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The Social Shortfall and Ecological Overshoot of Nations

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Previous research has shown that no country currently meets the basic needs of its residents at a level of resource use that could be sustainably extended to all people globally. Using the doughnut-shaped "Safe and Just Space" framework, we analyse the historical dynamics of 11 social indicators and 6 biophysical indicators across more than 140 countries, from 1992 to 2015. We find that countries tend to transgress biophysical boundaries faster than they achieve social thresholds. The number of countries overshooting biophysical boundaries increased over the period from 32–55% to 50–66%, depending on the indicator. At the same time, the number of countries achieving social thresholds increased for 5 social indicators (in particular life expectancy and educational enrolment), decreased for 2 indicators (social support and equality), and showed little change for the remaining 4 indicators. We also calculate "business-as-usual" projections to 2050, which suggest deep transformations are needed to safeguard human and planetary health. Current trends will only deepen the ecological crisis, while failing to eliminate social shortfalls.

Introduction

The doughnut-shaped Safe and Just Space framework (also called "the Doughnut of social and planetary boundaries") has received widespread attention as a holistic tool for envisioning human development on a stable and resilient planet[1,2]. However, despite the urgent need to define, and move toward, a safe and just future[3], little is known about the pathways of countries over time with respect to the multi-dimensional social and ecological goals of the Doughnut. This article advances integrated global sustainability research by assessing whether any countries have lived within the Doughnut in recent decades, or are on track to do so in the future, based on current trends.

The Doughnut combines two core concepts: (i) an ecological ceiling that avoids critical planetary degradation, which is informed by the planetary boundaries framework for Earth-system stability[4], and (ii) a sufficient social foundation that avoids critical human deprivation, which is closely aligned with the 12 social priorities of the Sustainable Development Goals (SDGs)[5]. The Doughnut visualises the goal of meeting the needs of all people within the means of the living planet[6].

Empirical research that combines social and biophysical indicators in the Doughnut framework is maturing, and the framework has been applied to evaluate the performance of cities[7,8], regions[9,10], countries[2,11,12], and the world as a whole[1,6]. In general, places that do well in terms of social achievement use resources at unsustainable levels, while places that use resources sustainably do not reach a sufficient social foundation[2].

A large body of empirical research finds diminishing returns in social performance as resource use increases, and this finding holds across different social indicators or baskets of indicators, such as life satisfaction, life expectancy, or composite indices, together with CO_2 emissions[13,14], energy use[15–17], ecological footprint[18–20], and others[2,21]. Modellers have described the impact on planetary boundaries of achieving the SDGs[22], the socioeconomic effects of CO_2 mitigation pathways[23,24], and the energy requirements of meeting a set of basic needs[25,26]. However, these studies either do not disaggregate from the global to the national scale, or they do not include multiple planetary boundaries and social indicators. To date, O'Neill et al.[2] provide the only global cross-country analysis of the level of resource use associated with achieving minimum social thresholds using the Safe and Just Space framework, but their study is limited to a single year.

There is an emerging view that achieving social thresholds without overshooting biophysical boundaries requires a dual focus on curbing excessive affluence and consumption by the rich, while avoiding critical human deprivation among the least well-off[27–29]. A better understanding of country trajectories with respect to the Doughnut could provide insights into the type of action needed to transform unsustainable systems of social and technical provisioning[30].

Biophysical boundaries and social thresholds

We gathered historical data from 1992 to 2015, and analysed national performance on 6 consumption-based environmental indicators (relative to downscaled biophysical boundaries) and 11 social indicators (relative to social thresholds) for over 140 countries (Table 1). We also used these data to estimate dynamic statistical forecasting models within each country, which act as empirical constraints on a simple "business-as-usual" projection of current trends for each social and biophysical indicator, out to the year 2050.

The 11 social indicators include two measures of human well-being (self-reported life satisfaction and life expectancy), and nine need satisfiers (nutrition, sanitation, income poverty, access to energy, education, social support, democratic quality, equality, and employment). To assess social performance over time, we compared these indicators to the minimum threshold values identified by O'Neill et al.[2], with some adjustments and caveats (Table 1; see Methods). Since the social support indicator series does not begin until 2005, only ten indicators were considered in total for cross-country comparisons over the 1992–2015 analysis period.

We compared three downscaled planetary boundaries (climate change, biogeochemical flows, and land-system change) to environmental footprint indicators at the country scale. Following O'Neill et al.'s[2] analysis, we also included two separate footprint measures (ecological footprint and material footprint), and analysed these with respect to their suggested globally sustainable levels. Since the biogeochemical flows boundary is measured with two indicators (nitrogen and phosphorus), we analysed six biophysical indicators with respect to downscaled boundaries at the national scale (Table 1). All six indicators are consumption-based footprint measures that account for international trade, as well as changes in population over time. No suitable time series data were available for the blue water footprint at the country scale (although there are estimates available at the global scale[31]).

Results

At the global scale, we find that billions of people currently live in countries that do not achieve most of the social thresholds in our analysis, and yet humanity is collectively overshooting 6 of the 7 global biophysical boundaries (Figure 1). We find that humanity is closer to reaching the social thresholds than it was in the early 1990s (with the notable exceptions of equality and democratic quality), but significant shortfalls remain. At the same time, global resource use has overshot two additional boundaries (material footprint and blue water) and extended significantly further beyond the ecological ceiling over the 1992–2015 period, especially with respect to material footprint and CO_2 emissions.

National progress towards the Doughnut. At the national scale, we find that the average country has achieved one additional social threshold at the cost of transgressing one more biophysical boundary over the 1992–2015 period (Supplementary Figure 1). Most countries are currently failing to achieve the majority of social thresholds (~4 out of 10 achieved, on average), and they are also failing to stay within the majority of the biophysical boundaries (~2 out of 6 respected). Fewer social thresholds were being achieved during the early 1990s (~3 out of 10, on average), but more biophysical boundaries were being respected (~3 out of 6). Taken together, these historical results show poor progress from the perspective of the Doughnut's "Safe and Just Space", especially given that the achievement of social thresholds cannot be substituted for the transgression of biophysical boundaries in this framework.

There are more countries transgressing boundaries across all six biophysical indicators compared to the early 1990s (Table 1). CO_2 emissions show the biggest change over the historical period: the number of countries overshooting their share of this cumulative boundary increased from 47 in 1992 to 74 in 2015 (an 18 percentage point increase). The proportion of countries overshooting the per capita boundaries for land-system change, ecological footprint, and material footprint increased by ~15 percentage points. Meanwhile, the proportion of countries overshooting the phosphorus and nitrogen boundaries increased by less (3 and 8 percentage points, respectively), but these indicators already showed a majority of countries in overshoot at the beginning of the analysis period.

