Ecological Indicators 169 (2024) 112864

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Living in the 'doughnut': Reconsidering the boundaries via composite indicators

Gianluca Gucciardi [a], Tommaso Luzzati [b,*]

[a] Università degli Studi di Milano-Bicocca – Department of Economics, Management and Statistics (DEMS), Italy
[b] Università di Pisa: Dipartimento di Economia e Management and REMARC, Italy

ARTICLE INFO

JEL classification:
G21
G22
G23
G24

Keywords:
Doughnut economics
Sustainable development
Composite indicators
Robustness

ABSTRACT

The concept of planetary boundaries (Rockström et al., 2009) and the need for social minima were integrated by Raworth (2012, 2017) into a 'doughnut-shaped' framework, representing a 'safe and just space' for humanity. Empirical assessments have revealed that no country currently falls within this 'doughnut'. However, to what extent do the results depend on the methodological assumptions, and could a less stringent metric, allowing trade-offs between indicators, improve these outcomes? Preserving the core of Raworth's theoretical framework, we address these questions by constructing two separate sets of composite indicators for the social and environmental dimensions. Following an uncertainty-based approach, we obtain the two sets by combining alternative normalisation, weighting, and aggregation techniques. This approach yields a new, easily communicable, and robust metric for the 'safe and just space'. Our analysis strengthens previous findings, showing that even with less stringent criteria, no country currently falls within the doughnut, underscoring the substantial gap to be addressed in both social and environmental policies.

1. Introduction

According to doughnut economics (Raworth, 2012; Raworth, 2017), a country should place itself within a 'safe and just space' by reaching some minimum levels of social standards and simultaneously keeping anthropogenic pressure on the environment within safe boundaries. Offering a holistic approach to the most notable global challenges, doughnut economics integrates social well-being and ecological limits. By focusing on social justice, sustainability and long-term well-being over relentless growth, this approach is intended to steer communities and policymakers towards achieving a more equitable, resilient, and sustainable world (Martiskainen et al., 2020).

To date, there have been few attempts to measure whether countries lie within the 'safe and just space'.[1] O'Neill et al. (2018) and Fanning et al. (2022) focused on almost 20 dimensions, each of which was measured by one indicator, as listed in the Annex, Table A.1. Their approach enables a straightforward visual representation of the extent to which a country aligns with the social and/or environmental boundaries or exceeds/falls short in certain dimensions.[2] Since no country was found to be 'living within the doughnut', Fanning et al. (2022) also consider the relative number of met dimensions within the doughnut for each country, which itself is a composite indicator.

This approach is characterised by two elements. First, it retains a binary assessment – whether a criterion is satisfied or not – and overlooks the matter of proximity, meaning the distance of a given indicator from the doughnut is not considered for the evaluation. Second, it involves the risk of perfunctory assessments due to exactly identified thresholds and the unavoidable degree of arbitrariness in the choice of indicators.

The issue of measuring proximity can be tackled by aggregating the several dimensions into composite indicators, while a way to address the challenge of arbitrariness involves applying various techniques to the same data and constructing several composite indicators to ensure robustness. So far, to the best of our knowledge, only Gómez-Alvarez

* Corresponding author.
E-mail addresses: gianluca.gucciardi@unimib.it (G. Gucciardi), tommaso.luzzati@unipi.it (T. Luzzati).

[1] O'Neill et al. (2018) use 18 indicators updated to 2011, while Fanning et al. (2022) use 17 indicators updated to 2015. Both these articles cover the same set of indicators, except for 'Blue water', which is only included in O'Neill et al. (2018). We base our analysis on the operationalisation of Fanning et al. (2022) with 17 indicators, as they use and provide more updated data.

[2] Another more recent strand of literature has focused on the quantification of the doughnut for single countries, e.g., Philippines (Castro et al., 2022), Thailand (Luukkanen et al., 2021) and Cuba (Saunders and Luukkanen, 2022), rather than adopting a worldwide perspective.

https://doi.org/10.1016/j.ecolind.2024.112864
Received 29 July 2024; Received in revised form 2 November 2024; Accepted 15 November 2024

Díaz et al. (2024) used composite indicators to investigate the issue of proximity for the 'doughnut' for 26 European countries.[3] The discussion will illustrate in detail the many differences between their study and the present one.

