CO_2 price and historical responsibility – A cardinal measure of emissions rights

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Abstract

A method to set the relative price of CO2 is proposed. We develop an indicator defining each country's bonus/malus with respect to a market-established price. The indicator, based on the cumulated fossil fuels carbon dioxide emission per capita, can be used to weight each country ton of CO2-equivalent price. The sum of yearly per capita emissions can be seen as a justice-based criterion as it gives the same value to each citizen's emission over time. Although for some countries the data on fossil emissions start in the XVIII century, while for many developing countries information begins in 1950, we find that the choice of the starting date for the sum is irrelevant; indeed the indicator calculated as deviation from the mean is very stable compared to variations of the starting date. Our indicator can be used as a steering instrument to enhance market-based mechanism to achieve emission reduction targets.

1 - Introduction

Carbon pricing is a long-debated subject, as well as how to price greenhouse gas emission; nevertheless the CO_2 market is a failure, so far. The emissions market is not working properly, the price of a ton of CO2 is seriously under-evaluated and the dispute about single country allowances (quantities) does not seem close to turn into an international agreement. Developing countries claim the right to emit "more" than OECD members, considering themselves as "latecomers" in the industrialization. Rich countries bet on "fair" CO2 pricing to stabilize emissions, even though the Clean Development Mechanism (CDM) is under heavy criticism (REFERENCE needed). Recent studies estimate the ton of CO2 should be multiplied a factor 10 (form 2 to 20 $/tonCO2) for the emission market to effectively stabilize emission below the 2 degrees Celsius global warming threshold.

This article does not pretend to set the right price for CO_2 or the emissions allowances of each country. Rather, basing our analysis on historical data on emission, we calculate a indicator of the historical impact for each country. Such indicator could be used to weight each country's carbon price. The indicator, developed as the sum of yearly fossil fuel emission per capita, and it can be used to determine the relative CO2 price of each country with respect to a market-established international price. The next section details the methodology, section 3 gives the results, section 4 the conclusions.

The main research motivation is that world's carbon dioxide emissions are raising and no efficient market-based mechanism seem to be efficient in reverting the trend (Metcalf 2009). Our indicator could result in setting an agreement for a market driven mechanism conjugating efficiency and justice.

2 - CO_2 pricing methodology

Carbon dioxide production is a natural phenomenon occurring on earth from both biological and chemical activity. In living organisms like animals and plants cell breathing is a fundamental part of earth metabolism linking life to global gases cycles, while in earth thin crust volcanoes, hot springs and geysers CO2 produce by carbonate rocks dissolution. Thus, pre-XIX century variations in CO2 atmospheric concentration are due to natural cycles, while post-XIX century emission records relate to anthropogenic emissions caused by fossil energy use. Then began the Industrial Revolution and related coal use.

In this article we suggest a rationale to determine the relative price of 1 ton of CO_2 based on the total emission activity of each country relative to its inhabitants. At this purpose, we consider the cumulated per capita emissions of each country of the world based on historical data publicly available. The information was assembled using UN sources for population[1] and fossil CO_2 emissions from the Carbon Dioxide Information Analysis Center (CDIAC)[2]. The CDIAC database report fossil fuel emissions from both national statistical offices and other sources. Although the CDIAC team estimate fossil fuel emissions since 1751, in 1900 there are records for 37 countries only. The number of reported countries rises to 44 in 1910, 52 in 1920, 60 in 1930 and 69 in 1940.

In order to control the influence of the variability in starting date we considered both 1900 and 1950 as starting year. Then we proceeded to sum the per capita emissions. The sum over the period is a cumulated amount of CO_2 emissions per capita representing an indicator of the greenhouse impact of the country over its "fossil history". The final weight for CO_2 pricing can be calculated as distance from the sample mean. In an alternative method, the median can be used. In short, the novel indicator is developed in three steps:

- Calculation of countries per-capita fossil-generated CO_2 emissions (CO_2);
- Calculation of cumulated per-capita fossil-generated CO_2 emissions (W_i);
- Calculation of each country cumulated per-capita fossil-generated CO_2 emissions deviation from the population mean (or median), ΔW.

