Working
Paper Series
05/2025

Satisfying human needs at low material footprints: an investigation on the role of provisioning systems

Félix Garnier

Post-Growth
Economics Network

Satisfying human needs at low material footprints: an investigation on the role of provisioning systems

Félix Garnier*[1]

[1]Bordeaux School of Economics, University of Bordeaux

March 14, 2025

Abstract

To achieve social and environmental sustainability, humankind must balance satisfying human needs and preventing ecological collapse. The material footprint—the total materials required for production and consumption—plays a crucial role in this dynamic. This study uses data from 151 countries and a regression-based moderation approach to analyse how material footprints and human need satisfaction are influenced by socio-economic factors known as "provisioning factors."Countries with strong socio-ecological performance were characterized by factors such as democracy, rule of law, public health coverage, effective corruption control, access to electricity and clean fuels, trade and transport infrastructure, and urbanization. In contrast, weaker socio-ecological performance was often marked by extractivism and inequality. Improving provisioning systems could help countries reduce material use while enhancing need satisfaction. Yet, even under favorable conditions, the current economic system remains incompatible with socio-ecological sustainability, highlighting the need for more radical changes to meet human needs with minimal material consumption.

Keywords: material footprint; human needs ; provisioning systems ; sustainability

JEL Classifications: C51, C53, Q56, Q57

---

*felix.garnier@u-bordeaux.fr

1 Introduction

In 1950, the world consumed approximately 7 billion tons of materials annually. By 2020, this figure had skyrocketed to over 100 billion tons, driven by rapid industrialization and globalization (Wiedmann et al., 2013; IRP, 2019). Yet, despite this fourteen-fold increase in material consumption, 1 in 3 people globally still lack access to adequate sanitation, and 800 million people go to bed hungry every night (UNDP, 2020; FAO, 2021). This stark disconnect between material use and human well-being highlights the inefficiency of current economic systems and raises critical questions about how societies can better meet human needs without further straining planetary boundaries.

Consider Costa Rica, a small Central American nation that has achieved 95% access to clean water and 99% literacy rates with a material footprint of just 8 tons per capita—well below the global average (Bringezu, 2015). In contrast, the United States, with a material footprint of 28 tons per capita, struggles with 12% of its population living in poverty and millions lacking access to healthcare (Guzman and Kollar, 2023; OECD, 2021). This striking contrast underscores that material consumption alone is not the key to human well-being—provisioning systems matter just as much. By examining how countries like Costa Rica achieve high levels of need satisfaction with relatively low material footprints, this study seeks to uncover the socio-economic factors that can help bridge the gap between human needs and ecological sustainability.

Excessive material consumption is a well-documented obstacle to sustainability (Arshad Ansari et al., 2020; Dall'Orsoletta and Matthews, 2021; Giljum et al., 2015; Hickel, 2020; Razzaq et al., 2021; Wiedmann et al., 2013; Wiesen and Wirges, 2017). While some countries may require increased material consumption to achieve basic social outcomes, a global reduction in material use remains essential to reduce waste, pollution, and land use change, which are all threatened planetary boundaries (Richardson et al., 2023; Rockström et al., 2009), as well as to prevent resource exhaustion for future generations. Studying the role provisioning systems take in moderating the material consumption-need satisfaction relationship could help us to better understand how to satisfy human needs at lower material requirements. This could lead to reductions in material consumption from over-consuming, socially secure countries, freeing up ecological space that could be used by countries where basic human needs are not met, all while ensuring a more sustainable aggregate level of material consumption.

The question of how much material is needed to satisfy human needs remains largely unexplored, despite the fact that any sustainable transition will require finite materials. This study aims at shedding some light on this particular research area. While there is now a rather good understanding of how to achieve well-being in a sustainable manner (Bohnenberger, 2020;

Creutzig et al., 2021; Hickel, 2019; Kallis et al., 2012, 2020; Parrique, 2019), few empirical analyses exist. Previous studies have been made to estimate what would be a sufficient material footprint, but only for households and on a national scale (Buhl et al., 2017, 2019; Lettenmeier et al., 2014).

This analysis builds upon Vogel et al. (2021), who examined the relationship between energy use and need satisfaction and established the methodological framework used here. It also builds on previous attempts to define human needs, characterize them and how to fulfill them (Doyal and Gough, 1991; Max-Neef et al., 1991; Rao and Min, 2018).

Therefore, this paper makes two novel contributions:

- First, it applies the framework developed by O'Neill et al. (2018) and made operational by Vogel et al. (2021) (Fig. 1) to the relationship between material footprint and need satisfaction, using 20 indicators (national material footprints, six need satisfaction variables, and 13 provisioning factors) in 151 countries.
- Second, it looks at which socioeconomic conditions (i.e., which combinations of provisioning factors) have a beneficial or detrimental effect on this relationship and thus enable satisfying human needs at low material use.

More specifically, it asks the following research questions:

1. What is the relationship between material footprints and human need satisfaction across different socio-economic contexts?
2. How do different provisioning systems influence the material footprint required to achieve basic human well-being?

Section 2 will introduce the theoretical framework and describe the data used in this study, while Section 3 will present the methods. Section 4 will be dedicated to delivering the results, which will be discussed in Section 5. Finally, Section 6 will summarize and conclude the study.

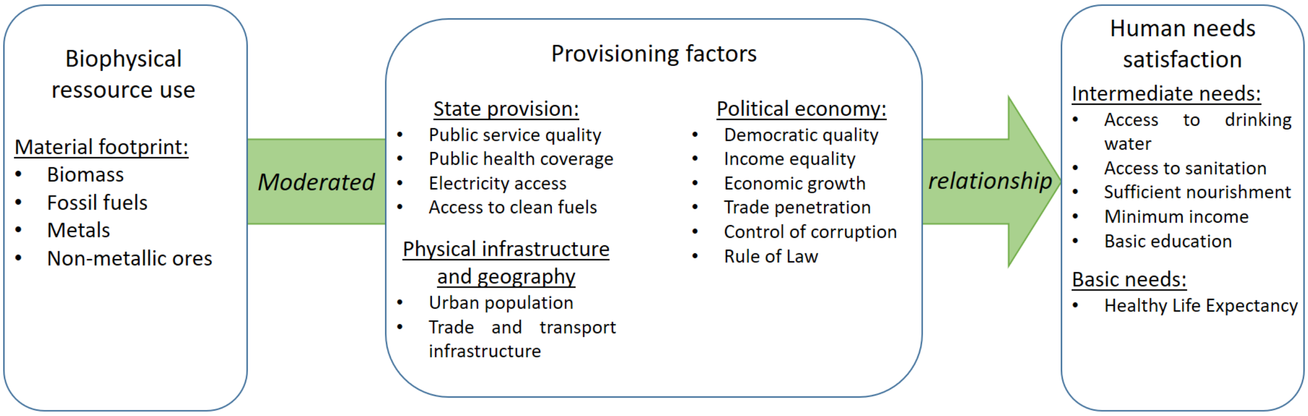
2 Theoretical framework and data

2.1 Theoretical framework

This study builds on the literature on socio-ecological provisioning systems, in which the provisioning of human need satisfaction is conceptualized in an Ends-Means spectrum (Daly, 1973; Fanning et al., 2020; O'Neill et al., 2018). Specifically, it follows on the operationalization of the concept developed by Vogel et al. (2021). In this framework, material consumption (here expressed via the national average per capita material footprint and abbreviated MF) is considered as a mean, and need satisfaction as the end, with provisioning factors operating as moderators of the means-end relationship.

Provisioning factors are any characteristics of socio-economic systems influencing the provisioning of goods and services, at any stage of the economic process (extraction, production, allocation, consumption and disposal). They can be economical, geographical, institutional, social, historic, political, cultural… and reflect the diversity and specificity of provisioning systems, here studied at the national scale. Hereby, provisioning factors are any element framing the socio-economic processes that can influence the relationship between material use and need satisfaction. For example, the results may vary between urban and rural societies, depending on the economy's growth rate and the quality of existing infrastructures. The idea of provisioning systems is very wide, potentially abstract and conceptual. Meanwhile, breaking them into individual provisioning factors makes them measurable and allow for international and intertemporal comparison.

Figure 1. Theoretical framework, adapted from Vogel et al. (2021)



The relationship between material consumption and well-being is still unclear, mainly due to a lack of literature on the subject. However, material footprints are closely correlated with economic growth (Wang et al., 2022) and countries with higher footprints also tend to have high GDP per capita levels, which themselves tend to have higher levels of need satisfaction. Therefore, one can assume that the relationship between material consumption and need satisfaction is a positive one. However, and as I described in the introduction by comparing Costa Rica and the United States, material consumption alone is not enough to explain need satisfaction. Provisioning systems play a crucial role, and it is very important to better understand it if we want to comply with sustainable development.

Moreover, an estimation for what would be sustainable material footprints has already been made by Bringezu (2015). In this study I will be using their limit of 2.2t/year/capita for biotic resources and 11.6t/year/capita for abiotic resources, making it 13.8t/year/capita when combined. These thresholds correspond to an intermediate scenario, with a global population peaking at 10 billion people and a return to 2000-levels of aggregate material consumption.

2.2 Data sources

Alongside footprints, this study uses two sets of variables: need satisfaction variables (NSV) and provisioning factors (PF). Following on Vogel et al. (2021), the NSV capture six key dimensions of human need: health, education, nourishment, access to sanitation and protection from poverty (Table 1). The 13 chosen PF deemed relevant to the analysis cover economic, geographic, infrastructural and political factors (Table 2). The rationale behind the selection of these variables is twofold: first, they are available for most countries in our sample; second, being similar to the ones selected in Vogel et al.'s paper, they allow for a comparison of our results. The thresholds indicated in Table 1 for 'sufficient' need satisfaction are based on previous work on the idea of a 'good life within planetary boundaries' (O'Neill et al., 2018).

Material footprints quantify the total material flows required for consumption and production within a given territory (Wiedmann et al., 2013). A key strength of this indicator is its inclusion of trade flows, accounting for both imports and exports. However, by aggregating diverse material types — biomass, fossil fuels, metal ores, and non-metallic minerals — it sacrifices informational granularity. An intermediate layer of granularity, which will be used here to compare data with sustainability thresholds, is to distinguish between biotic and abiotic matter: biomass is deemed biotic while fossil fuels, metals and non-metallic ores are considered abiotic.

Most components of the material footprint are non-renewable, and most of them generate waste and/or environmental degradation. Reducing the global levels of material consumption is an imperative if we are to ensure inter-generational solidarity and try to preserve resource availability in the long term, as well as mitigating the impacts of economic activity on our environment.

The material footprint data comes from the UNEP-IRP[1] material flows database and represents the national material footprints divided by each country's population in 2019. The choice of using material footprints instead of the Domestic Material Consumption indicator was made because the former incorporates material consumption alongside the supply chain of products consumed in the final destination countries, and therefore accounts for imports and transport (Wiedmann et al., 2013). This focus on the end-use of materials is important in a study on sus-

---

[1] United Nations Environment Programme – International Ressource Panel

tainability, as international trade and international supply-chains tend to plunder Global South countries for ressources at the benefit of Global North economies (Hickel et al., 2021, 2022). All data was collected for 2019, or the closest possible year in case of missing observations.

Table 1. Human need satisfaction variables (NSV) used in this study

Variable name (abbreviation)	**Description and [units]**	**Sufficiency threshold**	**Indicator source**
Healthy life expectancy (HLE)	Average life expectancy at birth [years]	65 years	Institute for health metrics and evaluation
Sufficient nourishment (SN)	Percentage of population meeting dietary energy requirements [%]	95%	World Bank WDI 2019
Drinking water access (DWA)	Percentage of population with access to an improved water source [%]	95%	World Bank WDI 2019
Safe sanitation access (SSA)	Percentage of population with access to improved sanitation facilities [%]	95%	World Bank WDI 2019
Basic education (BE)	Education index (score)	Score of 75	UNDP HDR 2019
Minimum income (MI)	Absence of income shortfall below \$3.65/day [%], calculated as the reverse of the Poverty gap at \$3.65 a day (2017 PPP)	95%	World Bank WDI 2019

2.3 Data transformation

The regressions performed in this study have been made on centered and transformed variables, denoted by a $\widetilde{tilde}$. These transformations are either:

- Identity: $\widetilde{var_i} = var_i$;
- Logarithmic: $\widetilde{var_i} = \log(var_i)$;
- Saturation: $\widetilde{var_i} = \log(var_{sat} - var_i)$, where var_{sat} is a value 5% higher than the maximum observed, to take into account asymptotic effects without ever crossing the asymptote.

