$I = PAT$ equation: the weight of the P factor in addressing climate change

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$I = PAT$ equation: the weight of the P factor in addressing climate change

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Abstract

A dominant narrative is that addressing population is not relevant to mitigating climate change because population is only growing in the poorest countries, whose contribution to global emissions is negligible. An analysis of carbon emissions and population for the World Bank's four income-based country groups, however, shows that: (i) the low-income group represents the smallest fraction of the global population (8%), while the largest fraction (43%) belongs to the lower-middle group, whose contribution to global emissions is not negligible; (ii) population is growing not only in the low-income group, but in all four groups; (iii) fertility remains above replacement rate in almost all countries in the low-income and lower-middle groups, in about half of the countries of the upper-middle group, and in 3 countries of the high-income group; (iv) population growth has been the main driver of increased carbon emissions over the last three decades, both in the high-income group and at the global level.

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1 Introduction

The Rio de Janeiro Earth summit took place exactly 30 years ago, in June 1992. It was the first international conference on environmental sustainability and climate change, and laid the foundations for all subsequent work done under the UNFCCC umbrella, such as the Kyoto Protocol and the Paris Agreement. Thereafter, IPCC reports, scientists, environmentalists and other activists have constantly reminded us that we urgently need to reduce our greenhouse gas emissions and more generally our global environmental impact.

According to Ehrlich and Holdren's well known $I = P \times A \times T$ equation, the environmental impact of human activity I is the product of 3 factors: population P, affluence A or average individual demand, and the technology T used to produce goods and services to satisfy the demand (Holdren and Ehrlich 1972; York et al. 2003). This equation would suggest that population is a multiplier, which could nullify or drastically diminish any ecological gain that can be obtained through a reduction in consumption and/or technological improvements (Dodson et al. 2020; Tamburino and Bravo 2021). Moreover, the multiplicative nature of the relationship suggests that no factor matters less or more than another for generating environmental impacts. Nevertheless, if we focus on the variation of a product, then it is possible to establish if one of the factors affected the result more than the others. For instance, if the area of a rectangle increased, while the base stayed constant or even decreased, then it is clear that increased height determined the variation of the total area (see Methods Sec. 2).

When considering carbon emissions, it is a common idea that affluence and not population is the main driver of the global increase that has occurred in the last decades, passing from 20.7 million of kt in 1992 to 34.04 million of kt in 2018. This idea is widely spread and shared, and it is well expressed also in the call of this very conference: *"Population size [...] matters less for human impacts on the climate and other earth systems as compared to affluence and consumption"*. An argument supporting this view is that population is mainly increasing in poor countries, whose contribution to global emissions is negligible.

Albeit dominant, this idea lacks the support of solid data and is in conflict with several lines of evidence. For example, population growth is not limited to poor countries: if we divide world countries into four income-based groups according to the common and accepted economic classification from the World Bank —low, lower middle, upper middle and high-income countries— we see that population is growing in all the four groups albeit at different rates. The existence of some countries where population is stable or declining does not change the overall trend.

Depending on the group, the main causes of the growth vary. But regardless of the causes, population growth contributes to total emissions and preliminary analyses indicate that its contribution is not negligible (Bongaarts and O'Neill 2018; Rosa et al. 2004). For instance, the high-income group has reduced its per-capita emissions in the last three decades but failed to reduce total emissions, which clearly indicates that the cause of such a failure can only be population growth. At the global level, per-capita emissions did not grow in the last decade and currently are at the same level or even lower than the per-capita emissions in the 1970s (source: World Bank). In spite of this, today's total emissions are more than 150% of total emissions in the 1970s.

This suggests that a careful analysis of data is needed to better investigate this issue and shed light on the weight of the P factor in the $I = PAT$ equation. Here, we analyze data from 1992 to 2018 to quantitatively assess the contribution to carbon emissions of the P factor, both at the global level and in the different country groups. Methods, results and discussions are presented in the following sections.

