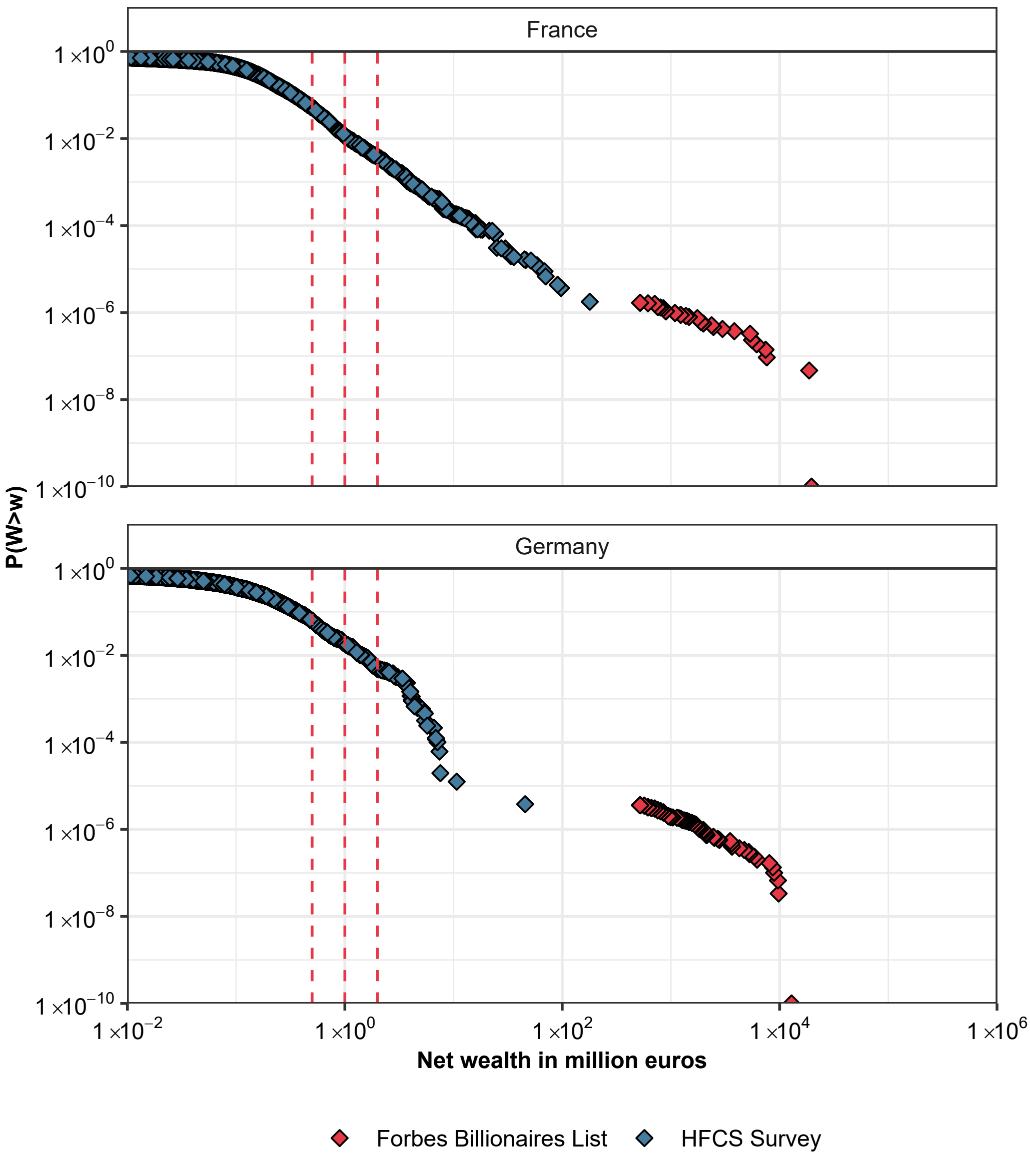
Note: Schematic illustration of the iterative process suggested by Vermeulen (2016) to align wealth in surveys with national account aggregates in the presence of underreporting. Process implemented in Section 2.4.3 and 2.4.4.

Table A.11: Estimated Pareto coefficient $\hat{\alpha}$ in the top wealth tail (2017)

	France	Germany
Threshold: 0.5 million euros		
Survey	1.90 (0.067)	1.89 (0.119)
Survey + Forbes	1.69 (0.057)	1.38 (0.086)
Survey + Forbes + prelim. adjustment	1.59 (0.041)	1.43 (0.084)
Survey + Forbes + 30 iterations	1.60 (0.042)	1.37 (0.086)
Net wealth survey/national accounts	*1.00*	*1.00*
Threshold: 1.0 million euros		
Survey	1.70 (0.085)	2.08 (0.156)
Survey + Forbes	1.46 (0.070)	1.33 (0.091)
Survey + Forbes + prelim. adjustment	1.61 (0.055)	1.38 (0.092)
Survey + Forbes + 30 iterations	1.62 (0.057)	1.32 (0.093)
Net wealth survey/national accounts	*1.00*	*1.00*
Threshold: 2.0 million euros		
Survey	1.81 (0.139)	2.44 (0.275)
Survey + Forbes	1.39 (0.093)	1.26 (0.104)
Survey + Forbes + prelim. adjustment	1.56 (0.073)	1.37 (0.101)
Survey + Forbes + 30 iterations	1.55 (0.075)	1.26 (0.105)
Net wealth survey/national accounts	*1.00*	*0.98*