In each case the most suitable transformation was selected based on Akaike's Information Criteria (Akaike, 1974). Every need satisfaction variable uses a saturation transformation, material footprints use a logarithmic transformation, and the chosen ones for the provisioning factors are displayed in Table 2.

3 Methods

In this section, I will present the methods used in the analysis. While most of it is derived from the operationalization of the provisioning systems framework made in Vogel et al. (2021), I also introduced a new dimension with the introduction of quantile regressions, as well as an additional effort of decomposition due to the nature of material footprints as composite indicators. It will be divided in three parts: first the empirical strategy, then the modeling efforts made thanks to the results derived from the empirical analysis, and finally an extension of the model focusing on the material footprints sub-components.

3.1 Empirical study

3.1.1 Bivariate analysis of the relationship between need satisfaction and material consumption

In econometrics, the standard way to assess the relationship between two variables is through the use of ordinary least squares (OLS) regressions, which are linear models. Here, a set of OLS regressions were performed to cover every need – footprint combination, as presented in equation (1):

$$\widetilde{NS_i} = \beta_0 + \beta_1 \widetilde{MF_i} + \epsilon_i \tag{1}$$

Here, β_1 should be interpreted as the estimated marginal effect of material footprint on need satisfaction. However, the relationship between material consumption and need satisfaction is seemingly not linear, a "saturation" effect appearing when we plot the data. To check whether this is statistically true or not, a quantile regression is performed to assess whether the β_1 coefficients diminish as material footprints increase.

Quantile regressions help us illustrate how the effect of a variable X on the dependent variable Y changes as we move along the distribution of X, instead of assuming this effect remains unchanged for all values of X, as is the case in OLS models. A more complete description of quantile regressions can be found in D'Haultfœuille and Givord (2014). Due to the limited size of the dataset, the quantiles used will be the median ($\tau = 0.5$) as well as the first and third quartiles ($\tau = 0.25; 0.75$). The generic expression of the model is given by equation (2):

$$NS_i = \beta_\tau MF_{i,\tau} + \epsilon_\tau \tag{2}$$

3.1.2 Introducing provisioning factors as moderators

One of the hypotheses of this study is that provisioning factors play a moderating role in the relationship between material consumption and need satisfaction. In order to study this effect, a multivariate interaction model must be used integrating material footprints, provisioning factors and an interaction term, as described in equation (3):

$$\widetilde{NS}_i = \beta_0 + \beta_1\widetilde{MF}_i + \beta_2\widetilde{PF}_i + \beta_3\widetilde{MF}_i * \widetilde{PF}_i + \epsilon_i \tag{3}$$

Contrary to the standard OLS model presented in equation (1), this model introduces an interaction term. As such, β_1 and β_2 cannot be interpreted as the relative marginal effect of the material footprint or of a provisioning factor on the need satisfaction variable; the same is true for their respective statistical significance. Rather, as described in Brambor et al. (2006), calculating both manually is required: $\frac{\partial \widetilde{NS}}{\partial \widetilde{MF}} = \beta_1 + \beta_3\widetilde{PF}_i$ and $\frac{\partial \widetilde{NS}}{\partial \widetilde{PF}} = \beta_2 + \beta_3\widetilde{MF}_i$. It is now possible to calculate their respective standard errors and, therefore, confidence intervals. Since it is possible that both effects are significant only for a specific range of the distribution of PF and MF respectively, minimum and maximum significant values can be derived $(\widetilde{PF_{min^{**}}}/\widetilde{PF_{max^{**}}}/\widetilde{MF_{min^{**}}}/\widetilde{MF_{max^{**}}})$. These will be used later in the modeling part.

3.1.3 Multivariate analysis with provisioning factors combinations

In the real world, provisioning factors are numerous and they collectively moderate the relationship between material consumption and need satisfaction. It is thus necessary to observe their statistical effect when multiple factors are introduced at once. In order to do this, I performed a set of OLS regressions described in equation (4):

$$\widetilde{NS}_i = \beta_0 + \beta_1\widetilde{MF}_i + \beta_2\widetilde{PF_{1,i}} + \beta_3\widetilde{PF_{2,i}} + \beta_4\widetilde{PF_{3,i}} + \epsilon_i \tag{4}$$

Because of the relatively small sample size, the expected correlations between the variables, and the estimators' limitations in terms of accuracy, it was preferable not to include interaction terms for all four variables.

3.1.4 Assessing model validity and strength

Model validity and strength are assessed through a series of statistical measures and robustness checks. Robust standard errors (HC2) are computed in all regression models to address potential heteroskedasticity[2]. The normality of residuals is checked by means of a Kolmogorov-Smirnov test. Furthermore, in the context of multivariate regressions, the presence of multicollinearity[3] among the individual predictors is evaluated through an examination of Variance Inflation Factors (VIF). It is noteworthy that a threshold of VIF ≥ 5 is considered to indicate significant variance inflation. These procedures collectively serve to ensure the robustness and reliability of the models being employed in the analysis. Moreover, in the case of the quantile regressions, the statistical difference between the estimated coefficients is checked by performing a Wald test, a common ANOVA (Analysis of variance) test.

To check the robustness of the models, each analysis was made twice - the second time after potential outliers have been removed. Outliers identification is based upon the countries' material footprints, and was performed using an Inter Quantile Range (IQR) method.

3.2 Modeling

One of this study's main objectives is to determine the potential role of provisioning factors in reaching sufficient need satisfaction at sustainable levels of material use. Now that the statistical relationship between these factors and need satisfaction have been empirically determined, it is possible to try to model the effect on need satisfaction if different levels of provisioning were generalized to all countries on the planet.

3.2.1 Single provisioning factor

Thanks to the coefficients β_1, β_2 and β_3 estimated in equation (3), it was possible to calculate the minimum and maximum values for which each provisioning factor has a significant statistical effect ($\widetilde{PF_{min^{**}}}/\widetilde{PF_{max^{**}}}$). By combining these coefficients with the minimum / maximum significant values of provisioning factors, it becomes possible to model a prediction of need satisfaction at observed material footprints. To make a better comparison, these predictions are also made with the mean provisioning values. Equation (5) exemplifies the modeling strategy in the case of a generalization of($\widetilde{PF_{max^{**}}}$):

$$\widetilde{NS_{pred,i}}(\widetilde{PF_{max^{**}}}) = \beta_0 + \beta_1 \widetilde{MF_i} + \beta_2 \widetilde{PF_{max^{**}}} + \beta_3 \widetilde{MF_i} * \widetilde{PF_{max^{**}}} \tag{5}$$

---

[2] Heteroskedasticity refers to a situation in which the variance of residual terms ϵ_i is not constant. In econometrics, the normality of residuals is necessary to get unbiased estimators.

[3] Multicollinearity is a situation in which the predictors in a regression model are linearly dependent. This can generate instability and prevent a good interpretation of the estimated coefficients.

By pooling together these predictions over all the need satisfaction variables, and for all the statistically significant material footprints, it becomes possible to obtain a measure of the overall statistical effect and relevance of each provisioning factor. To achieve this in a standardized way, I compare the difference between the predicted need satisfaction levels and the observed ones, as described by equation (6):

$$\Delta \widetilde{NS_{pred,i}}(\Delta \widetilde{PF}) = \frac{\widetilde{NS_{pred,i}}(\widetilde{PF_{max^{**}}}) - \widetilde{NS_{pred,i}}(\widetilde{PF_{min^{**}}})}{NS_{max} - NS_{min}} \tag{6}$$

This gives a comparable metric for how need satisfaction can change with any provisioning factor for a given level of material consumption. It gives information on the general direction, strength and consistency of statistical effect of a provisioning factor. However, because human needs are considered non-substitutable and incommensurable, as explained by Doyal and Gough (1991), this metric is better used as a qualitative indication than an exact quantitative measure.

3.2.2 Combinations of provisioning factors

In order to estimate whether “good provisioning” can allow sufficient need satisfaction at low material use levels, the coefficients β_1, β_2, β_3 and β_4, estimated in equation (4) can be used to predict need satisfaction under stylized scenarios of “jointly beneficial” or “median” provisioning. These alternative provisioning scenarios are denoted c in equation (7):

$$\widetilde{NS_{pred,c,i}} = \beta_0 + \beta_1 \widetilde{MF_i} + \beta_2 \widetilde{PF_{1,c}} + \beta_3 \widetilde{PF_{2,c}} + \beta_4 \widetilde{PF_{3,c}} \tag{7}$$

Because there are no interaction terms, it is not necessary to compute the range for which the marginal effects are significant, contrary to what was described in section 3.1.2. Instead, to create the "jointly beneficial" scenarios I will be using the value of the 90th percentile of beneficial provisioning factors and the value of the 10th percentile of detrimental ones. This would still represent a massive improvement for most countries, but would not be as extreme as giving to everyone the provisioning levels of the best performers. More detail on how beneficial and detrimental provisioning factors are identified is given in section 4.2. "Median" provisioning represents a situation in which every country is given the median value for each provisioning factor.

3.3 Decomposing the material footprint

The material footprint is an aggregated measure of material consumption, computed as the sum of biomass, fossil fuels, metals, and minerals consumption. As such, it is interesting to look at the effect of provisioning factors on those sub-components, both as a robustness check of our results and as a way to explore potential heterogeneity.

Therefore, I will be looking at how the trends in material footprint composition may change as material footprints increase, and then examine how provisioning factors may interact differently with them. In section 2.1 I presented, with equation (6) a metric allowing the comparison of the general statistical effect of each provisioning factor. By using the same methods I have been describing for each component of the material footprint, this metric can be obtained for any of these components.

4 Results

4.1 Cross-country analysis of the relationship between need satisfaction and material consumption

Among the 151 countries in the sample, only 34[4] ($\approx 22,16\%$) reach sufficient levels of need satisfaction for all of the selected NSV. The average MF of these successful countries is 26.32t/year/capita, which is lowered to 23.64t/year/capita when population is used as a ponderation, making it about 70% higher than the 13.8t/year/capita that can be used as a baseline of what a “sustainable” material footprint could be (Bringezu, 2015). However, even among these countries, there is an important heterogeneity: for example, Italy’s material footprint per capita is about 11.87t/year, putting it below the sustainability threshold, whereas Iceland’s is 58.86t/year, highlighting the importance of exploring the role of provisioning factors in explaining this relationship.