Composite indicators are very popular, at both institutional levels and within policy debates, particularly in the context of progress measurement and the 'beyond-GDP' discourse (e.g., Paruolo et al., 2013; Fleurbaey, 2009; Fleurbaey and Blanchet, 2013; Hoekstra, 2019). They have the compelling ability to distil multifaceted data into a single value, making it more accessible to a wider audience, serving as a communication tool, and catalysing policy discussions. Composite indicators also enable international comparisons, allowing countries to assess their advancement relative to global peers. However, it is crucial to acknowledge the trade-off inherent in these indicators. The subjective nature of indicator selection and the building methodology can undermine reliability, potentially leading to oversimplification and misinterpretation (Böhringer and Jochem, 2007; Valdés, 2018). Balancing comprehensibility with accuracy remains a key challenge in well-being and sustainability assessment.

In the sustainability discourse, a relevant objection to composite indicators is that they contradict the idea of strong incommensurability which posits that certain values cannot be traded off against others (see, e.g., Doyal and Gough, 1991; Gough, 2015; Max-Neef 1991). We support this idea and that one should strive for strong sustainability (e.g., Munda, 1997; Biggeri et al., 2019), despite the presence of potential trade-offs and complementarities of sustainable development dimensions (Barbier and Burgess, 2019; Qizilbash, 2001). At the same time, strong sustainability does not logically imply that composite indicators must never be used, but rather that they should be 'carefully handled'. In this case, for example, not using them here would prevent the previously highlighted proximity issue from being tackled. Moreover, by allowing for some compensation between good and poor performance, composites offer us an indulgent criterion for assessing whether a country lives within the doughnut. Do these less stringent assessment criteria lead to a more optimistic picture? The answer provided by this piece of research is "no". However, building composites should not be mistaken for the end of the story; instead, they offer initial insights that must be harmonised with in-depth analyses of each indicator.

Given the previous considerations, this research aimed to provide a robustness check for the results in the existing literature by using a new metric that addresses the proximity issue in a robust manner, thereby avoiding an oversimplified view of the multifaceted nature of sustainability. To address the proximity issue, we aggregated the dimensions into two distinct composite indicators for each of the two macro-themes, that is, one for planetary boundaries and another for social foundations. To mitigate the challenge of arbitrariness, we employed uncertainty analysis, that is, we combined different normalisation, aggregation, and weighting techniques to calculate a set of composite indicators. This approach yields a range for the country's performance and boundaries within each of the two macro-themes. Consequently, this offers a robust assessment of the size of the 'safe and just' space against which to evaluate each country.

The rest of the paper is structured as follows. Section 2 presents our approach and its contribution to Doughnut Economics, and Section 3 provides a description of the dataset. The main results are discussed in Section 4, while Section 5 gives some hints about countries' distance from the doughnut. Section 6 discusses possible concerns, and Section 7 concludes.

[3] Other papers built composite indicators, but either for the environmental boundaries (Dao et al., 2018, and Li et al. 2019), or for social foundations (Desmoitier et al., 2023).

2. The doughnut and its empirical definition

2.1. Foundation

The need for economics to consider society and the economy as open systems embedded within the natural environment was loudly spelt out by some heterodox economists, especially K. W. Kapp whose ideas are still topical (see, e.g., Luzzati, 2010; 2023). Already in 1950, well ahead of his time, he argued that the incompatibilities arising between ecological and economic systems can threaten the economic process, its social reproduction, and jeopardise human well-being and even survival (Kapp, 1976, 98; see also Kapp, 1977, 531-32). Putting human well-being at the centre of his ethics, he proposed that the aim of political economy is to give the highest priority to "the social and moral imperative of minimising human suffering" (Kapp, 1977, 538). Therefore, in his view, policies should prioritise the satisfaction of basic needs and the compliance with environmental limits (Kapp, 1976, 101).

