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Carbon and inequality: From Kyoto to Paris

Trends in the global inequality of carbon emissions (1998-2013)
& prospects for an equitable adaptation fund

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Abstract. This study presents evolutions in the global distribution of CO_2e emissions (CO_2 and other Green House Gases) between world individuals from 1998 and 2013 and examines different strategies to finance a global climate adaptation fund based on efforts shared among high world emitters rather than high-income countries. To this end, we combine data on historical trends in per capita country-level CO_2e emissions, consumption-based CO_2e emissions data, within-country income inequality and a simple income-CO_2e elasticity model. We show that global CO_2e emissions inequalities between individuals decreased from Kyoto to Paris, due to the rise of top and mid income groups in developing countries and the relative stagnation of incomes and emissions of the majority of the population in industrialized economies. Income and CO_2e emissions inequalities however increased within countries over the period. Global CO_2e emissions remain highly concentrated today: top 10% emitters contribute to about 45% of global emissions, while bottom 50% emitters contribute to 13% of global emissions. Top 10% emitters live on all continents, with one third of them from emerging countries.

The new geography of global emitters calls for climate action in all countries. While developed and developing countries already engaged in mitigation efforts, contributions to climate adaptation funds remain almost entirely financed by developed nations, and for the most part by Europe (62%). In order to increase climate adaptation finance and better align contributions to the new distribution of high emitters, we examine the implications of a global progressive carbon tax to raise €150 billion required annually for climate adaptation. In strategy 1, all emitters above world average emissions (i.e. all individuals emitting more than $6.2tCO_2e$ per year) contribute to the scheme in proportion to their emissions in excess of this threshold. North Americans would contribute to 36% of the fund, vs. 21% for Europeans, 15% for China, and 20 % for other countries. In strategy 2, the effort is shared by all top 10% emitters in the world (i.e. all individuals emitting more than 2.3 times world average emissions), again in proportion to their emissions in excess of this threshold. North Americans would then contribute to 46% of the fund, vs. 16% for Europeans, 12% for China. In strategy 3, the effort is shared by all top 1% emitters in the world (i.e. all individuals emitting more than 9.1 times world average emissions). North Americans would then contribute to 57% of the tax, vs. 15% for Europeans, 6% for China. In these strategies, European contributions to adaptation finance would decrease in proportion compared to today, but substantially increase in absolute terms. In these strategies, European contributions to adaptation finance would decrease in proportion compared to today, but largely increase in absolute terms. American contributions would increase both in absolute and relative terms. We also discuss possible implementations via country-level carbon and income taxes or via a generalized progressive tax on air tickets to finance the adaptation fund. This latter solution might be easier to implement but less well targeted at top emitters.

Disclaimer: Responsibility for the views expressed in this study lies entirely with the authors and does not necessarily reflect those of the Paris School of Economics or Iddri.

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RÉSUMÉ DE L'ÉTUDE EN FRANÇAIS

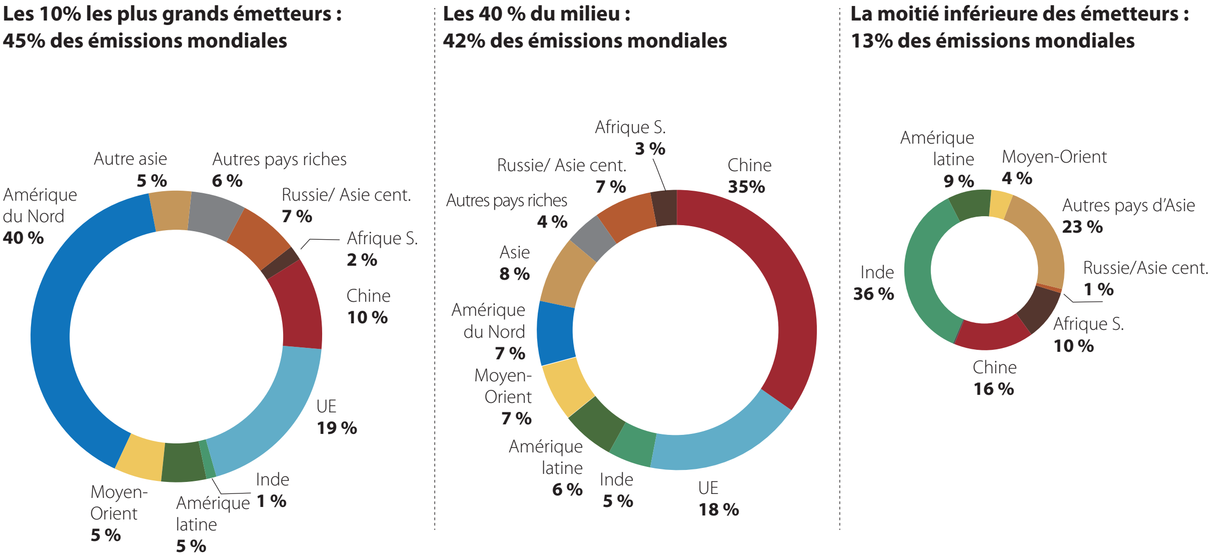
Cette étude analyse l'évolution des inégalités d'émissions de CO_2e (CO_2 et autres gaz à effet de serre) entre individus, dans le monde entier, de 1998 à 2013. Nous utilisons ces résultats pour construire et examiner différentes stratégies de financement d'un fond mondial pour l'adaptation au changement climatique, fondé sur un principe d'équité entre individus et non entre pays. A cette fin, l'étude combine des données historiques sur l'évolution des inégalités de revenus à l'intérieur des pays ainsi que des données sur les émissions nationales liées à la consommation (incluant donc les imports et les exports de CO_2e). Une loi simple reliant revenu individuel et émissions, à l'intérieur de chaque pays, est utilisée. Nos données couvrent approximativement 90% de la population, du PIB et des émissions mondiales de CO_2e. Les résultats ne dépendent pas seulement des inégalités de revenu à l'intérieur des pays, mais aussi des évolutions en matière d'émissions liées à la consommation entre pays.

L'étude montre que les inégalités mondiales d'émissions de CO_2e entre individus ont diminué entre 1998 et aujourd'hui, en raison de la progression des classes moyennes et aisées dans les pays émergents et la stagnation relative des revenus et des émissions de la majorité de la population dans les pays industrialisés. Les inégalités de revenus et de CO_2e ont cependant augmenté à l'intérieur des pays au cours des quinze dernières années. Les émissions de CO_2e demeurent fortement concentrées aujourd'hui: les 10% des individus les plus émetteurs sont aujourd'hui responsables de 45 % des émissions mondiales alors que les 50 % les moins émetteurs sont responsables de moins de 13% des émissions (Figure E.1). Les grands émetteurs sont aujourd'hui sur tous les continents et un tiers d'entre eux vient des pays émergents.

Parmi les individus les plus émetteurs de la planète en 2013, nos estimations mettent en avant les 1% les plus riches Américains, Luxembourgeois, Singapouriens et Saoudiens, avec des émissions annuelles par personne supérieures à 200 tCO_2e. A l'autre extrémité de la pyramide des émetteurs, on retrouve les individus les plus pauvres du Honduras, du Mozambique, du Rwanda et du Malawi, avec des émissions 2000 fois plus faibles, proches de 0,1 tCO_2e par personne et par an. Au milieu de la distribution mondiale des émetteurs (entre 6 et 7 tCO_2e par an), on retrouve des groupes tels que les 1 % les plus riches tanzaniens, une partie de la classe moyenne chinoise ou des Européens aux revenus modestes (deuxième et troisième décile français et allemand par exemple).

Les classes moyennes et aisées des pays émergents ont accru leurs émissions plus rapidement que tous les autres groupes sociaux à l'échelle mondiale au cours des 15 dernières années, avec des taux de croissance cumulés des émissions atteignant 40 % (Figure E.2). Certains groupes sociaux ont vu leurs émissions croître beaucoup moins rapidement depuis 1998, voire diminuer dans le cas des individus les plus faiblement émetteurs. Au sommet de la pyramide des émetteurs, la majorité de la population des pays industrialisés a vu ses émissions croître relativement modestement (10 %). Si les différences d'émissions entre le milieu de la distribution et le sommet se sont réduites, elles se sont accrues entre le bas de la pyramide des émetteurs et le milieu. Ces tendances sont positives du point de vue des revenus (émergence d'une classe moyenne mondiale) mais elles constituent un réel défi en matière climatique.

FIGURE E.1. RÉPARTITION GÉOGRAPHIQUE DES ÉMETTEURS DE CO$_2$e



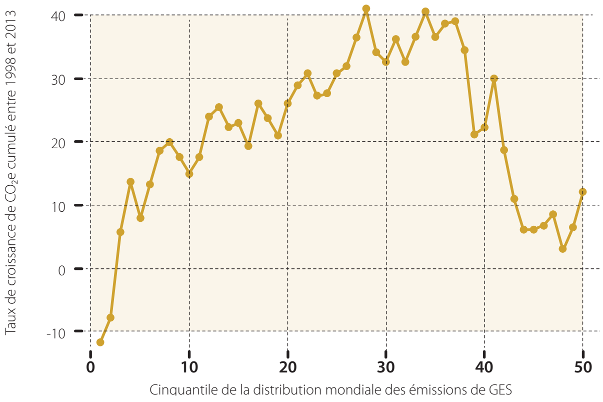
Les 10% les plus grands émetteurs : 45% des émissions mondiales

Les 40 % du milieu : 42% des émissions mondiales

La moitié inférieure des émetteurs : 13% des émissions mondiales

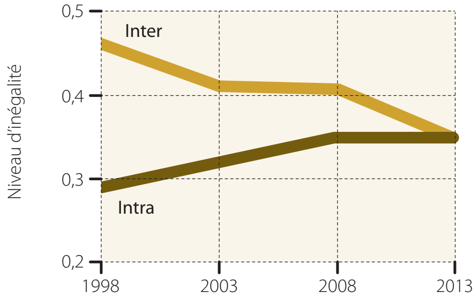
Source: auteurs. Lecture : Parmi les 10 % des individus les plus émetteurs au niveau mondial, 40 % des émissions de CO$_2$e satisfont les besoins des Nord-Américains, 20 % des Européens et 10 % des Chinois.

FIGURE E.2. COMMENT LES ÉMISSIONS DE CO$_2$e ONT-ELLES ÉVOLUÉ ENTRE KYOTO ET PARIS POUR DIFFÉRENTS GROUPES D'ÉMETTEURS ?



Source : auteurs. Lecture: le groupe représentant les individus les 2 % les moins émetteurs au monde a vu ses émissions de CO$_2$e par tête baisser de 12 % en 1998 et 2013.

FIGURE E.3. INÉGALITÉS MONDIALES D'ÉMISSIONS DE CO$_2$e: IMPORTANCE DES INÉGALITÉS INTRA ET INTER PAYS



Source : auteurs. Lecture: En 2008, la composante intra-pays de l'indice de Theil était de 0,35 et la composante entre-pays de 0,40, i.e. les inégalités intra-pays contribuaient à hauteur de 47 % à l'inégalité globale contre 53 % pour les inégalités mondiales - telles que mesurées par l'indice de Theil.

TABLEAU E.4. QUI DEVRAIT CONTRIBUER AUX FONDS D'ADAPTATION POUR LE CLIMAT?

Régions	Financement en proportion des émissions totales (taxe proportionnelle sur le CO2e) (%)	Financement par des taxes progressives sur le CO_2e			Financement selon une taxe sur les billets d'avion (%)
		Stratégie 1	Stratégie 2	Stratégie 3	
		Partage du financement parmi tous les émetteurs au-dessus de la moyenne mondiale (%)	Partage du financement parmi les 10% les plus émetteurs (2,3 x au-dessus de la moyenne mondiale) (%)	Partage du financement parmi les 1% les plus émetteurs (9,1 x au-dessus de la moyenne mondiale) (%)	
Amérique du Nord	21,2	35,7	46,2	57,3	29,1
UE	16,4	20,0	15,6	14,8	21,9
Chine	21,5	15,1	11,6	5,7	13,6
Russie/Asie centrale.	6,0	6,6	6,3	6,1	2,8
Autres riches	4,6	5,8	4,5	3,8	3,8
Moyen-Orient/Afrique du Nord	5,8	5,4	5,5	6,6	5,7
Amérique latine	5,9	4,3	4,1	1,9	7,0
Inde	7,2	1,0	0,7	0,0	2,9
Autres Asie	8,3	4,7	4,1	2,7	12,1
Afrique subsaharienne	3,1	1,5	1,5	1,1	1,1
Monde	100	100	100	100	100

Source: auteurs. Lecture: l'Amérique du Nord représente 46,2 % des émissions mondiales générées par des individus émettant plus de 2,3 fois la moyenne mondiale. Les individus émettant 2,3 fois plus que la moyenne mondiale (soit 14,3 tCO_2e) appartiennent aux 10 % les plus émetteurs. Note : 27 % des émetteurs mondiaux émettent plus que la moyenne mondiale (Stratégie 1). Ces calculs correspondent aux émissions liées à la consommation des individus.

Nos résultats montrent que les inégalités d'émissions de CO_2e mondiales sont de plus en plus expliquées par les inégalités à l'intérieur des pays – et non entre pays. En effet, les inégalités intra-pays expliquaient un tiers de l'inégalité mondiale des émissions de CO_2e individuelles en 1998 et représentent aujourd'hui la moitié de cette inégalité (Figure E.3). Cela renforce la pertinence d'un focus sur les individus plutôt que sur les pays fortement émetteurs.

La nouvelle géographie des émetteurs appelle à des actions de lutte contre le changement climatique dans tous les pays. Alors que les pays en développement et émergents contribuent de manière croissante aux efforts de réduction des émissions (efforts dits d'atténuation), la contribution aux fonds internationaux de financement de l'adaptation au changement climatique demeure essentiellement le fait des pays développés (et principalement de l'UE, avec plus de la moitié des financements, cf. section 2). Si une hausse des contributions des pays du Nord est nécessaire, notre étude montre que les classes aisées des pays émergents, du fait de la hausse de leurs revenus et de leurs émissions, pourraient également contribuer à ces fonds. Avec les contributions récentes de la Corée du Sud, du Mexique et de la Colombie au Fonds Vert pour le Climat, des pays émergents et en développement financent de facto l'adaptation au changement climatique et remettent en cause les principes de répartition qui semblaient prévaloir jusqu'à présent. Toutefois, leur contribution demeure symbolique à l'heure actuelle et ne reflète ni la répartition des émissions historiques de gaz à effet de serre, ni la nouvelle géographie des grands et petits émetteurs individuels.

Cette étude examine de nouvelles stratégies en vue d'augmenter le volume global de l'aide pour l'adaptation au changement climatique. Dans ces stratégies, les émissions individuelles et non les émissions nationales ou le PIB par tête, seraient la base de calcul des contributions. Afin de mieux aligner les contributions aux fonds d'adaptation à la nouvelle distribution mondiale des émetteurs, l'étude examine les implications d'une taxe mondiale progressive sur le CO_2e afin de lever 150 milliards d'euros nécessaires pour financer l'adaptation (Tableau E.4). Dans la stratégie 1, tous les émetteurs au dessus de la moyenne mondiale (i.e. tous les émetteurs au dessus de 6,2 tCO_2e par an) contribuent à l'effort en proportion de leurs émissions dépassant le seuil. Les Nord-Américains contribueraient à hauteur de 46 % des efforts, contre 16 % pour les Européens et 12 % pour les chinois. Dans la stratégie 3, les efforts sont répartis entre les 1% les plus émetteurs (i.e. tous les individus au-dessus de 9,1 fois la moyenne mondiale). Les Nord-américains contribueraient à hauteur de 57 % des efforts, contre 15 % pour les Européens et 6 % pour les Chinois. Dans ces nouvelles clefs de répartition des efforts, la part des financements provenant de l'Europe diminuerait en proportion mais augmenterait en absolu. En effet, dans la stratégie 3, la plus favorable aux Européens, le volume de financement provenant du Vieux continent atteindrait 23 milliards d'euros, soit plus de trois fois sa contribution actuelle.

Nous discutons également de la mise en place de telles mesures via des taxes nationales sur le revenu et via une taxe progressive généralisée sur les billets d'avion. Une taxe sur les billets d'avions a déjà été mise en place dans 9 pays et est actuellement utilisée pour financer des programmes de développement international. La taxation de tous les billets de première classe à hauteur de 180 € et de tous les billets de classe économie à hauteur de 20 € permettrait de générer 150 milliards d'euros pour l'adaptation chaque année. Cette solution serait plus facile à mettre en oeuvre qu'une taxe progressive sur le CO_2 mais ciblerait moins bien les grands émetteurs individuels.

EXECUTIVE SUMMARY IN ENGLISH

This study presents evolutions in the global distribution of CO_2e emissions (CO_2 and other Green House Gases [GHG]) between world individuals from 1998 and 2013 and examines different strategies to contribute to a global climate adaptation fund based on efforts shared among high emitters rather than high-income countries. To this end, we combine data on historical trends in per capita country-level emissions, within-country income inequality, as well as environmental input-output data (capturing consumption-based CO_2 emissions and other GHG gases) and a simple income-CO_2e elasticity model. Our data covers approximately 90% of world GDP, population and CO_2e emissions. Our results depend not only on within country inequalities, but also on changes in consumption-based CO_2e emission levels of countries.

We show that global CO_2e emissions inequalities between individuals decreased from Kyoto to Paris, due to the rise of top and mid income groups in developing countries and the relative stagnation of incomes and emissions of the majority of the population in industrialized economies. Income and CO_2e emissions inequalities however increased within countries over the period. Global CO_2e emissions remain highly concentrated today: top 10% emitters contribute to 45% of global emissions, while bottom 50% contribute to 13% of global emissions. Top 10% emitters live on all continents, with one third of them from emerging countries (Figure E.1).

