Article

Allocation of Greenhouse Gas Emissions Using the Fairness Principle: A Multi-Country Analysis

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Received: 3 June 2020; Accepted: 15 July 2020; Published: 20 July 2020

Abstract: This study presents an analysis of the allocation of greenhouse gas emissions based on a comparison of criteria for 66 countries and fairness-based indicators. The academic literature contains very few broad multi-country studies. The large sample of countries included in our analysis has allowed us to make a more comprehensive, holistic comparison than other studies with similar characteristics. The United States and China must make the greatest effort to fight climate change worldwide, but all countries have a responsibility, including some that are not usually analyzed in this type of research.

Keywords: emission reduction; greenhouse gases; climate change; carbon emission allocation; fairness principle

1. Introduction

Burning fossil fuels has led to an increase in greenhouse gas (GHG) emissions and ushered in a global energy transition [1–4], which in turn has sparked a profound and growing interest in reducing these emissions due to their devastating effect on our planet. Emission reduction has been the focus of the discussions held in the latest climate summits, particularly the 2015 Paris Summit. The global agreement on climate change signed in Paris in 2015 set out a framework for limiting global warming to well below 2 °C compared to pre-industrial levels [5,6]. The response to this problem was in turn formalized in each state's commitments to reduce GHG emissions in the framework of the Paris Agreement [7,8]. However, these commitments are incongruous on two levels: first, they are voluntary [9,10]; second, if all were met, the average temperature would increase by 3 °C [10,11]. In Conference of the Parties, COP25, in Madrid, progress was checked against outstanding rules, an assessment of loss and damage was made as per the Warsaw International Mechanism, and commitments were made toward financial support and capacity building [12], but the decision to withdraw from the Paris accord limited the summit success.

Finding the best way to share global emission reductions among all countries is a top priority for researchers [13], given the need to limit the increase in GHG emissions in carbon budgets [14]. In fact, as detailed in the following section, the allocation of emission quotas has received considerable attention in the academic literature, but the scope of the analysis has so far been restricted to limited groups of companies and countries.

Therefore, in this article we propose various GHG emission allocation schemes for a broader sample of countries based on different criteria. The aim of the study is to determine and compare the responsibility of each country studied using various fairness-based indicators. Several authors

have compared burden sharing rules at the country level. However, these studies have used other objectives, other allocation methods, or other samples (see, for example, [15–19]). This article, inspired by the proposals presented by Ringius et al. [20] and Winkler et al. [21], is the first of its kind to study the allocation of responsibilities in a larger group of countries.

The rest of the document is structured as follows: Section 2 describes the methodology of the different allocation criteria used. Next, Section 3 presents the different allocation results according to the criteria used. Finally, Section 4 establishes the most relevant conclusions.

2. Brief Literature Review

Research into carbon dioxide emissions allocation and convergence is a fertile field that includes literature reviews and meta-analyses, such as Pettersson et al. [22], Zhou and Wang [23], Acar et al. [7], and Payne [24], or more recently, Duro, Giménez-Gómez, and Vilella [25]. The academic literature also includes studies that have addressed emission allocation at the company level, particularly through the game theory approach [26–29] and linear programming models such as data envelope analysis [30–32].

Since the 1990s, a considerable body of literature has focused on emission allocations in each country [23,33]. In this corpus, emissions have variously been allocated by zoning, to a small group of countries [20,21,34–36], or by limiting the research to a single country [37–39]. Studies on allocations in China [40,41], for example, Chinese regions [42–46], Chinese cities [8], and Chinese sectors and industries [39,43] are particularly abundant. Other studies have focused on groups of countries, such as North America [44–46], Latin America [45], or three high-emission Asian countries—China, Japan, and South Korea (ROK)—by Ma, Cai, Ye, and Gu [47].

In the European Union (EU), since its inception in 2005, the EU Emissions Trading Scheme (EU ETS) has limited the annual aggregate emissions of carbon dioxide by allocating a certain amount of pollution permits. The available evidence [48] suggests that the EU ETS has had a robust negative impact on the carbon emissions, without strong detrimental effects in economic performance. In terms of financial performance of firms, Oestreich and Tsiakas [49] report a large and statistically significant carbon premium in stock returns. However, studies on Europe [50–52] and the USA [53,54] are less common, and those presenting a more global, holistic perspective, such as ours, are particularly scarce [55,56].

