Global Carbon Inequality, 1990-2019

The Impact of Wealth Concentration
on the Distribution of World Emissions

LUCAS CHANCEL
World Inequality Lab, Paris School of Economics

First draft: October 2021

This version: 28 February 2022

Abstract

All humans contribute to climate change but not in the same proportions. This paper estimates the global inequality of individual greenhouse gas (GHG) emissions between 1990 and 2019, using a newly assembled data set of income and wealth inequality, and Environmental Input-Output tables and a framework distinguishing between emissions from consumption and investments. I find that the bottom half of the world population emits 12% of global emissions, while the top 10% emits 48% of the total in 2019. Since 1990, the global top 1% has been responsible for 23% of all emissions and the bottom 50% for only 16% of the total. While per capita emissions of the global top 1% increased since 1990, emissions from low and middle income groups in rich countries declined. As a result, 63% of the global inequality in individual emissions is now due to gaps between low and high emitters *within* countries rather than *between* countries. In 1990, the situation was the reverse. The paper finds that emissions from investments, rather than from consumption, represent 70% of total emissions from the global top 1%. These findings have implications for contemporary debates on fair climate policies and stress the need for more systematic individual emissions data production efforts by governments.

I Introduction

Climate change and economic inequalities are among the most pressing challenges of our times, and they are interrelated: failure to contain climate change is likely to exacerbate inequalities within and between countries [1, 2, 3, 4] and economic inequalities within countries tend to slow the implementation of climate policies [5, 6]. In order to properly understand the relationship between economic inequality and climate change, sound, timely and systematic data is needed about the distribution of greenhouse gases (GHG) emissions between individuals and across the globe. Such information is currently missing.

As a matter of fact, researchers, policymakers and civil society struggle to establish even basic facts about individual carbon footprints. National carbon footprints (i.e. emissions net of the GHG content of goods and services traded with the rest of the world) are not systematically published by most statistical institutions around the world, and when this information is released, it comes with several years of delay. In addition, official publications about GHG emissions are typically blind to the distribution of these emissions: which population groups contribute most to GHG emissions growth or to mitigation efforts remains unknown.

This paper addresses these issues by harnessing recent conceptual and empirical progress in the measurement of income, wealth and GHG emissions. Compared with previous work on global carbon inequality [7, 8, 9, 7, 10], this paper presents three major developments in terms of data, method and scope.

First, the paper uses novel income and wealth inequality data from the World Inequality Database [11] based on state-of-the-art methods to track inequality from the bottom to the top of the distribution. This economic inequality data is combined with GHG footprints from Input-Output models thanks to a newly assembled set of country-level information on the link between individual emissions, consumption and income in more than 100 countries. The methodology therefore makes it possible to track individual GHG emission levels with more precision than previous longitudinal estimates. Second, the method developed allows to distinguish explicitly between emissions from private consumption and investments, making it possible to better understand the drivers of emissions among top groups of the population. Third, the paper focuses on the distribution of emissions over the 1990-2019 period, that is from the first Intergovernmental Panel on Climate Change (IPCC) report to the eve of the Covid-19 pandemic. The three decades saw critical shifts in the distribution of world economic growth [12], which had not been systematically studied from the point of view of GHG emissions inequality.

There are two broad approaches to the measurement of global carbon inequality, namely *bottom-up* approaches and *top-down* approaches. Each has its strengths and weaknesses. The *bottom-up* approach uses household-level micro data to produce macro estimates. This is the approach taken by Bruckner et al. [8] for instance, who mobilize the large set of consumption surveys available from the World Bank Global Consumption Database (WBGCD), as well as additional consumer expenditure surveys done in rich countries. These surveys are linked to Environmental Multi Regional Input Output models (EMRIOs) to provide estimates of emissions per consumption group. To the extent that micro-level data is available, this method is the best way to measure global carbon inequality associated with individual *consumption*. However, it requires a vast set of standardized micro data on the household consumption level for all countries in the world, making longitudinal studies challenging.[1] One limitation of survey-based studies is that they tend to underestimate the consumption levels of the richest groups, due to well documented misreporting and sampling errors [14]. Using household surveys without additional information about top-end inequality is therefore likely to underestimate the carbon emissions associated with rich individuals' consumption.

Top-down approaches to the measurement of global carbon inequality use the regularities observed in micro-level data to provide modeled estimates based on elasticity parameters (see Methods). This is the approach taken, for instance, by Chakravarty et al. [7], who look at territorial emissions only and therefore miss the potentially large share of emissions embedded in international trade [15]. Chancel and Piketty [9] follow a similar method but use the GTAP Environmental Multi Regional Input Output (EMRI0) database [16] to take into account emissions embedded in trade and to look at a longer period. This approach was also used by [10] and [17]. These studies typically use one single elasticity for all countries, which limits the

[1] See also Hubacek et al. [13] who use a similar approach.

precision of their analysis. Another limitation of both top-down and the bottom-up approaches is that they do not treat investment-related emissions particularly well.

The present paper builds on the strengths of both approaches and offers novel developments to build on earlier limitations. By mobilizing country-level elasticities from over a hundred countries, rather than a unique elasticity for all countries, the paper departs from previous top-down approaches. By focusing on the 1990-2019 period, the paper adds historical depth to single year *bottom-up* studies and by distinguishing between emissions from personal consumption and from investments, the paper makes it possible to shed new light on the dynamics of emissions among top groups. The general approach followed here can be summarized as follows: using EMRIOs, I obtain country-level GHG emissions for the household sector, the investment sector and the government sector across countries (emissions are net of imports and exports embedded in goods and services traded with the rest of the world). These emissions are distributed to individuals in each country using country-level data on the elasticity of emissions and consumption, income and wealth. A variety of alternative estimation strategies are tested and it appears that the key results are robust to a large range of parametric assumptions on the relationship between emissions, income, consumption and wealth (see Methods).

The rest of this paper is structured as follows: Section II presents the main findings of the work, Section III discusses the relevance of these results and Section IV concludes. The methodology is detailed in the Methods section at the end of the paper as well as in the Supplementary Information (SI).

II RESULTS

Global equally-split carbon budget and average emissions by region

According IPCC AR6 report [18], there are approximately 300 Giga tonnes (Gt) of Carbon Dioxide (CO_2) left to be emitted to limit global warming below 1.5°C and nearly 900 $GtCO_2$ to keep it to 2°C, with an 83% confidence of remaining under the temperature limit. At 2019 global emissions rates (that is, circa 35 $GtCO_2e$ in 2019), the 1.5°C budget will be depleted in nine years and the 2°C budget in 26 years. The global GHG emissions (including CO_2 and other GHGs) amounted to 45.8 $GtCO_2e$

in 2019,[2] with a global per capita average of 6 tCO_2e. In comparison, to have a high chance of staying below 1.5°C , the Global Equally-split Carbon (GEC) budget is 1.9 tCO_2e per person per annum (assuming that the entire budget will be spent by 2050). This value corresponds approximately with the emissions created by an economy-class round-trip flight between London (UK) and New-York (USA). The GEC budget for staying below 2°C is 4.9tCO_2e per person per year. GEC budgets are obtained by dividing the remaining global carbon budget by the cumulative global population that will be emitting it during the coming decades. Remaining Global Carbon budgets used in this paper include values for CO_2 presented above (300-900 GtCO_2) and additional values to account for non-CO_2 gases (about 200-400 GtCO_2e) obtained from the latest IPCC report (see Methods). Alternative budgets, which take into account historical responsibilities, are presented in the **SI** (section 3). Factoring in historical responsibilities indeed reduces the per capita carbon budgets for high-income countries (down to negative values for certain of them) and increases the available per capita budget for low-income countries. The main purpose of presenting per capita GEC budgets is to provide reference points to help assess the gap between current and required emissions reduction.[3]

Average emissions in most world regions are above the 1.5°C GEC budget and only three regions are below the 2°C GEC budget in 2019, as shown in Figure I (these estimates are net of imports and exports of CO_2e embedded in goods and services, as discussed in the Methods section).[4] Per capita emissions in Sub-Saharan Africa are 15% lower than the 1.5°C GEC budget, representing 0.3x the 2°C GEC budget. At the other end of the spectrum, emissions in North America are 21 tCO_2e per capita (three times the world average and more than four times the 2°C GEC budget). In between these two extremes stand South and Southeast Asia, at 2.6 tonnes per capita (0.5x the 2°C GEC budget) and Latin America at 4.8 tonnes (roughly the 2°C GEC budget), followed by the Middle East and North Africa, East Asia, Europe,

[2]Unless specified, all figures are reported in CO_2e and include all GHG emissions from human activity, except those from land use, land use change, and forestry (LULUCF). If we include LULUCF emissions, then a total of about 50GtCO_2e were emitted in 2019.

[3]For discussions on climate justice principles and applications to different carbon budget sharing strategies, see [19, 20, 21].

[4]See also **SI**, Table 4.5, which compares territorial emissions with carbon emissions net of imports and exports of carbon embedded in goods and services, presented here.

and Russia and Central Asia, whose averages fall in the 7.5-10 tonnes range (1.5-2x more than the 2°C GEC budget).

[Figure 1 about here.]

Carbon emission inequalities within regions

On top of large carbon inequalities between regions, significant inequalities in carbon footprints are observed within regions of the world. Figure II presents the carbon footprints of the poorest 50%, the middle 40% and the richest 10% of the population across regions. Emission levels and shares for other groups are presented in the **SI** (section 7).

In East Asia, the poorest 50% emit on average 2.9 tonnes per annum while the middle 40% emit nearly eight tonnes, and the top 10% almost 40 tonnes. This contrasts sharply with North America, where the bottom 50% emit fewer than 10 tonnes, the middle 40% around 22 tonnes, and the top 10% around 69 tCO_2e. This in turn can be contrasted with the emissions in Europe, where the bottom 50% emit five tonnes, the middle 40% around 10.5 tCO_2e, and the top 10% around 30 tCO_2e. Emissions levels in South and Southeast Asia are significantly lower than in the these regions, from around 1 tCO_2e for the bottom 50% to 11 tonnes on average for the top 10%.

It is striking that the poorest half of the population in the US has emission levels comparable with the European middle 40%, despite being almost twice as poor as this group in purchasing power parity terms [22]. This difference is largely due to the carbon-intensive energy mix in the US (where emissions from electricity are about twice as much as in the European Union) and to more energy-intensive infrastructures and devices.[5]

[Figure 2 about here.]

European emissions among the various income groups are very high by global standards: the European middle class emits significantly more than its counterparts in East Asia (10.7 tonnes compared with 7.9 tonnes) and all other regions except

[5] See e.g. [23] for a discussion of the drivers behind these differences.

North America. Yet it is also remarkable that the top 10% in East Asia and in the MENA region emit more than the top 10% of Europeans (40, 34, and 29 tCO_2e respectively). This difference is essentially driven by the higher economic inequality levels observed in East Asia and the MENA region than in Europe. The top 10% income share is indeed 43% in East Asia, 58% in the MENA region, and 36% in Europe [24].

Turning to other regions, it appears that Russia & Central Asia have an emissions distribution broadly similar to that of Europe, but with higher top 10% emissions (due to higher income and wealth inequalities in Russia & Central Asia) and lower bottom 50% emissions. Sub-Saharan Africa lags behind, with the bottom 50% emitting around 0.5 tonnes per capita and per year, and the top 10% emitting around 7.5 tonnes. Overall, it stands out that the bottom 50% of the population in Sub-Saharan Africa, Latin America, MENA and South and Southeast Asia come in under or close to the 1.5°C GEC budget. Measuring levels against the 2°C GEC budget, it is found that the bottom half of the population in each region is below or close to the threshold, except in North America. I discuss the importance of within-country inequality for climate policy further below.

