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Lucas Chancel

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Lucas chancel[1,2]

[1]Paris School of Economics, World Inequality Lab

[*]lucas.chancel@sciencespo.fr

ABSTRACT

This paper estimates global greenhouse gas (GHG) emissions inequality between 1990 and 2019, based on a newly assembled global dataset of income and wealth inequality from the World Inequality Database and on Environmental Input-Output tables. We find that the richest 10% of the global population emits nearly 48% of global emissions in 2019, the top 1% emits 17% of the total, whereas the poorest half of the global population emits 12% of global emissions. While two thirds of the inequality in individual emissions was due to emissions inequalities *between* countries in 1990, the situation has entirely reversed in 2019: 63% of the global inequality in individual emissions is now due to gaps between low and high emitters *within* countries. Our main results appear to be robust to a wide range of parametric assumptions on the relationship between carbon emissions and economic inequality. We stress at the onset that a lot of efforts need to be done by governments to properly monitor carbon inequalities. Absent such information, it is impossible to properly asses the distributional impacts of climate policies.

Introduction

Climate change and rising economic inequality are among the main challenges of our times and there is growing evidence that these issues are interrelated. On the one hand, climate change has already exacerbated inequalities within and between countries and will do so in the future[1–4] and on the other, economic inequalities are a challenge for the implementation and effectiveness of sound climate policies[5,6]. A vast body of work has shown that income and wealth inequality have been rising in most countries since the early 1980s[7]. It remains unclear, however, how this has materialized in terms of the global inequality of carbon emissions between individuals.

Modern statistical apparatuses have not been designed to properly track income and wealth inequality, as a result, researchers and tax authorities still experience difficulties when measuring international financial flows and how these impact income and wealth inequality. This measurement challenge is even more pronounced when it comes to properly estimating and comparing the distribution of individual carbon emission levels across and within countries. As a result, researchers, policymakers and civil society still struggle with basic facts about carbon footprints across the world. National carbon footprints (i.e. emissions net of the GHG content of goods and services traded with the rest of the world) are not published by most statistical institutions across the globe (and when they are, this is done with several years of delay) and their distribution across the population is mostly unknown.

The present paper addresses this issue by combining recent progress in income and wealth inequality research, with data on the GHG content of individuals' consumption and wealth ownership. The rest of this paper is organized as follows: (i) Section I presents the main data sources and measurement methods use in this paper, (ii) section II presents our main results on the global inequality of carbon emissions, (iii) section III discusses these results. The Methods section as well as the Supplementary Information document presents additional methodological details.

Measuring the global inequality of individual carbon emission

Taking stock of recent progress in global inequality research

The past decade was marked by important breakthroughs in researcher's ability to monitor global income and wealth inequality, thanks to the development of new concepts and methods as well as to the release of new income and wealth tax data. The standard method used to track inequality within countries and globally in the second half of the 20th century relied on household surveys. This was problematic given that surveys are hardly comparable across countries, fail to properly measures incomes at the top of the distribution and are not consistent with macroeconomic totals[1,8,9].

The Distributional National Accounts (DINA) methodology[10,11] developed by a large network of researchers affiliated to the World Inequality Database (wid.world), in partnership with national and international statistical organizations, sought to address these issues by systematically combining household surveys with additional sources of information on economic inequality, namely administrative tax data and National Accounts. Tax data offer a more reliable account of income and wealth dynamics among wealthy groups than do self-declared values report in household surveys and enable long term comparisons, spanning over decades and centuries in some countries. National Accounts enable more robust international comparisons of income and wealth growth rates.

This body of work contributed to improve collective understanding of the ultimate beneficiaries of economic growth within countries and at the global level. Within countries, it was shown that contemporary societies recorded a significant rise in income and wealth disparities after the 1980s, following a historical decline in inequality between the 1940-1980s.[7,12]. At the global level, this body of work revealed that the top 1% global income distribution captured significantly more economic growth than the entire half of the global population, since 1980[7] and that inequalities remain very large, despite strong growth in the emerging world over the past decades. While such dynamics can have important impacts on global carbon emissions, these interactions between global inequality of income, wealth, and emissions have attracted only a limited amount of attention among researchers to date.[13,14] They constitute the topic of this paper.

The link between carbon emissions inequality and economic inequality

The study of the global inequality in individual carbon emissions faces informational, conceptual and methodological challenges. Most countries do not publish standardized data sources on individual emissions levels. Researchers looking for such information can use household socio-economic surveys to estimate people's carbon footprints, but this requires significant efforts. Some researchers and statistical agencies have produced such estimates, combining individual level socio-economic surveys with energy databases and Input-Output tables (see below) or with life cycle analyses[2] to estimate the carbon footprints of different groups of individuals in countries.[15–19]

This literature typically finds that carbon emissions associated to individual consumption depend on several factors including income and expenditure as well as households' location, technologies, occupation, habits, age or regulations.

[1](that is, the sum of incomes in surveys does not match the sum of incomes used to measure standard aggregate indicators such as the Gross Domestic Product, GDP)

[2]Life cycle analyses, contrary to Input-Output estimates, estimate GHG footprints following a "bottom-up" approach, i.e. using product-level information on the carbon content of goods and services. Input-Output approaches typically mobilize less granular data, but offer macroeconomic consistency, i.e. one tonne of carbon cannot be counted twice. Double-counting can be an issue with Life-Cycle methods.

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), it is found that income inequality levels are the main driver of indirect emissions (emissions associated to energy mobilized to produce goods and services consumed by individuals), and of overall emissions inequalities. The reason for the dominance of income in the determination of overall emission levels is relatively straightforward: at a given income level, two individuals may 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 (the clothes or appliances they buy, the food they eat, the services they purchase, etc.), differences in direct energy needs are comparably small.