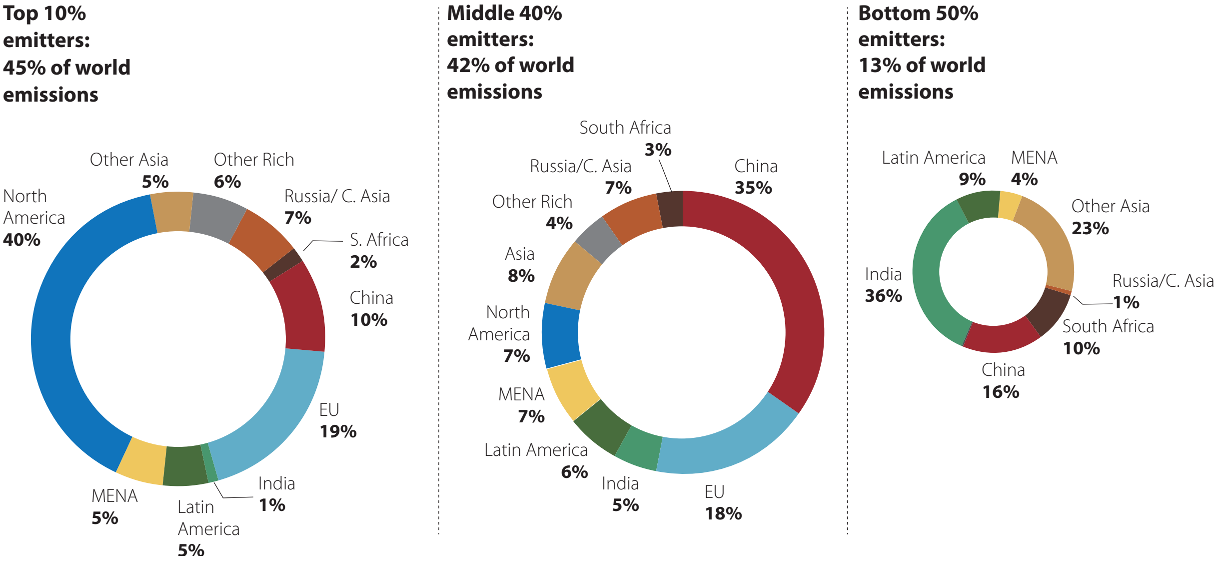
Our estimations show that the top 1% richest Americans, Luxemburgers, Singaporeans, and Saudi Arabians are the highest individual emitters in the world, with annual per capita emissions above 200tCO_2e. At the other end of the pyramid of emitters, lie the lowest income groups of Honduras, Mozambique, Rwanda and Malawi, with emissions two thousand times lower, at around 0.1tCO_2e per person and per year. In the middle of the world distribution of emitters (between 6 and 7tCO_2e per person and per year), lie groups such as the top 1% richest Tanzanians, the Chinese 7th income decile, the French second income decile or the third German income decile.

Middle and upper classes of emerging countries increased their CO_2e emissions more than any other group within the past 15 years. This led to a reduction in the global dispersion of CO_2e emissions - especially between the middle of the income distribution and the top (Figure E.2). However, the inequality of CO_2e emissions increased between the bottom of the distribution and the middle. While these trends, if continued, are positive from an income point of view (emergence of a global middle class), they constitute a real challenge for future global CO_2e emissions levels.

Our estimates also show that within-country inequality in CO_2e emissions matters more and more to explain the global dispersion of CO_2e emissions. In 1998, one third of global CO_2e emissions inequality was accounted for by inequality within countries. Today, within-country inequality makes up 50% of the global dispersion of CO_2e emissions (Figure E.3). It is then crucial to focus on high individual emitters rather than high emitting countries.

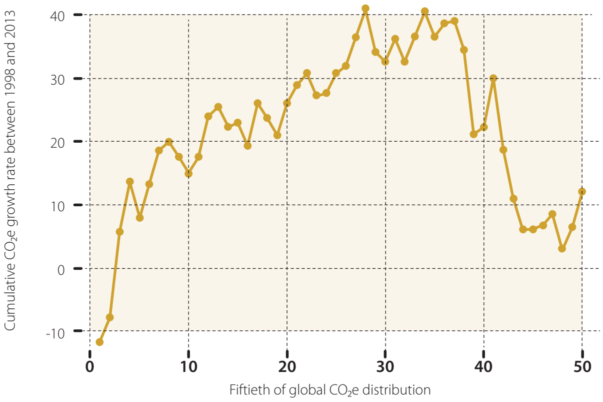
The new geography of global emitters calls for climate action in all countries. While developed and developing countries already engaged in mitigation efforts, contributions to climate adaptation funds remain almost entirely financed by

FIGURE E.1. BREAKDOWN OF TOP 10, MIDDLE 40 AND BOTTOM 50% CO_2e EMITTERS



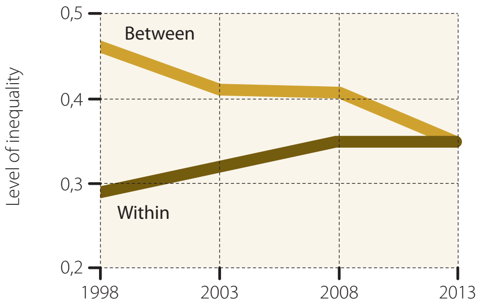
Source: authors. Key: Among the top 10% global emitters, 40% of CO_2e emissions are due to US citizens, 20% to the EU and 10% from China.

FIGURE E.2. HOW DID CO_2e EMISSIONS GROW FROM KYOTO TO PARIS FOR DIFFERENT GROUPS OF EMITTERS?



Source: authors. Key: the group representing the 2% lowest CO_2e emitters in the world, saw its per capita CO_2e emissions level decrease by 12% between 1998 and 2013.

FIGURE E.3. WORLD CO_2e EMISSIONS INEQUALITIES: WITHIN AND BETWEEN COUNTRY IMPORTANCE



Source: authors. Key: in 2008, the within-country component of the Theil index was of 0.35 and the between-country component of 0.40, i.e. between-country inequalities contributed to 53% of total inequalities - as measured by the Theil index.

developed nations, and for the most part by Europe (with more than half total contributions, see section 2). If it is necessary to increase the volume of adaptation finance from developed countries, our study shows that upper income groups of emerging countries, who benefited from income growth and resulting CO_2e emissions growth over the past decades, could also participate in to such funds. With the contributions of South Korea, Mexico or Colombia to the Green Climate Fund, emerging and developing countries are committing to finance adaptation and broke the standard developed-developing countries divide which seemed to prevailed so far. However, their contributions remain symbolic at this stage (less than 1% of all global adaptation funds) and the equity logic behind adaptation funding remains unclear.

TABLE E.4. WHO SHOULD CONTRIBUTE TO CLIMATE ADAPTATION FUNDS?

Regions	Effort sharing according to all emissions (flat carbon tax) (%)	Progressive carbon tax strategies			Effort sharing according to a global tax on air tickets (%)
		Strategy 1	Strategy 2	Strategy 3	
		Effort sharing among all emitters above world average (%)	Effort sharing among top 10% emitters (above 2.3x world average) (%)	Effort sharing among top 1% emitters (above 9.1x world average) (%)	
North America	21.2	35.7	46.2	57.3	29.1
EU	16.4	20.0	15.6	14.8	21.9
China	21.5	15.1	11.6	5.7	13.6
Russia/C. Asia	6.0	6.6	6.3	6.1	2.8
Other Rich	4.6	5.8	4.5	3.8	3.8
Middle East/N.A.	5.8	5.4	5.5	6.6	5.7
Latin America	5.9	4.3	4.1	1.9	7.0
India	7.2	1.0	0.7	0.0	2.9
Other Asia	8.3	4.7	4.1	2.7	12.1
S.S. Africa	3.1	1.5	1.5	1.1	1.1
World	100	100	100	100	100

Source: Authors. Air passenger data from World Bank (2015). Key: North Americans represent 46.2% of global emissions released by individuals who emit 2.3 times more than the global average. Individuals who emit more than 2.3 times average emissions (14.3 tCO2e per year) belong to the top 10% emitters. Note: 27% of individuals emit more than world average emissions (Strategy 1). These estimations focus on consumption-based emissions.

This report suggests novel strategies to increase global climate adaptation funding, in which individual CO_2e emissions (rather than national CO_2e or income averages) are the basis for contributions. In order to better align these contributions to the new distribution of high emitters, we first examine the implications of a global progressive carbon tax to raise €150 billion required annually for climate adaptation (Table E.1). In strategy 1, all emitters above world average emissions (i.e. all individuals emitting more than 6.2t per year) contribute to the scheme in proportion to their emissions in excess of this threshold. North Americans would contribute to 36% of the fund, vs. 20% for Europeans, 15% for China. In strategy 2, the effort is shared by all top 10% emitters in the world (i.e. all individuals emitting more than 2.3 times world average emissions), again in proportion to their emissions in excess of this threshold. North Americans would then pay 46% of the tax, vs. 16% for Europeans, 12% for China. In strategy 3, the effort is shared by all top 1% emitters in the world (i.e. all individuals emitting more than 9.1 times world average emissions). North Americans would then contribute to 57% of efforts, vs. 15% for Europeans, 6% for China. In these new strategies to finance climate adaptation, the share of Europe would decrease in proportion, but increase in absolute terms. In strategy 3, the most favourable to Europeans, the volume of finance coming from Europe would reach €23 billion, more than three times its current contributions.

We also discuss possible implementations via country-level carbon and income taxes or via a generalized progressive tax on air tickets to finance the adaptation fund. A tax on air tickets has already been implemented in 9 countries and is currently used to finance development programs. Taxing all business class tickets at a rate of €180 and all economy class tickets at a rate of €20 would yield €150 billion required for climate adaptation every year. This latter solution might be easier to implement but less well targeted at top emitters.

SECTION 1. INTRODUCTION

Environmental degradation, in particular climate change (IPCC, 2014a), and rising economic inequalities (Piketty, 2014; OECD, 2011) are two key challenges for policymakers in the decades to come. Both challenges endanger democratic institutions and social contracts. In order to address these two challenges, it is essential to better understand interactions between economic inequalities and environmental degradation.

Different types of "environmental inequalities" can be distinguished: inequalities in terms of *exposure* to environmental degradation, and inequalities in contribution to pollution. Exposure inequalities occur between countries (tropical countries are more exposed to climate change than more temperate zones, for instance- see IPCC, 2014), but also within countries and among social or ethnic groups. Aizer et al. (2015), for instance, showed how African-Americans are more likely to suffer from exposure to lead pollution in Northeastern USA, which in return affects their life chances and capabilities. The second type of environmental inequality, upon which we focus in the present study, relates to *contribution to pollution* inequalities, or to the differentiated impacts of social groups or individuals on environmental degradation (see Chakravarty and Ramana, 2011). Environmental inequalities can also take a third form, namely *policy effect* inequalities. These are inequalities generated by environmental policies that alter income distributions. Energy policies which increase the price of energy can have regressive impacts, i.e. hit the poor relatively more than the rich (Sterner, 2011). A fourth form of environmental inequalities relates to *policy making* inequalities, i.e. different social groups do not access environmental policy making in the same way (Martinez-Alier, 2003).

This study focuses upon the second type of environmental inequalities (unequal contributions to pollution). We present novel and up-to-date estimates of the global distribution of individual CO_2e emissions (and other green house gases[1]) between world individuals from 1998 and 2013. We then examine different strategies to contribute to a global climate adaptation fund based on efforts shared among high emitters rather than high-income countries or historical emissions. In effect, we simulate different variants of a global progressive carbon tax. We also discuss possible implementations via country-level carbon and income taxes or via a generalized progressive tax on air tickets. Our basic premise is that in order to increase funding and acceptability for a world adaption fund, it is necessary to deepen our understanding of what an equitable distribution of efforts between countries should look like. Rather than clearing developed countries from their responsibilities, this approach calls for an increase in current contributions from high emitters wherever they are on the planet.

The rest of this report is organized as follows: in section 2, we review the current debate on climate adaptation funds and the need to find new financing schemes. Section 3 provides data on historical regional CO_2e emissions trends. Existing literature on global distributions of CO_2e emissions is discussed in section 4 and section 5 presents the methodology followed. Section 6 presents our results of the current distribution of individual CO_2e emissions and its evolution over the past 15 years (1998-2013). Finally, section 7 applies our results to different progressive carbon tax options on the world top carbon emitters in order to finance adaptation funds.

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[1] Unless specified, CO_2e and CO_2 equivalent (CO_2e) are used interchangeably.

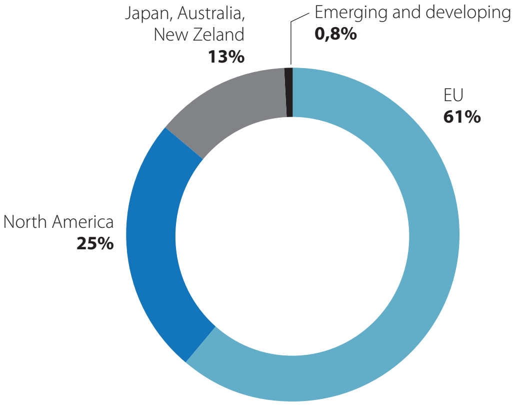
SECTION 2. CLIMATE ADAPTATION FUNDING: THE GAP

The effects of climate change are already palpable: warmer temperatures, ocean and sea level rise as well increased frequency of high precipitations events (IPCC, 2013). Further warming will inevitably occur in the decades to come - the question is whether it can be limited to a two degree rise - and will place higher pressure on ecosystems and human populations, particularly those living in tropical areas and close to seashores of the developing world[2] (IPCC, 2014a). Estimates of costs to adapt to such changes in developing countries range from €60 billion per year according to the IPCC (2014b) up to €300 billion per year[3], according to the United Nations Environmental Program (UNEP, 2014). It should however be reminded that many types of climate change impacts cannot easily (or not at all) be valued in economic terms (for e.g. human losses or the extinction of living species).

Current flows for climate adaptation in developing countries fall short of these figures. According to the OECD (2015), they reached only about €10bn in 2014, with less of €2bn in donations. In comparison, funds allocated to climate mitigation in developing countries (i.e. actions to reduce carbon emissions rather than adapt to a warmer climate) are four times higher. The OECD and the UNEP anticipate a climate adaptation finance gap, despite the diversity of global funds existing to finance adaptation in developing countries: the newly established Green Climate Fund should in theory dedicate half of its resources to adaptation, but only 20% of the €4.3bn pledged currently support adaptation programs. Other international funds are specifically directed at adaptation, such as the World Bank's Pilot Program for Climate Resilience and the UNFCCC Least Developed Countries Fund but their volume remains low compared to the requirements[4].

As crucial as the question of the volume of finance required for adaptation is the repartition of the financial effort and the equity logic followed to share the contributions. In order to increase the total volume of finance that countries are ready to allocate to the fund, it seems critical to better understand how an equitable distribution of contributions should look like. Figure 1A presents the regional breakdown of global climate adaptation funds contributors. Such data is indeed imperfect given the difficulty to measure such financial flows, but remains a useful benchmark. According our estimates, the European Union provides more than 60% of funds, the USA a quarter, other rich countries making up 13% of the effort.

FIGURE 1A. CONTRIBUTORS TO GLOBAL ADAPTATION FUNDS (2014)



Source: Authors. Data from climatefundsupdate.org and gcca.eu. Key: Western Europe contributes to 61% of global climate adaptation funds.Note: the breakdown is based on a total value of funds of €7.5bn. The focus is solely on global funds pledged and/or actually disbursed. Bilateral funds and funds disbursed by developing countries for themselves are not taken into account.

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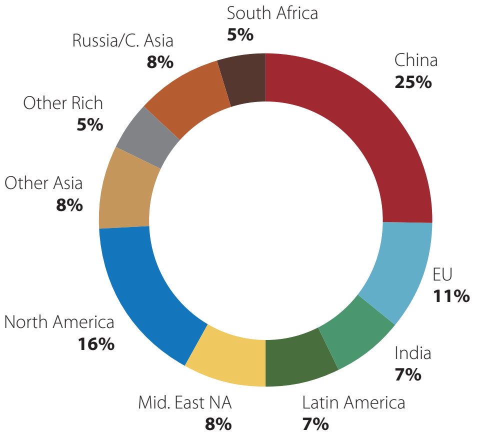
2. Even though other zones, including temperate regions in developed countries are also at risk.
3. According to the latest Adaptation Gap publications (UNEP, 2014), adaptation costs could climb as high as $150 billion (€125bn) by 2025/2030 and $250-500 billion per year (€208bn - €416bn) by 2050.
4. These two schemes respectively operated €800m and €750m in 2014. Other schemes include the Special Climate Change Fund with €280m, both established by the UNFCCC and operated by the Global Environmental Facility, the Adaptation for Smallholder Agriculture Program with €250m, administered by the UN International Fund for Agricultural Development as well as the Adaptation Fund established by the UNFCCC, with €180m. The Global Climate Change Alliance of the European Union also acts in the field of Adaptation with about €120m in 2014. In addition, not listed here, are all the funds directly disbursed by developing countries.