Global carbon inequality between individuals

Figure III presents the inequality of carbon emissions between individuals at the world level. The global bottom 50% emit on average 1.4 tCO_2e per year and contribute to 11.5% of the total. The middle 40% emit 6.1 tonnes on average, making up 40.5% of the total. The top 10% emit 28.7 tonnes (48% of the total). The top 1% emits 101 tonnes (16.9% of the total). Error bars present results from scenarios with extreme parametric assumptions on the relationship between emissions and income within each country. Global carbon emissions inequality thus appears to be great: close to half of all emissions are created by one tenth of the global population, and just one hundredth of the world population (77 million individuals) emits about 50% more than the entire bottom half of the population (3.8 billion individuals).

[Figure 3 about here.]

Table I presents more detail on the global distribution of carbon emissions. The bottom 20% of the world population (1.5 billion individuals) emit fewer than 1.5 tonnes per capita per annum. The entry threshold to get in the middle 40% is 2.9 tonnes, and it takes 12 tonnes per capita per annum to get in the top 10%. It takes 118 tonnes to break into the global top 0.1% of emitters (7.7 million individuals).

[Table 1 about here.]

The evolution of individual carbon emissions inequalities

How has global emissions inequality changed over the past few decades? A simple way to represent the evolution is to plot the average emissions growth rate of each percentile of the global distribution. Global polluters are ranked from the least emitting to the highest on the horizontal axis of Figure IV, and their per capita emissions growth rate is presented on the vertical axis. Since 1990, average global emissions per capita grew by 2.3% (and overall emissions grew by about 50%, see Table II). The per capita emissions of the bottom 50% grew faster than the average (26%), while those of the middle 40% as a whole was negative (-1.2%), and some percentiles of the global distribution actually saw a reduction in their emissions of between 5 and 25%. Per capita emissions of the top 1% emissions grew by 26% and top 0.01% emissions by 80%.

Per capita emissions matter, but understanding the contribution of each group to the overall share of total emissions growth is crucial. Groups starting with very low per capita emissions levels can increase their emissions substantially over a given period yet still contribute little to the overall growth in global emissions. This is in effect what has happened since 1990 (Table II, column 6). The bottom half of the global population contributed only 16% of the growth in emissions observed since then, while the top 1% (77 million individuals in 2019) was responsible for 23% of total emissions growth. In fact, the top 0.1% (7.7 million individuals in 2019) contributed two nearly three-quarters of the entire growth in emissions associated to the poorest half of the global population (3855 million individuals in 2019).

[Figure 4 about here.]

[Table 2 about here.]

One of the most striking results shown in Figure IV is the reduction in the emissions of about 5-15% for percentiles p75 to p95. This segment of the world population largely corresponds to the lower and middle income groups of the rich countries. In these countries, the working and middle classes have reduced their emissions over the past 30 years thanks to a combination of improvements in overall energy efficiency and a compression of their wages compared with richer groups of the population [12]. These reductions are insufficient to meet the goals of the Paris Climate Agreement to limit global warming to 1.5°C or 2°C, but they contrast nevertheless with the emissions of the top 1% in these countries (and at the global level), which have significantly increased. I discuss the implications of these dynamics in section III.

Figure V presents the evolution of the top 1% and the bottom 50% shares in total emissions between 1980 and 2019. Between 1990 and 2019, the global bottom 50% increased its share of total emissions, from around 9.5% to 11.5%. At the same time, the top 1% share rose from 13.7% to nearly 17%. Put differently, the gap in emissions between the top of the distribution and the bottom remained substantial over the entire period, despite relatively strong growth in emissions by the bottom 50% of the world population.

[Figure 5 about here.]

Global carbon inequality dynamics are governed by two forces: the evolution of average emission levels *between* countries and the evolution of emission inequalities *within* countries. Which one of these two forces has been driving the dynamics of global carbon inequality over the past few decades? Figure VI compares the share of global emissions due to within-country differences with the between-country differences, using a Theil-index decomposition. In 1990, most global carbon inequality (62%) was due to differences between countries: then, the average citizen of a rich country polluted unequivocally more than the rest of the world, and social inequalities within countries were on average lower across the globe than today. The situation has entirely reversed in 30 years. Within-country emissions inequalities now account for nearly two thirds of global emissions inequality. To be clear: this does not mean that significant (often huge) inequalities in emissions between countries and regions have disappeared. On the contrary, it means that on top of the great inter-national inequality in carbon emissions (see Figure I), there are also even greater emissions inequalities between individuals. This has major implications for global debates about climate policies. **SI** Table 7.1 presents the evolution of the Theil and Gini index over the time period and for various scenarios. It appears that despite important shifts in the distribution of world emitters, global inequality remained fairly stable through the lens of summary measures. The Gini index of global carbon inequality slightly decreased (from 0.64 to 0.61) but the Theil index slightly increased over the period (from 0.87 to 0.9) in the benchmark scenario. The results presented above indeed highlight the importance to look beyond summary distributional statistics to properly understand how emissions growth was distributed.

[Figure 6 about here.]

Figure VII (panel A), presents the global distribution of individual carbon emissions in 2019. Each color wedge is proportional to the population of a region, and the total colored area represents the global population. The Figure makes clear that the bulk of the world population emits between 1 and 8 tCO_2e p.a., with a mode at c. 2 tonnes. Around 1 billion individuals emit less than one tonne of CO_2e per year, three billion individuals are found to emit between 2.8 tonnes and 13 tonnes and eight million individuals (approximately the top 0.1% of the population) emit more than 125 tonnes per year (see also Table I). Panel B of Figure VII presents the population share of each region in each percentile of the global carbon distribution. Sub-Saharan Africa, India and the rest of Asia (excluding China) represent roughly 90% of emitters from the bottom 30% of the global distribution. China (which represents the vast majority of East Asia), Latin America, and the MENA countries are well represented at nearly all levels of the global distribution, from relatively low to very high emitter groups. This reflects the dual nature of these societies, where extreme polluters live close to very low polluters. Europe and North America are essentially represented in the top half of the global distribution. North Americans represent 30-40% of emitters from the top 1%, whereas Europeans are much less represented at the very top of the distribution. Also significant is the large representation of East Asians and Chinese among very top global emitters. SI Figure

6.2 shows the equivalent of VII (Panel B) for year 1990 and reveals the large changes in the geographical composition of each global emitter group over the time period.

[Figure 7 about here.]

The weight of investments in the carbon footprints of wealthy individuals

The results presented above show that global carbon inequalities are currently very great and that the share of emissions of the very top groups has been rising since 1990. What is driving this rise in emissions at the top of the distribution? The rise in emissions at the top is due to the increase in income and wealth inequalities within countries as well as to the rising share of emissions generated by wealthy individuals' investments.

Individual carbon footprints can indeed be split into emissions generated by private consumption, investments and government spending. Consumption-related emissions come from the carbon released by the direct use of energy (e.g. fuel in a car) or its indirect use (e.g. energy embedded in goods and services consumed by individuals). In line with earlier studies of carbon footprints, emissions associated with the actual production of the final and intermediary goods are attributed to the ultimate consumers of those goods. Investment-related emissions are emissions associated with choices made by capital owners about new investments in the production process (i.e. the construction of the new machines, new factories, etc. that will serve the production of goods and services tomorrow).

Focusing on the breakdown between consumption and investment emissions, I find that a large proportion of the emissions generated by the global top 1% comes from their investments rather than their consumption. In a world where the poorest half of the population within countries typically owns less than 5% of total wealth [24], and typically makes less than 5% of all savings, it can be expected that investment-related emissions are highly concentrated both within countries and globally. The question is how much? and how has the weight of investments in the carbon budgets of wealthy individuals changed in the past few decades?

Figure VIII provides some answers to these questions by presenting the share of investments in total emissions of various groups of emitters at the global level (the global bottom 50%, middle 40% top 10%, top 1%). The emissions of the top groups (top 10% and above) largely come from their investments. Investments represent around 50% of emissions of the global top 10% and slightly above 70% of global top 1% emissions in 2019. Conversely, emissions from investments by the global bottom 50% represent represent less than 10% of their total emissions (i.e. only 0.14 tonnes per capita in 2019 (or 10% of their total emissions of 1.4 tonnes on average). It also appears that the weight of investments in the per capita footprint of the top groups has been rising significantly since the 1990s. This is due to the rise in wealth inequality (wealth and investments are concentrated today than they were in 1990), as well as the rise in overall emissions associated with investments over the period (see **SI** Table 1.1.).

[Figure 8 about here.]

III Discussion

The results presented in this paper reveal the very highly skewed concentration of individual carbon emissions that characterizes the contemporary global economy: while one tenth of the global population is responsible for nearly half of all emissions, half of the population emits less than 12% of it.[6] Global carbon inequalities have been rising at the top of the distribution (Figure V) since 1990. How to explain this rapid increase at the top of the distribution of world emitters? Focusing on rich countries, we see that average per capita emissions have declined since 1990 (even when we factor in embedded emissions), but incomes and wealth have become more concentrated at the top of the distribution. In this context, the carbon footprint of wealthy individuals has followed a different trend from that of the rest of the population. What is observed is a ”rebound effect” associated with high income and wealth levels: rising income and wealth have been more important than gains in the GHG intensity of per capita income. I stress that this effect appears to be robust to different assumptions about the link between emissions and income, consumption

[6] Seen in perspective, carbon inequalities are lower than income and wealth inequalities (the global top 10% of earners captures 52% of total income and the global top 10% of wealth owners owns three quarters of total wealth [24].

and wealth at the household level.[7] In emerging countries such as China and India, average emissions levels have been growing for nearly all groups of the population, but the wealthy account for a disproportionate share of economic and emissions growth.

The increased emissions by top global emitters since 1990 is particularly striking when compared with the emission trajectories of other population groups. Indeed, the emissions of the poorest 50% in Europe and the US have dropped by approximately 15%-20% since 1990. These reductions are the result of the combined effect of compressed wages and consumption and a reduced national per capita footprint in most rich countries driven by climate and energy policies and efficiency gains in industrial processes. As a consequence, a large part of the population in rich countries already appears to be near 2030 national climate targets, when these are expressed in per capita terms. Nationally Determined Contributions (NDCs) established under the rubric of the Paris Agreement imply a per capita target of around 10 tonnes of CO_2e in the US in 2030, but around five tonnes for European countries (see Methods). In the US and most European countries, I find that the bottom 50% of the population meets these 2030 targets (Figure IX and **SI** Section 8.1). This is not the case for the middle 40% and top 10% of the income distribution in these countries. Wealthier groups emit largely above the 2030 climate target. In the US, the top 10% would have to reduce its average per capita emissions by 86% to reach the 2030 target, the value is 81% in France.

In emerging and developing countries, 2030 climate targets imply an increase in average per capita emissions rather than a reduction. But there, too, inequality matters a lot: in China and India, emissions of the bottom 90% of the population are below the target, while those of the wealthiest 10% are already well above it. In China, the richest 10% of the population would have to reduce its emissions by more than 70% to reach the 2030 target, and the figure is over 50% for India (Figure IX and **SI** Section 8).

[Figure 9 about here.]

To be clear, no country currently envisages the enforcement of strict per capita

[7] See **SI** Section 7.

targets in order to meet its 2030 objectives. Nonetheless, the gaps between individual emissions levels and the implied national target raise important questions about the design of climate policies in the years to come: how do we ensure that regulations, tax instruments and other climate policies effectively address the emissions of the high emitters? Put differently, how do we reduce emissions in increasingly unequal societies?

