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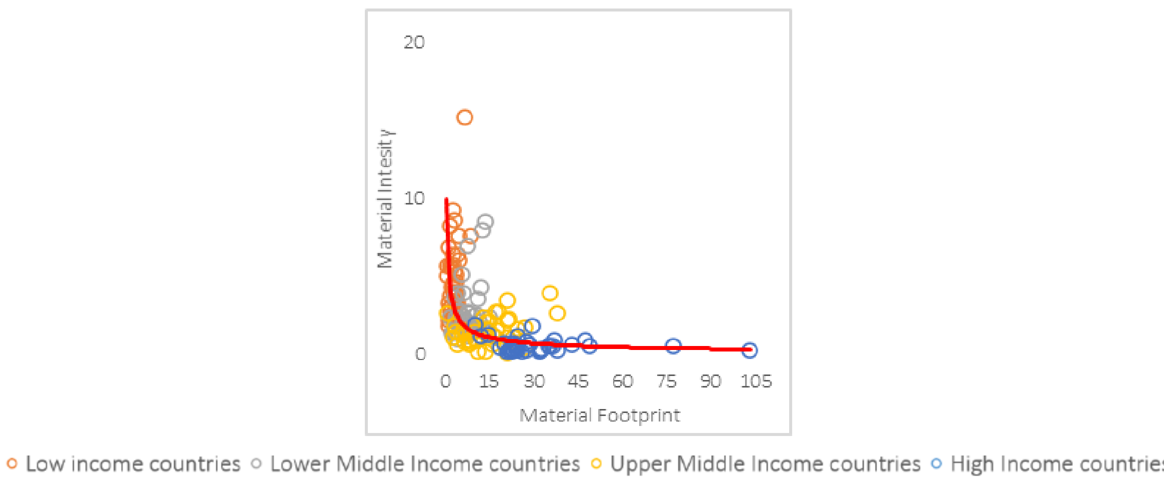
In this supplementary document, we provide some of the subplots of Figures 1 and 2 and some complementary information for Table 2 and Table 3. In addition, we add some more information about the selected indicators and index: how are they constructed, what are the main aims of their creators (when constructing these indicators), and how have they evolved over time/ What are the main criticisms of them?

Supplementary Tables and Figures

Supplementary information Table 2.

We have also computed a matrix correlation according to a best fit curve. The best-fit curve is the one that minimizes the sum of squared residuals (García, 2008) according to the highest R^2 and using Akaike's Information Criterion (AIC) (O'Neil *et al.*, 2018). We have followed these steps:

1. First: we chose the best fit curve according to the highest R^2. For instance, the best fit curve for the relationship between Material Footprint (x) and Material Intensity (y) is Power, as shown:



2. Once we found the model that fits best to the (according to the lowest AIC), we linearized it, applying the following transformations:

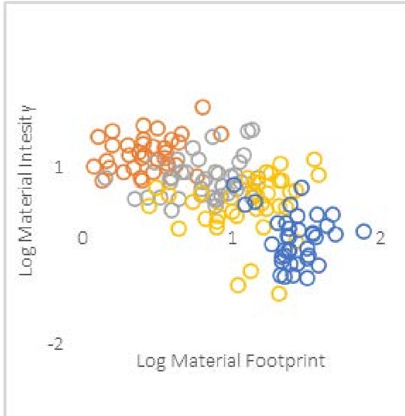
L=Linear. The two variables are considered in levels.

Log=Logarithmic. Variable x (column) was transformed into a log.

Pow=Power. Both variables were transformed into logs.

Exp=Exponential. Variable y (row) was transformed into a log.

In the case of the relationship between Material Footprint (x) and Material Intensity (y) we transformed both variables into log.



3. After that we computed the correlations.

We correlated Log Material Intensity and Log Material Footprint.

X \ Y	Material Footprint	Domestic Material Consumption	Material Intensity	Environmental Performance Index	Ecological Footprint	Carbon Footprint	Co2 Emission (territorial)
Material Footprint	1	0.78**Pow	-0.64**Pow	-0.74**Log	0.77**Pow	0.84**L	0.76**Pow
Domestic Material Consumption	0.78**Pow	1	-0.34**Log	-0.62**Log	0.8**Pow	0.8**Pow	0.84**Pow
Material Intensity	-0.64**Pow	-0.34**Exp	1	0.78**Pow	-0.58**Pow	-0.68**Pow	-0.58**Pow
Environmental Performance Index	-0.74**Exp	-0.62**Exp	0.78**Pow	1	-0.71**Exp	-0.71**Exp	-0.65**Exp
Ecological Footprint	0.77**Pow	0.8**Pow	-0.58**Pow	-0.71**Log	1	0.86**Pow	0.85**Pow
Carbon Footprint	0.84**L	0.8**Pow	-0.68**Pow	-0.71**Log	0.86**Pow	1	0.93**Pow
Co2 Emission (territorial)	0.76**Pow	0.84**Pow	-0.58**Pow	-0.65**Log	0.85**Pow	0.93**Pow	1

Supplementary Table 2: Correlations between all measurements. N=155 countries; 97,32% of the populations; all the correlations are significant at 99% level of confidence Source: Own figure based on Environmental Performance Index database, UN Environment International Resource Panel, Environment Live / Global Material Flows and Global Footprint Network and EORA database.

Supplementary information Table 3 and Table 4

Calculating the strength of relationships. The strength of the relationship between each measurement and GDP per capita pair was estimated using ordinary least squares (OLS) regression. Three curves were tested in each case: (1) linear, (2) linear–logarithmic and (3) Quadratic. The equation for each curve is provided below:

1) Linear: $y = a + bx$ *if* $b < 0$ *negative linear relationship, scenario: Productive Confidence. Green Growth, if* $b > 0$ *positive linear relationship, scenario Ecological Prevention. Degrowth* critique

2) Linear-logarithmic $y = a + b\ logx$ *if* $b < 0$ *negative log-linear relationship, scenario Productive Confidence Green Growth, if* $b > 0$ *positive log-linear, scenario: diminishing resource use* with higher GPD per capita, as some of the theories embedded in the Productive Confident are arguing.

3) second grade polynomial function $y = a + b_1 X + b_2(x - \overline{x})^2$ *if* $b_2 < 0$ *and the peak of income (*$peak\ of\ income = \bar{x} - (\frac{b_1}{2\ b_2})$ *) should be within the range of the incomes existing in the sample: otherwise, only one half of the inverted U is observed. Then the curve is concave and inverted U shape, scenario: Productive Confidence. EKC.* The square Predictor has been centred to prevent co-linearity between the linear and quadratic income terms (Steinberger *et al*., 2013)

We chose these models for testing which scenario (Ecological Prevention or Productive Confidence) fits better for all measurements.

The Ecological Prevention scenario argues that environmental sustainability measurements increase linearly with GDP (equation 1 if $b > 0$).

On the contrary, some theories embedded in the Productive Confidence argue that environmental sustainability measurements decrease with GDP per capita (negative relationship following equations 1 or 2).

Others, like EKC posits that various environmental problems will get worse as economies grow, but then decline as economic activity and environmental governance act to clean up and repair current damage (equations 2 if $b_2 < 0$ and the peak of income was overstepped – an inverted U shape.

Following O'Neil *et al.* (2018) the best-fit curve was determined using Akaike's Information Criterion (AIC).

