Reconciling a positive ecological balance with human development: the role of population in low-fertility countries

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Abstract

To be sustainable, humanity needs to reduce its overall environmental impact. Even if technology can help to reduce it while keeping human well-being, a positive correlation is observed between human development and several relevant indicators of environmental impact, such as carbon or ecological footprint. Reconciling human development and environmental sustainability is hence a challenge, and the current global population growth makes it even harder. Nevertheless, in some countries there is currently an opposite trend, with low fertility rates and, sometimes, a local depopulation. In this work, I present a sustainability criterion based on two constraints — an environmental and a human constraint — which are able to reconcile a positive ecological balance and human development if simultaneously satisfied. Analysing demographic data, ecological indicators and Human Development Index, I apply this criterion to low-fertility countries assessing which changes are required to fulfil both constraints. Results clearly show that many low-fertility countries have a very high population compared with their biocapacity, which makes hard to achieve ecological sustainability only through technological improvements and/or consumption reduction. Even if these countries have a population that does not grow any longer — and sometimes is slightly declining — they need a further population reduction in order to become environmentally sustainable without violating the human constraint. This highlights an often neglected side of the debate on the relation between environmental impact and population, showing how the issue is not limited to developing countries with a rapidly growing population but involves several low-fertility countries as well.

1 Introduction

To be sustainable, humanity needs to reduce its environmental impact below planetary boundaries (O'Neill et al. 2018; Steffen et al. 2015). Humanity's total impact is given by the product of population by per capita impact, which in turn depends on the level of consumption and the adopted technology (Ehrlich and Holdren 1971; York et al. 2003). Although per capita impact can be decreased through reduced consumption and smarter technology, it cannot be reduced to zero because a certain amount of natural resources and ecological services is required to satisfy people's basic needs (Goodland 1995; Knight and Rosa 2011). When multiplied by a large population, even a small impact can become significant causing overshoot of planetary boundaries.

An important question hence is whether changes in consumption patterns and technological improvements enable a sufficient reduction of humanity's footprint without reducing human well-being and development at unacceptable levels, or whether the population lever needs to be used as well. In a recent work, a colleague and I addressed this question by using a new sustainability criterion based on two constraints, which are able to reconcile a positive ecological balance with human development if simultaneously satisfied (Tamburino and Bravo 2021). In that work, we applied the criterion to all world's countries and to the world as a whole. Here, I apply the same criterion focusing on low-fertility countries, namely countries with a fertility rate below the replacement rate (2.1 children per woman). All these countries may face depopulation in the near future and some of them are already experiencing population decrease, even if in most cases they still have a growing population due to demographic momentum or/and immigration.

Through a quantitative analysis, I address here the following research questions: *i)* how is the ecological balance for low-fertility countries? *ii)* what is their level of human development? *iii)* do they satisfy both constraints of the sustainability criterion? *iv)* if not, what can they do in order to satisfy them and hence reconcile ecological sustainability and human development? *v)* what is the role of population? By analysing demographic data, ecological indicators and Human Development Index, I apply the new sustainability criterion to these countries and I assess which changes are required in order to fulfil both constraints of the criterion.

The constraints are formulated in order to capture both the environmental and human dimensions of sustainability. The environmental constraint is defined through a novel ecological indicator, the *eco-balance*, grounded on the well known concepts of ecological footprint and biocapacity (Wackernagel and Rees 1996; Wackernagel et al. 1999). Developed in the 1990s by Mathis Wackernagel and colleagues, the ecological footprint estimates people's consumption of ecological capital and is expressed in "global hectares" (gha) — units of surface with world average bio-productivity (Global Footprint Network 2020). The biocapacity is expressed in the same units and refers to the amount of ecological services provided by the natural and man-managed lands of a given area. An advantage of the EF is that is based on consumptions, hence internalising any eventual displacement of environmental impact outside national borders (Andersson and Lindroth 2001; Grazi et al. 2007; Peters et al. 2011; Hoekstra and Wiedmann 2014). A disadvantage is that it focuses on carbon balance, hence neglecting other crucial aspects of environmental sustainability, such as water consumption, soil health, and biodiversity losses (Blomqvist et al. 2013; Giampietro and Saltelli 2014). Nevertheless, a recent review recognises significant merits to the EF method for both scientific research and policy making, especially when used in conjunction with other indicators and sustainability criteria (Zhang et al. 2017).