Micro-level studies focusing on the inequality of overall energy use, or overall emissions typically find that the elasticity of individual carbon emissions, or the strength of the relationship between rising individual income and CO_2 emissions (or energy consumption) (see Methods),[3] is contained in the 0.5-0.9 range depending on countries and model specifications, with a median value around 0.7-0.8 when focusing on expenditure and a little less when focusing on income income[?,?,?,?,?,16,20,21] (see **Supplementary Information**, Table 1).

Using these observed regularities, one can estimate emissions inequalities within countries and globally, provided they have access to standardized global income and consumption datasets. Some studies have followed this strategy[22–24] and provided useful benchmarks numbers about global carbon inequality levels, that have been mobilized in global policy debates[25,26].[4]

In this paper, we build up on this approach to develop a novel framework, which distributes the totality of global emissions to individuals within countries, taking into account their emissions as consumers, beneficiaries of public expenditures and as asset owners (that is, when individuals own wealth). We take into account the role of both consumption and capital ownership in individual carbon footprints. Our basic framework is as follows: carbon emissions are generated by economic activity, which results in the production of goods and services, which generates flows of income. These flows can be either consumed or saved and invested, in line with the standard national accounting[27] framework. In our basic framework, any flow of anthropogenic GHG emissions can be traced to a flow of consumption or to a flow of savings and investments.[28] In this approach, it is essential to start with correct emission totals.

Getting macroeconomic emissions levels right: Input-Output tables

Governments around the globe do not release data on carbon footprints, i.e. information which takes into account the carbon associated to the production of goods and services imported and exported to other countries. To recover these levels, we rely on Input-Output tables. The Input-Output framework is quantitative model of the economy initially developed to represent the inter-dependencies between different economic sectors (households, governments, firms) within and between a countries[29]. The framework was extended to economy-environment interactions[30] 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[31,32].

The strength of the Input-Output framework applied to carbon accounting is that it relies 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[5]. The environmental Input-Output approach is also particularly useful because it

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

[4] While[22] does not factor in emissions embodied in international trade[22–24] do not treat investment related emissions differently than consumption-related emissions.

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

can distinguish between emissions from household consumption, emissions associated to firms investments and to government expenditures – again perfectly in line with National Accounts concepts.

Input-Output estimates typically find that 60-70% carbon footprints can be traced to households (or individuals)' private consumption, 10-20% to public consumption [6] and 15-25% of emissions are associated to firms' investments. Significant variations occur across countries.[7]

In this study, we distribute the totality of global GHG emissions to individuals. We assume that: (i) aggregate carbon footprints of the household sector in a given country are distributed following a power law of individual income. We test a wide range of parametric assumptions to accommodate for a diversity of relationships between carbon emissions and income (see Methods); (ii) aggregate emissions associated to investments and capital stock replacement are distributed following the distribution of asset ownership within countries; (iii) aggregate emissions from the Government sector (emissions from the public health sector, education, infrastructure defense, etc.) are distributed equally to individuals. We test multiple parametric assumptions and define more than 20 scenarios, which are presented in the **Supplementary Information** (SI) to this paper.

The global inequality of individual carbon emissions

Carbon inequality levels within and between world regions

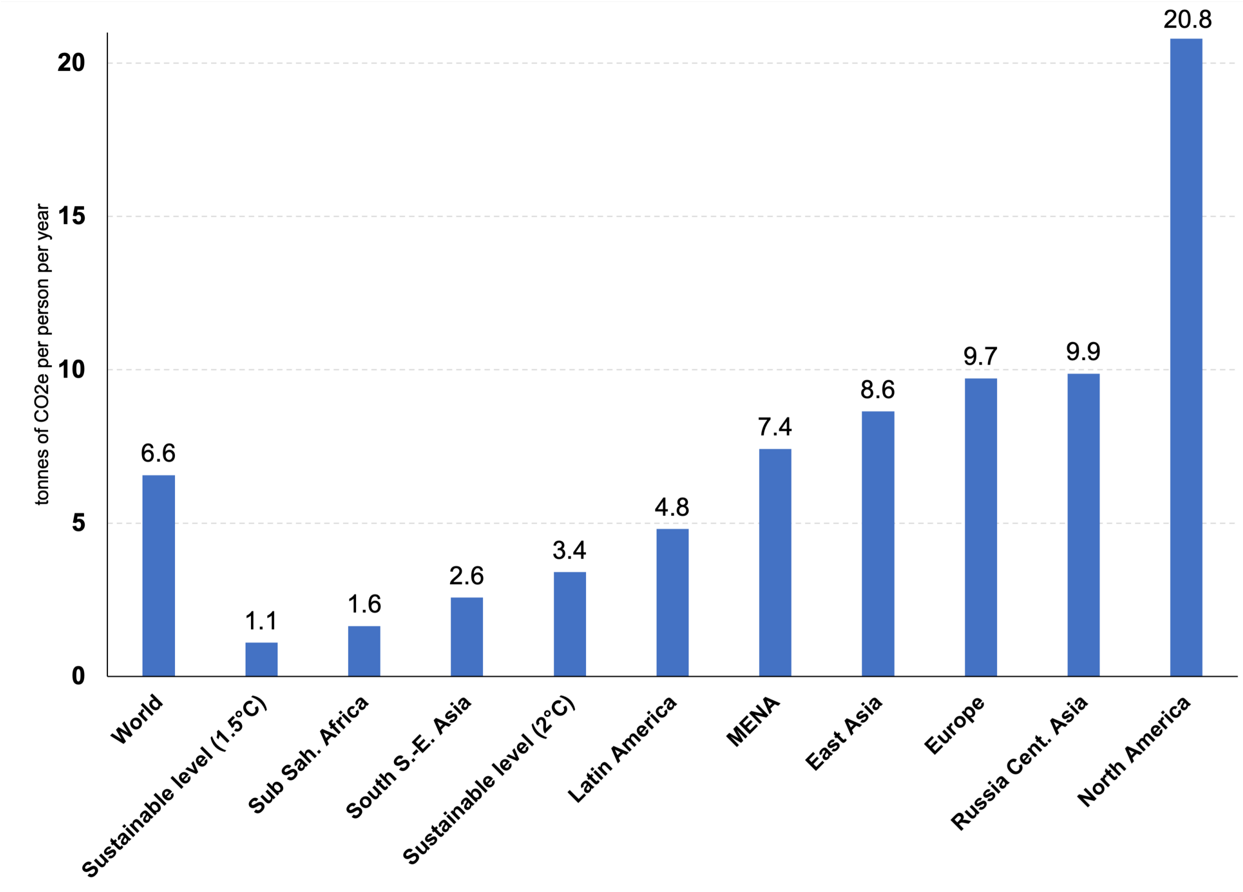
Figure 1 presents average GHG emissions by region in 2019, while SI Table 2 presents these values as a ratio world average. Per capita emissions in Sub-Saharan Africa (1.6 tonnes per person per annum) represent just one quarter of the average global per capita emissions. Thus, average emissions in Sub-Saharan Africa are close to 50% above the 1.5°C sustainable level and about half of the 2°C budget. At the other end of the spectrum, per capita emissions in North America are 21 tonnes per capita (three times the world average and six times higher than the 2°C sustainable level). In between these two extremes stand South and South-East Asia, at 2.5 tonnes per capita (40% of the current world average and 80% of the 2°C budget) and Latin America at 4.8 tonnes (70% of world average, 1.4 times the 2°C 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 sustainable level). Note that these values include emissions embedded in the goods and services traded with the rest of the world (see Methods and SI Table 3).