The expression is:

$$W_i = \sum_{j=1}^{n} \frac{CO2_{ij}}{Pop_{ij}} \tag{1}$$

$$\Delta W_i = W_i - \overline{W} \tag{2}$$

Where,

W_i : cumulated per-capita CO_2,

CO_{2ij} : fossil fuel emissions of country *i* in year *j*,

Pop: population *i* at time (*j* = *1950, …, 2009),*

$\overline{W}$: indicator mean (or median),

ΔW_i price weight of country *i*.

The underlying rationale for indicator *W* being that each individual on earth has the right to emit an equal amount of greenhouse gases over time. In this way per capita emissions have the same value over space and time. Per capita yearly right-to-emit are summed resulting in each country's cumulated per capita emissions from fossil fuels exploitation W_i. The distance from the mean ΔW_i is the (relative) weight

[1] United Nations, Dep. Of Economic and Social Affairs, Population division, Population Estimates and Projections Section, World Population Prospects: The 2012 Revision, Extended Dataset http://esa.un.org/unpd/wpp/ASCII-Data/DISK_NAVIGATION_ASCII.htm#DB01_Period_Indicators2, accessed on September, 19, 2014.

[2] Carbon Dioxide Information Analysis Center, Fossil-Fuel CO2 Emissions by Nation http://cdiac.ornl.gov/trends/emis/tre_coun.html, accessed on September, 19, 2014.

for country *i* CO_2 price. It is incorporates the country total contribution to climate change and it justifies the different price for the right-to-emit today. In this sense this approach is in line with the position held by developing countries claiming that past emissions need to be included in greenhouse gas emission accounting and rights. The underlying rationale being that past emissions should be also included, following a criterion of inter-generational justice not only present (or recent) emission level.

3 – Results, sensitivity and simulations

The first step was to calculate the ratio between the CO_2-equivalent emissions and the population for each year using CDIAC data (Boden et al. 1995). The series of world countries per-capita CO_2 emissions for the period 1950-2009 is presented in *Figure 1*.