The academic literature includes various methods or approaches using several different allocation criteria based on two principles: efficiency, namely the economic efficiency of restricting emissions [23], and fairness, namely the fair distribution of emissions liability [20]. Each allocation criterion can be implemented using different indicators [23,37]. According to the latter authors, composite and above all simple indicators are the most common methods used. The indicator approach is almost compulsory, but “it is difficult to reach a consensus on the indicator used since the variation in the allocation results by different indicator methods is rather large” [23]. Therefore, it is probably advisable to use several indicators to enrich the comparison and strengthen the analysis.

3. Methodology and Data

The main obstacle to achieving the global energy transition lies in meeting the Paris Agreement target to reduce global GHG emissions based on the fairness principle. CO₂ allocation-based methods are an appropriate conceptual tool for distributing emission of this gas [20] because they are transparent and specifiable with perfect certainty [37].

In order to estimate the capacity to mitigate climate change, we based our analysis on studies that incorporate the fairness principle and the indicator method, which is the most appropriate approach to use when applying the fairness principle [23].

The global emissions budget differs according to whether reductions, growth, or rights are allocated [21]. Since the objective of this study is to allocate reductions, we assume that global emissions will return to 1990 levels by 2050 (target year for the Paris Agreement), which is a 54% reduction. For the empirical study, we used BP’s emissions data and the World Bank’s population and

Gross Domestic Product (GDP) data to allocate reductions to 66 countries, representing just over 90% of the global total, through to 2050.

3.1. Simple Indicator

Given the criteria and indicators shown in Table 1, we developed various emission distribution schemes using the formulas put forward by Ringius et al. [20] and Winkler et al. [23].

In the first scheme we use a simple indicator to assess the allocation of emissions between sample countries. A simple indicator can be described as a quantitative or qualitative measure derived from a series of observed facts that can provide the relative position of a country, for example, in any given area [57].

Table 1. Selected criteria and indicators.

Allocation Criteria	Interpretation	Indicator	Unit
Historical responsibility: This criterion is also known as the Brazilian Proposal [58] (HR)	Countries with most historical emissions must achieve greater reductions	Cumulative emissions between 1965 and 2016	Tonnes of CO ₂
Egalitarian	All countries have the same right to use the atmosphere	Population	No. of inhabitants
Ability to pay	Rich countries must shoulder more reduction burdens	GDP	US \$
Sovereignty	Nations with more emissions at present must take on a greater reduction burden	Current emissions	Tonnes of CO ₂

Source: Author, Ringius et al. [20], and Zhou and Wang [23].

3.2. Historical Responsibility Criterion (HR)

First, we used the HR criterion between 1965 and 2016 to estimate the emission reduction quota for each country according to our global emission reduction budget. This criterion indicates that emission reduction is allocated according to the level of accumulated emissions over a period of time [23]. Ridgley [34] used several criteria, including HR (in terms of global and per capita emissions), to distribute the burden of emissions among 11 world regions (Africa, China, Latin America, the Middle East/North Africa, Eastern and Western OECD (Organization for Economic Co-operation and Development), the United States, South Asia, Southeast Asia, and the former USSR). Their results indicate that the greatest burden of responsibility lies with the United States. Later, Winkler et al. [16] applied this and other criteria to six developing countries (China, India, Brazil, South Africa, Argentina, and Nigeria), and concluded that in absolute terms the largest emissions reduction quota should be allocated to China.

In our case, the participation of *country i* in the distribution of emissions reduction (X_i) is calculated using the following formula:

$$X_i = \text{Global reduction budget} \times \frac{\text{Historical emissions as a percentage of the world total between 1965–2016}}{100}$$