Significant inequalities in carbon footprints are observed in every region of the world. Figure 2 presents the carbon footprints of the poorest 50%, the middle 40% and the richest 10% of the population across the 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. This difference is largely due to the carbon-intensive energy mix in the

[6] i.e. these correspond to emissions of the government, which are associated to public spending (i.e. collective consumption expenditure such as schools, healthcare, defense, etc.)

[7] Estimates obtained with[33–35].



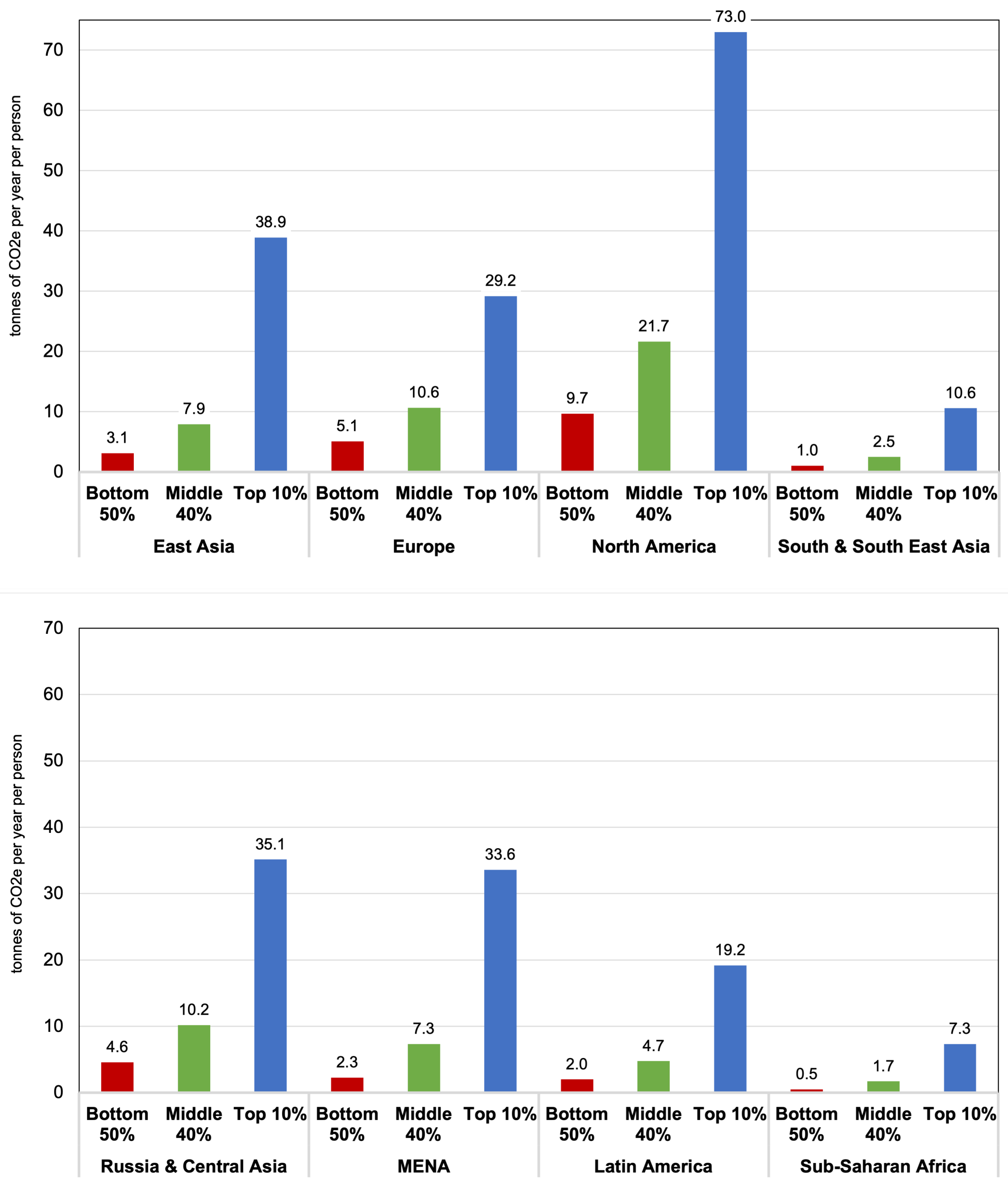
Interpretation: Values include emissions from domestic consumption, public and private investments as well as imports and exports of carbon embedded in goods and services traded with the rest of the world. Sustainable level correspond to an egalitarian distribution of the remaining carbon budget until 2050. *Source and series*: See Supplementary Information, Chancel (2021).