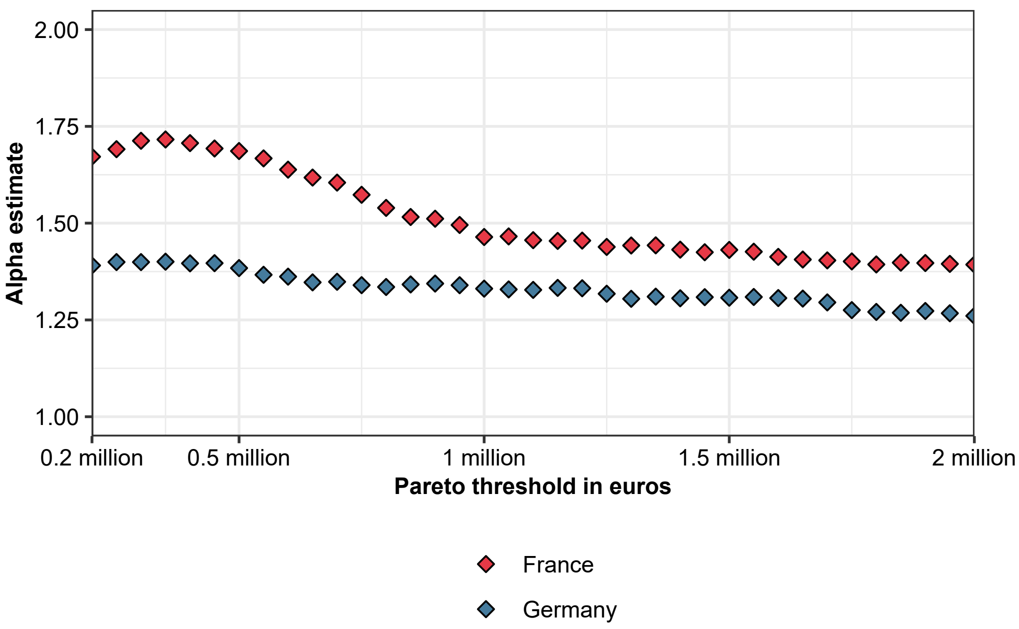
Note: The table presents the OLS-estimated Pareto coefficient $\hat{\alpha}$ in the top tail for different scenarios and steps of the adjustment process. Regression according to Equation 7. Robust standard errors in brackets based on bootstrap and 1,000 replicate weights. The line item in italic refers to the share of aggregate national account wealth represented in the survey after 30 iterations of the adjustment routine. Based on data from Eurostat, Forbes, and HFCS.

Figure A.7: Wealth tails in HFCS and in the Forbes list (2017)



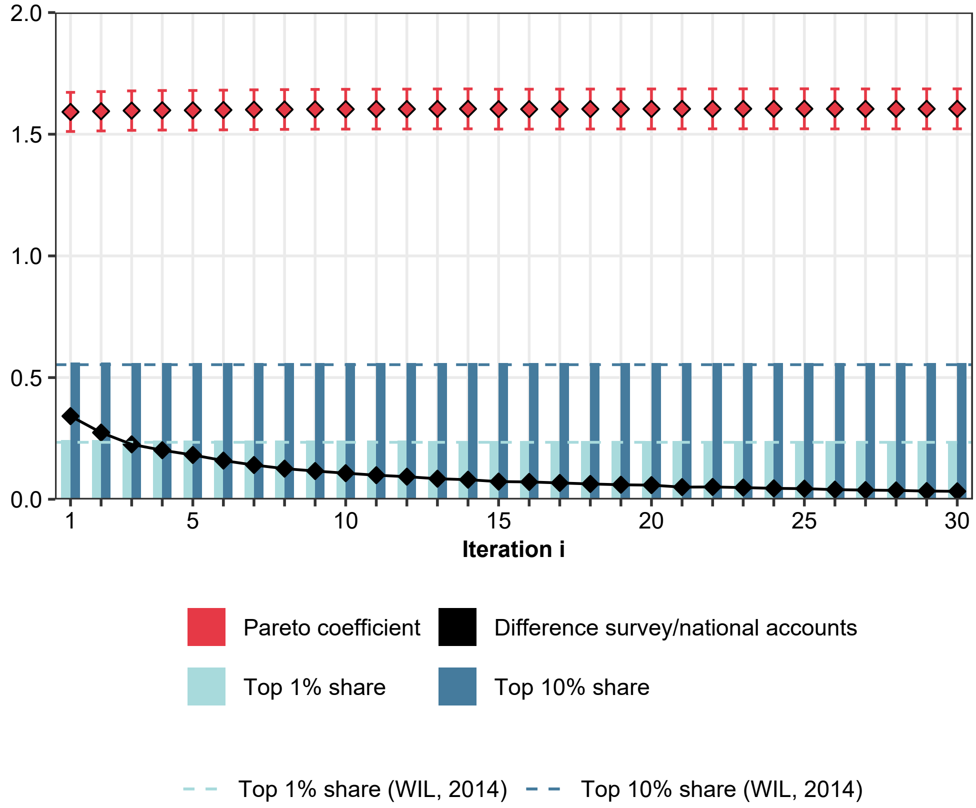
Note: The log-log pot presents log net wealth on the x-axis and the log of the empirical survival function $1 - F(w_i) = P(W > w_i)$ on the y-axis. Observations for France and Germany from the third wave of HFCS after adding high wealth observations from the Forbes Billionaires list. The dashed lines represent three potential thresholds for the survey tail at 0.5, 1, or 2 million euros. Survey top wealth slightly obscured to avoid identification of individual wealth holders. Based on data from Forbes and HFCS.