There is no straightforward answer to such questions, but it appears that climate policies over the past decades have often targeted low-income and low-emitter groups disproportionately, while leaving high emitters relatively unaffected. The trends documented in this paper support this view. In fact, key climate policy instruments (such as carbon taxes, for instance) have done little to address the vast inequalities in carbon footprints - and may have in some cases exacerbated them. Carbon taxes have been found to place a disproportionate burden on low-income and low-emitter groups [25, 26, 27] while the carbon price signal for high and wealthy emitters seems too low to force changes in consumption patterns among wealthy individuals. Based on the results presented above, it appears that carbon taxes on consumption are likely to be even more regressive than previously estimated. Progressive carbon tax rates could be used to address this issue.

There are several ways to make carbon taxes more progressive. One option is to combine carbon pricing with cash transfers for certain categories of the population, as has been done in British Columbia (Canada) since 2008. Another option is to make carbon tax rates increase with emission levels. This is indeed difficult to implement in the context of carbon taxes paid by consumers however it could be achieved via a combination of taxes focusing not only on consumers but also on investors. This paper's findings indeed suggest that there could be a rationale to tax individual carbon-intensive investment decisions: while investments represent a significant and rising share of the carbon footprints of the top emitters, states typically do not impose taxes or regulations on the basis of the pollution content of individual asset portfolios or of investments. This can be seen as paradoxical given that investors have a variety of options for investing their wealth, and it stands in stark contrast with low and middle income consumers who do not always have alternatives, in the short run, to using fossil fuels, but who must pay carbon consumption taxes.

Using the data constructed for this paper, it appears that the global top 1% would contribute to about 40% of total revenues from a carbon tax on investments and the top 10% three quarters of the total. With a tax rate r equal to 0 for annual investments with a carbon content below 5tCO_2e per capita and $r > 0$ for investments with a carbon content above this threshold, close to 100% of the tax would fall on the top 10% of the global population. Under this schedule, the poorest 77% of the US population, the bottom 90% of the European population and the bottom 99.5% of the Sub-Saharan African population would not pay the tax at all (see **SI** Table 8.3). Such a tax could therefore be used to make overall carbon tax systems significantly more progressive. While accelerating the shift to low-carbon production processes, such taxes could raise additional revenues to invest in low-carbon infrastructures or to compensate losers of the transition. They could therefore help to avoid the risk of political backlash against carbon taxation, as has been seen in several countries in the recent years [5, 28].

The information, technical and economic conditions under which policies targeting the carbon investments of individuals are developed is a matter for further research. Crucial progress will have to be made by governments if we are to properly monitor individual emissions in a timely and systematic manner, in particular those associated with investment portfolios. Capacity to produce this information will also depend on government capacities to enforce financial transparency in order to effectively trace the end-user beneficiaries of financial transactions and of the emissions generated by financial assets. [8]

IV Conclusion

This study used state-of-the art data on global income and wealth inequality and systematically combines it with carbon footprint estimates to track the distribution of individual carbon emitters between 1990 and 2019. I found that global inequality in carbon emissions is both high and persistent despite strong economic growth in the emerging economies over the past three decades. The top 10% of global emitters are responsible for around 48% of global emissions while the entire bottom

[8] See [29] for a discussion of the many issues associated with the development of financial asset registries.

50% released less than 12% of emissions in 2019. While significant inequalities in average emissions persist between countries, the bulk of global inequalities in individual emissions is now explained by within-country inequalities. The emissions of lower income groups of rich countries declined over the period while emissions by top groups were either maintained at high levels or increased significantly. In emerging countries, emissions by the top income groups are now comparable to the top groups in rich countries. Finally, I find that a large and growing share of the biggest individual carbon emitters come from their investments rather than their consumption. These results highlight the need for more policy instruments that specifically address the emissions released by the wealthy. While the results presented here appear to be robust to a wide range of alternative estimation strategies, I stress at the outset that a lot of work still needs to be done in order to properly track carbon emissions inequality between and within countries and in particular those associated with investments. Without such information, designing fair climate policies will remain a very problematic task. All estimates are published online on the World Inequality Database, along with the set of computer codes, with the aim of contributing to more transparency about these important matters.

References

[1] Noah S. Diffenbaugh and Marshall Burke. "Global warming has increased global economic inequality". In: *Proceedings of the National Academy of Sciences* 116.20 (2019), pp. 9808–9813.

[2] Stephane Hallegatte and Julie Rozenberg. "Climate change through a poverty lens". In: *Nature Climate Change* 7.4 (2017), pp. 250–256.

[3] Marshall Burke, Solomon M Hsiang, and Edward Miguel. "Global non-linear effect of temperature on economic production". In: *Nature* 527.7577 (2015), pp. 235–239.

[4] Melissa Dell, Benjamin F Jones, and Benjamin A Olken. "Temperature shocks and economic growth: Evidence from the last half century". In: *American Economic Journal: Macroeconomics* 4.3 (2012), pp. 66–95.

[5] Lucas Chancel. *Unsustainable Inequalities: Social Justice and the Environment*. Harvard University Press (Belknap), 2020.

[6] United Nations Development Programme, Human Development Report Office. *Human Development Report 2019. Beyond income, beyond averages, beyond today: Inequalities in human development in the 21st century*. 2019.

[7] S. Chakravarty, A. Chikkatur, H. de Coninck, S. Pacala, R. Socolow, and M. Tavoni. "Sharing global CO2 emission reductions among one billion high emitters". In: *Proc Natl Acad Sci* 106.29 (2009), pp. 11884–11888.

[8] Benedikt Bruckner, Klaus Hubacek, Yuli Shan, Honglin Zhong, and Kuishuang Feng. "Impacts of poverty alleviation on national and global carbon emissions". In: *Nature Sustainability* (2022), pp. 1–10.

[9] Lucas Chancel and Thomas Piketty. *Carbon and inequality from Kyoto to Paris (1998-2013) and prospects for an equitable adaptation fund*. October. Paris School of Economics, 2015.

[10] Gregor Semieniuk and Victor M Yakovenko. "Historical evolution of global inequality in carbon emissions and footprints versus redistributive scenarios". In: *Journal of Cleaner Production* 264 (2020), p. 121420.

[11] Facundo Alvaredo, Anthony B. Atkinson, Thomas Blanchet, Lucas Chancel, Luis Bauluz, Matthew Fisher Post, Ignacio Flores, Bertrand Garbinti, Amory Gethin, Jonathan Goupille-Lebret, Clara Martínez-Toledano, Marc Morgan, Theresa Neef, Thomas Piketty, Anne-Sophie Robilliard, Emmanuel Saez, Daniel Waldenstrom, Li Yang, and Gabriel Zucman. *Distributional National Accounts (DINA) Guidelines: Concepts and Methods used in WID.world*. World Inequality Lab, 2020.

[12] Facundo Alvaredo, Lucas Chancel, Thomas Piketty, Emmanuel Saez, and Gabriel Zucman. "The elephant curve of global inequality and growth". In: *AEA Papers and Proceedings*. Vol. 108. 2018, pp. 103–08.

[13] Klaus Hubacek, Giovanni Baiocchi, Kuishuang Feng, Raúl Muñoz Castillo, Laixiang Sun, and Jinjun Xue. "Global carbon inequality". In: *Energy, Ecology and Environment* 2.6 (2017), pp. 361–369.

[14] Thomas Blanchet, Ignacio Flores, and Marc Morgan. “The weight of the rich: Improving surveys using tax data”. In: *The Journal of Economic Inequality* (2022), pp. 1–32.

[15] Glen P Peters. “From production-based to consumption-based national emission inventories”. In: *Ecological economics* 65.1 (2008), pp. 13–23.

[16] Angel Aguiar, Badri Narayanan, and Robert McDougall. “An overview of the GTAP 9 data base”. In: *Journal of Global Economic Analysis* 1.1 (2016), pp. 181–208.

[17] Ivan Kartha, Eric Kemp-Benedict, Emily Ghosh, Aisha Nazareth, and Tim Gore. *The Carbon Inequality Era: An assessment of the global distribution ofconsumption emissions among individuals from 1990 to 2015 and beyond*. Oxfam and Stockholm Environmental Institute Joint Research Report, 2020.

[18] V. Masson-Delmotte, P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.) *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, 2021.

[19] Marco Grasso and J Timmons Roberts. “A compromise to break the climate impasse”. In: *Nature Climate Change* 4.7 (2014), pp. 543–549.

[20] Jan S Fuglestvedt and Steffen Kallbekken. “Fair shares?” In: *Nature Climate Change* 6.1 (2016), pp. 19–20.

[21] H Damon Matthews. “Quantifying historical carbon and climate debts among nations”. In: *Nature Climate Change* 6.1 (2016), pp. 60–64.

[22] Thomas Blanchet, Lucas Chancel, and Amory Gethin. “Why is Europe More Equal than the US?” In: *American Economic Journal: Applied Economics* forthcoming (2022).

[23] Lucas Chancel. “Are younger generations higher carbon emitters than their elders?: Inequalities, generations and CO2 emissions in France and in the USA”. In: *Ecological Economics* 100 (2014), pp. 195–207.

[24] Lucas Chancel, Thomas Piketty, Emmanuel Saez, and Gabriel Zucman. *World inequality report 2022*. Harvard University Press, 2022.

[25] Francis Dennig, Mark B Budolfson, Marc Fleurbaey, Asher Siebert, and Robert H Socolow. "Inequality, climate impacts on the future poor, and carbon prices". In: *Proceedings of the National Academy of Sciences* 112.52 (2015), pp. 15827–15832.

[26] Mireille Chiroleu-Assouline and Mouez Fodha. "From regressive pollution taxes to progressive environmental tax reforms". In: *European Economic Review* 69 (2014), pp. 126–142.

[27] Simon Feindt, Ulrike Kornek, José M Labeaga, Thomas Sterner, and Hauke Ward. "Understanding regressivity: Challenges and opportunities of European carbon pricing". In: *Energy Economics* 103 (2021), p. 105550.

[28] Thomas Sterner. *Fuel taxes and the poor: the distributional effects of gasoline taxation and their implications for climate policy*. Routledge, 2012.

[29] Delphine Nougayrede. "Towards a Global Financial Register? The Case for End Investor Transparency in Central Securities Depositories". In: *Journal of Financial Regulation* 4.2 (2018), pp. 276–313.

[30] Thomas Piketty and Emmanuel Saez. "Inequality in the long run". In: *Science* 344.6186 (2014), pp. 838–843.

[31] A. B. Atkinson and Thomas Piketty, eds. *Top incomes: a global perspective*. Oxford: Oxford University Press, 2010.

[32] Facundo Alvaredo, Lucas Chancel, Thomas Piketty, Emmanuel Saez, and Gabriel Zucman. "The Elephant Curve of Global Inequality and Growth". In: *AEA Papers and Proceedings* 108 (2018), pp. 103–08.

[33] Thomas Piketty, Emmanuel Saez, and Gabriel Zucman. "Distributional national accounts: methods and estimates for the United States". In: *The Quarterly Journal of Economics* 133.2 (2018), pp. 553–609.

[34] Facundo Alvaredo, Lucas Chancel, Thomas Piketty, Emmanuel Saez, and Gabriel Zucman. *World inequality report 2018*. Harvard University Press, 2018.

[35] Manfred Lenzen, Mette Wier, Claude Cohen, Hitoshi Hayami, Shonali Pachauri, and Roberto Schaeffer. “A comparative multivariate analysis of household energy requirements in Australia, Brazil, Denmark, India and Japan”. In: *Energy* 31.2-3 (2006), pp. 181–207.

[36] Christopher L Weber and H Scott Matthews. “Quantifying the global and distributional aspects of American household carbon footprint”. In: *Ecological economics* 66.2-3 (2008), pp. 379–391.