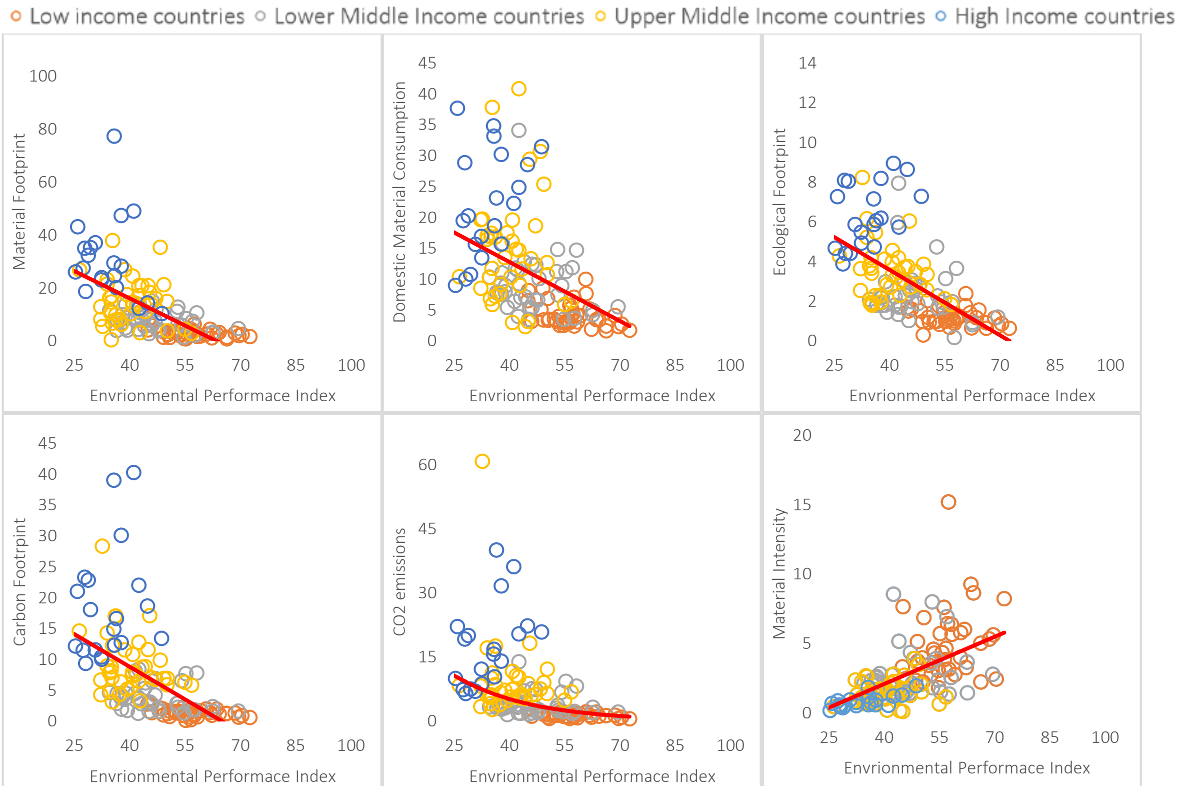
Supplementary Figure 1. Comparing all the measures against each other.
Grouped by income national per capita level (GDP ppp 2018)

N=155 countries; 97.32% of the populations; all the correlations are significant at 99% level of confidence

Source: Own figure based on Environmental Performance Index database, UN Environment International Resource Panel, Environment Live / Global Material Flows, Global Footprint Network and EORA database and The World Bank Database.

Material Footprint against the other measurements

Environmental Performance Index against the other measurements

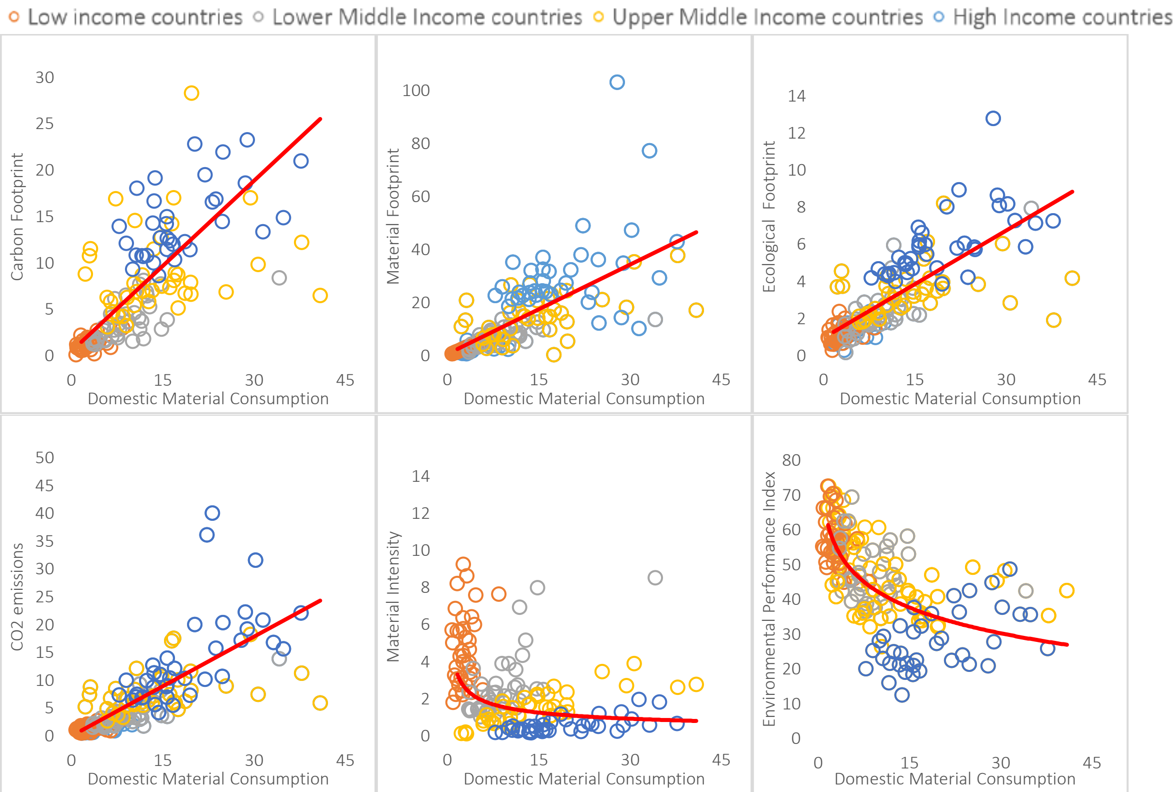


Carbon Footprint against the other measurements

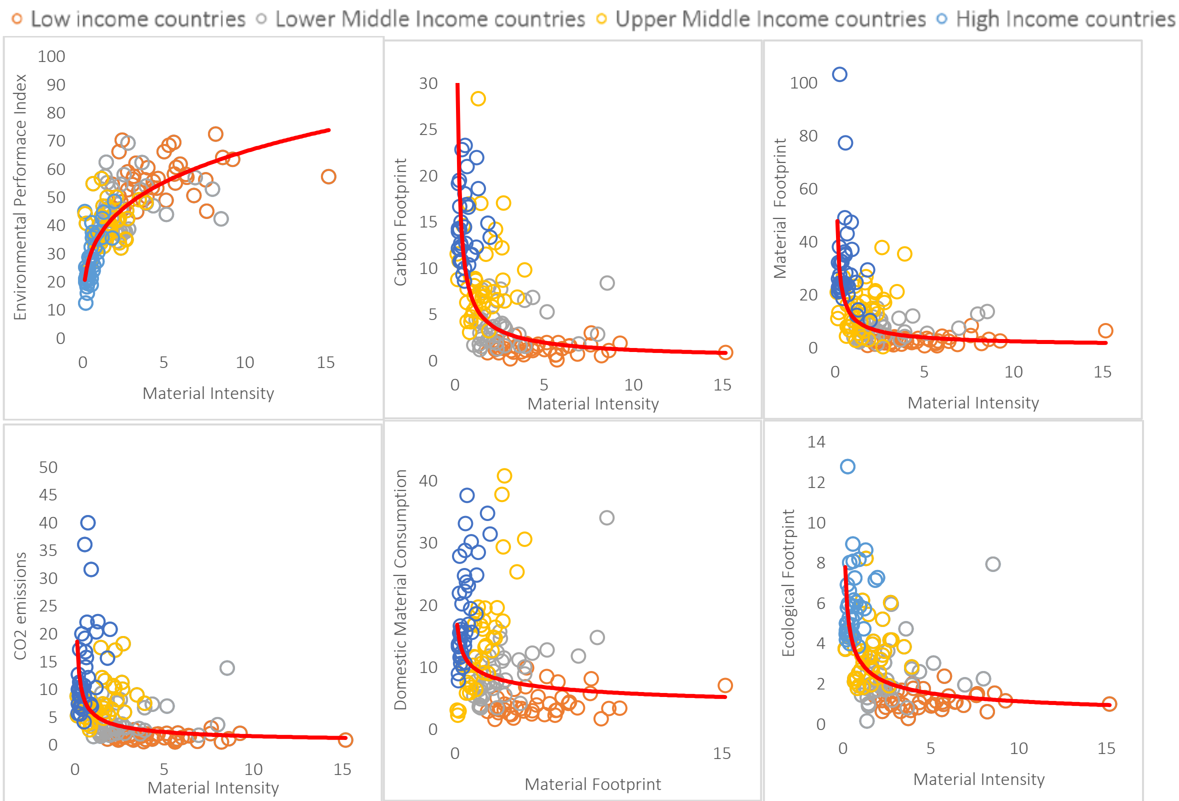
Ecological Footprint against the other measurements