Figure A.8: Pareto coefficients $\hat{\alpha}$ for varying thresholds in France and Germany



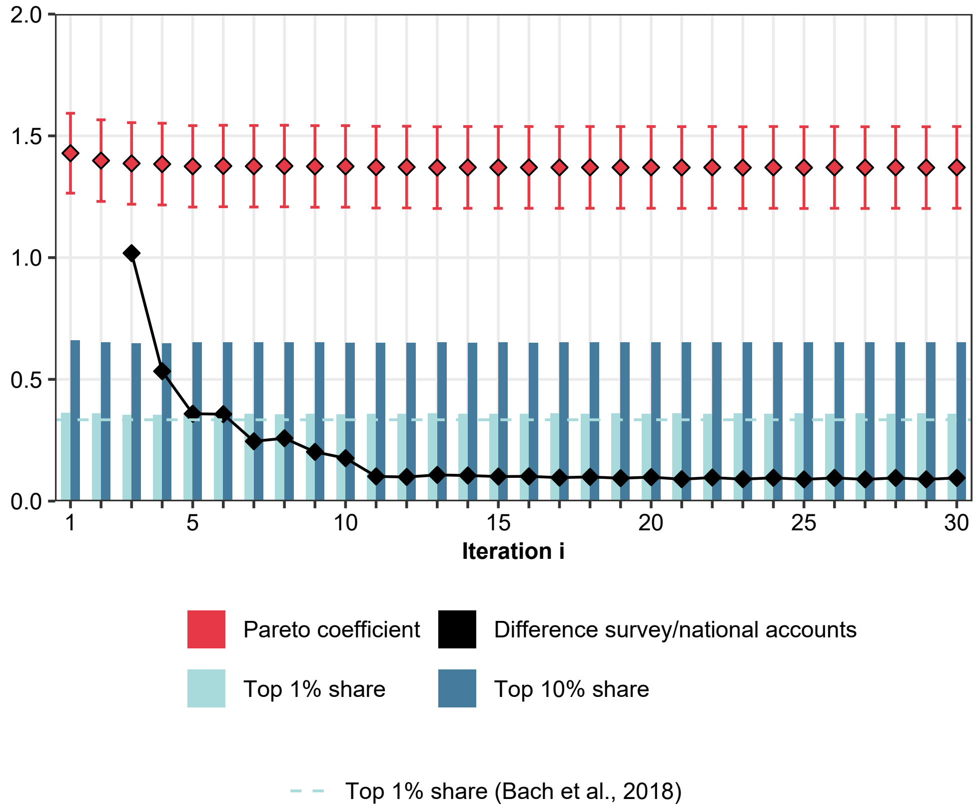
Note: The graph presents estimates of the Pareto coefficient $\hat{\alpha}$ in the top tail of the wealth distribution in France and Germany (2017) for a set of potential thresholds w_{min} between 0.2 and 2 million euros. Estimates according to Equation 7. Survey tail includes Forbes observations. Based on data from Forbes and HFCS.

Figure A.9: Parameters across iterations for $w_{min} = 0.5\text{m}$ in France (2017)



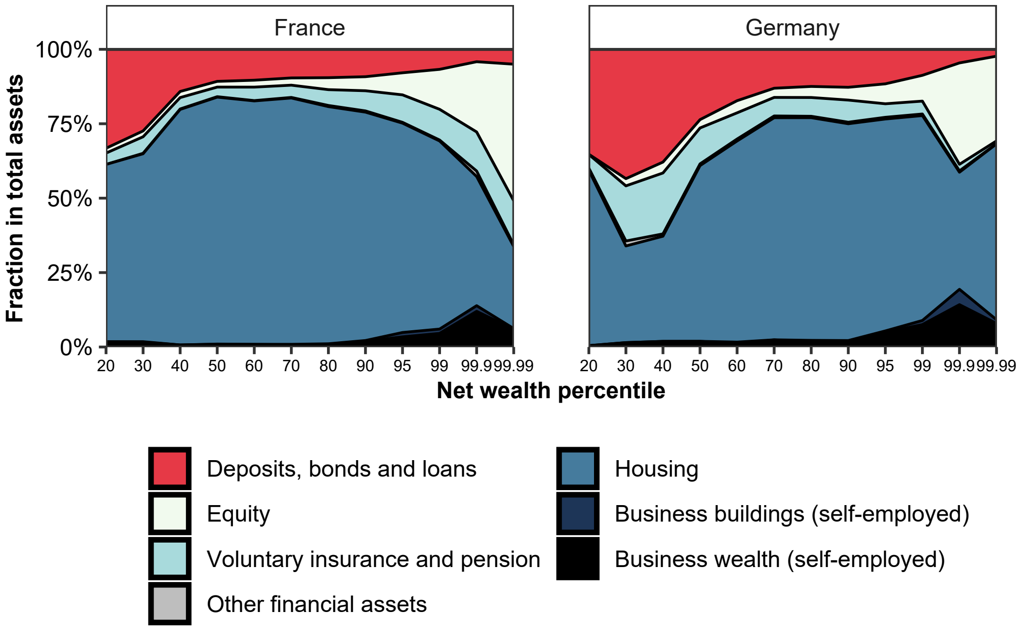
Note: The graph shows key parameters across the 30 iterations of the adjustment process. It aligns survey wealth (in the third wave of the HFCS) with wealth recorded in national accounts for each asset category. Red dots represent the $\hat{\alpha}$ coefficients estimated from Equation 7 with 95% confidence intervals. The black line depicts the average (among the 7 asset categories, liabilities, and net wealth) absolute percentage difference between wealth in the survey and wealth in national accounts. Blue bars depict the top 10% and top 1% net wealth share in the survey. The dashed lines compare the survey statistics to the latest top wealth shares available in the World Inequality Lab database. Data from Eurostat, Forbes, and HFCS.