2 Methods

I divided the world's countries into four income-based groups according to the World Bank's common division, currently favored within economics: high income (H), upper middle (MH), lower middle (ML) and low income countries (L). For the division, I used the per-capita GNI thresholds indicated by the World Bank for 2018. Therefore, the resulting groups are consistent with the classification valid in 2018, which may slightly differ from today's division or from the classification in other years. The map in Figure 1 shows the four income-based groups.

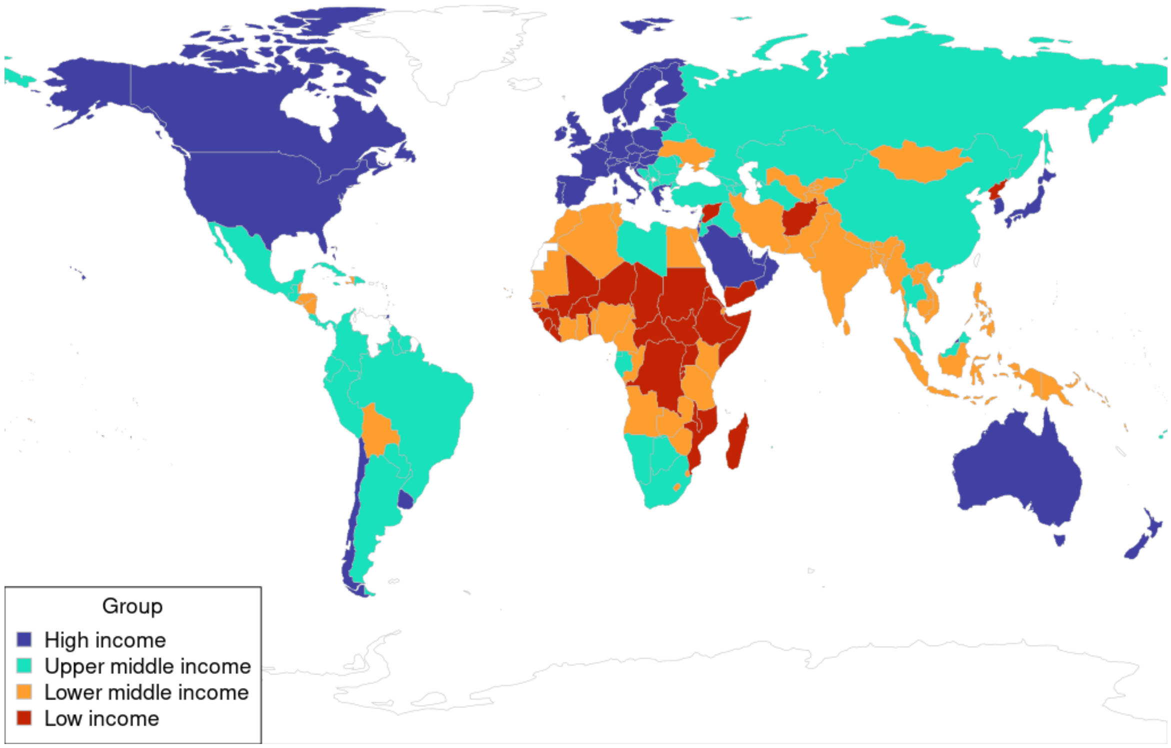

Figure 1: World countries according to the World Bank's division into four income-based groups: low income ($< 1,006$ current US\$ average GNI/capita), lower middle income ($[1,006 - 3,955]$), higher middle income ($[3,956 - 12,235]$) and high income ($> 12,235$).

To estimate contributions to climate change, I chose total and per-capita carbon emissions as indicators, although there are other factors than emissions that exacerbate climate change, such as deforestation.

Further, I added population and fertility rates to my data-set. The data source used is the World Bank. As the most recent available data on carbon emissions are updated to 2018, my analyses cover the time span between 1992 —the year of the Rio de Janeiro Earth Summit— and 2018.