CO_2 emissions against the other measurements

Domestic Material Consumption against the other measurements



Material Intensity against the other measurements



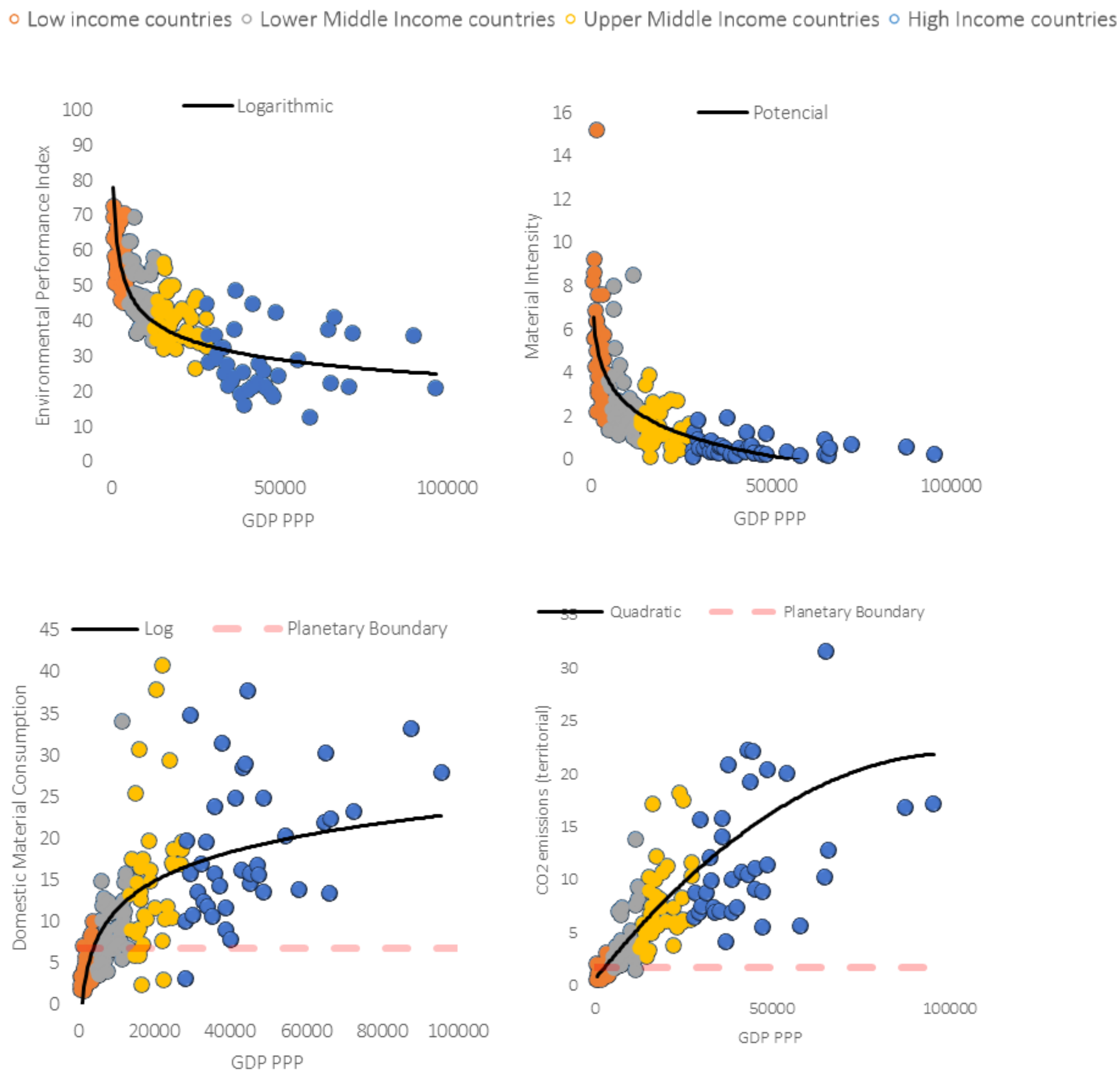
N=155 countries; 97,32% of the populations; all the correlations are significant at 99% level of confidence

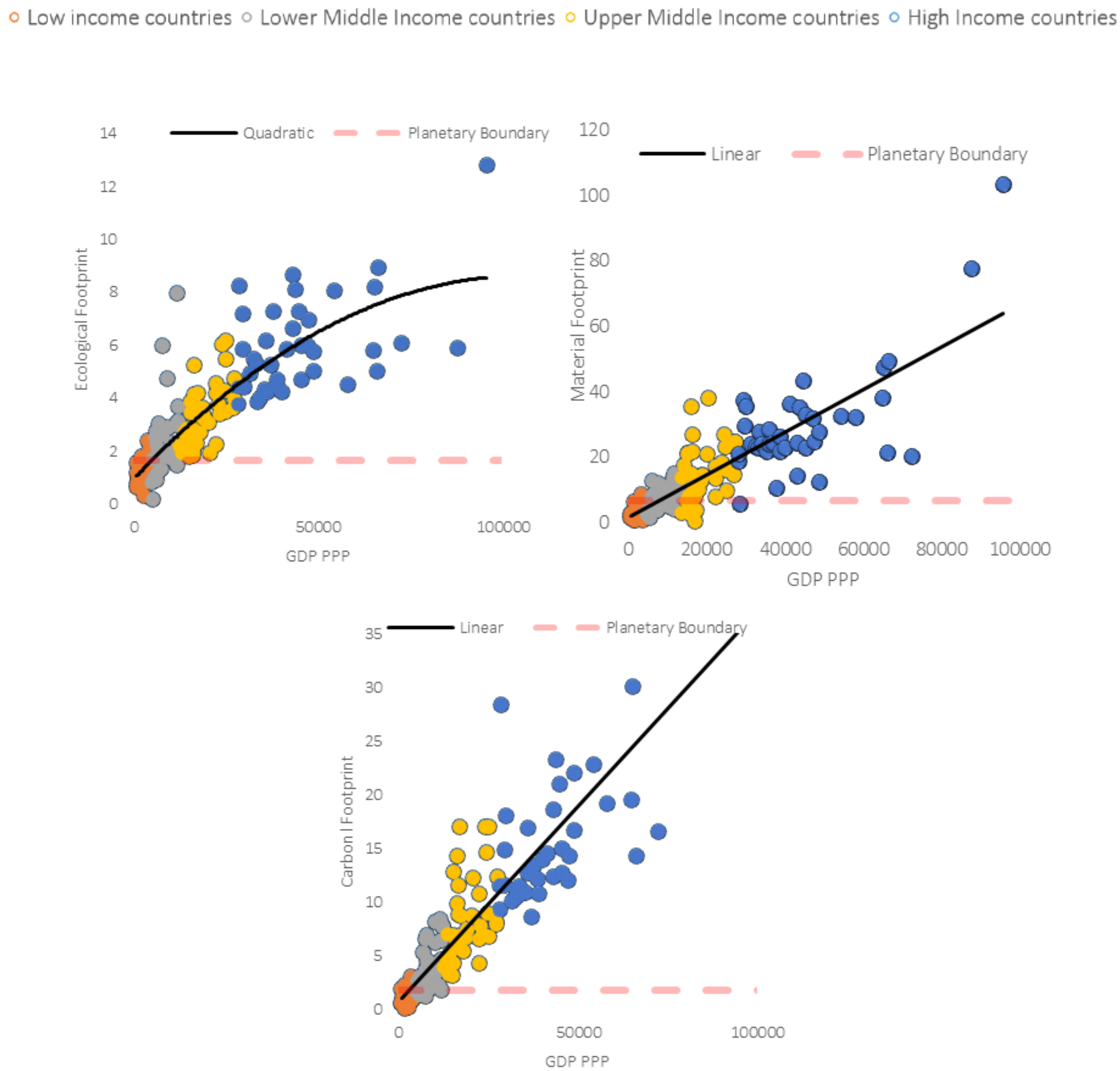
Source: Own figure based on Environmental Performance Index database, UN Environment International Resource Panel, Environment Live / Global Material Flows, Global Footprint Network and EORA database and The World Bank Database.

Supplementary Figure 2. Relationships between all measurements and GDP
Grouped by income national per capita level (GDP ppp 2018)

N=155 countries; 97,32% of the populations; all the correlations are significant at 99% level of confidence

Source: Own figure based on Environmental Performance Index database, UN Environment International Resource Panel, Environment Live / Global Material Flows, Global Footprint Network and EORA database and The World Bank Database





Source: Own figure based on Environmental Performance Index database, UN Environment International Resource Panel, Environment Live / Global Material Flows, Global Footprint Network and EORA database and The World Bank Database. N=155 countries; 97,32% of the populations; all the correlations are significant at 99% level of confidence.