Figure 1. Per capita emissions (incl. imports) by world region (tCO2/year), 2019

US, where emissions from electricity are about twice as much as in the European Union. In the US, basic infrastructure consumes much more energy (because of the more widespread use of cars, for example), and devices tend to be less energy efficient (on average, cars are larger and less fuel efficient in the US than in Europe).

Nevertheless, European emissions remain 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) 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, and to the fact that investments by wealthy Chinese are associated with significant volumes of emissions.

Turning to other regions, we find that Russia and Central Asia have an emissions profile close to that of Europe, but with higher top 10% emissions. Sub-Saharan Africa lags behind, with the bottom 50% emissions around 0.5 tonnes and top 10% emissions around 7 tonnes per person per annum. 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 per capita budget. Measuring levels against the 2°C per capita budget, we observe that the bottom half of the population in each region is below or



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**: See Supplementary Information, Chancel (2021).

Figure 2. Carbon footprints by income group across the world, 2019

	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 1. 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*: See Supplementary Information, Chancel (2021).

close to the threshold. In fact, it is striking that the bottom 50% in high and middle income regions such as Europe, and Russia and Central Asia emit levels that fall within the 2°C budget. This shows that climate mitigation is largely a distributional issue, not only between countries but also within them.

Global carbon inequality between individuals

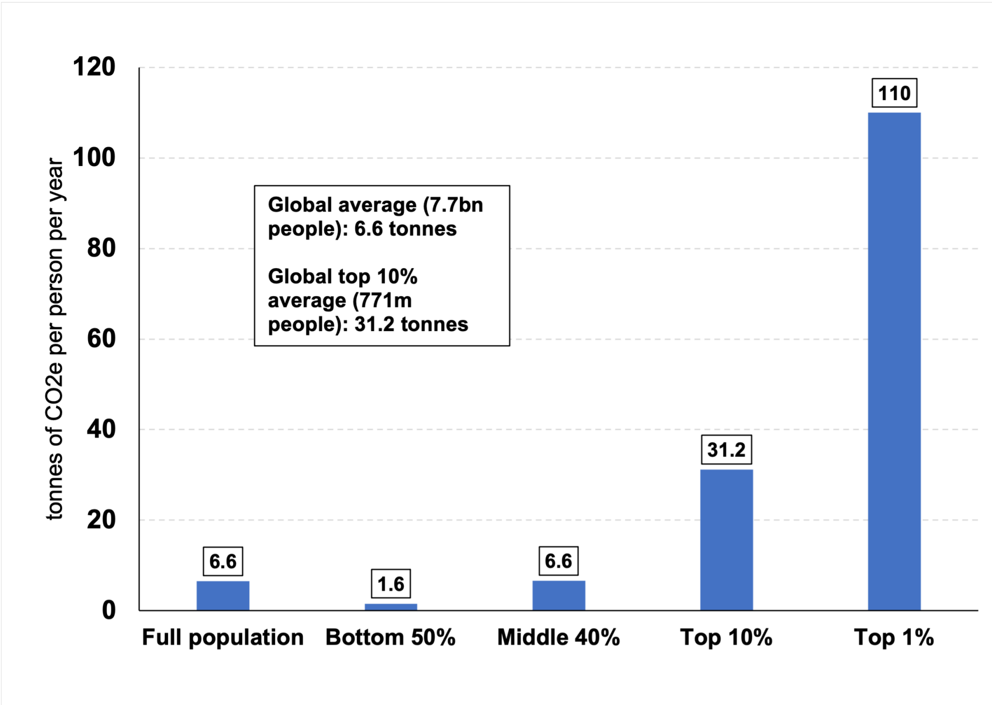
Figure 3 present the inequality of carbon emissions inequality between individuals at the world level. The global bottom 50% emit on average 1.6 tonnes per annum and contribute 12% of the total. The middle 40% emit 6.6 tonnes on average, making up 40.4% of the total. The top 10% emit 31 tonnes (47.6% of the total). The top 1% emits 110 tonnes (16.8% of the total). Global carbon emissions inequality thus appears to be very great: 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).

Table 1 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. In fact, about one billion individuals emit less than a tonne per capita. 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% group of emitters (7.7 million individuals).

