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The sustainable development index: Measuring the ecological efficiency of human development in the anthropocene

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ABSTRACT

When the Human Development Index (HDI) was introduced in the 1990s, it was an important step toward a more sensible measure of progress, one defined less by GDP growth and more by social goals. But the limitations of HDI have become clear in the 21st century, given a growing crisis of climate change and ecological breakdown. HDI pays no attention to ecology, and retains an emphasis on high levels of income that – given strong correlations between income and ecological impact – violates sustainability principles. The countries that score highest on the HDI also contribute most, in per capita terms, to climate change and other forms of ecological breakdown. In this sense, HDI promotes a model of development that is empirically incompatible with ecological stability, and impossible to universalize. In this paper I propose an alternative index that corrects for these problems: the Sustainable Development Index (SDI). The SDI retains the base formula of the HDI but places a sufficiency threshold on per capita income, and divides by two key indicators of ecological impact: CO2 emissions and material footprint, both calculated in per capita consumption-based terms and rendered vis-à-vis planetary boundaries. The SDI is an indicator of strong sustainability that measures nations' ecological efficiency in delivering human development.

1. Introduction: the quest to overcome the ecological limitations of HDI

The Human Development Index (HDI) was invented by Pakistani economist Mahbub ul Haq and introduced in 1990 (UNDP, 1990). At the time, there was a growing realization among development economists that national income, or Gross Domestic Product (GDP), does not adequately account for the social or human dimensions of development (Kelly, 1991; Anand and Sen, 1994). The goal of HDI was to shift the focus of development economics from national income accounting to people-centered policies with a measure that could be used to assess countries' progress not only in terms of economic expansion, but also in terms of key social outcomes. HDI is presently calculated as the geometric mean of three indicators: life expectancy at birth; education (the average of mean years of schooling and expected years of schooling); and income (GNI per capita, PPP), which is placed on a natural logarithmic scale.

HDI is an objective metric of human development in that it relies on indicators that can be observed and compared meaningfully across contexts. This distinguishes it from other human development metrics that include indicators of subjective well-being (such as happiness or life satisfaction). The longevity and education components of HDI have substantial theoretical underpinning in Amartya Sen's notion of basic functionings and capabilities, and have been buttressed in more recent theories of human need (Gough, 2015). HDI has been promoted through the United Nations Development Program's annual reports, and has become the single most widely-used indicator of human development. The principles behind HDI informed the Millennium Development Goals, which were launched in 2000.

The HDI has come under critique from a variety of angles. It has been to some extent adjusted accordingly (see UNDP, 2011 for a review of critiques and changes), but key limitations remain – most notably the absence of any indicator of ecological sustainability. This limitation is becoming acutely evident given a growing crisis of climate change and ecological breakdown.

In recent high-profile studies, Rockström et al. (2009) and Steffen et al. (2015) conclude that human economic activity has transgressed four critical planetary boundaries: climate change, biodiversity loss, chemical loading (nitrogen and phosphorous) and land-system change. Ocean acidification and freshwater use are two-thirds of the way toward the planetary boundaries, relative to pre-industrial levels. Human consumption of material resources has reached 91 billion tons per year, overshooting the sustainable level by 82% (Dittrich et al., 2012; Hoekstra and Wiedmann, 2014; Bringezu et al., 2015). In light of this, Raworth (2012, 2017) has argued that any vision for development needs to "fit within" planetary boundaries: in other words, resources should be mobilized to improve human well-being, but without violating sustainability parameters. Raworth termed this the "safe and just space". The objective is to accomplish both human development *and* ecological sustainability – an aim that is now widely accepted and officially reflected in the Sustainable Development Goals.

The ecological limitations of HDI have been explored by a number

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of scholars (Desai, 1995; Dahme et al., 1998; Sagar and Najam, 1998; Ramathan, 1999; de la Vega and Urratia, 2001; Neumayer, 2001; Morse, 2003; Togtokh, 2011; Pelenc et al., 2013). Several attempts have been made to integrate environmental dimensions into HDI (Hirai, 2017). The most notable is that developed by Togtokh and Gaffney (2010) and improved by Bravo (2014), which includes an index of per capita CO2 emissions in a geometric mean alongside the three original HDI indicators. Kai et al. (1998) developed an alternative that incorporates "material footprint" (the total weight of material extraction and consumption, including biomass, minerals, fossil fuels and construction materials) into the mean alongside the three original indicators. Türe (2013) takes a different approach and divides HDI by "ecological footprint", which accounts for not only carbon emissions but also the biocapacity of cropland, grazing land, forests and fisheries. Most recently, Biggeri and Mauro (2018) have developed an alternative index that incorporates not only an ecological indicator (CO2 emissions) but also an additional social indicator, freedom (defined as political rights and civil liberties).

All of these alternatives build on the underlying logic and structure of the HDI. Many others do not. The Happy Planet Index (HPI), developed by the New Economics Foundation (see Jeffrey et al., 2016), abandons income and education altogether and incorporates happiness and equality instead, alongside life expectancy, and then divides the result by ecological footprint. More recently, attempts have been made to dispense with a single index altogether in favor of disaggregated metrics that cover a range of key ecological indicators (such as those captured by the planetary boundary framework) as well as a range of social indicators (such as those covered by the Sustainable Development Goals), allowing us to see important information that is otherwise hidden in single indexes. The method developed by O'Neill et al. (2018) is perhaps the most comprehensive attempt at this to date, building directly on the "safe and just space" approach articulated by Raworth. Finally, there are a number of national accounting metrics that have been developed specifically in order to correct or complement GDP, such as the Index of Sustainable Economic Welfare (ISEW) and the Genuine Progress Indicator (GPI), both of which start with personal consumption expenditure (also the starting point for GDP) and then adjust for ecological and social costs not captured by GDP (while including the benefits of non-market activity and accounting for inequality).