We find mixed results from a social perspective, although some improvements have been made (Table 1). The number of countries achieving the social thresholds increased for five of the 11 indicators, it was stable for four indicators, and it declined for two indicators. At the beginning of the 1990s, only two social thresholds (access to energy and employment) had been relatively widely achieved (i.e. by close to half of the countries we analysed). An additional two social thresholds (life expectancy and nutrition) were being achieved by about half of the countries in 2015. However, there are still seven basic needs that most countries are currently falling short on. Less than 30% of countries achieve the thresholds for life satisfaction, democratic quality, social support, and equality, and performance on these indicators has either stagnated or declined over the analysis period (depending on the indicator).

Number of boundaries transgressed and thresholds achieved over time. We categorise countries by the number of social thresholds that they achieve (high, middle, or low shortfall) versus the number of biophysical boundaries they transgress (low or high overshoot). We then track their movement over time, from 1992 to 2015. We find that no country has met the basic needs of its residents at a sustainable level of resource use over this period. Moreover, countries tend to transgress most (or all) of the biophysical boundaries before achieving a significant number of social thresholds (Figure 2).

Nearly half of the 26 countries that moved significantly over time in Figure 2 have moved out of the High Social Shortfall and Low Ecological Overshoot group since the early 1990s (orange circles outside the bottom-left section). However, most of these countries moved into the High Ecological Overshoot group, while none of them achieve more than half of the social thresholds. China and Peru are good examples. Meanwhile, most of the countries that were in either the High or Middle Social Shortfall groups during the early 1990s (brown and blue circles in Figure 2) have improved social performance, but they were already in the High Ecological Overshoot group. Mexico and Hungary are good examples. Costa Rica is noteworthy for consistently transforming resources into social achievement more efficiently than any other country, although it also follows the general trend of increasing transgression of biophysical boundaries over time.

The countries that moved relatively little in Figure 2 (N = 65) are overwhelmingly in either the High Social Shortfall and Low Ecological Overshoot group, such as India and Nigeria (bottom-left), or in the Low Social Shortfall and High Ecological Overshoot group, such as Germany and the United States (top-right).

Extent of ecological overshoot and social shortfall over time. The results in Figure 2, which show the *number* of social thresholds achieved and biophysical boundaries transgressed, do not show the *extent* of ecological overshoot or social shortfall. Figure 3 shows the changing extent of social shortfall and ecological overshoot by comparing an index of average shortfall to an index of average overshoot for each country. The calculations build on an approach developed by Hickel[32] (see Methods).

Importantly, the average indices that we present are not intended to suggest that a country can trade-off individual social or biophysical goals against one another. Within the Safe and Just Space framework, these goals are seen as non-substitutable (better education does not mean we can have inadequate nutrition; mitigating climate change does not mean we can ignore land-system change). However, the indices provide a helpful way to visualise the average extent of shortfall and overshoot across countries and over time (see Supplementary Figures 2 and 3 for the extent of overshoot for each biophysical indicator and the extent of shortfall for each social indicator, respectively).

We find significant changes in the extent of social shortfall and ecological overshoot, notably among country groups with little change in the absolute number of social thresholds achieved and biophysical boundaries transgressed. Wealthy countries in the Low Social Shortfall and High Ecological Overshoot group (purple circles in Figure 3) increase the extent of ecological overshoot over the 1992–2015 period (from 3.0 times beyond fair shares of the ecological ceiling at the beginning of the period to 3.5 times beyond at the end, on average), and they show little change in the extent of social shortfall over the same period (from 1.7% below the social foundation to 1.4%, on average).

Meanwhile, countries in the High Social Shortfall and Low Ecological Overshoot group (orange circles in Figure 3) show an increase in ecological overshoot (from 6% beyond fair shares of the ecological ceiling at the beginning of the period to 19% beyond at the end, on average), and a welcome reduction in social shortfall over the same period (from 43% to 33% below the social foundation, on average). However, this group of countries is still overshooting the ecological ceiling faster than they are reaching the social foundation.

Although there are no countries that eliminate social shortfalls without overshooting biophysical boundaries, the results in Figure 3 do reveal several countries with promising trajectories, such as Costa Rica, Jordan, Albania, and Mauritius. Our results also show the alarming extent and lack of progress in reducing the level of resource use needed to live within fair shares of planetary boundaries by many wealthy countries, such as Australia, Canada, the United States, and Norway. Overall, countries tend to follow a path of transgressing biophysical boundaries before achieving social thresholds (Figure 2), and a path of escalating ecological overshoot that yields diminishing returns in reducing social shortfall (Figure 3).

“Business-as-usual” projections based on historical trends. Figure 4 shows our national historical findings together with “business-as-usual” projections and likely prediction intervals for each biophysical and social indicator between 2016 and 2050. We use the term “likely” to signify a 66% chance of the result occurring, based on historical trends. These values were estimated using the best-fit model from two established non-linear methods in statistical time-series analysis: exponential smoothing and auto-regressive integrated moving averages (ARIMA). These dynamic statistical forecasting methods account for patterns within the data over time, and give more weight to recent data, thereby offering a more nuanced approach to estimate empirical time trends compared to linear models, such as ordinary least squares (OLS) regression. The estimation procedure is described in detail in the Methods.

For the biophysical indicators, the business-as-usual projections suggest even fewer countries are likely to respect biophysical boundaries in 2050 compared to today (Figure 4a). If current trends continue, more than 100 countries (out of 147) would overshoot their share of the cumulative CO_2 emissions boundary by 2050, which is more than twice the number of countries in climate overshoot compared to the early 1990s.

Meanwhile, the number of countries that overshoot the per capita boundaries for land-system change, ecological footprint, and material footprint is projected to increase by roughly 10–15 percentage points in 2050 compared to today (and roughly 25 percentage points compared to 1992). The overshoot trends for the nutrient boundaries (nitrogen and phosphorus) are less concerning by comparison. In fact, the number of countries overshooting the phosphorus boundary is projected to remain stable (in line with results showing phosphorus use declining in many high-income countries[33]).

For the social indicators, the business-as-usual projections suggest that the number of social thresholds achieved by at least 50% of countries would likely increase from 4 out of 11 in 2015 to 7 out of 11 by 2050, based on historical trends (Figure 4b). However, we find that less than one-third of countries would be likely to achieve the remaining four social thresholds (life satisfaction, social support, democratic quality, and equality).

Although these projected levels of social performance suggest that much of humanity would likely remain below the social foundation in 2050, our projections may still be optimistic as they are based on within-country historical trends, which do not consider the potential social disruption from the negative impacts of ecological overshoot. Such disruption could include increased morbidity, mortality, and migration due to extreme climate events; shifts in the geographic range and transmissibility of infectious diseases; and increased poverty given that climate change disproportionately affects the world's poorest and most vulnerable people[34]. Moreover, although countries may overshoot biophysical boundaries for some time (e.g. by running down stocks of natural capital), the degradation of planetary health cannot continue indefinitely[35,36].

