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Lucas Chancel (lucas.chancel@sciencespo.fr)
Paris School of Economics

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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

Abstract

This paper estimates the global inequality of individual greenhouse gas (GHG) emissions between 1990 and 2019, using a newly assembled dataset of income and wealth inequality and Environmental Input-Output tables. I find that the bottom half of the world population emits 12% of global emissions, while the top 10% emits 48% of the total. The global top 1% share in world emissions rose from 14% in 1990 to 17% in 2019. While two thirds of the inequality in individual emissions was due to inequalities *between* countries in 1990, the situation has entirely reversed: in 2019, 63% of the global inequality in individual emissions was due to gaps between low and high emitters *within* countries. Emissions from investments, rather than from consumption, represent the bulk of emissions of the rich: around 70% of global top 1% emissions come from their investments. This has major implications for contemporary debates on fair climate policies. I stress the need for more systematic data on individual carbon emissions to allow informed policy debates.

INTRODUCTION

Climate change and economic inequalities are among the most pressing challenges of our times. They are also interrelated: failure to contain climate change is likely to exacerbate inequalities within and between countries [29, 41, 15, 27] and economic inequalities within countries tend to slow the implementation of climate policies [20, 82]. In order to properly understand interactions between economic inequality and climate change, systematic data is needed on the distribution of greenhouse gases (GHG) emissions between individuals and across the globe, and its evolution. Such information is currently missing.

As a matter of fact, researchers, policymakers and civil society struggle to establish basic facts about individuals' 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 this information is released, it is with several years of delay. In addition, official publications about GHG emissions are typically blind to the distribution of these emissions: i.e. which groups of the population contribute most to GHG emissions growth or to mitigation efforts remains unknown.

The present paper addresses these issues by harnessing recent conceptual and empirical progress in income, wealth and GHG emissions measurement. I mobilize state-of-the-art global income and wealth inequality data from the World Inequality Database [3] and GHG emissions data associated to individuals' consumption and investments, from Multi-Regional Input-Output (MRIO) tables. Compared to previous work [17, 12, 21], the novelty of this approach is to distribute the totality of GHG emissions to the totality of the world population, from lowest income groups to the richest, in a systematic and transparent manner and over a thirty-year period. The method developed in this paper also makes it possible to distinguish between emissions from individuals' consumption and emissions from investments and wealth ownership (see Methods).

I. RESULTS

Global equally-split carbon budget and average emissions by regions

According IPCC AR6 report [55], there are approximately 300 Giga tonnes (Gt) of Carbon Dioxide equivalent (CO_2e) left to be emitted to limit global warming below 1.5°C and nearly 900 $GtCO_2e$ to limit it to 2°C.[1] At current global emissions

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[1] Both budgets and given with an 83% confidence to remain under the temperature limit.

rates (that is, circa 50 GtCO_2e in 2021), the 1.5°C budget will be depleted in six years and 2°C budget in 18 years.

In 2021, per capita global emissions neared 6.5 tCO_2e[2], significantly above the Global Equally-split Carbon (GEC) budget.[3] The GEC budget compatible with keeping global warming under +2°C is of 3.4 tonnes per person per annum (assuming that the entire budget is spent by 2050). The GEC budget compatible with keeping global warming under +1.5C° is of 1.1 tonne of CO_2 per annum per person, i.e. about six times less than the current global average.[4]

Average emissions in most world regions are above the 1.5°C and 2°C GEC budgets, as shown in Figure I (these estimates are net of imports and exports of CO_2e embedded in goods and services).[5] Per capita emissions in Sub-Saharan Africa are around 50% above the 1.5°C GEC budget and are around half of 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 six times higher than the 2°C GEC budget). In between these two extremes stand South and South-East Asia, at 2.5 tonnes per capita (80% of the 2°C GEC budget) and Latin America at 4.8 tonnes (70% of world average, 1.4 times the 2°C GEC budget), followed by the Middle East and North Africa, East Asia, Europe, and Russia and Central Asia, whose averages fall in the 7.5-10 tonnes range (between one and 1.5 times the world average, and two to three times more than the 2°C GEC budget).

[Figure 1 about here.]

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[2] Unless specified, all figures are reported in CO_2e and include all GHG emissions from human activity, except emissions from land use, land use change and forestry (LULUCF).

[3] To obtain these numbers, I divide the remaining global carbon budget by the cumulative global population that will be emitting it over the coming decades. According to the United Nations [32], there will be 265 billion individual-years between 2020 and 2050.

[4] Assuming that the GEC budget is shared by 2100 rather than 2050 mechanically means smaller per capita values (i.e. 0.4 tonne and 1.1 tonnes to stay below 1.5°C and 2°C, respectively).

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

Carbon emissions inequalities within world 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 world regions. In East Asia, the poorest 50% emit on average around three 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% over 70 tonnes of carbon dioxide equivalent. This in turn can be contrasted with the emissions in Europe, where the bottom 50% emit nearly five tonnes, the middle 40% around 10.5 tonnes, and the top 10% around 30 tonnes. Emissions levels in South and South East Asia are significantly lower, from one tonne for the bottom 50% to fewer than 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. Indeed, 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) as well as to more energy-intensive infrastructures and energy devices.[6]

[Figure 2 about here.]

European emissions of various income groups are indeed very high by global standards: the European middle class emits significantly more than its counterparts in East Asia (around 10.5 tonnes compared with eight tonnes, respectively) and all other regions except North America. Yet it is also remarkable that the richest East Asians and the richest 10% in the Middle East emit more than the richest Europeans (39 tonnes, 34 tonnes, and 29 tonnes, respectively). This difference results from the higher income and wealth inequality levels in East Asia and the MENA region than in Europe.

Turning to other regions, I find that Russia Central Asia have an emissions distribution similar to that of Europe, but with higher top 10% emissions (due to

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[6] See for e.g. [18] for a discussion of the drivers behind these differences.

higher income and wealth inequalities in Russia Central Asia). Sub-Saharan Africa lags behind, with the bottom 50% emissions around 0.5 tonnes per capita and per year and top 10% emissions around 7 tonnes. Overall, it stands out that only the poorest 50% of the population in Sub-Saharan Africa and South and South-East Asia come in under the 1.5°C GEC budget. Measuring levels against the 2°C GEC budget, I observe that the bottom half of the population in each region is below or close to the threshold (apart from North America). Emissions of the poorest half of Europeans, for instance, are 50% above the 2°C GEC budget. The gap is significant but within relatively close reach.

Global carbon inequality between individuals

Figure III presents the inequality of carbon emissions inequality between individuals at the world level. The global bottom 50% emit on average 1.6 tCO_2e per annum and contribute to 12% of the total. The middle 40% emit 6.6 tonnes on average, making up 40.4% of the total. The top 10% emit 31 tonnes (47.6% of the total). The top 1% emits 110 tonnes (16.8% of the total). Global carbon emissions inequality thus appears to be very large: close to half of all emissions are due to 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 details on the global distribution of carbon emissions. The bottom 20% of the world population (1.5 billion individuals) emit fewer than 1.8 tonnes per capita per annum. The entry threshold to get in the middle 40% is 3.1 tonnes, and it takes 13 tonnes per capita per annum to get in the top 10%. It takes 130 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 evolved over the past decades? A simple way to represent the evolution of carbon emissions inequality is to plot the average emissions growth rate of each percentile of the global distribution. Global polluters are ranked from the least emitter to the richest 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 about 7% (and overall emissions grew by 58%, see Table II). The per capita emissions of the bottom 50% grew faster than the average (32%), while those of the middle 40% as a whole grew more slowly than the average (4%), and some percentiles of the global distribution actually saw a reduction in their emissions of between five and 25%. Per capita emissions of the top 1% emissions grew by 26% and top 0.01% emissions by more than 110% revealing very unequal dynamics.