3.3. Ability to Pay Criterion

Secondly, we use the ability to pay criterion (according to this criterion, the emission reduction allocation is linked to the country's wealth [34]) The GDP of *country i* as a percentage of total world GDP in 2016 is a simple indicator to mitigate climate change. According to this criterion, the richest countries would have to shoulder a greater burden than poor countries when it comes to reducing emissions [23]. On a regional scale, Rose and Zhang [37] and Zhou et al. [38] used this criterion to assign CO₂ emission permits to different regions of the United States and China, respectively. The same criterion was also used in the aforementioned studies by Ridgley [34] and Winkler et al. [21] and yielded

the same results after applying the HR criteria: in the first case, the largest reductions correspond to the United States, and in the second to China. In this document, the participation of *country i* in the distribution of emissions reduction (X_i) is calculated using the following formula:

$$X_i = \text{Global reduction budget} \times \text{GDP US \$ of country } i \text{ as a percentage of total world GDP (2016)}.$$

3.4. Composite Indicator

In the first schemes we use a composite indicator to distribute emissions reductions among a sample of countries. The distribution of emission reductions has been made on the basis of the countries available in the BP yearbook [59], as it includes information from a broad set of regions and countries, as well as emissions data after 1965. A synthetic or composite indicator is an aggregate index of simple indicators and is obtained by weighting these indicators according to their relative importance in the index. Thus, while a simple indicator refers to a single dimension or magnitude, a composite indicator refers to several multidimensional concepts [57].

In this study, we used the composite indicator method based on one of the proposals made by Ringius et al. [20], who used three specific formulas each with a group of indicators, to allocate GHG emission reductions to some OECD member countries (except Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, Luxembourg, The Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States). Using Formula 2 ($X_i = \{wExE_i + wPxP_i + wGxG_i\}$), they found that the greatest reduction in emissions as a percentage of the total reduction of all OECD countries would correspond to the United States. In this document, the participation of *country i* in the distribution of emissions reduction (X_i) is calculated from an index based on this formula. Thus, two general GHG emission reduction allocation schemes are analyzed using the composite indicator method.

The first scheme (Formula 1) obeys the four criteria mentioned in Table 1: egalitarianism (population), ability to pay (GDP), current responsibility (current emissions), and historical responsibility (emissions accumulated between 1965 and 2016). In our case, X_i is the percentage participation of *country i* in the distribution of emissions reduction. E_i is the CO₂ emissions of *country i* as a percentage of the world total in 2016. EH_i is the cumulative CO₂ emissions of *country i* as a percentage of the world total between 1965 and 2016. P_i is the population of *country i* as a percentage of the world total in 2016, and G_i is the US\$ GDP of *country i* as a percentage of the world total. In this study, a single aggregation method has been used: each indicator is weighted at 0.25 and considered to be equally relevant.

$$X_i = \{wExE_i + wEHxEH_i + wPxP_i + wGxG_i\} \times \text{Overall reduction budget} \quad (1)$$

The second scheme (Equation (2)) obeys three criteria: egalitarianism (population), ability to pay (GDP), and current responsibility (current emissions). As in the previous case, X_i is the percentage participation of *country i* in the distribution of emissions reduction. E_i is the CO₂ emissions of *country i* as a percentage of the world total in 2016. P_i is the population of *country i* as a percentage of the world total in 2016. G_i is the US\$ GDP of *country i* as a percentage of the world total. The sum of weights (w) is equal to 1. In this study, a single aggregation method has been used: each indicator is weighted at 0.33 and considered to be equally relevant.

$$X_i = \{wExE_i + wPxP_i + wGxG_i\} \times \text{Overall reduction budget} \quad (2)$$

4. Results

Table 2 summarizes the emission allocation for the 66 countries studied according to the Formulas 1 and 2. Both formulas coincide in the top 10 countries that must further reduce their emissions: five of them belong to the OECD (the United States, Japan, Germany, United Kingdom, and France), one of them is a candidate for accession (Russia), and the rest are acceding countries with which the organization maintains enhanced cooperation (for example, China and India).

Table 2. Reductions allocated according to Formula 1 and 2.