[37] Shonali Pachauri. “An analysis of cross-sectional variations in total household energy requirements in India using micro survey data”. In: *Energy policy* 32.15 (2004), pp. 1723–1735.

[38] Angela Druckman and Tim Jackson. “Household energy consumption in the UK: A highly geographically and socio-economically disaggregated model”. In: *Energy Policy* 36.8 (2008), pp. 3177–3192.

[39] Mette Wier, Manfred Lenzen, Jesper Munksgaard, and Sinne Smed. “Effects of Household Consumption Patterns on CO2 Requirements”. In: *Economic Systems Research* 13.3 (2001), pp. 259–274.

[40] Jordi Roca and Mònica Serrano. “Income growth and atmospheric pollution in Spain: an input–output approach”. In: *Ecological Economics* 63.1 (2007), pp. 230–242.

[41] Christopher L Weber and H Scott Matthews. “Quantifying the global and distributional aspects of American household carbon footprint”. In: *Ecological economics* 66.2-3 (2008), pp. 379–391.

[42] GP Peters, J Aasness, N Holck-Steen, and EG Hertwich. “Environmental impacts and household characteristics: an econometric analysis of Norway 1999–2001”. In: *Proceedings, Sustainable Consumption Research Exchange, Wuppertal* (2006).

[43] Milena Buchs and Sylke V. Schnepf. “Who emits most? Associations between socio-economic factors and UK households home energy, transport, indirect and total CO2 emissions”. In: *Ecological Economics* 90 (2013), pp. 114 –123.

[44] Jonas Nässén. “Determinants of greenhouse gas emissions from Swedish private consumption: Time-series and cross-sectional analyses”. In: *Energy* 66 (2014), pp. 98–106.

[45] Antonin Pottier. “Expenditure elasticity and income elasticity of GHG emissions: A survey of literature on household carbon footprint”. In: *Ecological Economics* 192 (2022), p. 107251.

[46] Sanna Ala-Mantila, Jukka Heinonen, and Seppo Junnila. “Relationship between urbanization, direct and indirect greenhouse gas emissions, and expenditures: A multivariate analysis”. In: *Ecological Economics* 104 (2014), pp. 129–139.

[47] Jane Golley and Xin Meng. “Income inequality and carbon dioxide emissions: The case of Chinese urban households”. In: *Energy Economics* 34.6 (2012), pp. 1864–1872.

[48] Brantley Liddle. “What are the carbon emissions elasticities for income and population? Bridging STIRPAT and EKC via robust heterogeneous panel estimates”. In: *Global Environmental Change* 31 (2015), pp. 62–73.

[49] Wassily Leontief. *Input-output economics*. Oxford University Press, 1986.

[50] Wassily Leontief. “Environmental repercussions and the economic structure: an input-output approach”. In: *The review of economics and statistics* (1970), pp. 262–271.

[51] Steven J Davis and Ken Caldeira. “Consumption-based accounting of CO2 emissions”. In: *Proceedings of the National Academy of Sciences* 107.12 (2010), pp. 5687–5692.

[52] UN, WB, EC, and IMF. *System of National Accounts 2008*. 2008.

[53] Lucas Chancel. “Towards Distributional National and Environmental Accounts”. In: *Statistical Journal of the IOAS* 36.3 (2020), pp. 597–605.

[54] Pierre Friedlingstein, Michael O’sullivan, Matthew W Jones, Robbie M Andrew, Judith Hauck, Are Olsen, Glen P Peters, Wouter Peters, Julia Pongratz, Stephen Sitch, et al. “Global carbon budget 2020”. In: *Earth System Science Data* 12.4 (2020), pp. 3269–3340.

[55] Lenzen Manfred, Daniel Moran, Keiichiro Kanemoto, and Arne Geschke. "BUILDING EORA: A GLOBAL MULTI-REGION INPUT–OUTPUT DATABASE AT HIGH COUNTRY AND SECTOR RESOLUTION". In: *Economic Systems Research* 25.1 (2013), pp. 20–49.

[56] François Burq and Lucas Chancel. "Aggregate Carbon Footprints on WID.world". In: *World Inequality Lab Technical Notes* 3 (2021).

[57] Yannic Rehm and Lucas Chancel. "Measuring the carbon content of wealth. Evidence from France and Germany". In: *World Inequality Lab Working Paper* (2022).

[58] Carbone4. "Estimation de l'empreinte carbone du patrimoine financier en France". In: *Note Méthodologique* (2020).

[59] Emmanuel Saez and Gabriel Zucman. "Wealth inequality in the United States since 1913: Evidence from capitalized income tax data". In: *The Quarterly Journal of Economics* 131.2 (2016), pp. 519–578.

[60] *Climate Action Tracker*. 2021.

[61] United Nations. Dept. of Economic and Social Affairs. Population Division. *World Population Prospects: The 2019 Revision*. United Nations Publications, 2019.

[62] *OECD GDP long term forecast*. 2021.

[63] D Wiedenhofer. "Unequal household carbon footprints in China". In: *Nature Climate Change* 7.1 (2017), pp. 75–80.

[64] Christoph Weber and Adriaan Perrels. "Modelling lifestyle effects on energy demand and related emissions". In: *Energy policy* 28.8 (2000), pp. 549–566.

[65] Bernhard Gill and Simon Moeller. "GHG emissions and the rural-urban divide. A carbon footprint analysis based on the German official income and expenditure survey". In: *Ecological Economics* 145 (2018), pp. 160–169.

[66] Gilang Hardadi, Alexander Buchholz, and Stefan Pauliuk. "Implications of the distribution of German household environmental footprints across income groups for integrating environmental and social policy design". In: *Journal of Industrial Ecology* 25.1 (2021), pp. 95–113.

[67] Rosa Duarte, Alfredo Mainar, and Julio Sánchez-Chóliz. “Social groups and CO2 emissions in Spanish households”. In: *Energy policy* 44 (2012), pp. 441–450.

[68] Juudit Ottelin, Jukka Heinonen, and Seppo Junnila. “Carbon and material footprints of a welfare state: Why and how governments should enhance green investments”. In: *Environmental Science & Policy* 86 (2018), pp. 1–10.

[69] Juudit Ottelin, Jukka Heinonen, and Seppo Junnila. “Carbon footprint trends of metropolitan residents in Finland: how strong mitigation policies affect different urban zones”. In: *Journal of cleaner production* 170 (2018), pp. 1523–1535.

[70] Fabrice Lenglart, Christophe Lesieur, and Jean-Louis Pasquier. “Les émissions de CO2 du circuit économique en France”. In: *L’économie Francaise* (2010).

[71] Jan C Minx, Thomas Wiedmann, Richard Wood, Glen P Peters, Manfred Lenzen, Anne Owen, Kate Scott, John Barrett, Klaus Hubacek, Giovanni Baiocchi, et al. “Input–output analysis and carbon footprinting: an overview of applications”. In: *Economic systems research* 21.3 (2009), pp. 187–216.

[72] Giovanni Baiocchi, Jan Minx, and Klaus Hubacek. “The impact of social factors and consumer behavior on carbon dioxide emissions in the United Kingdom: A regression based on input- output and geodemographic consumer segmentation data”. In: *Journal of Industrial Ecology* 14.1 (2010), pp. 50–72.

[73] Ian Gough, Saamah Abdallah, Victoria Johnson, Josh Ryan-Collins, and Cindy Smith. “The distribution of total greenhouse gas emissions by households in the UK, and some implications for social policy”. In: *LSE STICERD Research Paper No. CASE152* (2011).

[74] Milena Büchs and Sylke V Schnepf. “Who emits most? Associations between socio-economic factors and UK households’ home energy, transport, indirect and total CO2 emissions”. In: *Ecological Economics* 90 (2013), pp. 114–123.

[75] Mohammad Iqbal Irfany and Stephan Klasen. “Inequality in emissions: evidence from Indonesian household”. In: *Environmental Economics and Policy Studies* 18.4 (2016), pp. 459–483.

[76] Jyoti K Parikh, Manoj K Panda, and NS Murthy. “Consumption patterns by income groups and carbon–dioxide implications for India: 1990–2010”. In: *International Journal of Global Energy Issues* 9.4-6 (1997), pp. 237–255.

[77] Jyoti Parikh, Manoj Panda, Anand Ganesh-Kumar, and Vinay Singh. “CO2 emissions structure of Indian economy”. In: *Energy* 34.8 (2009), pp. 1024–1031.

[78] Annemarie C Kerkhof, René MJ Benders, and Henri C Moll. “Determinants of variation in household CO2 emissions between and within countries”. In: *Energy policy* 37.4 (2009), pp. 1509–1517.

[79] Elisabeth T Isaksen and Patrick A Narbel. “A carbon footprint proportional to expenditure-A case for Norway?” In: *Ecological Economics* 131 (2017), pp. 152–165.

[80] Kjartan Steen-Olsen, Richard Wood, and Edgar G Hertwich. “The carbon footprint of Norwegian household consumption 1999–2012”. In: *Journal of Industrial Ecology* 20.3 (2016), pp. 582–592.

[81] Moises Neil V Seriño and Stephan Klasen. “Estimation and Determinants of the Philippines’ Household Carbon Footprint”. In: *The Developing Economies* 53.1 (2015), pp. 44–62.

[82] Lutz Sager. “Income inequality and carbon consumption: Evidence from Environmental Engel curves”. In: *Energy Economics* 84 (2019), p. 104507.

[83] Christopher M Jones and Daniel M Kammen. “Quantifying carbon footprint reduction opportunities for US households and communities”. In: *Environmental science & technology* 45.9 (2011), pp. 4088–4095.

[84] Kevin Ummel. “Who pollutes? A household-level database of America’s greenhouse gas footprint”. In: *Center for Global Development Working Paper* 381 (2014).

[85] Kaihui Song, Shen Qu, Morteza Taiebat, Sai Liang, and Ming Xu. “Scale, distribution and variations of global greenhouse gas emissions driven by US households”. In: *Environment international* 133 (2019), p. 105137.

[86] Anders Fremstad, Anthony Underwood, and Sammy Zahran. "The environmental impact of sharing: household and urban economies in CO2 emissions". In: *Ecological economics* 145 (2018), pp. 137–147.

[87] Maarten Christis, Koen Breemersch, An Vercalsteren, and Evelien Dils. "A detailed household carbon footprint analysis using expenditure accounts–Case of Flanders (Belgium)". In: *Journal of Cleaner Production* 228 (2019), pp. 1167–1175.

[88] Bastien Girod and Peter De Haan. "More or better? A model for changes in household greenhouse gas emissions due to higher income". In: *Journal of industrial ecology* 14 (2010).

[89] Yannick Rehm. "Estimating the carbon content of wealth". In: *Paris School of Economics Working Paper* (2021).

[90] J. Gütschow, L. Jeffery, R. Gieseke, R. Gebel, D. Stevens, M. Krapp, and M. Rocha. "The PRIMAP-hist national historical emissions time series". In: *Earth Syst. Sci. Data* 8 (2016), pp. 571–603.

[91] Thomas Blanchet, Luis Bauluz, Clara Martinez-Toledano, and Alice Sodano. "Estimation of Global Wealth Aggregates in WID.world: Methodology". In: *WID.world Technical Note 2021/13* (2021).

[92] Felix Bajard, Lucas Chancel, Rowaida Moshrif, and Thomas Piketty. "Global wealth inequality on WID.world: estimates and imputations". In: *World Inequality Lab Technical Notes* 16 (2021).