Figure A.10: Parameters across iterations with $w_{min} = 0.5$m in Germany (2017)



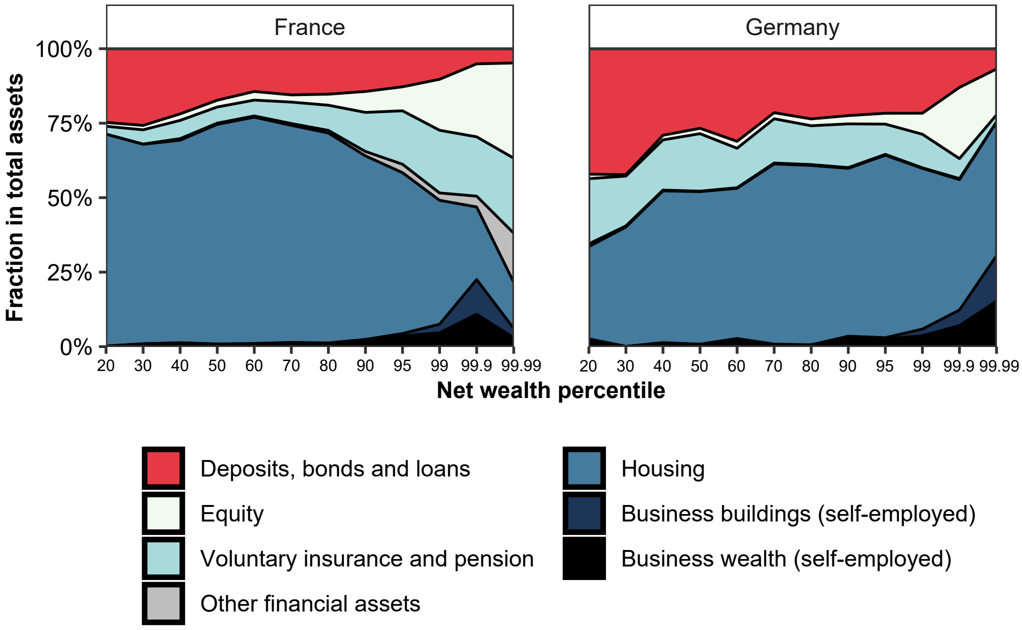
Note: The graph shows key parameters for Germany in the third survey wave across 30 iterations of the adjustment process, which aligns survey wealth in each asset category with aggregate wealth in national accounts. Red dots represent the $\hat{\alpha}$ coefficients estimated according to Equation 7 with 95% confidence intervals. The black line depicts the average (among the 7 asset categories, liabilities, and net wealth) absolute percentage difference between wealth in the survey and wealth in national accounts. Blue bars depict the top 10% and top 1% net wealth share in the survey. The dashed line compares the survey statistics to the top 1% wealth shares in 2014 as estimated by Bach et al. (2019). Top 10% shares are neither reported in the publicly available World Inequality database (WIL) nor in Bach et al. (2019). One point of reference could be the latest estimate published in the Global Wealth Report 2020. Its authors estimate the top 10% wealth share in Germany (2010) at 59.2%, which is close to what I find (dark blue bar). Alternatively, I use unpublished preliminary WIL estimates on wealth inequality in Germany (see text). Data from Eurostat, Forbes, and HFCS.

Figure A.11: Asset composition by wealth level in the HFCS (2017)



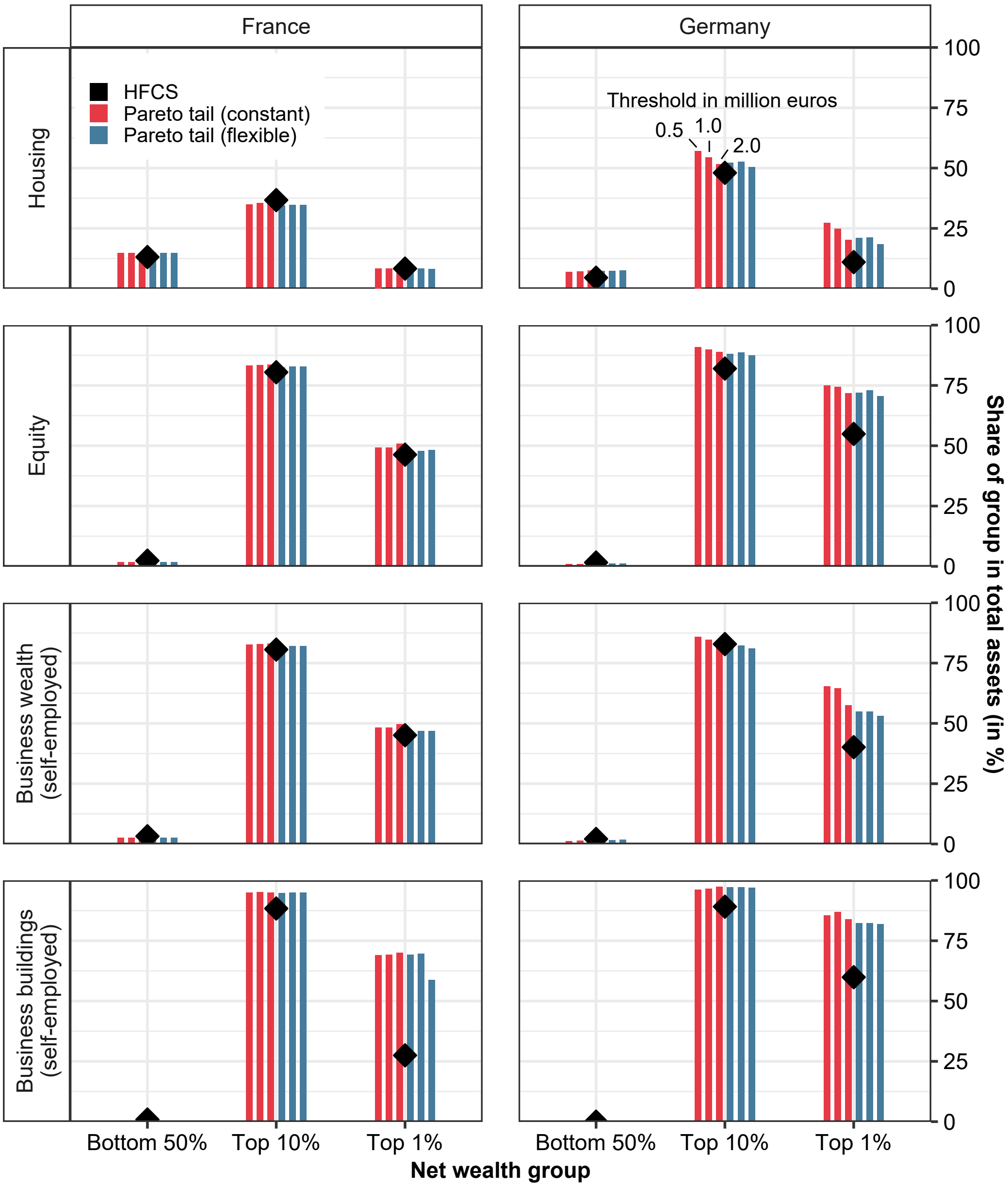
Note: The graph shows the average asset composition in the third wave of the HFCS survey before adjusting the top tail and aligning aggregates to national accounts in France and Germany. The x-axis depicts the net wealth percentile. Classification as developed in Section 2.4.2. Based on data from Eurostat and HFCS.