While this breakdown could a priori be justified by countries' historical responsibilities for climate change – in line with "retributive justice" principles and the UNFCCC "Common But Differentiated Responsibilities" (CBDR) principle, such arguments need to be made more explicit. We show below that European countries are responsible for less than 11% of current emissions, and 20% of cumulated emissions since the industrial revolution - and emerging countries already account for more than a third of cumulated historical CO_2e emissions (see figures 1B-1C). Another logic which could justify such a breakdown of the contributions to adaptation could be ability to pay of contributors (for e.g. their GDP per capita and income levels – see figure A.1.) following a "distributive justice" principle or the "Respective Capabilities" principle of the UNFCCC. This logic may however also be challenged, given the importance of within-country inequalities. Once again, our objective is not to clear Europe (or the USA) from their responsibilities - their contributions to adaptation should substantially increase, but rather examine novel effort sharing strategies in which within-country inequalities would also be taken into account.

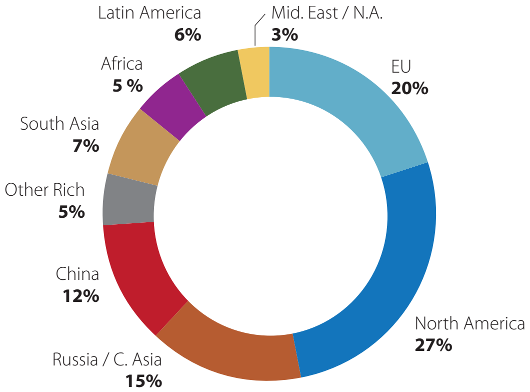
It is interesting to note the presence of contributors from emerging and developing countries in Fig. 1A. South Korea, Mexico, Peru and Colombia contribute to global climate adaptation finance via their recent pledges to the Green Climate Fund. Their contributions only represent 1% of all adaptation finance, but it is noteworthy because it is de facto calling into question standard understanding of climate equity principle in climate debates. There is thus an opportunity to reassess the current repartition of climate adaptation funding efforts -with the objective to increase the volume of efforts- in the light of new equity principles[5]. In this paper, we examine a logic in which individuals, rather than countries would contribute to adaptation efforts, on the basis of their current contributions to climate change. This calls for the construction of an up-to-date global distribution of individual CO_2e emissions, as it does not exist so far.

FIGURE 1.B. DISTRIBUTION OF CURRENT PRODUCTION-BASED CO_2e EMISSIONS



Source: authors based on CAIT (WRI, 2015). Key: China represents 25% of global CO_2e emissions when measured from a production base. Note: data from 2012.

FIGURE 1.C. DISTRIBUTION OF CUMULATED PRODUCTION-BASED HISTORICAL CO_2e EMISSIONS



Source: authors based on CAIT (WRI, 2015) and CDIAC (Boden et al., 2015). Key: Emissions from North America represent 27% of all CO_2e emissions ever emitted since the industrial revolution. Note: these are production-based emissions estimates. Regions may slightly vary from those of other graphs, see Boden el at. (2015).

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[5] For a review of different proposal for climate adaptation finance and different equity approaches to it, see Brown and Vigneri (2008) and Baer (2006).

SECTION 3. HISTORICAL CO_2e EMISSIONS: KEY FACTS AND FIGURES

Section 3.1. Global CO_2e budget and annual emissions

Before turning to a global distribution of individual CO_2e emissions, and its implications for climate adaptation finance, we review a few key facts and figures of global climate change debates, which will be referred to later in this report. In order to secure reasonable chances to limit global warming to a 2°C average temperature rise the Intergovernmental Panel on Climate Change (IPCC) estimates that we are left with the equivalent of about 1000 gigatonnes (Gt) of CO_2e to emit before 2100. In 2014, global CO_2e emissions reached approximately fourty-five $GtCO_2e$[6]. At this rate of emissions, the world will reach the 2°C limit in about twenty years and a prolongation of current emissions trends throughout the century will increase global temperatures by more than 4°C by 2100 (IPCC, 2014a). From the 1000 Gt budget, it is possible to calculate the sustainable level of emissions per capita, i.e. the amount of CO_2e emissions each individual is entitled to emit, between now and 2100. The sustainable level of CO_2e to emit per person per year, from now to 2100 is approximately $1.2tCO_2e$[7] - about 6 times lower than the current average annual per capital emission level of $6.2tCO_2e$.

Since the first industrial use of coal in the early 18th century Britain, the geographical repartition of CO_2e emissions changed constantly and radically (Fig. 2A). At the end of the first industrial Revolution, in the 1820s, emissions from Western Europe accounted for more than 95% of the global total. A hundred years later, in 1920, North America was the highest emitting region in the world, with 50% of global emissions. Another hundred years down the line (that is today), both Western Europe and North America's shares in global emissions had shrunk, though not at the same pace: Western Europe represents 9% of global emissions today (about 3.6 Giga tonnes of CO_2e per year), while North America maintains itself at a relatively high level: it represents 16% of emissions (7 Gt). The new high global emitting region is indeed Asia, and in particular China, which emits close to 25% of world CO_2e emissions (11 Gt). Fig. 2B shows the change in cumulated historical emissions per region. It comes out that emissions stemming from Western Europe, North America, Japan and Australia account for less than 50% of global historical emissions since the industrial revolution[8]. China accounts for 12% of all anthropic emissions ever produced.

Section 3.2. Per capita emissions over time

China is the world's highest emitter today, but its emissions per head are still below those of most of western European countries and the USA. It is essential to go beyond national totals in order to get a sense of how CO_2e is distributed among humans. In 1820, per capita CO_2e emissions were zero for most of the world and 0.5t per person in Western Europe. In 1920, world CO_2e emissions' average was close to 3.4 tonnes per capita: the second industrial revolution had occurred and spread to the North American continent. North American emissions had skyrocketed to 19 tonnes per person, while Western Europeans emitted about 6 tonnes of CO_2e.

This early gap between American and European per capita emissions deserves attention: as early as the 1920s, Americans were consuming three times more energy per capita than Europeans and emitting three times more CO_2e emissions as a result. If Europeans slightly caught up with their American counterparts after the second World War (thanks to the so-called "Golden age of growth", the development of mass private transportation and mass consumption) a 10 tonnes difference persisted between Americans and Western Europeans throughout the 20th century, despite

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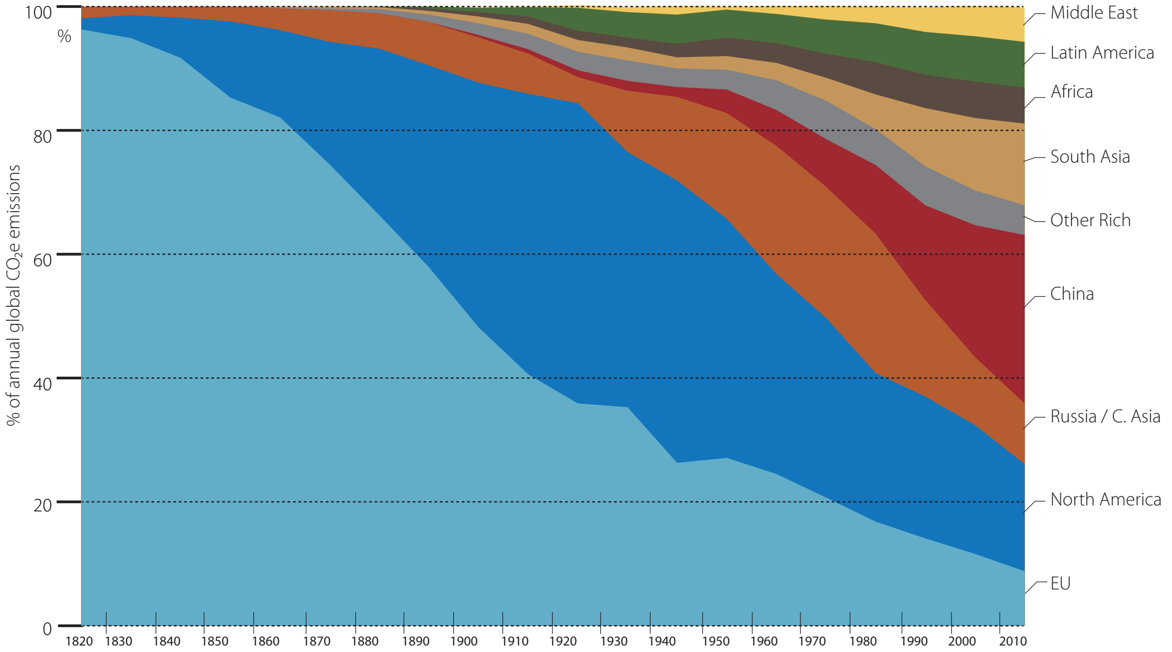
[6] It is about 43 $GtCO_2e$ excluding for all GHGs excluding land-use change and $46GtCO_2e$ including land-use change (such as deforestation for agriculture for instance).

[7] The IPCC RCP 2.6 scenario (IPCC, 2013) estimates that the leftover budget, accounting for non-CO2 GHG, is 275 PgC, i.e. about 1000GtCO2e. We divide the 1000GtCO2e by estimated cumulated annual population from now to 2100, i.e. 795 billion-year individuals according to the UN.

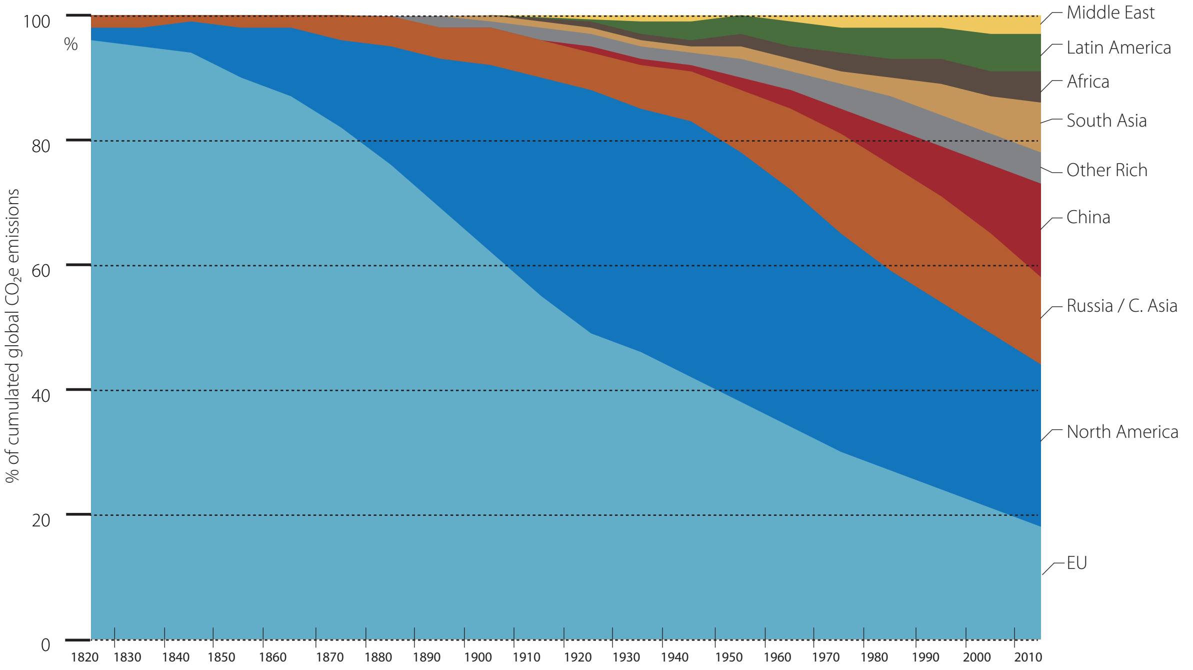
[8] Looking at consumption-based emissions (as we do below) rather than production base emissions would increase the share and responsibility for developed countries.

FIGURE 2A. SHARE IN GLOBAL CO_2e EMISSIONS SINCE 1820



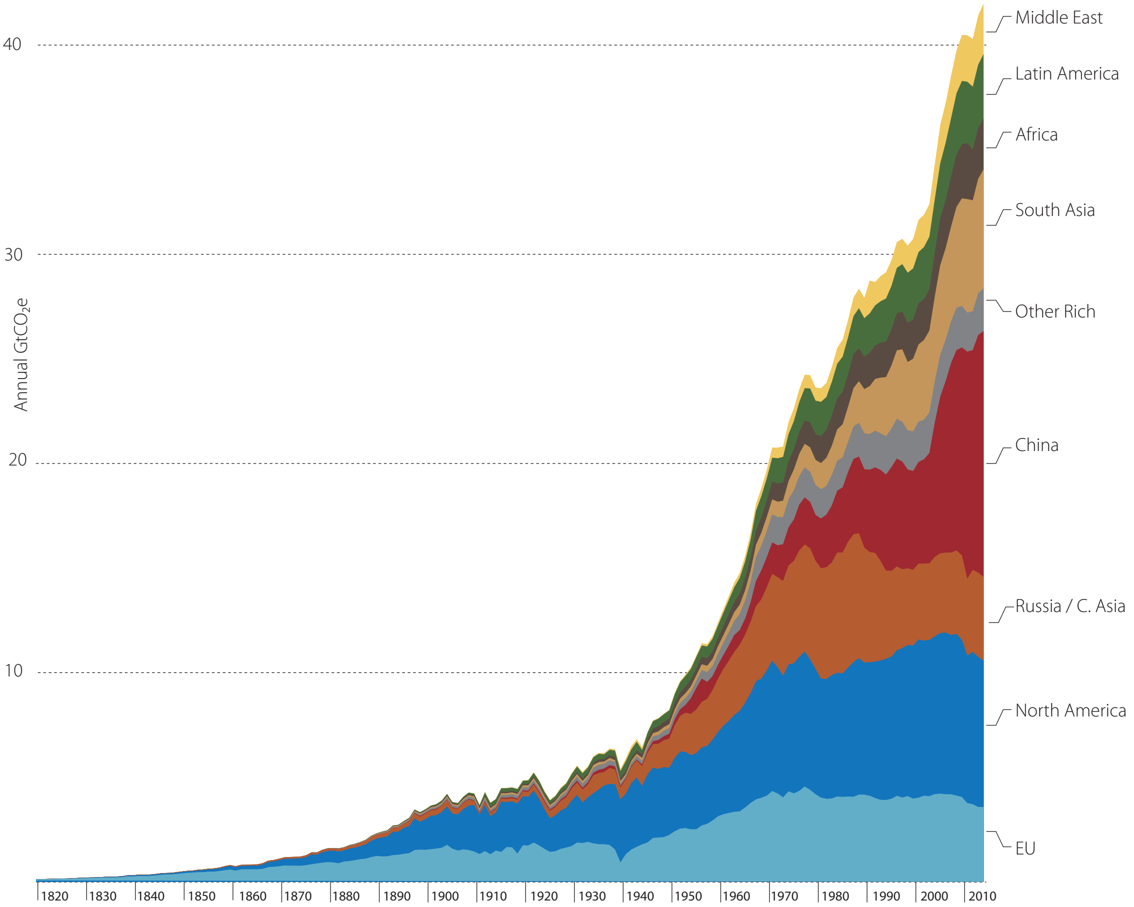
Source: authors' estimates based on CAIT (WRI, 2015), CDIAC (Boden et al., 2015), Maddison (Maddison, 2013). Key: in 2010, 9% of global CO_2e emissions are emitted in Western Europe. Note: data is smoothed via 5-year centred moving averages. The composition of each region in this graph may slightly vary from the rest of the study, see Boden et al. (2015) for details.

FIGURE 2B. SHARE IN CUMULATED GLOBAL CO_2e EMISSIONS SINCE 1820



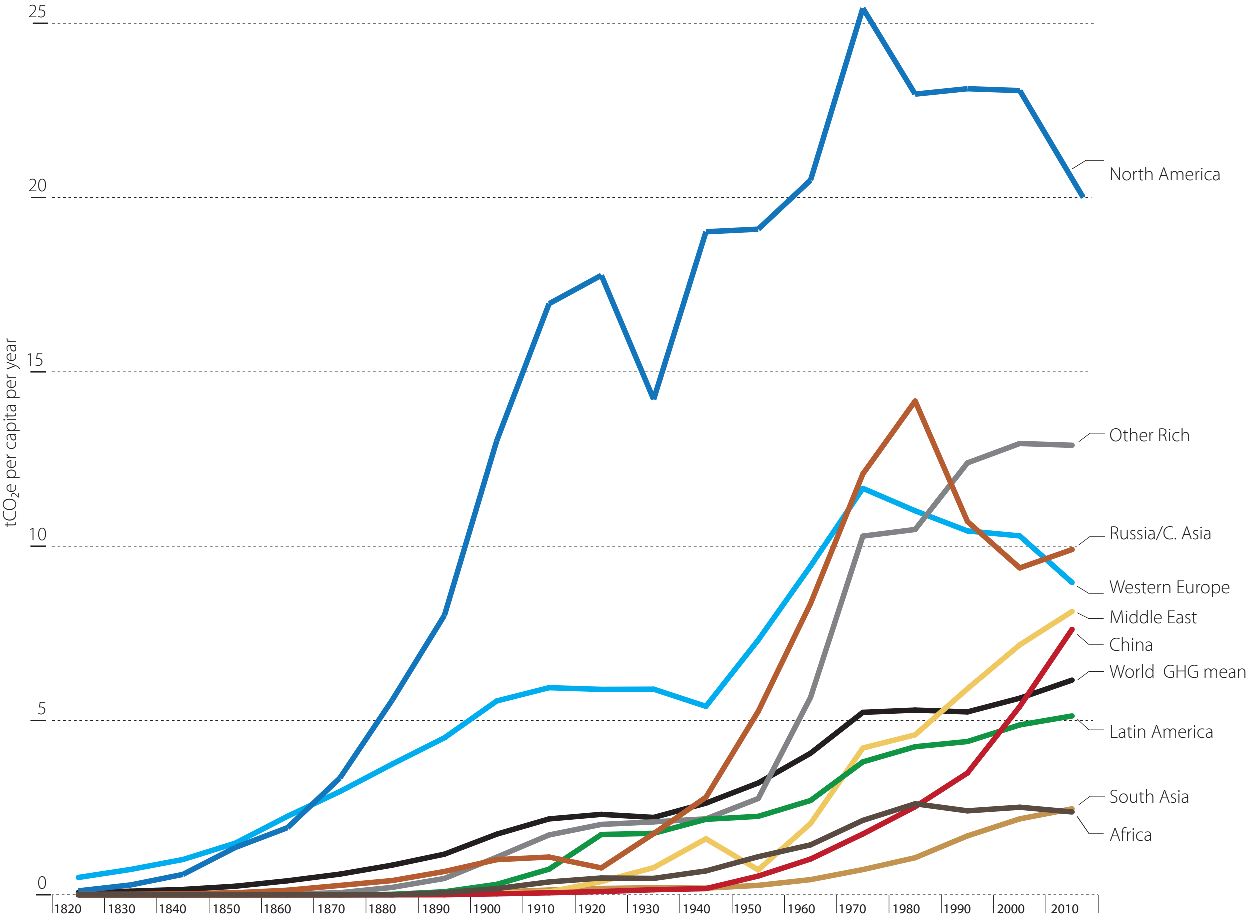
Source: authors' estimates based on CAIT (WRI, 2015), CDIAC (Boden et al., 2015), Maddison (Maddison, 2013). Key: In 2010, 12% of cumulated global CO_2e emissions, since the Industrial revolutions, were emitted in China. Note: data is smoothed via 5-year centred moving averages. Composition of each regionsin this graph may slightly vary from the rest of the study, see Boden et al. (2015) for details.