Information about the selected indicators

1. The Environmental Performance Index

The Environmental Performance Index is produced by the Centre for Environmental Law and Policy in Yale University, the Yale Data-Driven Environmental Solutions Group and the Centre for International Earth Science Information Network in Columbia University. It is used by the World Economic Forum. The objective that underlines this index were explained in the 2018 Environmental Performance Index report:

> To meet the ambitious targets outlined in the United Nations 2015 Sustainable Development Goals (SDGs) and the Paris Climate Agreement, countries must integrate environmental performance metrics across a range of pollution control and natural resources targets. (…) The Environmental Performance Index thus offers a scorecard that highlights leaders and laggards in environmental performance, gives insight on best practices, and provides guidance for countries that aspire to be leaders in sustainability. (Wendling, *et. al*, 2018: vi)

The Environmental Performance Index uses a hierarchical framework that groups indicators within issue categories, issue categories within policy objectives, and policy objectives within the overall index (see Table 1). **However, to be consistent with the other indicator's convention of a higher value on the indicators representing poor environmental performance, we have inverted the scores for the purpose of this analysis so that higher values indicate poor performance.** The EPI is based upon two policy objectives: Environmental Health, which measures threats to human health, and Ecosystem Vitality, which measures natural resources and ecosystem services... In the 2018 EPI, 24 indicators are grouped within 10 issue categories: Air Quality, Water & Sanitation, Heavy Metals, Biodiversity & Habitat, Forests, Fisheries, Climate & Energy, Air Pollution, Water Resources, and Agriculture. A country's EPI score can be disaggregated to levels of the policy objectives or the issue categories, allowing performance to be tracked at different levels (see Table 1).

	Policy Objective		**Issue Category**			**Indicator**		
	Title	Weight	Title	Intermediate Weight	Weight	Title	Intermediate Weight	Weigh
	Environmental Health	40%	Air Quality	65%	26%	Household Solid Fuels	40%	10%
						$PM_{2.5}$ Exposure	30%	8%
						$PM_{2.5}$ Exceedance	30%	8%
			Water & Sanitation	30%	12%	Drinking Water	50%	6%
						Sanitation	50%	6%
			Heavy Metals	5%	2%	Lead Exposure	100%	2%
	Ecosystem Vitality	60%	Biodiversity & Habitat	25%	15%	Marine Protected Areas	20%	3%
						Biome Protection (National)	20%	3%
						Biome Protection (Global)	20%	3%
						Species Protection Index	20%	3%
						Representativeness Index	10%	2%
						Species Habitat Index	10%	2%
			Forests	10%	6%	Tree Cover Loss	100%	6%
			Fisheries	10%	6%	Fish Stock Status	50%	3%
						Regional Marine Trophic Index	50%	3%
			Climate & Energy	30%	18%	CO_2 Emissions – Total	50%	9%
						CO_2 Emissions – Power	20%	4%
						Methane Emissions	20%	4%
						N_2O Emissions	5%	1%
						Black Carbon Emissions	5%	1%
			Air Pollution	10%	6%	SO_2 Emissions	50%	3%
						NO_X Emissions	50%	3%
			Water Resources	10%	6%	Wastewater Treatment	100%	6%
			Agriculture	5%	3%	Sustainable Nitrogen Management	100%	3%
EPI	EPI	100%			100%			100%

Table 1. Components and weights and of 2018 EPI: Source: 2018 Environmental Performance Index database.

Several steps are undertaken to prepare the data for the EPI. First, each indicator is assembled. In some cases, this process requires calculations. Some variables must be standardized in order to be comparable across countries and over years. Greenhouse Gas (GHG) emissions, for example, must be divided by the size of each country's economy, as measured by GDP, to calculate carbon intensity. Other normalizations include dividing by units of area or population, calculating percentage change, developing trends over time, or taking weighted averages of several variables. The Technical Appendix of the EPI 2018 describes these normalizations for relevant indicators in greater detail.

After that, the data of every indicator is rescaled into a 0–100 score. This process puts all the indicators on a common scale that can be compared and aggregated into the composite index. Then the 24 indicators (Table 1) are aggregated at each level of the framework hierarchy. Aggregation entails combining weighted variables. The composite index is derived from K variables x_i thus:

(1)

$$Environmental\ Performance\ Index_j = \sum_{i=1}^{K} W_i X_{ij}$$

Where *j* is one of the countries being measured by the composite indicator, *Environmental Performance Index$_j$* its score, and $X_{j1}, X_{j2}, \cdots, X_{jk}$ are its normalized scores on the k variables (either Issue categories, Policy Objective or Indicators). The weights W_i are determined by the index's developers (see Table 1 and see Saltelli *et al.*, 2008).

Here we use the results from 2018 Environmental Performance Index obtained directly from the Environmental Performance Index database.

The Econometrics and Applied Statistics Unit at the European Commission Joint Research Centre (JRC) has criticized this index (Athanasoglou *et al*., 2014; Saisana and Saltelli, 2010). According to them, although several and different indicators compound the Environmental Performance Index, few are strong determinants of good environmental performance. They have questioned the differences between the weights that have been given to some indicators (that are compounding this index) and their real impact on it (*ibid*.). According to Saltelli *et al.* (2011) the weights as used in the Environmental Performance Index are not measures of importance, but rather measures of trade of among variables.

More precisely the ratio of the weights measures how much of a given indicator must be given up to offset or balance a unit increase in another indicator. Imagine an EPI that has only two indicators (i.e. CO_2 Emissions and Drinking Water) given the same weight (0.5 each indicator). If a given country wants to lose 1 point in CO_2 Emissions but does not want to lose units of EPI, how much should the Drinking Water Indicator vary to offset a unit decrease in CO_2 Emissions? $\frac{\text{CO2 Emissions } Weight}{\text{Drinking Water } Weight} = \frac{0.5}{0.5} = 1$. Therefore, if a country decreases a unit of CO_2 emissions but increases a unit of Drinking Water the EPI remains constant (see Figure 1). That is why, according to Saltelli *et al.* (2011) weights are not a measure of importance, but a measure of trade-offs of total emissions.

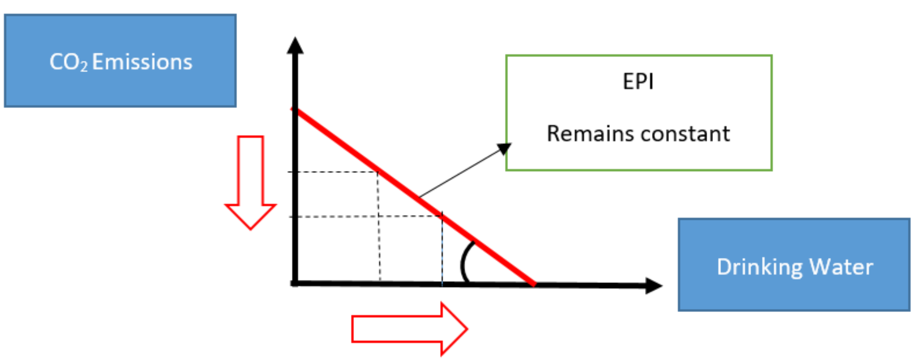


Figure 1: Example trade-off between EPI indicators. Source: Own elaboration.

Following Saltelli *et al.* (2011) and Becker *et al.* (2017), we distinguish between weights (W_i) and importance (I_i) ($W_i \neq I_i$). According to these authors, importance has to do with how much of the variance of the EPI is explained by each indicator. They use three measures of importance: r_s (Spearman correlation coefficient); R^2 (coefficient of determination); S_i (First Order Sensitivity Index, for more details see Becker, *et al*. (2017)). One would expect that a measure of importance of an indicator will give a value which, while not identical to the weight, would at least not contradict it openly (Saltelli *et al.*, 2011). However, this is not the case for 2018 EPI. For instance, Tree Loss Cover and Wastewater Treatment with the same weighting (6%) are differently presented in the EPI. The measures of importance with respect to the EPI for Tree Loss cover are r_s =0.099 non-significant, R^2 = 0.000 non-significant and S_i = 0.045, whilst for Wastewater treatment these measurements are r_s =0.82, R^2 = 0.612 and S_i = 0.665 (all of them statistically significant). We have also plotted this graphically (Figures 2 and Figures 3).

The red lines in Figures 2 show a linear regression used for computing R^2. The wastewater treatment indicator explains 61.15% of the linear variability in the EPI, while the Tree Loss Cover does not explain much variability (R^2=0.000) The black line pictures a non-linear regression used for computing S_i.