It is important to acknowledge the virtues of these approaches for their own purposes. ISEW and GPI are valuable as socially and ecologically-minded alternatives to national accounting, but they are not designed to address the question of human development, which is what concerns us here. The disaggregated dashboard developed by O'Neill et al. (2018) is a comprehensive approach to assessing human development and ecological impact, but does not set out to correct HDI or to provide a direct alternative. By contrast, the approach I take in this paper is very specific: to correct HDI for ecological impact and to provide a simple alternative that retains the basic logic and structure of the original. HDI enjoys widespread use and is deeply entrenched in policy discourse. By developing a direct modification we can hope to maximize its accessibility and uptake to an extent that more complex alternatives – like the disaggregated dashboard approach – may not be able to achieve. While a single index might obscure the more detailed information that is revealed by a dashboard approach, it is nonetheless useful for direct comparisons, and can in any case be presented alongside its constitutive elements in order to render them visible (as I do here, and as is common practice with HDI).

This paper seeks to advance the longstanding quest to modify HDI for ecological impact. The attempts that have been made thus far all suffer from notable weaknesses that render them ultimately unsuitable. First, most of the alternatives described above (except for Ture) are indicators of weak sustainability, in that they permit trade-offs between development and ecology. Strong performance on development compensates for high ecological impact, and vice versa. This is inconsistent with the principles of ecology, and inconsistent with the planetary boundary framework. O'Neill et al. (2018) reject this approach and insist on strong sustainability, with ecological impact measured against planetary boundaries, and no trade-offs permitted. Any attempt to correct HDI for ecological impact must therefore take this into account. Second, existing alternatives do not adequately account for the full extent of ecological impact. While including CO2 emissions (as Togtokh/Gaffney, Biggeria/Mauro and Bravo have done) is a sensible move, this represents only one dimension of ecological impact, leaving other crucial dimensions unexamined. Eliminating CO2 emissions would still leave critical overshoot on biodiversity loss, nitrogen loading, phosphorous loading, and land-use change, according to the planetary boundary framework. One can imagine a global civilization powered entirely by solar and wind and yet nonetheless unsustainable in terms of its extraction from and impact on terrestrial and marine ecosystems.

Using material footprint is one way of incorporating other ecological dimensions, as material extraction from terrestrial and marine ecosystems has an impact on land-use change, chemical loading, biodiversity loss and other key processes represented in the planetary boundary framework. While material footprint is not a direct indicator of ecological impact, it is a well-established and widely-used proxy in the policy literature and enjoys robust empirical grounding for this purpose (Krausmann et al., 2009, p. 2703). Van der Voet et al. (2004) find that while the mass flows of individual materials are not indicative of their ecological impacts, and while impacts vary as technologies change, at an *aggregate* level there is a high degree of correlation (0.73) between material throughput and ecological impacts. But while material footprint does include the weight of fossil fuel extraction, it does not directly measure emissions. Given that climate change is among the most urgent ecological crises we face, it makes little sense to incorporate material footprint into a modified HDI (as Kai et al. have done) without also incorporating emissions.

It might seem that using ecological footprint (as Ture has done, and as the Happy Planet Index does) would provide a sensible omnibus measure, transcending the limitations of using only CO2 emissions or material footprint, as it promises to incorporate a broad range of ecological impacts into a single unit ("global hectares"). In reality, however, ecological footprint is disproportionately reliant on CO2 emissions. Its accounting of biological resource use – cropland, grazing land, forests and fisheries – is measured not in terms of specific ecological impacts, but rather in terms of the capacity of different ecosystems to absorb CO2. As a result, if CO2 emissions were reduced to zero, the ecological footprint metric would show no indication of ecological crisis even if terrestrial and marine ecosystems continue collapsing, at least as long as their capacity to absorb CO2 is in excess of emissions. It is therefore not clear that ecological footprint is an adequate indicator of ecological impact (Van den Bergh and Grazi, 2014). Indeed, the concept of ecological footprint is rapidly being replaced by the concept of planetary boundaries, which is more scientifically robust.

Given the limitations of relying on either of these ecological indicators alone, the modification I propose here – which I call the Sustainable Development Index (SDI) – divides human development by a composite metric of ecological impact that incorporates both key indicators: CO2 emissions per capita and material footprint per capita. This is the first development index to take this dual approach. I render both indicators in consumption-based terms; in other words, they account for international trade by adding the emissions and materials embodied in imports (including the upstream emissions and resources involved in producing and shipping imported goods) and subtracting that of exports (see Wiedmann et al., 2015; Gutowski et al., 2017). This allows us to account for the fact that, in an era of globalization, high-income countries have shifted much of the extraction and production side of their consumption abroad, effectively outsourcing their ecological impact.

One concern about combining material footprint and CO2 emissions

Table 1
Top 10 performers on the Human Development Index (2015).[a]

HDI Rank	Country	HDI	GNI PPP (2011$/cap)	Life expect. (years)	Material Footprint (tns/cap)	CO2 emissions (tns/cap)
1	Norway	0.948	67,028	82.0	37.71	14.38
2	Switzerland	0.942	58,280	83.1	31.73	11.83
3	Australia	0.936	43,138	82.7	42.70	19.08
4	Germany	0.933	44,766	80.8	22.31	10.02
5	Sweden	0.929	46,380	82.3	31.72	8.97
6	Ireland	0.929	48,551	81.3	21.08	9.91
7	Singapore	0.929	78,742	82.8	74.19	28.78
8	Iceland	0.927	42,425	82.6	33.94	12.97
9	Netherlands	0.926	46,239	81.7	26.73	11.41
10	Denmark	0.926	47,000	80.6	24.27	10.39
Average of top 10			52,255	82.0	34.64	13.77
Overshoot (multiple of boundary)					5.09	7.91

[a] Material footprint data is derived from materialflows.net, and CO2 emissions data are derived from the Eora MRIO database.

is that because material footprint includes fossil fuels there is some

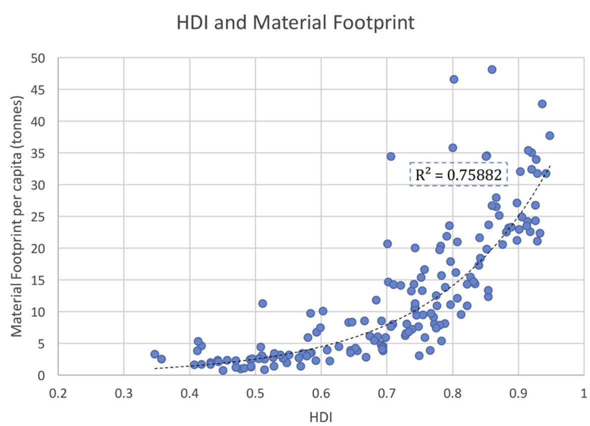

Fig. 1. Scatterplot of HDI and material footprint for the year 2015.