METHODS

Income and wealth inequality data. The methodology used in this paper requires precise data on the distribution of income and wealth within countries. The past two decades were marked by important breakthroughs in our capacities to monitor global income and wealth inequality [30, 24], which the paper builds upon. The standard source of information for tracking inequality within countries is household surveys. While these surveys constitute a rich source of information for grasping various facets of socio-economic inequality, they do not provide statistics comparable across countries, typically fail to properly measure incomes and wealth at the top of the distribution, and are usually not consistent with macroeconomic totals [31, 32].

The Distributional National Accounts (DINA) methodology [33, 11], developed by a large network of researchers affiliated with the World Inequality Database (wid.world) in partnership with national and international statistical organizations and the United Nations, seeks to address these issues by systematically combining household surveys with additional sources of information on economic inequality (including, in particular, administrative tax data and national accounts). On the one hand, tax data offer a more reliable account of income and wealth dynamics among wealthy groups than those reported by individuals in household surveys, and they enable long term comparisons, spanning decades (even centuries, in some countries). On the other hand, using national accounts concepts makes it possible to compare income and wealth levels and dynamics more systematically across countries.

DINA made it possible to improve our collective understanding of the ultimate beneficiaries of economic growth within countries and at the global level. This body of work reveals that most societies went through a decline in inequality between the 1920s and the 1970s and then saw a return of inequality since the 1980s [34]. Such findings have generated significant academic and public debate on the causes and consequences of inequality within countries. While such dynamics can have important impacts on the inequality of carbon emissions, the connections between income, consumption, wealth and GHG emissions have attracted limited attention to date. In fact, there have been no attempts to measure the dynamics of the global distribution of carbon emissions taking stock of recent progress in global inequality research in the context of Distributional National Accounts ([9] use a very preliminary version of the World Inequality Database and focus on the 1998-2013 period, that is just half of the period of this study). More recent work by Bruckner et al. [8] focuses on a single year and authors stress that their estimates do not cover the emissions of top income groups particularly well. The purpose of this paper was to study the dynamics of global carbon emissions over several decades, with a particular focus on emissions at the top of the distribution.

The economic inequality data sets used in this study, developed in the context of the World Inequality Database research (wid.world) [11], provide income and wealth inequality series for 174 countries for the 1990-2019 period, i.e. for more than 97% of the world population and 97% of global Gross Domestic Product or global income. (See **SI** Section 2.) The general guidelines and methods underlying these data series are described in the Distributional National Accounts Guidelines [11]. Income inequality levels for all countries are presented in **SI** Table 9.1.

Elasticity between carbon emissions and consumption or income. Most countries do not publish standardized data sources on individual emissions, but such information can be reconstructed from household surveys with additional data on energy and emissions. Data on individual emissions inequalities have been produced for several countries and years by researchers using input-output tables (see below) [35, 36, 37, 38].

Available literature typically finds that carbon emissions associated with individual consumption depend on several factors, including income and expenditure, as well as household location, energy conversion technologies, occupation status, habits, age, national regulations, and energy mixes [35, 39, 40, 41, 42, 43, 44, 45] (see also **SI** section 5 for complete list of studies on the matter). While non-income factors play a significant role in determining direct individual emissions (i.e. emissions stemming from the direct use of energy, such as those associated with car driving), income is found to be the main driver of indirect emissions (those associated with energy used to produce goods and services that are consumed by individuals), and of overall emissions inequalities between individuals. At a given income level, two individuals may have very different heating and transportation needs, implying different direct energy requirements and different direct emissions. However, when we take into account the carbon content of their overall consumption and their indirect energy requirements (the energy used to produce the clothes and appliances they buy, the food they eat, the services they purchase, etc.), income differences explain most of the differences observed in carbon footprints.

Studies measuring the *elasticity* of individual carbon emissions (or the strength of the relationship between rising individual income and CO_2 emissions, see Methods)[9] are presented in **SI** section 5. These studies find that the elasticity of household

[9]In a model of the form $\log(CO_2) = \alpha. \log(income)$, where α is the elasticity

consumption to emissions typically falls in the 0.9-1.1 range, while the elasticity of household income to emissions typically falls in the 0.5-0.7 range [35, 39, 40, 41, 46, 47, 42, 43, 45].[10] The benchmark results presented in this paper are based on elasticities from the literature, which are available for most countries (see below).

Environmental input-output data. The most straightforward way to obtain internationally comparable direct and indirect emission levels of individuals is via the Input-Output (IO) framework. The IO framework is a quantitative model of the economy, initially developed to represent dependencies between different economic sectors (households, governments, firms) within and between countries [49]. The framework was extended to economy-environment interactions [50] in order better to understand the material content of production and the impact of environmental policies, and then relatively recently to study the flows of carbon embodied in international trade [51, 15].

In the context of carbon accounting, the strength of the IO framework is its reliance on a systematic representation of the world economy that avoids double counting: the same tonne of carbon cannot be ultimately attributed to two different agents[11]. The environmental IO approach is also useful because it can distinguish between emissions from household consumption, investments and government expenditures, in line with national accounts concepts [52, 53].[12]

Let Z be the inter-industry transactions matrix (i.e. the flow of intermediary goods and services between industries required to produce the final products), Y the final demand matrix (the final demand associated with the household, investment and government sectors of the economy), Q the carbon emissions matrix and x the vector of gross output by country sector (See **SI** Section 1). Leontief's inverse (or

[10] See also [48] for elasticity estimations based on macroeconomic data, rather than micro-level household data.

[11] In other carbon accounting methodologies, such as the life-cycle analyses, the double counting problem is omnipresent

[12] Changes in inventories and stocks are also reported in the data set. Since these only represent a small fraction of emissions, I include them in GFCF totals so as to keep fully consistent data sets that always match aggregate totals. I also include the emissions of non-profit institution serving households in the household sector as a first approximation.

the impact of final demand on the output of a given sector) is given by:

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

With:

$$A = Zx^{-1} \tag{2}$$

The carbon intensity of production is then given by:

$$C = (Qx^{-1})L \tag{3}$$

Carbon emissions associated with final demand of each sector of the economy is obtained as follows:

$$N = CY \tag{4}$$

The IO framework makes it possible to calculate N for the government sector (S13 in the National Accounts [52]), the household sector (S14) and separately for Gross Fixed Capital Formation (P51). For each of these ”institutional” sectors, emissions can be calculated for each production sector (construction, food, etc.). In that sense, we are able to isolate emissions which enter the production chain of goods and services consumed by households and government and to also isolate emissions associated with the production of fixed capital by the private or government sector, i.e. with private or public investments. For each production sector and each institutional sector, within each country and year, it is possible to obtain different average emissions intensities per dollar spent.

The benchmark MRIO data source used in this paper is the Global Carbon Project (GCP) [54]. In certain cases, GCP provides no data for a given country or a given type of emissions. In order to cover all countries and all types of emissions, the paper also relied on the EORA dataset [55].[13]

Distributing emissions among individuals. In line with the national accounts methodology, I break down national-level distributions (of income, wealth or carbon emitters) in 127 generalized percentiles: 99 percentiles from $p = 0\%$ to $p = 99\%$, nine tenths of a percentile from $p = 99\%$ to $p = 99.9\%$, nine hundredths of a

[13]For details on the construction of aggregate series used in this study, see **SI** Section 1 and [56].

percentile from $p = 99.9\%$ to $p = 99.99\%$, 10 thousandths of a percentile from $p = 99.99\%$ to $p = 100\%$. In order to determine carbon emission levels associated with each of these generalized percentiles of income, in each country of the world, I proceed as follows: average per capita emissions at percentile p, in a given year and country are defined as

$$E_p^{tot} = E_p^{cons} + E_p^{inv} + E_p^{gov} \tag{5}$$

Where E_p^{cons}, E_p^{inv}, E_p^{gov} are individual average footprints at percentile p, associated with consumption, private investment and public spending, respectively. More precisely:

$$E_p^{cons} = f(E^{cons}, y_p, \alpha) \tag{6}$$

$$E_p^{inv} = f(E^{inv}, w_p, \gamma) \tag{7}$$

$$E_p^{gov} = f(E^{gov}, y_p, \delta) \tag{8}$$

Where E^{cons} is the average carbon footprint associated with a unit of consumption in the country, y_p the average income level of individuals in percentile p, α the elasticity of household consumption carbon emissions to income (in a model of the form $E_p^{cons} = kE^{cons} \times y_p^{\alpha}$); E^{inv} is the average emissions level associated with investments (or asset ownership, in this framework), w_p the average wealth level of individuals in percentile p, γ the elasticity of wealth to investment emissions; E^{gov} is the average emission level of the government sector (associated with in-kind redistribution) and δ, is the elasticity of government emissions to individual income.

The benchmark results presented in this paper are based on α values available from country-level studies based on micro-data. For several countries, income-carbon elasticity (α) values are not directly available, but consumption-carbon elasticities are available. In these cases, income-carbon elasticities are predicted from observed regularities between consumption-carbon and income-carbon elasticities (see **SI** section 5). In a few countries, it is possible to observe different α values over time. These values do not indicate any clear trend over time. Given that there are no time-series for α for most countries, I opt for constant country-level α for the period considered. I also test a variety of α values for each country, and find that these have relatively little impact on global and regional levels as well as trends observed (see Robustness checks below).

Fitting the model with observed γ is a challenging task given how few studies of the matter exist. Rehm and Chancel [57] find that the elasticity of asset ownership to wealth is in the [0.95;1.15] range (see also **SI** section 5). This finding is corroborated by the data produced by [58], which give an elasticity of the carbon content of asset portfolios to income slightly above unity. Limited available evidence therefore suggests that the distribution of emissions associated with wealth ownership is close to proportional to the distribution of wealth ownership. If anything, it appears that there is little justification to assume that γ is significantly below unity. I opt for $\gamma = 1$ as the benchmark parameter and see this choice as a relatively conservative and as a transparent option. Under this rule, a group owning $x\%$ of the total capital stock is attributed $x\%$ of total emissions associated with capital formation.

It is possible, however, that γ is actually higher than one. One reason is that I assume that investments are proportional to the distribution of wealth in the benchmark scenario. This assumption is due to the absence of global time series on the distribution of investments across countries and wealth groups. Empirically, it is found that investments and savings are often more unequally distributed than personal wealth over the period considered. To the extent that investments are more concentrated than the distribution of total wealth (as was for instance the case in the US over the past decades [59]), the benchmark scenario is conservative, i.e. it tends to underestimate the levels of carbon inequality associated with capital formation, rather than overestimate them. In which case, $\gamma > 1$ should be preferred. This issue is further discussed in **SI** section 5 and results for different γ values are presented in **SI** section 7.

The benchmark scenario is based on $\delta = 0$. This amounts to distributing collective government consumption expenditure equally to individuals, as a lump-sum. Given the little available data on the distribution of government consumption expenditure, it is necessary to make a preliminary assumption. If anything, delta=0 should be seen as a conservative choice, which tends to minimize inequality in carbon emissions between income groups. In alternative scenarios, the paper distributes emissions in proportion to individuals' consumption. This mechanically increases top emitters' emissions and reflects a world in which individuals benefit from government spending in proportion to their private spending. This view cannot be ruled out, although it is unclear whether emissions associated with primary education, justice or military expenses can realistically be distributed proportionally to private spending. In any case, given that overall government emissions remain relatively low as compared with private consumption and investments, the impact of setting $\delta = 1$ appears to be fairly limited on bottom and top groups' overall emissions, as can be seen in **SI** Table 7.2.

Besides the benchmark scenario, I produce results for the following set of parameters: $\alpha = \{0.4; 0.5; 0.6; 0.7; 0.8\}$; $\gamma = \{0.8; 0.9; 1; 1.1; 1.2\}$; $\delta = \{0; 1\}$. Extreme scenario bounds presented in the main paper are based on extreme bounds observed in available country-level data, that is $\alpha = [0.4; 0.8]$ and $\gamma = [0.9; 1.1]$. In all countries, I assume that emissions are split equally within households.