Finally, in order to estimate the contribution of population —as well as per-capita emissions— to the emission variation, I used a simple geometrical formula. The total emissions E^{tot} is given by the product of two factors, namely population P and per-capita emissions E^{pc}, which represents the composite factor $A \times T$ (affluence $\times$ technology) in the $I = PAT$ equation. Thus, the variation in total emissions ΔE^{tot} can be split into three terms:

$$\Delta E^{tot} = \Delta P \cdot E_0^{pc} + \Delta E^{pc} \cdot P_0 + \Delta E^{pc} \cdot \Delta P \tag{1}$$

where E_0^{pc} and P_0 indicate respectively the per-capita emissions and the population at the initial year of the period, namely 1992. The first term of the sum in Equation 1 clearly represents the population contribution, the second term the per-capita emission contribution, and the third term the contribution of the interaction of both (see Fig. 2).

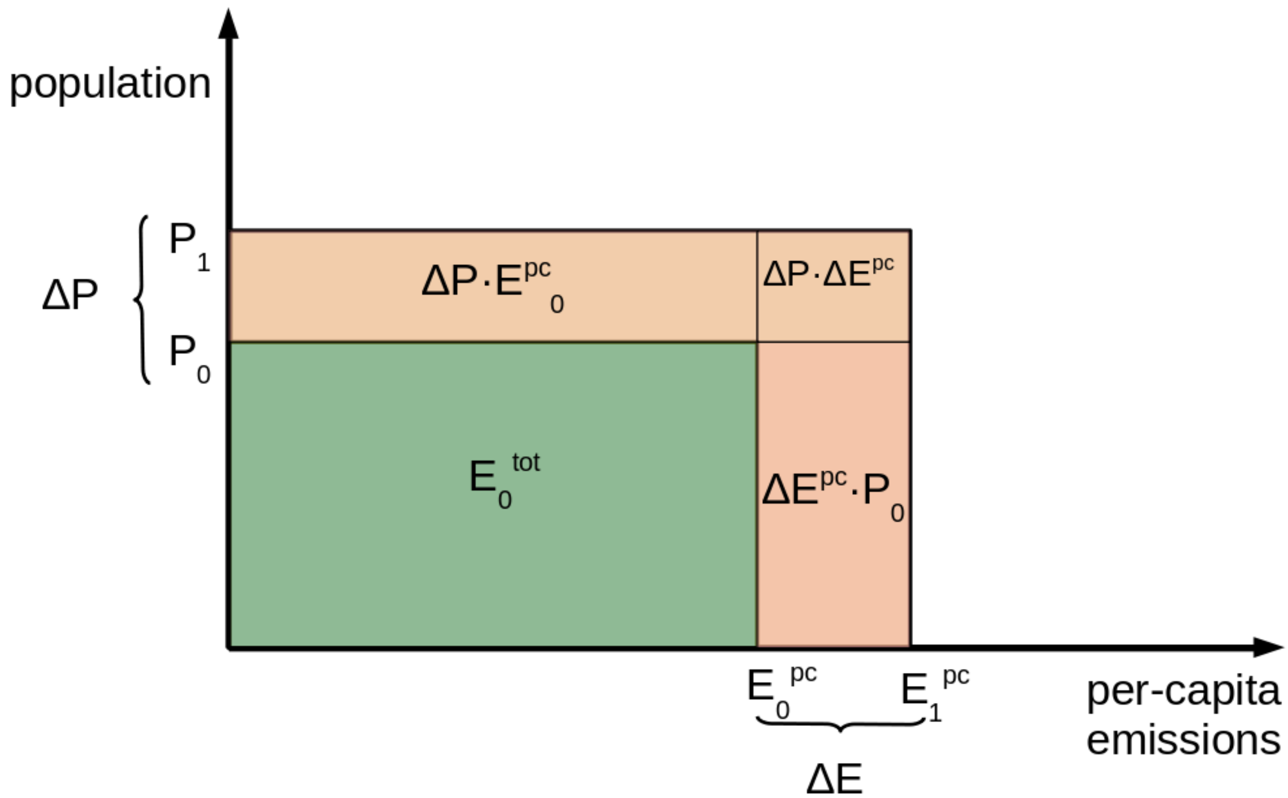

Figure 2: Total emissions at the initial time (${E_0}^{tot}$) are represented by the green rectangle; total emissions at the final time (${E_1}^{tot}$) are represented by the big rectangle given by the green and the pink parts together. The pink parts represent the variation ΔE^{tot}.