The human constraint represents a condition to achieve an acceptable level of human development. In order to reduce arbitrariness, we defined it based on the United Nations' *Human Development Index* (HDI), a commonly accepted composite indicator of human development, which aggregates data on life expectancy, access to education, and income (UNDP 2020). Our approach is however more general and can easily adapt to alternative definitions of human development. More complex analyses could make it more comprehensive by including other dimensions of human sustainability, such as life satisfaction, social support or the quality of democracy (O'Neill et al. 2018; Knight and Rosa 2011).

The rest of the paper is organized as follows: the new sustainability criterion is presented in details in the Method section along with all indicators and variables used to define it. The criterion is then applied to all low-fertility countries and the results are presented and discussed in the two subsequent sections. Finally, caveats and limitations of this research are discussed in the last section.

2 Method

2.1 Dataset

A new dataset has been built including all countries with fertility rates below the replacement rate (2.1 child./w.). The dataset includes data aggregated from different sources: *(i)* Global Footprint Network for the ecological footprint and biocapacity (Global Footprint Network 2021), *(ii)* World Bank for population and fertility rates and *(iii)* United Nations for the Human Development Index. All data refers to 2017.

Starting from these data, two further indicators have been computed and added to the dataset: *population biodensity* PB and *eco-balance* EB. All indicators are described in the next subsections (Sec. 2.2) and summarized in Table 1. The indicators are used to define two constraints, which are then combined in a new sustainability criterion (Sec. 2.3). The criterion is then applied to the dataset. For a detailed description of the method, see Tamburino and Bravo (2021).

2.2 Constraints

The environmental constraint (E) is defined through a novel indicator, the *eco-balance* EB, which can be applied to any country or geographical area and is based on the population biodensity PB (namely the ratio between population and biocapacity) and the per capita ecological footprint EF_{pc}.

In formula, the eco-balance EB is defined through the following equation:

$$EB = 1 - PB \times EF_{pc} \tag{1}$$

It is easy to prove that a positive eco-balance is equivalent to the common sustainability condition used by the Global Footprint Network, namely $BC \geq EF$. However, the eco-balance is more similar to the concept of Earth-fullness already proposed in Toth and Szigeti (2016), which is able to reflect the ecological burden of a country better than the per capita eco-deficit because it depends on the ratio between ecological footprint and biocapacity. Moreover, being computed per unit of biocapacity, the eco-balance allows comparability between countries of different sizes.

The human constraint *(H)* represents a condition to achieve an acceptable level of human development. In order to reduce arbitrariness, we defined it based on the United Nations' *Human Development Index* (HDI), a commonly accepted composite indicator of human development, which aggregates data on life expectancy, education, and income (UNDP 2020). We hence estimated the threshold τ, namely the amount of per capita EF needed to achieve $HDI \geq 0.7$, where 0.7 is the minimum level for high human development according to the UNDP definition. The problem is that per capita EF is neither an indicator of well-being nor human development. Depending on the adopted technology, different entities (countries, regions, single individuals) may achieve similar well-being levels with different ecological footprints, and vice-versa. Nevertheless, EF_{pc} strongly correlates with several income and development indicators. Most notably, it correlates with the HDI: the linear correlation coefficient is $r = 0.74$ and the Spearman's coefficient (which only assumes a monotonic relation) is even higher ($\varrho = 0.87$). We estimated the threshold τ based on this strong correlation, finding $\tau = 2.14$ gha per capita (Tamburino and Bravo 2021).

Note that we chose to estimate τ it on the basis of a single, although widely adopted indicator, namely the UN's Human Development Index, but our approach is general and could easily adapt to alternative definitions.