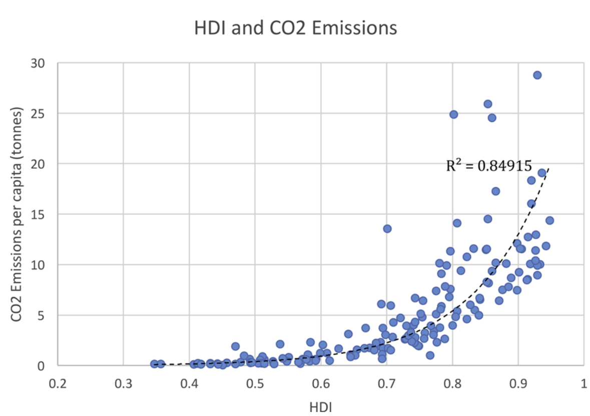

Fig. 2. Scatterplot of HDI and CO2 emissions for the year 2015.

overlap between the two. To address this, we might opt to subtract fossil fuels from material footprint. I have chosen not to do so, however, reasoning that the extraction of fossil fuels (measured by weight) has an ecological impact aside from the emissions that come from combustion. For example, strip-mining for coal has a similar impact to strip-mining for gold. Subtracting fossil fuels from material footprint would be tantamount to ignoring this impact, which is not acceptable. In short, the two ecological indicators must be seen here as measuring different things: one is about the impact of material throughput and the other is about emissions. In the SDI, these two indicators are rendered in terms of per capita planetary boundaries.

In addition, the SDI includes a second key modification. It introduces a sufficiency threshold on the income indicator, at a point above which additional income becomes unnecessary to achieve high levels of human development. This allows us to resolve a longstanding problem with the Human Development Index. Because there is a tight coupling between income and both emissions and material footprint, to achieve the levels of income necessary for "very high" HDI locks in very high levels of ecological impact. While we know that it is possible to decouple income from CO2 emissions, extant empirical evidence indicates that it is infeasible for high-income nations to decouple income from material footprint at a rate sufficient to meaningfully reduce ecological impact (Hickel and Kallis, 2019). Instead of promoting very high levels of income (and therefore consumption), the SDI promotes income *sufficiency*, while celebrating countries that achieve high levels of human development with minimal ecological impact. I further explain the rationale for this approach in what follows, before laying out the SDI formula and country results.

2. HDI and the income problem

The problem with the HDI is that all of the top performers are notable for high and unsustainable levels of ecological impact. Table 1 lists the 10 top-ranked nations alongside their CO2 emissions and material footprint. For reference, a sustainable level of CO2 emissions is about 1.74 t per person, and a sustainable material footprint is about 6.8 t per person, if we divide the material use and emissions permissible within global planetary boundaries by world population in 2015.[1] The final row shows the extent to which the average emissions and material use of the top 10 overshoot these boundaries.

We can see this relationship more broadly by plotting the whole HDI series against the CO2 emissions and material footprint for each nation (Figs. 1 and 2).[2]

[1] For material footprint, Bringezu et al. use a planetary boundary of 50 billion tonnes per year. Dividing this by 7.358 billion people in 2015 gives us 6.8t per person per year. For CO2 emissions, we can use the IPCC's 2018 report to estimate what the remaining carbon budget for the century was in 2015 if we are to have a 67% chance of staying between 1.5C and 2C, averaging the two budgets for 2018, subtracting emissions since 2015, and dividing by the remaining years of the century. Dividing the result by 7.358 billion people gives us 1.74 billion tonnes per person per year until 2100. This assumes no population growth, however. Furthermore, we must note that applying the same boundary to each country brackets the principle of climate fair shares, whereby richer countries must observe a smaller carbon budget in order to leave more space to poorer countries.

[2] HDI data is derived from the UNDP. Material footprint data is derived from materialflows.net.

Figs. 1 and 2[3] show that as HDI rises, so too do CO_2 emissions and material footprint. The indicators are correlated on an exponential curve (the R-squared value is 76% for material footprint and 85% for CO_2 emissions). There are a few nations that achieve "high" HDI (which the UN defines as between 0.70 and 0.79) while maintaining sustainable CO_2 emissions (below 1.74 t per capita) and sustainable material footprint (below 7.2 tonnes per capita). But there are no nations that achieve "very high" HDI (0.8 and above) while remaining within these ecological boundaries. As HDI increases above 0.8, CO_2 emissions and material footprint rise steeply.

One of the reasons for this disappointing result has to do with the composition of HDI itself. As mentioned above, the HDI is calculated as the geometric mean of three indicators: life expectancy at birth; education (the average of mean years of schooling and expected years of schooling); and income (GNI per capita, PPP) on a natural logarithmic scale. Each of these indicators is indexed within a range defined by maximum and minimum values.

$$\text{Life Expectancy Index} = \frac{\text{LE} - 20}{85 - 20}$$

- The maximum value is 85 years and the minimum value is 20 years.
- The result is 1 when life expectancy at birth is 85 and 0 when it is 20.

$$\text{Education Index} = \frac{\text{MYSI} + \text{EYSI}}{2}$$

Mean Years of Schooling Index (MYSI) = MYS / 15

- The maximum value is 15 years of schooling, which is the projected maximum for 2025. The minimum value is 0.
- MYSI is 1 when MYS is 15, and 0 when MYS is 0.

Expected Years of Schooling Index (EYSI) = EYS / 18

- The maximum value is 18 years of schooling, which is equivalent to achieving a master's degree in most countries. The minimum value is 0.
- EYSI is 1 when EYS is 18, and 0 when EYS is 0.

$$\text{Income Index} = \frac{\ln(\text{GNIpc}) - \ln(100)}{\ln(75{,}000) - \ln(100)}$$

- The maximum value is $75,000 per capita and the minimum value is $100.
- The result is 1 when income is $75,000 and 0 when income is $100.