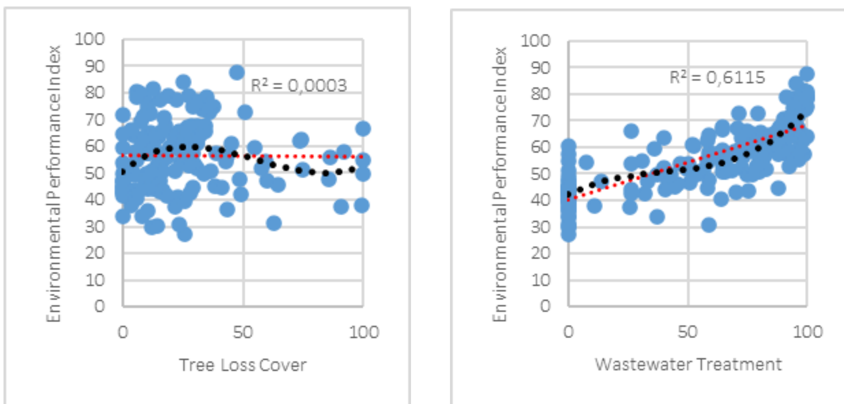


Figure 2: Relationships between Environmental Performance Index score and Tree Loss Cover Score and Relationships between Environmental Performance Index score and Wastewater Treatment Score. Source: Own figures based on Environmental Performance Index database.

In Figure 3, we can observe the Spearman rank correlation (r_s) between the selected indicators and the EPI. Wastewater Treatment is strongly and positively correlated with the Environmental Performance Index (r_s=0.82). Meanwhile Tree Loss cover has a weak and non-significant correlation with the Environmental Perfomance Index (r_s=0.09).

The three measures of importance of some indicators are in contradiction with their assigned weights. As showed in Table 3, the three measures of importance are indicating that the main driver indicators of the 2018 EPI are: Exposure to indoor air pollution from Household Solid Fuels, Unsafe drinking water, Unsafe Sanitation, Lead exposure and Wastewater treatment. However, the indicators that are weighting the most on the Environmental Performance Index are not the same ones: Household Solid fuels, PM2.5 Exceedance, PM2.5 Exposure and CO_2 total emissions.

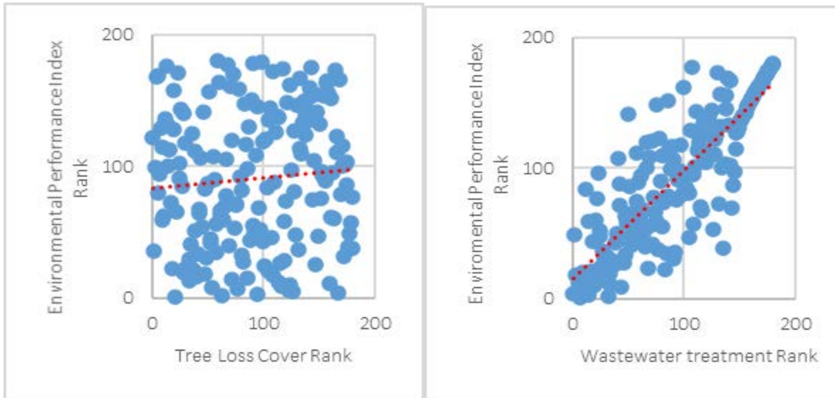


Figure 3: Relationships between Environmental Performance Index Rank and Tree Loss Cover rank and relationships between Environmental Performance Index Rank and Wastewater Treatment Rank. Source: Own figures based on Environmental Performance Index Table 3. The three measurements of importance and weights of the 24 indicators of the EPI.

	S_I ***First-order sensitivity Index***	r_s **Spearman Correlation Coefficient**	R^2 **Coefficient of determination**	W_i **% weight %**	W_i **weight**
Drinking Water	0.753	0.840	0.748	6.00	0.06
Sanitation	0.750	0.843	0.739	6.00	0.06
Household Solid Fuels	0.666	0.819	0.648	10.40	0.10
Wastewater Treatment	0.665	0.820	0.612	6.00	0.06
Lead Exposure	0.512	0.700	0.512	2.00	0.02
Black Carbon Emissions	0.313	0.556	0.307	0.90	0.01
Methane Emissions	0.290	0.509	0.279	3.60	0.04
Species Protection Index	0.278	0.519	0.202	3.00	0.03
CO_2 Emissions – Power	0.249	0.316	0.085	3.60	0.04
SO_2 Emissions	0.239	0.393	0.149	3.00	0.03
Sustainable Nitrogen Management	0.221	0.236	0.086	3.00	0.03
Marine Protected Areas	0.178	0.433	0.172	3.00	0.03
NO_X Emissions	0.173	0.368	0.144	3.00	0.03
Biome Protection (National)	0.166	0.419	0.164	3.00	0.03
Biome Protection (Global)	0.148	0.397	0.144	3.00	0.03
$PM_{2.5}$ Exceedance	0.147	0.168	0.105	7.80	0.08
$PM_{2.5}$ Exposure	0.122	0.186	0.100	7.80	0.08
N_2O Emissions	0.116	0.350	0.114	0.90	0.01
Representativeness Index	0.115	0.284	0.085	1.50	0.02
Fish Stock Status	0.100	-0.263	0.058	3.00	0.03
Species Habitat Index	0.081	-0.136*	0.002*	1.50	0.02
Regional Marine Trophic Index	0.075	0.253	0.044	3.00	0.03
CO_2 Emissions – Total	0.073	0.239	0.057	9.00	0.09
Tree Cover Loss	0.045	0.099*	0.000*	6.00	0.06
				100	1.00

Table 2: Measures of importance between the 24 indicators and EPI. Source: own table based on EPI database *non-significant at 95% confidence level.

How has the Environmental Performance Index evolved over time?

The Environmental Performance Index was constructed on a 0–100-point scale which make difficult to track if a global scale the environment has improved or worsened over time. However, this Index allows us to see differences in timing between countries.

The 2016 Environmental Performance Index developers back-casted data[1] that enables EPI users to analyse changes in EPI scores over time (2007-2016). As is shown in the following Figure, neither the scores of the Environmental Performance Index by country nor the relationships between this Index and GDP per capita have seen much change over time. The Environmental Index Scores improve as GDP per capita rises. But eventually, when a country has high levels of GDP per capita (more than US$35,000), the EPI scores does not progress, but rather stabilizes. Nonetheless, countries like Qatar or United Arab Emirates would be the exception. Although these countries have a high level of GDP per capita, their Environmental Index Score is low (not higher than 70 points).

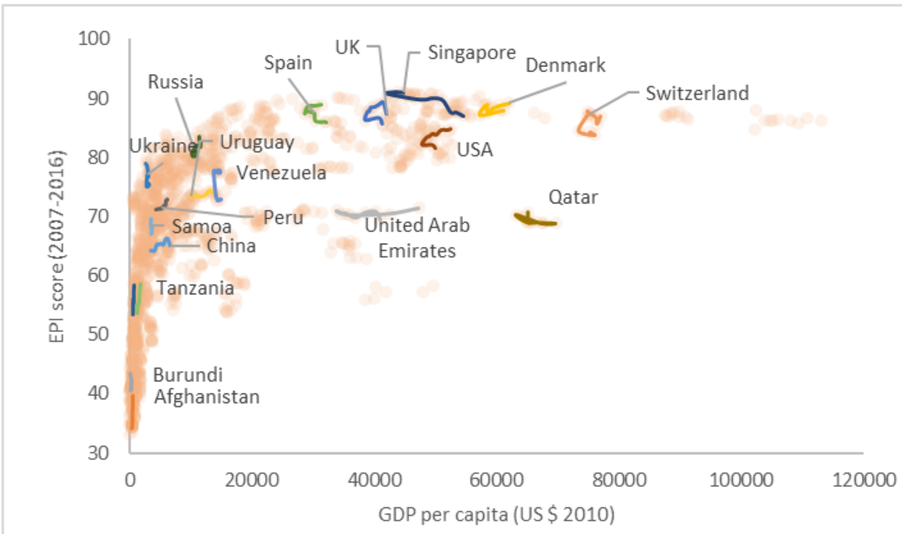


Figure 4: Relationship between GDP per capita and The Environmental Index Score (2007-2016).[2] Source: own figure based on EPI database.

2. Domestic material consumption and Material Intensity

Domestic material consumption is the most common Economy-Wide Material Flow Accounting and Analysis indicator and is currently the most widely used and accepted consumption indicator. Economy-wide material flow accounts (EW-MFA) are a statistical accounting framework describing the physical interaction of the economy with the natural environment and the rest of the world economy in terms of flows of materials (EUROSTAT, 2018). These economy-wide material flow accounts and balances show the amounts of physical inputs into an economy, material accumulation in the economy and outputs to other economies or back to nature as illustrated in Figure 5.