Figure A.12: Macro-aligned asset composition by wealth level (2017) – constant Pareto tail with $w_{min} = 0.5$m



Note: The graph shows the average asset composition in the third wave of the HFCS survey after adjusting the top tail and aligning aggregates to national accounts in France and Germany. Net wealth above $w_{min} = 0.5m$ follows a Pareto tail with constant shape parameter $\hat{\alpha}$. The x-axis depicts the net wealth percentile. Classification as developed in Section 2.4.2. Figure A.11 in the appendix presents the same statistics for the unadjusted HFCS survey. Based on data from Eurostat, Forbes, and HFCS.

Figure A.13: Macro-aligned asset composition by net wealth group (2017)



Note: The figure presents a robustness check on the asset composition by net wealth group in France and Germany in 2017. Asset compositions presented for three top tail thresholds (0.5, 1.0, and 2.0 million euros, from left to right) and two Pareto-based adjustment methods (standard and alternative). Asset composition in the original HFCS in black. Only assets relevant for emission attribution included. Based on data from Eurostat, Forbes, HFCS, and WIL.

A.4 Steps to obtain emissions associated with final demand

Steps to obtain the matrix of final demand-related emissions E used in 2.5.3 from the WIOD (2015) input-output database. These steps are well-known and frequently explained or referenced in the literature (Leontief, 1970; Kitzes, 2013; Chancel and Piketty, 2015; Berglund et al., 2021), so that I merely reproduce them here for the sake of completeness:

- Step 1: Use the symmetric inter-industry transaction matrix Z embedded in the Input-Output table, and the inverse of the diagonalize vector of total output by industry $\hat{x}$ to calculate the technology matrix A:

$$A = Z\hat{x}^{-1}$$

- Step 2: Calculate the Leontief inverse L by finding the inverse of the difference between the identity matrix I and the technology matrix A:

$$L = (I - A)^{-1}$$

- Step 3: Calculate the emission intensity matrix I from the vector of country-industry emissions c divided by total output (as reflected in matrix x) and the Leontief inverse L:

$$I = cx^{-1}L$$

- Step 4: Obtain input-adjusted emissions E linked to the matrix of final demand Y. The dimensions of matrix E reflect the number of countries × industries (rows) and countries × final demand categories (columns):

$$E = IY$$

A.5 Additional material on the partial attribution of emissions to capital

Table A.12: Emissions attributed to capital-owning sectors in France (2017) – partial attribution

Sector/asset type	Direct ownership	Indirect ownership*	
		Resident corporations	Non-resident corporations
Households			
Business buildings and land	2.0	6.4	-
Business capital	10.7	18.4	12.6
Housing	0.0	0.0	-
Government			
Business buildings and land	10.9	2.3	-
Business capital	6.0	6.6	4.5
Housing	0.0	0.0	-
Corporations			
Business buildings and land	10.6	-	-
Business capital	30.3	-	-
Housing	0.0	-	-
Rest of the world			
Business buildings and land	-	1.8	-
Business capital	-	5.3	-
Housing	-	0.0	-
Total	70.5	40.9	17.2
+ Direct household emissions	125.2	-	-
+ Household final consumption	290.2	-	-
+ Government final consumption	54.9	-	-

* *Through the ownership of resident and non-resident corporations.*

Note: Annual emissions in million tons of CO2 equivalents. The table presents the result of the three attribution steps detailed in Section 2.3 under the partial attribution of emissions to capital stock owners through final demand shares (see Figure 12 and Table 13 in 2.5.3 for results). For full assignment, compare to Table A.8. Sectors either own parts of the capital stock directly or indirectly through the ownership of corporate equity. The black rectangle represents the emissions allocated to resident wealth-holding households. The red rectangle represents total national residence-based emissions as recorded in air emission accounts, excluding direct emissions by households. Each blue rectangle represents the total emissions of resident corporations. Business buildings and land (AN.112), business capital (AN.113-7), and housing (AN.111) aggregated after emission assignment. Housing includes land. Household and government final consumption emissions include indirect production emissions. Based on data from Corsatea et al. (2019), Crippa et al. (2020), Eurostat, Insee, Nardo et al. (2017), WIL, and WIOD (2015).

Table A.13: Emissions attributed to capital-owning sectors in Germany (2017) – partial attribution

Sector/asset type	Direct ownership	Indirect ownership*	
		Resident corporations	Non-resident corporations
Households			
Business buildings and land	10.1	32.6	-
Business capital	20.5	46.3	47.7
Housing	0.0	0.0	-
Government			
Business buildings and land	30.5	4.2	-
Business capital	8.7	6.0	6.2
Housing	0.0	0.0	-
Corporations			
Business buildings and land	45.2	-	-
Business capital	64.2	-	-
Housing	0.0	-	-
Rest of the world			
Business buildings and land	-	8.4	-
Business capital	-	11.9	-
Housing	-	0.0	-
Total	179.3	109.5	53.9
+ Direct household emissions	198.8	-	-
+ Household final consumption	519.2	-	-
+ Government final consumption	77.9	-	-

* *Through the ownership of resident and non-resident corporations.*

Note: Annual emissions in million tons of CO2 equivalents. The table presents the result of the three attribution steps detailed in Section 2.3 under the partial attribution of emissions to capital stock owners through final demand shares (see Figure 13 and Table 14 in 2.5.3 for results). For full assignment, compare to Table A.9. Sectors either own parts of the capital stock directly or indirectly through the ownership of corporate equity. The black rectangle represents the emissions allocated to resident wealth-holding households. The red rectangle represents total national residence-based emissions as recorded in air emission accounts, excluding direct emissions by households. Each blue rectangle represents the total emissions of resident corporations. Business buildings and land (AN.112), business capital (AN.113-7), and housing (AN.111) aggregated after emission assignment. Housing includes land. Household and government final consumption emissions include indirect production emissions. Based on data from Bundesbank, Corsatea et al. (2019), Crippa et al. (2020), Destatis, Eurostat, Nardo et al. (2017), WIL, and WIOD (2015).