FIGURE 3. GLOBAL CO_2e EMISSIONS PER REGION, FROM 1820 TO TODAY



Source: authors' estimates based on CAIT (WRI, 2015), CDIAC (Boden et al., 2015), Maddison (Maddison, 2013). Key: Western European countries emit 3.5 billion tonnes of CO_2e in 2012.

FIGURE 4. PER CAPITA CO_2e EMISSIONS PER WORLD REGION



Source: Authors' estimates based on CAIT (WRI, 2015), CDIAC (Boden et al., 2015), Maddison (Maddison, 2013). Key: in 2012, the North American per capita CO_2e emission average is 20.5tCO_2e.

harmonization in per capita income between the two regions[9].

Today, each American emits about 20 tonnes of CO_2e per year, while a typical Western European emit more than two times less: 9 tonnes, in a close range to average the Russian. An average person from the Middle East emits around 8 tonnes per capita, a figure similar to Chinese per capita emissions, above the world average, i.e. 6.2 tonnes per capita, while south Asians and Africans emit respectively close to 2.4tCO_2e per capita[10].

Table 1 presents the ratio between regional per capita emissions and world average. Regional averages are all above the sustainable level of CO_2e emissions of 1.2tCO_2e per head.

Such values however suffer from two key limitations. The first one is that they reflect production-base (or territorial) emissions. Production-base emissions relate to all CO_2e emitted on a given territory: emissions attributed to China take into account all emissions which were produced

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9. The Europe/US gap is further discussed in section 4.1 below.

10. Note that when emissions from land use change are included, world average is 6.5CO_2etCO_2e, African average emissions are 3.4CO_2etCO_2e and Latino American average emissions come about 7.4CO_2etCO_2e, a large difference explained by deforestation in tropical regions. However, the proper way to measure emissions associated with land use is still debated and it is very hazardous to reconstruct historical series accounting for land -use change - we thus only include all GHG without land use change values in our figures.

TABLE 1. CURRENT PER CAPITA CO_2e EMISSIONS

	tCO_2e per person per year	Ratio to world average
World average	6.2	1
N. Americans	20	3.2
Russians / C. Asians	10	1.6
West. Europeans	9	1.5
Chinese, Middle East	8	1.3
S. Americans	5.2	0.8
S. Asians, Africans	2.4	0.4
Sustainable level	1.3	0.2

in China, even if these emissions were used to produce goods or services consumed elsewhere in the world. It is then misleading to only focus on production base emissions and one should also look at "consumption-based emission": emissions attributed to countries or individuals on the basis of what they really consume. There is a growing amount of work on consumption-based emissions (see for instance Peters and Hertwich, 2008; Wood et al., 2014), but constructing these estimates is a complicated task and they are available for a few years only, certainly not in relatively homogenous series dating back to 1820 as we present here - that is why only production base emissions are presented in this historical section.

The second key limitation of these graphs is that they inform on national per capita averages and not on any disparity within countries. Indeed, within countries, individuals do not have the same energy consumption and resulting CO_2e emission levels as lifestyles and income levels are not homogenous: in Western Europe for instance, urban dwellers, using public transportation will not have the same level of energy consumption and CO_2e emissions as peri-urban neighbours, who take the car every day - even if a few holiday air trips (or inefficient heating systems) can counterbalance differences in CO_2e emissions from daily transportation. In India, individual emissions between a peasant of rural Maharashtra (Bombay State) and a motorized urban upper middle class individual living in Bombay are even more likely to differ.

SECTION 4. COMBINING INCOME INEQUALITY STATISTICS WITH CO_2e EMISSIONS: A LITERATURE REVIEW

Section 4.1. CO_2e emissions, living standards and income levels

National statistical institutes were not historically well equipped to provide detailed information of environmental resource consumption, and even less on individual level consumption of environmental goods and services. There have been important evolutions over the past decade to better account for the evolution of the environmental resources and services, as well as of the evolution of within country income distributions (UN, 2014). However, detailed statistics on the distribution of pollution or consumption of environmental within countries is still among individuals is generally missing.

Existing research however lays the ground to develop such statistics. There is an important amount of work on the determinants of energy consumption and CO_2e emissions for instance, and a growing interest in the specific question of CO_2e emissions and income distributions (Jackson and Papathanasopoulou, 2008; Lenzen et al., 2006; Weber and Matthews, 2008). Such literature puts forward income or expenditure level as the most important driver of CO_2e emissions, even though other important variables have a role to play.

Section 4.1.1. Income, expenditure, energy consumption CO_2e emissions

Income or expenditure levels are generally put forward as the main drivers explaining energy consumption or total CO_2e emissions differences among individuals and households (see for instance Wier et al., 2001; Lenzen et al., 2006). It is important here to define what we call *total* individual CO_2e emissions: these refer to the sum of *direct* emissions (emitted directly by individuals, such as emissions from individual car transportation, or from personal gas heating devices) and *indirect* (or consumption-based) emissions (emissions embedded in the consumption of goods and services consumed by individuals).

Income or overall consumption level is particularly closely correlated with *indirect* individual emissions, while direct individual CO_2e emissions rise less proportionally than income or consumption (Herendeen and Tanaka, 1976). One way to explain this is that there is a limit to the amount of heat most individuals use every day, or to the amount of fuel they put in their cars (when they have several cars, people cannot drive them all at the same time). On the opposite, there is little limit to the amount of "stuff" (and services) purchased by wealthy individuals. While cars parked in garages all day to not add to direct CO_2e emissions of individuals, the CO_2e used for their construction is taken into account in indirect CO_2e estimates[11]. This explains why the share of indirect CO_2e emitted by individuals within a given country rises with their income level: two thirds of total emissions are indirect for bottom decile in China, versus about four fifths for the top decile (Golley and Meng, 2012). The top 3% urban earners emit more than 83% of their total emissions as indirect CO_2e, and it is generally less than 75% for other groups (Parikh et al., 2009). Top 20% Americans and top 20% French income earners emit more than 75% of their total emissions as indirect emissions against two thirds for bottom quintiles (Lenglart et al., 2010; Weber and Matthews, 2008).

Even if there are a few (and a growing) number of studies measuring inequalities in individual or household CO_2e emissions, precise estimation of indirect CO_2e of individuals remains a complex task, with no harmonized methodologies to do so (see the methodology section[12]). Nevertheless, several studies provide estimates for CO_2e (or energy) to consumption expenditure *elasticity*, that is the ratio informing on the percentage change in CO_2e associated to a percentage change consumption expenditure, within a given country. When the

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[11] Pourouchottamin et al. (2013) show that indirect required for transportation (i.e. for the production of transportation material, sales, and repair) falls in a similar range to direct energy required to fuel cars.

[12] Physical data for CO_2e emissions at the household level have to be reconstructed from household consumption surveys and national physical energy and CO_2e accounts. To do so, one must attribute CO_2e emissions of various production sectors (such as "shoe production sector" or "electronic appliances production sector") to various consumption categories used in household surveys (in our cases, shoes, TVs or HIFI systems). Data for the indirect CO_2e requirements of production sectors are obtained from Input-Output studies (see Peters et al., 2011), following the work of W. Leontief (1970).

CO_2e-income elasticity is 0.9, this means that a household earning (or spending) 10% more than its neighbour emits 9% more CO_2e. Elasticity values for consumption expenditures to energy and CO_2e collected by Chakravarty et al. (2009) from 17 countries and time periods, range from 0.4 to 1 for energy and from 0.6 to 1 for CO_2e, with most results in the 0.8-1 range. Nevertheless, as reminded by Lenzen et al. (2006) there is no "one fits all" value for elasticity, which varies from country to country and over time. In addition, such multi-study aggregations suffer from systematicity as different studies do not necessarily use the same definitions of consumption, or the same formulas, to derive elasticity values.

One specific issue relates to the measurement of emissions associated to savings and investments of individuals. Complicated methodological and normative issues are raised here: in the case of the construction of a factory, who should be attributed emissions from the initial construction of the building? The ultimate consumers of the goods produced by the factory? Or the owners of that factory? Such questions have been rarely discussed in the literature and have no simple answer. Choices made to reallocate emissions from capital spending to individuals can clearly alter the elasticity values presented above. While data from CICERO (Peters and Andrew, 2015) tends to support that overall investments are less carbon intensive than overall consumption[13], this is clearly not the case if we compare certain sectors (indeed, the construction is highly CO_2e intensive per euro spent) to the environmental footprint of overall consumption. The question thus remains open and calls for the use of multiple elasticity values as well as a cautious interpretation of results based such elasticities.

Section 4.1.2. Beyond income

If income stands out as the main driver of total CO_2e emission levels among individuals, it is not the only one. There are many other factors which play a role in determining energy consumption and CO_2e requirements. The first way to illustrate this is to compare Americans and Europeans average incomes (which are fairly similar) to their CO_2e emissions levels (which are twice bigger in the American case - as we have seen in section 3, Figure 4). The US-Europe gap can be explained by differences in the efficiency of energy production process, a different relationship to space (massively available in the USA and lacking in Europe), which determines the organization of cities and the distances travelled by individuals and goods, and the energy and CO_2e associated to it; as well as by different forms taken by the consumer culture (see for instance Flacher, 2003 or Kenworthy, 2003). This shows that national level drivers (energy mixes, urban forms and national consumption patterns) have a very important role to play on individual or household CO_2e emissions[14].

At the individual level as well, several drivers play on CO_2e emissions levels beyond income levels. They can be distinguished in three categories: *socio-demographic, geographic* and *technical* factors. Among socio-demographic drivers, size of household is often presented as a key determinant of total individual CO_2e emissions, as several energy consumption devices can be shared among individuals of the same house (heating and cooling systems), thus reducing the individual footprints of people living in large families. Education or social status have also been discussed as a significant driver of CO_2e emissions - but with varying effects according to countries and studies. Education can act negatively on energy consumption - once income is controlled for- in developing countries (Pachauri, 2004) but can also play a significant role in shaping individual preferences towards more energy-intensive lifestyles. In France, Nicolas and Verry (2015) show that *educational degree*, rather than income, determines a high propensity to emit transport - related CO_2e emissions among top income groups. It is important here to stress that their study does not focus on CO_2e emissions other than from transport (if it were focusing on

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[13] The CO_2e per euro spent ratio is 2.4 and 3.8 times lower in France and the USA respectively for investments than for household consumption.

[14] See also Lamb et al. (2014; Wiedenhofer et al. (2013)but little is known about factors driving these dynamics. In this letter we estimate the cross-sectional economic, demographic and geographic drivers of consumption-based carbon emissions. Using clustering techniques, countries are grouped according to their drivers, and analysed with respect to a criteria of one tonne of carbon emissions per capita and a life expectancy over 70 years (Goldemberg's Corner. Note that we show in Section 6, Figure 8 that national level drivers are becoming less and less important to explain the global disparity in individual CO_2e emissions.

total CO_2e emissions, consumption level would most likely be more important than education level). *Age* has also been discussed on several occasions (Wilson et al., 2013; Lenglart et al., 2010), with an inverse U-shape relationship between age and CO_2e emissions. These interactions are however complex: retired persons may use their car less on a daily basis than professionals, but may travel more to leisure places, using air transport; in addition, retired people are also more likely to live alone, requiring more energy to heat. The impact of *date of birth* on CO_2e emissions was also looked at in the USA and in France (Chancel, 2014) and it was shown that beyond differences attributed to income differentials between generations, date of birth may also influence CO_2e emissions via differences in habits.

Turning to *geographic drivers*, it is possible to cite *local climate*, with 1° temperature change across regions associated with an additional 5% energy consumption in a country like France, controlling for other factors (Cavailhes and Hilal, 2012)[15]. Proximity to public transport or to urban centres also plays a role in determining transport related emissions. Ummel (2014) shows that there is a strong, negative correlation between urban density and CO_2e footprint in the USA above a certain density threshold[16]. Kenworthy (2003) shows a general negative pattern between urban density and energy use required for transport in 84 global cities.

Technical factors also have a role to play, as households and individuals make different choices with respect to their energy appliances, and can also be trapped in certain infrastructure contexts which they could alter but which are difficult to change for economic, legal or psychological reasons (like energy inefficient homes for instance - see Chancel, 2014). Pourouchottamin et al. (2013) compare two households, one equipped with energy appliances from the 1990s and another one with 2010s top efficiency energy appliances (as well as highly efficient insulation system) and show that emissions can differ in their energy and CO_2e emission levels by factor 3, for the same level of energy service.

All in all, it clearly stands out that income alone cannot predict an individual CO_2e emissions level within a country with a high degree of precision. However, income or consumption level remains the main driver explaining variations in *total* CO_2e emissions among households and individuals and it is the best available proxy if we want to construct a global distribution of CO_2e with individual level emissions, rather than national per capita averages, as the building block.

Section 4.2. Previous work on the global distribution of CO_2e emissions

Section 4.2.1 Previous estimates of the global distribution of CO_2e consumption

At the national level, several studies, already mentioned above, focus on within country distribution of CO_2e footprints (Pachauri, 2004; Jackson and Papathanasopoulou, 2008; Weber and Matthews, 2008; Lenglart et al., 2010; Ummel, 2014)2004; Jackson and Papathanasopoulou, 2008; Weber and Matthews, 2008; Lenglart et al., 2010; Ummel, 2014. Such studies even date back several decades: Herendeen and Tanaka, as soon as the 1976, derived the direct and indirect energy footprint of American households[17].

Attempts to build a world distributions of CO_2e emissions on the basis of individual emissions, have been less frequent. The previous attempt (and first, to our knowledge) to achieve such a task is Chakravarty et al. (2009). In their study, Chakravarty et al. use a straightforward method: CO_2e emissions of individuals are assumed to be a simple power law of income:

$$CO_2e_{ic}=k_c y_i^e \qquad (1)$$

Where CO_2e_{ic} is the CO_2e emission level of individual i from country c, with income y. k_c is a country-specific term and e is the income elasticity of CO_2e emissions.

Authors derive Gamma probability density

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[15] See Wiedenhofer et al. (2013) for a review on these factors in the case of Australia.

[16] i.e. densities over 6000 persons per square mile.

[17] The authors concluded that affluent households used about 35% of its total energy requirement in the form of direct energy, while the figure would be inversed for poor household, using 65% their requirement as direct energy and 35% as indirect energy. Nevertheless, there is a renewed interest in the distribution of CO_2e within countries.

functions from seven income or consumption quantile shares obtained from World Development Indicators and then modify these density functions into Generalized gamma CO_2e density functions, using income elasticity *e* and national emissions average as parameters. They then measure the number of individuals in each region of the world, over and under a global cap and floor of CO_2e emissions. The authors' main interest lie in *"the reality that emissions from OECD countries and from countries outside the OECD are now roughly equal, and therefore tough global atmospheric stabilization targets require the participation of the developing countries"*. According to the authors, regardless of where people lived, individuals emitting similar amounts of CO_2e should contribute to CO_2e emissions reductions in the same way.

This study attracted considerable attention before the Copenhagen Summit of 2009 in part because it called into question the Annex I non Annex one differentiation principle, one of the pillars of the IPCC. According to this principle, Annex I countries (mostly rich countries) had a higher responsibility burden than non-Annex I countries (developing and emerging nations). By measuring and revealing the number of high emitters in non-Annex I countries, the study may well have contributed to shift climate policy debates within certain countries (Chakravarty and Ramana, 2011).

However, as we noted in section 1, if both developing and developed countries contribute to mitigation efforts today, this is still not the case for adaptation efforts - in other words, Chakravarty et al.'s main message didn't completely make its way through climate changes debates. In addition, Chakravarty et al.'s estimates had several limitations, some of them criticized by Grubler and Pachauri (2009) for instance, who rejected the unitary elasticity assumption. In our opinion, one strong limitation is that the income or consumption distribution statistics they used were based on 2003 estimates and dependent on data shortcomings of the time. Since then, there are more up to date and more precise world inequality datasets. On the environmental side, authors' interest lied only in CO_2e emissions and neglected about a quarter of all green house gases. And finally, the authors did not take into account consumption-based emissions. For a country like China, the gap between production and consumption-based emissions is as high as 25% (CICERO, 2015). It is thus important to correct national emissions for trade exchanges in order to better represent carbon footprints associated to one's lifestyle rather than with the production structure of one's national economy.