Robustness checks. Upper and lower bounds are presented on the main graphs of this paper. The Supplementary Information also provides additional results for different parametric assumptions at the global, regional and country levels. This set of information reveals that the main results appear to be quite robust to these changes. In the extreme lower-bound scenario (i.e. a scenario in which all countries would have the lowest empirically observed α value, which is very unlikely), I find that the global top 10% share of emissions nears 45% in 2019 (vs. 48% in the benchmark scenario). In the extreme upper-bound scenario (i.e. a scenario in which all countries would have the highest empirically observed α value), I find that the global top 10% share is 51%. Setting different γ parameters affects results at the top of the distribution, although in a moderate way: with γ=0.9 (and using empirically observed α values), the global top 10% share is equal to 46% in 2019. With γ=1.1 the global top 10% share is equal to 50% in 2019. Opting for $\delta = 1$ yields a global top 10% of around 50% and a bottom 50% share near 10%.

Global dynamics between 1990 and 2019 also appear to be robust across these different scenarios and are not particularly sensitive to changes in parameter values within the bounds considered, as presented in Figures IV orV. Changes in parameter values over time also tend to have little impact on the key results, as illustrated on Figure VI, for instance: if α had decrease in all countries from 0.8 to 0.4 between 1990 and 2019 (that is, if the wealthy had done much more decarbonization efforts than the rest of the population, per dollar spent), global emissions inequality we would still be essentially driven by within-country dynamics today.

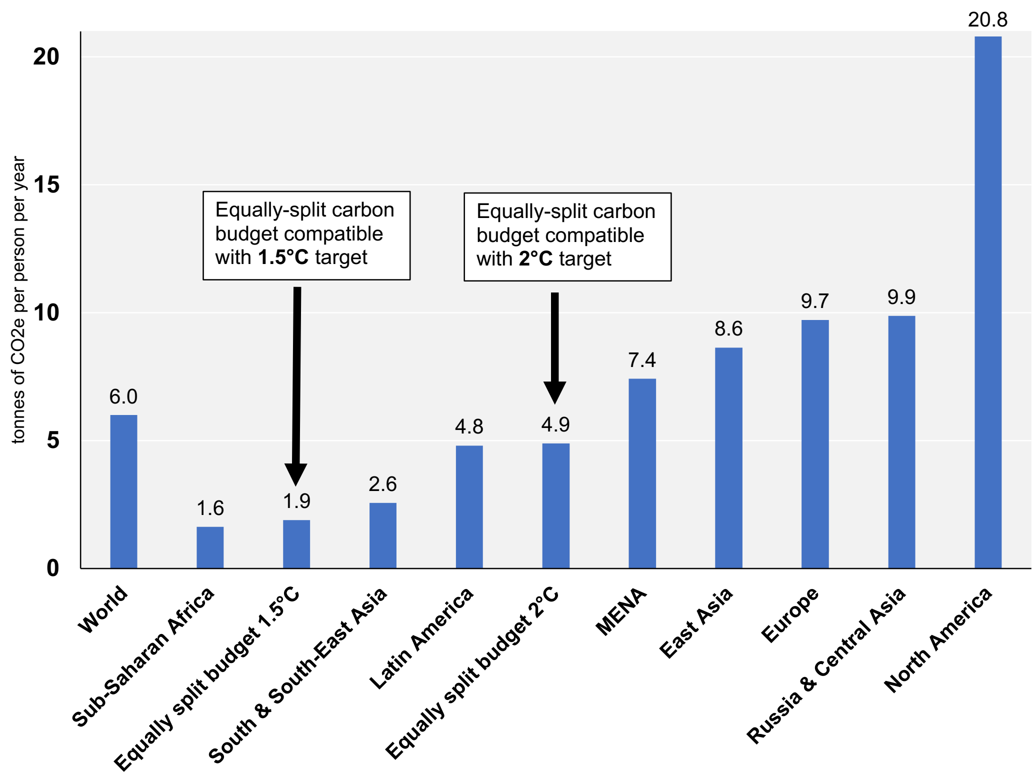
Tables in the **SI** (section 7) provide regional and national values for a wide range of scenarios, regions and emitter groups, over the time period considered. While none of the set of scenarios presented (or other combinations) cannot be entirely ruled out, the benchmark results presented in the main part of the paper stand out as the best available options given the current state of knowledge on the relationships between emissions, income, consumption and wealth.

The flexible framework developed in this paper makes it possible to use other country-level studies to study the dynamics of global carbon inequality over relatively long time-spans in the future, when these studies are published. All the data gathered for this study, as well as the computer codes, will be posted online on the World Inequality Database, making it possible for researcher to expand this work, or change key assumptions.

National 2030 targets. Per capita national targets are based on countries' Nationally Determined Commitments as of July 2021. Values are obtained from [60]. Rich countries typically express their targets in terms of percentage reductions to be achieved by a certain date rather than a benchmark date. For instance, the US objective is to cut its total emissions by 50-52% over 2005 levels. In order to obtain per capita targets in 2030, I divide the implied 2030 emissions total by the US population in 2030, using UN Population Prospects [61]. In emerging countries, targets are typically expressed as changes in the carbon intensity of GDP. In that case, I use GDP forecasts produced by the OECD [62] and calculate the implied per capita emission target, based on the carbon intensity targets announced by the country (see also **SI** Section 8).

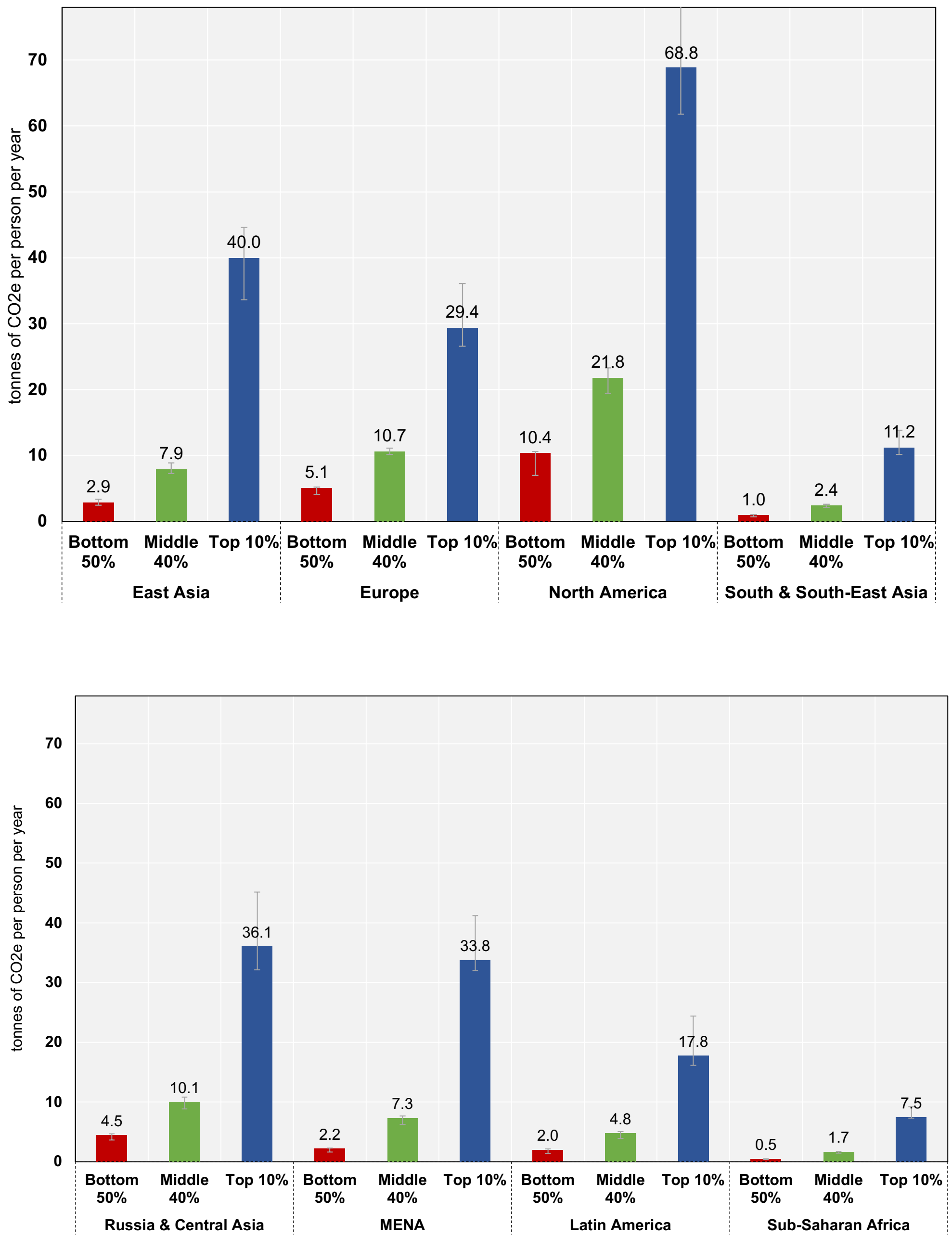
Acknowledgements

The author thanks Felix Bajard, François Burq Aymeric Capitaine for research assistance as well as Thomas Piketty, Tancrède Voituriez, Thomas Blanchet, Rowaida Moshrif, the UNPD HDRO team, participants at the Paris School of Economics, the London School of Economics, Harvard Kennedy School and Sciences Po seminars, for their valuable insights.



Notes: Sharing the remaining carbon budget to have 83% chances to stay below 1.5°C global temperature increase implies an estimated annual GHG per capita emissions near 1.9 tonnes per person per year between 2021 and 2050 (and zero CO_2 emissions afterwards). Emission levels present regional per capita emissions and include all emissions from domestic consumption, public and private investments as well as imports and exports of carbon embedded in goods and services traded with the rest of the world (LULUCF emissions are excluded). **Source and series**: Author, see Methods and Supplementary Information.

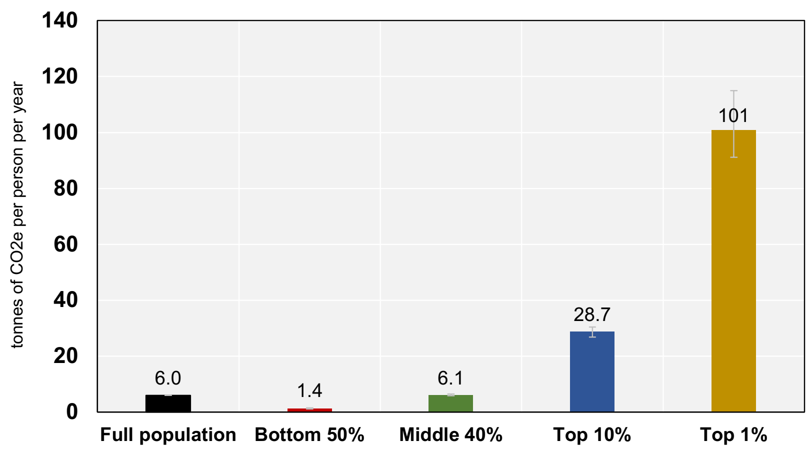
Figure I
Average GHG emissions by world region, 2019



Notes: Individual carbon footprints include emissions from domestic consumption, public and private investments, and imports and exports of carbon embedded in goods and services traded with the rest of the world. Benchmark scenario with modeled estimates based on the systematic combination of tax data, household surveys and input-output tables. Emissions split equally within households. Error bars show estimates for extreme scenarios (with $\alpha = 0.4$ and $\alpha = 0.8$ in the other). **Source and series**: Author, see Methods and Supplementary Information.