Per capita emissions matter, but understanding the contribution of each group to the overall share of total emissions growth is critical. Groups starting with very low per capita emissions levels can increase their emissions substantially over a given period, yet still contribute very little to the overall growth in global emissions. This is in effect what has happened since 1990 (see Table II, last column). 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) was responsible for 21% of emissions growth. These values are reported in the two boxes of Figure IV.

[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 resulting of a combination of improvements in overall energy efficiency and a compression of their wages as compared to richer groups of the population [4]. 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 II.

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 12%. At the same time, the top 1% share rose from 14% to close to 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 from 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 decades? Figure VI compares the share of global emissions that is due to within-country differences with the between-country differences, using a Theil-index decomposition. In 1990, most global carbon inequality (63%) was due to differences between countries: then, the average citizen of a rich country polluted unequivocally more than the rest of the world's citizens, and social inequalities within countries were on average lower across the globe than today. The situation has almost 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 there do not remain significant (often huge) inequalities in emissions between countries and world regions, on the contrary (see Figure I). In fact, it means that on top of the great inter-national inequality in carbon emissions, there also exist even greater inequalities in emissions between individuals. This has major implications for global debate on climate policies.

[Figure 6 about here.]

Figure VII (panel A), presents the global distribution of individual carbon emissions. Each color wedge is proportional to the population of a region, and the total colored area represents the global population. The Figures makes it clear that the bulk of the world population emits between 1.5 and 8 tonnes, with a mode at c. 2 tonnes. Around 1 billion individuals emit less than 1 tonne of CO_2e per year, 3 billion individuals are found to emit between 3.1 tonnes and 13 tonnes and 7 million individuals (approximately the top 0.1% of the population) emit more than 130 tonnes per year. Figure VII (panel B) presents the share of population of each region in each percentile of the global carbon distribution. Sub-Saharan Africa, India and the rest of Asia excluding China represent the bulk of emitters from the bottom 30% of the global distribution. Countries like China (which represents the vast majority of East Asia), Latin America, and MENA are well represented at nearly all levels of the global distribution, from relatively low emitter groups 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, to the right hand side of the graph. A important result from this graph is the small relative representation of top European emitters among very top global emitters, especially as compared to North American emitters. Also significant is the large representation of Chinese among very top global emitters.

[Figure 7 about here.]

The weight of investments in wealthy individuals' carbon footprints

The results presented above show that global carbon inequalities are currently very large and that the share of emissions of very top groups has been rising since 1990. What is driving the rise of 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 and to the rising share of emissions from wealthy individuals' investments.[7] I stress that this rise can be observed in all scenarios, even when taking implausibly low assumptions on the country-level elasticity of emissions between income and emissions.[8]

Individual carbon footprints can be split into emissions from private consumption, investments or government spending. Consumption related emissions come from the

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[7] In the benchmark scenario, the carbon content of a euro of investment is the same across income groups. Alternative assumptions are tested in the Supplementary Information. Even with an elasticity lower than one, the share of investments in wealthy groups' total footprints remains very large (see Methods).

[8] See Methods section (Robustness checks).

carbon released by the direct use of energy (i.e. fuel in a car) or its indirect use (i.e. energy embedded in goods and services consumed by individuals. Investment-related emissions are emissions associated to choices made by capital owners about new investments in the production process (i.e. the construction of new machines, new factories, etc. which will serve the production of goods and services tomorrow). These emissions are to be attributed to investors, rather than to consumers, because investors are the sole decision-makers about these investment choices. In line with earlier studies on carbon footprints, consumers are attributed emissions associated to the production of the goods they consume. [9]

Focusing on the breakdown between consumption and investment emissions, I find that a large part of emissions from the global top 1% comes from their investments, rather than from their consumption. In a world where the poorest half of the population within countries typically owns less than 5% of total wealth [22], and typically makes less than 5% of investments, it can be expected that investment-related emissions are highly concentrated, both within countries and at the global level. The question is how much exactly - and how has the weight of investments in wealthy individuals' carbon budget evolved over the past decades?

Figure VIII presents the share of investments in total emissions of various groups of emitters at the global level (the global bottom 50%, top 1%, top 0.1% and top 0.01%). Emissions of top groups (top 1% and above) essentially come from their investments. Investments represent 70% of global top 1% emissions in 2019 vs. over 90% for the global top 0.01% in my benchmark scenario. In effect, this means that the global top 1% (77 million individuals) has an investment-related carbon footprint of 77 tonnes of CO_2e per capita and per year (vs. 33 tonnes due to their private consumption), on average in my benchmark estimates. Conversely, emissions from investments of the global bottom 50% represent only 0.16 tonnes per capita in 2019 (or 10% of their total emissions of 1.6 tonnes on average). It also appears that the weight of investments in top groups' per capita footprint has been rising

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[9] The notion of responsibility is indeed complex: many consumers are constrained in their consumption choices. Disentangling willing and constrained choices goes beyond the scope of this paper. However, the approach proposed here provides a nuanced approach to individual responsibility, in which consumers are not held responsible for investment decisions made by others, but are responsible for the carbon embedded in their own consumption choices.

significantly since the 1990s. This is due to the rise in wealth inequality (meaning that investments are more concentrated today than they were in 1990), as well as to the rise in overall emissions associated to investments over the periodn (because of a change in the nature of investments).[10]

[Figure 8 about here.]

II. DISCUSSION

The results presented in this paper reveal the very large level of concentration of individual carbon emissions that characterizes contemporary global economy: while a tenth of the global population is responsible for nearly half of all emissions, a half of the population emits no more than 12% of it.[11] Global carbon inequalities have been rising at the top of the distribution (Figure V) since 1990. How to explain this fast increase at the top of the distribution of world emitters? Focusing on rich countries, we observe that average per capita emissions declined in rich countries since 1990 (even when factoring 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 followed a different trend as compared to that of the rest of the population. What is observed is a ”rebound effect” associated to high income and wealth level: rising income and wealth levels have been more important than gains in the GHG intensity of per capita income. I stress that this effect is very robust to different assumptions on the link between emissions and income at the household level.[12] In emerging countries such as China or India, average emissions levels have been growing for nearly all groups of the population, but the wealthy accounted for a disproportionate share of this growth (they account for a disproportionate share in consumption growth as well as in investments growth, see [4, 22]).

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[10] In 1990, global emissions from the investment sector of the economy represented 25.6% of the total, vs. 32.3% in 2019, see **SI** Table 1.

[11] Replaced in perspective, carbon inequalities are lower than income or wealth inequalities (the global top 10% of earners captures 52% of total income and the global top 10% of wealth owners owns 76% of total wealth, see [22]).