Each of the component indexes correlates with ecological impact on an exponential curve; in other words, as life expectancy, education and income improve, ecological impact rises exponentially. Improvements in these social indicators from very low levels can be accomplished with little additional impact, while gains at the higher end entail a rapidly rising ecological cost. But this relationship is strongest for the income index, which has a R-squared value of 88% for CO_2 emissions and 74% for material footprint. High levels of income drives rising ecological impact much more aggressively than education and life expectancy do. In order to achieve a score of "very high" on the income index (0.8 or above), a nation must have a GNI of at least $20,000 per capita (2011 PPP). The average material footprint of nations with income between $20,000 and $25,000 per capita is 17 t per capita, while the average CO_2 emissions of nations in this range is 7 t per capita, both many times in excess of sustainable levels. A score of 1 on the income index requires $75,000 per capita. The average material footprint of nations with income over $60,000 is 40 t per capita, with CO_2 emissions of 22 t per capita – levels of ecological impact that are highly destabilizing. In other words, the income index effectively precludes nations from achieving very high HDI while at the same time being ecologically sustainable, at least given the existing dominant economic model.

There are two problems to consider here. First, HDI celebrates the very nations that are contributing most to climate change and other forms of ecological breakdown, in terms of their per capita rates of emissions and material use (e.g., the USA, Australia, Germany). In doing so, it promotes a model of development that is empirically incompatible with ecology. The average material footprint of nations with "very high" HDI scores is 26 t per capita, (four times over the sustainable boundary), while their average CO_2 emissions is 11 tonnes per capita (six times over the boundary). It is not ecologically possible for all nations to consume at this level. In other words, the pursuit of development according to HDI – the objective that the UN and virtually every international development agency promotes – requires that the world "develops" to the point of ecological collapse. This is not a tenable approach for the 21st century.

The second problem is related to the first. We know that the countries of the global South suffer disproportionately from the negative impact of climate change and ecological breakdown on economic and human development, in terms of loss of life, financial cost, and lost potential income; indeed, climate change is now beginning to reverse key human development indicators in some regions, as agricultural yields decline and hunger rates rise (Hickel, 2017). In this sense, HDI embodies a contradiction whereby the process of maintaining high levels of development in high-income nations constrains development – and even drives de-development – in poorer nations. For a development indicator that purports to be universal, such a contradiction is indefensible.

3. Prospects for improving the ecological efficiency of income

The tight coupling between income and ecological impact is due to the fact that the income indicator (GNI) is a measurement of economic production and exchange, which has an intrinsic relationship to material use and (in a fossil fuel energy system) emissions. The only way to resolve the problems with the HDI identified above is to break this relationship – to somehow achieve absolute decoupling of income from material use and emissions, such that high-income nations can maintain income per capita at very high levels while ecological impact falls to sustainable thresholds, and low-income nations can rise to high income per capita without overshooting sustainability thresholds.

We know that it is technically possible to absolutely decouple income from CO_2 emissions, by switching from fossil fuels to clean energy (e.g., Jacobson and Delucchi, 2011). Indeed, a number of high-income nations have already achieved some reductions in annual CO_2 emissions, even in consumption-based terms. A more difficult question is whether it is possible to accomplish this transition quickly enough to reduce emissions in time to stay within the carbon budget for 1.5 or 2C, as per the Paris Agreement, while at the same time growing GDP at normal rates. Holz et al. (2018) find that the required rate of decarbonization for the Paris targets is "well outside what is currently deemed achievable, based on historical evidence and standard modelling" (see also Anderson and Bows, 2011; Schroder and Storm, 2018). Grubler et al. (2018) and Van Vuuren et al. (2018) conclude that achieving these targets will require high-income nations to adopt what scholars call "degrowth" strategies, i.e., reducing aggregate economic activity in order to reduce energy demand, therefore making a rapid transition to clean energy easier to accomplish. Indeed, this approach is highlighted by the IPCC (2018) as the most feasible pathway to sufficient emissions reductions.

The evidence on decoupling income from material footprint is

[3] HDI data is derived from the UNDP. CO_2 emissions data is derived from the Eora MRIO database.

perhaps even more concerning. There are no historical or contemporary examples of nations reducing their material footprint while at the same time increasing GDP at normal rates. Some hope that a policy-driven shift to more efficient technologies might make economies more materially-efficient, so that fewer materials are required per unit of GDP. Three recent studies (Dittrich et al., 2012; Schandl et al., 2016; UNEP, 2017a) have explored this question, looking at whether aggressive policy measures can drive decoupling of GDP from material footprint on a global level, with normal rates of GDP growth (2–3% per year). All of them conclude that *relative* decoupling can be achieved, but not *absolute* decoupling – even under highly optimistic assumptions. In other words, while an economy can become more materially efficient, efficiency gains are not adequate to reduce aggregate material use. Models that incorporate the "rebound effect" yield particularly discouraging results, suggesting that relative decoupling can be achieved at only about 1% per year (UNEP, 2017b:106ff).

The same conclusion holds for high-income nations specifically. While one well-known model (Hatfield-Dodds et al., 2015) suggests absolute decoupling of GDP from material footprint may be possible (in Australia), it assumes an unrealistic rate of efficiency improvement (Alexander et al., 2018). Moreover, Ward et al. (2016) demonstrate that the result holds only in the short term. As efficiency improvements approach physical limits, the scale effect of growth drives material use back up. Ward et al. conclude that this implies a "robust rebuttal to the claim of absolute decoupling": "decoupling of GDP growth from resource use, whether relative or absolute, is at best only temporary. Permanent decoupling (absolute or relative) is impossible for essential, non-substitutable resources because the efficiency gains are ultimately governed by physical limits. Growth in GDP ultimately cannot plausibly be decoupled from growth in material and energy use, demonstrating categorically that GDP growth cannot be sustained indefinitely."

The conclusions of the literature reviewed above hold that it is not empirically feasible to reduce material footprint while at the same time growing GDP at normal rates, and that it is not empirically feasible to reduce emissions in line with the Paris targets while at the same time growing GDP at normal rates. What implications does this literature hold for the question of how we might reconsider the income component of the Human Development Index?