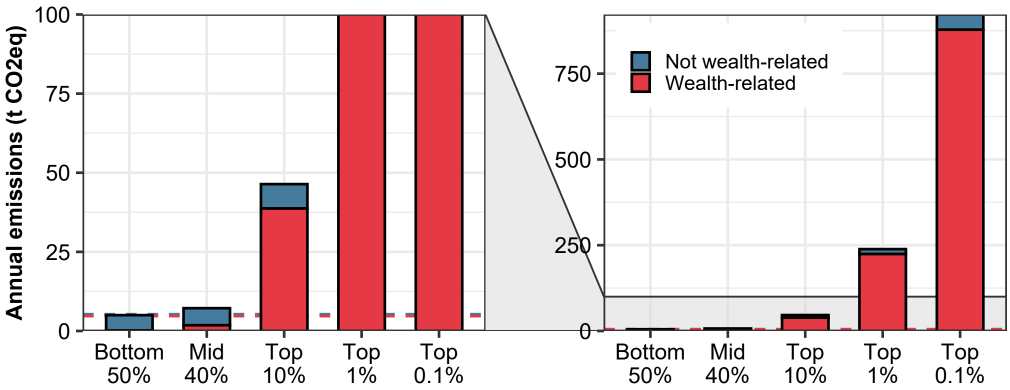
Table A.14: Full vs. partial attribution of annual emissions to capital stock owners (2017) – by industry

	France			Germany		
	Full attribution *in m tons*	Partial attribution *in m tons*	Share *in %*	Full attribution *in m tons*	Partial attribution *in m tons*	Share *in %*
Agriculture, forestry and fishing	89.4	5.2	5.8	73.3	4.5	6.2
Mining and quarrying	1.1	0.3	23.6	5.8	1.6	28.0
Manufacturing	94.6	33.1	35.0	178.0	70.5	39.6
Electricity, gas, steam and air conditioning supply	34.2	4.2	12.2	319.3	66.7	20.9
Water supply; sewerage, waste management and remediation activities	24.0	5.3	22.2	20.1	4.3	21.3
Construction	9.4	8.0	85.1	10.3	7.6	73.7
Wholesale and retail trade; repair of motor vehicles and motorcycles	15.1	2.6	17.0	17.3	3.3	19.2
Transportation and storage	44.4	7.0	15.8	90.2	16.8	18.7
Accommodation and food service activities	3.2	0.2	6.7	3.4	0.1	2.7
Information and communication	1.3	0.5	41.5	1.7	0.5	29.1
Financial and insurance activities	1.0	0.2	15.0	1.7	0.2	12.1
Real estate activities	0.5	0.0	6.5	0.4	0.0	10.3
Professional, scientific and technical activities	2.5	1.2	49.6	4.2	1.9	44.4
Administrative and support service activities	7.5	2.0	27.1	1.2	0.3	27.4
Public administration and defence; compulsory social security	3.4	0.1	2.7	5.4	0.3	6.0
Education	5.0	0.2	3.2	3.4	0.3	7.4
Human health and social work activities	7.2	0.0	0.6	6.8	0.1	1.3
Arts, entertainment and recreation	2.5	0.2	7.3	1.2	0.1	5.6
Other service activities	1.7	0.1	7.3	3.0	0.2	5.6
Attributed to owners of the capital stock (resident and non-resident)	348.1	70.5	20.3	746.8	179.3	24.0
+ Direct household emissions	125.2	125.2	-	198.8	198.8	-
+ Household final consumption	-	290.2	-	-	519.2	-
+ Government final consumption	-	54.9	-	-	77.9	-

Note: The table presents, by industry, the share of direct production emissions attributed to the owners of the capital stock in 2017 in France and Germany under the partial attribution scenario (see Figure 12-13 and Tables 13-14 in 2.5.3 for results). Partial attribution emissions refer to the direct and indirect emissions associated with global final investment (gross fixed capital formation) demanded from each industry in the given year. Household and government final consumption emissions include indirect production emissions. The last rows of Column (2) and (5) form the basis of Table 12. Columns (1) and (4) are identical to what is presented in Tables A.3-A.4. Based on data from Corsatea et al. (2019), Eurostat, and WIOD (2015).

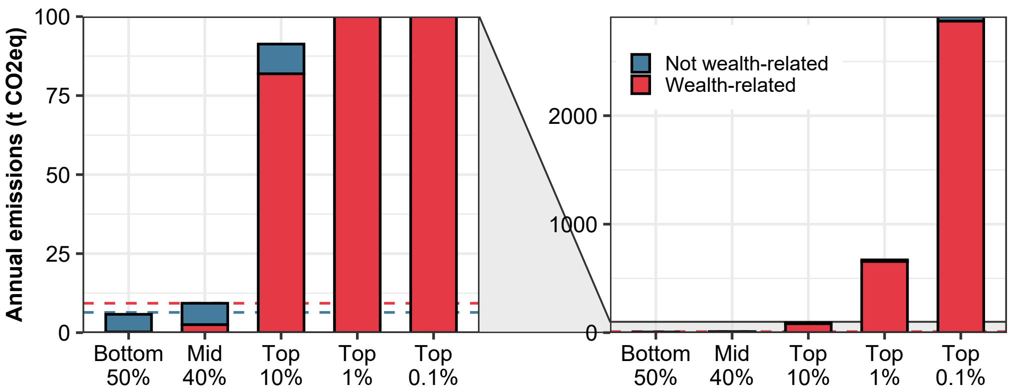
A.6 Additional material on the carbon content of wealth