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

The rise in emissions from top global emitters since 1990 is even more striking when compared to emission trajectories of other groups of the population. Indeed, the poorest 50% in Europe and the US saw their emissions reduced by approximately 15%-20% since 1990. These reductions are due to the combined effect of compressed wages and consumption and reduced national per capita footprint in most rich countries. The consequence is that a large part of the population in rich countries already appears to be near 2030 national climate targets, when these targets are expressed in per capita terms. Nationally Determined Contributions (NDCs) established in the context of the Paris Agreement imply a per capita target of around 10 tonnes of CO_2e in the US in 2030, vs. around 5 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). This is not the case for the middle 40% and top 10% of the income distribution in these countries. Wealthier groups are indeed largely above the 2030 climate target. In the US, the top 10% would need to reduce its average per capita emissions by 87% 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 as well, inequality matters a lot: in China and India, emissions of the bottom 90% of the population is below the target, while the wealthiest 10% is already well above it. In China, the richest 10% of the population would actually need to reduce its emissions by more than 70% to reach the 2030 target, the figure is 60% in India (Figure IX and **SI** Section 8).

[Figure 9 about here.]

To be clear, no country currently envisages the enforcement of strict per capita targets to meet its 2030 objectives. These gaps between individual emissions levels and the implied national target nonetheless raise important questions about the design of climate policies in the years to come: how to ensure that regulations, tax instruments and other climate policies effectively address emissions of high emitters? Put it differently, how to 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. Carbon taxation, for instance, has been found to place a disproportionate burden on low-income and low-emitter groups [28, 23, 33]. On the contrary, the carbon price signal for high and wealthy emitters is often too low to force changes in consumption patterns. In some cases, price signals are close to nonexistent (for e.g. private jet fuel is significantly undertaxed as compared to road transport fuels in Europe or the US).

It also appears that emissions associated to investment decisions have attracted only little policy attention so far.[13] While investments represent a significant and rising share of top emitters' carbon footprints, countries do not impose taxes or regulations based on the pollution content of individual asset portfolios. This is paradoxical given that investors have a variety of options at hand to invest their wealth. This contrasts with low and middle income consumers who might not always have alternatives, in the short run, to the use of fossil fuels. Taxes on the carbon content of investments, or on the ownership of polluting assets, could in principle become attractive tools when more standard carbon taxes fail to address inequality concerns. Such options could help avoid the risk of political backlash against carbon taxation, as has been seen in several countries in the recent years [20, 78].

The informational, technical and economic conditions under which policies targeting carbon investments of individuals is a matter of further research. In that respect, some developments are worth following: the recent European Union financial taxonomy on sustainable investments [81] could enable a better monitoring of the carbon content of assets - although the inclusion of gas investments has raised concerns. Critical progress will also need to be made by governments to properly monitor individual emissions, in a timely and systematic manner. Ability to produce this information will also depend on governments' ability to enforce more financial transparency to trace end-user beneficiaries of financial transactions.[14]

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[13] See also [63] who discuss the need to focus on top emitters.

[14] See [58] for a discussion of the many issues associated to the development of financial asset registries.

CONCLUSION

This paper mobilizes state-of-the art data on global income and wealth inequality and systematically combines it with carbon footprints estimates to track the distribution of individual carbon emitters between 1990 and 2019. I find that the global inequality of carbon emissions is both high and persistent, despite strong economic growth in the emerging world over the past three decades. The top 10% of global emitters are responsible for around 48% of global emissions while the entire bottom 50% emits 12% of emissions in 2019. While significant inequalities in average emissions persist between countries, I find that the bulk of global inequalities in individual emissions is now due to within-country inequalities. A large and growing share of top-emitters carbon footprints come from their investments, rather than from their consumption. In rich countries, emissions of lower income groups declined while emissions of top groups increased significantly. In emerging countries, emissions of top income groups are now comparable to top groups in rich countries. These results highlight the need for more policy instruments specifically addressing emissions of the wealthy. While the results presented in the paper 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 made to properly track carbon emissions inequality between and within countries. Absent such information, designing fair climate policies will remain an overly challenging task. All estimates are published online on the World Inequality Database, as well as the set of computer codes to contribute to more transparency about these important matters.

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METHODS

Relationship to earlier studies. There are two broad approaches to measure global carbon inequality, namely *bottom-up* approaches and *top-down* approaches. Both have strengths and limitations. The bottom-up approach mobilizes household-level micro-data to produce macro estimates. This is the approach followed by Bruckner et al. [12] 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 for rich countries. These surveys are linked to 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 to individual *consumption*. However, it requires a vast set of standardized micro data on consumption at the household level for all countries in the world, making longitudinal studies extremely difficult. This explains why Bruckner et al. [12] solely focus on year 2014.[15]

In addition, it is now well-known that household consumption surveys tend to underestimate consumption levels of richest groups, due to misreporting and sampling errors (see [11]). Using household surveys without additional datasets on inequality therefore tends to underestimate carbon emissions associated to rich individuals' consumption by construction. Another limitation of this approach is that it does not treat wealth (or investment-related emissions) particularly well. For instance, Bruckner et al. do not treat investment related emissions differently from emissions associated to household consumption. More precisely, emissions linked to investments in the car industry (construction of new factories or new machines) are distributed to individuals in proportion their consumption of cars, rather than to individuals' investments in the car industry. It is however well know that inequalities in investments are much larger than inequalities in consumption [22].

Top-down approaches to the measurement of global carbon inequality use the regularities observed in micro-level data to provide modeled estimates, typically over longer time spans. This is the approach for instance of Chakravarty et al. [17], who look at territorial emissions only and therefore miss the potentially large share of emissions embedded in international trade (see [67]). Chancel and Piketty (see [21]) follow a similar method but use the GTAP Environmental Multi Regional Input Output (EMRI0) database [1] to take into account emissions from consumption and to look at a longer period. This approach was also used by [47].

The basic framework developed in this study builds on the top-down approach, to be able to study global carbon inequality over relatively long time-spans. The methodology can however incorporate findings from country-level micro studies on

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[15] also Hubacek et al. [43] who use a similar approach.

the link between income or consumption and emissions. In that sense, I mobilize strengths of both approaches. Departing from earlier studies, I also provide a more accurate treatment of investment-related emissions, based on novel data about income and wealth inequality within countries and on a specific treatment of emissions of the private investment sector of the economy (see below).

The general approach followed in this study can be summarized as follows. Based on Environmental Multi Regional Input Ouptut Tables, I obtain country-level GHG emissions for the household sector, the investment sector and the government sector of the economy (emissions are net of imports and exports embedded in goods and services with the rest of the world). These emissions are distributed in the following way to individuals: (i) aggregate carbon footprints of the household sector in a given country are distributed following a power law of individual income, which can change from country to country or over time; (ii) aggregate emissions associated to investments and capital stock replacement are a function of the distribution of asset ownership within countries; (iii) emissions from the Government sector (emissions from the public health sector, education, infrastructure defense, etc.) are distributed as lump-sum to individuals, or as a function of individuals' income (depending on the specification chosen). I detail the main specification chosen below and present results from various parametric assumptions in the **Supplementary Information** of this paper.

Income and wealth inequality data. The methodology followed 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 researchers' ability to monitor global income and wealth inequality [69, 22], which I build upon. The standard source of information mobilized to track inequality within countries is via household surveys. While surveys constitute a rich source of information to track the 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 typically not consistent with macroeconomic totals [7, 5].