First, it is reasonable to expect that low-income nations can grow their incomes significantly without breaching ecological boundaries. But it is not reasonable to expect that they can do so indefinitely, i.e., to the point of reaching the levels of income that presently characterize high-income countries, given existing empirical evidence and modelling. As of 2015, $8600 GNI per capita (PPP) is the average level of income that nations achieve at the ecological boundaries of material footprint and CO2 emissions; the highest is about $17,000. This can be improved upon, but – given the tight coupling between income and material footprint – only with relatively low rates of income growth (i.e., no more than 1% per year, as per UNEP, 2017b), and this trajectory may not be sustainable in the long-term (as per Ward et al., 2016).

Second, for middle-income nations that have material footprint and CO2 emissions only modestly in excess of ecological boundaries, it is reasonable to expect that they would be able to reduce their emissions and material footprint down to sustainable levels while maintaining their per capita income, and perhaps while growing income at a slow rate, but not while growing income at a rate adequate to reach "very-high" levels within any meaningful timeframe, particularly given the patterns identified by Ward et al. (2016) regarding prospects for absolute decoupling of income from material footprint over the long term.

Finally, for high-income nations, it is empirically feasible for them to reduce their material footprint at a rate of 1% per year while maintaining their existing levels of income (albeit not over the long-term), and it is technically feasible for them to gradually reduce their CO2 emissions while maintaining their existing levels of income. But it is not feasible for them to reduce their material footprint down to sustainable levels, and not feasible for them to reduce emissions rapidly enough to meet the Paris climate targets, without also reducing aggregate economic activity (Hickel and Kallis, 2019). Importantly, reducing aggregate economic activity need not entail any reductions to human development indicators. Research indicates that it is possible for high-income countries to maintain or even improve their levels of human development while reducing throughput and output (i.e., Alier, 2009; Jackson, 2019; Kallis, 2011; Victor, 2019), for example by distributing income more fairly, investing in public services, shortening the working week and improving wages.

4. Reformulating the income index

In light of the two preceding sections, it seems reasonable to reconsider the extent to which high income serves as a useful indicator of human development. While nations with high income generally perform better on key social indicators than nations with lower income, the relationship is not determinate; indeed, ul Haq himself was intent on highlighting this point. There are a number of countries with relatively low income that nonetheless achieve high levels of human development. Greece, Chile, and Portugal have higher life expectancy than the US with less than half the income per capita. Costa Rica has a life expectancy that exceeds that of the US with one-fourth of the income per capita. Similarly, there are a number of countries that score highly on the education index with relatively low levels of income. Kazakhstan's education levels rival Austria's, with half of the income per capita. Belarus exceeds Austria with one-third of the income per capita. Georgia and Ukraine rival Austria with less than one-fifth of the income per capita.

These are the results that should be highlighted within any framework of sustainable development: middle-income nations that perform well on key social indicators while staying close to or within the boundaries of ecological sustainability. Given that income is so tightly coupled with ecological impact, it would make sense to look at nations that achieve high levels of human development with relatively low levels of income as models to emulate in the process of designing more sustainable approaches to development, rather than punishing them for not having high income, as the HDI does.

One way to correct for this problem is to simply remove the income component from HDI. There are a number of composite human development indicators that have made this move, eschewing income in favor of subjective measures such as happiness, life satisfaction and well-being (e.g., the Happy Planet Index, Gross National Happiness Index, Gross National Wellbeing Index, etc). This approach departs significantly from the objective approach of the HDI that I seek to retain, and is in any case not without its problems, which I will discuss in a later section. Moreover, we must allow that income might contribute meaningfully to human development in ways that education and life expectancy cannot capture; for instance, in terms of choice, economic agency, empowerment and security, which is what the designers of HDI had in mind when they chose to include income as a key component. Rather than jettison the income index from HDI altogether, then, I propose to modify it with a sufficiency threshold.

Toward this end, there are a few considerations to bear in mind. According to the 2015 dataset for HDI, some nations achieve very high levels (0.8 or above) on the life expectancy index with as little as $3,300 per capita (or 0.9 with as little as $11,000), and very high levels on the education index with as little as $8,700 per capita, while keeping ecological impact at sustainable levels. According to the O'Neill et al. (2018) database of social and ecological indicators, a number of nations achieve impressive levels of sustainable development with as little as $10,000 to $14,000 per capita (Hickel, 2018). Finally, we know that as GNI exceeds this level it begins to cause net negative social and ecological consequences (Kubiszewski et al., 2013; Lamb et al., 2014; Max-Neef, 1995; Deaton, 2008; Inglehart, 1997).

With this range of figures in mind, we might set $20,000 per capita

(PPP) as the maximum value on the income index scale, thus introducing a sufficiency threshold at a point above which additional income becomes socially unnecessary. This function creates a curve that crosses 0.8 on the income index at about $7,000, crosses 0.9 at about $12,000, and crosses 0.95 at about $15,000, all of which is possible to achieve without excessive ecological impact. The sufficiency threshold brings the income index in line with the other human development indices, in terms of what we know of the relationship between income and social outcomes, while ensuring that countries need not pursue ecologically destructive levels of economic growth in order to score well. It is important to note that countries are of course not punished for exceeding $20,000; rather, it is simply that any additional income over this level does not boost a country's score or improve its ranking.

5. The sustainable development index

The Sustainable Development Index proposed here includes five indicators, then: education, life expectancy, income, CO2 emissions and material footprint. The SDI is calculated as the quotient of two figures: (1) a "development index" calculated as the geometric mean of the education index, the life expectancy index, and the modified income index; and (2) an "ecological impact index" calculated as the average overshoot of CO2 emissions and material footprint vis-à-vis their per capita planetary boundaries, indexed on a natural exponential scale. The formula can be described as follows:

$$\text{SDI} = \frac{\text{Development Index}}{\text{Ecological Impact Index}}$$

$$\text{Development Index} = \sqrt[3]{\text{Educ Idx*Life Exp Idx*Income Idx}}$$

Education Index is as in HDI
Life Expectancy Index is as in HDI

$$\text{Income Index} = \frac{\ln(\text{GNIpc}) - \ln(100)}{\ln(20{,}000) - \ln(100)}$$

$$\text{Ecological Impact Index} = 1 + \frac{e^{\text{AO}} - e^{1}}{e^{4} - e^{1}}$$

if AO > 4, then EII = AO – 2

$$\text{AO} = \sqrt[2]{\left(\frac{\text{MF}}{\text{boundary}} \geq 1\right) * \left(\frac{\text{CO2}}{\text{boundary}} \geq 1\right)}$$

Average overshoot (AO) is calculated as follows. Material footprint and emissions values are each divided by their respective per capita planetary boundary (which varies by year depending on population size) to determine the extent of boundary overshoot (or undershoot). This also standardizes the units. If the result of either division is less than 1 (undershoot) it is rendered as 1. Then the results are averaged using the geometric mean. This method ensures that a country cannot compensate for overshooting one boundary by undershooting the other. Overshoot of either boundary will yield average overshoot of greater than 1.