Section 4.2.2. Previous estimates of global distribution of CO_2e production

Taking a standpoint opposite to the one presented above, some authors have also looked at the concentration of emissions from the point of view of CO_2e "producers"[18]. Such studies are interesting as they call into question the very notion of what being "responsible" of emissions means. Heede (2014), for instance, attributes all CO_2e emissions since 1854 to oil and gas majors which extracted these emissions. It comes out that close to 70% of all CO_2e emissions ever emitted by humans can be traced back to only 86 oil or gas majors or other industries such as cement producers. Such a distribution reminds us that, at the beginning of the pipe, there are only a few actors extracting fossil fuels. However, the concept of CO_2e production and of responsibilities in CO_2e emissions used in Heede's study are criticisable. First, oil producers extract oil from the ground, but do not emit most of the CO_2e emissions associated to oil consumption: other industries, or households -using their cars for instance- do so. Second, policy options based on such a concept of responsibility may in fact fail to reach their objective (i.e. make the industries pay). Richards and Boom (2014), on the basis of this study, suggest a tax on oil and gas majors to raise climate adaptation and mitigation funds. While taxing producers may *a priori* seem to be a fair idea, such an option is in fact blind to the distributional effects of taxes on energy producers. Fossil energy being constitutive of the way of life of billions of individuals, it cannot easily be replaced[19]. As a result, a tax on producers ultimately passes on to consumers - and generally has regressive - i.e. unequal - effects on income distributions.

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[18] The standpoint is in fact that of oil producers - and some industrial CO_2e producers, such as cement. Extracting oil and releasing CO_2e is however not the same.

[19] For other types of pollutants (CFCs for instance, responsible for Ozone layer destruction and used in fridges up to the Montreal protocol which banned them), specifically targeting producers may lead to rapid shifts in production patterns. In the case of oil, which cannot easily be replaced (even though there are plenty alternatives to it, their implementation takes time), the tax passes on to consumers.

Section 4.3. Recent research on the world distribution of income

Moving on to income inequalities, recent years triggered renewed interest in inequality debates, in particular following the publication of new long run historical series on top income shares (see e.g. Piketty and Saez, 2003; Atkinson et al., 2011; Alvaredo et al., 2013; Piketty, 2014). While the availability and quality of national level inequality statistics is growing, there is still a limited amount of work on the combination of such data into a coherent, systematic, global distribution of income and wealth. In sum: we know a bit more than we used to, but we still know far too little.

In parallel to these attempts to improve country-level inequality estimates, there has been some attempts to aggregate within-country data into estimates of the world distribution of income. In particular, Lakner and Milanovic (2013) produced a harmonized dataset representing the evolution of income distribution, for approximately 90% of world population, using a combination of income and consumption expenditure surveys throughout the world, from 1988 to 2008. Survey data is well-known to suffer from several limitations, including underreporting at the top of the distribution. In order to better represent top incomes, Lakner and Milanovic apply Pareto interpolation techniques for the top 1% and top 5% of the population.[20] In one of their variant, they also attribute the difference between survey total income and national accounts statistics to the top 1%, thus assuming that the totality of the difference between survey and national accounts is income accruing to the richest segments of society.

One problem with this method is that the attribution of the difference between survey income and national accounts very likely leads to an overestimation of top incomes. Not all the difference between surveys and national accounts accrues to the richest. The Pareto interpolation technique is potentially a better way to proceed. However WTID series indicates that Pareto coefficients are not completely stable within top deciles. In the future, it would be desirable to develop flexible, non-parametric techniques to interpolate Pareto curves (see e.g. Fournier, 2015).

In order to further refine Lakner and Milanovic's global distribution estimates, Anand and Segal (2014) attempt to use WTID data in a more direct way in order to correct with top 1% and top 5 % income shares obtained from tax statistics. Contrarily to survey data, tax statistics provide a much more detailed representation of top incomes - either under-represented or missing in household surveys. Combining the two datasets is however not straightforward and would require the development of more sophisticated estimation techniques. Anand and Segal (2014) adopt a more direct and simpler method and regress existing top 1% shares from WTID data on top ten percent share and GDP per capita data in Lakner-Milanovic in order to predict top 1 shares for countries and periods with missing WTID data. Anand and Segal then assume that survey data in the Lakner-Milanovic dataset represent only 99% of the population, and append the top percentile with its income share from the tax data (the share of control income is assumed to be equal to the share of survey income). As a result, authors have to re-estimate (i.e. increase) mean income for each country. This method is not perfectly satisfactory, but it provides a reasonable compromise. Below we explain how we have followed the general methodology pioneered by Lakner-Milanovic (2013) and Anand-Segal (2014) - although our method slightly differs from theirs[21].

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[20] Computed from the top 20% and top 10% shares, such that

$$\alpha = \frac{1}{1 - \ln\left(\frac{share_n}{share_{n+1} \times \ln(2)}\right)}$$

assuming the coefficient is constant, the share of top 1% income is then derived from the formula:

$$s_1 = s_{10} \times (0.1)^{\frac{\alpha-1}{\alpha}},$$

where s1 and s10 are the respective income shares of top 1 and 10%.

[21] We are most grateful to Lakner-Milanovic and Anand-Segal for sharing their data sets and computer codes with us.

SECTION 5. OUR METHODOLOGY

In this section we describe the main steps of the methodology that we use in order to estimate trends in the world distribution of carbon emissions over the 1998-2013 period. For further details, we refer interested readers to our computer codes and data files, which are all available online,[22] so that robustness checks can easily be carried out and alternative estimation strategies can be implemented.

Section 5.1. Distribution of income

We start from the Lakner-Milanovic data set and proportionally rescale each income group's income so that all country income totals matches Household Final Consumption Expenditures (HFCE) values provided by the World Bank. This scaling choice is motivated by the fact that HFCE definition and data is more homogenous across countries than income and consumption surveys. In order to estimate top 1% income shares, we follow the Anand-Segal methodology and regress existing top 1% income shares (from WTID) on top 10%, bottom 10% share present in Milanovic dataset and a time indicator.[23] That is, each country is simulated with a distribution comprising 11 synthetic individual observations (one for each of the bottom nine deciles, one for fractile P90-99, and one for the top 1%), all of which are weighted by the relevant population weight and merged in order to estimate the world income distribution.[24] We stress that the estimates used in this study should not be seen as definitive values for the world income distribution, but as a first attempt to combine global income distributions with top incomes data, following Lakner-Milanovic (2013) and Anand-Segal (2014). This will clearly need to be improved in the future: this includes the need to develop more flexible Pareto interpolation techniques (see the above discussion) and to simulate higher numbers of country-level synthetic observations. We have made a large number of robustness checks (in particular regarding the regression specification), and the main conclusions that we stress in the present report appear to be robust to alternative specifications.

We also update GDP, HFCE and population data in order to expand the Lakner-Milanovic dataset to 2013 (initial data stops in 2008). The strong assumption that we make here is that income distribution within countries does not change between these years (note however that we correct top 1% estimates for countries with available WTID data in 2013). The Lakner-Milanovic dataset is in 2005 USD PPP. It is converted back into Local Currency Unit of 2005 transformed into its 2014 equivalent and then converted back into 2014 € PPP, using World Bank PPP estimates[25].

Finally, we reconstruct income distributions for certain countries not present in the Lakner-Milanovic dataset (Gulf countries and Iran). For Arab Gulf countries, we follow Alvaredo and Piketty (2014) and assume that Saudi Arabia and the United Arab Emirates (for which raw data sources are inadequate) have very high inequality levels (similar to Colombia). For Iran, inequality estimates for one year is missing and we assume no change occurred in the distribution of income between this year and the closest year available.

Section 5.2. Distribution of CO_2e emissions

Section 5.2.1. Life cycle analyses vs. Input Output methods

In order to measure the pollution or energy consumption associated to individuals' lifestyles, two approaches can be followed. One way - call it the *micro* method—consists in measuring the pollution associated to each and every good or serviced consumed by the household using Life Cycle Analyses (LCA). These are accounting techniques to trace the amount of pollutants, reconstructing the production chain of a good. Such a method

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22 http://piketty.pse.ens.fr/files/ChancelPiketty2015Data.zip

23. Note that our regression is slightly different to Anand and Segal, who regress top shares on top 10% shares and GDP per capita.

24. For China, India and Indonesia, we use separate distribution estimates for the rural and urban sectors, so in effect we have 21 synthetic observations for each of these three countries. See on-line computer codes and data files for details.

25. WB estimates for 2014 are derived from a statistical model based on the 2011 ICP.

delivers precise data on specific goods or services. However, it can suffer from multiple counting (one unit of energy used in production processes is counted more than once), which would result in national totals higher than their real values. As such, the LCA method is pertinent when we focus on individual level or sectoral studies, but the construction of national and global level estimates on the basis of LCA is hazardous. In practice, very few studies use LCA to derive macro-economic estimates because of this[26].

The second method - the *macro* method - is based on the work of V. Leontief (1941), known as the Input-Output (I-O) framework, extended to the environment (Leontief, 1970). It does not provide detailed information on the energy or CO_2e content of precise types of good or services (it is impossible to discern whether an "Iphone" is more carbon intensive than a "Galaxy phone" for instance), however, it provides macro-economic consistency, i.e. one unit of energy or one unit of CO_2e cannot be counted twice. In addition, the I-O approach makes it easy to trace back the origins of CO_2e or energy imports embedded in a certain sector.

In this study, we use an existing environmental IO database. There are a few good candidates for the provision of environmental Input Output estimates. To name but a few, we can cite GTAP (Andrew and Peters, 2013), Exiobase (Wood et al., 2014), WIOD (Genty et al., 2012) or EORA (Lenzen et al., 2012). Our main interest was two-fold: we wanted to go as far as possible back in time and have an important number of countries to cover as much as possible the Lakner-Milanovic income distribution dataset. This left aside Exiobase and WIOD which are relatively well disaggregated at the within country level (it is possible to know the CO_2e emissions associated to the consumption of several sectors of the economy - up to 163 in Exiobase), but which display a limited number of countries (about 40 countries or regions only). EORA and GTAP were candidates with a large number of countries represented (more than a 100 in 2007 for GTAP, and about 70 in 1997).

For certain countries, EORA values were surprising: Sudan and Central African Republic ranked highest in world CO_2e per capita consumption levels. This indeed cannot reflect true CO_2e consumption statistics: living standards of a few elite Sudanese or Central Africans cannot be so high that the country average would rank first in the world. GTAP itself is not deprived from limitations. For instance, its global CO_2e emissions level is smaller than in other databases (22.8Gt-CO_2e in GTAP compared to 28.2 in EORA and 25.3 in WIOD for year 1997), we thus have relatively low world per capita GHG averages compared to other databases. Nevertheless, GTAP data standed as the best available source of consumption data for our purposes. Other I-O databases will be made available in the near future (Exiobase for instance, will soon provide historical estimates, rather than only two years currently available), and can also be used to refine our methodology.

GTAP consumption-based data provided by G. Peters and R. Andrew[27] was itself harmonized. In particular, the few countries (representing 13% of total emissions in the database in 1997-8 and 5% in 2007-8) which are aggregated into regions were assigned national totals. In order to do so, we assume that emissions are proportional to the population of the country within the region. In other words, we assumed that all individuals in the region have the same CO_2e emissions per capita level. This assumption can be justified by the fact that we are talking about neighbour countries, with relatively homogenous average standard of living and production structures. In order to construct 2003 and 2013 consumption-based emissions levels, not available in the I-O database, we assume that the ratio between production-based emissions and consumption-based emissions for 2003 is the same than for 1997 and that the 2013 ratio equals that of 2007. Given that we have production-based emissions in 2003 and 2013 for all countries, it is possible to approximate consumption-based emissions.

5.2.2. From national averages to individual emissions

In order to move from country average emissions to emissions of different individual (income) groups within countries, we use the following formula:

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[26] One method using elements of LCA analysis to derive macro estimates is the Environmental Footprint.

[27] We are most grateful to them and the CICERO team for sharing with us their CO_2e consumption-based data and exchanging on the methodology.

$$CO2_i = f_i \times \frac{CO_2e_{tot}}{\sum_{j=1}^{N} f_j \times y_j^e} \times y_i^e \qquad (2)$$

Where f_i is the total population share of income group i in total population, y_i is mean income in group i, CO_2e_{tot} represents total emissions in the country, N the number of income groups, and e is the income-CO_2e elasticity. We then divide CO_2e_i by the total population of group i to obtain per capita estimates. Note that our income/consumption dataset doesn't provide information on the age of individuals: it is assumed that all individuals living in a household share household income and CO_2e emissions equally. We also chose to redirect all consumption-based emissions of a given country to individuals of this country, i.e. this includes emissions associated to government expenditures and investments. This choice is motivated by the fact that these emissions ultimately serve households' actual final consumption.

We use several elasticity values from 0.6 to 1.5 in order to account for different forms of the CO_2e-income relationship. Our core results are based on an elasticity value of 0.9, which comes out as a median value of existing estimates (see section 4.1.1), the same for all countries even though as mentioned above, these are likely to differ. However, in the absence of systematic income-elasticity studies over the world, it seemed to us more straightforward to present standard results based on a single elasticity for all nations rather than modify them for a few countries. We nevertheless tested scenarios with elasticity modified for a few countries with specific elasticity data and our main results seem robust to such changes.

Section 5.3. Coverage of the study

Our dataset covers approximately 95% of GDP from 1993 onwards, about 90% of world population and slightly under 90% of world GHG emissions from 1998 to 2013. The share of world GDP, population and GHG emissions not covered is explained by the lack of GHG emissions or income distribution data for specific years (see Lakner and Milanovic (2013) for income and Andrew and Peters (2013) as well as (WRI, 2015) for more details).

TABLE 2. GLOBAL GDP, POPULATION AND GHG COVERAGE (%)

Year	GDP	Population	CO_2e
1988	91.8	79.1	NA
1993	97.1	89.9	NA
1998	96.7	89.4	87.2
2003	96.1	89.6	87.1
2008	93.9	87.8	89.1
2013	93.6	87.2	88.1

Source: authors. Key: The dataset covers 96.7% of world GDP in 1998, 89.4% of world population and 87.2% of world CO_2es emissions

SECTION 6.

A GLOBAL DISTRIBUTION OF CARBON EMISSIONS: FROM KYOTO TO PARIS

We now present the results of our estimates of the world distribution of carbon emissions over the 1998-2013 period.

Section 6.1. From production to consumption-based emissions

TABLE 3. CURRENT PER CAPITA CO_2e EMISSIONS - CONSUMPTION-BASED

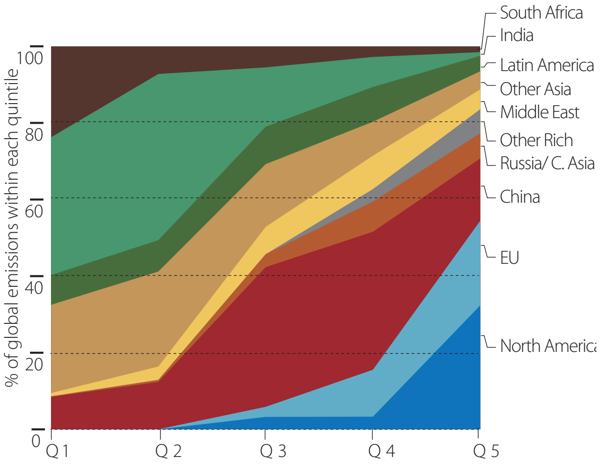
	tCO_2e per person per year	% change with production	ratio to world average
World average	6.2	0	1
N. Americans	22.5	13	3.6
West. Europeans	13.1	41	2.1
Middle East	7.4	-8	1.2
Chinese	6	-25	1
Latino Americans	4.4	-15	0.7
S. Asians	2.2	-8	0.4
Africans	1.9	-21	0.3
Sustainable level	1.3	0	0.2

Source: authors' calculations based on (Peters and Andrew, 2015) and (WRI, 2015). Key: Western Europeans emit on average $13.1tCO_2e$ per year and per person, including consumption-based emissions. This figure is 41% higher than production base emissions and 2.1 times higher than world average. Note: data for 2013.

In order to better represent individual responsibilities to climate change, we believe it is essential to move from production-based emissions (see Table 1) to consumption-based emissions. Below, we present consumption-based per capita averages for the different regions of the world (Table 3) and variations between production base emissions and consumption-based estimates. Unsurprisingly, emissions of North Americans and Europeans are higher than when measured from a production or territorial perspective (13% higher for North Americans, 41% higher for Western Europeans[28]) and lower for emerging or developing countries (25% lower for China, 21% lower for Africans). Moving from production base emissions to consumption-based emissions reallocates emissions from a large number of relatively poor individuals (Chinese, South Asians) to a fewer number of relatively rich individuals (North Americans and Western Europeans): focusing on consumption-based emissions thus tends to increase the level of global individual CO_2e emissions inequalities[29].

Section 6.2. Where do high and low emitters live?

FIGURE 5. REGIONAL COMPOSITION OF EMISSIONS PER GLOBAL CO_2e QUINTILE.



Source: authors. Key: 36% of emissions within the first decile of the global CO_2e distribution (i.e. bottom 20% global emitters) come from India.

Figure 5 presents the regional breakdown of CO_2e emissions according to different world regions, over five quintiles of the global CO_2e distribution. Sub Saharian Africa, India and South East Asia make up most of emissions at the bottom of the distribution, while North America and Europe, absent among bottom quintiles, are over represented at the top. China, Latin

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[28] The percentage change between consumption and production-base emissions is much larger in Europe than in the USA, largely because production base emissions are already extremely high in the USA (see Figure 4) compared to Europe.