Table 1: Used indicators with definitions and units

Variable	Definition	Unit
BC	Biocapacity	gha (global hectares)
EF_{pc}	Per capita ecological footprint	gha/people
P	Population	people
PB	Population biodensity $PB = P/BC$	people/gha
EB	Eco-balance $EB = 1 - EF_{pc} \times PE$	pure number
HDI	Human Development Index	pure number
τ	Threshold of minimum EF_{pc} required to achieve HDI≥ 0.7, $\tau = 2.14$	gha/people

2.3 Criterion

Combining the eco-balance EB with the threshold τ, we obtained a new sustainable criterion summarized by the following two disequations:

$$\begin{cases} (E) \quad EB = 1 - PB \times EF_{pc} \geq 0 \\ (H) \quad EF_{pc} \geq \tau \end{cases} \tag{2}$$

Note that the eco-balance EB depends on PB and EF_{pc}. Adjusting these two variables, each country can hence change its eco-balance. For example, a way to improve the eco-balance is to reduce the per capita ecological footprint, which can be done through the adoption of a smarter and greener technology or/and through a reduction in consumption. Nevertheless, the variation range for EF_{pc} is limited by the *(H)* constraint in the criterion (2). As a consequence, the possible ecological gains that can be achieved by only changing this variable are also limited. The question is whether these gains are sufficient to make the eco-balance positive or a change in the other variable — namely the population biodensity PB — is also needed.

To address this question for low-fertility countries, I apply the criterion (2) to the dataset described above (Sec. 2.1). Results are shown in the following section.

3 Results

3.1 Eco-balance and *HDI*

Using the criterion (2), world's countries can be split into four groups depending on which constraint they satisfy: E+H+ is the group of countries that fulfil both constraints, E-H- the group of countries that do not fulfil either constraint, E+H- and E-H+ the groups of countries that satisfy only one of the two constrains. When applying the criterion to the countries with fertility rates smaller than the replacement rate 2.1, results show that most of these countries belong to the groups E+H+ or E-H+ (see Fig. 1).

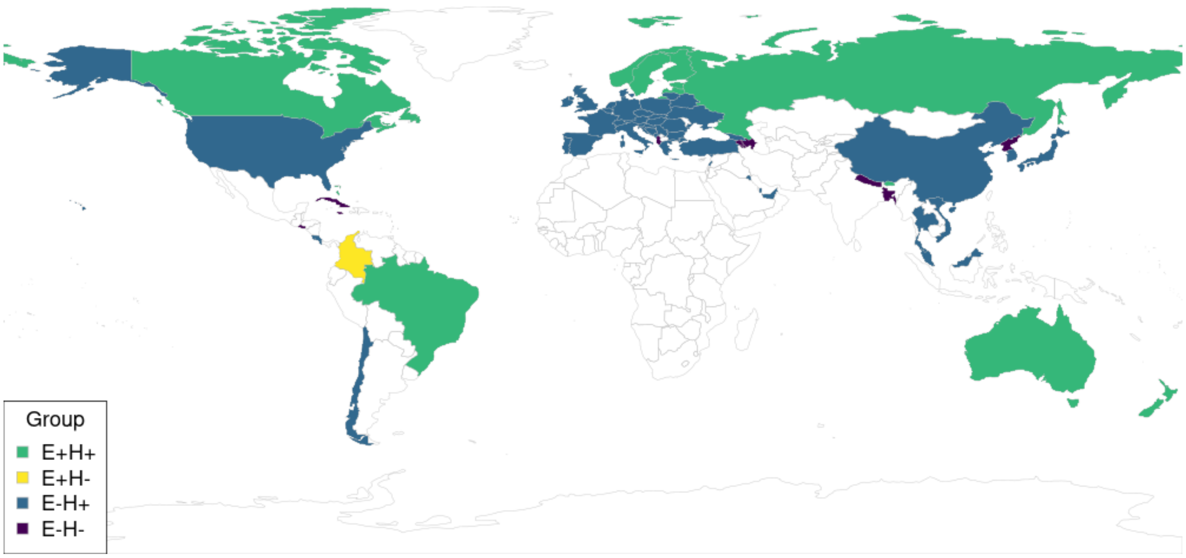

Figure 1: World map with countries with fertility rate below 2.1 (replacement rate). The E+H+ group includes countries that satisfy both the ecological (E) and human (H) constraints, E-H- countries that do not satisfy any constraints;, E-H+ countries that only satisfy the human constraint (H).