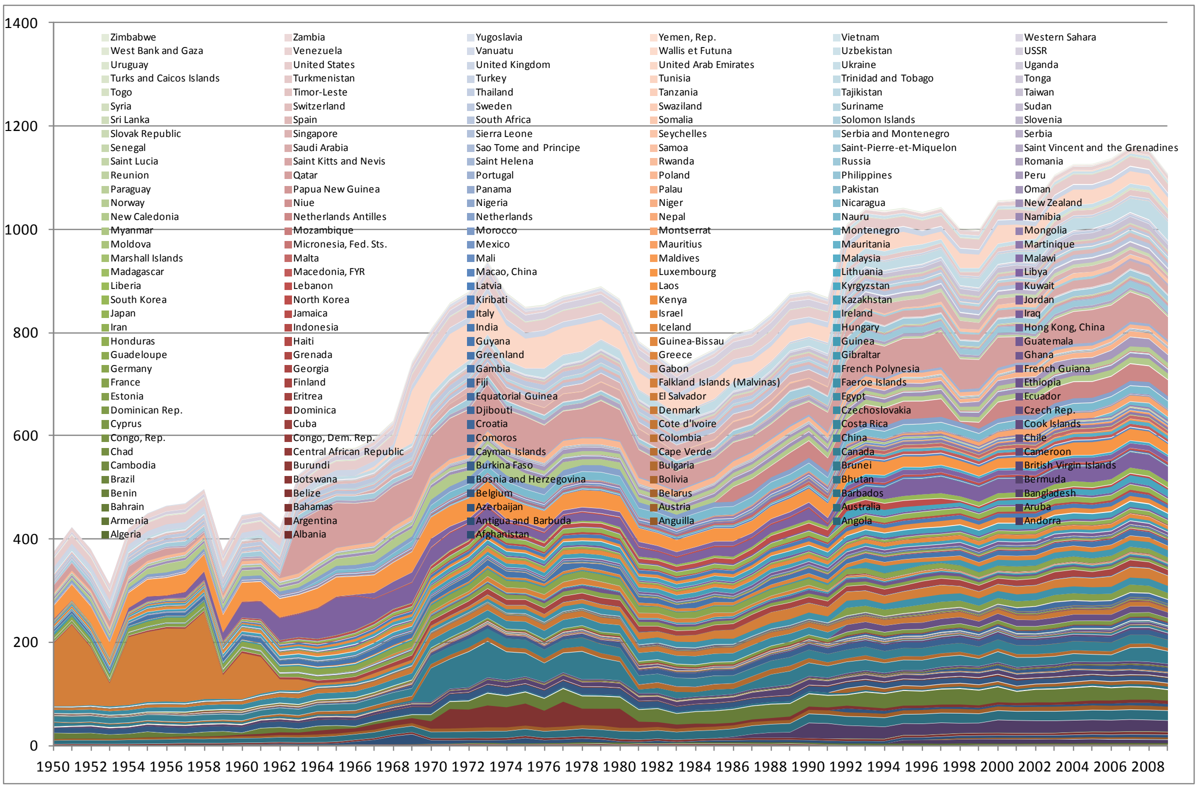

Figure 1 – W_i - Fossil CO_2 per capita (1950 to 2009)

Then we summed the per capita emissions and we calculated the distance of the cumulated 2009 per capita emissions from respectively the population mean and the median. The results are presented in *Table 1* and in *Figure 2* and *3*. It can be seen how the indicator calculated from the median has higher extreme positive values. Deviation from the mean span from Qatar 12 to -1 of Tchad, Eritrea, Mali an others. The indicator calculated from the median from Qatar's 34 to -0.9 recorded in Georgia, Armenia and Pakistan. The threshold of positive values changes significantly between the two approaches: it is positive in 63 countries considering the mean and in 109 countries the median.