The Distributional National Accounts (DINA) methodology [70, 3], 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. These additional sources of information include, 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. Tax data also enable long term comparisons, spanning over decades (and centuries, in some countries). On the other hand, the use of National Accounts concepts makes it possible to compare income or wealth levels 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 revealed that most societies went through a decline in inequality between the 1920-1970s and then observed a return of inequality since the 1980s [6]. Such findings generated significant academic and public debates on the causes and consequences of inequality within nations. While such dynamics can have important impacts on the inequality of carbon emissions, the interactions between income, consumption, wealth and GHG emissions have attracted only a limited amount of attention to date [43, 60]. In fact, there have been no attempts to measure to dynamics of the global distribution of carbon emissions taking stock of recent progress in global inequality research in the context of Distributional National Accounts.[16] The purpose of this paper is to study dynamics of global carbon emissions over several decades, with a particular focus on emissions at the top of the distribution.

The economic inequality datasets used in this study are those we have developed in the context of the World Inequality Database (wid.world) [3]. They provide income and wealth inequality series for 174 countries over the 1990-2019 period, i.e. more than 97% of the world population and 97% of global Gross Domestic Product or global income. (See **SI** Section 2). WID.world contains reproducible inequality statistics based on the systematic combination of household surveys, tax data and national accounts, produced by an international network of researchers contributing

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[16] Recent work by Bruckner et al. [12] focus on a single year and authors stress that their estimates do not cover emissions of top income groups particularly well (see above).

to the dataset. The general set of guidelines and methods underlying these data series is described in the Distributional National Accounts Guidelines [3]. Income inequality levels for all countries are presented in **SI** Table 9.10.

The link between carbon emissions inequality and economic inequality. Most countries do not publish standardized data sources on individual emissions levels. Such information can be reconstructed from household surveys and with additional data on energy. Data on individual emissions inequality have been produced for several countries and years by researchers mobilizing Input-Output tables (see below) [50, 84, 64, 30].

Available literature typically finds that carbon emissions associated to individual consumption depend on several factors including income and expenditure, as well as households' location, energy conversion technologies, occupation status, habits, age, national regulations and energy mixes [50, 87, 73, 85, 68, 13, 57, 71] (see also **SI** Tables 3.1 and 3.2 for a complete list of studies on the matter). While non-income factors play a significant role in determining direct individual emissions levels (i.e. emissions stemming from the direct use of energy, such as emissions associated to car driving), income is found to be the main driver of indirect emissions (emissions associated to energy mobilized to produce goods and services consumed by individuals), and of overall emissions inequalities between individuals. At a given income level, two individuals may indeed have different heating or transportation needs, implying different direct energy requirement and different direct emissions levels. However, when taking into account the carbon content of their overall consumption and of their indirect energy requirements (the energy used to produce the clothes or 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)[17] are presented in **SI** Table 3.1 and A3.2. These studies find that the elasticity of household 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 [50,

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

87, 73, 85, 2, 38, 68, 13, 71].[18] Using these observed regularities, and taking stock of recent progress in income inequality measurement, it is possible to estimate emissions inequalities between world individuals in a relatively straightforward and transparent manner, over long time spans.

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 quantitative model of the economy, initially developed to represent inter-dependencies between different economic sectors (households, governments, firms) within and between a countries [52]. The framework was extended to economy-environment interactions [51] to better understand the material content of production and the impact of environmental policies and relatively recently to study international flows of carbon embodied in international trade [26, 67].

In the context of carbon accounting, the strength of the IO framework is to rely on a systematic representation of the world economy which avoids any double-counting: the same tonne of carbon cannot be ultimately attributed to two different agents[19]. The environmental IO approach is also particularly useful because it can distinguish between emissions from household consumption, investments and to government expenditures – in line with National Accounts concepts [80, 19].[20]

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

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[18] See also [53] for elasticity estimations based on on macroeconomic data, rather than micro level household data.

[19] In other carbon accounting methodologies, such as the life-cycle analyses, the issue of double counting is omnipresent

[20] Changes in inventories and stocks are also reported in the dataset. Since they only represent a marginal fraction of emissions, I include them in GFCF totals so as to keep fully consistent datasets which always match with aggregate totals. I also include emissions of Non-Profit Institution Serving Households in the Household Sector as a first approximation.

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 to final demand is obtained as follows:

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

Our benchmark MRIO data source is the Global Carbon Project (GCP) [35]. In certain cases, GCP does not provide data for a given country or for a given type of emissions. In order to cover all countries and all types of emissions, I also rely on the EORA dataset [54].[21]

Distributing emissions to individuals. In line with the National Accounts Methodology, I decompose national-level distributions (of income, wealth or carbon emitters) in 127 generalized-percentiles: 99 percentiles from $p = 0\%$ to $p = 99\%$, 9 tenths of a percentile from $p = 99\%$ to $p = 99.9\%$, 9 hundredths of a 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 to 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 to consumption, private investment and public spending, respectively. More precisely:

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[21] For details on the construction of aggregate series used in this study, see **SI** Section 1 and [16].

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

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

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

Where E^{cons} is the average carbon footprint associated to 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 $E_p^{cons} = E^{cons} \times Y_p^{\alpha}$); E^{inv} is the average emissions level associated to investments (or asset ownership, in our framework), γ the elasticity of wealth to investment emissions; E^{gov} is the average emission level of the government sector (associated to in-kind redistribution) and δ, is the elasticity of government emissions to individual income.

The results presented above are based on $\alpha = 0.6$, $\gamma = 1$, $\delta = 0$. The benchmark α value is based on the large regularity observed in available studies focusing on *income* and carbon emissions. This is also the value that corresponds to a *consumption*-carbon elasticity near 1, which is also what Bruckner et al.[12] find for most countries in 2014. I also produce results for $_alpha$ values varying country by country and corresponding to available $_alpha$ from micro studies. Given that changing $_alpha$ does not significantly impact results, and given that there are no available $_alpha$ for countries over the time period considered, I opt for a constant elasticity to ensure a greater consistency.

In the benchmark scenario, investment-related emissions are attributed in proportion to individuals' wealth (that is, the share of investment related emissions of the top 1% in a given country is equal to its share of wealth in that country). This implies that γ=1 in the benchmark scenario. This choice is probably conservative as Rehm [72] finds that emissions incorporated in wealth ownership could rise more rapidly than wealth (i.e. the carbon intensity of high net wealth is higher than at low or moderate levels of wealth). $\delta = 0$ amounts to distributing collective consumption expenditure of governments equally to individuals, as a lump-sum. This has been a relatively standard choice in earlier studies. In alternative scenarios, I distribute emissions in proportion to individuals' consumption. This alternative choice mechanically increases top emitters' contributions.

I produce results for the following range of parameters: $\alpha = (0.4; 0.5; 0.6; 0.7; 0.8; 0.9; 1)$; $\gamma = (1; 1.2; 1.4)$; $\delta = (0; 1)$. In all countries, I assume that emissions are split equally within households.

Robustness checks. The Supplementary Information document provides results for different parametric assumptions at the global, regional and country level. Overall, my main results appear to be robust to a wide set of parameters. In the extreme lower-bound scenario (i.e. a scenario which leads to a very low level of emissions inequalities within countries, with α=0.4, γ=1), I find that the global top 10% emissions' share nears 45% in 2019. In my extreme upper-bound scenario, the global top 10% emissions' share is of 56%. Using parameters closer to what is observed within countries (α around 0.6-0.8) yields values in the 46%-52.5% range, that is within a 5-10% range of our benchmark estimate for the global top 10% share.