More specifically, 64 countries in the world have fertility rate lower than the replacement rate 2.1. Of these, 42 belong to the E-H+ group; 12 belong to the E+H+ group; 9 belong to the E-H- group; and only 1 country (i.e., Colombia) belongs to the E+H- group.

This means that the large majority of low-fertility countries (54 over 64) have a per capita ecological footprint greater than the τ threshold. With two exceptions (Bhutan and Vietnam), they all have a high value of human development index (namely $HDI \geq 0.7$). All these 54 countries can in principle improve their eco-balance by reducing their per capita ecological footprint without loosing the possibility of achieving a high HDI, as long as they remain above τ.

In relation to eco-balance, the large majority of low-fertility countries (51 over 64) has a negative EB; only 13 over 64 have a positive EB.

3.2 Potential eco-balance and the role of population

Countries in the E+H+ group already satisfy both constraints in the criterion (2) and do not need to do anything, although they can improve both their eco-balance and their human development, for example by using their biocapacity more efficiently. Countries in the E-H+ group need to improve their eco-balance, which is currently negative. They can for example reduce consumption and/or invest in greener technology in order to reduce EF_{pc}. Is this sufficient to make the eco-balance positive? To address this question, the subset of the 42 countries in the E-H+ group (blue countries in Fig. 1) has been selected. Fore those countries, I computed the *potential eco-balance*, defined as the eco-balance they would achieve by reducing their per capita ecological footprint to τ. Results are showed in Figure 2: 18

of these 42 countries have a positive potential eco-balance, 24 have a negative potential eco-balance.

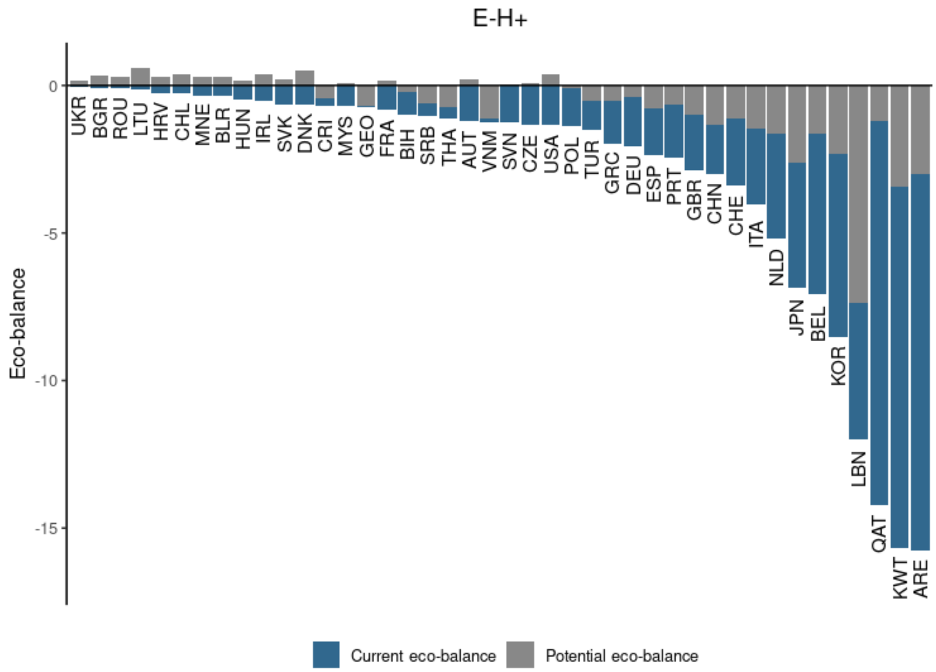

Figure 2: Current eco-balance (in blue) and potential eco-balance (in grey) of the countries with fertility rate < 2.1 belonging to the E-H+ group (in blue in the map of the Fig. 1). The potential eco-balance is defined as the eco-balance the country would have by reducing its per capita ecological footprint to the threshold τ.