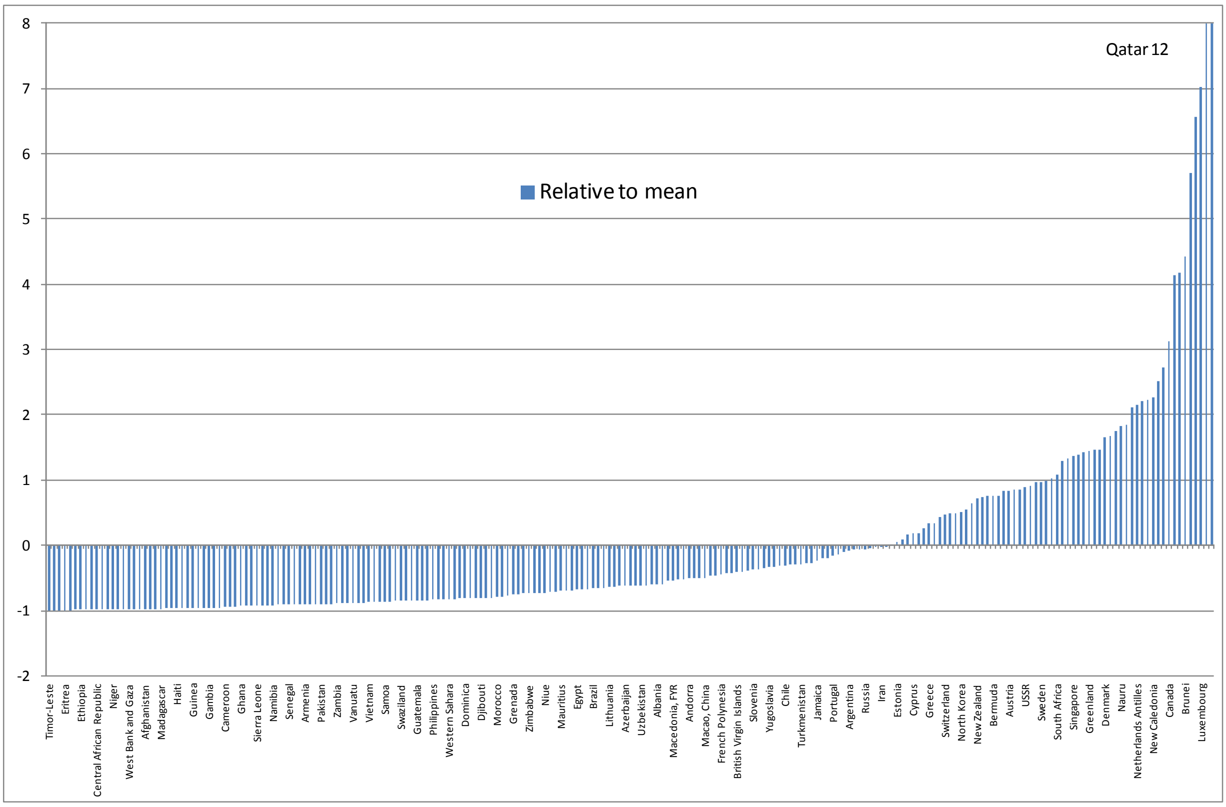

Figure 2 – ΔW_i as *distance from the mean*

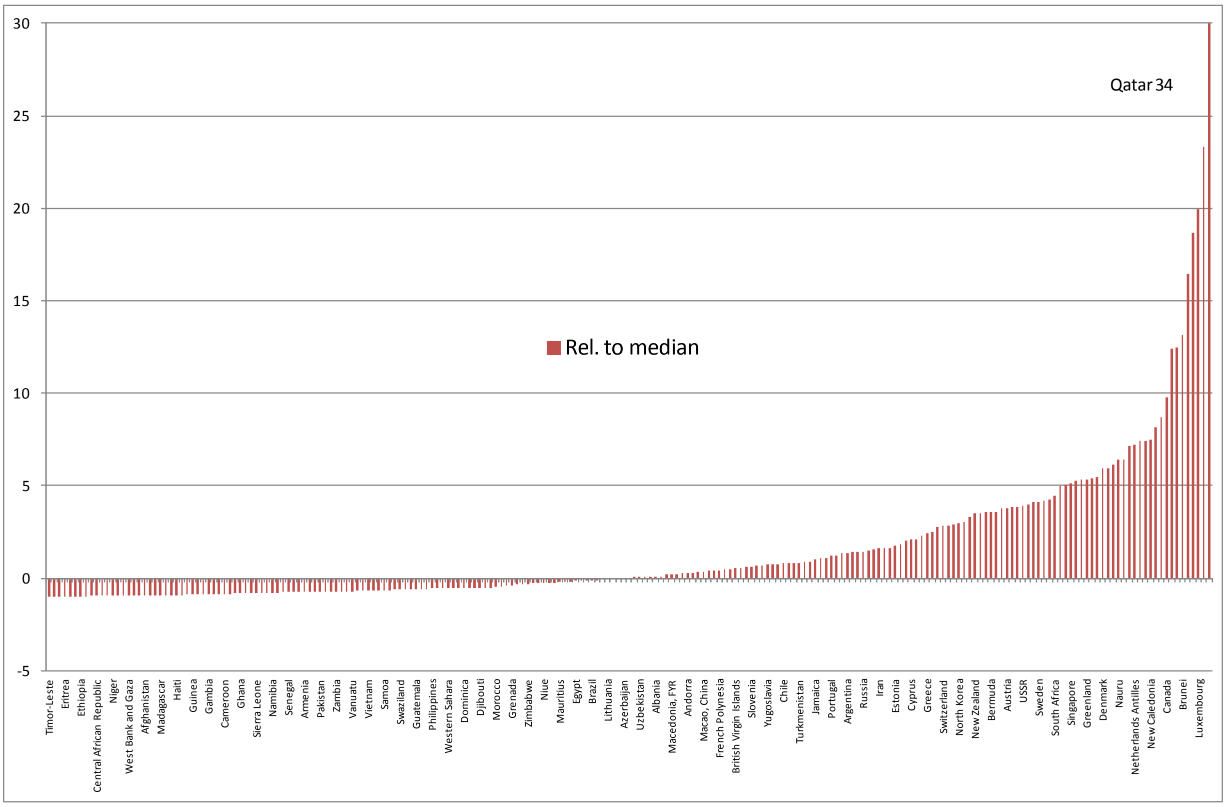

Figure 3 – ΔW_i as distance from the median

Table 1 – Country's weight for pricing CO_2 (starting year = 1950)