I also observe that the global dynamics between 1990-2019 are robust across these different scenarios, and are not particularly sensitive to changes in choices of parameters over time. In **SI** Figure 7.5, I reproduce Figure IV across dozens of scenarios and find that the pattern and levels are consistent with benchmark results presented above (see also **SI** Fig. 7.6 and **SI** Table 7.8). Investment share at the top of the distribution also appear to be very large, irrespective of the assumptions made parameters. The top 0.1% has between 65% and 90% of its emissions from investments, even when using very different α and γ values.

The flexible framework developed in this paper makes it possible to use a variety of country-level studies to study the dynamics of global carbon inequality over relatively long time-spans. The bottom line is that using available country-level data does not modify the general conclusions presented above. All the data mobilized for this study, as well as the computer codes are to be posted online on the World Inequality Database, making it possible for researcher to make alternative assumptions in the future.

National 2030 targets. Per capita national targets are based on countries' Nationally Determined Commitments as of July 2021. Values are obtained from [25].

Rich countries typically express their targets in terms of percentage reduction by a certain date, as compared to a benchmark date. For instance, the US objective is to cut its total emissions by 50-52% as compared to 2005 level. 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 [32]. 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 [59] and calculate the implied per capita emission target, based on carbon intensity targets announced by the country (see also **SI** Section 8).

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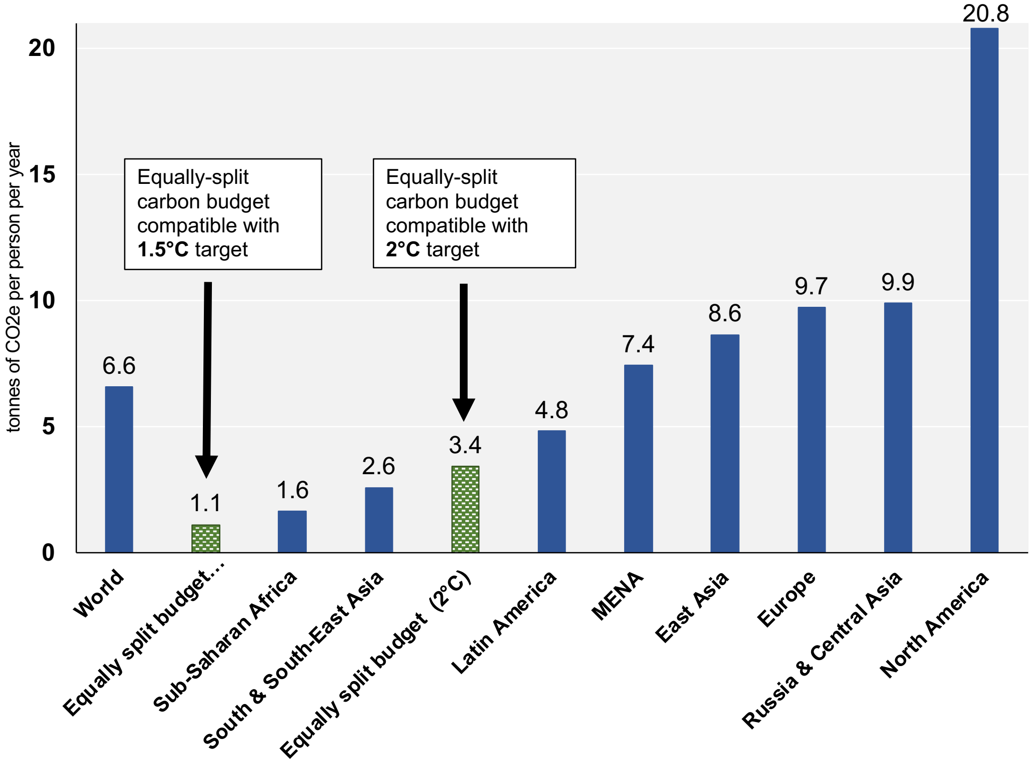
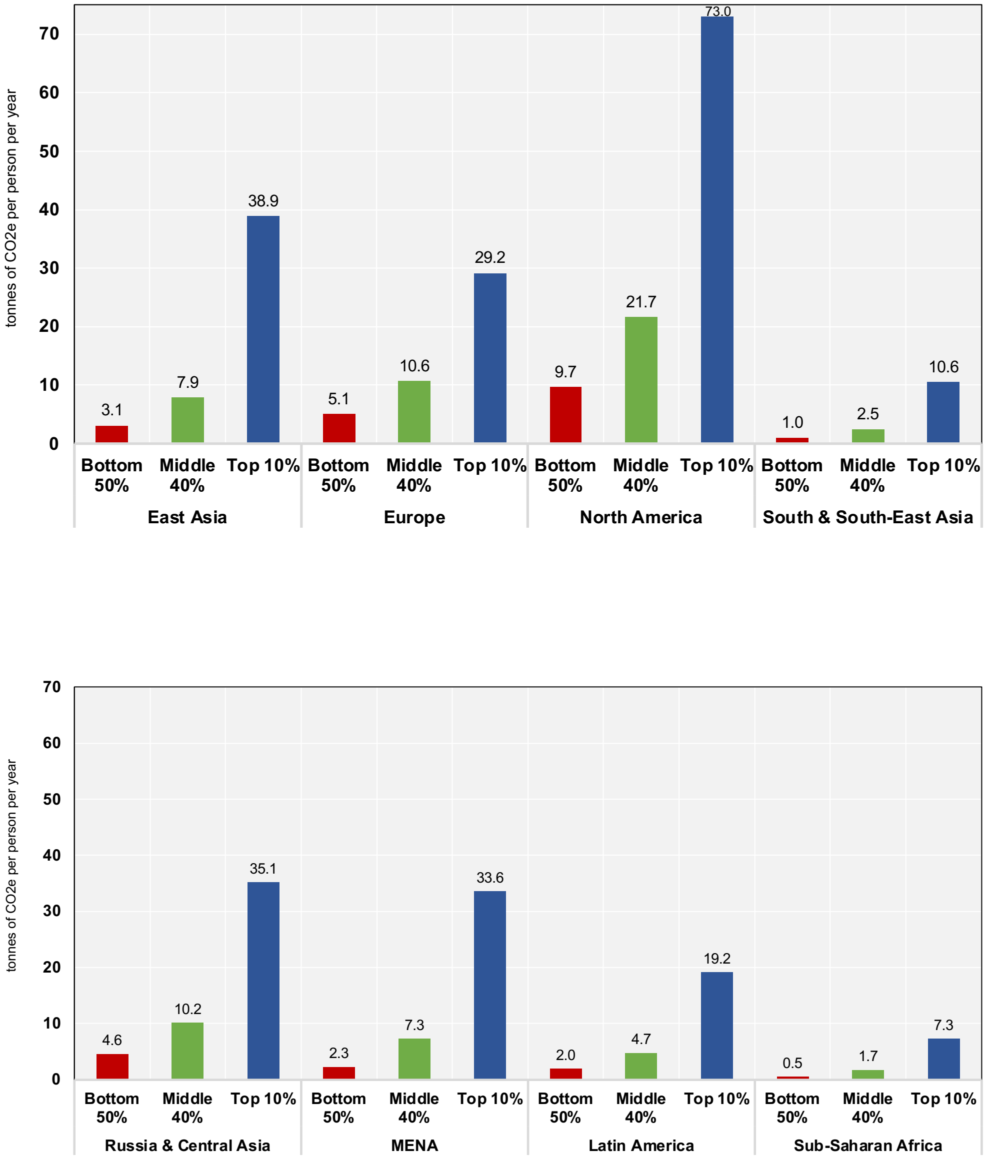


Interpretation: Sharing the remaining carbon budget to have 83% chances to stay below 1.5°C global (see [55]) temperature increase implies an annual per capita emissions level of 1.1 tonnes per person per year between 2021 and 2050 (and zero afterwards). Emission levels present regional per capita emissions 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.