Figure A.14: Average per adult emissions by net wealth group in France (2017)



Note: The figure presents the estimated average annual per adult emissions by net wealth group in France (2017) under full attribution of emissions to capital stock owners. See Table 8 for details. For comparative purposes, emissions not related to household wealth are depicted in blue. These include direct household emissions, attributed based on individual gross annual income, and government emissions (through capital ownership), which are flatly assigned to individuals. The dashed lines represent the average level of emissions. Own calculations based on data from Corsatea et al. (2019), Crippa et al. (2020), Eurostat, Forbes, HFCS, Insee, Nardo et al. (2017), WIL, and WIOD (2015).

Figure A.15: Average per adult emissions by net wealth group in Germany (2017)



Note: The figure presents the estimated average annual per adult emissions by net wealth group in Germany (2017) under full attribution of emissions to capital stock owners. See Table 9 for details. For comparative purposes, emissions not related to household wealth are depicted in blue. These include direct household emissions, attributed based on individual gross annual income, and government emissions (through capital ownership), which are flatly assigned to individuals. The dashed lines represent the average level of emissions. Own calculations based on data from Bundesbank, Corsatea et al. (2019), Crippa et al. (2020), Destatis, Eurostat, Forbes, HFCS, Nardo et al. (2017), WIL, and WIOD (2015).

A.7 Optimal capital taxation with carbon-intensive assets

Which trade-offs and economic channels determine in an optimal taxation framework how much carbon wealth can and should be taxed? Consider the simplified model of capital taxation proposed by Saez and Stantcheva (2018). Instead of homogeneous capital let us introduce two stylized heterogeneous capital goods: A renewable, carbon-free asset k^R with rate of return r^R and a fossil fuel, carbon-heavy asset k^F with rate of return of r^F. In the first step, following Saez and Stantcheva (2018), I apply a linear capital tax of τ_k to both assets, independent of their carbon content. In every time period t, each individual i in the economy needs to decide how much to consume c_i and how much to invest in k_i^R and k_i^F. In the model, utility increases linearly with consumption. Furthermore, we assume that holding wealth not only provides utility through increasing future consumption. Individuals also derive direct positive, but concave, utility $a_i(k_i^R, k_i^F)$ from being wealthy. If individuals discount future utility by δ_i, one can show that (see Saez and Stantcheva (2018)) – due to the unambiguous and immediate steady-state levels of k_i^R and k_i^F – the dynamic utility maximization problem $U_i = \delta_i \int_{t=0}^{\infty} u_i \left[c_i(t), a_i(k_i^R(t), k_i^F(t))\right] e^{-\delta_i t}$ has an equivalent static problem.

$$U_i = c_i + a_i(k_i^R, k_i^F) + \delta_i \left[(k_i^{init,R} - k_i^R) + (k_i^{init,F} - k_i^F)\right] \tag{8}$$

with:

$$c_i = \underbrace{(1-\tau_k)(r^R k_i^R + r^F k_i^F)}_{\text{Net-of-tax capital income}} + \underbrace{\tau_k(r^R k^{m,R} + r^F k^{m,F})}_{\text{Average tax revenue}} + \underbrace{z}_{\text{Labor income}} \tag{9}$$

The initial level of wealth in period $t = 0$ is denoted by k_i^{init}, the mean level of wealth in the population by $k^m = \int_i k_i di$, and the uniform and fixed labor income by z.

For homogeneous capital, it is intuitive to see that the individual, when she decides to depart from k_i^{init} in $t = 0$, increases k_i up to the point where $a'(k_i) = \delta_i - (1-\tau_k)r$. Remember that the marginal utility of holding wealth $a'(.)$ is decreasing with the level of wealth k_i. Given the marginal utility of consumption $\delta_i - (1-\tau_k)r$ is constant, there comes a point where using wealth for consumption trumps the utility gain of holding even more wealth. The discount rate δ_i must be higher than the net-of-tax rate of return – otherwise zero consumption would be optimal. Saez and Stantcheva (2018) refer to this property as the "limit on individuals' impatience to consume". In our case, the utility of holding wealth is jointly determined by k_i^R and k_i^F. The decision to allocate assets therefore involves the two partial derivatives of the wealth utility function: $a_{i,k^R} = \delta_i - (1-\tau_k)r^R$ and $a_{i,k^F} = \delta_i - (1-\tau_k)r^F$.

Taking into account the individual decision mechanism and a set of marginal social welfare weights $g_i = \omega_i U_i'(c_i) = \omega_i \geq 1$ with $\int_i \omega_i di = 1$, the government sets the tax rate τ_k to maximize social welfare:

$$SWF = \int_i \omega_i U_i di \tag{10}$$

Based on the condition $dSWF/d\tau_k = 0$, one can find the optimal linear capital tax rate τ_k:

- Define the elasticity of wealth holding with respect to the net-of-tax return $\bar{r} = r(1-\tau_K)$ for the renewable, carbon-free asset R and the fossil fuel, carbon-heavy asset F:

$$e_{k^R} = \frac{dk^{m,R}}{d\bar{r}^R}\frac{\bar{r}^R}{k^{m,R}}; \quad e_{k^F} = \frac{dk^{m,F}}{d\bar{r}^F}\frac{\bar{r}^F}{k^{m,F}}$$