3 Results

3.1 Population variation in country groups

Population grew in the observed period and is still growing in all four income-based groups. The increases ranged from 21% in the H group to 175% in the L group.

Causes of growth are different; in the H group, demographic momentum and immigration prevail as fertility rates are usually below the replacement rate (2.1 children per woman). However, there are three remarkable exceptions: Israel, Oman and Saudi Arabia. In the ML and L groups, fertility rates are usually above the replacement rate, indicating that the prevalent causes for demographic growth are demographic momentum and high fertility. Even in this case, there are exceptions: Bangladesh, Bhutan, Nepal, El Salvador, Ukraine and Vietnam in the ML group and North Korea in the L group all have fertility rates below replacement. In the MH group, the situation is mixed: 27 of 49 countries have lower than replacement fertility, 22 (45%) have higher than replacement fertility. Notably, all African countries in the MH group have high fertility, including four countries with fertility rates > 3 and one with a fertility rate > 4 children per woman.

3.2 Emissions in country groups

Currently, per-capita carbon emissions are highest in the H group followed by MH, ML and L, while total emissions are highest in the MH group, which is responsible for 46.4% of total global emissions, followed by the H group with 36.1% and the ML group with 16.7%. The contribution from the L group is a negligible 0.4% (see Tab. 1). Note that there are several missing data and all those missing occur in the L and ML groups, so actually these figures may underestimate the contributions of low income and lower middle countries.

Looking at the variations, the middle groups —MH and ML— are the ones that increased most their emissions, both total and per-capita, while the L group decreased both during the study period. The H group decreased its per-capita emissions (from 11.5 to 10.4 t/capita), but failed to reduce its total emissions (see Fig. 3). Notably, the majority of countries in the H

Table 1: Carbon emissions in 2018

Group	Per-capita emissions	Total emissions	% of global emissions	% of global population
High income	10.4 t/capita	12.13 Gt	36.1%	15.9%
Upper middle	6.2 t/capita	15.56 Gt	46.4%	32.9%
Lower middle	1.7 t/capita	5.60 Gt	16.7%	42.6%
Low income	0.2 t/capita	0.15 Gt	0.4%	8.23%