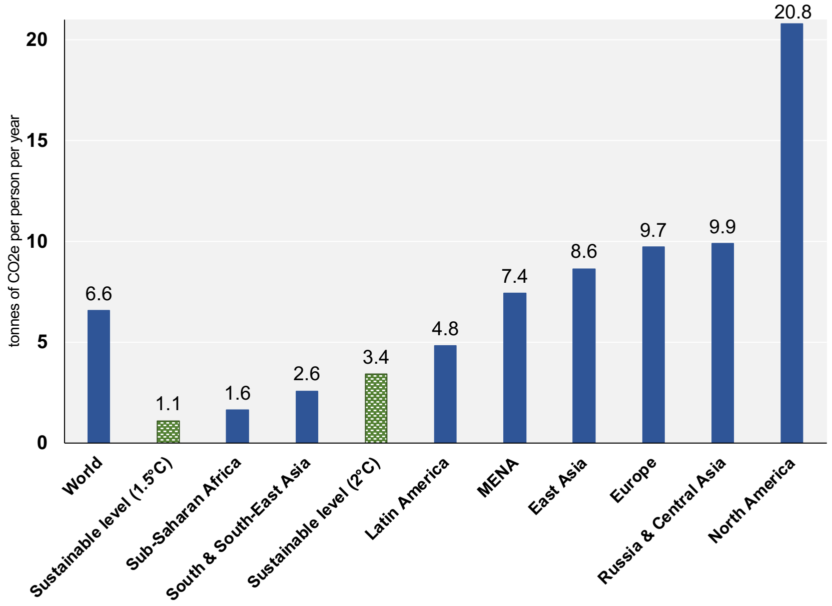
Figure I
Average GHG emissions by world region, 2019



Interpretation: 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 the systematic combination of tax data, household surveys and input-output tables. Benchmark scenario. Emissions split equally within households. *Source and series*: Author, see 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

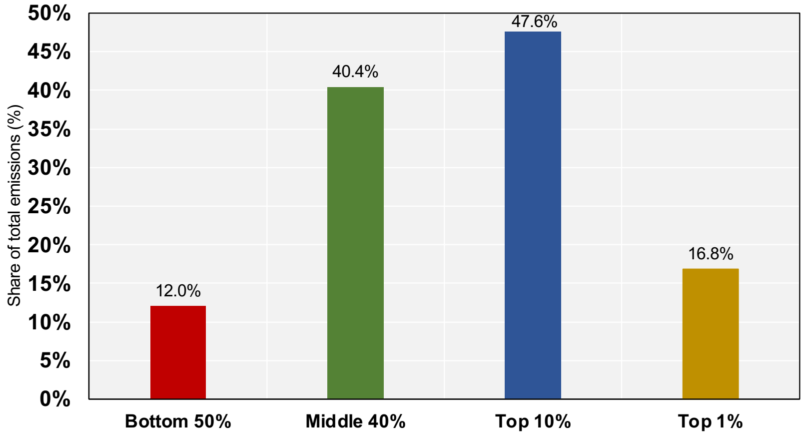
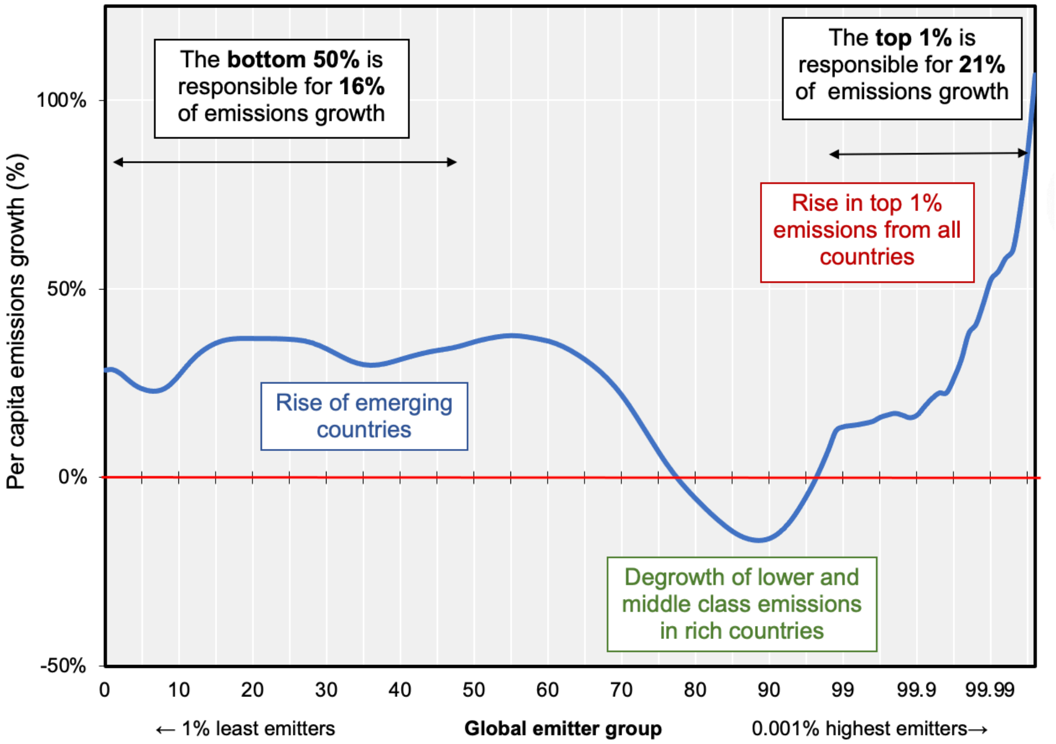


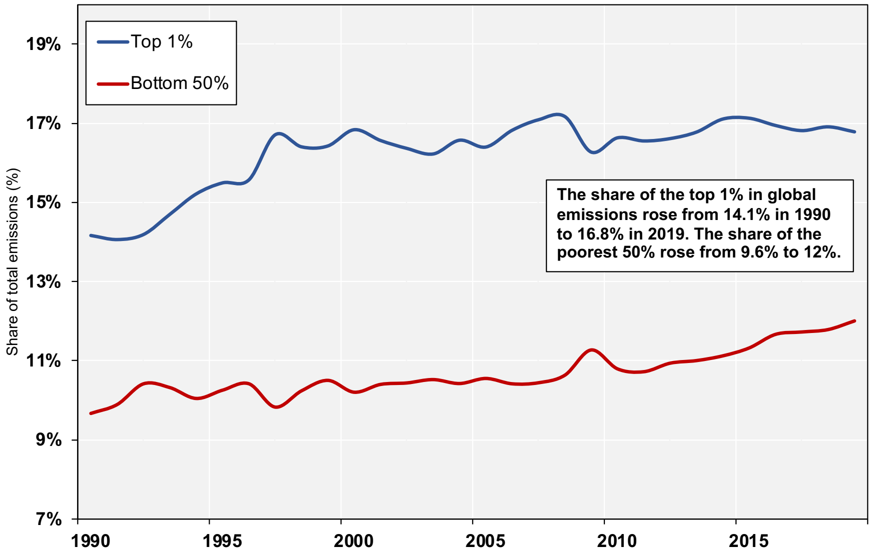
Figure III
Global inequality in individual carbon emissions, 2019

Interpretation: 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 the systematic combination of tax data, household surveys and input-output tables. Benchmark scenario. Emissions split equally within households. **Source and series**: Author, see Supplementary Information.