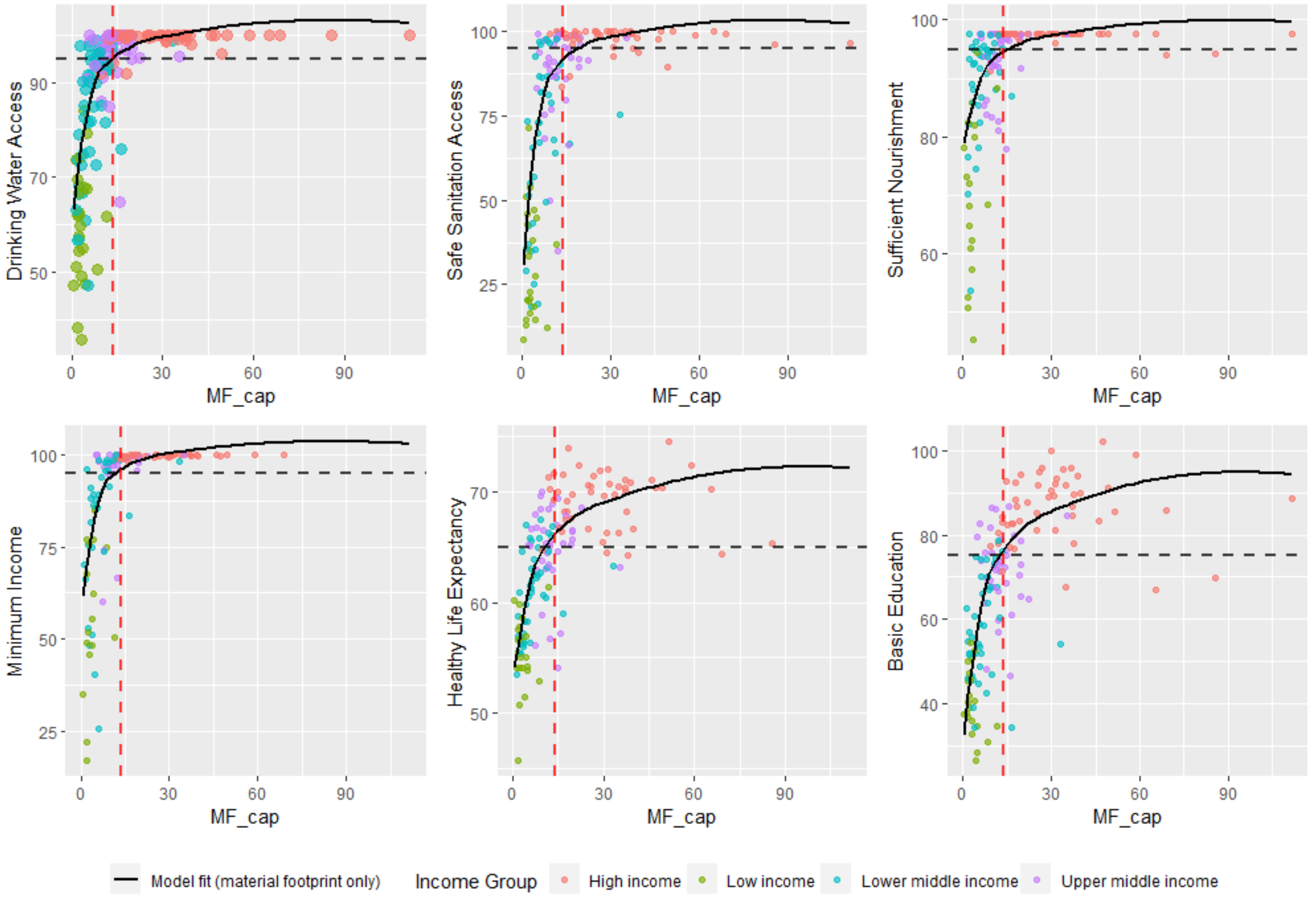
The OLS regressions presented in Table 3 show a very high degree of correlation between need satisfaction and material consumption. For each of our six variables, the statistical effect is significant and implies an increase by $\approx 0.75\%$ to $\approx 0.81\%$ for every 1% increase in the material footprint per capita.

---

[4] Australia, Austria, Belarus, Belgium, Canada, Chile, Costa Rica, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Israel, Italy, South Korea, Luxembour, Malta, the Netherlands, New Zealand, Norway, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkiye, the United Kingdom, the United States and Uruguay

However, as noted in section 3.1.1, the relationship between material consumption and need satisfaction is not linear. This can be seen visually in Figure 2, which compares the per capita material footprints of nations to their need satisfaction, for each of the selected needs. The dashed grey horizontal line represents the threshold for "sufficient" need satisfaction as explained in Figure 1, and the dashed red line represents the "sustainable" limit for material consumption of 13.8t/year/capita. What is interesting is that, in this "sustainability space" represented by sufficient need satisfaction and sustainable material use, we can find countries from every income group[5] bar the low income ones. This also shows that material consumption alone is not enough to understand and predict need satisfaction, which further justifies the need to investigate the role of provisioning factors.

Figure 2. The relationship between material consumption and need satisfaction saturates as material consumption increases



The visual impression left by Figure 2 need to be statistically validated however, which is why I also used quantile regressions to support the saturation argument. Table 4 shows the results of these regressions: in most cases (with the notable exception of the educational performance),

---

[5] I am using the World Bank's classification for income groups here.

the statistical effect of an increase in material consumption is significant but gets smaller and smaller as the material footprint per capita increases.

As can be seen in Table 4, the results of the quantile regressions tend to confirm the hypothesis of diminishing returns of increasing material consumption, i.e. the "saturation effect" is clearly highlighted. The two NSV for which the effect is not as clear, between the first quartile and the median at least, are Basic education and Healthy Life Expectancy , which are the two for which the saturation effect is not as clear and striking (cf. Fig. 2). Moreover, a Wald test was performed on each regression to check whether the coefficients were significantly different or not. The results were positive for all except Basic education (which could be inferred by looking at the estimated coefficients).

4.2 Moderating effect of single provisioning factors

The purpose of this section is to investigate how individual provisioning factors moderate the relationship between need satisfaction and material footprints. The addition of a provisioning factor in the regression (3), as a moderator of the relationship between material footprints and need satisfaction, results in a generally statistically improved explanation of this relationship, as indicated by higher adjusted R^2 values on average. When the marginal effect of a provisioning factor is significant, both the need satisfaction associated with a particular material footprint and the extent to which need satisfaction depends on material footprint vary with the value of the provisioning factor. Thus, provisioning factors shape the relationship between material footprint and need satisfaction. Interestingly, out of the 78 possible combinations, 8 (10,25%) display a lower adjusted R^2, the majority of which resulting from models integrating economic growth and trade penetration as provisioning factors[6]. This hint that economic growth may not be a consistently relevant provisioning factor is compounded by the fact that in two cases (for Drinking Water Access and Minimum Income) there are no cases where the computed marginal effect of material consumption on need satisfaction $\frac{\partial \widetilde{NS}}{\widetilde{MF}}$ is significant. In other words, once we integrate an interaction with economic growth, material consumption ceases to be a relevant predictor of need satisfaction.

In section 3.2.1, I used equation (5) to explain how different values of a provisioning factor could be used to model need satisfaction, the implicit assumption being that in each cases these values were given to every country in our sample. This allows for a comparison of predicted need

---

[6] The models displaying lower adjusted R^2 are the following: Drinking water access: econ. growth; Safe sanitation access: econ. growth; Sufficient nourishment: trade penetration; Minimum income: trade and transport infrastructure, economic growth; Healthy life expectancy: economic growth, trade penetration; Basic education: trade penetration.

satisfaction in each scenario, both between each scenario and with respect to our current situation. In Figure 3 I give examples of these predictions for three need satisfaction variables (Healthy Life Expectancy, Sufficient Nourishment and Drinking Water Access) and three provisioning factors (Income equality, Public Service Quality and Extractivism). It illustrates how provisioning factors have moderate the relationship between need satisfaction and material footprint. Public service quality, and Income equality can be seen as beneficial provisioning factors, because the predicted need satisfaction is higher when we generalize higher levels of provisioning. On the other hand, Extractivism can be seen as detrimental because generalizing higher levels of this factor generates worse need satisfaction.

To go in further detail, generalizing the highest significant value of extractivism results in an average decrease of seven years in terms of Healthy life expectancy, for any given material footprint; it also drastically reduces the predicted outcomes in terms of access to drinking water or to a sufficient nourishment. The opposite is true for income equality, for example. If the level of income equality found in Iceland was generalized, world hunger would virtually disappear according to this prediction. In most cases, the provisioning factors are significant and the strongest at low material footprints, meaning that the potential to improve social-ecological performance is highest in the countries that are consuming the least materials right now, i.e. mainly countries from the majority world or "Global South".

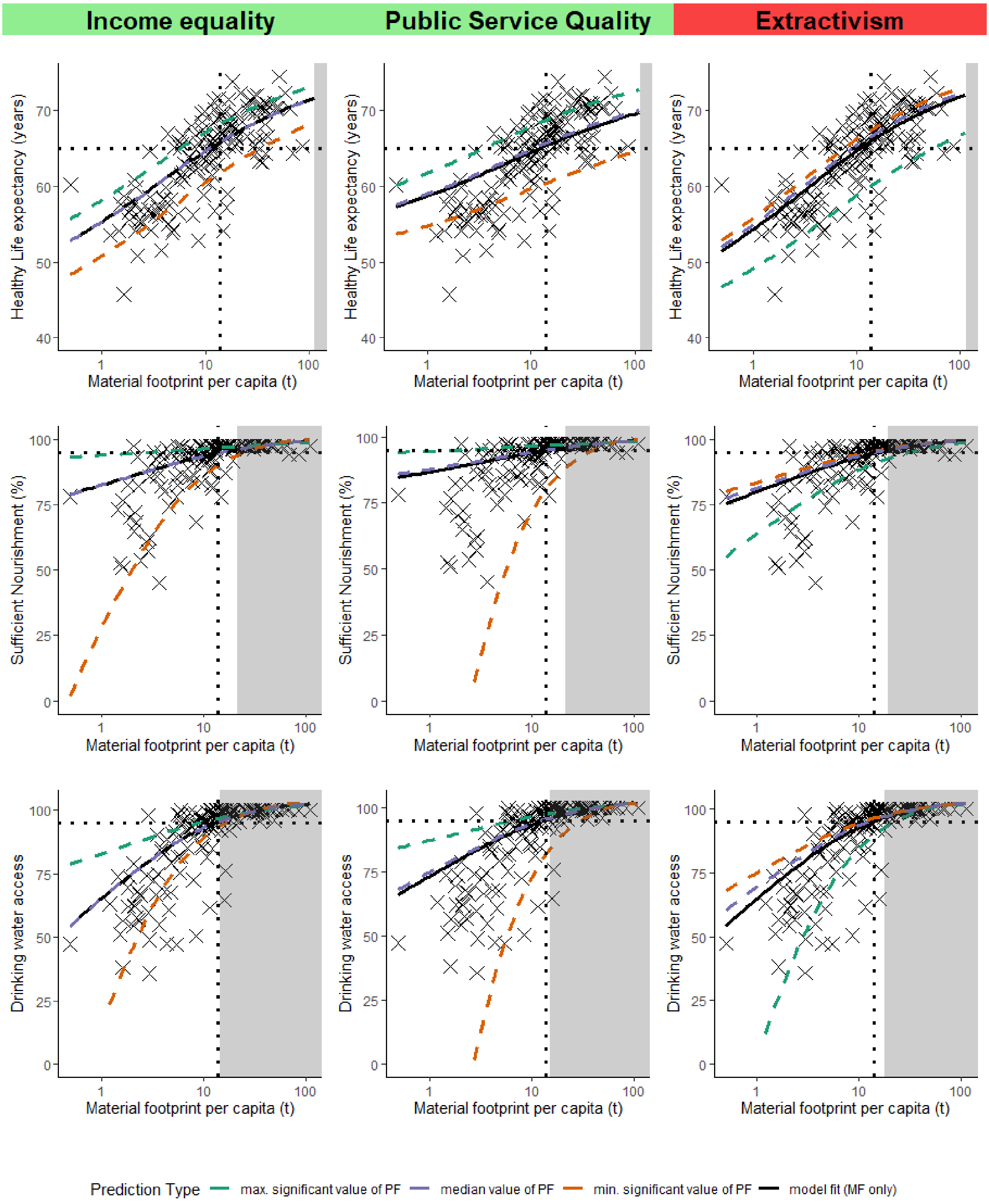
Therefore, by looking at the effects of individual provisioning factors, it appears that they can be sorted into three categories (as already evidenced by Vogel et al. (2021)):

- Beneficial provisioning factors: these PF are associated with socio-ecologically beneficial performance, i.e. higher achievement in, and/or lower material requirements of, human need satisfaction.
- Detrimental provisioning factors: these PF are associated with socio-ecologically detrimental performance, i.e. lower achievement in, and/or higher material requirements of, human need satisfaction.
- Non-significant provisioning factors: these PF do not show significant interactions with the relationship between material footprints and need satisfaction.

The (significant) marginal effects of the provisioning factors are consistent in direction (detrimental or beneficial) across almost all need satisfaction variables, but may vary in amplitude and significance. The two significant exceptions are Trade and Growth.