In the ecological impact index, AO is indexed on a natural exponential scale. Given the uncertainties around the precise definition of the planetary boundaries, this allows some leeway for small amounts of overshoot. Adding 1 ensures that the minimum result is 1 (no overshoot). For countries that have no overshoot, their development index is therefore unaffected. Once overshoot reaches four times the planetary boundary the ecological impact index registers 2, thus cutting the development index in half. Thereafter a linear function applies. This method ensures that the SDI is an indicator of strong sustainability. Countries cannot use low ecological impact to compensate for poor performance in human development. And strong performance in development cannot compensate for high ecological impact.

There are 163 countries that have data points for all five of the metrics included in the SDI for 2015. The top ten performers on the SDI are listed in Table 2. Table 3 presents a selection of countries from across the range, for comparison. The overshoot calculation here assumes a boundary of 6.8 t per person per year for material footprint (Bringezu et al., 2015), and a boundary of 1.74 t per person per year for CO2 emissions (IPCC, 2018).

The best performers are Cuba, Costa Rica, Sri Lanka and Albania, which achieve high levels of social performance with low levels of ecological impact. The degree of overshoot on material footprint and CO2 emissions of the top 10 is significantly lower than under the HDI (compare with Table 1). The nations that dominate HDI (Norway, etc.) fall toward the bottom of the SDI range, dragged down by their high ecological impact. The bottom of the SDI range is populated by very poor countries (like Niger) as well as countries with very high ecological impact (like Qatar).

Of course, what the SDI ranking reveals is that no countries truly succeed at sustainable development, with scores over 0.9. There are no countries that achieve top scores for human development (with life expectancy and education at the level of Switzerland, for example) while at the same time remaining within or even remotely near ecological boundaries. In contrast to the HDI, wherein more than 20 countries score over 0.9, the SDI ranking reveals that all countries are still "developing": countries with the highest levels of human development still need to significantly reduce their ecological impact, while countries with the lowest levels of ecological impact still need to significantly improve their performance on social indicators.

6. Additional considerations

My goal in designing the Sustainable Development Index is to retain the base logic of the HDI, which I have done. Nonetheless, I considered

Table 2
Top 10 performers on the Sustainable Development Index (2015).[a]

SDI Rank	Country	SDI	Life Expect. (years)	Education Index	GNI per capita (PPP)	Material Footprint (tns/cap)	CO2 emissions (tns/cap)
1	Cuba	0.859	79.6	0.768	21,000	8.04	3.42
2	Costa Rica	0.830	79.6	0.713	14,086	8.08	2.66
3	Sri Lanka	0.825	75.1	0.751	10,791	3.88	1.03
4	Albania	0.811	78.2	0.733	11,083	10.92	2.32
5	Panama	0.808	77.8	0.681	18,167	7.85	3.77
6	Algeria	0.805	75.9	0.662	13,338	3.03	1.96
7	Georgia	0.801	73.1	0.831	8,766	9.12	3.07
8	Armenia	0.800	74.4	0.746	8,517	7.63	1.99
9	Azerbaijan	0.798	71.9	0.709	16,334	5.91	3.24
10	Peru	0.788	74.7	0.686	11,420	9.38	2.14
Average of top 10			76.03	0.728	13,350	7.38	2.56
Overshoot (multiple of boundary)						1.09	1.47

[a] Life expectancy, Education Index, and GNI are derived from the UNDP dataset for HDI 2015. Material footprint data is derived from materialflows.net, and CO2 emissions data is derived from the Eora MRIO database.

Table 3
Selection of countries from the Sustainable Development Index (2015).

SDI Rank	Country	SDI	Life Expect. (years)	Education Index	GNI per capita (PPP)	Material Footprint (tns/cap)	CO2 emissions (tns/cap)
16	Jordan	0.775	74.2	0.706	8,392	6.78	2.99
27	Belize	0.745	70.2	0.704	7,666	7.95	2.84
55	India	0.675	68.3	0.542	5,691	4.46	1.68
95	France	0.549	82.4	0.840	38,367	21.20	7.47
100	China	0.532	76.1	0.641	13,519	20.01	6.68
131	United Kingdom	0.399	81.4	0.911	38,146	22.57	10.08
136	Niger	0.374	59.7	0.208	889	3.27	0.55
152	Qatar	0.251	78.0	0.698	117,896	13.35	25.91
157	Norway	0.200	82.0	0.908	67,028	37.71	14.38
159	USA	0.184	79.2	0.900	53,741	32.36	18.35

a number of possible alternative formulations. I review them here along with the reasons I chose to reject them.

First, it might seem reasonable to consider including additional indicators of human development in the SDI, alongside life expectancy and education, such as literacy and infant mortality (which are included in the SDGs). But infant mortality overlaps substantially with life expectancy, and therefore cannot be granted equal weight as a third term (the Physical Quality of Life Index has been criticized for doing so). Moreover, infant mortality is a "weaker" or lower-order measure, in that it is easier to accomplish a reduction in infant mortality than to accomplish an improvement in the life expectancy of non-infants. Countries that have achieved higher levels of life expectancy have generally also already succeeded at reducing infant mortality, but the opposite does not generally hold. In the same way, literacy is weaker than and overlaps substantially with the education index. In short, then, infant mortality and literacy are trumped by life expectancy and education, respectively, and do not warrant inclusion in the SDI.