Overall, our findings suggest deep transformations are needed in all countries to reverse current trends and move towards the Doughnut of social and planetary boundaries. In high-income countries such as Germany, there is an urgent need to radically reduce levels of resource use without adversely affecting relatively high levels of social performance (Figure 5a). Middle-income countries such as China face the dual challenge of needing to accelerate improvements in social performance, while simultaneously scaling back resource use to be within biophysical boundaries (Figure 5b). In low-income countries such as Nepal, resource use could generally be increased and remain within most biophysical boundaries, but there is an urgent need to accelerate improvements in social performance to avoid critical human deprivation (Figure 5c).

Discussion

Overall, we find no evidence that any country is currently moving towards the doughnut-shaped "Safe and Just Space". Current trends will likely deepen the climate and ecological crisis, while failing to eliminate social shortfalls. Despite decades of sustainable development rhetoric, countries with high levels of social achievement have levels of resource use far beyond anything that could be sustainably extended to all people, and their extent of ecological overshoot has generally been increasing. Although low-income countries have shown progress in reducing social shortfalls, they have generally been transgressing biophysical boundaries faster than they have been achieving social thresholds. The slow rate of social progress is coupled with ecological overshoot at the global scale, which is already overwhelming the regenerative capacity of the biosphere[35] and exposing humanity to a high risk of destabilising the Earth-system[4].

Previous research has shown the unsustainability of current development trajectories[18,37]. Where the Doughnut provides new insights is that it contains plural and non-substitutable goals for which absolute (not relative) performance matters, both socially and ecologically. Building on the Doughnut, our analysis shows that past, current, and business-as-usual future levels of resource use associated with meeting basic needs are too high. To meet the needs of all people within planetary boundaries, current relationships between social performance and biophysical resource use must be radically transformed in all countries, albeit in different country-specific ways depending on the extent of social shortfalls and ecological overshoot[2,21,38].

For wealthy countries with high ecological overshoot, resource use needs to be dramatically reduced to get within fair shares of biophysical boundaries — a transition that is unlikely to be accomplished with efficiency improvements alone[39]. It may also require post-growth and degrowth policies that redesign current growth-dependent economic systems, and reduce the overconsumption of resources directly[40,41]. Simulation models have shown that it is possible for wealthy countries to improve social outcomes without growth by reducing inequality and prioritising social provisioning[16,24]. Given our finding that current trends in collective social indicators, such as social support, democratic quality, and equality, are most in need of transformation, and given that these social indicators are only weakly coupled to resource use[2], there is broad scope to improve them by transforming provisioning systems in non-materialistic ways (e.g. by distributing income more fairly and universalising access to basic goods and services). However, a growing body of research shows that such transformations must confront powerful industries and other vested interests that benefit from the unequal and extractive status quo both within and across countries[42–44].

For countries with high social shortfalls, a focus on meeting basic needs is required, with an emphasis on capacity-building and sovereign economic development[47]. Nutrition, sanitation, and income poverty deserve priority attention, as the number of countries that achieve the thresholds for these three social indicators is projected to slow in the coming decades, based on current trends. For nutrition, evidence suggests current relationships could be transformed by practicing sustainable farming methods, which would improve livelihoods in the process[45]. In addition, regulating water use by industrial agriculture could be aligned with investments in water supply and sanitation, thereby addressing water scarcity while contributing to better health outcomes[46]. For income poverty, the World Bank estimates a global poverty gap of 21% at $5.50 a day (2011 PPP) in 2015, which translates to $3.1 trillion (2011 PPP) to lift everyone above this threshold. This amount represents less than 3% of total global income. In other words, a small shift in the flow of global income from rich to poor, such as ensuring fairer wages and prices for producers, could alleviate extreme poverty without the need for additional global growth.

An important limitation of our analysis is that the statistical forecasting models we have applied are constrained by historical data, and thus our projections only show what is probable, given current relationships. In other words, the projections assume current provisioning systems and policies, and do not take into account the types of radical transformations that have been suggested by degrowth[41,48] and post-growth[6,49] scholars (see Methods for a discussion of limitations).

While important advances have recently been made in the development of ecological macroeconomic models[24,50], to date there is still no national model that explores the interconnected relationships between the plural social and biophysical objectives of the Doughnut. A more systemic perspective is needed to explore and compare plausible scenarios that move countries towards a safe and just space. Current trajectories are either dangerously unsustainable for the biosphere, or strikingly insufficient for human well-being — or both.

Methods

This section summarises how we collect, analyse, and track national biophysical indicators with respect to biophysical boundaries, and national social indicators with respect to social thresholds.

We provide a more complete discussion of indicator-specific methods for each biophysical and social indicator in the Supplementary Information.

Theoretical framework. Following O'Neill et al.[2], the theoretical framework that we adopt in our analysis integrates Daly's Ends–Means Spectrum[51] with human needs theory[52], and includes the emerging concept of "provisioning systems" as a conceptual intermediary between Earth-system processes and social outcomes[2,30,44,53]. A provisioning system can be defined as a set of related elements that work together in the transformation of resources to satisfy a foreseen human need, such as nutrition, access to energy, or social support[44].

This framework postulates that some of the observed variation in international performance can be explained by differences in the set of underlying provisioning systems, and recognises that these complex systems can be transformed (with or without intent). For example, different forms of transportation infrastructure (tracks for trains and trams, versus roads for private cars) can help satisfy particular needs with very different levels of energy use, land use patterns, public transit opportunities, and ultimately, resource use lock-ins[30,54].

Time series data. We collected available national time series data for population, social performance, and environmental footprints from a number of global databases, such as the World Bank's *World Development Indicators*, the Eora Multi-Regional Input-Output (MRIO) database[55], and other sources (see Supplementary Information Tables 1 and 2 for data sources). Countries with an average population below 1 million people were not included in our analysis, as they tend to have relatively sparse data coverage and/or be highly trade-dependent countries that are not well-modelled in global input–output databases. Years with missing data were linearly interpolated (see Supplementary Information for details on the individual biophysical and social indicators).

For comparability and continuity, we aimed to collect the data for our global time series analysis from the same sources that O'Neill et al.[2] used in their global cross-sectional study. That being said, this criterion could not be fully met for some of the indicators (i.e. nitrogen, phosphorus, and life expectancy) due to inadequate or non-existent time series coverage. As a result, data for these indicators were collected from alternative sources. No suitable time series data were available for the blue water footprint, so this indicator was not included in our national analysis. Although all of the data used in our analysis measure progress over time at the national scale, we acknowledge that measurements undertaken based on different models, data sources, and system boundaries can generate inconsistencies and may not be fully comparable. The multi-dimensional nature of the Doughnut of social and planetary boundaries makes this unavoidable to some degree, based on current data availability at least.