Figure II
Carbon footprints by income group across the world, 2019

(a) Per capita emissions by group (tCO_2 / year)



(b) Group share (%) in world total emissions

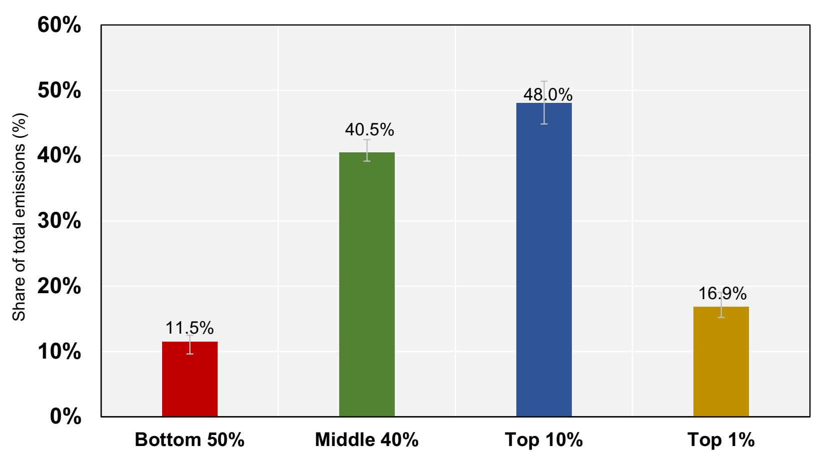
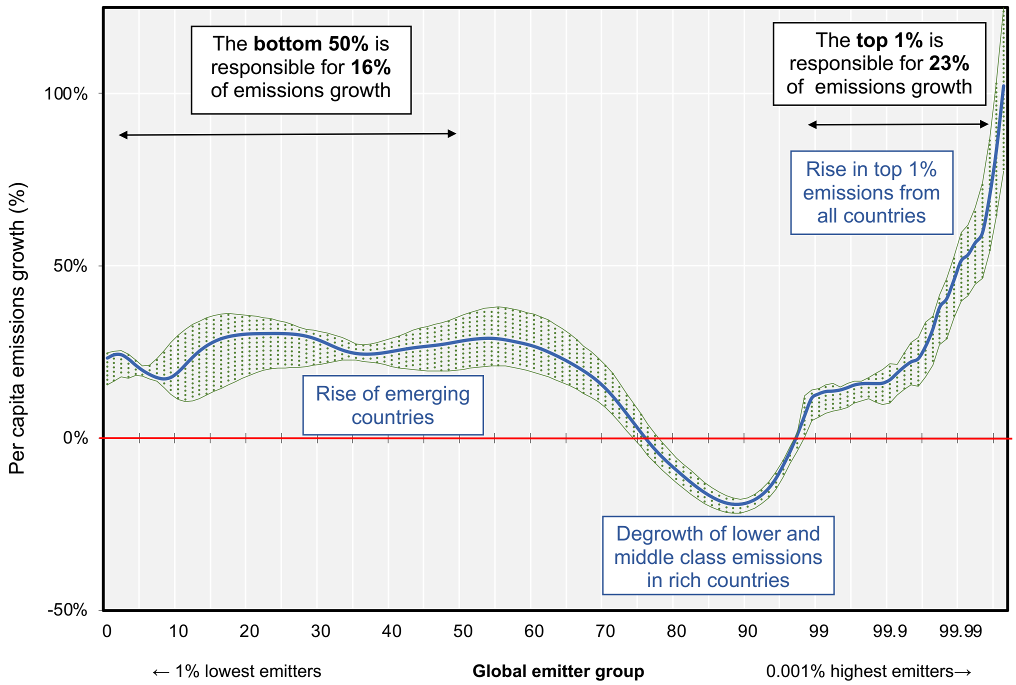


Figure III

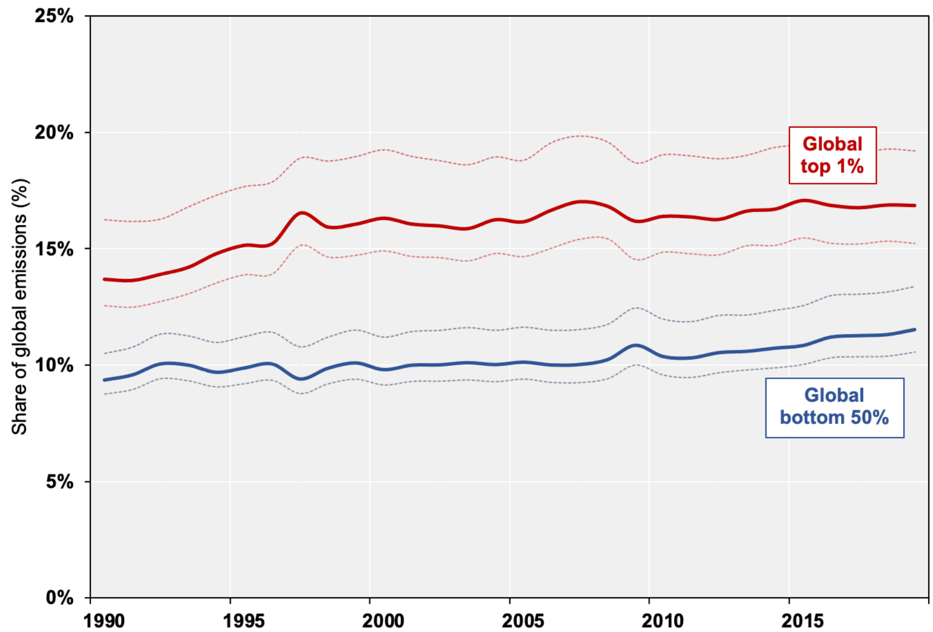
Global inequality in individual carbon emissions, 2019

Notes: Personal carbon footprints include emissions from domestic consumption, public and private investments as well as imports and exports of carbon embedded in goods and services traded with the rest of the world. Modeled estimates are based on the systematic combination of tax data, household surveys and input-output tables. Emissions split equally within households. Benchmark scenario. Error bars show estimates for extreme scenarios (with $\alpha = 0.4$ in one case and $\alpha = 0.8$ in the other).
Source and series: Author, see Methods and Supplementary Information.



Notes: Emissions of the global bottom 50% rose by around 20-40% between 1990 and 2019. Emissions notably declined among groups above the bottom 80% and below the top 5% of the global distribution, these groups mainly correspond to lower and middle income groups in rich countries. Emissions of the global top 1% and richer groups rose substantially. Personal carbon footprints include emissions from domestic consumption, public and private investments as well as imports and exports of carbon embedded in goods and services traded with the rest of the world. Modeled estimates based on the systematic combination of tax data, household surveys and input-output tables. Benchmark scenario. Emissions split equally within households. Dotted area represents the range of extreme scenarios. **Source and series**: Author, see Methods and Supplementary Information.

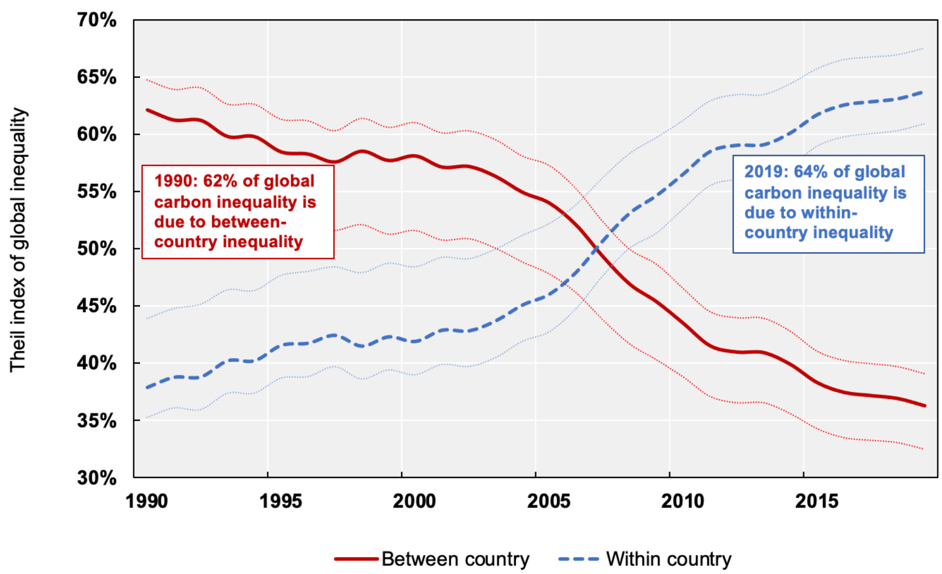
Figure IV
Global inequality and carbon emissions, 1990-2019



Notes: This figure presents the share of global GHG emissions by the top 1% and bottom 50% of the global population between 1990 and 2019. GHG emissions measured correspond to individual footprints, i.e. they include indirect emissions produced abroad and embedded in individual consumption. Modeled estimates based on the systematic combination of tax data, household surveys and input-output tables. Thick line shows the benchmark scenario. Dotted lines show results for $\alpha = 0.4$ and $\alpha = 0.8$. Emissions split equally within households. **Source and series**: Author, see Methods and Supplementary Information.

Figure V

Top 1% and bottom 50% shares in global carbon emissions, 1990-2019

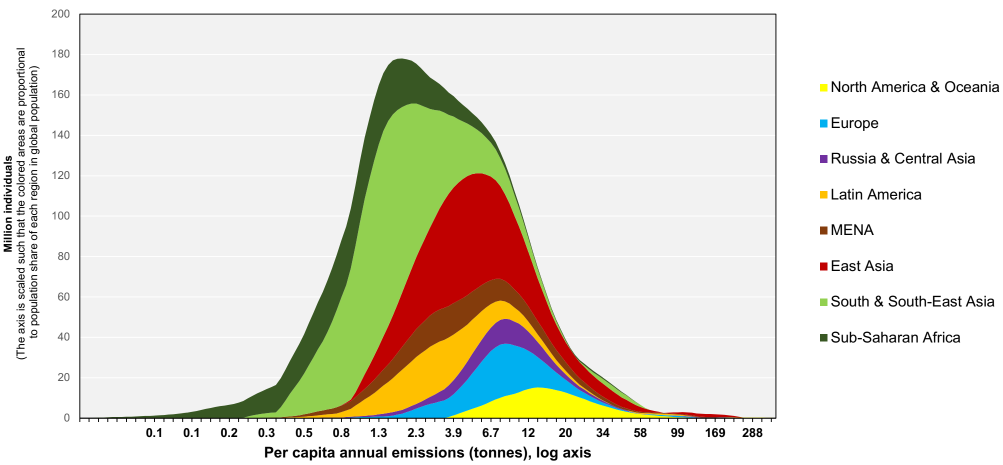


Notes: 37% of global carbon inequality between individuals is due differences in emissions levels between countries while 63% is explained by inequality within countries in 2019. Modeled estimates based the systematic combination of tax data, household surveys and input-output tables. Benchmark scenario. Dotted lines represent scenarios with $\alpha = 0.4$ and $\alpha = 0.9$ **Source and series**: Author, see Methods and Supplementary Information.