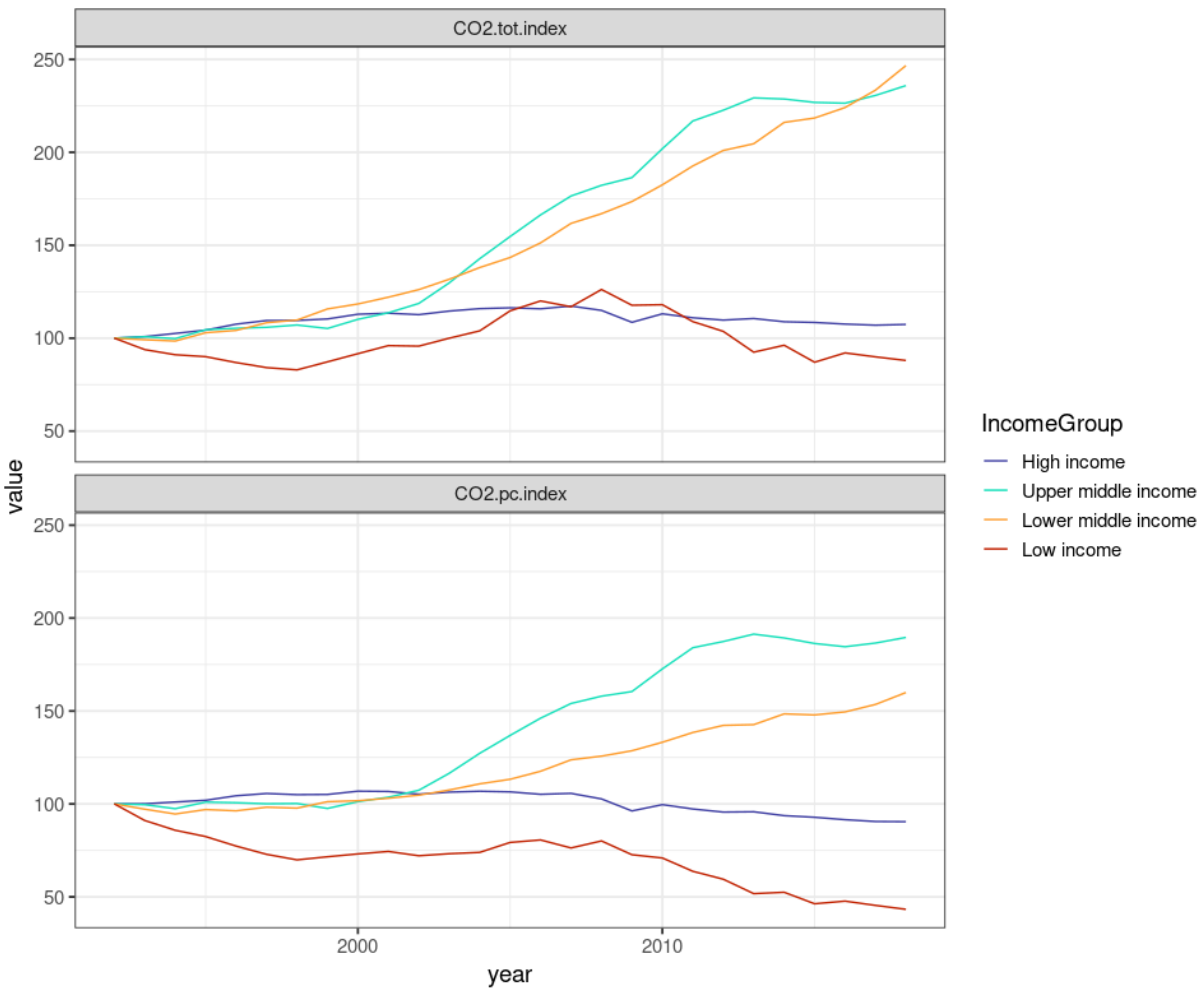

Figure 3: Total and per-capita carbon emissions from 1992 to 2018. All the values have been set = 100 in the initial year, so percentage variations are shown.

group (38 over 56) decreased their per-capita emissions, while 17 increased them, among which are Canada, Australia and all the rich countries of the Arabian Gulf.

3.3 Population contribution

Using Equation 1, I estimate the contribution to carbon emission variation from 1992-2018 of per-capita emissions E, population P and the interaction of both. The resulting contributions for all the country groups and for the world as a whole are shown in Table 2.

Table 2: Contribution of population ($\Delta P \cdot E_0^{pc}$), per capita emissions ($\Delta E^{pc} \cdot P_0$), and interaction of both ($\Delta E^{pc} \cdot \Delta P$) to the total emission variation (ΔE^{tot}) from 1992 to 2018. Absolute increase in CO_2 millions of tons (Mt) and percentage of the total increases.