[29] This holds true for several environmental indicators except for biomass, see for instance (Teixidó-Figueras and Duro, 2015).

America or Middle East/North Africa embrace the entire spectrum of the global emissions distribution, with significant emissions among the bottom 2 quintiles as well as emission among top quintiles.

In appendix figure A2, we show the absolute number of emitters for different categories of emissions across all world regions. In particular, it shows that half of the world population emits below 3tCO_2e per person and per year, while 90% of the world population emit below 15tCO_2e per year.

Section 6.3. Who is hiding behind the numbers? Focus on top, bottom and middle emitters

If we zoom into the very bottom of the distribution of GHG emitters, we find the bottom decile of African and Latino-american least developed countries: Honduras, Mozambique, Rwanda, Malawi and Zambia (Table 4). Emission levels among these population are extremely low—ten to twenty times below the continental average—and about 50 times below world average.

TABLE 4. BOTTOM GLOBAL CO_2e EMITTERS, 2013

Country	Population (million)	Group	Income PPP	CO_2e emissions (Annual tCO_2e p.c.)
Honduras	0.8	Bottom 10%	64	0.09
Mozambique	2.6	Bottom 10%	117	0.11
Rwanda	1.2	Bottom 10%	215	0.12
Malawi	1.6	Bottom 10%	72	0.14
Zambia	1.5	Bottom 10%	188	0.16

Source: authors. Key: the bottom 10% of income earners in Honduras (0.8 million individuals) earned 64€ (2014 PPP) on on average in 2013 and emitted 0.09tCO_2e per person that year.

Such values match with existing studies on CO_2e emissions of very low income groups in the developing world. For instance, Parikh et al. (2009) find a similar value of 0.15tCO_2e for the poorest 7% of the population in India. In rural areas of developing countries (as well in several urban places), households still largely rely on traditional energy sources[30] such as charcoal or firewood to cook and heat (IEA, 2014). As long as such fuels are sustainably harvested[31], the net cooking and heating CO_2e emissions of individuals using these traditional fuels can be close to zero[32]. Kerosene or candle lighting is sometimes used and can add 0.05 tCO_2e per year to individual CO_2e budget. Another 0.1tCO_2e is associated to the few goods purchased by individuals.

Let us now turn to the other end of the distribution of emitters and focus on the 5 highest emitting groups in the world. At the top of the world CO_2e distribution lie, unsurprisingly, top 1% Americans, Luxembourgers, Saudis and Canadians.

TABLE 5. TOP GLOBAL CO_2e EMITTERS, 2013

Country	Pop (million)	Group	Income PPP	CO_2e emissions (annual tCO_2e p.c.)
USA	3.16	Top 1%	542453	318.3
Luxembourg	0.01	Top 1%	220709	286.8
Singapore	0.05	Top 1%	250492	250.7
Saudi Arabia	0.29	Top 1%	569063	246.7
Canada	0.35	Top 1%	257085	203.9

Source: authors. Key: the top1% Americans earned 542 453€ (2014 PPP) on average in 2013 and emitted 318tCO_2e per person that year.

These groups are comprised of individuals emitting more than 200tCO_2e per year and per person. Our figures go as high as 320tCO_2e per year per individual for top 1% Americans, i.e. about 50 times world average and 2500 times the lowest CO_2e emitters groups presented above. Our results are higher than those of the few studies existing on CO_2e emissions of very top income earners. Ummel (2014), for instance, using a different method to ours, estimates CO_2e emissions of top 2% Americans to be close to 55tCO_2e. However, the data he uses does not allow him to precisely capture top incomes[33].

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[30] 2.7 billion individuals currently use traditional biomass for cooking purposes (IEA, 2014).

[31] This is indeed not always the case, but it surely is in many places.

[32] It is of 0.008CO_2etCO_2e for poorest Indians according to Parikh et al. (2009)

[33] Since he uses consumer spending data - see the methodology section for a discussion on consumer budget vs. tax data to capture top incomes.

The $300tCO_2e$ figure for the top 1% Americans can then be seen as a plausible value for the top1% richest individuals of this planet. In order to better represent what $300tCO_2e$ per year and per person mean in practice, we present a possible breakdown of such a carbon budget: a rich American travelling 5 times a year from New York to Los Angeles (round trips, first class) and twice a year to Europe can emit up to $35tCO_2e$ per year, solely for her air transport emissions - indeed, for some Americans among the top 1%, air emissions will be less than that, but they can also be much higher for very frequent travellers or for those who have private jets for instance[34].

Car emissions can add another $10tCO_2e$ per year (that's twice the average figure for top10% Americans - see Chancel, 2014). CO_2e emissions associated to household energy requirements (cooling, heating, electrifying) can reasonably add another $10tCO_2e$, assuming, here again, the individual is twice more "energy opulent" than the average top 10% American - note that top 1% Americans earn four times more than the average top 10% American, so our assumption can be seen as conservative. Transport and household energy thus represent about $55tCO_2e$ per year for our top 1% income earner. In order to come up to the $300tCO_2e$, another $250tCO_2e$ of carbon must then be associated to the production of all the services and goods purchased by the household that given year: i.e. for the production, transport, trade and sale of food, cars, apparel, water, hotel services, etc. purchased by the individual as well as the CO_2e associated his or her investments.

Referring to the values used by Ummel (2014), it comes out that twelve dollars spent on home maintenance and repairs everyday correspond to 10 tCO_2e in indirect emissions at the end of the year, thirty dollars spent every day on beef add another 10 tCO_2e to an annual individual budget. In other words, indirect emissions can be very carbon intensive and the $250tCO_2e$ figure is an enormous one, but, again may correspond to actual emission levels of very top earners - especially if we take into account the carbon content of their investments (see the discussion in the methodology section).

Now, looking at the middle of the distribution of global emitters, say individuals emitting around 7 tCO_2e per person and per annum, slightly above world average, we find groups as diverse as the top 1% earners from Tanzania, the upper middle class (7th decile) in Mongolia and China as well as poor French and Germans (respectively 2nd and 3rd income deciles), Table 6.

TABLE 6. AVERAGE WORLD EMITTERS IN 2013

Country	Pop (million)	Group	Income PPP	CO_2e emissions (annual tCO_2e p.c.)
Tanzania	0.5	Top 1%	9716	7.3
Mongolia	0.3	7th decile	3129	7.1
Germany	8.1	2nd decile	8921	7.1
China	58.5	73-77th pct.	3277	7.1
France	6.6	3rd decile	9347	6.5

Source: authors. Key: the top1% Tanzanians earned 9716€ (2014 PPP) on average in 2013 and emitted $7.3tCO_2e$ per person that year.

French individuals in this group (i.e. the 3rd decile of income earners) are likely to emit 2.5 tCO_2e for housing (heating, furniture, home repairs, etc.), close to $1tCO_2e$ for food (mostly at home and some outside), $2tCO_2e$ for transport (fuel and car purchases)[35]. The 2nd decile from Germany is likely to follow a similar breakdown - though with higher emissions for housing, due to a more carbon intensive energy mix and a different climate than in France. Breakdowns for top 1% Tanzanians, or upper middle classes in Mongolia or China are likely to differ however, not only because of national level differences, but also because of different consumption patterns (rich Tanzanians probably have individual electric generators, Air Conditioning systems or water purifiers which low income Europeans are less likely to possess).

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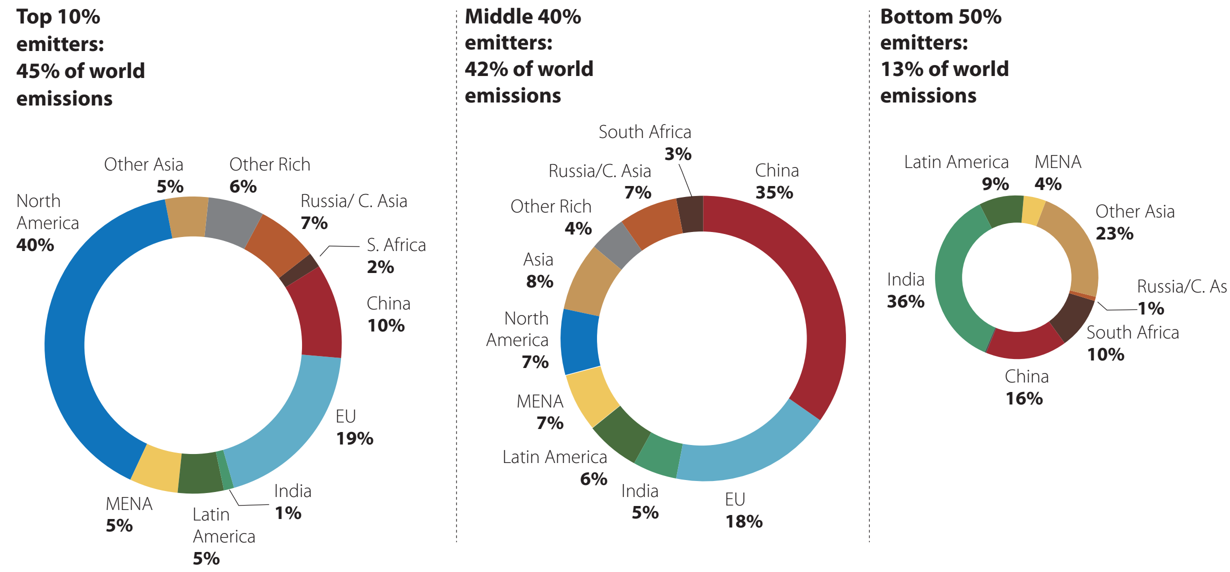
[34] There are 11 000 jets in the USA.

[35] These are derived and adapted from Lenglart et al. (2010).

FIGURE 7. REGIONAL COMPOSITION OF TOP 10, MIDDLE 40 AND BOTTOM 50% EMITTER GROUPS



Source: authors. Key: Among the top 10% global emitters, 40% of CO_2e emissions are due to US citizens, 20% to the EU and 10% from China.

Section 6.4. How unequal are global carbon emissions? The “ten-fifty relationship”

In order to better represent the contribution of different groups of emitters to total CO_2e emissions, we now split the world in three groups: top 10%, middle 40% and bottom 50% CO_2e emitters. For each of these groups, we present the percentage of the group’s emissions stemming from each region of the world.

According to our estimates, top 10% emitters account for 45% of emissions. Middle 40% emitters for 42% of emission and bottom 50% for a meagre 13% of global emissions. At the very top of the distribution, the 1% highest emitters, represent 14% of emissions while the bottom 10% less emitting individuals emit about 1% of global emissions. Indeed, assuming other elasticities would change this repartition (Table 7): with a lower elasticity assumption (say 0.7), emissions are less concentrated at the top of the distribution in each country and globally: the top 10% figure falls to 40%. Conversely, with a higher elasticity assumption (1.1), top 10% emitters are responsible for more than half of the world CO_2e budget (51.3%). As a gross rule of thumb, and assuming an elasticity of 0.9, it is possible to recall the “ten-fifty” relationship, with 10% emitters responsible for close to fifty percent of emissions and the bottom fifty percent emitting slightly over ten percent of emissions.

Focusing on the geographical origin of emitters, it comes out that close to 1/3rd of emissions within the top 10% group are from developing and emerging countries. Clearly, industrialized countries still dominate top emissions, but the contribution of top emitters from developing countries is already substantial.

TABLE 7. CO_2e EMISSIONS CONCENTRATION SHARES IN 2013 (%)

Year	elast	top1	top5	top10	mid40	bot50	bot10
2013	0.9	13.8	31.5	45.2	41.8	13.0	1.2
2013	0.7	9.9	26.6	40.0	44.8	15.3	1.5
2013	1.1	19.0	38.0	51.3	38.0	10.7	0.9

Source: authors. Key: assuming an income-CO_2e elasticity of 0.9, the top10% highest emitters are responsible for 45% of global emissions.

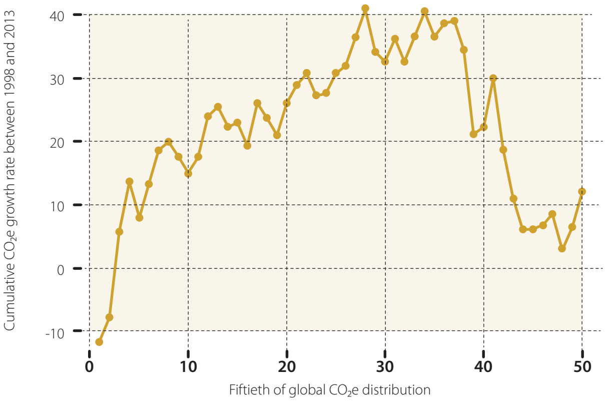
One can also compare concentration values for CO_2e with income concentrations worldwide (see appendix table A1). While CO_2e is very concentrated, income is even more unequally distributed than CO_2e: at the world level, top 1% earners concentrate close to 20% of global income, that is twice more than the bottom 50% earners who concentrate less than 10% of income. The top 10% earners captured 57% of world income before the economic crisis of 2008, and fell to 53% in 2013 following the Great Recession. It is interesting to see how income concentration at the very top of the global distribution, i.e. the top 1% earners, was only slightly hit by the financial crisis. This was not the case when we look at top 10% global earners (which include, in particular, middle classes in industrialized countries) and whose income shares in global income was significantly reduced during the recession. We stress again, however, that these estimates should be seen as provisional, in particular because available top income data for a number of countries (e.g. China) is unsatisfactory and might well underestimate the level and change in top end inequality.

Section 6.5. Who benefitted from the highest growth in CO_2e emissions since Kyoto?

Is the distribution of global CO_2e emissions more unequal today than it was 15 years ago? If CO_2e emissions had remained at the same level within each country between 2013 than in 1998, a more equal concentration of income would mean a more unequal distribution of CO_2e, and vice versa. However, the answer to our question is not trivial, as not only within country income distributions evolved over time, but national emissions as well (resulting of economic development, evolutions in energy production sectors, changing consumption patterns, etc.) and so did international flows of CO_2e exchanged from countries to countries. Our estimates depend not only on income inequalities within countries, but also of evolution in CO_2e emissions of each countries and international trade in CO_2e emissions (enabling us to account for consumption-based CO_2e). As a result, it is difficult to say, *a priori*, whether CO_2e emissions are more concentrated among certain individuals in the world today than 15 years ago.

Figure 7 presents “growth incidence curves” for CO_2e emissions. On the x-axis, we ranked groups of synthetic individuals (fiftieths[36]) according to their per capita CO_2e emission level in 2013. On the y-axis, we show by how much CO_2e emissions grew for each of these groups between 1998 and 2013[37]. We observe that for the first two fiftieths of the CO_2e emissions distribution, i.e. the 4% lowest emitters, emissions actually decrease over the period by more than 10%. From the 3rd to the 37th fiftieth, the growth rate of emissions rises with the position in the global distribution of emissions, among these groups, the more per capita emissions in 1998 meant the higher growth between 1998 and 2013. For groups between the 27th and 37th fiftieth, emissions grew at a rate higher than 30% over the period.

FIGURE 7. GROWTH OF CO_2e EMISSIONS FROM 1998 TO 2013



Source: authors. Key: the group representing the 2% lowest CO_2e emitters in the world, saw its per capita CO_2e emissions level decrease by 12% between 1998 and 2013. Note that the composition of each quantile of the distribution can vary over time, i.e. the 2% lowest emitters group is not necessarily made up of the same country-income groups in 1998 and 2013.

Remarkably, emissions' growth falls back after the 37th fiftieth: low and middle income groups in rich countries exhibit a limited increase in CO_2e emissions. This difference can be attributed to different factors: slowdown in growth and incomes in rich countries (as shown by Lakner and Milanovic,

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[36] i.e. fifty groups ranked in ascending per capita emission order and representing each of them 2% of the world population.

[37] We compare, for instance the CO_2e emission level of the 25th percentile of the world CO_2e distribution in 1998 with the CO_2e emission level of the 10th ventile in 2013, in order to derive CO_2e emissions growth for this ventile over the two dates. Indeed, individuals within the two groups are not the same at the two points of time.

2013) combined with a slowdown in energy consumption at the end of the period associated to economic slowdown, higher efficiency in energy production processes associated to energy and climate policies as well as technological change. At the top of the CO_2e emissions distribution, growth seems to recover slightly: this reflects the very good economic situation of top income earners over the period. A similar graph, focusing on income growth rather than CO_2e, is presented in the appendix (see appendix figure A2). The profile of the curve is very close to that of CO_2e and confirms the pattern found by Lakner and Milanovic (2013) between 1988 and 2008.

Another way to look at the rise in CO_2e emissions at different points of the world distribution is to compare different parts of the CO_2e distribution with one another, i.e. focus on the evolution of percentile ratios as is often done for income or wealth inequalities. Table 8 shows that inequalities in CO_2e emissions were reduced between the top and the middle of the distribution (the p90-p50 ratio falls from 6 to 4.9 over the period) whereas inequalities between the top and the bottom of the distribution increased as per the p75-p25 ratio. Inequalities also increased between the bottom and the middle of the distribution, as shown by the reduction in the p10-p50 ratio.

TABLE 8. EVOLUTION OF PERCENTILE RATIOS FOR CO_2e EMISSIONS

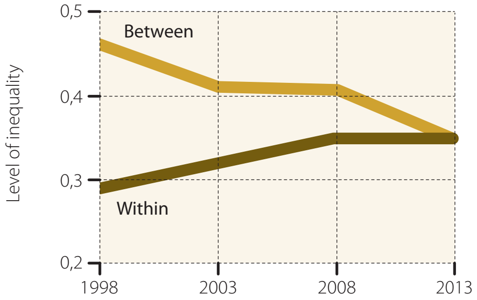
	p90/p10	p90/p50	p10/p50	p75/p25
1998	15.4	6.0	0.39	4.27
2013	15.2	4.9	0.32	4.64

Source: authors. Key: In 2013, individuals at the 75th percentile of the global CO_2e distribution emit 4.6 times more than individuals at the 25th percentile of the global CO_2e distribution.