Figure VI

Theil index decomposition of global carbon inequality

(a) Global carbon emissions density function



(b) Share of each region in the emissions of global emitter groups

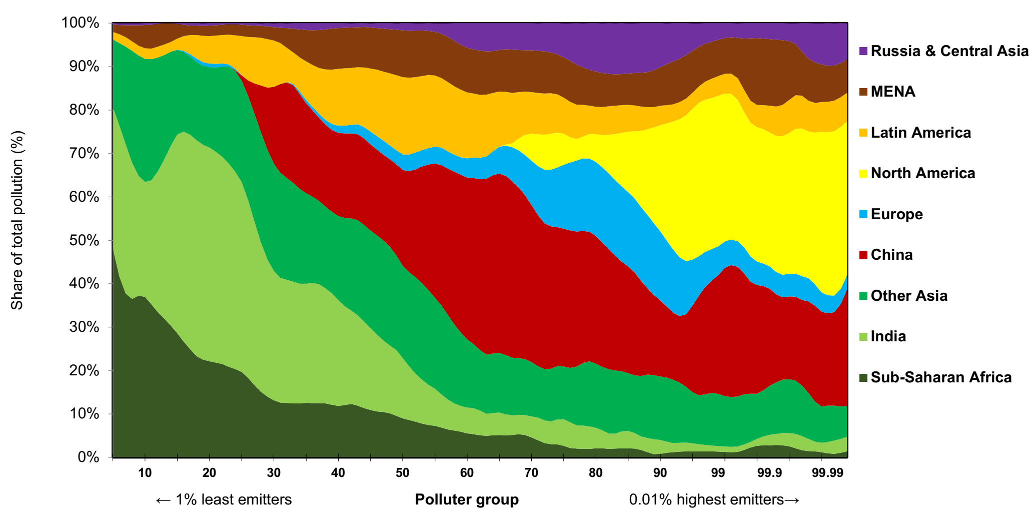
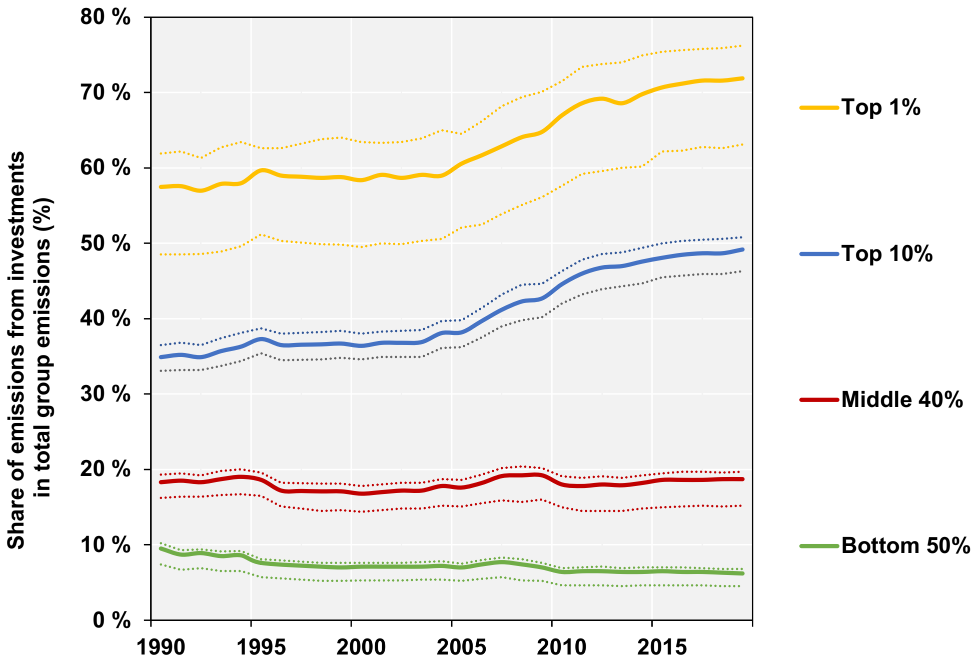


Figure VII
Geographical breakdown of global emitters, 2019

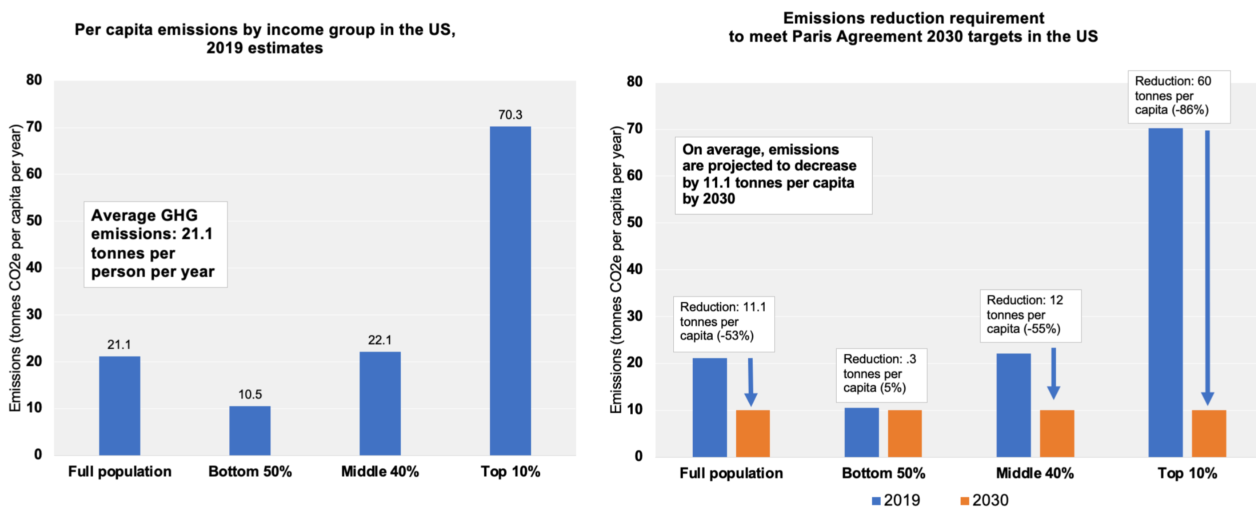
Notes: Panel A shows the number of emitters from each world region across the per-capita emissions scale. The Y axis is scaled such that the colored areas are proportional to the population share of each region in total world population. The X axis is log-scaled. **Panel B** shows the share of each region's population within each global emitter group. Among the lowest emitter groups, about 30-40% of the population lives in Sub-Saharan Africa. GHG emissions measured correspond to individual footprints, i.e. they include indirect emissions produced abroad and embedded in individual consumption. Modeled estimates are based on the systematic combination of tax data, household surveys and input-output tables. Benchmark scenario. Emissions split equally within households. **Sources and series**: Author, see Methods and Supplementary Information.



Notes: This figure presents the share of GHG emissions by different groups of emitters that can be traced to their investments, rather than to their consumption. Modeled estimates based the systematic combination of tax data, household surveys and input-output tables. Benchmark scenario with values from extreme scenarios (with $\alpha = 0.8$ and $\gamma = 1.1$). **Source and series**: Author, see Methods and Supplementary Information.

Figure VIII
The share of investments in emissions of global emitter groups, 1990-2019

(a) Emissions inequality and climate targets in the US



(b) Emissions inequality and climate targets in China

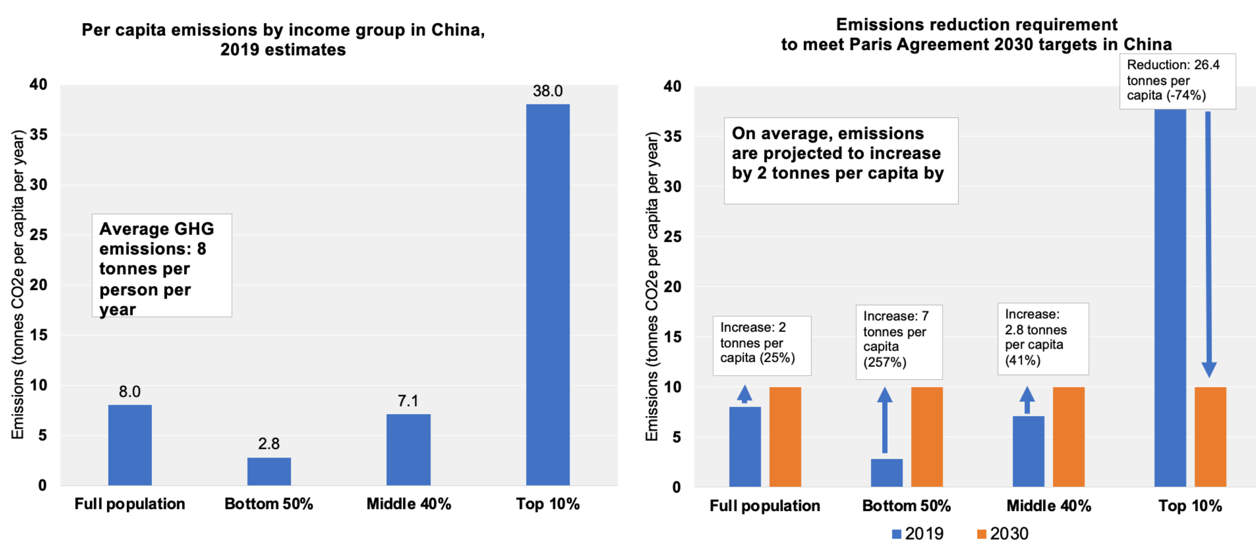


Figure IX
Emissions inequality and climate targets

Notes: The graph shows national emissions targets (NDCs) expressed in per capita terms, and compares these with current emission levels of different income groups in the US and in China. For China, targets are expressed in efficiency terms so I use GDP projections to obtain overall emissions levels. **Sources and series**: Author, see Methods and Supplementary Information.

Table I
Global carbon inequality, 2019

	Population (million)	**Avg. emissions** (tCO2e / cap.)	**Threshold** (tCO2e / cap.)	**Share** (% world emissions)
Full pop.	7710	6	<0.1	100%
Bottom 50%	3855	1.4	<0.1	11.5%
incl. Bottom 20%	*1542*	*.7*	*<0.1*	*2.3%*
incl. Next 30%	*2315*	*1.8*	*1.1*	*9.2%*
Middle 40%	3084	6	2.8	40.5%
Top 10%	771	29	13	48%
incl. Top 1%	*77.1*	*101*	*47*	*16.9%*
incl. Top 0.1%	*7.71*	*425*	*125*	*7.1%*
incl. Top 0.01%	*.771*	*2332*	*566*	*3.9%*

Notes: Individual carbon footprints include emissions from domestic consumption, public and private investments, as well as the carbon emissions embedded in goods and services traded with the rest of the world. Modeled estimates are based on the systematic combination of tax data, household surveys and input-output tables. Benchmark scenario. Emissions split equally within households. **Source and series**: Author, see Methods and Supplementary Information.

Table II
Inequality and global emissions growth, 1990-2019

	Total emissions 1990	2019	**Emissions growth** 1990-2019			
	(GtCO2e)	(GtCO2e)	(Δ GtCO2e)	(Total growth)	(Per cap. growth)	(Share in total growth)
Full pop.	30.5	45.8	15.3	50.2%	2.3%	100%
Bottom 50%	2.9	5.3	2.4	82.8%	26%	15.8%
incl. Bottom 20%	.6	1.1	.5	83.3%	22%	3%
incl. Next 30%	2.3	4.2	2	82.6%	27%	12.8%
Middle 40%	12.8	18.5	5.7	44.5%	-1.2%	37.5%
Top 10%	14.9	22	7.1	47.7%	.9%	46.6%
incl. Top 1%	4.2	7.7	3.6	83.3%	26.1%	23.2%
incl. Top 0.1%	1.5	3.3	1.7	120%	45%	11.3%

incl. Top 0.01%	.7	1.8	1.1	157.1%	78.5%	7.2%

Notes: Individual carbon footprints include emissions from domestic consumption, public and private investments, as well as the carbon emissions embedded in goods and services traded with the rest of the world. Modeled estimates are based on the systematic combination of tax data, household surveys and input-output tables. Benchmark scenario. Emissions split equally within households. **Source and series**: Author, see Methods and Supplementary Information.