Countries/Areas	Formula 1		Countries/Areas	Formula 2	
	(Mt CO ₂)	(% of Total)		(Mt CO ₂)	(% of Total)
China	2251.13	19.02%	China	2365.70	19.99%
US	2019.82	17.07%	US	1753.44	14.82%
India	920.51	7.78%	India	1076.68	9.10%
Japan	487.29	4.12%	Japan	460.44	3.89%
Russian Federation	380.60	3.22%	Russian Federation	315.86	2.67%
Germany	359.99	3.04%	Germany	311.30	2.63%
United Kingdom	245.02	2.07%	Brazil	254.94	2.15%
Brazil	225.15	1.90%	Indonesia	247.09	2.09%
Indonesia	213.14	1.80%	United Kingdom	219.94	1.86%
France	203.00	1.72%	France	198.97	1.68%
Canada	181.82	1.54%	South Korea	176.92	1.50%
Italy	176.93	1.50%	Mexico	175.76	1.49%
South Korea	174.42	1.47%	Italy	166.86	1.41%
Mexico	170.26	1.44%	Canada	159.41	1.35%
Iran	137.94	1.17%	Pakistan	138.26	1.17%
Australia	130.25	1.10%	Iran	137.40	1.16%
Saudi Arabia	125.39	1.06%	Turkey	128.56	1.09%
Spain	122.47	1.03%	Saudi Arabia	122.85	1.04%
Turkey	117.86	1.00%	Australia	122.44	1.03%
Pakistan	115.29	0.97%	Spain	120.86	1.02%
South Africa	110.17	0.93%	Bangladesh	106.08	0.90%
Poland	106.89	0.90%	South Africa	94.25	0.80%
Thailand	85.11	0.72%	Egypt	93.12	0.79%
Egypt	83.35	0.70%	Thailand	91.20	0.77%
Bangladesh	83.28	0.70%	Philippines	83.91	0.71%
The Netherlands	82.04	0.69%	Poland	79.10	0.67%
Ukraine	73.26	0.62%	Vietnam	78.72	0.67%
Argentina	71.86	0.61%	Argentina	73.79	0.62%
Philippines	70.28	0.59%	The Netherlands	73.77	0.62%
Vietnam	65.96	0.56%	Malaysia	62.65	0.53%
Malaysia	59.64	0.50%	Venezuela	59.20	0.50%
Venezuela	59.39	0.50%	United Arab Emirates	56.46	0.48%
United Arab Emirates	56.02	0.47%	Ukraine	52.59	0.44%
Belgium	50.85	0.43%	Colombia	50.46	0.43%
Kazakhstan	45.81	0.39%	Algeria	45.38	0.38%
Singapore	45.28	0.38%	Singapore	44.93	0.38%
Colombia	44.78	0.38%	Belgium	44.11	0.37%
Algeria	42.40	0.36%	Switzerland	43.04	0.36%
Czech Republic	41.44	0.35%	Kazakhstan	40.61	0.34%
Switzerland	38.08	0.32%	Sweden	37.36	0.32%
Romania	37.82	0.32%	Uzbekistan	33.84	0.29%
Sweden	37.33	0.32%	Chile	33.46	0.28%
Uzbekistan	34.87	0.29%	Peru	32.81	0.28%
Austria	32.07	0.27%	Austria	31.99	0.27%
Chile	30.98	0.26%	China Hong Kong SAR	31.18	0.26%
China Hong Kong	29.75	0.25%	Israel	29.21	0.25%
Peru	28.17	0.24%	Romania	28.08	0.24%
Israel	27.72	0.23%	Czech Republic	27.91	0.24%
Greece	27.29	0.23%	Norway	26.24	0.22%
Denmark	25.45	0.22%	Greece	23.46	0.20%
Norway	24.11	0.20%	Denmark	23.36	0.20%
Finland	22.30	0.19%	Ireland	22.70	0.19%
Portugal	22.09	0.19%	Portugal	22.19	0.19%

Table 2. Cont.