In the first case, Trade's marginal effect is detrimental to the relationship between material consumption and Healthy life expectancy for every material footprints in the significant range.

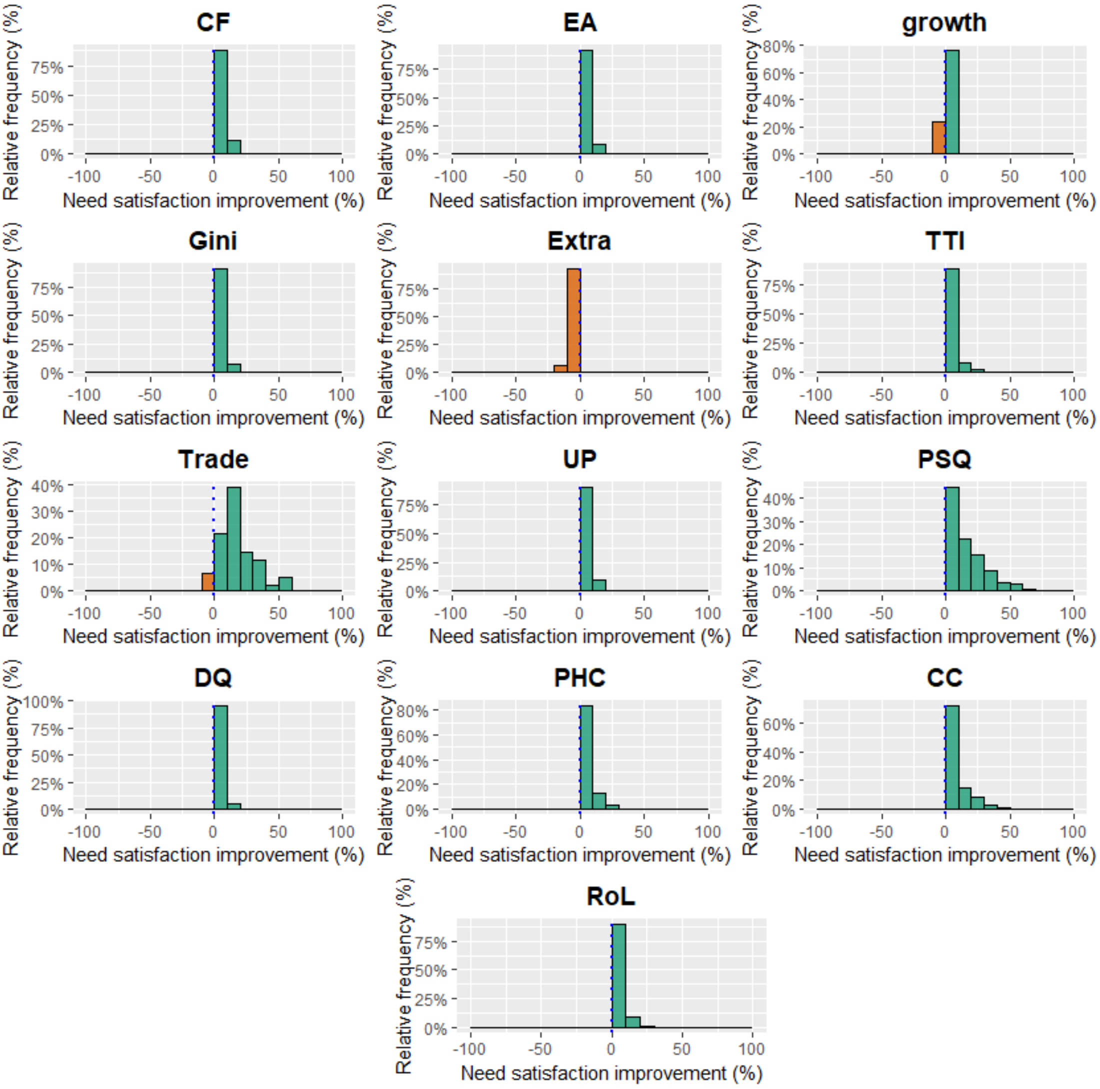
Figure 3. Modeled Relationship Between Material Footprints and Need Satisfaction, for different Provisioning Factors levels



The dotted vertical line represents the maximum sustainable footprint and the horizontal one represent the need satisfaction threshold. The relationship between material consumption and need satisfaction improves with beneficial provisioning factors and deteriorates with detrimental ones. The grey areas correspond to material footprints where the effect of a variation in material consumption on need satisfaction is not significant ($MF < \widetilde{MF}_{min**}$ or $MF > \widetilde{MF}_{max**}$).

Growth has a detrimental effect on life expectancy and nourishment, but only for low values of material consumption in the case of the former. The variations in amplitude explain why the same provisioning factor has such different results on the predicted need satisfaction outcomes, even among the examples in Fig. 3.

Figure 4. General direction and strength of each provisioning factor's statistical effect



Each provisioning factor can be classified as beneficial (green) or detrimental (orange) to the relationship between material consumption and need satisfaction.

Pooling together the significant effects for each provisioning factor, as described in equation 6, reveals that they are highly consistent in their direction and effect, with the aforementioned exception of Trade and Growth. The results are depicted in figure 4. This analysis confirms the categorization introduced earlier between constantly beneficial (beneficial in some or all cases but never detrimental), detrimental (detrimental in some or all cases but never beneficial) and non-significant provisioning factors (predominantly non-significant). Extractivism is the only consistently detrimental factor, while Growth and Trade are ambivalent. Every other provisioning factor can be categorized as beneficial, the differences appearing in the amplitude of the effects with which they are associated. The provisioning factors with the strongest beneficial marginal effects are Public service quality (PSQ), Trade and Rule of law (RoL).

4.3 Joint effect of multiple provisioning factors arranged in different combinations

As explained in section 3.1.3, I reassessed the statistical effect of provisioning factors when they are included together (see equation 4). Among the 1716 three-way combinations of provisioning factors, 1394 pass both the heteroskedasticity and multicollinearity tests devised in section 3.1.4, and only 268 of those show some level of significance for all observed variables (material footprints and provisioning factors). Unfortunately, there is no combination of provisioning factors for which all variables are significant across every need satisfaction variable. Therefore, I will be presenting in the following two combinations, Model A and Model B, for which only three variables are consistently significant.

Model A tests the joint effects of Extractivism, Income equality and Urban population, while Model B is a combination of Public service quality, Income equality and Trade and Transport Infrastructure. While this choice is partly dictated by their respective statistical significance, they are also theoretically relevant - and thus are acceptable choices both for this empirical analysis and for the modeling exercise detailed later in this section. Several studies have been pointing the detrimental effect of Extractivism on socio-environmental outcomes (Bainton et al., 2021; Brand et al., 2017; Stratford and O'Neill, 2020; Martinez-Alier and Walter, 2016), an effect that tends to be confirmed by the results shown in the previous section. Inequality has also been touted as having a similar detrimental effect by Zhang et al. (2023), particularly in urban contexts - which can also help reduce material consumption according to Nathaniel (2021). On the opposite, strong public services and equality have been found to have a positive effect on environmental sustainability and social outcomes (Büchs and Koch, 2017; Jorgenson, 2015; Wilkinson and Pickett, 2010). Finally, it is quite well known and studied in the development literature that transport infrastructures, while potentially environmentally harmful, help a lot in improving economic dynamism and social performance (Quium, 2019; Ijirshar, 2022).

Regression results for Model A are shown in Table 5, and show that the effects obtained are consistent in terms of direction with those obtained for individual provisioning factors. Extractivism has a negative effect on need satisfaction, while higher income equality is consistently associated with better performance. Table 6 shows the results of Model B, which are also consistent with the results obtained before and the literature.

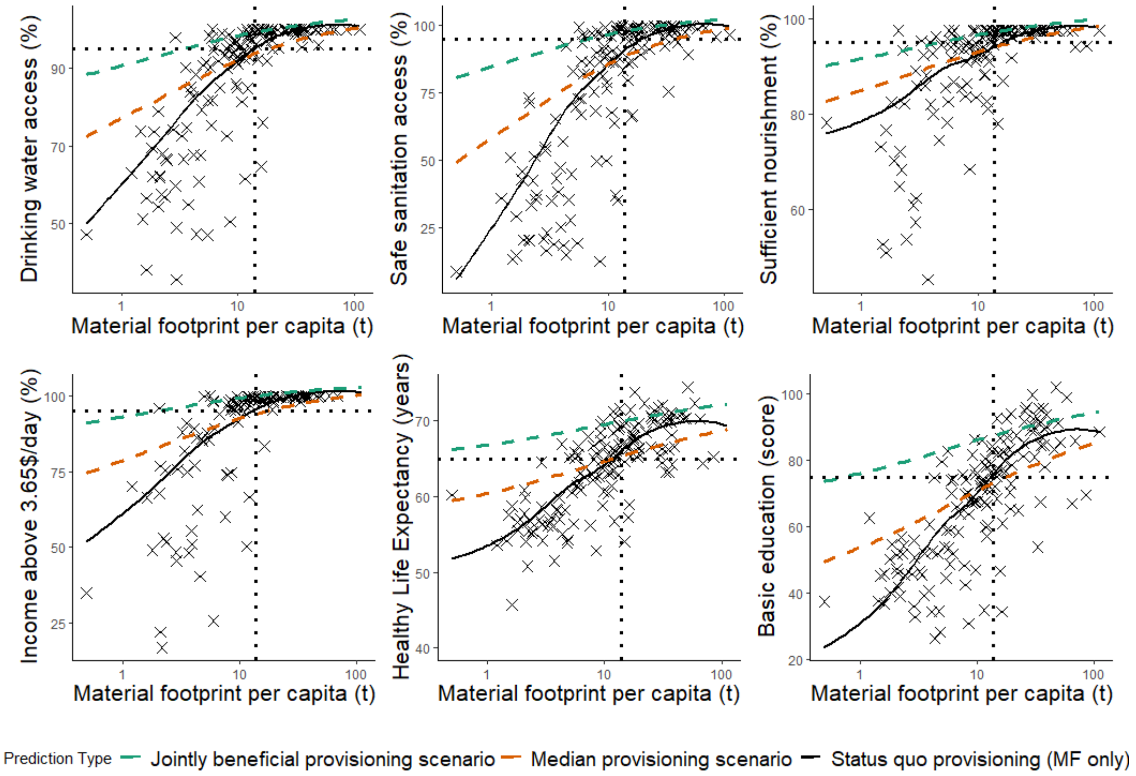
Countries displaying high levels of beneficial provisioning combinations also tend to display the best social-ecological performance, and the opposite is also true. For example the Republic of Congo is the country with the highest value for Extractivism, rents from natural ressource extraction representing 66% of its GDP; it's also ranked at the 142nd position in terms of Public service quality and 136th in terms of income equality. On the other hand, Iceland ranks first in terms of income equality, 16th in terms of Public service quality, and 151st in terms of Extractivism. A less extreme but interesting case is Costa Rica, which reaches every need satisfaction threshold while also maintaining a sustainable material footprint: it is characterized by low Extractivism, and better than average provisioning for most beneficial provisioning factors. This suggests that qualitative changes in poor performers' provisioning systems could result in important increases in their citizen's needs fulfillment while not increasing (as much) their material throughput.

Using these results, it is possible to model need satisfaction under a "jointly beneficial" provisioning scenario for both models, as described in equation (7). These will be compared to a "median" provisioning scenario, as well as to the current situation "status-quo provisioning". The results of the predictions for Model A are displayed in Figure 5 and those for Model B are displayed in Figure 6.

As both figures show, jointly beneficial provisioning consistently improves need satisfaction. In the case of Model B, the jointly beneficial scenario even implies that every country could reach the need satisfaction threshold for Healthy Life Expectancy and Basic education. This improvement is particularly notable for countries with low material consumption levels, which is to be expected since they also tend to be those faring the worst in terms of provisioning. In this sense, it is important to note that the median provisioning scenario also significantly improves need satisfaction: this implies that an improvement on certain key provisioning factors could play a huge role in improving livelihoods in poorer countries without threatening sustainability.