Country	Rel. to mean	Rel. to median	Country	Rel. to mean	Rel. to median	Country	Rel. to mean	Rel. to median	Country	Rel. to mean	Rel. to median	Country	Rel. to mean	Rel. to median
Timor-Leste	-0,99	-0,98	Georgia	-0,90	-0,75	St Lucia	-0,72	-0,26	Turkmenistan	-0,29	0,85	Ireland	1,02	4,26
Chad	-0,99	-0,98	Armenia	-0,90	-0,74	Latvia	-0,71	-0,25	Iraq	-0,28	0,87	South Africa	1,09	4,45
Burundi	-0,99	-0,98	Kyrgyzstan	-0,90	-0,74	Mauritius	-0,70	-0,21	Barbados	-0,27	0,91	Aruba	1,29	4,98
Eritrea	-0,99	-0,97	Liberia	-0,90	-0,73	Peru	-0,70	-0,21	Jamaica	-0,24	0,99	Finland	1,33	5,06
Mali	-0,99	-0,97	Pakistan	-0,90	-0,73	Cook Islands	-0,69	-0,19	Mongolia	-0,20	1,09	Singapore	1,36	5,16
Burkina Faso	-0,99	-0,97	Cote d'Ivoire	-0,89	-0,72	Egypt	-0,68	-0,15	Mexico	-0,19	1,11	St Pierre & Miquelon	1,39	5,24
Ethiopia	-0,99	-0,97	Congo, Rep.	-0,89	-0,72	Dominican Rep.	-0,67	-0,15	Portugal	-0,16	1,20	Czechoslovakia	1,43	5,35
Nepal	-0,99	-0,97	Zambia	-0,89	-0,71	Belize	-0,67	-0,15	Martinique	-0,15	1,22	Greenland	1,44	5,35
Rwanda	-0,98	-0,96	Sao Tome & Principe	-0,89	-0,71	Brazil	-0,66	-0,11	French Guiana	-0,10	1,35	Poland	1,46	5,43
Central African Rep.	-0,98	-0,96	Papua New Guinea	-0,89	-0,71	Ecuador	-0,65	-0,09	Argentina	-0,09	1,38	Faeroe Islands	1,47	5,45
Somalia	-0,98	-0,96	Vanuatu	-0,88	-0,70	Tunisia	-0,65	-0,08	Hong Kong, China	-0,07	1,42	Denmark	1,65	5,91
Malawi	-0,98	-0,95	Montenegro	-0,88	-0,69	Lithuania	-0,64	-0,07	Kazakhstan	-0,06	1,45	Netherlands	1,67	5,96
Niger	-0,98	-0,95	Paraguay	-0,88	-0,69	Saint Kitts & Nevis	-0,64	-0,07	Russia	-0,06	1,46	Saudi Arabia	1,75	6,17
Uganda	-0,98	-0,95	Vietnam	-0,87	-0,67	Croatia	-0,62	-0,01	Gabon	-0,04	1,51	Nauru	1,83	6,38
Cambodia	-0,97	-0,93	Nigeria	-0,87	-0,66	Azerbaijan	-0,62	0,00	Malta	-0,02	1,56	United Kingdom	1,85	6,43
W Bank & Gaza	-0,97	-0,93	Marshall Islands	-0,86	-0,65	Colombia	-0,62	0,00	Iran	0,00	1,60	Belgium	2,12	7,14
Micronesia, Fed. Sts	-0,97	-0,93	Samoa	-0,86	-0,64	Equatorial Guinea	-0,61	0,01	Czech Rep.	0,00	1,60	Netherlands Antilles	2,15	7,22
Laos	-0,97	-0,93	Mauritania	-0,86	-0,63	Uzbekistan	-0,61	0,02	Montserrat	0,01	1,62	Germany	2,22	7,39
Afghanistan	-0,97	-0,93	Angola	-0,85	-0,61	Thailand	-0,61	0,02	Estonia	0,06	1,75	Bahamas	2,24	7,44
Bangladesh	-0,97	-0,92	Swaziland	-0,85	-0,61	Panama	-0,60	0,05	Suriname	0,08	1,83	New Caledonia	2,26	7,50
Tanzania	-0,97	-0,92	Moldova	-0,85	-0,61	Albania	-0,60	0,05	Antigua & Barbuda	0,17	2,05	Trinidad & Tobago	2,51	8,16