Countries/Areas	Formula 1		Countries/Areas	Formula 2	
	(Mt CO ₂)	(% of Total)		(Mt CO ₂)	(% of Total)
Ireland	21.63	0.18%	Qatar	21.67	0.18%
Kuwait	21.56	0.18%	Kuwait	20.52	0.17%
Hungary	21.43	0.18%	Finland	20.05	0.17%
Qatar	20.03	0.17%	Ecuador	17.76	0.15%
Bulgaria	16.87	0.14%	Hungary	17.06	0.14%
Belarus	15.91	0.13%	New Zealand	16.22	0.14%
New Zealand	15.84	0.13%	Turkmenistan	14.89	0.13%
Ecuador	15.59	0.13%	Belarus	13.69	0.12%
Turkmenistan	15.20	0.13%	Bulgaria	11.65	0.10%
Slovakia	14.08	0.12%	Azerbaijan	11.03	0.09%
Azerbaijan	11.31	0.10%	Slovakia	11.00	0.09%
Trinidad & Tobago	5.66	0.05%	Lithuania	5.26	0.04%
Lithuania	5.48	0.05%	Trinidad & Tobago	4.89	0.04%
OECD	5053.04	42.70%	OECD	4597.92	38.85%
UE	1700.52	14.37%	UE	1523.58	12.87%
No OECD	6780.78	57.30%	No OECD	7235.91	61.15%
Total top 10	7305.64	61.74%	Total top 10	7204.38	60.88%
Total considered	10,654.69	90.04%	Total considered	10,516.54	88.87%
Rest	1179.13	9.96%	Rest	1317.28	11.13%
Total World	11,833.82	100.00%	Total World	11,833.82	100.00%

Source: Author, using BP [59] and World Bank data [60].

Table 3 summarizes the allocation of emissions according to the HR criteria (Formula 3) for the five main CO₂ emitters and the country groupings considered in this study. Based on our global reduction budget, the results confirm that the burden falls on OECD countries. This organization accounts for 53% of emissions that must be reduced; therefore, the greatest responsibility, according to the HR criterion, lies with developed countries. Furthermore, the countries made up of the G20 (G8 nations plus other recently industrialized countries), account for more than 81% of the total. On an individual level, the United States heads the list.

Table 3. Reductions allocated according to the HR criterion * (Formula 3).

Countries/Areas	(Mt CO ₂)	(% del Total)
US	2765.83	23.37%
China	1835.75	15.51%
Russian Federation	565.24	4.78%
Japan	553.86	4.68%
Germany	496.61	4.20%
OECD	6272.30	53.00%
No OECD	5561.53	47.00%
North America	3158.51	26.69%
South and Central America	328.37	2.77%
Africa	238.35	2.01%
Europe and Eurasia	3119.94	26.36%
Asia Pacific	3603.47	30.45%
G8	5350.48	46.00%
G20	9691.08	81.54%
Total top 5	7605.59	52.54%
Total considered	10,750.46	90.85%
Rest	1083.36	9.15%
Total World	11,833.82	100.00%

Source: Author, using BP data [59]. Note: The grouping of countries is detailed in Appendix A * See the results of the 166 countries in Appendix B: Table A1.

Taking only the ability to pay criterion into account (Formula 4), the OECD accounts for 62.76% of emissions that must be reduced to achieve the Paris target. In fact, the reduction quota allocated to the top five countries, which includes many OECD countries accounts for 53.93% of the world total (Table 4). Taking this criterion into account, it is observed that the difference between the US and China is greater than in comparison with the others. The high percentages of North America and the G-20 countries stand out.

Table 4. Reductions allocated according to the ability to pay criterion * (Formula 4).

Countries/Areas	(Mt CO ₂)	(% of Total)
US	2905.80	24.56%
China	1747.30	14.77%
Russian Federation	771.28	6.52%
Japan	542.61	4.59%
Germany	413.13	3.49%
OECD	7426.95	62.76%
No OECD	4406.87	37.24%
North America	3307.82	27.95%
South and Central America	732.82	6.19%
Africa	122.28	1.04%
Europe and Eurasia	3097.68	26.18%
Asia Pacific	382.29	32.28%
G8	3344.67	48.58%
G20	7749.23	85.79%
Total top 5	7926.86	53.93%
Total considered	11,229.57	94.89%
Rest	604.25	5.11%
Total World	11,833.82	100.00%

Source: Author, using BP [50] and World Bank data [51]. * See the results of the 166 countries in Appendix B: Table A2.

The results of the four emission reduction allocation formulas for the United States and China, as the two main emitters, and the groupings of countries analyzed in this document are summarized in Table 5. A comparison between the HR and ability to pay criteria shows that the list is headed to a large extent by the same countries, although the distribution of emission reduction quotas differs: under the second (ability to pay) criterion, the most developed countries (OECD) have to make more significant reductions. It is important to note that, under the criteria of historical responsibility and ability to pay (with a similar participation in the distribution), the United States has to make the greatest commitment to mitigating climate change. It also ranks second according to the fairness criterion measured by the composite indicator approach. China has to make a greater effort, taking into account the HR criterion as well as India and the Russian Federation. On the other hand, Japan is more sensitive to the ability to pay criterion. This highlights that the non-OECD countries have a relatively high reduction in the criterion of historical responsibility that shows their greater participation in global cumulative emissions. Meanwhile, OECD countries have a greater goal of reducing the ability to pay criterion.