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 average emissions growth rate by percentile of the global income distribution. Global polluters are ranked from the least emitter to the richest on the horizontal axis of Figure 4, 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%). 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 distribution actually saw a reduction in their emissions of between five and 25%. Per capita emissions of the top 1% emissions grew

Per capita emissions by group (tCO2 / year)



Group share (%) in world total emissions

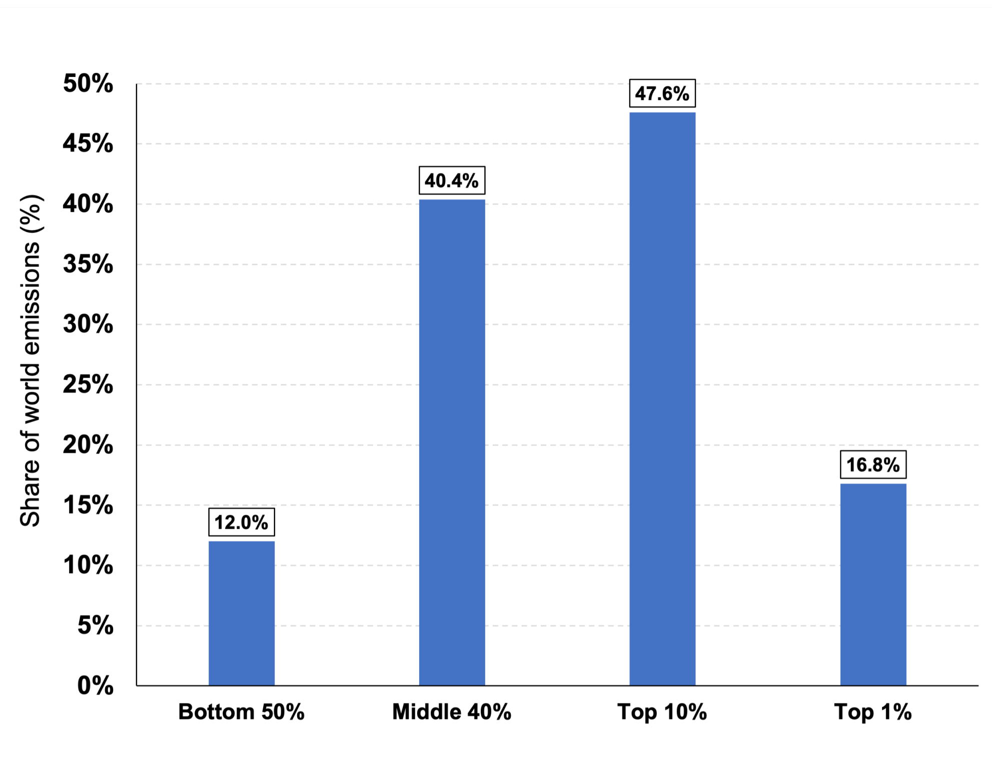
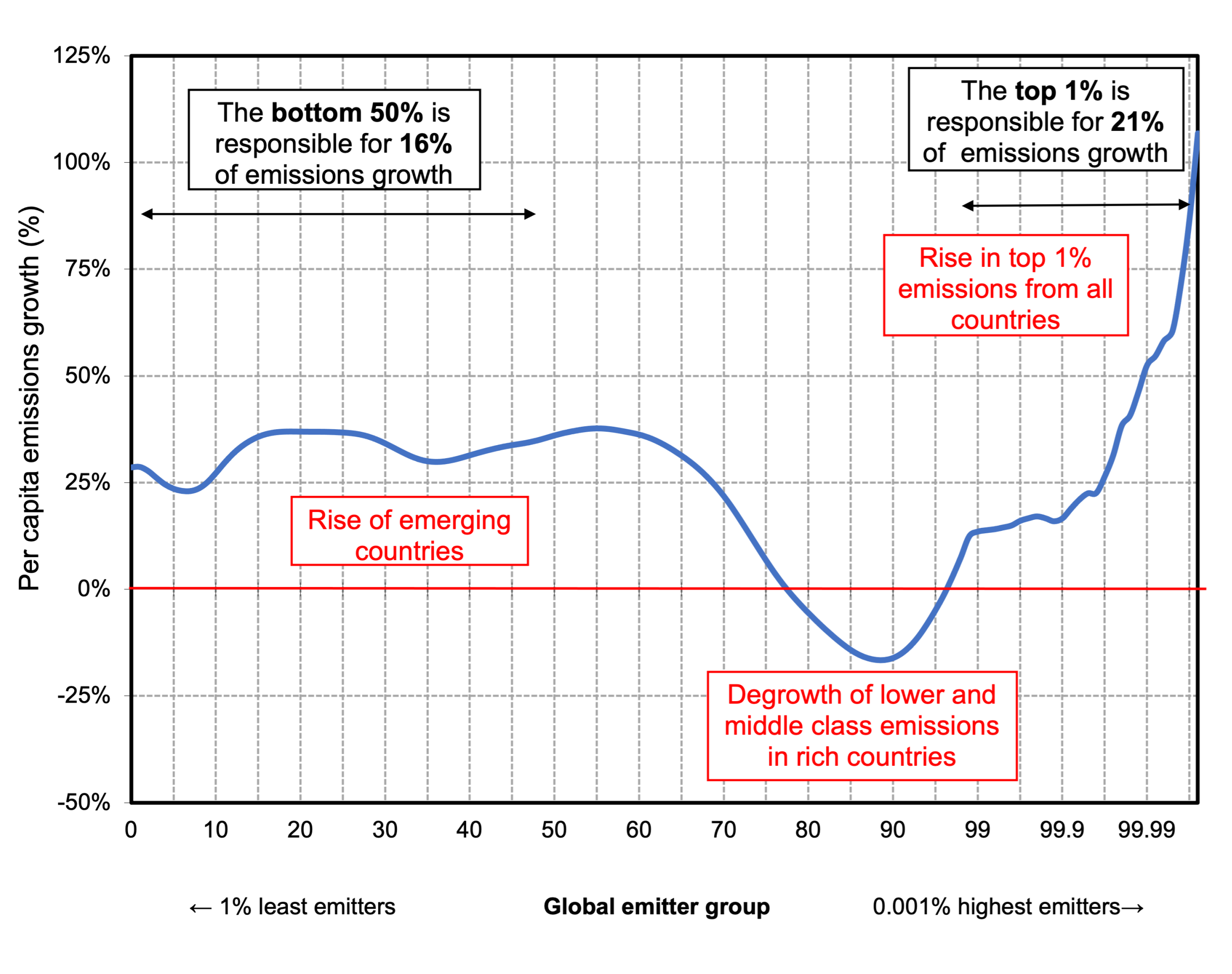