Section 6.6. Did global CO_2e emission inequalities increase or decrease over the past decades?

Are the trends highlighted above the result of dynamics of CO_2e emission levels between countries (toput it simply: China, as a whole, catches up with the industrialized world), or are they due to a rise in within country inequalities (the middle class is getting thinner in the USA and CO_2e emissions are more unequal there)? One way to answer this question is to look at evolutions of the Theil index. This index is useful because it can be broken into two components informing the relative importance of "within-group" and "between group" inequalities: it is then possible to represent the contribution of between country differences to global GHG emissions inequalities (evolution of total emissions for each country) and the contribution of within-country differences (that is national level inequalities in CO_2e emissions).

FIGURE 8. EVOLUTION OF WITHIN & BETWEEN COUNTRY CO_2e EMISSIONS INEQUALITIES



Source: authors. Key: in 2008, the within country component of the Theil index was of 0.35 and the between-country component of 0.40.

From the Kyoto protocol in 1998 to the Paris Climate Conference in 2015, three important facts must be highlighted. The first one is that overall carbon inequalities decreased over the period, as measured by the Theil index - which moves from 0.75 to 0.70. CO_2e emissions are more equally distributed among world individuals and regions today than fifteen years ago. This is the direct consequence of figure 7: the middle 40% emitters caught up with the top emitters thanks to (much) higher growth rates in emissions. However, this reduction in CO_2e emissions inequalities hides two opposite trends. On the one hand, we notice a clear reduction in between-country inequalities. The Theil index was 0.46 in 1998 and falls to 0.35 in 2013. This is the "rise of China effect" (and other "BRICS" countries). But we also see a clear increase in within country CO_2e emissions inequalities. The within country component of the Theil index moves from 0.29 to 0.35. What is striking here is that the two lines of Fig. 8 cross each other in 2013. In 1998, between country differences contributed to about two third of overall CO_2e emissions inequalities. Fifteen years later, between country and within country inequalities contribute in the same proportion to overall inequalities[38].

The evolution of within and between country *income* inequality displays similar results: i.e. a reduction in between country inequalities driven by economic development, in particular among BRICS countries, coinciding with an increase in within country inequalities over the same period. However income inequalities between countries are more important than CO_2e emissions inequalities. One way to illustrate this is to compare American and Indian mean income and mean CO_2e emissions: per capita emissions are on average 12 times higher in the USA, while average income is on average 15 higher in the USA.

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[38] Indeed, with different income-CO_2e elasticity values, the within country component of inequality would differ. With an elasticity of 0.7, only 37% of global inequality is explained by within country differences in 2013. With an elasticity of 1.1, 62% of global inequality is explained by within country differences.

SECTION 7. FINANCING ADAPTATION VIA A GLOBAL PROGRESSIVE CARBON TAX

Results from section 6 show to what extent the geography of individual CO_2e emissions changed from the Kyoto Conference in 1998 to the Paris Conference of Parties. A significant number of high emitters can now be found in emerging countries. Inequalities increased between the bottom of the CO_2e emissions pyramid and the middle, and were reduced between the middle and the top. Our results thus corroborate and support the key messages of Chakravarty et al. (2009), for whom all countries should contribute to climate mitigation efforts and emerging countries in particular had to stop "hiding behind their poor" (see Chakravarty and Ramana, 2011), given the presence of high emitters in China, India or Brazil. On the other hand, our results show that the vast majority of high emitters still come from rich countries (particularly North America). Thus our estimates can be used to provide a more balanced and neutral basis to approach these highly controversial issues.

Our estimates can also prove helpful to frame equity debates on the financing of a climate adaptation fund. In terms of climate mitigation efforts, emerging and developing countries have already stopped hiding "behind their poor". In fact, under the Intended Nationally Determined Contribution logic, all countries contribute to climate mitigation efforts - see for instance DDPP, 2015. This is not the case for adaptation financing, for which efforts remain concentrated among a few countries only (Fig. 1). As we have shown in section 2, the current breakdown of contributors neither reflects ability to pay principles, nor historical responsibilities.[39]

In order to better align the amount of funds required for adaptation with adaptation needs, contributions to climate change and individuals' ability to pay, we propose an equity logic in which efforts would be split among the world top current emitters - rather than countries. When it comes to equity debates, there is clearly no "good" allocation rule or formula and our objective is certainly not to discover the perfect solution. At a more modest level, we hope that our examination of the implications of a global progressive carbon tax on all world emitters can contribute to a more informed discussion. Our exercise clearly has limits - due to the assumptions made to construct our estimates and because of simplicity of the allocation logic we follow- but it also has interests: it provides order of magnitude on "who should pay what" under different options for adaptation finance.

Section 7.1. Proposed strategies for climate adaptation contributions

In its simplest version, our proposed allocation rule works as follows: all individuals in the world emitting above a given emission threshold should contribute to the world adaptation fund, in proportion to their emissions in excess of the threshold. In effect, this is equivalent to a two-bracket global progressive carbon tax, with a 0% marginal tax rate on carbon emissions below a threshold, and a positive marginal tax rate above the threshold (the upper tax rate being set so as to raise the desired budget for the world adaptation fund).

We present results for four main thresholds. We first look at the case with a zero threshold: this corresponds to a flat carbon tax with a proportional rate on all world emitters, no matter how small or how large their carbon emissions. In strategy 1, we set the threshold at the level of average world emissions above (6.2tCO_2e per year per person). In effect, the top 28% emitters of the world population have to contribute. In strategy 2, we set the threshold so as to target the top 10% world emitters (i.e. individuals emitting more than 2.3 times average world emissions). In strategy 3, we set the threshold so as to target the top 1% world emitters (i.e. individuals emitting more than 9.1 times average world emissions).

For example, take a Chinese high-income urban dweller emits 10.2 tonnes of CO_2e emission per year. In our "average emission threshold" (strategy 1), she would contribute to the fund on the basis of 4 tonnes of CO_2e (10.2tCO_2e minus the world average, 6.2tCO_2e). The amount paid is then proportional to the share of the individual's emissions above the threshold in all global emissions above the threshold. We provide estimates to generate €150bn per year (about 0.2% of world GDP), clearly above the €42bn ($50bn) per year that is supposed to be raised via the Green Climate Fund,

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[39] i.e. in terms of historical production-based responsibilities. The estimation of historical consumption-based emissions remains to be done.

TABLE 9A. POPULATION, MEAN EMISSIONS AND WORLD SHARES IN STRATEGIES 0-1

Region	Flat carbon tax on all world emitters (100% world population)			Strategy 1. Progressive carbon tax above average emissions (27% world population)		
	Population concerned (millions)	MeanCO$_2$e emissions (annual tCO$_2$e per capita)	Contribution to emissions (%)	Population concerned (millions)	MeanCO$_2$e emissions (annual tCO$_2$e per capita)	Contribution to emissions above average (%)
North America	351.3	22.5	21.2	316.1	24.6	35.7
EU	494.9	12.4	16.4	409.1	14.1	20.0
China	1357.0	5.9	21.5	428.1	11.8	15.1
Russia/C.Asia	222.7	10.0	6.0	123.4	14.8	6.6
Other Rich	127.3	13.4	4.6	114.6	14.4	5.8
Mid. East/N.A	310.8	7.0	5.8	108.8	14.2	5.4
Latin America	493.1	4.5	5.9	82.7	14.6	4.3
India	1252.0	2.1	7.2	37.0	10.6	1.0
S.S.Africa	610.1	1.9	3.1	31.4	13.8	1.5
Other Asia	995.3	3.1	8.3	102.0	13.6	4.7
World	6214.4	6.2	100%	1753.1	15.4	100%

Source: authors. Key: Under strategy 1 (taxing all emissions above world average), 316 North Americans would be concerned, their average emissions are 24.6tCO$_2$e, and they represent 35.7% of all emissions above world average.

TABLE 9B. POPULATION, MEAN EMISSIONS AND WORLD SHARES IN STRATEGIES 2-3

Region	Strategy 2. Progressive carbon tax on top 10% world emitters (2.3 times above world avg. emissions)			Strategy 3. Progressive carbon tax on top 1% world emitters (9.1 times above world avg. emissions)		
	Population concerned (millions)	Mean CO$_2$e emissions (annual tCO$_2$e per capita)	Contribution to emissions above threshold (%)	Population concerned (millions)	Mean CO$_2$e emissions (annual tCO$_2$e per capita)	Contribution to emissions above threshold (%)
North America	210.8	32.1	46.2	32.0	85.8	57.3
EU	141.4	22.8	15.6	4.8	107.4	14.8
China	58.5	30.3	11.6	13.6	63.2	5.7
Russia/C.Asia	43.8	25.6	6.3	1.4	126.5	6.1
Other Rich	50.9	20.9	4.5	1.3	106.2	3.8
Mid. East/N.A	31.2	28.5	5.5	4.5	80.7	6.6
Latin America	36.2	23.0	4.1	3.3	65.7	1.9
India	12.5	17.9	0.7	0.0	0.0	0.0
Other Asia	33.8	23.7	4.1	1.1	98.5	2.7
S.S.Africa	9.3	26.7	1.5	0.5	89.7	1.1
World	628.4	27.0	100	62.4	82.7	100

Source: authors. Key: 58.5 million individuals living in China emit above 2.3 average emissions levels. They contribute to 11.6% of emissions over the threshold and their mean emissions are 11.6tCO$_2$e.

but clearly under the estimated true costs of adaptation according to the UNEP, which can be higher than €300 bn (see section 2). The reference value we take falls in the mid range of recent estimates for climate adaptation.

We should make clear from the outset that we do not view any of these strategies as fully satisfactory. The ideal solution from a world social welfare viewpoint - whatever the way one defines such an optimum - would presumably involve a mixture of these different strategies, i.e. a many-bracket progressive carbon tax with graduated rates on the different interval of carbon emissions. Given the enormous inequality of the world distribution of carbon emissions, we feel that the flat tax can hardly be regarded as an equitable solution. In our view, the best compromise probably involves a combination of strategies 1, 2 and 3. In particular, strategy 2 - with its focus on top 10% world emitters, who are responsible for nearly 50% of all

TABLE 10. IMPLEMENTATION VIA COUNTRY-LEVEL PROGRESSIVE INCOME TAXATION

Region	Above average				Top 10% emitters (Above 2.3x average)			
	Pop. share concerned	Mean income (€)	Marginal income tax (%)	Lower income threshold (€)	Pop. share concerned	Mean income (€)	Marginal income tax (%)	Marginal income threshold (€)
North America	90%	32600	0.6	5851	60%	43400	1.2	14278
EU	83%	18200	0.7	6155	29%	30100	1.2	13797
China	32%	5900	1.6	2730	4%	16800	2.9	6663
Russia/C.Asia	55%	15900	0.8	5904	20%	29200	1.4	14609
Other Rich	90%	19200	0.6	7083	40%	28900	1.1	17284
Mid. East/N.A	35%	18000	0.6	6512	10%	41300	1.1	16657
Latin America	17%	23700	0.5	10330	7%	37200	1	23982
Other Asia	5%	14800	0.8	5600	6%	26200	1.5	14406
S.S. Africa	10%	13200	0.9	5522	1%	29200	1.6	11051

Region	Top 1% emitters (Above 9.1x average)			
	Pop. share concerned	Mean income (€)	Marginal income tax (%)	Marginal income threshold (€)
North America	9.1%	130100	5.3	73218
EU	0.96%	171000	5.4	71922
China	1.0%	37300	13.9	32799
Russia/C.Asia	0.6%	168200	6.4	68377
OtherRich	1.0%	172300	5.2	85082
Mid.East/N.A	1.4%	141100	4.5	79693
Latin America	0.7%	115200	4.8	117726
Other Asia	0.2%	100000	7.9	45791
S.S.Africa	0.1%	105200	7.1	62644

Source: authors. Key: emitters from North America with individuals CO_2e emissions levels above world average earn 32600€ per person (on average). The lower income threshold to be part of this group in the USA is 5851€. The tax would correspond to 0.6% of their income above the threshold.

world emissions—can be regarded as a reasonable middle ground and reference point. In particular, although we do not provide explicit estimates of negative externalities and associated social welfare computations, it should be noted that the tax burden imposed on this group (about 0.2% of world GDP) is much less than the reduction in welfare imposed on the rest of the world by their emissions (middle-range estimates of the long-run annual costs of global warming typically range from 2% to 10% of world GDP, and are higher under some estimates; see e.g. Stern et al., 2006).

Tables 9A and 9B present populations concerned, mean emissions, and emissions contributions of each region under different contribution strategies.

The main conclusions emerging from tables 9A-9B are relatively clear. According to the flat carbon tax strategy, China and North America should both contribute about 21% of the world adaptation fund, and EU should contribute 16% (strategy 0). However most emitters in China are very low emitters, so this does not look like an equitable solution. In strategy 1, we split the burden on individuals polluting more than world average emissions (28% of the world population). The share of North America jumps to 36%, while that of China falls to 15%, and that of Europe rises to 20%. When we split the burden between top 10% world emitters, the share of North America further rises to 46%, while China stands at 12% and Europe at 16% (strategy 2). When we split the burden between top 1% world emitters, the share of North America further rises to 57%, while China falls at 6% and Europe stands at 15% (strategy 3). Interestingly, the share of China falls below that of Russia/Central Asia or Middle-East/North Africa in the most progressive strategy).

To summarize: equitable adaptation finance requires to define neutral criteria applying to all citizens of the world equally, whether they come from rich, emerging or developing countries. We certainly do not know with certainty how to combine the different strategies so as to reach an equitable solution to all. But the bottom line of our simulations is that, at the end of the day, by far the largest contribution to world adaption funds should come from rich countries: contributions from European countries should increase by more than 3 times and those from the USA by more than 15 times so as to reach € 150 billion for adaptation.

Section 7.2. Implementation via country-level progressive taxation

Our preferred strategy for equitable adaptation finance is a global progressive carbon tax. However enforcing a progressive carbon tax at the global level seems very difficult, to say the least. Another strategy might be to use the global progressive carbon tax simulations to determine country shares in global adaptation funding, and then to let each country raise the required amount as they see fit. Ideally each country could raise the required amount via a contry-level progressive carbon tax. This is technically challenging but not impossible. In order to fix ideas, we also illustrate on table 10 how each country could raise the required amount via country-level supplement to existing progressive income taxes. To summarize: in order to raise the equivalent of 150 billions € per year (about 0.2% of world GDP), one can use income tax supplements with marginal rates around 1-2% of income on the top 10% emitters of the world, or around 5-10% on the top 1% emitters of the world. Note that the required tax rates vary across countries because the carbon intensity of income is not the same everywhere. We should stress again, however, that this is not our favoured solution: for given income, different individuals have different carbon emissions, and it is highly preferable —whenever possible—to use a progressive carbon tax, either at the country or world level.

Section 7.3 Implementation via a global progressive tax on air tickets

Yet another possible option to implement a tax on the world's highest emitters is to tax certain consumption items - those associated with high individual energy consumption and CO_2e emissions levels. Car ownership, being an air transport passenger or possessing an AC system may constitute such markers. Indeed, none of them are ideal ways to identify high CO_2e emitters or high energy consumers: car ownership is a relatively poor marker of high emitting lifestyles and this is even more true for ownership of AC system. Air transport may stand out as a relatively good marker of high income and high CO_2e emitting lifestyles. It is generally associated with high living standards - at the world level at least - and it generally also operates a distinction between different income or social groups with the economy/ first and business class system. A global tax on air transport could thus have two interesting properties: it would reach high-income individuals and high emitters.

Table 11 shows how each region of the world contributes to global air passengers[40] and also presents the contribution of world regions to each of the three groups targeted in section 7.1. The repartition between different regions for air tickets is relatively to each region's contribution to emissions above world average, i.e. in terms of regional efforts, taxing flights (without distinguishing business or economy, national or international) would then be close to our first strategy.

A tax on flights to finance specific development schemes was in fact discussed and established after the Paris International conference on the finance of development in 2005. Initially signed by 30 countries, the tax was implemented in 9 countries. The tax generates about €200m per year and its revenues are used to finance an international organizations (UNITAID and the International Finance Facility for Immunisation) which act in the field of vaccination and fight against epidemics. According to our estimates, the tax reaches about only 4.3% of flights worldwide (and much less in terms of km travelled).

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[40] The data informs on the share of flights by passengers of a given region in global air trafic.

TABLE 11. WHO SHOULD CONTRIBUTE TO CLIMATE ADAPTATION FUNDS?

Regions	Effort sharing according to all emissions (flat carbon tax) (%)	Progressive carbon tax strategies			Effort sharing according to a global tax on air tickets (%)
		Strategy 1	Strategy 2	Strategy 3	
		Effort sharing among all emitters above world average (%)	Effort sharing among top 10% emitters (above 2.3x world average) (%)	Effort sharing among top 1% emitters (above 9.1x world average) (%)	
North America	21.2	35.7	46.2	57.3	29.1
EU	16.4	20.0	15.6	14.8	21.9
China	21.5	15.1	11.6	5.7	13.6
Russia/C. Asia	6.0	6.6	6.3	6.1	2.8
Other Rich	4.6	5.8	4.5	3.8	3.8
Middle East/N.A	5.8	5.4	5.5	6.6	5.7
Latin America	5.9	4.3	4.1	1.9	7.0
India	7.2	1.0	0.7	0.0	2.9
Other Asia	8.3	4.7	4.1	2.7	12.1
S.S. Africa	3.1	1.5	1.5	1.1	1.1
World	100	100	100	100	100

Source: Authors. Air passenger data from World Bank (2015). Key: North Americans represent 46.2% of global emissions released by individuals who emit 2.3 times more than the global average. Individuals who emit more than 2.3 times average emissions (14.3 tCO2e per year) belong to the top 10% emitters. Note: 27% of individuals emit more than world average emissions (Strategy 1). These estimations focus on consumption-based emissions.