Another option might be to incorporate indicators related to basic physical needs, such as access to food, electricity, improved sanitation facilities and housing, all of which are targeted by the SDGs. The problem here is that high levels of access to these basic goods is "easy" to deliver, and at this point most of the world's nations have done so: for instance, of the 100 best-performing countries in each indicator, the average electricity provision is 100%, and the average proportion of the population that achieves the nutrition threshold set by the Food and Agricultural Organization is 98%. All of the nations that perform well (or even modestly) in terms of life expectancy and education have universal coverage of these basic needs. For this reason, we can assume that provision of basic needs is already "covered" by the higher-order (or more difficult to achieve) social indicators included in the SDI.

Apart from basic physical needs, there are a number of qualitative indicators that we might consider for inclusion in the SDI: social support, democratic quality and employment – all of which are aspirations represented in the SDGs. These are covered by the Better Life Index, an alternative measure of progress devised for the OECD. The problem here is that all of these indicators have a weak relationship with ecological impact (O'Neill et al., 2018). While improving indicators like education and life expectancy clearly requires some additional ecological impact (since schools and hospitals, for instance, require materials to construct and energy to run), improving social support, democratic quality and employment does not (Hickel, 2018). Social support is largely a cultural phenomenon; the indicator measures whether or not people have someone to count on in times of need, which can be improved without additional ecological impact. Similarly, one can imagine a government delivering dramatic improvements in democratic quality without any additional ecological impact (for instance, South Africa's transition to democracy in 1994 caused no increase in impact). Moreover, there is no necessary relationship between democracy and ecological impact: low-impact nations like India as well as high-impact nations like Norway can have robust democracies, while dictatorships can be present in low-impact nations like Swaziland as well as high-impact nations like Saudi Arabia. As for employment, O'Neill et al. (2018) show that there is no statistical relationship between employment and impact at all. Once again, both poor nations and rich nations can have either high or low employment. And all nations can improve their employment levels simply and without any additional ecological impact by introducing specific policy settings (for example, by reducing the length of the working week and sharing necessary labour). There is therefore little reason to measure these indicators against ecological impact.

Moreover, it is possible for poor countries to have high levels of social support, democratic quality and employment while at the same time performing poorly in terms of life expectancy and education. It seems reasonable, then, to exclude these from the SDI on the grounds that, because they can and often do move in the opposite direction to life expectancy and education, they would muddy the results (see Streeten, 1994), a problem to which all composite indexes are vulnerable. For these reasons I depart from Biggeri and Mauro (2018), whose alternative formulation of the HDI (mentioned in the opening section of the paper) incorporates an indicator for "freedom".

It might seem reasonable to consider including subjective indicators of happiness or well-being, as the Happy Planet Index has done. I chose not to do so because it would depart from the objective approach that the SDI seeks to retain, but also because the data (which is derived from the World Happiness Report) presents a number of problems. (1) The question asks about people's feelings of well-being "at the present time", which leaves it vulnerable to being skewed downward by temporary events such as natural disaster, military conflict, or change of government. Including such a measure in the SDI would risk obscuring countries that otherwise perform well at the core objective of delivering ecologically efficient human development. (2) The question asks people to place themselves on a ladder, where "the top of the ladder represents the best possible life for you; and the bottom of the ladder represents the worst possible life for you", but such a scale is not comparable across contexts. The best possible life imaginable by someone in the UK is not comparable to the best possible life imaginable by someone in Bangladesh. Indeed, the happiness indicator risks rewarding people in poor countries for low expectations. By the same token, people in rich countries who should be satisfied with their prospects compared to the rest of the world may feel that they nonetheless need more. (3) Finally, the ladder metaphor embodies a particularly Eurocentric conception of progress: unilineal, unidirectional, hierarchical, individualistic, etc. It is possible that this metaphor is less meaningful to people who do not subscribe to these underlying principles. If that is the case, then it may not be suitable for use in cross-country comparisons (see Mathews and Izquierdo, 2009; Mathews, 2012). Indeed, cultures that value modesty (such as in East Asia) tend to report lower levels of well-being, because to do otherwise would seem impertinent, and might risk inviting misfortune (see Gough, 2017: 40). There are more general formulations of the evaluative question, and evidence to suggest that responses are more comparable across contexts, but the data remains subjective and therefore incompatible with the objective approach I have selected.

A final consideration has to do with inequality. Greater equality is associated with a variety of positive social outcomes (greater happiness, better health, less anxiety, less depression, etc.; see Wilkinson and Picket, 2009). Recognizing this, the UNDP has designed an inequality-adjusted HDI (IHDI). According to the 2016 Human Development Report, "The IHDI can be interpreted as the level of human development when inequality is accounted for," whereas the normal HDI is "an index of potential human development (or the maximum IHDI that could be achieved if there were no inequality)." The concept of development *potential* is interesting here. I have chosen to render the SDI without adjusting for inequality because, when it comes to the question of sustainable development, what is important is the *potential* of nations to achieve high levels of human development at a given level of ecological impact. Inequitable countries that have relatively low levels of impact are theoretically capable of improving their human development outcomes considerably by distributing existing domestic resources more fairly, without any additional ecological impact. By not adjusting for inequality, the SDI highlights these countries as models of efficiency in human development *potential*.

A brief note about the education index is in order here. The inclusion of the education index in HDI has come under criticism for a variety of reasons. First, it is an input metric that does not guarantee consistent outcomes. In other words, it is possible that a country could achieve maximum years of schooling, but if the schooling is of a poor standard it will do little to improve the actual education of the population. Moreover, it is potentially problematic to combine an input-based metric like the education index together with an outcomes-based metric like life expectancy, given the dissimilarities between the two. Second, the education index measures education in terms of an institutional model, and therefore effectively discriminates against cultures that may have historically valued different approaches. For instance, indigenous people living in Bolivia may have few years of formal schooling but nonetheless have mastery of botany and ecology and other fields crucial to their context, acquired through rigorous training and mentorship – a kind of education that would be difficult to gain through institutional schooling. These are important critiques that need to be addressed, but I have chosen to put them aside here for the sake retaining the underlying logic of the HDI, and because there is no readily available alternative metric.