Table 5. Allocated emission reductions according to the different calculations (% of the total).

Countries/Areas	Formula 1	Formula 2	Formula 3	Formula 4
US	19.02%	14.82%	23.37%	24.56%
China	17.07%	19.99%	15.51%	14.77%
India	7.78%	9.10%	3.54%	2.98%
Japan	4.12%	3.89%	4.68%	6.52%
Russian Federation	3.22%	2.67%	4.78%	1.69%
OECD	42.70%	38.85%	53.00%	62.76%
No OECD	57.30%	61.15%	47.00%	37.24%

Source: Author.

5. Discussion and Conclusions

The global agreement on climate changes signed in Paris in 2015 set out a framework for limiting global warming to well below 2 °C compared to pre-industrial levels. However, emissions have only increased since then [61] (Figure 1).

Figure 1. Evolution of global CO₂ emissions from the use of fossil fuels and industrial activity. (Gt CO₂). Source: Global Carbon Project [61]. * Forecast.

Our study confirms the findings of earlier authors. Under the criteria of historical responsibility and ability to pay, the United States has to make the greatest commitment to mitigating climate change [34]. Nevertheless, this leadership position is not echoed in its contribution to climate change literature, particularly compared to the number of Chinese studies published. Nevertheless, our analysis differs from previous studies [20,21] insofar as it includes a broader sample of countries.

Our analysis of the responsibility of developed countries shows that according to the HR and ability to pay criteria, the OECD accounts for the highest percentage of emissions that need to be reduced to meet the Paris objective. This has important implications for the OECD as a whole, as it needs to make significant reductions in CO₂ emissions to mitigate the problem of climate change. However, using the composite indicator, our results show that the greatest responsibility lies with non-OECD member states. Obviously, these results could change if a different weight is assigned to each indicator.

Although our results show the importance of distributing emissions reduction quotas, they also demonstrate the need for caution when distributing reductions according to composite indicators, and probably explain why many experts choose to use simple indicators.

Our analysis suggests that the United States and China are the greatest contaminators and have the greatest responsibility when it comes to reducing emissions, a situation that highlights the major impact that the United States' decision to abandon the Paris agreement in 2017 will have on climate change in the future. The United States might not reduce its emissions at all, and its decision to stop contributing to the Global Environment Fund will most likely hinder progress in meeting the Paris Agreement targets [62].

It is imperative that fossil fuel producing countries modify their business models to combat climate change, and all countries in general should realize that increasing the global share of clean energy in the energy consumption structure and restructuring industries would be an effective policy. Theoretical claim problem (a claim problem is a particular distribution problem in which the amount to be distributed, *endowment E*, is not enough to cover the agents' claims on it [20]) approaches are impracticable due to the absence of a supra-national authority—a social planner—with

the capacity to propose a fair and egalitarian system for allocating resources based on different socially accepted principles [25], and allocation agreements that impose convergence would result in significant international income transfers. It is important to underline the responsibility of each government in achieving higher targets. In fact, the Paris Agreement places special value on voluntary contributions and national circumstances, but some studies have reported that the voluntary mitigation targets expressed in the Intended Nationally Determined Contributions are insufficient [55,63], which further enhances the need of discussing emission allowances of the countries. Our article informs policymakers of more countries about the importance of carbon emissions reduction in order to tackle environmental challenges and Nationally Determined Contributions. In particular for the European countries, the European Commission intends to propose, as part of the Green Deal, to increase the EU's 2030 target for greenhouse gas emission reductions to at least −50% and towards −55% compared to 1990 levels, in a responsible way. This should be an example to follow by the rest of the countries analyzed in our study.