In the results presented in this study, we analyse time series data for 148 countries, although not all indicators were available for all countries (see Figure 4). The first year considered in our analysis is 1992, which is regarded as less uncertain in global input–output databases than years prior to 1992, largely due to structural changes to the global economic system caused by the dissolution of the Soviet Union.

Downscaling planetary boundaries. There are different ways to downscale planetary boundaries based on alternative views of distributive fairness[56]. Common approaches to downscale planetary boundaries to the national scale include methods based on different sharing principles, including equality, sovereignty, and capability to reduce environmental pressure, among others[57]. Following O'Neill et al.[2] and Hickel[58], we apply equality-based shares of each planetary boundary throughout our analysis, which spans the 1992–2050 period. This choice is motivated by our research question, which asks whether any countries have historically met the basic needs of their residents at a level of resource use that could be sustainably extended to all people on the planet, and/or whether any are on track to do so in the future, based on current trends. Our calculations take into account United Nations population projections under a medium fertility scenario[59].

We downscale four planetary boundary variables (climate change, phosphorus, nitrogen, and land-system change). Following Hickel[58], the climate change boundary is downscaled using an equality-based cumulative approach, which takes into account the safe carbon budget associated with historical CO_2 emissions over the 1850–1988 period that caused the global atmospheric concentration of CO_2 to overshoot the 350 ppm boundary. The remaining planetary boundaries are downscaled to annual per capita equivalents, following the same methods as O'Neill et al.[2]

Biophysical boundaries that account for changes in population over time were then compared to consumption-based footprint indicators that account for international trade. For CO_2 emissions, we calculated cumulative historical CO_2 emissions from 1850 to 2015 for each country and compared these country-level cumulative CO_2 emissions to national fair shares of the safe carbon budget on a yearly basis. For biogeochemical flows (nitrogen and phosphorus), in the absence of a reliable consumption-based time series at the national scale, we calculated consumption-based proxy time series for both indicators by mapping territorial N and P fertiliser use data from Bouwman et al.[33] to trade coefficients derived from Oita et al.'s[60] data available in the Eora global MRIO database. For land-system change, we obtained national data series that measure the consumption-based allocation of human appropriation of net primary productivity (HANPP) to final agricultural and forestry products, where international trade is accounted for using physical bilateral trade matrices[61]. The resulting indicator is called *embodied* human appropriation of net primary production (eHANPP).

In addition, we include two further consumption-based footprint indicators (ecological footprint and material footprint) and analyse these with respect to their suggested maximum sustainable levels per capita, accounting for changes in population over time. We acknowledge that these biophysical indicators partially overlap. For instance, the ecological footprint and material footprint both include fossil energy as a component, thus overlapping with each other and with the climate change indicator. However, this basket of indicators captures different notions of absolute sustainability: planetary boundaries aim to avoid tipping points in the Earth-system, the ecological footprint measures how much of the regenerative capacity of the biosphere is occupied by human demand, and the material footprint is a mass-based proxy of overall resource use[62].

In total, six biophysical indicators are investigated, over the historical 1992–2015 period, and with projections out to 2050. The projections are based on within-country time series relationships observed over the historical 1992–2015 period. See Supplementary Information for additional details on each biophysical indicator, and Supplementary Table 1 for data sources.

Establishing social thresholds. We base our selection of social indicators and thresholds on O'Neill et al.'s[2] study, which operationalises the doughnut-shaped "Safe and Just Space" framework[1,11,63] at the national scale. O'Neill et al.'s framework classifies life satisfaction and life expectancy as measures of well-being[2,14], while the other nine social indicators are classified as need satisfiers. This classification is consistent with the basic needs approach[27,52], and also reflects empirical results indicating that the more need satisfiers a country achieves, the happier and healthier its residents generally are[2].

With the exception of two indicators (life expectancy and income poverty), we use the same threshold values for the social indicators as O'Neill et al.[2]. For life expectancy, we use overall life expectancy, rather than "healthy life expectancy", as the latter indicator was not available for our time series analysis. We use a life expectancy threshold of 74 years, compared to 65 healthy years, based on the observation that life expectancy is 9 years higher than healthy life expectancy on average.

For income poverty, we use the percentage of the population living on less than the World Bank's poverty line of $5.50 per day at 2011 PPP international prices (following Edward and Sumner[64]), rather than the extreme poverty line of $1.90 per day used by O'Neill et al.[2], as the latter has been criticised for being too low to be considered a minimum standard[32]. The World Bank's approach to measuring poverty is limited, however, in that it does not tell us whether people have access to the context-specific forms of provisioning that are necessary to meet basic needs in a given country[65]. What ultimately matters is people's income vis-à-vis the costs of satisfying basic needs, and these costs vary substantially across countries and over time due to local factors such as climate, price controls, and levels of public provisioning (see Allen[66] for a review). There are alternative approaches to measuring poverty, which define the costs of country-specific baskets of essential goods and services[67,68], but no suitable data were available for our time series analysis.

In total, we include 11 social indicators, with projections of social outcomes (relative to social thresholds) out to 2050. The projections are based on within-country time series relationships observed over the historical 1992–2015 period. The two self-reported indicators included in our analysis are available for either fewer countries (life satisfaction) or zero countries (social support) in the earlier 1992–2004 period. For these two indicators, we considered the larger country sample available over the 2005–2015 period for all summary comparisons by indicator. See Supplementary Information for additional details on each social indicator, and Supplementary Table 2 for data sources.

Comparing biophysical indicators with respect to boundaries and social indicators with respect to thresholds. Within our results throughout the main text (and in the accompanying Supplementary Data), biophysical indicators are presented relative to the biophysical boundary, while social indicators are presented relative to the social threshold. In each case, we follow the same normalisation procedure employed by O'Neill et al.[2], which involves dividing the indicator value by the given boundary or threshold.

In the case of the biophysical indicators, which have an absolute zero, the value for a given country is calculated directly: the normalised biophysical data for a given year *t* are given by $x_t' = x_t \div x_t^*$, where x_t is the biophysical indicator in year t, and x_t^* is the biophysical boundary in year t. Note that the per capita biophysical boundaries change over time in absolute terms (i.e. as population grows).

In the case of the social indicators, which do not have a clear absolute zero, the lowest value observed for a given indicator over the 1992–2015 period is assigned the value of zero, while the social threshold is assigned the value of one. This normalisation procedure preserves the social threshold in absolute terms (it is always one, regardless of the data), and it also allows the differences between countries to be visualised more clearly in the Doughnut plots. In mathematical terms, the normalised social data for a given year *t* are given by $y_t' = (y_t - y_{min}) \div (y^* - y_{min})$, where y_t is the social indicator in year t, y^* is the social threshold (which does not change over time), and y_{min} is the lowest value for the social indicator observed over the analysis period.