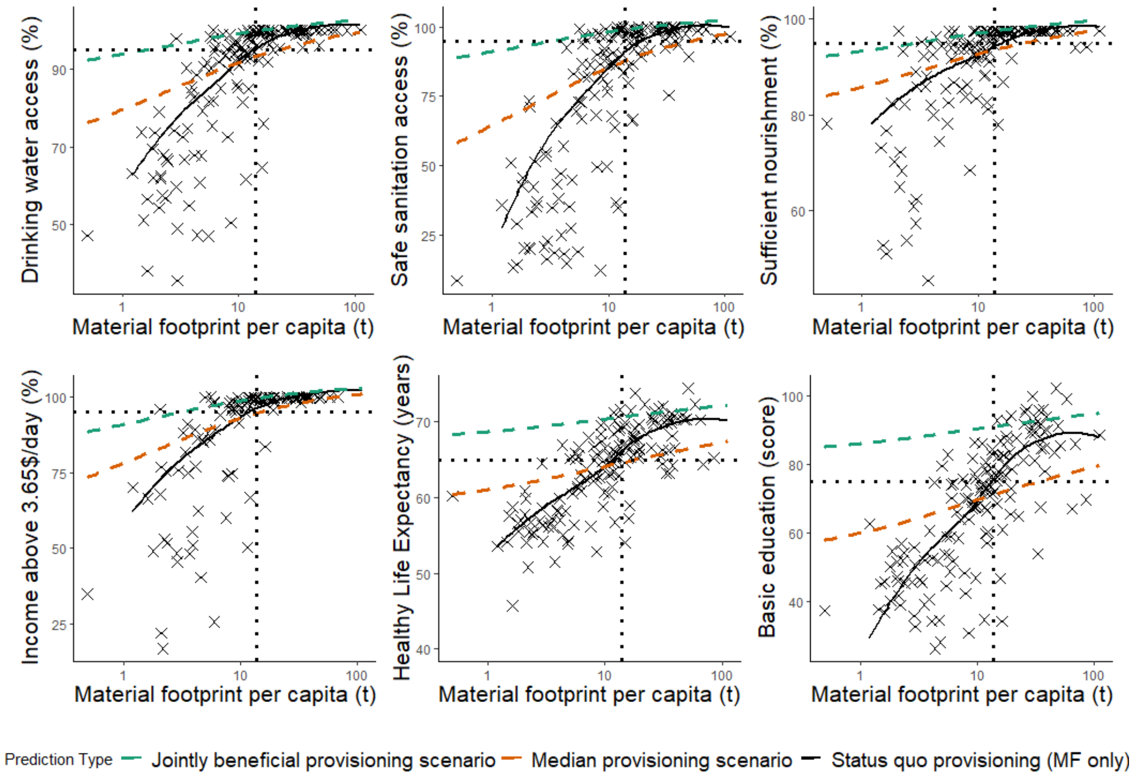
However, it is also important to point out that in both models predictions show no situation where a country presents both a sustainable level of material use and sufficient need satisfaction for all six need satisfaction variables. In each case, Safe sanitation access and Sufficient nourishment are the ones for which it seems the hardest to reconcile both objectives. Additionally, the jointly beneficial provisioning scenarios don't show a very high potential to reduce material footprints in the countries where it's the highest. This can be explained by the fact that the most material-intensive countries also tend to be those with the highest levels of provisioning already. Therefore, generalizing the 90th percentile value of provisioning factors to them too can actually lead to a decrease in socio-environmental performance if they are above that limit. This doesn't necessarily

Figure 5. Modeled need need satisfaction under different scenarios for Model A



The dotted vertical line represents the maximum sustainable footprint and the horizontal one represent the need satisfaction threshold.

Figure 6. Modeled need need satisfaction under different scenarios for Model B



The dotted vertical line represents the maximum sustainable footprint and the horizontal one represent the need satisfaction threshold.

bear implications in the real world, as improving the situation of the worse-off is not conditioned to degrading the situation for the highest performers.

4.4 Decomposed material footprints

As explained previously, the material footprint is a composite indicator. It is therefore necessary to look more closely at how its components may evolve, and how they may interact with the provisioning factors examined thus far. In particular, Figure 7 shows that the material footprint components don't scare linearly. The share of biomass tends to decrease significantly, whereas the shares of fossil fuels and minerals get higher with the material footprint. The share of metals is roughly constant throughout. The bottom graph in the figure also displays how the distribution of biotic and abiotic resource use compare to their respective sustainability threshold. While around the two-thirds of countries are below or adjacent to the threshold for abiotic resource use, most of them overshoot the limit for biotic resources. In the worst cases, the overshoot can be around or more than ten-fold (Brunei Darussalam, Iceland, Hong Kong) for biotic resources, and between six to nine-fold for abiotic resources (Hong Kong, Kuwait, United Arab Emirates, Brunei Darussalam).

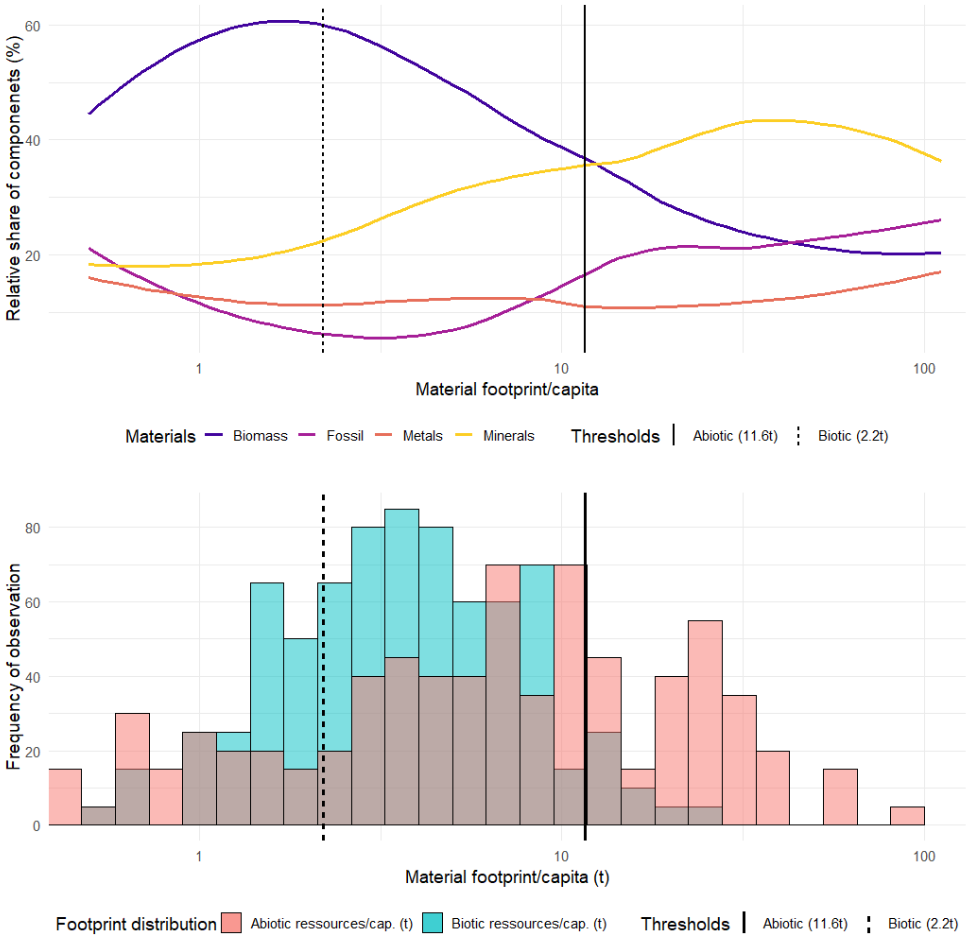
In order to look at the way provisioning factors interact with the components of the material footprint, I replicated the steps that led to figure 4 for each of them. The results are visible in Figure 8.

The effects of each provisioning factor are largely consistent over all components of the material footprint. The only cases where Extractivism has a positive, for Fossil fuels and Minerals, are countries with a very low material footprint and low natural resources rents. In each case, the positive effect is found only for education performance. Trade and Growth also had an ambiguous effect in the results from Figure 4, so the results here are consistent.

4.5 Outliers analysis

Thanks to the Inter Quantile Range method, 9 outliers were identified: Hong Kong, Brunei Darussalam, the United Arab Emirates, Kuwait, Iceland, Singapore, Australia and Luxembourg. All of them show very high material footprints, comprised between 46 and 111 tons per year per capita. Removing these from the dataset has very limited consequences: it doesn't significantly change the estimated coefficients in the models estimated from equations 1, 3 and 4, nor their direction. In the quantile regressions (equation 2), the estimated coefficients for material footprints

Figure 7. Composition of the Material footprint as it increases



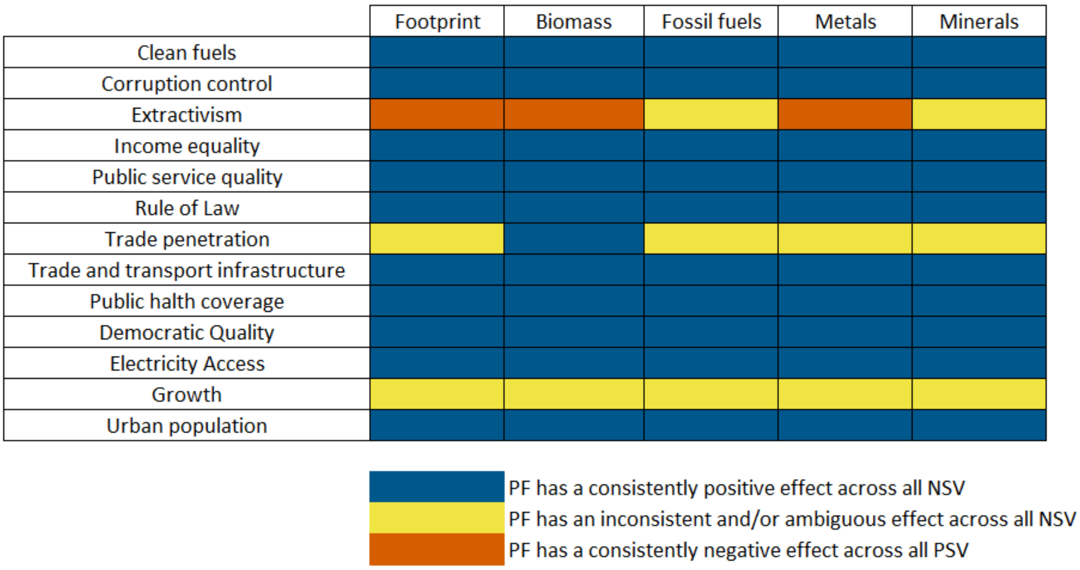
The top graph shows how the relative share of each component of the material footprint evolves as material footprints increase. The bottom graph shows the distribution of the material footprint once decomposed between biotic (biomass) and abiotic (fossil fuels + metals + minerals). In both graphs, the sustainability thresholds of 2.2t/capita for biotic resources and 11.6t/capita for abiotic resources are displayed

are systematically more important, but the general saturation effect and specificities highlited in Table 4 remain consistent.

5 Discussion

The findings of this study suggest that human need satisfaction does not only depend on the level of material consumption, here represented by the national material footprints per capita, but also on the quality of national provisioning systems, which act as intermediaries and moderators in the material footprint-need satisfaction relationship. As shown in Fig. 3 and Fig. 5, modeled social outcomes greatly vary at similar material footprints, depending on the configuration of provisioning factors. At the same time, high material footprints do not guarantee

Figure 8. The effects of provisioning factors are largely consistent across different material dimensions



	Footprint	Biomass	Fossil fuels	Metals	Minerals
Clean fuels	🟦	🟦	🟦	🟦	🟦
Corruption control	🟦	🟦	🟦	🟦	🟦
Extractivism	🟧	🟧	🟨	🟧	🟨
Income equality	🟦	🟦	🟦	🟦	🟦
Public service quality	🟦	🟦	🟦	🟦	🟦
Rule of Law	🟦	🟦	🟦	🟦	🟦
Trade penetration	🟨	🟦	🟨	🟨	🟨
Trade and transport infrastructure	🟦	🟦	🟦	🟦	🟦
Public halth coverage	🟦	🟦	🟦	🟦	🟦
Democratic Quality	🟦	🟦	🟦	🟦	🟦
Electricity Access	🟦	🟦	🟦	🟦	🟦
Growth	🟨	🟨	🟨	🟨	🟨
Urban population	🟦	🟦	🟦	🟦	🟦

🟦 PF has a consistently positive effect across all NSV
🟨 PF has an inconsistent and/or ambiguous effect across all NSV
🟧 PF has a consistently negative effect across all PSV

sufficient social outcomes. Tables 3, 5, and 6 confirm that the strength of the material footprint-need satisfaction relationship is greatly overestimated if one does not take provisioning factors into account. Therefore, exploring further the roles of provisioning systems and key provisioning factors could be key in reaching the double objective of satisfying human needs while remaining below the planetary boundaries—goals which, under the current development pathways and economic systems we live in, seem incompatible (Fanning et al., 2020; Hickel, 2019; O'Neill et al., 2018).