One way to go forward would be to generalize such a tax to all flights in the world and increase the per ticket cost. Taxing all flights at a rate of €52 per ticket would yield €150bn, required to finance climate adaptation in our adaptation scenario. Indeed, there can be many ways to make such a tax more 'progressive': different tax levels according to regions, on the basis of their contributions to top income emissions can be thought of. A differentiation between economy class and business class is also an option—already implemented in a country like France. With simple assumptions, we estimate that taxing business class at a rate of €180 per flight and economy class at a rate of €20 would yield about the same amount of money[41]. Here, we do not differentiate between national and international flights. Indeed, the former could be taxed at lower rate, and the latter at a higher rate.

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[41] Assuming that 20% of total flights are business or premier class, which is a typical breakdown for medium size planes (Boeing 747-400 for instance).

SECTION 8.
CONCLUSIONS AND PROSPECTS FOR FUTURE RESEARCH

In this report, we have presented new estimates on the evolution of the global distribution of CO_2e emissions between world individuals from 1998 and 2013. We then applied our findings to examine different strategies to finance a global climate adaptation fund based on efforts shared among high world emitters rather than high-income countries.

Our estimates are provisional and should be refined in many ways. In particular, world income distribution estimates need to be improved, as well as the reference values for carbon-income elasticities and how they vary between countries. However our main conclusions appear to be relatively robust to alternative specifications.

To summarize: equitable adaptation requires to define neutral criteria applying to all citizens of the world equally, whether they come from rich, emerging or developing countries. We certainly do not know with certainty how to combine the different strategies so as to reach an equitable solution to all. But the bottom line of our simulations is that, at the end of the day, by far the largest contribution to world adaption funds should come from rich countries—particularly from the USA, but also from the EU. Even if high income groups from emerging and developing countries were to contribute to adaptation efforts, Americans and Europeans would need to substantially scale up their current contributions to fill the adaptation gap.

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APPENDIX FIGURES AND TABLES

(For additional details, see on-line computer codes and data files, http://piketty.pse.ens.fr/files/ChancelPiketty2015Data.zip)

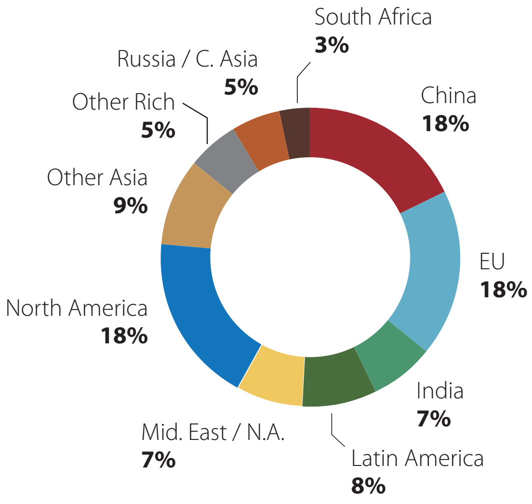
FIGURE A.0. LIST OF COUNTRIES AND AVAILABLE YEARS

Region	Country	Y1998	Y2003	Y2008	Y2013
China	China	Yes	Yes	Yes	Yes
EU	Austria	Yes	Yes	Yes	Yes
EU	Belgium	Yes	Yes	Yes	Yes
EU	Bulgaria	Yes	Yes	Yes	Yes
EU	Czech Republic	Yes	Yes	Yes	Yes
EU	Denmark	Yes	Yes	Yes	Yes
EU	Estonia	Yes	No	Yes	Yes
EU	Finland	Yes	Yes	Yes	Yes
EU	France	Yes	Yes	Yes	Yes
EU	Germany	Yes	Yes	Yes	Yes
EU	Greece	Yes	Yes	Yes	Yes
EU	Hungary	Yes	Yes	Yes	Yes
EU	Ireland	Yes	Yes	Yes	Yes
EU	Israel	Yes	Yes	Yes	Yes
EU	Italy	Yes	Yes	Yes	Yes
EU	Latvia	Yes	Yes	Yes	Yes
EU	Luxembourg	Yes	Yes	Yes	Yes
EU	Netherlands	Yes	Yes	Yes	Yes
EU	Norway	Yes	Yes	Yes	Yes
EU	Poland	Yes	Yes	Yes	Yes
EU	Portugal	Yes	Yes	Yes	Yes
EU	Singapore	Yes	Yes	Yes	Yes
EU	Slovakia	Yes	Yes	Yes	Yes
EU	Slovenia	Yes	Yes	Yes	Yes
EU	Spain	Yes	Yes	Yes	Yes
EU	Sweden	Yes	Yes	Yes	Yes
EU	Switzerland	Yes	Yes	Yes	Yes
EU	United Kingdom	Yes	Yes	Yes	Yes
India	India	Yes	Yes	Yes	Yes
Latin America	Bolivia	Yes	Yes	Yes	Yes
Latin America	Brazil	Yes	Yes	Yes	Yes
Latin America	Colombia	Yes	Yes	Yes	Yes
Latin America	Costa Rica	Yes	Yes	Yes	Yes
Latin America	Dominican Republic	Yes	Yes	Yes	Yes
Latin America	Ecuador	Yes	Yes	Yes	Yes
Latin America	El Salvador	Yes	Yes	Yes	Yes
Latin America	Guatemala	Yes	Yes	Yes	Yes
Latin America	Honduras	Yes	Yes	Yes	Yes

Latin America	Jamaica	Yes	Yes	No	No
Latin America	Mexico	Yes	Yes	Yes	Yes
Latin America	Nicaragua	Yes	Yes	Yes	Yes
Latin America	Panama	Yes	Yes	Yes	Yes
Latin America	Paraguay	Yes	Yes	Yes	Yes
Latin America	Peru	Yes	Yes	Yes	Yes
Latin America	Uruguay	Yes	Yes	Yes	Yes
Mid.East/N.A	Egypt	Yes	Yes	Yes	Yes
Mid.East/N.A	Iran, Islamic Republic of	Yes	Yes	Yes	Yes
Mid.East/N.A	Jordan	Yes	Yes	Yes	Yes
Mid.East/N.A	Morocco	Yes	Yes	Yes	Yes
Mid.East/N.A	Saudi Arabia	Yes	Yes	Yes	Yes
Mid.East/N.A	Tunisia	Yes	Yes	No	No
North America	Canada	Yes	Yes	Yes	Yes
North America	United States of America	Yes	Yes	Yes	Yes
Other Asia	Bangladesh	Yes	Yes	Yes	Yes
Other Asia	Cambodia	Yes	Yes	Yes	Yes
Other Asia	Indonesia	Yes	Yes	Yes	Yes
Other Asia	Korea, Republic of	Yes	Yes	Yes	Yes
Other Asia	Malaysia	Yes	Yes	Yes	Yes
Other Asia	Mongolia	No	Yes	Yes	Yes
Other Asia	Nepal	Yes	Yes	Yes	Yes
Other Asia	Pakistan	Yes	Yes	Yes	Yes
Other Asia	Philippines	Yes	Yes	Yes	Yes
Other Asia	Sri Lanka	Yes	Yes	Yes	Yes
Other Asia	Thailand	Yes	Yes	Yes	Yes
Other Asia	Vietnam	Yes	Yes	Yes	Yes
OtherRich	Australia	Yes	Yes	No	No
OtherRich	Japan	Yes	Yes	Yes	Yes
OtherRich	New Zealand	Yes	No	No	No
Russia/C.Asia	Albania	Yes	Yes	Yes	Yes
Russia/C.Asia	Armenia	Yes	Yes	Yes	Yes
Russia/C.Asia	Azerbaijan	No	Yes	Yes	Yes
Russia/C.Asia	Belarus	Yes	Yes	No	No
Russia/C.Asia	Croatia	Yes	Yes	Yes	Yes
Russia/C.Asia	Georgia	Yes	Yes	Yes	Yes
Russia/C.Asia	Kazakhstan	Yes	Yes	No	No
Russia/C.Asia	Kyrgyzstan	Yes	Yes	Yes	Yes
Russia/C.Asia	Russian Federation	Yes	Yes	Yes	Yes
Russia/C.Asia	Tajikistan	Yes	Yes	Yes	Yes
Russia/C.Asia	Turkey	Yes	Yes	Yes	Yes
Russia/C.Asia	Ukraine	Yes	Yes	Yes	Yes
S.S.Africa	Angola	Yes	No	No	No
S.S.Africa	Benin	No	Yes	No	No

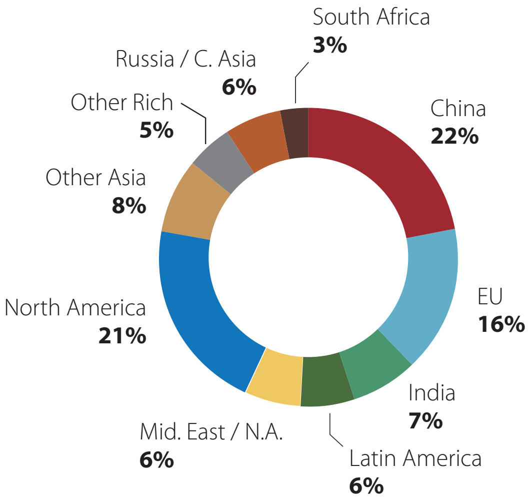
S.S.Africa	Burkina Faso	Yes	Yes	Yes	Yes
S.S.Africa	Burundi	Yes	No	Yes	Yes
S.S.Africa	Cameroon	Yes	Yes	Yes	Yes
S.S.Africa	Cote d'Ivoire	Yes	Yes	Yes	Yes
S.S.Africa	Ethiopia	Yes	Yes	No	No
S.S.Africa	Ghana	Yes	Yes	No	No
S.S.Africa	Guinea	No	Yes	Yes	Yes
S.S.Africa	Kenya	Yes	No	Yes	Yes
S.S.Africa	Liberia	No	No	Yes	Yes
S.S.Africa	Madagascar	Yes	Yes	Yes	Yes
S.S.Africa	Malawi	Yes	Yes	Yes	Yes
S.S.Africa	Mali	No	Yes	Yes	Yes
S.S.Africa	Mauritania	Yes	Yes	Yes	Yes
S.S.Africa	Mozambique	Yes	Yes	Yes	Yes
S.S.Africa	Namibia	No	Yes	No	No
S.S.Africa	Niger	No	No	Yes	Yes
S.S.Africa	Nigeria	Yes	Yes	Yes	Yes
S.S.Africa	Rwanda	Yes	Yes	Yes	Yes
S.S.Africa	Senegal	No	Yes	No	No
S.S.Africa	Sierra Leone	No	Yes	No	No
S.S.Africa	South Africa	Yes	Yes	Yes	Yes
S.S.Africa	Sudan	No	No	Yes	Yes
S.S.Africa	Tanzania, United Republic of	No	Yes	Yes	Yes
S.S.Africa	Uganda	Yes	Yes	Yes	Yes
S.S.Africa	Zambia	Yes	Yes	Yes	Yes

FIGURE A.1. BREAKDOWN OF GLOBAL GDP IN 2014



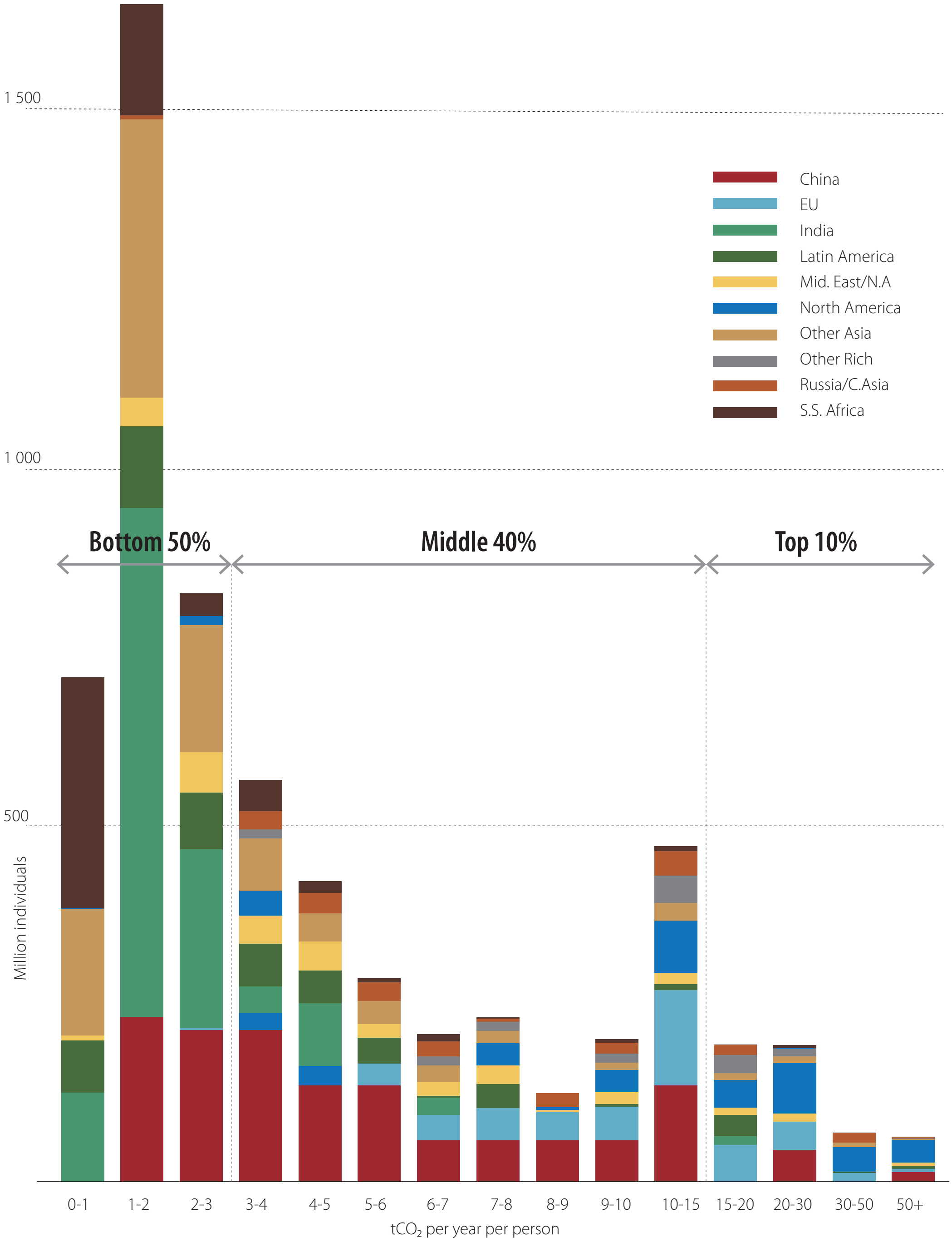
Source: authors based on World Bank (2015). Key: North America represents 18% of global PPP adjusted GDP in 2014.

FIGURE A.2. BREAKDOWN OF CONSUMPTION-BASED CO_2e EMISSIONS IN 2013



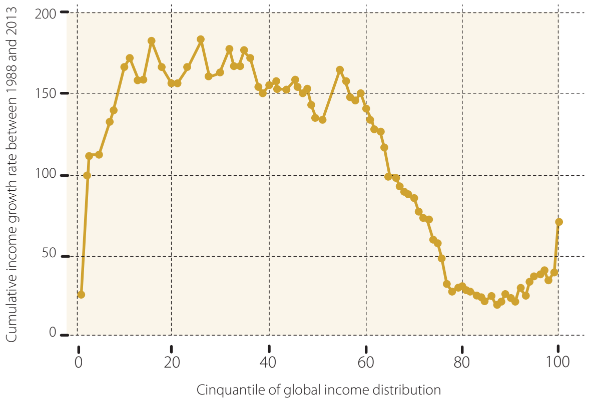
Source: authors. Key: China represents 22% (21.5%) of global CO_2e emissions when measured from a consumption-based perspective.

FIGURE A.3. DISTRIBUTION OF WORLD EMITTERS ACCORDING TO GHG EMISSION CATEGORIES



Source: authors. Key: 708 million individuals emit below 1 tonne of CO_2e emissions per year. 324 million people in this category live in Sub-Saharian Africa, 125 million in India, 177 million in South Asia and 73 million in Latin America.

FIGURE A.4. INCOME GROWTH FROM 1998 TO 2013



Source: authors. Key: the group representing the 2% lowest income earners in the world, saw its per capita income level increase by 28% between 1998 and 2013.

TABLE A.1. INCOME CONCENTRATION SHARES OVER TIME (%)

year	Top 1%	Top 5%	Top 10%	Middle 40%	Bottom 50%	Bottom 10%
2013	17.8	38.2	52.7	36.3	11.0	1.0
2008	18.9	39.8	55.3	35.4	9.3	0.8
2003	18.7	41.0	57.1	34.7	8.1	0.7
1998	17.9	39.9	56.5	35.6	7.9	0.7
1993	16.3	38.9	56.3	36.1	7.7	0.7
1988	16.0	38.2	55.5	37.9	6.6	0.6

Source: authors. Note: these are preliminary reconstructions used to derive a global GHG distribution of emissions and could be subject to ulterior modifications.

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