[1] According to The EPI developers, EPI has always been considered a work in progress, requiring updates to underlying raw data and methods with each edition. These changes in raw data and methods mean that each EPI is not comparable with previous editions. Backcasted scores contained in Figure 1were produced using the 2016 EPI methodology and historical time series of raw data to calculate a country's score for previous years. The 2016 EPI differs from the 2018 EPI. This difference is due to changes in raw data sources, underlying differences in methodologies, changes to targets and weightings. For more details see: https://sedac.ciesin.columbia.edu/data/set/epi-environmental-performance-index-2016

[2] The Orange bubbles plot scores for all 181 countries from 2007 to 2016. We have highlighted some specific countries.

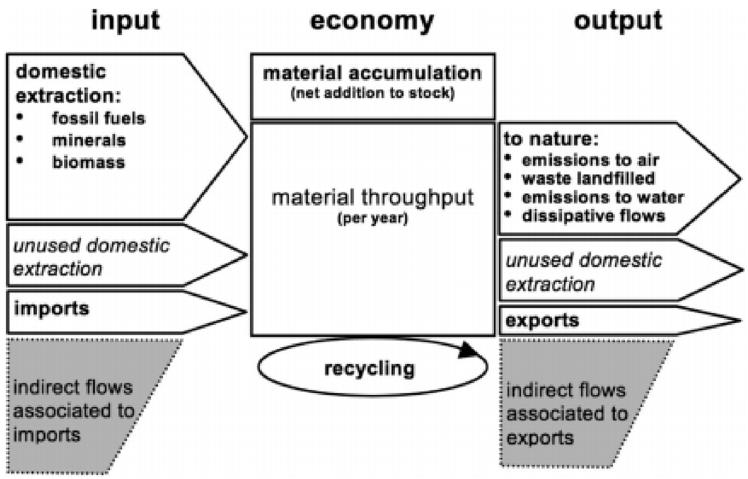


Figure 5: Scope of economy-wide material flow indicators. Source: EUROSTAT, 2001.

Indicators derived from the EW-MFA accounts tell us about the overall physical size of an economy. MFA-based indicators provide background information in aggregated form on the composition of, and changes to, the physical structure of socioeconomic systems (Fischer-Kowalski, *et al.*, 2011). Those indicators are conceptually based on a simple environment-economy model where the latter is embedded into the former (see Figure 3). The economy relates to the surrounding environment via material and energy flows. To illustrate these material and energy flows, terms such as 'industrial metabolism' (Ayres 1989) or 'societal metabolism' (Fischer-Kowalski and Haberl 1993) have been suggested. Such terms metaphorically consider modern economies as living organisms with a characteristic 'metabolic profile' (Schandl and Schulz 2000) whose dominance in, or impact on, the environment can be indicated by the size of the metabolic throughput (i.e., the number of materials these 'organisms' appropriate from their environment and return back to it in an altered form).

The Domestic Material Consumption is the total weight of raw material (biomass, minerals, metals and fossil fuels) extracted from domestic territory, plus all physical imports minus physical exports (Hickel and Kallis, 2019). However, it is important to note that the term 'consumption', as used in DMC, denotes apparent consumption and not final consumption. Domestic Material Consumption do not include the material impact involved in the production and transport of imported goods (Wiedmann *et al*. 2015)

Domestic Material Consumption was adopted as an international sustainability indicator (*ibid*.). It is used by international institutions such as the United Nations (see SDG 8 and 12), the OECD (OECD, 2017 and 2019) and the European Commission (European Commission 2011) among others. However, in order to compare Domestic Material Consumption levels between countries, this indicator is divided either by population (per capita) or by GDP (kilograms per constant 2010 $US, Material intensity[3]). Here we use both measures (DMC per capita and DMC/GDP), as the results derived from them are quite contradictory. The data was extracted from UNEPlive and the last data available is from 2017.

For instance, SDG 8 and 12 use Domestic Material Consumption as an indicator of green growth strategies. The European Commission uses a measure of "resource productivity", defined as gross domestic product (GDP) divided by Domestic Material Consumption, as the headline indicator of its "resource efficiency roadmap", one of the main building blocks of Europe's resource efficiency flagship initiative as part of the *Europe 2020* strategy (European Commission, 2011). In the same way, Eurostat uses GDP/Domestic Material Consumption as one of the significant indicators of the European Union sustainable development strategy, and

[3] Resource productivity (see Eurostat's methodology or OECD,) or resource efficiency (Hickel and Kallis,2019) is the inverse of Material intensity. It is a measured dividing GDP by DMC.

the Organization for Economic Cooperation and Development (OECD, 2017) uses Domestic Material Consumption as one of their Green Growth Indicators (Wiedmann *et al.*, 2015).

However, the scope of Domestic Material Consumption is limited to the quantity of materials directly used by any national economy. It does not include the upstream raw materials related to imports and exports originating from outside the national economy. Hence if a car is imported, only its weight is counted, and not all the energy, water and other materials required to produce the metal, rubber, and plastic it contains. It measures only raw material use, and thus is a poor device for examining the consequences of increased globalisation (Giljum 2014). It cannot capture the material effects of relocation of resource intensive production or in considering the substitution of domestic material extractions by imports (Lutter *et al.*, 2016).

3. Material Footprint

Material Footprint —first known as the Raw Material Consumption—measures the amount of used material extraction (minerals, fossil fuels, and biomass, in tonnes) associated with the final demand for goods and services, regardless of where that extraction occurs. It includes the upstream (embodied) raw materials related to imports and exports and is therefore a fully consumption-based measure.[4] The Material Footprint indicator therefore is the sum of domestic extraction plus imports minus exports. Three approaches can be distinguished to calculate Material Footprint: bottom-up methods using information from Life Cycle Assessment (LCA)5, top-down approaches applying various forms of Input-Output Analysis[6] (IOA), and hybrid approaches combining elements from LCA and IOA. For a comprehensive overview of available methods, see Lutter *et al*. (2016) and Giljum *et al*. (2019).

In recent years, the Material Footprint indicator has received considerable attention in publications by academic and statistical institutions Shortcomings of Domestic Material Consumption underpin the need for sustainable resource and materials policies to be informed by consumption-based indicators, in addition to accurate data on resource extraction and physical trade (European Commission, 2014; OECD, 2016). In this sense, the European Commission (2014) "plans to supplement or replace the Domestic Material Consumption indicator by publishing the Material Footprint indicator on a regular basis" (8904). Moreover, the OECD's report

[4] Domestic Material Consumption reports the actual amount of material in an economy, Material Footprint the virtual amount required across the whole supply chain to service final demand. A country can, for instance have a very high Domestic Material Consumption because it has a large primary production sector for export or a very low Domestic Material Consumption because it has outsourced most of the material intensive industrial process to other countries. The material footprint corrects for both phenomena.

[5] An LCA study involves a thorough inventory of the energy and materials that are required across the industry value chain of the product, process, or service, and calculates the corresponding emissions to the environment (EPA, 2006). LCA thus assesses cumulative potential environmental impacts. The aim is to document and improve the overall environmental profile of the product (Ibid.)

[6] Input-output analysis ("I-O") is a form of macroeconomic analysis based on the interdependencies between economic sectors or industries. This method is commonly used for estimating the impacts of positive or negative economic shocks and analysing the ripple effects throughout an economy. This type of economic analysis was originally developed by Wassily Leontief. The foundation of I-O analysis involves input-output tables. Such tables include a series of rows and columns of data that quantify the supply chain for all sectors of an economy. Industries are listed in the headers of each row and each column. The data in each column corresponds to the level of inputs used in that industry's production function. For example, the column for auto manufacturing shows the resources required for building automobiles (e.g., so much steel, aluminium, plastic, electronics, and so on). Thereby, IO models are flexible tools, which allow integrating data on production inputs (e.g. resources, labour or capital) and calculating indicators on input intensities (Miller and Blair, 2009). The so-called Leontief inverse shows, for each commodity or industry represented in the model, all direct and indirect inputs required along the supply chain for 1 unit of output delivered to final demand. When this model is extended with environmental data, e.g. on material extraction, the total upstream requirements to satisfy final demand of a country can be determined (Lutter et al, 2016). Hence, the key assumption in IO accounting is that all material use is driven by final demand and that all material use can be attributed to elements of final demand, following a consistent accounting logic (*ibid*.). In the past 15 years, along with the development of multi-regional input–output models covering the whole world economy, input–output analysis became an increasingly popular tool for trade-related environmental assessments as well as for the calculation of consumption-based indicators. While input-output analysis is not commonly utilized by neoclassical economics or by policy advisers in the West, it has been employed in Marxist economic analysis of coordinated economies that rely on a central planner.

on Resource Productivity in the G8 and the OECD pointed out that further progress can only be achieved through more integrated policy approaches that take account of the full life-cycle of materials. The Material Footprint is used in combination with Domestic Material Consumption as green growth indicator in the 12th and 8th Sustainable Development Goals.[7]

As the Domestic Material Consumption, Material Footprint is also used divided by population. The data was extracted from UNEPlive, which are at same time taken form Eora MRIO database. The last data available is 2017.