Madagascar	-0,97	-0,92	El Salvador	-0,85	-0,61	Bosnia & Herzeg.	-0,59	0,06	Cyprus	0,19	2,09	Australia	2,72	8,69
Comoros	-0,97	-0,92	Guatemala	-0,85	-0,61	Reunion	-0,54	0,20	South Korea	0,19	2,10	Canada	3,13	9,77
Congo, Dem. Rep.	-0,97	-0,91	Honduras	-0,85	-0,60	Macedonia, FYR	-0,53	0,22	Spain	0,27	2,31	Bahrain	4,15	12,42
Haiti	-0,97	-0,91	Nicaragua	-0,85	-0,60	Uruguay	-0,53	0,22	Greece	0,33	2,47	United States	4,17	12,47
Guinea-Bissau	-0,96	-0,90	Philippines	-0,83	-0,55	Guyana	-0,52	0,26	Taiwan	0,34	2,50	Brunei	4,43	13,16
Tajikistan	-0,96	-0,90	India	-0,83	-0,54	Andorra	-0,50	0,30	Oman	0,44	2,74	Kuwait	5,70	16,48
Guinea	-0,96	-0,89	Tonga	-0,82	-0,54	China	-0,50	0,30	Switzerland	0,48	2,86	United Arab Emirates	6,56	18,70
Benin	-0,96	-0,89	Western Sahara	-0,82	-0,53	Belarus	-0,49	0,32	Romania	0,48	2,86	Luxembourg	7,03	19,93
Myanmar	-0,96	-0,89	Turks & Caicos Is.	-0,82	-0,53	Macao, China	-0,49	0,32	Gibraltar	0,50	2,90	Falkland Is.	8,33	23,31
Gambia	-0,96	-0,89	Yemen, Rep.	-0,82	-0,52	Turkey	-0,46	0,40	North Korea	0,52	2,96	Qatar	12,26	33,58
Togo	-0,95	-0,88	Dominica	-0,81	-0,52	Syria	-0,46	0,41	Italy	0,55	3,03			
Mozambique	-0,95	-0,87	St Vincent & Grenad.	-0,81	-0,51	French Polynesia	-0,45	0,43	Hungary	0,65	3,30			
Cameroon	-0,94	-0,85	Maldives	-0,81	-0,50	Jordan	-0,43	0,49	New Zealand	0,73	3,50			
Bhutan	-0,94	-0,85	Djibouti	-0,81	-0,50	Algeria	-0,42	0,52	Bulgaria	0,74	3,54			
Sudan	-0,93	-0,83	Anguilla	-0,81	-0,50	British Virgin Is.	-0,41	0,55	Cayman Is.	0,75	3,56			
Ghana	-0,93	-0,81	Indonesia	-0,81	-0,49	Guadeloupe	-0,41	0,55	Bermuda	0,75	3,57			
Wallis et Futuna	-0,92	-0,80	Morocco	-0,78	-0,44	Slovak Rep.	-0,38	0,60	Israel	0,77	3,60			
Kenya	-0,92	-0,80	Bolivia	-0,78	-0,43	Slovenia	-0,37	0,64	Venezuela	0,84	3,78			
Sierra Leone	-0,92	-0,80	Saint Helena	-0,76	-0,38	Ukraine	-0,36	0,66	Austria	0,84	3,80			
Cape Verde	-0,92	-0,80	Grenada	-0,75	-0,36	Cuba	-0,34	0,72	Libya	0,85	3,82			
Sri Lanka	-0,92	-0,78	Fiji	-0,74	-0,33	Yugoslavia	-0,33	0,73	Norway	0,86	3,85			
Namibia	-0,91	-0,77	Costa Rica	-0,74	-0,31	Seychelles	-0,33	0,76	USSR	0,88	3,91			
Solomon Islands	-0,91	-0,77	Zimbabwe	-0,73	-0,30	Palau	-0,32	0,78	Japan	0,92	3,99			
Kiribati	-0,91	-0,75	Botswana	-0,73	-0,29	Chile	-0,31	0,81	France	0,96	4,12			
Senegal	-0,90	-0,75	Serbia & Montenegr	-0,72	-0,28	Malaysia	-0,30	0,84	Sweden	0,97	4,15			
Serbia	-0,90	-0,75	Niue	-0,72	-0,28	Lebanon	-0,30	0,84	Iceland	0,98	4,16			