Companies that possess resources of extraordinary importance need to be involved in reducing emissions. They can play a major role in halting global GHG emissions and introducing international global warming policies [64,65]. Taking the Paris goal seriously also involves limiting the use of fossil resources and leaving a percentage of fossil fuel reserves underground [66], since the emissions generated by these fuels are associated with an increase in CO₂ levels and global warming. Finally, let us not forget that the Paris Agreement also calls on all states, particularly the principle consumers, to reduce their consumption of fossil resources.

Our study is somewhat exploratory, given the large sample of countries studied, and this is its main limitation. However, it is the first analysis of such a large sample of countries, including some that are not usually analyzed in this type of research (i.e., Slovakia or Portugal). This broader comparison and our new results make an interesting contribution to the study of carbon emission quotas. A clear example of this is India, which in our study is always one of the top-ranking countries in the different indexes used but is not very often analyzed in the academic literature [67]. This also opens new avenues of research and encourages researchers to broaden their geographical approach to obtain more global, comprehensive results.

Author Contributions: L.R.-F., A.B.F.C. and M.B.-C. contributed equally to this work. All authors wrote, reviewed, and commented on the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Country Groups Used in the Document

- North America: US (excluding Puerto Rico), Canada, and Mexico.
- South and Central America: Caribbean (including Puerto Rico) and Central and South America.
- Europe: European members of the OECD plus Albania, Bosnia-Herzegovina, Bulgaria, Croatia, Cyprus, Former Yugoslav Republic of Macedonia, Gibraltar, Malta, Romania, Serbia and Montenegro, Slovenia.
- Former Soviet Union: Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Russian Federation, Tajikistan, Turkmenistan, Ukraine, Uzbekistan.
- Europe and Eurasia: All countries listed above under the headings Europe and the Former Soviet Union.
- Asia Pacific: Brunei, Cambodia, China, China Hong Kong SAR*, Indonesia, Japan, Laos, Malaysia, Mongolia, North Korea, Philippines, Singapore, South Asia (Afghanistan, Bangladesh, India, Myanmar, Nepal, Pakistan, and Sri Lanka), South Korea, Taiwan, Thailand, Vietnam, Australia, New Zealand, Papua New Guinea, and Oceania, *Special Administrative Region.
- G8: France, Germany, Italy, Japan, the United Kingdom, the United States, Canada and Russia.

- G20: France, Germany, Italy, Japan, United Kingdom, United States, Canada, Russia, Argentina, Australia, Brazil, China, India, Indonesia, Mexico, Saudi Arabia, South Africa, Republic of Korea, Turkey and the European Union.
- EU: Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, The Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden.
- OECD: Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, The Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, and the United Kingdom.

Appendix B. Reductions Allocated According to the Criteria HR Criterion and Reductions Allocated According to the Ability to Pay Criterion

Table A1. Reductions Allocated According to the Criteria HR Criterion.

Countries/Areas	(Mt CO ₂)	(% of Total)
US	2765.83	23.37%
China	1835.75	15.51%
Russian Federation	565.24	4.78%
Japan	553.86	4.68%
Germany	496.61	4.20%
India	419.36	3.54%
United Kingdom	313.58	2.65%
Canada	244.23	2.06%
France	209.07	1.77%
Italy	202.06	1.71%
Poland	187.87	1.59%
South Korea	161.58	1.37%
South Africa	155.07	1.31%
Australia	149.96	1.27%
Mexico	148.45	1.25%
Iran	135.39	1.14%
Ukraine	133.69	1.13%
Saudi Arabia	129.27	1.09%
Brazil	128.03	1.08%
Spain	123.64	1.04%
The Netherlands	104.64	0.88%
Indonesia	103.78	0.88%
Turkey	81.85	0.69%
Czech Republic	81.21	0.69%
Belgium	69.73	0.59%
Romania	66.19	0.56%
Thailand	64.06	0.54%
Argentina	63.82	0.54%
Kazakhstan	60.18	0.51%
Venezuela	58.17	0.49%
United Arab Emirates	53.00	0.45%
Egypt	51.22	0.43%
Malaysia	48.71	0.41%
Singapore	44.95	0.38%
Pakistan	42.19	0.36%
Greece	38.06	0.32%
Uzbekistan	36.93	0.31%
Sweden	36.10	0.31%
Hungary	34.03	0.29%
Bulgaria	32.16	0.27%
Algeria	32.05	0.27%

Table A1. Cont.