Interpretation: 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 the systematic combination of tax data, household surveys and input-output tables. Benchmark scenario. Emissions split equally within households. *Source and series*: Author, see Supplementary Information.

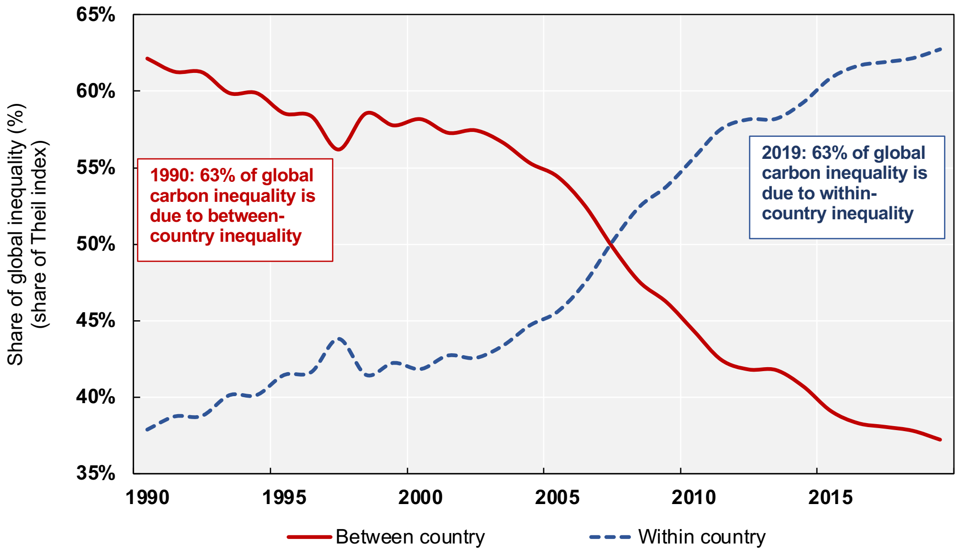
Figure IV
Global inequality and carbon emissions, 1990-2019



Interpretation: 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. Benchmark scenario. Emissions split equally within households.*Source and series*: Author, see Supplementary Information.

Figure V

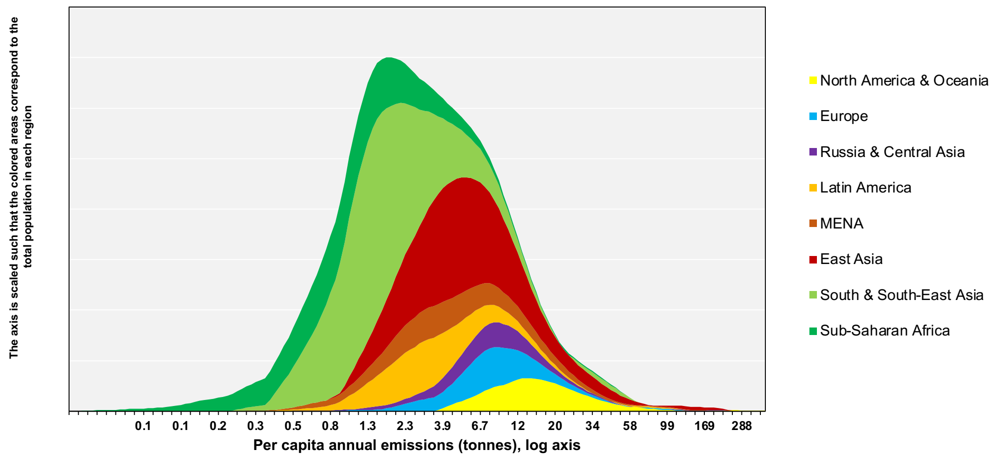
Top 1% and bottom 50% shares in global carbon emissions, 1990-2019



Interpretation: 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. *Source and series*: Author, see 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

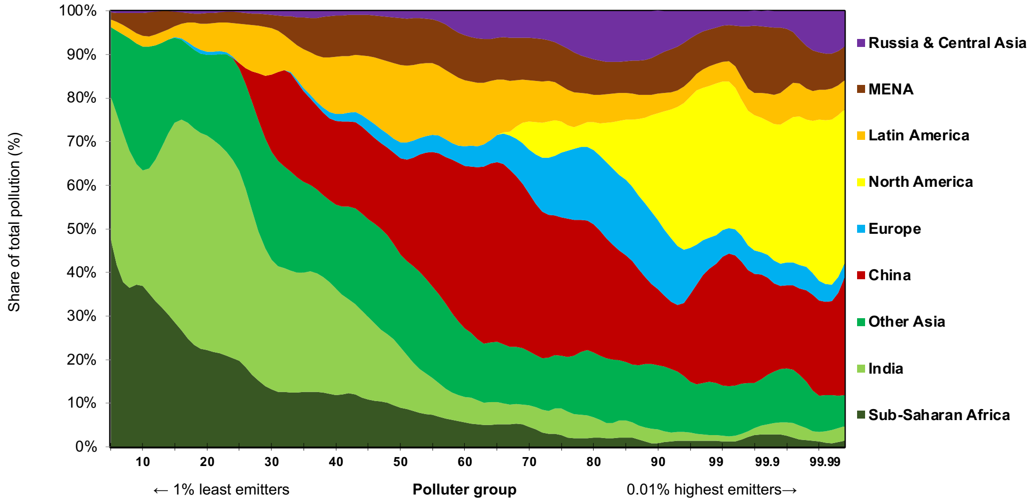
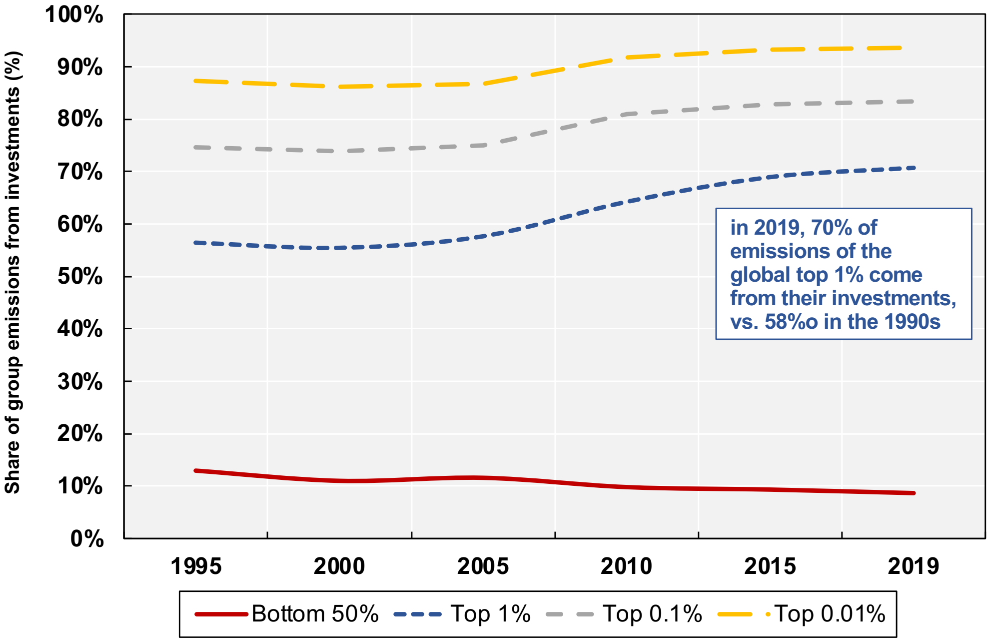