Finally, what can we say about the relationship between the SDI and the SDGs? Clearly the two draw on the same underlying conception of sustainable development, but the SDI incorporates a narrower range of indicators than are represented among the SDG targets. O'Neill et al. (2018) have proposed a broad dashboard of indicators of human development that derives from the SDGs, alongside indicators of ecological impact that derive from the planetary boundary framework. This is a robust and informative approach, but if we wish to use a single index, the SDI – as I have argued above – provides the most reasonable formulation, as it includes the three well-established indicators of human development derived from the HDI and the two keystone indicators of ecological impact (which are represented in Goals 12 and 13 of the SDGs), while retaining the principles of strong sustainability. Just as the HDI served us for the era of the Millennium Development Goals (which focused on human development to the exclusion of ecological considerations) without incorporating all of the MDG targets, so the SDI can serve us in the era of the SDGs. But it should not be used to the exclusion of disaggregated approaches.

7. Conclusion and discussion

The ecological limitations of the Human Development Index have long been apparent. For more than twenty years, scholars have attempted to modify HDI in order to overcome these limitations. These attempts suffer from significant flaws, which the Sustainable Development Index I have proposed here seeks to transcend. By correcting for both CO2 emissions and material footprint (rendered in per capita consumption-based terms), by placing a sufficiency threshold on income, and by dividing human development by ecological impact, the SDI offers an alternative index that is robust in terms of both ecology and social science, while upholding the principles of strong sustainability.

The SDI also makes an important contribution to development theory, inasmuch as it disrupts dominant development hierarchies. Arturo Escobar (2011) famously pointed out that conventional development indicators construct conceptual ladders of progress that place Western countries at the top and represent the rest of the world as lagging behind. Such representations have significant discursive power, and shape the way that people think about the world. This is clear in the case of HDI. Given HDI's reliance on income, it represents the countries of the global North as automatically superior to the countries of the South, erasing and indeed even legitimizing the violence that the former have deployed in order to accumulate their surplus, through for example colonization, the slave trade, structural adjustment, land grabs, labour exploitation, resource extraction and other methods by which nations at the core of the world system have sabotaged the periphery for the sake of their own development (Hickel, 2017). The SDI challenges this narrative (and the troubling racial overtones of the HDI hierarchy) by introducing ecological indicators that reflect the negative effects of the excess extraction, consumption and accumulation practiced by rich countries, and demoting them accordingly.

The SDI does however raise a number of practical issues. For one, there is an interesting question to be asked about the purpose of an index that mixes both human development and ecological impact. A critic might note that with human development indicators, the countries that rise to the top (like Switzerland and Denmark) do so because of intentional policies, like investment in public healthcare and education. These are policies that other countries can aspire to imitate. It is not quite so straightforward with the ecological indicators, however. Some of the nations that have low ecological impact use intentional policies to get there, such as Costa Rica's investment in renewable energy infrastructure and Cuba's focus on material reuse. But many others (like Sri Lanka) have low impact not because of intentional policies but rather because they have less intensive economies. So in what sense can Sri Lanka be held up as a model that should be imitated? What do they do better? What would it mean for a country to seek to be more like Sri Lanka, if there are no clear policies to follow?

In other words, one might say there is a deficit of success at the top of the SDI. This is in keeping with what I noted above, namely, that the SDI reveals that no nations are yet sustainably developed (with world-leading performance on social indicators and safe levels of ecological impact), and therefore none yet stand as an obvious champion for others to follow. This will begin to change, however, as middle and high-income countries implement ecological policy in order to reduce their emissions and material footprint, which they will have to do if they want to adhere to Paris Agreement targets and the Sustainable Development Goals. So for instance as countries like Switzerland and Chile (which have high levels of human development) invest in renewable energy, circular economy principles and post-growth policies, they will rise to the top of the SDI, and one could point to them as models. In this sense, the SDI is a metric that stands ready to measure progress toward the ecological transition that needs to happen, but which is not yet underway.

In the meantime, it is important to note that while the countries that rise to the top of the SDI may not provide a model for richer countries to follow, they do provide a model for poorer countries. All of the SDI leaders have succeeded in achieving high levels of human development with minimal GNI per capita and minimal ecological pressure. This is a remarkable accomplishment. In this sense, there is a great deal that a country like Bangladesh can imitate about Sri Lanka. Sri Lanka, which has invested heavily in public healthcare and education, illustrates that it is possible for poorer countries to dramatically improve their social outcomes without needing ecologically destructive levels of economic activity to do so.

What might appear at first glance as a flaw, then, is in fact a key strength of the SDI. The SDI charts out a conception of progress that allows for and indeed promotes different development trajectories depending on each nation's position. Under HDI, the objective is univocal and unidirectional. Those at the bottom of the ranking are enjoined to progress by growing GDP, without concern for ecological externalities, while investing in healthcare and education. Under the SDI, by contrast, the objective is more complicated. The bottom of the ranking is populated by both poor countries with low levels of human development as well as by rich countries with high levels of ecological impact. The United States, for instance, is ranked 159th, as a result of having very high levels of ecological impact. For rich countries at the bottom of the SDI, the path to progress requires reducing emissions and material footprint. For poor countries at the bottom of the SDI, the path to progress requires social policy, imitating countries like Costa Rica and Sri Lanka in order to deliver strong social outcomes with little additional ecological impact.

The SDI therefore implies heterogeneous prescriptions for progress, disrupting unilineal normative trajectories and usefully speaking to the varied predicaments of countries in the real world. And yet the goal that the SDI promotes is nonetheless singular: to achieve ecologically sustainable human development.

Seeing the world through the lens of the Sustainable Development Index illustrates how, when it comes to development in the 21st century, poor nations are the "easy" part. We know, from already-existing examples (such as those at the top of the SDI ranking), that it is possible for poor nations to achieve high levels of human development with sustainable levels of ecological impact, for instance by investing in universal social goods like public health and education (Martínez Franzoni and Sánchez Ancochea, 2016). It is rich nations that are the hard part, as reducing their emissions and material footprint down to sustainable levels will require not only aggressive efficiency improvements, but also a shift toward alternative economic models that allow aggregate economic activity to be scaled down (in order to dramatically reduce material and energy throughput) in a manner that maintains and even improves their performance on social indicators (Hickel, 2019). The SDI highlights this challenge.

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