Figure 3. Global inequality in individual carbon emissions, 2019

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**: See Supplementary Information, Chancel (2021).



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*: See Supplementary Information, Chancel (2021).

Figure 4. Global inequality and carbon emissions, 1990-2019

by 26% and top 0.01% emissions by more than 110%.

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 2, 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 4

One of the most striking results shown in Figure 4 is the reduction in the emissions of about 15-20% of the world population, which largely corresponds to the lower and middle income groups of the rich countries. In these countries,

	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 2. Emissions growth and inequality, 1990-2019

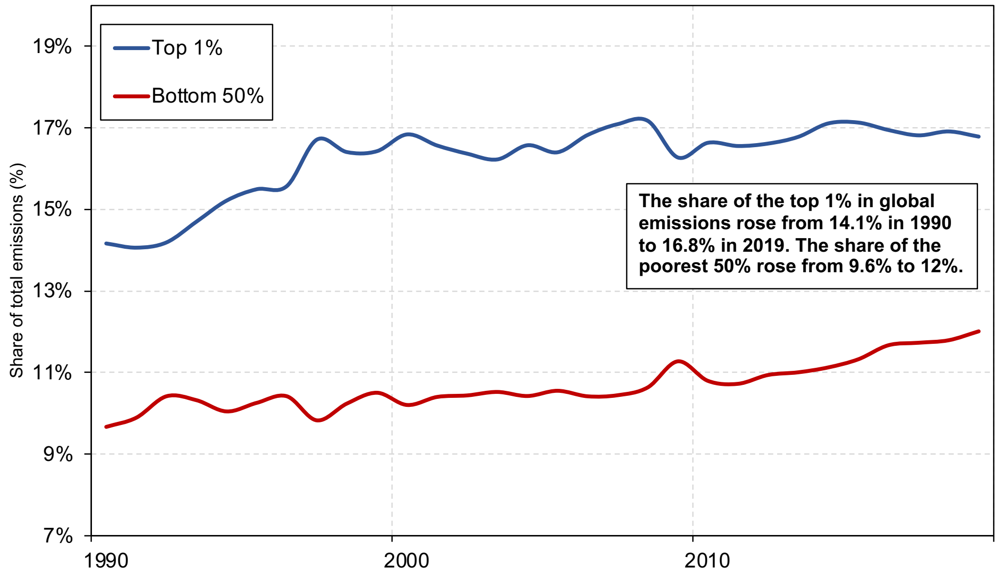
Interpretation: Individual carbon footprints include emissions from domestic consumption, public and private investments as well as imports and exports of carbon embedded in goods and services traded with the rest of the world. Modeled estimates based the systematic combination of tax data, household surveys and input-output tables. Benchmark scenario. Emissions split equally within households. *Source and series*: See Supplementary Information, Chancel (2021).

the working and middle classes have reduced their emissions over the past 30 years. To be sure, 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. Such a gap in carbon mitigation efforts between the rich and the less well-off in rich countries raises important questions about climate policies. In societies where the standards of living of the wealthy also shape the emissions of other social groups, this can have consequences for future emissions patterns. These dynamics also fuel criticisms of environmental policies such as carbon taxes, which have been shown to affect working and middle classes disproportionately in several countries (more on this below).

Figure 5 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 the total, from around 9.5% to 12%, but 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.

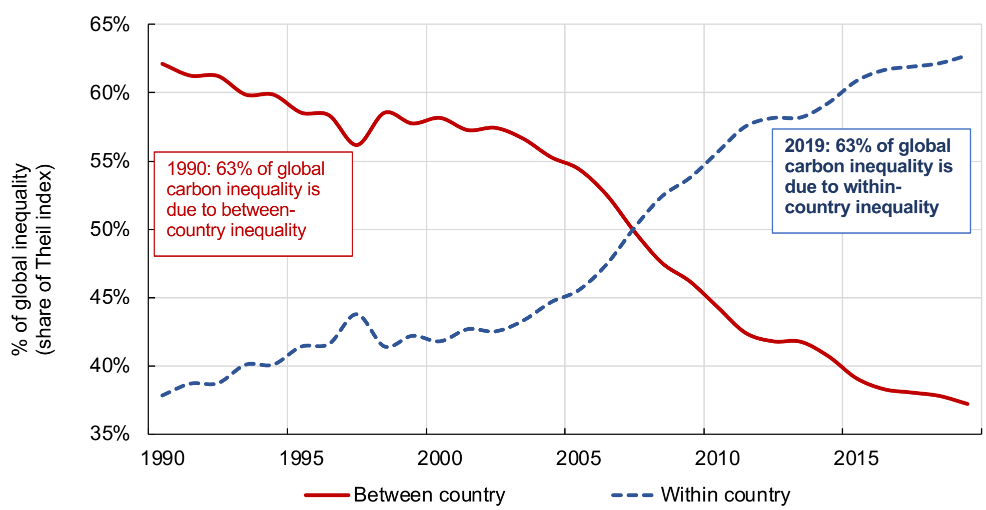
The rise in top 1% emissions is due to the increase in income and wealth inequalities within countries and to the rising share of their emissions from the assets they own. We find that around half of emissions from the global top 1% stemmed from asset ownership in 1990 and this value has risen over 70% in 2019.