Over the years, many other more renowned scholars have adopted this perspective, which was also core in the UN Brundtland report. In particular, just after the well-known definition of sustainable development, one reads about the importance of both satisfying "the essential needs of the world's poor, to which overriding priority should be given", and of considering the "limitations imposed by the state of technology and social organisation on the environment's ability to meet present and future needs" (Brundtland, 1987, 41). Agenda 2030 (UN, 2015) and the SDGs are indeed centred on basic needs and a healthy natural environment (e.g., Fisch-Romito, 2021).

Kate Raworth (2012) used the image of a doughnut[4] to expound the concept that every human being must be allowed to live with dignity without exceeding the safe limits imposed by the natural environment. The various human needs constitute the inner boundary of the doughnut, its 'social foundations', while the bio-geochemical constraints constitute the outer boundary, the so-called 'environmental ceilings' derived from the above-mentioned 'planetary boundaries' approach started by Rockström and colleagues (Rockström et al., 2009; Steffen et al., 2015, Richardson et al., 2023).[5] As a result, the doughnut represents the 'safe and just' space for humanity to live in: no country should fall within the hole of injustice while, at the same time, environmental impacts should remain within safe planetary boundaries. In other words, it is a compass for guiding humanity (and policy) in the 21st century (Raworth, 2017). Given its connections to environmental and social sustainability, the doughnut economics methodology is finding increasing use in ecological economics, such as determining income or wealth caps for degrowth (Buch-Hansen and Koch, 2019), identifying criteria for a sustainable welfare system (Büchs, 2021), measuring the population impact on the environment (Cripps, 2021), and establishing well-being approaches beyond the SDGs (Cook and Davíðsdóttir, 2021).

2.2. Challenges when assessing countries' position

The empirical assessment of the doughnut at the country level was started by O'Neill et al. (2018) and Fanning et al. (2022), who employed 17 indicators to assess the performance of each country. They compared this performance with the respective thresholds to determine whether a country operates within the 'safe and just space'. This operationalisation has several advantages. It is based on easy-to-calculate threshold values

[4] The Doughnut Economics approach received international acclaim after the publication of the book "Doughnut Economics: Seven ways to think like a 21st century economist" (Raworth, 2017).

[5] Research on planetary boundaries has recently expanded to include issues of justice, resulting in significant new publications such as Rockström et al. (2023) and Gupta et al. (2024). However, our paper elaborates on the existing empirical assessments of the 'Doughnut' model, which have been published previously.

and allows a simple graphical representation which immediately shows the dimensions at which a country falls within the social and environmental thresholds and those at which an overshoot or shortfall occurs. Identification of the critical dimensions makes this tool actionable from a policy perspective by indicating which dimensions have more room for improvement and can be prioritised.

At the same time, these advantages are matched by some potential limitations. A first, albeit minor, issue is that since a single picture maps the performance of 17 indicators against their thresholds, the reader needs to dwell analytically on each indicator to grasp how a country is behaving, which can prove difficult when performances are mixed. Second, this limitation is even more pronounced in international (and intertemporal) comparisons, where the reader has to look at several different maps based on 17 indicators to understand which country is performing comparatively better than others or improving or deteriorating over time. Third, the assessments might suffer from a lack of robustness since changes in the choice of the indicators can lead to different conclusions. Finally, this approach does not take into consideration the proximity of each country to the thresholds: indeed, a country that does not meet any criteria but is very close to meeting all of them is still deemed as well out of the doughnut.

Let us clarify this limitation through a simple hypothetical example with three different social dimensions and four countries. Table 1 shows the values of three social indicators – x, y, and z – for the countries and the respective thresholds. Those thresholds act as benchmarks and one can imagine a hypothetical country for which all the thresholds are precisely met. This benchmark is shortened as THR in all subsequent tables.[6] In Table 1 the bold values exceed THR and hence meet the social foundations.