5.1 Focusing on Provisioning Systems to reach Socio-ecological sustainability

This paper presents empirical associations between different combinations and configurations of provisioning factors and countries' socio-ecological performance. These associations can help predict, given a country's provisioning system, what material footprint is required to reach targeted social outcomes. Overall, countries with jointly beneficial provisioning systems are likely to achieve higher social outcomes for any material footprint and are more likely to reach sufficient social performance with a lower material footprint than the international trend. Therefore, the better the provisioning system, the better the socio-ecological performance. Given these associations and their statistical significance, this analysis suggests that, by improving countries' provisioning systems, it is possible to reach far better social outcomes at a similar level of material consumption. It also implies that, for countries with already-high social performance but unsustainable material footprints, a reduction in the latter can be achieved without jeopardizing social outcomes. Therefore, these associations could inform promising new policies for sustainability in both the majority and minority worlds.

Saturation effect and Policy implications

The quantile regression results (Section 4.1) reveal a "saturation effect," where the marginal benefits of increasing material consumption diminish as material footprints grow. This effect is particularly pronounced for needs such as Drinking Water Access, Safe Sanitation Access, and Sufficient Nourishment, but less so for Basic Education and Healthy Life Expectancy. This finding has important policy implications: low-income countries could achieve significant improvements in need satisfaction with relatively small increases in material use, while high-income countries, which already experience diminishing returns, should focus on reducing material consumption - which does not entail sacrificing well-being (Hickel, 2020; Vogel et al., 2021). This underscores the importance of targeted policies that prioritize material efficiency in low-consumption countries and sufficiency in high-consumption ones (Bohnenberger, 2020; Parrique, 2019).

Outliers and robustness

The study identifies nine outliers (e.g., Hong Kong, Brunei Darussalam, Iceland) with extremely high material footprints (46–111 tons per capita/year). Removing these outliers does not significantly change the regression coefficients, but the quantile regression coefficients for material footprints become more pronounced. This suggests that the findings are robust and not driven by extreme cases of overconsumption. However, these outliers represent critical examples of unsustainable material use, and their exclusion reinforces the need for radical changes in high-consumption economies (Hickel, 2019; Kallis et al., 2020).

5.2 Implications and Policy proposals

This study identifies both beneficial and detrimental provisioning factors moderating the relationship between need satisfaction and material consumption. As mentioned earlier, the statistical relationships studied are correlations and not direct causalities. On the one hand, countries with overall good provisioning systems are also those whose material footprint is the highest, suggesting that it might be hard to precisely distinguish between a consumption effect (higher material footprints = better social outcomes) and a beneficial provisioning effect (better provisioning systems = better social outcomes). On the other hand, countries with similar footprints display different social performances, and these differences can partly be statistically explained by the quality of the provisioning systems. As such, when looking at the significance and strength of the statistical associations highlighted, focusing on getting better provisioning systems seems like an "easy" way to improve socio-ecological performance. Improving public service quality, reducing income inequality and extractivism, investing in trade and transport infrastructures, fighting corruption... are all ways in which countries could improve their social outcomes without requiring too many additional materials.

Trade and Economic Growth: Ambiguous effects

The study finds that trade and economic growth have inconsistent effects on need satisfaction. Trade has a detrimental effect on healthy life expectancy but is beneficial in other contexts, while economic growth is sometimes detrimental (e.g., for life expectancy and nourishment) but often non-significant. This ambivalence suggests that trade policies should be redesigned to minimize negative impacts (e.g., on health) while maximizing positive ones (e.g., on education) (Razzaq et al., 2021; Ijirshar, 2022). Similarly, economic growth should be decoupled from material consumption, focusing instead on qualitative improvements in well-being.

Decomposed Material footprints

The decomposition of material footprints (Section 4.4) reveals that the composition of material use changes as consumption increases: biomass share decreases, while fossil fuels and minerals increase. Metals remain relatively constant. Most countries overshoot the biotic resource sustainability threshold, while two-thirds are below or adjacent to the abiotic resource threshold. This suggests that reducing biomass consumption (e.g., through sustainable agriculture) and shifting away from fossil fuels could be key strategies for reducing material footprints while maintaining need satisfaction (Bringezu, 2015; Giljum et al., 2015). Policies targeting these specific components of material footprints could yield significant environmental benefits without compromising human well-being (Creutzig et al., 2021; Sandberg, 2021).

Limit of Provisioning Systems

Modeling of jointly beneficial provisioning scenarios (Section 4.3) shows that even under the most favorable conditions, no country achieves both sustainable material use and sufficient need satisfaction for all six needs. Safe sanitation access and sufficient nourishment are particularly challenging to reconcile with sustainability. This finding underscores the limits of provisioning systems within the current economic framework and highlights the need for radical systemic changes

(Raworth, 2017; Stratford and O'Neill, 2020). Simply adjusting parameters within the existing system will not be enough to achieve socio-ecological sustainability.

5.3 Limitations and future research

I see four main limits to the work presented in this paper. First, there are currently no countries on Earth that reach sufficient satisfaction at a sustainable level of material consumption. As such, the results presented should be considered as exploratory. Second, this is a statistical analysis of association and moderation, and thus does not claim to show any causalities. Third, this study focuses on a set of six need-satisfaction variables and thirteen provisioning factors, among which only two represent international interactions; it is too few to be representative of the diversity of provisioning factors, or to cover the whole breadth of human needs. Despite this reduced scope, the number of interactions and regressions to analyze is already extremely important and prevents the presentation of all the results in a single paper. Finally, it is important to keep in mind that the cross-national nature of the study yields only very generic results, and that the proposals coming from these results would need to be adapted locally to keep their relevance (Fanning et al., 2020; O'Neill et al., 2018).

Future Research directions

This paper contributes to the study of socio-ecological provisioning systems and of the material footprint-need satisfaction relationship, which to the author's knowledge has not been explored before. Given the limits mentioned above, additional research is still required. Interesting follow-ups would be to study the temporal dynamics of this relationship, exploring other provisioning factors and needs, investigating the differences in results if the material footprint was swapped with the domestic material consumption, and integrating this work into more of a political economy framework to define which efficient policies would be the most easily implemented. Connections with the literature on social metabolism also should be made in the future, to bring another dimension to the analysis of energy and material flows within economies. This literature could also help better define what "good" provisioning systems could look like.

6 Conclusion

The relationship between material consumption, here expressed by the material footprint, and needs-satisfaction is still crucially understudied. Yet, it asks a most pressing question: can humankind satisfy its needs in an environmentally sustainable way? If so, how is this achieved? This study set out to address this very issue. It suggests that the current socio-economic organization (which is to say the way we organize economies and societies) both fails to fulfill human needs on a consistent basis for most of the planet, and does so while overconsuming materials: only 34 countries out of 151 ($\approx 22\%$) reach the sufficient level across all need-satisfaction variables, with an average material footprint of 23.64t/capita/year. However, these countries present an important heterogeneity in their material footprints, suggesting that provisioning systems play a crucial role in the moderation of this relationship.

The analyses performed highlight the beneficial role played by ten provisioning factors (Access to electricity, Access to clean fuel, Trade and Transport Infrastructure, Urban population, Public health coverage, Quality of public services, Control of corruption, Rule of law, Quality of democracy, Income equality) and the detrimental role played by one of them (Extractivism), while two of them Trade, Growth) prove to be inconsistent, ambiguous, and mostly non-significant. Countries with beneficial provisioning systems (high levels of beneficial provisioning factors, low levels of detrimental ones) are associated with better socio-ecological performance, while countries with detrimental provisioning systems (low level of beneficial provisioning factors, high level of detrimental ones) tend to display worse performances.

On that basis, it is suggested that countries should aim to align themselves with provisioning combinations identified as beneficial. However, modeling efforts show that, even by generalizing high-level provisioning factors to every country on the planet, it is very unlikely to reach sufficient social outcomes and sustainable material use at the same time. These results suggest that radical transformations to economic systems will be required to reach both of these objectives at the same time. It is of particular relevance for development practitioners, policymakers and sustainability professionals, as it highlights the factors that have a good or bad influence on achieving the Sustainable Development Goals. They are also interesting in their alignment with degrowth, doughnut-economics or sustainable welfare discourses and conclusions, as well as serving as evidence to the merits and relevance of their propositions, like universal basic services or capping income and consumption (Coote and Percy, 2020; Gough, 2019; Raworth, 2017).

Overall, this study follows-up on the work made by Vogel et al. (2021) in their study of the relationship between need satisfaction and energy use by applying their original method to a new biophysical resource. It helps strengthen our understanding of the role of provisioning systems, and of which provisioning factors are beneficial or detrimental across different dimensions of environmental sustainability. However, given its limits and the questions it asks in return, further research will be needed to understand these relationships fully, in particular as to how material footprints and energy use may or may not be linked.

References

H. Akaike. A new look at the statistical model identification. *IEEE Transactions on Automatic Control*, 19(6):716–723, Dec. 1974. ISSN 1558-2523. doi: 10.1109/TAC.1974.1100705. URL https://ieeexplore.ieee.org/document/1100705. Conference Name: IEEE Transactions on Automatic Control.

M. Arshad Ansari, S. Haider, and N. A. Khan. Environmental Kuznets curve revisited: An analysis using ecological and material footprint. *Ecological Indicators*, 115:106416, Aug. 2020. ISSN 1470-160X. doi: 10.1016/j.ecolind.2020.106416. URL https://www.sciencedirect.com/science/article/pii/S1470160X20303538.

N. Bainton, D. Kemp, E. Lèbre, J. R. Owen, and G. Marston. The energy-extractives nexus and the just transition. *Sustainable Development*, 29(4):624–634, 2021. ISSN 1099-1719. doi: 10.1002/sd.2163. URL https://onlinelibrary.wiley.com/doi/abs/10.1002/sd.2163. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/sd.2163.

K. Bohnenberger. Money, Vouchers, Public Infrastructures? A Framework for Sustainable Welfare Benefits. *Sustainability*, 12(2):596, Jan. 2020. ISSN 2071-1050. doi: 10.3390/su12020596. URL https://www.mdpi.com/2071-1050/12/2/596. Number: 2 Publisher: Multidisciplinary Digital Publishing Institute.

T. Brambor, W. R. Clark, and M. Golder. Understanding Interaction Models: Improving Empirical Analyses. *Political Analysis*, 14(1):63–82, 2006. ISSN 1047-1987, 1476-4989. doi: 10.1093/pan/mpi014. URL https://www.cambridge.org/core/journals/political-analysis/article/abs/understanding-interaction-models-improving-empirical-analyses/9BA57B3720A303C61EBEC6DDFA40744B. Publisher: Cambridge University Press.

U. Brand, T. Boos, and A. Brad. Degrowth and post-extractivism: two debates with suggestions for the inclusive development framework. *Current Opinion in Environmental Sustainability*, 24:36–41, Feb. 2017. ISSN 1877-3435. doi: 10.1016/j.cosust.2017.01.007. URL https://www.sciencedirect.com/science/article/pii/S1877343517300179.