Calculating the average extent of social shortfall and ecological overshoot. We calculated the extent of social shortfall and ecological overshoot for each country over time using simple average-based indices. Our approach builds on the methods developed by Hickel[32] for a single year, although our calculation procedure is slightly different.

To measure the extent of social shortfall, we subtract each normalised social ratio from the threshold value (i.e. one), and set any negative values to zero (given that scores below zero indicate no shortfall). The index of social shortfall is then calculated as the unweighted average of the transformed values (where zero represents no social shortfall).

To measure the extent of ecological overshoot, we follow a mirrored version of the same procedure. We subtract the boundary value (i.e. one) from each normalised biophysical ratio, and set any negative values to zero (given that scores below zero indicate no overshoot). The index of ecological overshoot is then calculated as the unweighted average of the transformed values (where zero represents no ecological overshoot). Our method differs from Hickel[32] in that we only measure the extent of overshoot (whereas Hickel[32] also measures "undershoot").

We acknowledge that creating aggregate measures of performance across non-substitutable goals, such as those contained in the Doughnut, is not fully consistent with the Safe and Just Space framework. Our measures of average shortfall and average overshoot allow for compensation *within* each social and biophysical index. By presenting these measures, we are not suggesting that it would be acceptable in practice to trade off individual goals against one another. The indices are presented simply to summarise the overall extent of social shortfall and ecological overshoot across countries and over time, which is hard to visualise otherwise. Importantly, we do calculate separate indices of social shortfall and ecological overshoot, in recognition that countries cannot compensate high social shortfalls for low ecological overshoot (or vice versa) within a "strong sustainability" framework[69], such as the Doughnut.

Projecting "business-as-usual" trends. We projected "business-as-usual" trends for each biophysical and social indicator for each country based on historical observations over the 1992–2015 period. For each indicator in each country, we used the best-fitting estimate of two distinct dynamic statistical forecasting models: (1) an ExponenTial Smoothing (ETS) state space model, and (2) an Auto-Regressive Integrated Moving Average (ARIMA) model. We followed a three-step process enabled by the *forecast* package in R[70], described in detail by Hyndman and Athanasopoulos[71].

First, for each country we estimated ETS models for each of the 17 time series indicators in our analysis (11 social and 6 biophysical). Projections based on ETS methods are weighted averages of past observations, with the weights decaying exponentially so more recent observations are weighted more highly than observations in the distant past[71]. Following Hyndman and Khandakar[70], we used an automated algorithm to select the best-fitting combination of ETS parameters for each indicator by minimising Akaike's Information Criterion, corrected for small sample bias (AIC_c).

Second, we estimated ARIMA models for each indicator within each country following a similar procedure. Projections based on ARIMA methods aim to describe the autocorrelations in the data through combinations of the order of the autoregressive part (p), degree of differencing needed for stationarity (d), and the order of the moving average part (q), often called an ARIMA(p, d, q) model[71]. Following Hyndman and Khandakar[70], we used an automated algorithm that selects the best-fitting combination of the p, d, and q parameters for each indicator by minimising AIC_c.

Although AIC_c is useful for selecting between models in the same class, it cannot be used to compare between ETS and ARIMA models because the maximum likelihood estimation is computed in different ways across model classes[71]. We therefore selected the best-fitting ETS or ARIMA model for each of the indicators for each country based on a time series cross-validation algorithm that minimises mean standard error (as described by Hyndman and Athanasopoulos, Section 3.4[71]). In each case, the best-fitting model was used to project point estimates out to 2050 together with 66% prediction intervals. Overall, these methods were used to compare more than 100,000 combinations of parameters to select the set of best-fit estimates for projecting business-as-usual trends in the social and biophysical indicators for 148 countries.

Limitations. Our statistical forecasting models are based on individual indicator trends that are constrained by historical data, and thus our analysis only shows what is likely given historical trends. Moreover, the dynamic statistical projections of individual indicators do not imply causal relationships. The links between biophysical resource use and social outcomes can be seen to run both ways, and our theoretical framework recognises that the relationships are mediated by dynamic and complex provisioning systems that can be restructured, intentionally or otherwise.

Our study does not attempt to characterise different types of provisioning systems or their effects on the relationships between resource use and social outcomes — these are complex and often context-specific challenges to incorporate across time and space. However, we do quantify the levels of resource use and social outcomes associated with business-as-usual trends, thus giving an indication of what could happen if recent trajectories continued.

Finally, our analysis is inevitably limited by the quality and availability of time series data (see Supplementary Information for descriptions of each biophysical and social indicator). Moreover, our selection of countries as the unit of analysis does not capture the wide disparities in resource use and social performance that occur within countries[17] (with the partial exception of the income equality indicator derived from the Gini Index). Similarly, countries are not isolated units — they are deeply interconnected through history, power, and international structures — but our cross-country analysis does not fully reflect these rich interconnections. That being said, all of the biophysical indicators in our analysis account for the upstream environmental burdens that arise from producing the goods that are consumed in a country, no matter where in the world those burdens take place (i.e. we use environmental footprints). A possible next step for future research would be to account for the upstream *social* burdens on communities and workers that arise worldwide from the consumption in a given country (i.e. social footprints), but substantial data gaps remain[8,72].

Data availability. The data produced in the analysis are included in the Supplementary Information accompanying this article. The data are also available via an interactive website (https://goodlife.leeds.ac.uk), which allows users to query the dataset, generate visualisations, and produce Doughnut plots similar to Fig. 5 for all countries.

Code availability. The R code used to generate the results is available from A.L.F. upon reasonable request.

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Author contributions

A.L.F. and D.W.O. designed the study. A.L.F. and N.R. assembled the data. A.L.F., D.W.O., J.H., and N.R. performed the analysis and wrote the manuscript.

Competing interests

The authors declare no competing interests.