Fanning et al. (2022) standardises the figures as ratios with respect to the thresholds (such that a value above 1 indicates that a country meets the specific social criterion) and aggregate the indicators by calculating the percentage of met thresholds – which is indeed a composite indicator. Table 2 shows the outcome when using also other aggregation rules. Columns 2–4 report the standardisation with respect to the benchmark THR, then three possible aggregations, namely the number of indicators for which the threshold is met, the arithmetic mean, and the geometric mean.

An assessment based on the percentage of met indicators implies that France and Spain are assessed as better than Germany and Portugal. At the same time, despite meeting only one threshold, Germany is close to all the others, while France, which meets two out of three indicators, is very poor in indicator y. Which country is closest to living in the doughnut? Of course, no objective answer exists. However, looking at the percentage of met criteria is only a possibility. Other answers come from the arithmetic or the geometric mean aggregation, which are shown in the last two columns of Table 2. Germany would be assessed as being in the doughnut, despite reaching only one threshold, while the

Table 1
A hypothetical example to illustrate our approach. In this hypothetical example, the values of three social indicators (x, y, and z) for four countries are reported, alongside their corresponding thresholds. The thresholds serve as benchmark values, and for comparative purposes, a hypothetical country that meets all threshold values exactly is referred to as THR.

	x	y	z
Portugal	**1600**	155	3
Germany	**1250**	150	5
France	**1000**	50	**7**
Spain	600	**170**	**8**
THR	*900*	*160*	*6*

[6] Similar considerations would apply to planetary boundaries.

Table 2
Standardisation and aggregation in our hypothetical example. This table displays the results when applying three aggregation methods to the three hypothetical social indicators reported in Table 1. Columns 2–4 calculate the indicators' values using the standardisation with respect to the benchmark (THR). Columns 5–7 present three possible aggregations: the number of indicators for which the threshold is met, the arithmetic mean, and the geometric mean.

	x	y	z	Indicators > threshold	Arithmetic mean	Geometric mean
Portugal	**1.78**	0.97	0.50	33 %	**1.08**	0.95
Germany	**1.39**	0.94	0.83	33 %	**1.05**	**1.03**
France	**1.11**	0.31	**1.17**	67 %	0.86	0.74
Spain	0.67	**1.06**	**1.33**	67 %	**1.02**	0.98
THR	*1.00*	*1.00*	*1.00*	–	*1.00*	*1.00*

poor performance of France in indicator y would lead to a poor synthetic assessment; Portugal would reach the threshold only for the arithmetic aggregation because its poor performance in indicator z would be strongly penalised by the geometric mean, which allows low compensation among indicators.

As is evident from the example, while the means allow the distance from the thresholds to be considered, the judgement heavily depends on which composite indicator is used as a basis for assessment, which involves a high risk of arbitrariness in the outcome and assessment. Such arbitrariness comes from several sources, namely the standardisation of the raw data, the weighting of the standardised data, and their final aggregation (Böhringer and Jochem, 2007; Ebert and Welsch, 2004; Valdés, 2018; Greco et al., 2019).

It must be highlighted that the standardisation used above is easy to communicate since the threshold value is 1. This is not the case for other standardisation techniques. For instance, using the distance from the best performer, the standardised value for social indicator x would be 900/1600, that is, 0.5625. This does not imply, however, not considering thresholds: all countries scoring below this value will be assessed as below the minimum floor for the indicator x.

2.3. A proposal for operationalising the "Doughnut"

To address the challenge of arbitrariness, the usual approach involves first building a single composite and then performing robustness checks by building alternative composite indicators (e.g., Nardo et al. 2005). In contrast, the approach taken here begins by building multiple indicators directly, providing a 'blurred' representation of the phenomenon, as in Luzzati and Gucciardi (2015) and Gucciardi (2022). In particular, for each of the two macro-themes – the 'social foundations' and the 'environmental ceiling' respectively – we built several composite indicators from which we calculated the ranks for each country and the benchmark THR, its range of variation, and its median. Importantly, such a procedure involves one-to-one mapping between rankings and actual threshold values, meaning that a country that has a better rank than the 'threshold country' also shows a composite indicator value that lies within the doughnut in that specific domain.