Figure VII

Global inequality in individual carbon emissions, 2019

Interpretation: **Panel** A The graph shows the share of world regions in each group of global emitters, from the lowest 1% to the highest 0.1%. **Panel B** shows the global distribution (density) of individual emitters in 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. Benchmark scenario. Emissions split equally within households. *Sources and series*: Author, see Supplementary Information.

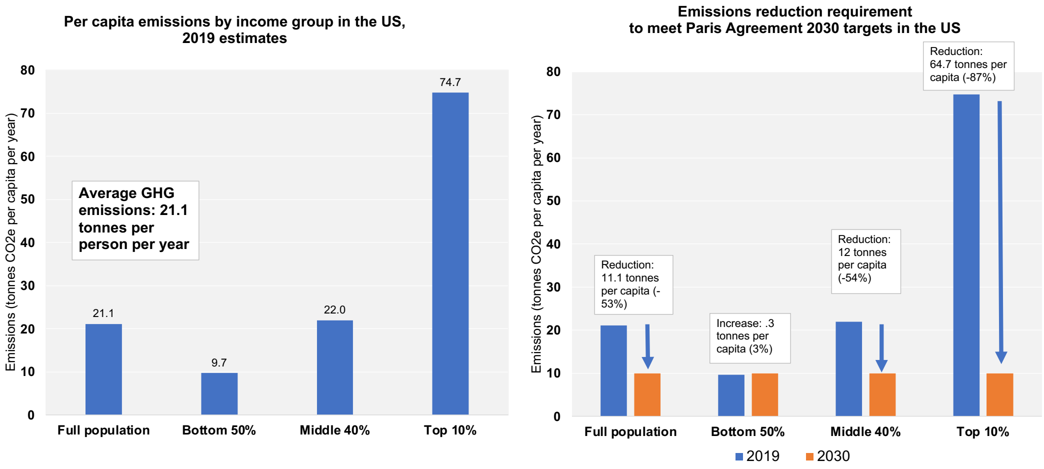


in 2019, 70% of emissions of the global top 1% come from their investments, vs. 58%o in the 1990s

Interpretation: 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. *Source and series*: Author, see also Supplementary Information.

Figure VIII
The share of investments in emissions of various global emitter groups, 1995-2019

(a) Emissions inequality and climate targets in the US



(b) Emissions inequality and climate targets in China

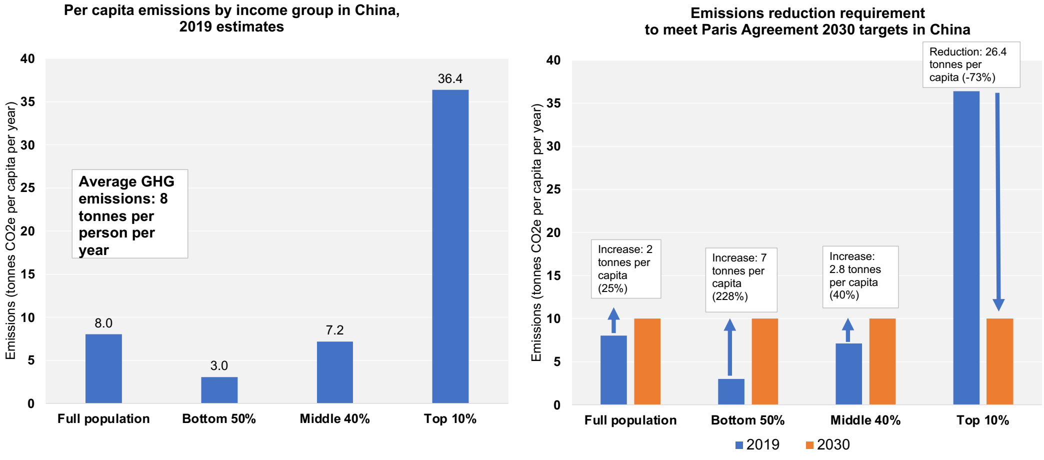


Figure IX

Emissions inequality and climate targets

Interpretation: 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 we use GDP projections to obtain overall emissions levels. *Sources and series*: Author, see Supplementary Information.

	Number of individuals (million)	Average (tonne CO2 per capita)	Threshold (tonne CO2 per capita)	Share (% total)
Full population	**7710**	**6.6**	**<0.1**	**100%**
Bottom 50%	**3855**	**1.6**	**<0.1**	**12.0%**
incl. Bottom 20%	*1542*	*0.8*	*<0.1*	*2.5%*
incl. Bottom 30%	*2313*	*2.1*	*1.8*	*9.5%*
Middle 40%	**3084**	**6.6**	**3.1**	**40.4%**
Top 10%	**771**	**31**	**13**	**47.6%**
incl. Top 1%	*77.1*	*110*	*46*	*16.8%*
incl. Top 0.1%	*7.71*	*467*	*130*	*7.1%*
incl. Top 0.01%	*0.771*	*2531*	*569*	*3.9%*

Table I

Global inequality of individual carbon emissions, 2019

Interpretation: Individual 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 the systematic combination of tax data, household surveys and input-output tables. Benchmark scenario. Emissions split equally within households. *Source and series*: Author, see Supplementary Information.

	Per capita emissions (tonnes CO2e per capita)		Total emissions (billion tonnes CO2e)		Growth in per capita emissions (1990-2019)	Growth in total emissions (1990-2019)	Share in emissions growth (1990-2019)
	1990	**2019**	**1990**	**2019**			
Full population	6.2	6.6	32.0	50.5	7%	58%	100%
Bottom 50%	1.2	1.6	3.1	6.1	32%	96%	16%
Middle 40%	6	6.6	13.3	20.4	4%	54%	39%
Top 10%	30	31	15.7	24.0	4%	54%	45%
Top 1%	87	110	4.5	8.5	26%	87%	21%
Top 0.1%	323	467	1.7	3.6	45%	114%	10%
Top 0.01%	1397	2531	0.7	2.0	81%	168%	7%

Table II

Emissions growth and inequality, 1990-2019

Interpretation: Individual 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 the systematic combination of tax data, household surveys and input-output tables. Benchmark scenario. Emissions split equally within households. *Source and series*: Author, see Supplementary Information.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Chancel2022SI.pdf