S. Bringezu. Possible Target Corridor for Sustainable Use of Global Material Resources. *Resources*, 4(1):25–54, Mar. 2015. ISSN 2079-9276. doi: 10.3390/resources4010025. URL https://www.mdpi.com/2079-9276/4/1/25. Number: 1 Publisher: Multidisciplinary Digital Publishing Institute.

J. Buhl, C. Liedtke, and K. Bienge. How Much Environment Do Humans Need? Evidence from an Integrated Online User Application Linking Natural Resource Use and Subjective Well-Being in

Germany. *Resources*, 6(4):67, Dec. 2017. ISSN 2079-9276. doi: 10.3390/resources6040067. URL https://www.mdpi.com/2079-9276/6/4/67. Number: 4 Publisher: Multidisciplinary Digital Publishing Institute.

J. Buhl, C. Liedtke, J. Teubler, and K. Bienge. The Material Footprint of private households in Germany: Linking the natural resource use and socioeconomic characteristics of users from an online footprint calculator in Germany. *Sustainable Production and Consumption*, 20:74–83, Oct. 2019. ISSN 2352-5509. doi: 10.1016/j.spc.2019.05.001. URL https://www.sciencedirect.com/science/article/pii/S235255091830407X.

M. Büchs and M. Koch. *Postgrowth and Wellbeing: Challenges to Sustainable Welfare*. Palgrave Macmillan, New York, NY, 1st ed. 2017 edition edition, Aug. 2017. ISBN 978-3-319-59902-1.

A. Coote and A. Percy. *The Case for Universal Basic Services*. John Wiley & Sons, Feb. 2020. ISBN 978-1-5095-3984-0. Google-Books-ID: xYDQDwAAQBAJ.

F. Creutzig, L. Niamir, X. Bai, M. Callaghan, J. Cullen, J. Díaz-José, M. Figueroa, A. Grubler, W. F. Lamb, A. Leip, E. Masanet, Mata, L. Mattauch, J. C. Minx, S. Mirasgedis, Y. Mulugetta, S. B. Nugroho, M. Pathak, P. Perkins, J. Roy, S. de la Rue du Can, Y. Saheb, S. Some, L. Steg, J. Steinberger, and D. Ürge Vorsatz. Demand-side solutions to climate change mitigation consistent with high levels of well-being. *Nature Climate Change*, pages 1–11, Nov. 2021. ISSN 1758-6798. doi: 10.1038/s41558-021-01219-y. URL https://www.nature.com/articles/s41558-021-01219-y. Bandiera_abtest: a Cg_type: Nature Research Journals Primary_atype: Research Publisher: Nature Publishing Group Subject_term: Climate-change mitigation;Socioeconomic scenarios Subject_term_id: climate-change-mitigation;socioeconomic-scenarios.

F. Dall'Orsoletta and B. Matthews. Material Footprint and Its Role in Agenda 2030. In W. Leal Filho, A. M. Azul, L. Brandli, A. Lange Salvia, and T. Wall, editors, *Decent Work and Economic Growth*, Encyclopedia of the UN Sustainable Development Goals, pages 683–695. Springer International Publishing, Cham, 2021. ISBN 978-3-319-95867-5. doi: 10.1007/978-3-319-95867-5_73. URL https://doi.org/10.1007/978-3-319-95867-5_73.

H. E. Daly, editor. *Toward a Steady-state Economy*. W.H.Freeman & Co Ltd, San Francisco, May 1973. ISBN 978-0-7167-0793-6.

X. D'Haultfœuille and P. Givord. La régression quantile en pratique. *Economie et Statistique*, 471:85–111, Oct. 2014. URL https://www.insee.fr/fr/statistiques/fichier/1377930/ECO471D.pdf.

L. Doyal and I. Gough. *A Theory of Human Need*. Guilford Press, 1991. ISBN 978-0-89862-419-9. Google-Books-ID: u8C8QgAACAAJ.

A. L. Fanning, D. W. O'Neill, and M. Büchs. Provisioning systems for a good life within planetary boundaries. *Global Environmental Change*, 64:102135, Sept. 2020. ISSN 0959-3780. doi: 10.1016/j.gloenvcha.2020.102135. URL `https://www.sciencedirect.com/science/article/pii/S0959378020307184`.

FAO. The State of Food Security and Nutrition in the World 2021. Technical report, Food and Agriculture Organization, 2021. URL `https://openknowledge.fao.org/items/efd29e45-4004-4ec0-baad-eb9ea69278eb`.

S. Giljum, M. Bruckner, and A. Martinez. Material Footprint Assessment in a Global Input-Output Framework. *Journal of Industrial Ecology*, 19(5):792–804, 2015. ISSN 1530-9290. doi: 10.1111/jiec.12214. URL `https://onlinelibrary.wiley.com/doi/abs/10.1111/jiec.12214`. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/jiec.12214.

I. Gough. Universal Basic Services: A Theoretical and Moral Framework. *The Political Quarterly*, 90(3):534–542, 2019. ISSN 1467-923X. doi: 10.1111/1467-923X.12706. URL `https://onlinelibrary.wiley.com/doi/abs/10.1111/1467-923X.12706`. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/1467-923X.12706.

G. Guzman and M. Kollar. Income in the United States: 2022. Technical report, US Census Bureau, Sept. 2023. URL `https://www.census.gov/library/publications/2023/demo/p60-279.html`. Section: Government.

J. Hickel. Is it possible to achieve a good life for all within planetary boundaries? *Third World Quarterly*, 40(1):18–35, Jan. 2019. ISSN 0143-6597. doi: 10.1080/01436597.2018.1535895. URL `https://doi.org/10.1080/01436597.2018.1535895`. Number: 1 Publisher: Routledge _eprint: https://doi.org/10.1080/01436597.2018.1535895.

J. Hickel. The sustainable development index: Measuring the ecological efficiency of human development in the anthropocene. *Ecological Economics*, 167:106331, Jan. 2020. ISSN 0921-8009. doi: 10.1016/j.ecolecon.2019.05.011. URL `https://www.sciencedirect.com/science/article/pii/S0921800919303386`.

J. Hickel, D. Sullivan, and H. Zoomkawala. Plunder in the Post-Colonial Era: Quantifying Drain from the Global South Through Unequal Exchange, 1960–2018. *New Political Economy*, 26(6): 1030–1047, Nov. 2021. ISSN 1356-3467. doi: 10.1080/13563467.2021.1899153. URL `https://doi.org/10.1080/13563467.2021.1899153`.

J. Hickel, C. Dorninger, H. Wieland, and I. Suwandi. Imperialist appropriation in the world economy: Drain from the global South through unequal exchange, 1990–2015. *Global Environmental Change*, 73:102467, Mar. 2022. ISSN 0959-3780. doi: 10.1016/j.gloenvcha.2022.102467. URL `https://www.sciencedirect.com/science/article/pii/S095937802200005X`.

V. U. Ijirshar. Trade Facilitation and Economic Growth Among Middle-Income Countries, Apr. 2022. URL `http://arxiv.org/abs/2204.11088`. arXiv:2204.11088 [econ].

IRP. Global Resources Outlook 2019: Natural Resources for the Future We Want. Technical report, United Nations Environment Program - International Resource Panel, 2019. URL `https://www.resourcepanel.org/reports/global-resources-outlook-2019`.

A. K. Jorgenson. Inequality and the carbon intensity of human well-being. *Journal of Environmental Studies and Sciences*, 5(3):277–282, Sept. 2015. ISSN 2190-6491. doi: 10.1007/s13412-015-0234-z. URL `https://doi.org/10.1007/s13412-015-0234-z`.

G. Kallis, C. Kerschner, and J. Martinez-Alier. The economics of degrowth. *Ecological Economics*, 84:172–180, Dec. 2012. ISSN 0921-8009. doi: 10.1016/j.ecolecon.2012.08.017. URL `https://www.sciencedirect.com/science/article/pii/S0921800912003333`.

G. Kallis, S. Paulson, G. D'Alisa, and F. Demaria. *The Case for Degrowth*. John Wiley & Sons, Sept. 2020. ISBN 978-1-5095-3564-4. Google-Books-ID: Xj4AEAAAQBAJ.

M. Lettenmeier, C. Liedtke, and H. Rohn. Eight Tons of Material Footprint—Suggestion for a Resource Cap for Household Consumption in Finland. *Resources*, 3(3):488–515, Sept. 2014. ISSN 2079-9276. doi: 10.3390/resources3030488. URL `https://www.mdpi.com/2079-9276/3/3/488`. Number: 3 Publisher: Multidisciplinary Digital Publishing Institute.

J. Martinez-Alier and M. Walter. Social Metabolism and Conflicts over Extractivism. In F. de Castro, B. Hogenboom, and M. Baud, editors, *Environmental Governance in Latin America*, pages 58–85. Palgrave Macmillan UK, London, 2016. ISBN 978-1-137-50572-9. doi: 10.1007/978-1-137-50572-9_3. URL `https://doi.org/10.1007/978-1-137-50572-9_3`.

M. A. Max-Neef, A. Elizalde, and M. Hopenhayn. *Human Scale Development: Conception, Application and Further Reflections*. Apex Press, 1991. ISBN 978-0-945257-35-6. Google-Books-ID: tHKzAAAAIAAJ.

S. P. Nathaniel. Natural Resources, Urbanisation, Economic Growth and the Ecological Footprint in South Africa: The Moderating Role of Human Capital. *Quaestiones Geographicae*, 40(2): 63–76, June 2021. doi: 10.2478/quageo-2021-0012. URL `https://sciendo.com/article/10.2478/quageo-2021-0012`.

OECD. Health at a Glance 2021: OECD indicators. Technical report, OECD, Paris, Nov. 2021. URL https://doi.org/10.1787/ae3016b9-en.

D. W. O'Neill, A. L. Fanning, W. F. Lamb, and J. K. Steinberger. A good life for all within planetary boundaries. *Nature Sustainability*, 1(2):88–95, Feb. 2018. ISSN 2398-9629. doi: 10.1038/s41893-018-0021-4. URL https://www.nature.com/articles/s41893-018-0021-4. Bandiera_abtest: a Cg_type: Nature Research Journals Number: 2 Primary_atype: Research Publisher: Nature Publishing Group Subject_term: Environmental social sciences;Sustainability Subject_term_id: environmental-social-sciences;sustainability.

T. Parrique. *The political economy of degrowth.* These de doctorat, Université Clermont Auvergne (2017-2020), Dec. 2019. URL https://www.theses.fr/2019CLFAD003.

A. S. M. A. Quium. Transport Corridors for Wider Socio–Economic Development. *Sustainability*, 11(19):5248, Jan. 2019. ISSN 2071-1050. doi: 10.3390/su11195248. URL https://www.mdpi.com/2071-1050/11/19/5248. Number: 19 Publisher: Multidisciplinary Digital Publishing Institute.

N. D. Rao and J. Min. Decent Living Standards: Material Prerequisites for Human Wellbeing. *Social Indicators Research*, 138(1):225–244, July 2018. ISSN 1573-0921. doi: 10.1007/s11205-017-1650-0. URL https://doi.org/10.1007/s11205-017-1650-0.

K. Raworth. *Doughnut Economics: Seven Ways to Think Like a 21st-Century Economist.* Chelsea Green Publishing, Feb. 2017. ISBN 978-1-60358-675-7. Google-Books-ID: SUYtDgAAQBAJ.

A. Razzaq, T. Ajaz, J. C. Li, M. Irfan, and W. Suksatan. Investigating the asymmetric linkages between infrastructure development, green innovation, and consumption-based material footprint: Novel empirical estimations from highly resource-consuming economies. *Resources Policy*, 74:102302, Dec. 2021. ISSN 0301-4207. doi: 10.1016/j.resourpol.2021.102302. URL https://www.sciencedirect.com/science/article/pii/S0301420721003123.