Overall, 33 of the 64 countries with low fertility rates cannot become environmentally sustainable by only reducing their per capita ecological footprint, unless they violate the *(H)* constraint. Nine of these countries are the countries in the E-H- group, which must increase their eco-balance because it is currently negative, but cannot reduce their per capita ecological footprint because it is already below the τ threshold. The other 24 ones are countries in the E-H+ group with a negative potential eco-balance. A reduction in their per capita impact is possible, because they are above the τ, and is useful to improve their eco-balance but not sufficient to make it positive: they would still remain environmentally unsustainable even if they reduced their per capita impact to τ. All these 33 countries hence need to reduce also their population biodensity in order to become environmentally sustainable without violating the *(H)* constraint(see Fig. 3).

4 Discussion

The issues of "planetary boundaries" and how to reorganize our societies and economies to reach sustainability goals have increased their prominence in the public and scientific debate in recent years. With environmental challenges becoming increasingly urgent, concerns about population growth resurfaced after a silence that lasted for decades. After being widely

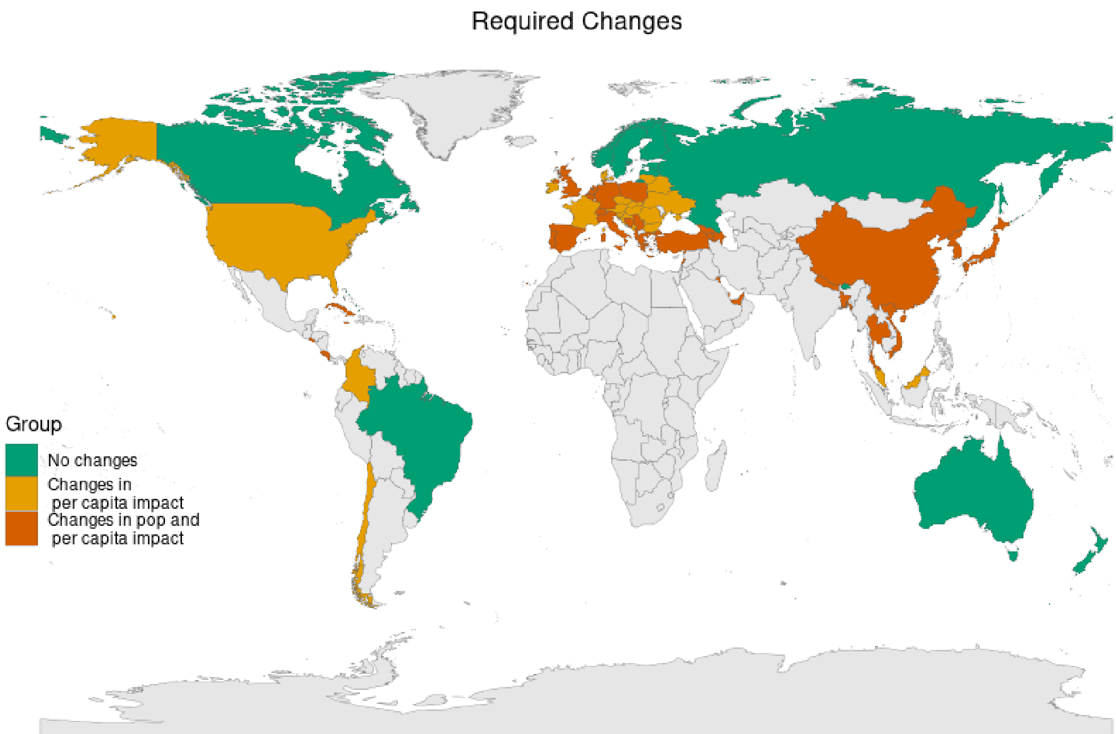

Figure 3: Low-fertility countries divided into 3 groups. **Green**: countries that already satisfy the sustainability criterion and do not need any change. **Orange**: countries that currently do not satisfy the sustainability criterion but have a positive potential eco-balance; they can become sustainable by adjusting their per capita impact. **Red**: countries with a negative potential eco-balance; they would stay unsustainable even if they reduced their EF_{pc} to the threshold τ and hence need a population reduction as well.

debated in 1970s and 1980s, the population issue was subsequently "left in the cold" and became almost a taboo in both the political and scientific discourses (Campbell et al. 2007; Bongaarts and O'Neill 2018; Tamburino et al. 2020). Even if the topic still remains very sensitive and controversial, recent years have seen increasing consensus that overpopulation should be back in the agenda, given its strong link with environmental impact, food demand and poverty (Bongaarts and O'Neill 2018; Crist et al. 2017; Dodson et al. 2020). However, it is usually thought that population issue only concerns developing countries where fertility rates are still high.