We checked for the influence of the starting year on indicator *ΔW* for both 1900 and 1950. Another reason to investigate the sensitivity of the indicator with respect to starting year being that CO_2 accounting goes back in time for early-industrialized countries - Europe, Canada and the USA – only. Thus, we tested the effect of choosing different starting dates for the calculation of the cumulated CO2 per-capita weight indicator, by calculating W_i and ΔW_i from 1900, 1910, 1920, 1930, 1940 and 1950.

The results show that although W_i changes relevantly for some countries (USA, UK, Bahrein, Canada, Belgium, etc.), ΔW_i is very stable. In fact, passing from 1900 to 1950 as starting year (*Figure 4)* produces significant positive difference (> 1) for United States (2.2), United Kingdom (1.8), Belgium (1.3), Bahrain and Canada (1.2) and Germany (1.1), while all negative differences are inferior to unity. We may conclude that the indicator of cumulated CO_2 per capita relative to the mean performs a good stability to the choice of the starting year. Such result enhances its use value in face of the possible debate about *when* to start the emissions calculation.

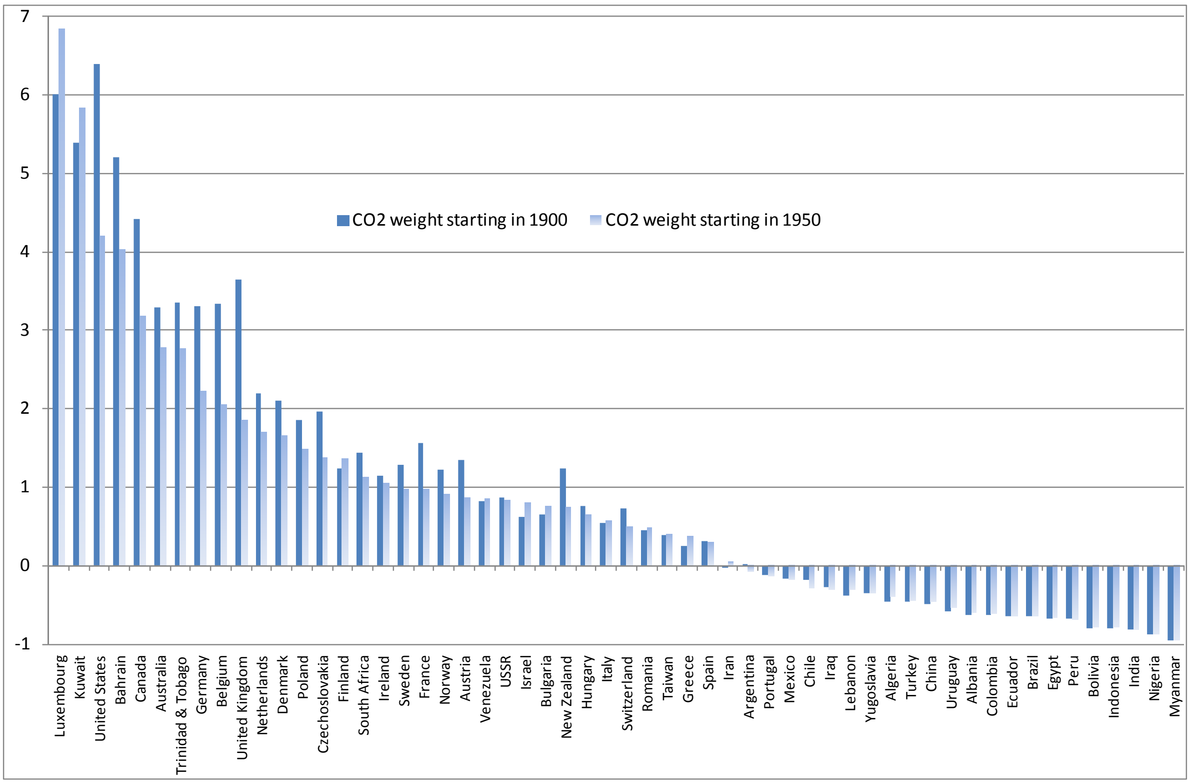

Figure 4 –ΔW$_i$ with 1900 and 1950 as starting year

We assumed the five major EU countries (FR; GE; IT, SP and UK) reduce the emissions by 50%, China and Russia add 50%, the USA stay at the same level and the Gulf countries (Kuwait, Qatar, Saudi Arabia, UAE) add 100% from 2015 and 2024. The result are presented (*Fig. 5*) as the variation from the status quo in 2009 real values and they show little variations in the index. Noticeably Qatar and UAE have a reduction in their indicator.