- Define the average social marginal welfare weight for holding k_R and k_F:

$$\bar{g}_R = \frac{\int_i g_i k_i^R di}{k_i^{m,R}} = \frac{\int_i g_i k_i^R di}{\int_i k_i^R di}; \quad \bar{g}_F = \frac{\int_i g_i k_i^F di}{k_i^{m,F}} = \frac{\int_i g_i k_i^F di}{\int_i k_i^F di}$$

- Define the share of renewable assets R in the total tax base:

$$s_R = \frac{r^R k^{m,R}}{r^R k^{m,R} + r^F k^{m,F}}$$

- Set $\frac{dSWF}{d\tau_k} = 0$:

$$\begin{aligned}
\frac{dSWF}{d\tau_k} &= \frac{d\int_i \omega_i U_i}{d\tau_k} = \int_i \omega_i \frac{dU_i}{d\tau_k} \\
&= \int_i \omega_i \left[\frac{dU_i}{dc_i}\frac{dc_i}{d\tau_k} + \underbrace{\frac{dU_i}{dk_i^F}\frac{dk_i^F}{d\tau_k} + ...}_{\text{Envelope theorem}\to=0}\right] = \int_i \underbrace{\omega_i U_i'(c_i)}_{=g_i}\frac{dc_i}{d\tau_i} \\
&= \int_i g_i \left[-(r^R k_i^R + r^F k_i^F) + (r^R k^{m,R} + r^F k^{m,F}) + \tau_k \left[r^R \frac{dk^{m,R}}{d\bar{r}^R}\frac{d\bar{r}^R}{d\tau_k} + r^F \frac{dk^{m,F}}{d\bar{r}^F}\frac{d\bar{r}^F}{d\tau_k}\right]\right] \\
&= \int_i g_i \left[(r^R k^{m,R} - r^R k_i^R) + (r^F k^{m,F} - r^F k_i^F) - \frac{\tau_k}{1-\tau_k}\left[r^R k^{m,R} e_{k^R} + r^F k^{m,F} e_{k^F}\right]\right] \overset{!}{=} 0
\end{aligned}$$

- Rearrange to find τ_K^*:

$$\begin{aligned}
&\Rightarrow r^R k^{m,R} \int_i g_i \left(1 - \frac{k_i^R}{k^{m,R}}\right) + r^F k^{m,F} \int_i g_i \left(1 - \frac{k_i^F}{k^{m,F}}\right) = \frac{\tau_k}{1-\tau_k}\left[r^R k^{m,R} e_{k^R} + r^F k^{m,F} e_{k^F}\right] \\
&\Leftrightarrow \frac{1}{\tau_k} = \frac{\left[r^R k^{m,R} e_{k^R} + r^F k^{m,F} e_{k^F}\right]}{r^R k^{m,R}(1-\bar{g}_R) + r^F k^{m,F}(1-\bar{g}_F)} + 1 \\
&\Leftrightarrow \tau_k^* = \frac{r^R k^{m,R}(1-\bar{g}_R) + r^F k^{m,F}(1-\bar{g}_F)}{r^R k^{m,R}(1-\bar{g}_R + e_{k^R}) + r^F k^{m,F}(1-\bar{g}_F + e_{k^F})} = \frac{s_R(1-\bar{g}_R) + (1-s_R)(1-\bar{g}_F)}{s_R(1-\bar{g}_R + e_{k^R}) + (1-s_R)(1-\bar{g}_F + e_{k^F})}
\end{aligned}$$

For the carbon-heavy asset F, e_{k^F} denotes the elasticity of carbon intensive wealth holding with respect to the net-of-tax return $\bar{r} = r^F(1-\tau_K)$, $\bar{g_F}$ denotes the average social marginal welfare weight for holding carbon-heavy wealth, and s_F denotes the share of the carbon intensive assets in the total tax base. The corresponding variables for the renewable asset R are e_{k^R}, $\bar{g_R}$, and $s_R = (1-s_F)$:

$$e_{k^F} = \frac{dk^{m,F}}{d\bar{r}^F}\frac{\bar{r}^F}{k^{m,F}}; \quad \bar{g}_F = \frac{\int_i g_i k_i^F di}{\int_i k_i^F di}; \quad s_F = \frac{r^F k^{m,F}}{r^F k^{m,F} + r^R k^{m,R}}$$

These properties reflect the classical equity-efficiency trade-off of taxation, weighted by the relative size of the tax bases. Lower behavioral responses decrease the efficiency cost of taxation and therefore tend to increase the optimal tax rate. Lower average social welfare weights (e.g., when low-welfare-weight individuals hold most of the wealth) increase the expected welfare gains of redistribution and hence tend to increase the optimal tax rate. So far, the social planner is agnostic about whether individuals invest in renewable or carbon-heavy assets. If this is the case (and under our standard assumptions), reductions in fossil-fuel investment are viewed purely negatively as the *cost of taxation*, which limit the desire to redistribute. With these properties, the standard uniform tax is unable to address the problem of the carbon content of wealth. Neither can the uniform capital tax recover the additional societal cost associated with holding the fossil-fuel asset, nor can it push total investment in these assets on a path towards zero. On the contrary: Precisely when the share of carbon assets in the economy is high (high s_F), and an increase in tax would greatly decrease the amount of environmentally harmful investment ($e_{k,F}$ high), the optimal tax formula would prescribe a low capital tax rate.

With asset-specific tax rates, the optimal tax applied to the carbon-intensive asset is equal to:

$$\tau_{k,F} = \frac{1 - \bar{g}_F - \tau_{k,R}\frac{r^R k^{m,R}}{r^F k^{m,F}} e_{k^R,(1-\tau_{k,F})}}{1 - \bar{g}_F + e_{k^F}} \tag{11}$$

This equation is a starting point for further interesting theoretical work. One could, in a next step, integrate the social cost of carbon through its damage function or define an intertemporal reduction path (or a total emission allotment) as an additional constraint, taking into account (i) the elasticities and (ii) carbon intensity of the carbon-heavy asset. In the simplest case, we could require the first derivative of *holdings of the asset* × *carbon intensity* over time to be negative.