This study shows instead that population biodensity needs to be reduced not only there but also in several low-fertility countries. Even if these countries have a population that no longer rapidly grows — and sometimes slightly declines — in many cases they have a population that is already too high compared with their biocapacity. In 33 cases, without a population reduction they cannot achieve a positive eco-balance, unless they go below the τ threshold, violating the human constraint of the sustainability criterion (2).

Given their low fertility rates, the population in these countries is spontaneously heading towards a reduction. This could be seen as positive for the environment but raises a dilemma, because a stabilizing or declining population implies a transition phase with an imbalanced demographic structure dominated by elderly groups. Such an ageing phase is usually perceived as negative for both the economy and society. However, countering the spontaneous decline with immigration and pro-natality policies does not solve the problem, but only postpones the inevitable moment of the ageing phase, and exacerbates even more the negative eco-balance.

This work seems to suggest a different solution: instead of countering depopulation, it should be supported and encouraged. Even if this argument sounds uncommon, it is supported by empirical examples showing that problems linked with ageing can be easily managed at affordable costs. For example, Japan still is a wealthy and innovative country (in the top 20 worldwide), despite its population has been decreasing for years. Data clearly indicate that the poorest and least innovative countries are countries with high fertility rates, not vice versa (Dutta et al. 2020). Moreover, there also are advantages and opportunities linked with an ageing and shrinking population, not only from an environmental point of view, but also for the quality of life (e.g., less traffic, lower house prices) (Götmark et al. 2018). Instead of trying to stop the depopulation trend, changing the approach to depopulation is an alternative strategy with great potential, which should be at least taken into consideration.

Research limitations

Several of the numeric results presented above depend on the specific estimation of the human sustainability threshold τ. With lower values of τ, a smaller population reduction would be required in many countries. However, our threshold is already low when compared with the world average, and it is much lower than the per capita EF of all the richest Arabian Gulf countries, as well as the per capita EF of the US, all countries in Europe, almost all countries in Latin America, and even some middle-income country in Africa, e.g., Botswana and Namibia. Moreover, it is based on a single albeit widely adopted indicator. More complex analyses could make it more comprehensive by using indicators that include other dimensions of human sustainability, such as life satisfaction, social support or the quality of democracy (O'Neill et al. 2018; Knight and Rosa 2011). Therefore, a realistic threshold is likely higher than our current estimate.

The assumption that countries should be self-sufficient in biocapacity can be also questioned. International trade could allow densely-populated/low biocapacity countries to "import sustainability" from others, eventually achieving on a larger scale a balance that is not achieved locally. However, this can work only if at the global level there is a surplus of biocapacity that can be redistributed. This unfortunately is not the case, currently there is a strong global deficit of biocapacity (Global Footprint Network 2021). Under these conditions, a sustainability trade risks exacerbating the current negative eco-balance, leading to a reduction in the resilience of importing countries and to an increase of environmental pressure in the exporting ones (Andersson and Lindroth 2001; D'Odorico et al. 2010).

Finally, being the eco-balance based on the ecological footprint, it mainly focuses on the carbon balance. Even if carbon is a necessary and fundamental aspect of sustainability, there are other important aspects, like water and biodiversity, which are not captured by the eco-balance indicator (Kitzes et al. 2009). As a consequence, there are countries with positive eco-balance even if they overexploit freshwater resources (e.g., Australia) or have high deforestation rates (e.g., Brazil). We estimated the population reduction required to achieve a positive eco-balance but for a more comprehensive sustainability, a larger reduction is probably needed.

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