Tables

Table 1. Country Performance with Respect to Social Thresholds and Biophysical Boundaries (1992–2015)

Indicator	***N***	**Threshold / Boundary**		**Unit**	**1992**	**2015**
Social					*Countries above threshold, %*	
Life Satisfaction	45 (119)	6.5		[0–10] Cantril ladder scale	(22)	21
Life Expectancy	147	74		Years	18	47
Nutrition	137	2700		Kilocalories per person per day	40	64
Sanitation	137	95		% with access to improved sanitation	25	35
Income Poverty	114	95		% who earn above $5.50 per day	29	33
Access to Energy	131	95		% with access to electricity	47	60
Secondary Education	129	95		% enrolment in secondary school	16	42
Social Support	(118)	90		% with friends or family they can depend on	(39)	28
Democratic Quality	144	7		[0-10] scale	29	28
Equality	125	70		[0-100] scale (Gini Index of 0.3)	21	15
Employment	148	94		% of labour force employed	50	49
Biophysical		*1992*	*2015*		*Countries within boundary, %*	
CO_2 Emissions	147	Population share of cumulative emissions		Mt CO_2 year^{-1}	68	50
Phosphorus	136	1.1	0.8	kg P year^{-1}	47	44
Nitrogen	136	11.3	8.4	kg N year^{-1}	45	38
Land-System Change	142	3.3	2.4	t C year^{-1}	61	47
Ecological Footprint	145	2.1	1.7	gha	51	34
Material Footprint	147	9.1	6.9	t year^{-1}	61	47

N is the number of countries considered. The social indicators for Life Satisfaction and Social Support have observations for a large number of countries only from 2005 onwards (2005 values in parentheses), and therefore a shorter time period (2005–2015) is used for all cross-country summary comparisons. The biophysical boundaries shown are global per capita values in 1992 and 2015 – they decline over time due to population growth, except for the CO_2 emissions boundary, which is calculated based on each country's population-weighted share of the 770 Gt of cumulative global CO_2 emitted from 1850 to 1988 (the year that the 350 ppm CO_2 boundary was crossed). See Supplementary Information for additional details and the data sources for each social and biophysical indicator.

Figures

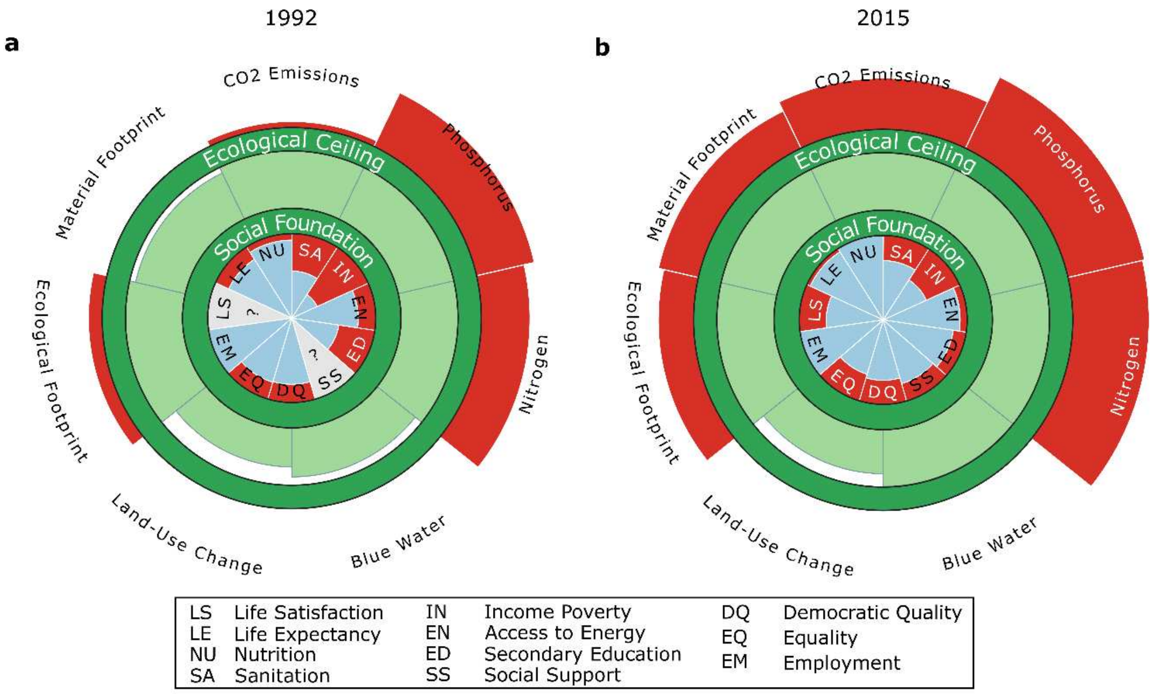

Figure 1. Global performance relative to the Doughnut's "Safe and Just Space" in 1992 and 2015, based on the biophysical boundaries and social thresholds measured in this study. Dark green circles show the ecological ceiling and social foundation, which encompass the Doughnut of social and planetary boundaries. The blue wedges show average population-weighted social performance relative to each social threshold. The green wedges show total resource use relative to each global biophysical boundary, starting from the outer edge of the social foundation. Red wedges show shortfalls below social thresholds, or overshoot beyond biophysical boundaries. Grey wedges show indicators with missing data.