Contribution →	Population growth		Per-capita emissions		Interaction		Total variation	
Group ↓	CO_2 Mt	Percent	CO_2 Mt	Percent	CO_2 Mt	Percent	CO_2 Mt	Percent
High income	2,122	261.4%	-1,103	-135.8%	-207	-25.4%	812	100%
Upper middle	1,612	18.0%	5,910	65.9%	1,444	16.1%	8,966	100%
Lower middle	1,230	37.0%	1,360	40.9%	738	22.2%	3,328	100%
Low income	170	-898.40%	-93	491.03%	-96	507.4%	-19	100%
World	8,080	61.6%	3,614	27.5%	1,427	10.9%	13,121	100%

Per-capita emission increase is the main driver for total emissions increase only in the MH group, accounting for 65.9% of the total increase, while population prevails both in the H group and at the global level, accounting respectively for 261.4% of the total increase in H and for 61.6% of the total global increase. In the ML group, the situation looks more mixed, with very similar contributions from both population and per-capita emissions. The L group is the only one that had a slight decrease in total emissions. This explains why the contribution of population growth is positive when expressed in CO_2 millions of tons but is a negative percentage of the total.

4 Discussion

A common narrative is that a small fraction of the world —the rich countries alone— emits more than all the rest of the world put together, and that population grows only in the poor countries, whose contribution to global emissions is negligible (Gore 2015). Thus, in order to mitigate climate change we have to focus on cutting per-capita emissions, while population growth does not play an important role. As shown in this analysis, such a narrative does not fit the data. It is true that the contribution of the world's poorest countries is negligible, but these countries represent the smallest fraction of the global population (8%), while the fraction of population living in rich countries is almost double (16%). The largest majority belongs to the middle groups (33% to the upper middle and 43% to the lower middle) whose contributions to global emissions are not negligible. Indeed, the contribution of the upper middle is the highest of all the groups (46%), while the contribution of the lower middle is smaller (17%) but significant and rapidly increasing. Looking at the variations over time, the middle groups are the only ones that dramatically increased both per-capita and total emissions, while rich countries decreased their per-capita emissions (still the highest of all the groups) but failed to reduce their total emissions, which increased, although less than in middle groups.

The most misleading part of the narrative presented above concerns population. Demographic growth is not limited to poor countries: population keeps growing both at the global level and in all the country groups, albeit at different rates and for different causes. Fertility is high not only in the low-income group but also in the large majority of countries in the lower middle group, in about half of the countries in the upper-middle group and in three countries of the high-income group. Population growth in the high-income countries is not only responsible for the increase in their total emissions but also responsible for the *missed decrease* that could have happened in these last three decades thanks to the reduction in per-capita emissions. This explains why the total contribution of population growth in this group exceeds 100% (261% of the total emission increase). In all the other groups, population growth is a significant driver of total emission increases and, at the global level, it is the main driver, accounting for 62% of the global increase.

Finally, two considerations about low-income countries. Their direct emissions are negligible, but as already mentioned, there are other factors besides carbon emissions contributing to climate change, such as deforestation. Deforestation rates in those countries are dramatically high and represent a danger not only for climate but also for biodiversity, especially when deforestation involves rain-forests, as is happening for instance in Congo. The main driver of deforestation in poor countries in poor countries is the expansion of subsistence agriculture (FAO 2017), which is directly linked to population growth. Therefore, population factor is relevant also in poor countries, albeit for different reasons. Moreover, the idea that population growth in poor countries is not worrisome because their carbon emissions are negligible implies the underlying assumption that they will stay poor also in the future. This assumption is questionable even from an ethical point of view, because getting out of poverty should be a goal for those countries, supported by everyone. But if they succeed in getting out of poverty, their emissions will increase. Then population growth would contribute to make them even higher and thus should not be neglected (Hickey et al. 2016). Actually, addressing population growth now with voluntary-based family-planning programs would help poor countries to improve their economic and social conditions, resulting in a double benefit, for both environment and humans (Sohn 2020; Sedgh et al. 2016; Bongaarts and Hardee 2019).

Thirty years ago, the Earth summit in Rio de Janeiro warned humanity that we were in emergency and urgently needed to cut our carbon emissions. Thirty years later we are still in emergency and the situation has gotten worse, despite efforts to reduce the per-capita impact, namely the composite factor $A \times T$ (affluence $\times$ technology) in the $I = PAT$ equation. Can we really keep neglecting the P factor?

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