How Material Footprint and Domestic Material Consumption have evolved?

At a global scale, Domestic Material Consumption is equivalent to the Material Footprint, and reached 92 billion metric tons in 2017.These indicators show that the use of natural resources (materials) and GDP have been growing exponentially as the times goes by. It is one indication of the pressures placed on the environment to support economic growth and to satisfy the material needs of people. The global material footprint rose from 43 billion metric tons in 1990 to 54 billion in 2000, and 92 billion in 2017—an increase of 70 per cent since 2000, and 113 per cent since 1990. The rate of natural resource extraction has accelerated since 2000. According to the UN, without concerted political action, it is projected to grow to 190 billion metric tons by 2060. What's more, the global material footprint is increasing at a faster rate than economic output. In other words, at the global level, there was no decoupling of material footprint growth from GDP growth. It is imperative that we reverse that trend. The following graphs (Figures 6) depict the current situation under the Ecological Prevention scenario the global material footprint is increasing at a faster rate than economic output. What our indicators are describing is that there is no such a thing as an absolute or relative decoupling. On the contrary, material consumption and economic output are still very strongly coupled (Jackson, 2017). The financial crises period illustrates that sustainability indicators decline as GDP declines and rise when it does.

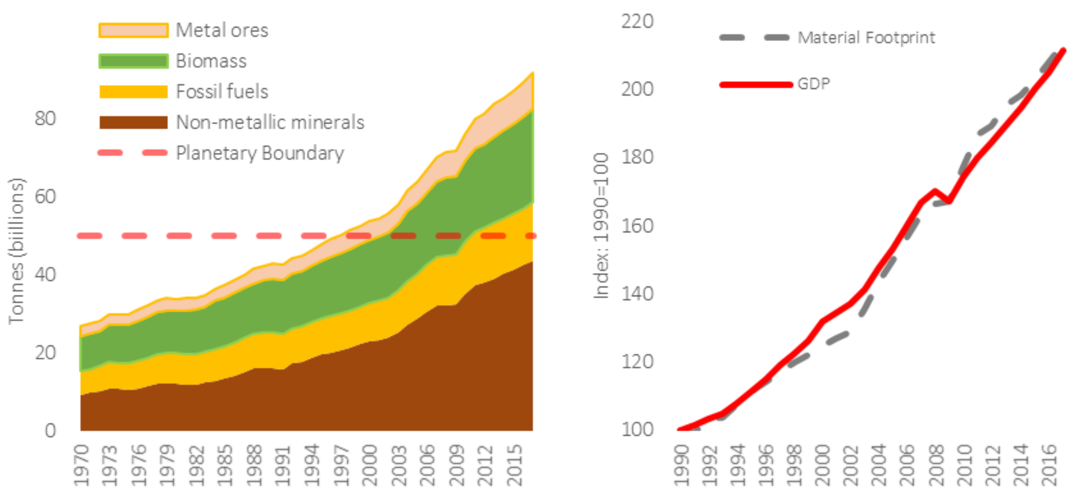


Figure 6. Domestic Material Consumption and Material Footprint of the world 1970-2017. Source: Own figure based on UN Environment International Resource Panel, Environment Live / Global Material Flows and World Bank

[7] "Domestic Material Consumption and Material Footprint need to be looked at in combination as they cover the two aspects of the economy, production and consumption. The Domestic Material Consumption reports the actual amount of material in an economy, Material Footprint the virtual amount required across the whole supply chain to service final demand. A country can, for instance have a very high Domestic Material Consumption because it has a large primary production sector for export or a very low Domestic Material Consumption because it has outsourced most of the material intensive industrial process to other countries. The material footprint corrects for both phenomena" (SDG goals metadata)

4. CO_2 emissions

Carbon dioxide (CO_2) is gas formed by combustion of carbon and in the respiration of living organisms and is considered a greenhouse gas. Emissions means the release of greenhouse gases and/or their precursors into the atmosphere over a specified area and period of time. Carbon dioxide emissions or CO_2 emissions are emissions stemming from the burning of fossil fuels and the manufacture of cement; they include carbon dioxide produced during consumption of solid, liquid, and gas fuels as well as gas flaring.

CO_2 emissions (CO_2) account for CO_2 emissions (in metric tonnes per capita) physically occurring in a country. Territorial emissions are taken from the EORA MIRO database, which in turn are taken from the PRIMAP emissions database.

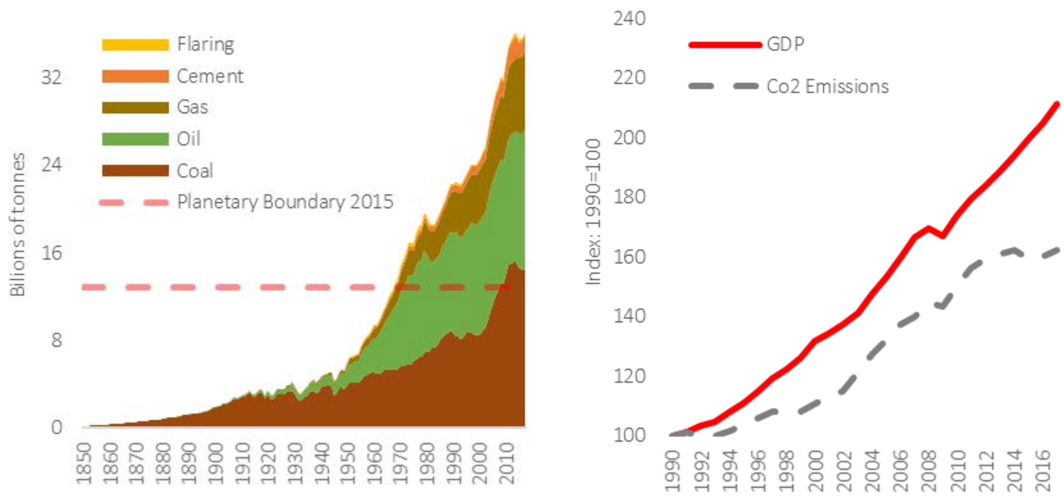
5. Carbon footprint

Carbon Footprint (CF) account for CO_2 emissions (in metric tonnes per capita). Carbon Footprint includes emissions associated with imported and exported goods. These data represent the consumption-based allocation of CO_2 emissions from energy production (excluding biomass burning) and cement production, where emissions embodied in imports and exports are added or subtracted, respectively, from national accounts.

Carbon Footprint results are from the Eora MRIO model (http://worldmrio.com) v199.82, years 1970-2017, developed by Daniel Moran, Keiichiro Kanemoto, and Arne Geschke. The Eora global supply chain database consists of a multi-region input-output table (MRIO) model that provides a time series of high-resolution Input-Output tables with matching environmental and social satellite accounts for 190 countries. For more methodological details see Lenzen *et al*. (2012, 2013), Moran (2013) and Moran and Wood (2014). All raw data are stored and processed together in one single balancing and optimization procedure.

How have Carbon Footprint and CO_2 emissions evolved?

At a global scale, CO_2 emissions production based and CO_2 emissions consumption-based (Carbon Footprint) are equivalent. Figures 7 (left) presents the long-run perspective on global CO_2 emissions. Global emissions increased from 2 billion tonnes of carbon dioxide in 1900 to over 36 billion tonnes 115 years later. Such amount oversteps the planetary boundaries set by Hickel (2020). Basing their calculations on the goal of limiting global warming to 1.5-2 °C, as emphasized in the 2018 IPCC report, Hickel (2020) established a planetary boundary of 12,803 billion tonnes per year until 2100. Thus Figure 7 (left side) would depict what the Ecological prevention scenario would also argue. On the contrary, Figure 7 (right) show that CO_2 emissions have been growing at a lower rate than GDP. This situation represents a relative decoupling of GDP growth and would partially explain the Green Growth Scenario. However, if we go back to Figure 7, left side, which accounts for emissions in absolute numbers and not using a 100 Index, we find that: i) CO_2 emission have not yet stabilized, as the proponents of Green Growth scenario have argued. On the contrary, CO_2 emissions have been growing exponentially since 1900 ii) CO_2 emissions have accelerated outstripping global planetary boundaries by far. Both arguments make the Green Growth scenario entirely futile.