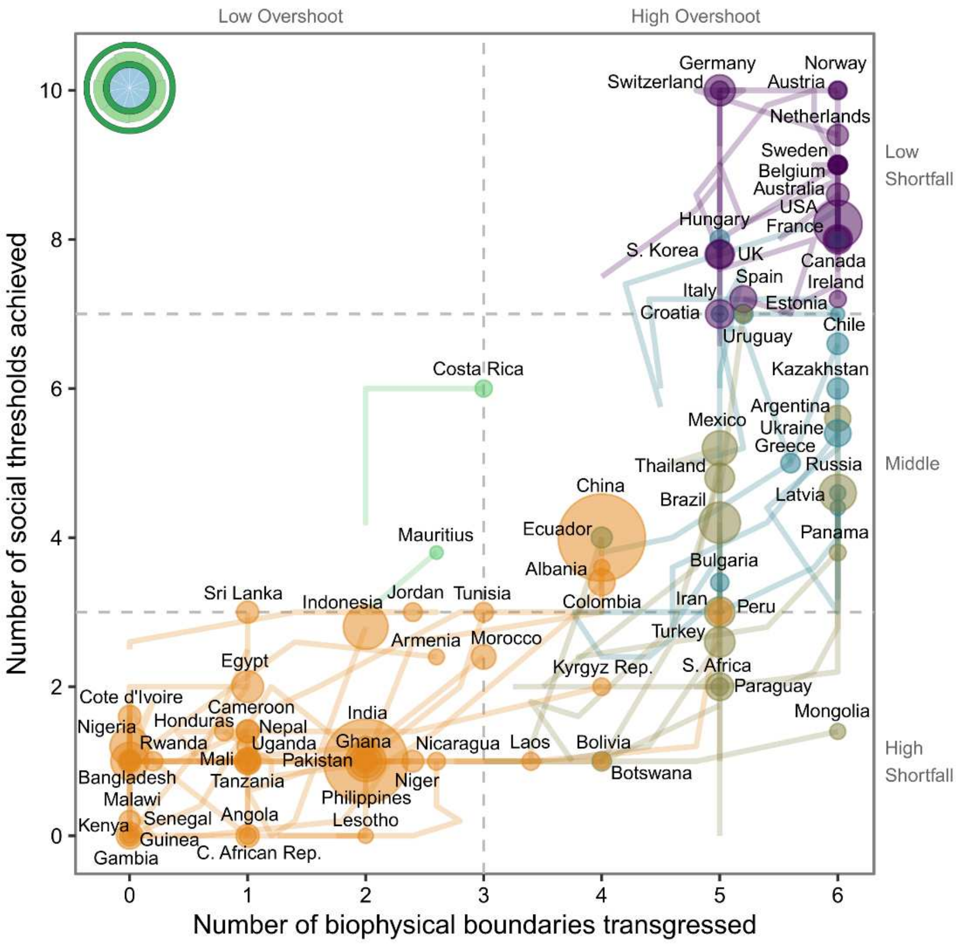

Figure 1. Number of social thresholds achieved versus number of biophysical boundaries transgressed by countries over time, 1992–2015. Country performance is divided into six sections based on the average number of social thresholds achieved (high, middle, and low shortfall) and the average number of biophysical boundaries transgressed (low and high overshoot). Circles indicate performance at the end of the analysis period (in 2011–2015) and are sized according to population. Country paths are shown in 5-year average increments. Countries are colour-coded relative to their performance at the start of the analysis period (in 1992–1995) clockwise from top right: Low Shortfall–High Overshoot (purple); Middle Shortfall–High Overshoot (blue); High Shortfall–High Overshoot (brown); High Shortfall–Low Overshoot (orange); Middle Shortfall–Low Overshoot (green). Only countries with data for all six biophysical indicators and at least 9 of the 10 social indicators are shown (*N* = 91). Ideally, countries would be in the Doughnut located in the top-left corner.

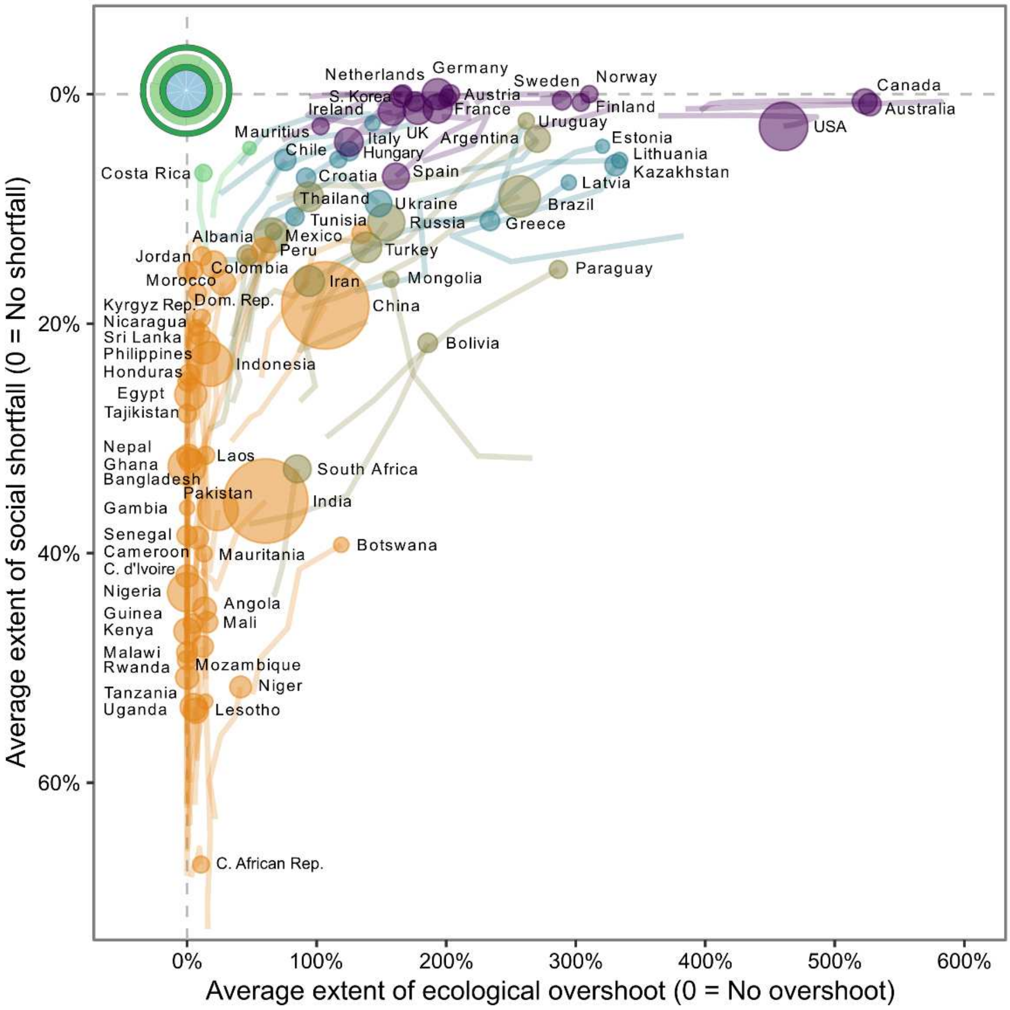

Figure 2. Extent of shortfall below the social foundation versus extent of overshoot beyond the ecological ceiling across countries, 1992–2015. Circles indicate performance at the end of the analysis period (in 2011–2015) and are sized according to population. Country paths are shown in 5-year average increments. Countries are grouped and colour-coded as per Figure 2, i.e. relative to their performance at the start of the analysis period (in 1992–1995). Only countries with data for all six biophysical indicators and at least 9 of the 10 social indicators are shown (*N* = 91). Ideally, countries would be in the Doughnut located at (0, 0) in the top-left corner.