What has been driving the dynamics of global carbon inequality over the past decades: average emission differentials between countries, or inequalities within them? Figure 6 compares the share of global emissions that is due to within-country differences with the between-country differences. 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. As for income, this does not mean that there do not remain significant (often huge) inequalities in emissions between countries and world regions, on the contrary. 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.



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*: See Supplementary Information, Chancel (2021).

Figure 5. 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. *Source and series*: See Supplementary Information, Chancel (2021).

Figure 6. Global carbon inequalities are mainly due to inequality within countries, 1990-2019

(Theil index decomposition of global carbon inequality)

Figure ?? (top panel) shows the geographical breakdown of each group of emitters. More precisely, the graph tells us about the share of population of each region in each percentile of the global carbon distribution. It shows, for example, that China, Latin America, and MENA are well represented among the low emitters as well as among the 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 (right hand side of the graph). The representation gap between Europe and North America among the very top of the distribution is clear in this graph, as is the large representation of Chinese among the highest polluters.

Figure ?? (bottom panel), provides another representation of the global carbon distribution. Each color wedge is proportional to the population of a region, and the total colored area represents the global population. The graph summarizes key insights about the global distribution of carbon emissions presented above.

Discussion

Our results highlight the very large inequality in carbon emissions at the global level: 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. Inevitably, the current lack of individual level data on carbon emissions inequality renders any global estimation exercise challenging. However, our results are found to be quite robust to a large set of parametric assumptions, which we present in the Supplementary Information. In our extreme lower-bound scenario (which we do not see as a plausible representation of within-country emissions distributions), the global top 10% emissions' share nears 45%, which is still considerably high. In our extreme upper-bound scenario (which we do not see as a plausible representation of within-country distributions either), the global top 10% emissions' share is of 56%. More realistic lower-upper bounds fall in the range 46%-52.5%,[8], that is within a 5-10% range of our benchmark estimate. We also observe that global dynamics between 1990-2019 are very robust across these different scenarios, and are not particularly sensitive to potential changes in choices of parameters over time. In SI figure 3, we reproduce Figure 4 across dozens of scenarios and find that the pattern and levels are consistent with our benchmark scenario.

A striking result from this paper is the reduction of per capita GHG footprints since 1990, for a large segment of the population in rich countries - and not for the richest groups in these countries. Indeed, the bottom 50% in Europe and the US saw their emissions reduced by approximately 15%-20% over the period considered, whereas emissions of the top 1% increased significantly within countries and at the global level. Such differentiated trends are explained by the rise of income, consumption and wealth inequalities within countries.

When expressing European and US 2030 climate targets in per-capita terms (i.e. about 5 tonnes of CO2 in Europe and about 10 tonnes of CO2 in the US), we find that the bottom 50% of the population already meets the 2030 targets (see SI). This is not the case for the middle 40% and top 10% of the income distribution, which remains largely above per-capita 2030 climate targets. This raises important questions for the design of climate policies in the years to come: how to ensure that regulations, tax instruments and other policies effectively address emissions of the wealthy, who represent a disproportionate share of national (and global) emissions? How to ensure that climate policy tools do not place too much burden on lower-income groups?

There is no straightforward answer to such questions, but it appears that little has been done over the past decades to regulate and tax the carbon content of wealth ownership. Carbon taxation so far has essentially been seen as a tax

[8] i.e. elasticity values ranging between 0.5 and 0.8, closer to values observed in the literature for carbon-income relationships