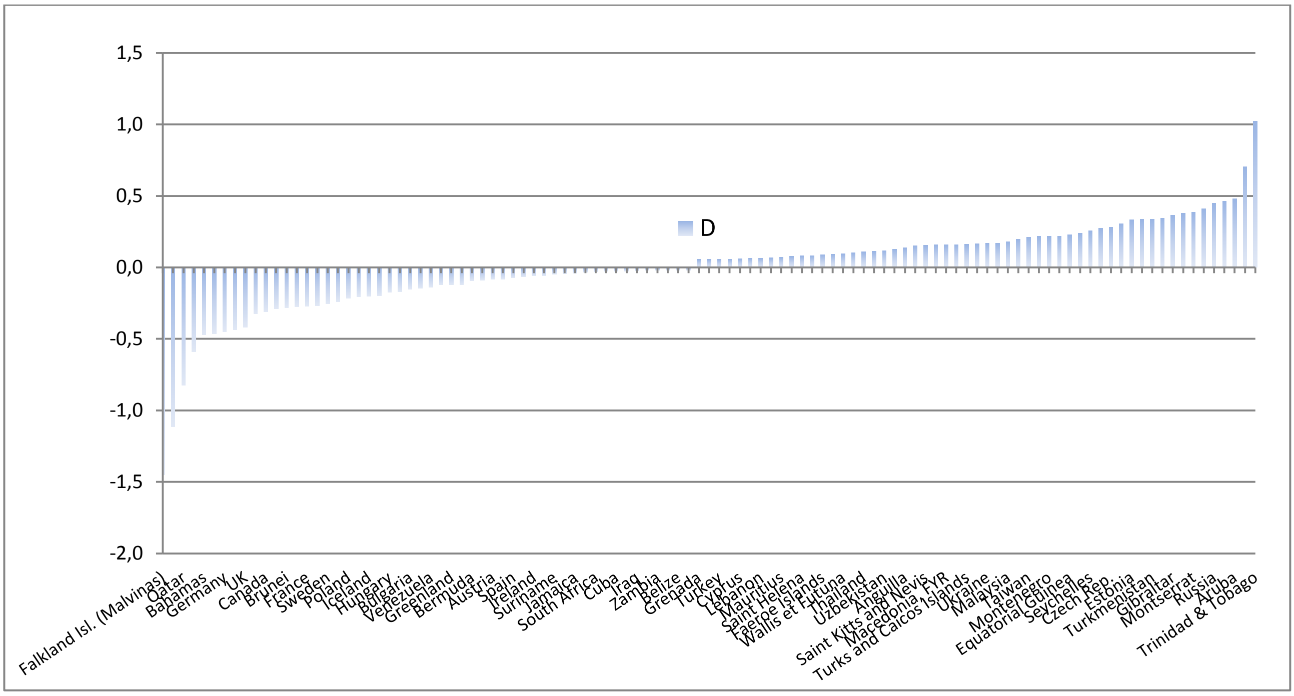

Figure 5 – Indicator variation following EU -50% Arab +100% China Russia +50% emission scenario

4 – Conclusions

We developed an approach to give the same CO2-equivalent emissions production rights to each individual in space and over time. Such egalitarian endowment is summed over all fossil fuel consumption history of each country. The resulting total ranks the different burdens. Countries may claim not to be responsible for fossil emission before their sovereignty, since international companies at the time of colonies might have established local factories, using local resources and emitting, but not benefitting the country. The starting date for the calculation of per capita emission could then be the year of independence. Inspired by caution, we choose to begin the calculations in 1950, when the majority of world countries have achieved a formal independence. It can be questioned if, from 1950 onward, the responsibility for the exploitation of fossil resources and the generation of emissions can reasonably be considered as belonging to the nation itself; further theoretical developments are needed.

The indicator is robust with respect to the starting year and it shows little variability between 1900 and 1950. As a practical application, in the case of the European Union Emission Trading Scheme, each country allowances could be weighted with our indicator. A final advantage of the developed weight being that could it can be applied both emissions allowances and to a downstream carbon-tax on fossil fuels. Finally, the indicator could also be used to determine the relative quantities allowed to each country.

It is known that there are two main types of carbon pricing: emissions trading systems (ETS) and carbon taxes. ETS – sometimes referred to as a cap-and-trade system – caps the total level of greenhouse gas emissions but then allows those industries with low emissions to sell their extra allowances to larger emitters. By creating supply and demand for emissions allowances, an ETS establishes a market price for greenhouse gas emissions. The cap helps ensure that the required emission reductions will take place to keep the emitters (in aggregate) within their pre-allocated carbon budget. A carbon tax directly sets a price on carbon by defining a tax rate on greenhouse gas emissions or – more commonly – on the carbon content of fossil fuels. It is different from an ETS in that the emission reduction outcome of a carbon tax is not pre-defined but the carbon price is. Our weight-indicator can be applied in both schemes.

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