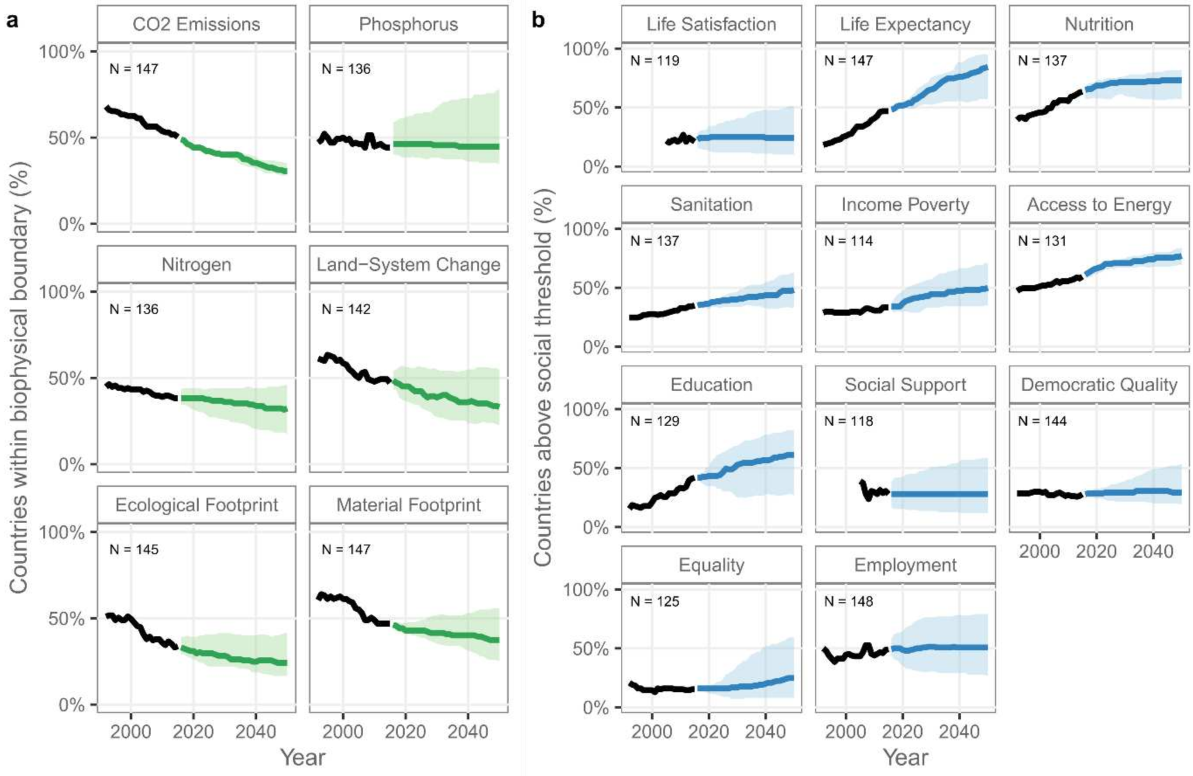

Figure 4. Historical trends (1992–2015) and projected "business-as-usual" trends (2016–2050) in country performance with respect to biophysical boundaries and social thresholds. a The historical percentage of countries with resource use within each biophysical boundary (black lines), and projected "business-as-usual" trends (green lines). **b** The historical percentage of countries with social performance that reaches each social threshold (black lines), and "business-as-usual" projections (blue lines). 66% (likely) prediction intervals are shown in a lighter tint. See Table 1 for additional detail on the indicators, including their respective biophysical boundaries and social thresholds, and Supplementary Data for country-level results.

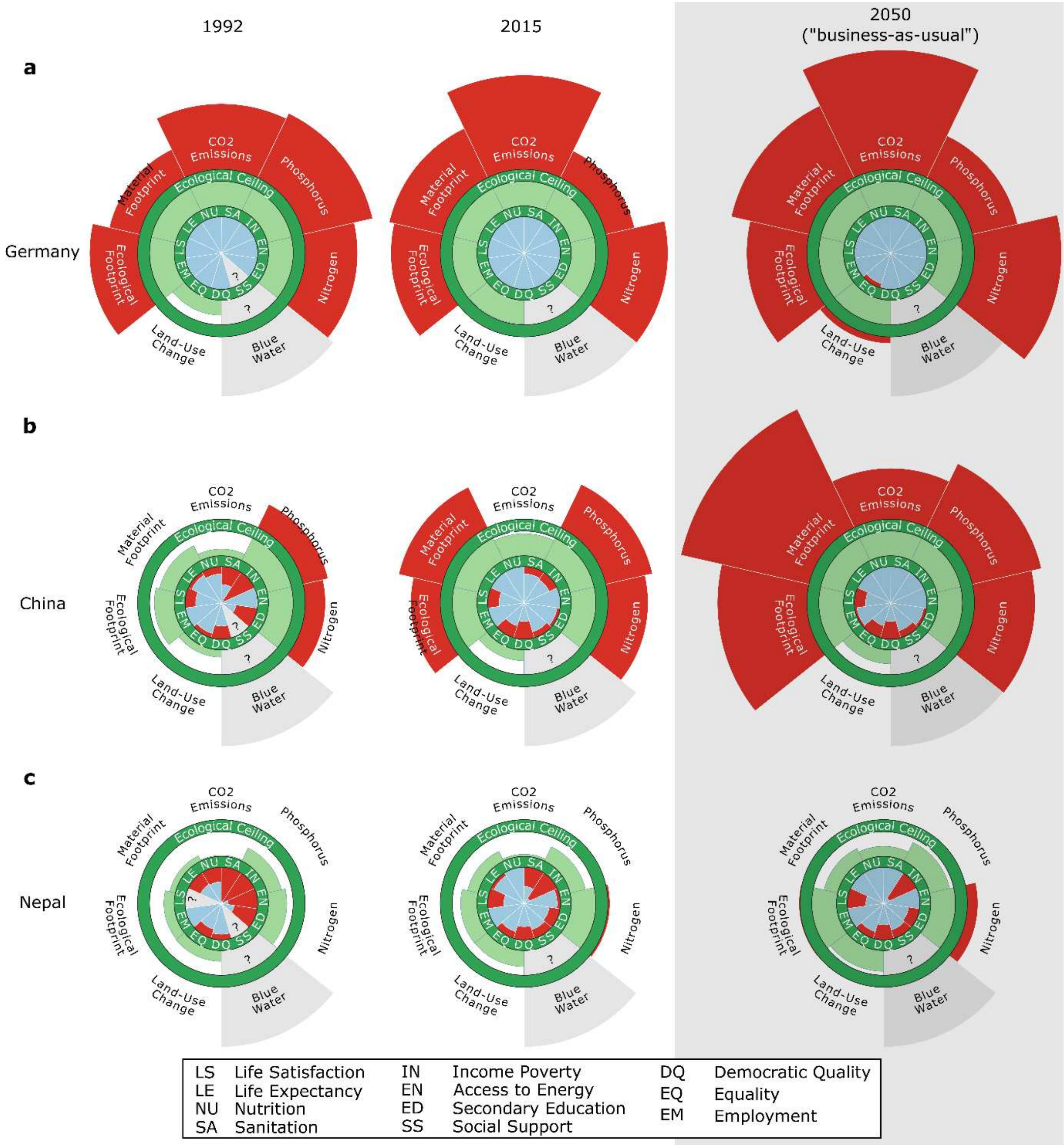

Figure 5. National performance relative to a "Safe and Just Space" for three countries in 1992, 2015, and with projections for 2050 based on business-as-usual trends for each social and biophysical indicator. a Germany, **b** China, and **c** Nepal. Colours are used as per Figure 1. The business-as-usual values are calculated for each indicator using the median estimate of the best-fitting ARIMA or exponential smoothing model, based on national historical trends (see Methods).

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