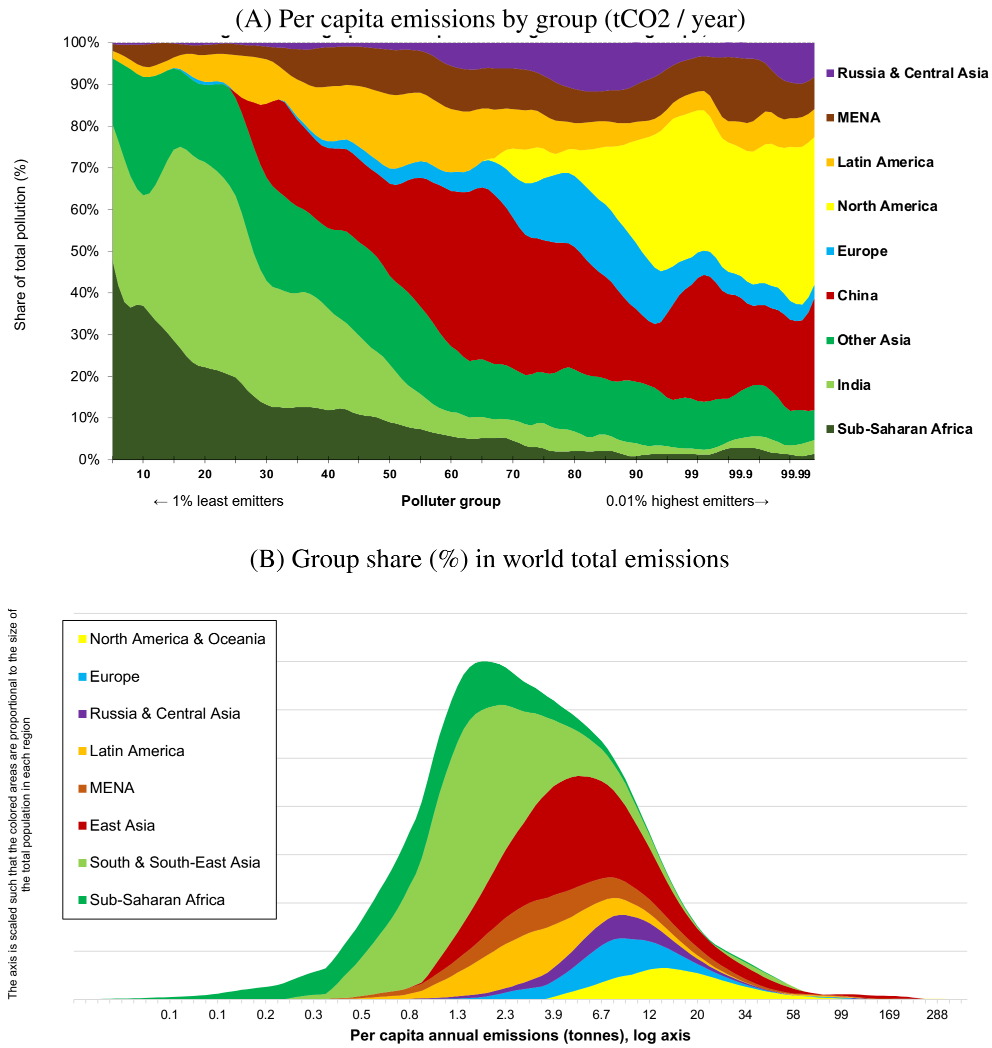


Figure 7. Global inequality in individual carbon emissions, 2019

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**: See Supplementary Information, Chancel (2021).

on consumption, and has often had disproportionate impacts on lower-income groups because taxes on consumption of basic goods (such as energy) tend to be regressive. Taxes on the ownership of polluting assets, or on dividends from pollution, could become attractive tools in contexts where carbon taxes on consumers face the risk of political backlash[5,36]. The informational, technical and economic conditions under which such taxes on carbon investments is a matter of further research.

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.

We 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 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, we find that the bulk of global inequalities in individual emissions is now due to within-country inequalities.

Over the past decades, emissions growth dynamics, driven by within country inequality growth dynamics, have been highly unequal. In rich countries, emissions of lower income groups declined while emissions of top groups increase significantly. In emerging countries (such as China), we find that emissions of top income groups are now comparable to top groups in rich countries. Our results highlight the need for more policy instruments specifically addressing emissions of the wealthy.

We 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.

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Methods

Economic inequality dataset

Our economic inequality datasets are those developed in the context of the World Inequality Database (wid.world), which now provides income and wealth inequality series for 174 countries over the 1990-2020 period, i.e. more than 97% of the world population and 97% of global Gross Domestic Product or global income. 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 to the dataset. The general set of guidelines and methods underlying these data series is described in the Distributional National Accounts Guidelines[11]. Table section 7 of the Supplementary Information presents inequality levels and macroeconomic indicators for each country used in this study.

The concept of income we use is equivalent to income measured after the operation of pension and unemployment systems (these represent the bulk of in-cash redistribution in most countries, which are thus taken into account in our income inequality estimate) and before the operation of other income and wealth taxes and transfers. Note that we opt for a relatively low benchmark emissions-income elasticity value (0.6) to account for the fact that we use income, rather than consumption inequality series.

Multi-regional Carbon Emissions Input-Output estimates

Aggregate carbon emissions data are based on multi-regional Input-Output (MRIO) tables. MRIO provide net emissions (i.e. emissions net of carbon embedded goods and services trade with the rest of the world), by institutional sectors of an economies. Institutional sectors are households, government and private investments (or Gross Fixed Capital Formation). In National Accounts, these sectors constitute "Final Demand". The sum of all "Final Demand" in an economy is equal to Gross Domestic Product (GDP).[9].

Our benchmark MRIO data source is the Global Carbon Project (GCP)[37], which we see as a global reference data source. 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, we also rely on the EORA dataset[33].[10].

Distribution of carbon emissions to individuals

In line with the National Accounts Methodology, we decompose national-level distribution (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, we proceed as follows. Average per capita emissions at percentile p, E_p, in a given year and country are defined as:

$$E_p^{tot} = E_p^{cons} + E_p^{inv} + E_p^{gov} \tag{1}$$

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:

$$E_p^{tot} = f(E^{cons}, Y_p, \alpha, \beta) + f(E^{inv}, W_p, \gamma) + f(E^{gov}, y_p, \delta) \tag{2}$$

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 $E_p^{cons} = E^{cons} \times Y_p^{\alpha}$), β a minimum threshold of emissions in the country, corresponding to a fraction of average consumption-related emissions; 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 income. Given that distribute consumption emissions, investment emissions and government emissions using different elasticity values, the overall elasticity of emissions to income is not constant across the income spectrum.

We use the following range of parameters to estimate emissions within countries: $\alpha = (0.4; 0.5; 0.6; 0.7; 0.8; 0.9; 1)$; $\beta = (0; 0.1; 0.2; 0.3)$; γ=1; δ=0 (in our benchmark scenario, government emissions are distributed equally to individuals in a country). In all countries we assume that emissions are split equally within households.

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

[10] For details on the construction of aggregate series used in this study and on WID.world, see Burq and Chancel[38]

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