K. Richardson, W. Steffen, W. Lucht, J. Bendtsen, S. E. Cornell, J. F. Donges, M. Drüke, I. Fetzer, G. Bala, W. von Bloh, G. Feulner, S. Fiedler, D. Gerten, T. Gleeson, M. Hofmann, W. Huiskamp, M. Kummu, C. Mohan, D. Nogués-Bravo, S. Petri, M. Porkka, S. Rahmstorf, S. Schaphoff, K. Thonicke, A. Tobian, V. Virkki, L. Wang-Erlandsson, L. Weber, and J. Rockström. Earth beyond six of nine planetary boundaries. *Science Advances*, 9(37):eadh2458, Sept. 2023. doi: 10.1126/sciadv.adh2458. URL https://www.science.org/doi/10.1126/sciadv.adh2458. Publisher: American Association for the Advancement of Science.

J. Rockström, W. Steffen, K. Noone, Persson, F. S. Chapin, E. Lambin, T. M. Lenton, M. Scheffer, C. Folke, H. J. Schellnhuber, B. Nykvist, C. A. de Wit, T. Hughes, S. van der Leeuw, H. Rodhe, S. Sörlin, P. K. Snyder, R. Costanza, U. Svedin, M. Falkenmark, L. Karlberg, R. W. Corell, V. J. Fabry, J. Hansen, B. Walker, D. Liverman, K. Richardson, P. Crutzen, and J. Foley. Planetary Boundaries: Exploring the Safe Operating Space for Humanity. *Ecology and Society*, 14(2), 2009. ISSN 1708-3087. URL `https://www.jstor.org/stable/26268316`. Number: 2 Publisher: Resilience Alliance Inc.

M. Sandberg. Sufficiency transitions: A review of consumption changes for environmental sustainability. *Journal of Cleaner Production*, 293:126097, Apr. 2021. ISSN 0959-6526. doi: 10.1016/j.jclepro.2021.126097. URL `https://www.sciencedirect.com/science/article/pii/S0959652621003176`.

B. Stratford and D. O'Neill. The UK's path to a Doughnut-Shaped Recovery. Policy Brief 5, University of Leeds, Leeds, UK, Dec. 2020. URL `https://goodlife.leeds.ac.uk/wp-content/uploads/sites/20/2020/11/doughnut-shaped-recovery-report.pdf`.

UNDP. The next frontier: Human development and the Anthropocene. Human Development Report, United Nations Development Programme, New York, USA, 2020. URL `https://report.hdr.undp.org/`.

J. Vogel, J. K. Steinberger, D. W. O'Neill, W. F. Lamb, and J. Krishnakumar. Socio-economic conditions for satisfying human needs at low energy use: An international analysis of social provisioning. *Global Environmental Change*, 69:102287, July 2021. ISSN 0959-3780. doi: 10.1016/j.gloenvcha.2021.102287. URL `https://www.sciencedirect.com/science/article/pii/S0959378021000662`.

H. Wang, Y. Wei, Y. Wu, X. Wang, Y. Wang, G. Wang, and Q. Yue. Spatiotemporal dynamics and influencing factors of the global material footprint. *Environmental Science and Pollution Research*, 29(12):18213–18224, Mar. 2022. ISSN 1614-7499. doi: 10.1007/s11356-021-16923-7. URL `https://doi.org/10.1007/s11356-021-16923-7`.

T. O. Wiedmann, H. Schandl, M. Lenzen, D. Moran, S. Suh, J. West, and K. Kanemoto. The material footprint of nations. *Proceedings of the National Academy of Sciences*, 112(20):6271–6276, Sept. 2013. doi: 10.1073/pnas.1220362110. URL `https://www.pnas.org/doi/abs/10.1073/pnas.1220362110`. Publisher: Proceedings of the National Academy of Sciences.

K. Wiesen and M. Wirges. From cumulated energy demand to cumulated raw material demand: the material footprint as a sum parameter in life cycle assessment. *Energy, Sustainability and*

Society, 7(1):13, May 2017. ISSN 2192-0567. doi: 10.1186/s13705-017-0115-2. URL https://doi.org/10.1186/s13705-017-0115-2.

R. Wilkinson and K. Pickett. *The Spirit Level: Why Equality is Better for Everyone*. Penguin Books Limited, Nov. 2010. ISBN 978-0-241-95429-4. Google-Books-ID: yKCBMncCw4kC.

S. Zhang, D. Zhu, and L. Li. Urbanization, Human Inequality, and Material Consumption. *International Journal of Environmental Research and Public Health*, 20(5):4582, Jan. 2023. ISSN 1660-4601. doi: 10.3390/ijerph20054582. URL https://www.mdpi.com/1660-4601/20/5/4582. Number: 5 Publisher: Multidisciplinary Digital Publishing Institute.

Table 2. Provisioning factors used in the study

Variable name (abbreviation)	**Description and [units]**	**Transformation used**	**Indicator source**
Access to clean fuel (CF)	Percentage of population with access to non-solid fuels [%]	Identity	World Bank WDI 2019
Electricity access (EA)	Percentage of population with access to electricity [%]	Saturation	World Bank WDI 2019
Economic growth (Growth)	3-year (2017, 2018, 2019) average percentage annual growth rate of GDP at market prices based on constant local currency	Saturation	World Bank WDI 2019
Income inequality (Gini)	Gini index	Logarithmic	World Bank WDI 2019
Extractivism (Extra)	Share of total value generation obtained from total natural resources rents [% of GDP]	Logarithmic	World Bank WDI 2019
Trade and transport infrastructures (TTI)	Quality of trade and transport-related infrastructures [1-5 scale]	Logarithmic	World Bank WDI 2019
Trade penetration (Trade)	Share of trade in the total value generation [% of GDP]	Logarithmic	World Bank WDI 2019
Urban population (UP)	Share of urban population [%]	Identity	World Bank WDI 2019
Public health coverage (PHC)	Percentage of total health expenditure covered by government, nongovernmental organisations, and social health insurance funds [%]	Identity	World Bank WDI 2019
Public service quality (PSQ)	Perception of the quality of public services, civil service, policy formulation, and implementation [score]. *Government effectiveness rescaled from 0 to 1.*	Logarithmic	World Bank WGI 2019
Democratic quality (DQ)	Citizen's ability to participate in selecting government, freedom of expression and association, free media [score]. *Voice and accountability rescaled from 0 to 1.*	Logarithmic	World Bank WGI 2019
Control of corruption (CC)	Extent to which public power is used for private gain through corruption and "capture" of the state by elites [score]. *Rescaled on a 100 scale.*	Logarithmic	World Bank WGI 2019
Rule of law (RoL)	Extent to which agents have confidence in and abide by the rules of society, as well as likelihood of crime and violence [score]. *Rescaled on a 100 scale.*	Logarithmic	World Bank WGI 2019

Table 3. Bivariate regression results

	Dependent variables:					
	$(\widetilde{DWA})$	$(\widetilde{SSA})$	$(\widetilde{SN})$	$(\widetilde{MI})$	$(\widetilde{HLE})$	$(\widetilde{BE})$
Mat. foot.	**0,796*** **	**0,771*** **	**0,717*** **	**0,813*** **	**0,748*** **	**0,739*** **
	(0.044)	(0.046)	(0.072)	(0.055)	(0.061)	(0.065)
Constant	-0.003	-0.000	0.011	0.0004	-0.013	0.005
	(0.049)	(0.052)	(0.062)	(0.059)	(0.056)	(0.055)
Adj. R^2	*0.6337*	*0.5914*	*0.4847*	*0.5983*	*0.5358*	*0.5427*

Note: *p<0.1; **p<0.05; ***p<0.01.
Coefficient signs have been reversed to fit the original variables space and ease the reading. DWA = Drinking water access; SSA = Safe sanitation access; SN = Sufficient nourishment; MI = Minimum income; HLE = Healthy life expectancy; BE = Basic education

Table 4. Quantile regression results

	Percentile	(Intercept)		(Material footprint)	
		Coefficient	Std. error	Coefficient	Std. error
DWA	25th	**70,67602*** **	4,33138	**0,5713*** **	0,15523
	50th	**89,16199*** **	2,188822	**0,29254*** **	0,07781
	75th	**96,32094*** **	1,50041	**0,12278***	0,06296
SSA	25th	**40,32946*** **	6,12105	**1,16262*** **	0,2987
	50th	**76,62241*** **	5,77342	**0,61878*** **	0,19733
	75th	**95,03266*** **	2,98665	0,14492	0,11752
SN	25th	**83,31610*** **	2,43086	**0,28709*** **	0,10329
	50th	**92,93483*** **	1,23316	**0,12352*** **	0,04204
	75th	**96,74981*** **	0,86717	0,02513	0,03296
MI	25th	**69,15371*** **	6,56477	**0,78490*** **	0,19563
	50th	**92,24853*** **	3,84938	**0,22949***	0,13162
	75th	**98,00774*** **	0,61794	**0,06618** **	0,03137
HLE	25th	**56,12312*** **	0,72692	**0,27511*** **	0,0414
	50th	**60,15542*** **	0,79098	**0,27602*** **	0,042
	75th	**64,07515*** **	0,86902	**0,20276*** **	0,04789
BE	25th	**45,60758*** **	2,87442	**0,82018*** **	0,22409
	50th	**56,31290*** **	3,55668	**0,88747*** **	0,18004
	75th	**65,36378*** **	3,45382	**0,82602*** **	0,16164

Note: *p<0.1; **p<0.05; ***p<0.01.
DWA = Drinking water access; SSA = Safe sanitation access; SN = Sufficient nourishment; MI = Minimum income; HLE = Healthy life expectancy; BE = Basic education

Table 5. Regression results for Model A

	Dependent variable:					
	$\widetilde{DWA}$	$\widetilde{SSA}$	$\widetilde{SN}$	$\widetilde{MI}$	$\widetilde{HLE}$	$\widetilde{BE}$
	(1)	(2)	(3)	(4)	(5)	(6)
$\widetilde{Mat.footprint}$	0.475^{***}	0.454^{***}	0.462^{***}	0.429^{***}	0.339^{***}	0.366^{***}
$\widetilde{Extractivism}$	-0.171^{***}	-0.110^{*}	-0.143^{**}	-0.113	-0.281^{***}	-0.151^{***}
$\widetilde{Income\,equality}$	0.105^{**}	0.188^{***}	0.259^{***}	0.192^{***}	0.225^{***}	0.267^{***}
$\widetilde{Urban\,pop.}$	0.341^{***}	0.315^{***}	0.159^{*}	0.342^{***}	0.375^{***}	0.338^{***}
R^2	0.723	0.674	0.579	0.685	0.726	0.676
Adjusted R^2	0.715	0.665	0.566	0.673	0.718	0.667

Note: *p<0.1; **p<0.05; ***p<0.01

Coefficient signs have been reversed to fit the original variables space and ease the reading. DWA = Drinking water access; SSA = Safe sanitation access; SN = Sufficient nourishment; MI = Minimum income; HLE = Healthy life expectancy; BE = Basic education

Table 6. Regression results for Model B

	Dependent variable:					
	$\widetilde{DWA}$	$\widetilde{SSA}$	$\widetilde{SN}$	$\widetilde{MI}$	$\widetilde{HLE}$	$\widetilde{BE}$
	(1)	(2)	(3)	(4)	(5)	(6)
$\widetilde{Mat.footprint}$	0.498^{***}	0.464^{***}	0.285^{***}	0.559^{***}	0.333^{***}	0.286^{***}
$\widetilde{Public\,service\,quality}$	0.251^{***}	0.161^{**}	0.515^{***}	0.335^{***}	0.207^{**}	0.225^{**}
$\widetilde{Income\,equality}$	0.042	0.089	0.155^{***}	0.124^{*}	0.140^{**}	0.180^{***}
$\widetilde{Trade\,and\,transp.\,infra.}$	0.134^{**}	0.229^{***}	0.043	0.098	0.338^{***}	0.350^{***}
R^2	0.689	0.666	0.661	0.648	0.716	0.716
Adjusted R^2	0.679	0.656	0.650	0.635	0.708	0.708

Note: *p<0.1; **p<0.05; ***p<0.01

Coefficient signs have been reversed to fit the original variables space and ease the reading. DWA = Drinking water access; SSA = Safe sanitation access; SN = Sufficient nourishment; MI = Minimum income; HLE = Healthy life expectancy; BE = Basic education

Post-Growth Economics Network
Working Paper 05/2025
February 2025
by Félix Garnier