Countries/Areas	(Mt CO ₂)	(% of Total)
Austria	31.36	0.27%
Denmark	31.03	0.26%
Finland	28.46	0.24%
Philippines	26.85	0.23%
Colombia	26.21	0.22%
Vietnam	25.30	0.21%
China Hong Kong SAR	24.53	0.21%
Kuwait	24.07	0.20%
Slovakia	22.99	0.19%
Chile	22.55	0.19%
Israel	22.35	0.19%
Belarus	22.13	0.19%
Switzerland	21.89	0.18%
Portugal	21.11	0.18%
Ireland	17.72	0.15%
Norway	16.94	0.14%
Turkmenistan	15.69	0.13%
Qatar	14.45	0.12%
New Zealand	14.19	0.12%
Peru	13.25	0.11%
Azerbaijan	11.80	0.10%
Bangladesh	11.69	0.10%
Ecuador	8.54	0.07%
Trinidad & Tobago	7.81	0.07%
Lithuania	5.98	0.05%
OECD	6272.30	53.00%
UE	2184.98	18.46%
No OECD	5561.53	47.00%
Total top 10	7605.59	64.27%
Total considered	10,750.46	90.85%
Rest	1083.36	9.15%
Total World	11,833.82	100.00%

Source: Author, using BP data [50].

Table A2. Reductions Allocated According to the Ability to Pay Criterion.

Countries/Areas	(Mt CO ₂)	(% of Total)
US	2905.80	24.56%
China	1747.30	14.77%
Japan	771.28	6.52%
Germany	542.61	4.59%
United Kingdom	413.13	3.49%
France	384.60	3.25%
India	353.20	2.98%
Italy	290.03	2.45%
Brazil	280.24	2.37%
Canada	238.67	2.02%
South Korea	220.11	1.86%
Russian Federation	200.20	1.69%
Spain	192.89	1.63%
Australia	187.95	1.59%
Mexico	163.34	1.38%
Indonesia	145.45	1.23%
Turkey	134.91	1.14%

Table A2. Cont.

Countries/Areas	(Mt CO ₂)	(% of Total)
The Netherlands	121.26	1.02%
Switzerland	104.14	0.88%
Saudi Arabia	100.86	0.85%
Argentina	85.11	0.72%
Sweden	80.47	0.68%
Poland	73.54	0.62%
Belgium	73.37	0.62%
Venezuela	72.21	0.61%
Iran	65.37	0.55%
Thailand	63.50	0.54%
Austria	60.35	0.51%
Norway	57.90	0.49%
United Arab Emirates	54.41	0.46%
Egypt	51.92	0.44%
Israel	49.70	0.42%
China Hong Kong SAR	49.70	0.42%
Singapore	48.52	0.41%
Denmark	47.88	0.40%
Ireland	47.34	0.40%
Philippines	47.34	0.40%
Malaysia	46.27	0.39%
South Africa	46.15	0.39%
Colombia	44.07	0.37%
Pakistan	43.52	0.37%
Chile	39.05	0.33%
Finland	36.68	0.31%
Bangladesh	34.55	0.29%
Vietnam	32.03	0.27%
Portugal	31.95	0.27%
Czech Republic	30.77	0.26%
Peru	29.99	0.25%
Greece	29.58	0.25%
New Zealand	29.58	0.25%
Romania	29.27	0.25%
Algeria	24.81	0.21%
Qatar	23.79	0.20%
Kazakhstan	21.42	0.18%
Hungary	20.12	0.17%
Kuwait	17.30	0.15%
Ecuador	15.38	0.13%
Ukraine	14.55	0.12%
Slovakia	14.20	0.12%
Uzbekistan	10.49	0.09%
Bulgaria	8.28	0.07%
Belarus	7.10	0.06%
Lithuania	7.10	0.06%
Azerbaijan	5.91	0.05%
Turkmenistan	5.64	0.05%
Trinidad & Tobago	3.42	0.03%
OECD	7426.95	62.76%
UE	2570.31	21.72%
No OECD	4406.87	37.24%
Total top 10	7926.86	66.98%
Total considered	11,229.57	94.89%
Rest	604,25	5.11%
Total World	11,833.82	100.00%

Source: Author, using World Bank data [51].

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