Figures 7: CO_2 emissions of the world (1850-2017). Source: own figures base on EORA MIRO database

6. The Ecological Footprint

The Ecological Footprint is an aggregated indicator of global environmental impact, and is measured using a standardized area unit equivalent to a world average productive hectare or 'global hectare' (gha), which is usually expressed in global hectares per capita (gha/cap). Conceived in 1990 by Mathis Wackernagel and William Rees at the University of British Columbia, The Ecological Footprint measures how much biologically productive land and sea area a population requires to produce the biotic resources it consumes and absorb the CO_2 emissions it generates, using prevailing technology and resource management practices (Borucke *et al*, 2013). The accounting framework is composed of two measures: *Ecological* – the demand that humans place on bioproductive areas, and *biocapacity*, nature's availability to provide the resources and ecosystem services that are annually consumed by humans (Borucke *et al*., 2013). Both metrics are expressed in terms of comparable equivalent land units, namely global hectares (gha), hectares of land or water normalized to have the world-average productivity of all biological productive land and water in a given year (Galli, 2015)

The Ecological Footprint of each country is the sum of six components (cropland, forestland, fishing grounds, grazing land, built-up land, and carbon land) and is calculated as in equation (2)

$$Ecological\ Footprint_j = \sum_i \frac{T_i}{Y_{j_i}} \times YF_i\ x\ EQF_i$$

Where *j* is one of the countries being measured by the composite indicator, *Ecological Footprint*$_j$ its score: *i* is the set of six land-use types; T_i is the annual tonnage of each product (or waste) flow i that are consumed (net consumption=production + import-export) in the country; Y_{ji} is the yield of i in the country j (yield= production/hectares) ; YF_i is the yield factor of i in a given country j (yield factor= yield of a given country/ yield of the world); and EQF_i is the equivalence factor of i.

The use of Yield Factors and Equivalence Factors allows the conversion of physical hectares into global hectares. Yield Factors capture the difference between national and world average productivity within a given land-use category. They show the differences in biological productivity between regions, and might reflect natural situations, such as temperature or precipitation. The Equivalence Factors represent the global average potential productivity for a given bioproductive area relative to the average potential productivity of all global production areas. Since the potential productivity of different bioproductive areas is different, it is necessary to multiply the equivalence factors to transform them into global hectares for the convenience of comparison.

The Biocapacity of each country is the sum of five components (cropland, forestland, fishing grounds, grazing land, built-up land). Note that the carbon component was excluded from biocapacity. The biocapacity in each country is calculated as in equation (3):

$$Biocapacity_j = \sum_i A_i \times YF_i \times EQF_i$$

where A_i represents the estimated bioproductive area that is available for the product *i* at country level; YF_i is the country-specific yield factor for the production of product I and EQF_i is the equivalence factor of the land producing each flow *i*.

Finally, we can calculate the Ecological Balance (= Biocapacity−Footprint) (Siche *et al.*. 2007). Monfreda *et al*. (2004) posited that a Footprint greater than total Biocapacity indicates that demands exceed the regenerative capacity of existing natural capital. For example, the products from a forest harvested at twice its natural regeneration rate have a Footprint twice the size of the forest. They call the amount of overuse "ecological deficit" (Siche, 2007).

The Ecological Footprint launched the broader Footprint movement, including the Carbon Footprint, and is now widely used by scientists, businesses, governments, individuals, and institutions working to monitor ecological resource use and to advance sustainable development. For instance, WWF use Ecological Footprint as an indicator in the *Living Planet Report*. The data was obtained from The Global Network Footprint and the latest date available was 2016. Although widely used, the Ecological Footprint has also been criticised. Five frequently-cited criticisms of the Ecological Footprint include:

1. The application of the Ecological Footprint to regions or countries gives rise to the notion of an ecological deficit, which is easily misinterpreted and supports anti-trade sentiments. It is particularly unfair to small countries (Van den Bergh and Verbuggen, 1999).
2. The illusion of the Footprint's veracity, as a result of the transformations aimed at arriving at the artificial unit, "global ha", for all land-use categories. The Ecological Footprint measures something unreal (i.e., land area is not literally used for such activities). This means that whereas an activity may be using only 1 hectare of available land, the Ecological Footprint would suggest that its "effective Ecological Footprint" could be larger (Van den Bergh and Grazi, 2013);
3. It excludes certain relevant, important environmental pressures created by humans and their activities such as water pollution, emissions of toxic substances, depletion of the ozone layer, and acid rain (Galli *et al*. 2012). As a consequence, it will underestimate the human impact on the biosphere;
4. Another weakness is how the Carbon Component is calculated (see equation 4 or see Mancini, *et al.*, 2015). This component tries to calculate the area of forestland that is required to absorb all the carbon emissions from human activity in excess of what the oceans already absorb. This fact involves the assumption of a so-called sustainable energy scenario under which CO_2 is being captured by planting trees or forestation as a kind of offsetting or compensation. However, this assumption can generate more environmental problems, i.e. this scenario does not take into account the water used to irrigate those trees.

$$(4) \quad Carbon\ component_{EF} = P_C \times \frac{(1 - S_{(OCEAN)})}{Y_W} \times EQF$$

Where P_C is the annual anthropogenic emissions of carbon dioxide measured in Mt CO_2; S_{OCEAN} is the fraction of anthropogenic CO_2 emission sequestered by oceans in a given year (1/4); EQF is the equivalence factor used to weight forest land; Y_w is the annual rate of carbon dioxide sequestration per hectare of forestland.

5. As an aggregated indicator of resource use with a single sustainability threshold, the footprint provides no information on when specific ecological limits might be reached (Wiedmann & Barrett, 2010).

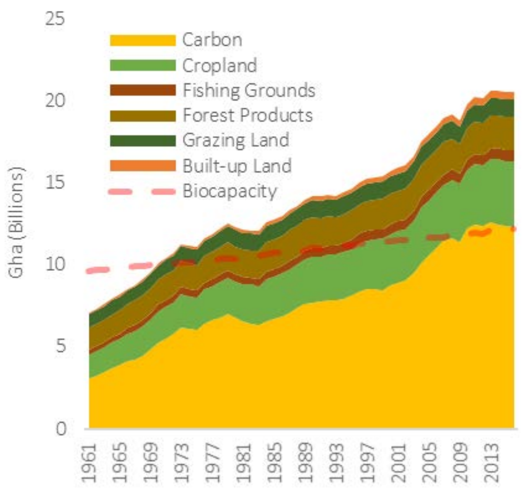
An examination of the Ecological Footprint based on a survey of 34 internationally recognised experts and an assessment of more than 150 articles concluded that the indicator is a strong communication tool, but that it has a limited role within a policy context (Wiedmann & Barrett, 2010). In the same way, Martinez-Alier (2004) posited that the Ecological Footprint "is easier to visualize. As a communication tool, it has merit and has been successful, but it contains no new information" (p. 24).

Nonetheless, the Ecological Footprint remains a well-known indicator of strong sustainability that is frequently cited in studies questioning the sustainability of global resource use (Hoekstra and Wiedmann, 2014). For instance, WWF's use in the *Living Planet Report* was to "provide the scientific evidence to what nature was telling us repeatedly: unsustainable human activity is pushing the planet's natural systems that support life on Earth to the edge" (WFF, 2018).

How has the Ecological Footprint evolved?

The following time-series graph (Figure 8) maps out the gap between human demand on nature (Ecological Footprint) and nature's capacity to meet that demand (biological capacity) for over 200 countries and regions from 1961. According to the Ecological Footprint, the world is running an ecological deficit and the Ecological Footprint exceeds biocapacity. And, GDP still growing.

According to the Ecological Footprint indicator, there is a relative decoupling. But what does this mean? It means that we have been consuming global hectares at a lower rate than economic growth has been advancing. Ultimately, at the global level, what counts is the sum of all the resources that are extracted from the ground, emitted to the atmosphere, or consumed. And the possibility of regenerating these resources. So, the final arbiter on material decoupling and the possibilities for escaping the dilemma of growth are worldwide trends on primary resource extraction and consumption (Jackson, 2017). Global use of natural resources continues to rise for many key resources, even is it a slower rate than economic growth rises.



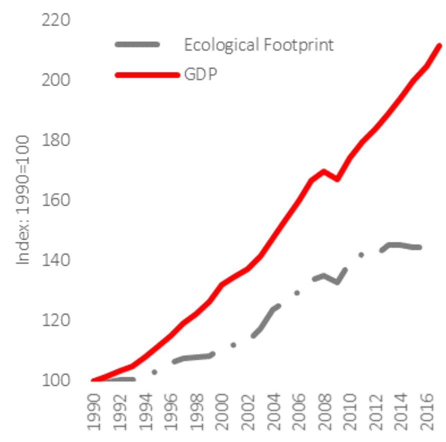


Figure 8. Ecological Footprint and GDP of the world (1961-2016). Source: Own figure based on Global Footprint Network and The World Bank database

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