For building the various composite indicators this research followed Nardo et al. (2005) and JRC-EC (2008) and relied on the far-reaching and rich scientific debate on composite indicators (for a comprehensive discussion see, e.g., Mazziotta and Pareto, 2017), which are relevant not only to policy but also to academic debate (e.g., Saltelli, 2007; Paruolo et al., 2013, Gan et al., 2017).

It should be emphasised that different building rules pursue different objectives. Concerning normalisation, one of the most impactful factors is whether data suffer from the presence of outliers: the 'Borda count' is not affected by outliers given that each country gets a decreasing score depending on its position in each variable's ranking; on the contrary, the distance from a reference point (leader or average) strongly depends on the behaviour of single units of analysis (e.g., the leader) or the overall distribution.

Table 3 shows the rules that have been used, that is, five normalisation, two weighting, and two aggregation rules, ending up with a total of 16 composite indicators and rankings per macro-theme.[7] Concerning weighting, we used both equal weights for each dimension within each macro-theme and data-based weights (principal component analysis) by allowing weights to be different.[8] While the first technique is easier to interpret and inherently considers that each of the indicators is equally important in the construction of the composite, the second enables the mitigation of the potential for double weighting, an issue that emerges in the equal-weighting when variables are strongly positively correlated (Yeheyis et al., 2013). Concerning aggregation rules, we used both the arithmetic and the geometric mean aggregations, where the latter allows low compensation between poor and good performances.[9]

As mentioned above, the 16 composites for the environmental ceilings and social foundations respectively, allowed us *(i)* to obtain the rank of each country and the 'threshold country', for each of the 16 composite indicators; *(ii)* to calculate the median, the minimum (i.e. the best) and the maximum rank (i.e. the worst)[10]; *(iii)* to compare each country against the 'threshold country'.

Before moving on to the data and the results, it is useful to illustrate our procedure by proceeding with the fictional example that was introduced earlier. For the sake of simplicity, let us build only six composites using three normalizations (distance from threshold, Borda, and distance from the best), equal weighting, and arithmetic and geometric mean (AM and GM). Table 4 reports the ranks according to each composite indicator. The first three columns of Table 5 report respectively the median, worst, and best ranks of the ranks' distribution obtained from the six composites used in this hypothetical example. The last two columns compare the metric used so far with ours, which is based on the comparison between the rank distributions of the threshold and the countries. The details of our assessment will be explained in the next section; for the moment it will suffice to note that our metric considers the proximity issue. For instance, Germany is assessed as 'broadly' respecting the social foundations because it shows rather balanced performances and is close to the threshold, despite meeting only one out of three social foundation criteria: the opposite considerations apply to France which performs very poorly in indicator *y*.

Table 3
Normalisation, weighting, and aggregation rules used in this paper. This table outlines the rules applied in constructing composite indicators. It includes five normalisation methods, two weighting schemes, and two aggregation approaches.

Phase	Name	Rule
Normalisation	Z-score	$I_d^c = \frac{x_d^c - \underline{x}_d^c}{\sigma_d^c}$
	Min-Max	$I_d^c = \frac{x_d^c - min_d^c}{max_d^c}$
	Distance from the best performance	$I_d^c = \frac{x_d^c}{max_d^c}$
	Distance from the average performance	$I_d^c = \frac{x_d^c}{\underline{x}_d^c}$
	Rank (or Borda score)	*Countries get a decreasing score depending on their position*
Weighting	Equal Weight for Dimension	$w_d = \frac{1}{D}$
	Principal Components Analysis / Factor Analysis	*Weights are calculated as the scaled-to-one value of the factor loading square, in proportion to the variance explained by each factor.*
Aggregation	Linear additive average	$CI_d^c = \sum_{d=1}^{D} w_d I_d^c$
	Geometric average	$CI_d^c = \prod_{d=1}^{D} I_d^{c\, w_d}$

Notes: I_d^c is the normalised indicator for dimension d and country c. For each indicator, $\underline{x}$ is the arithmetic mean, σ the standard deviation, and min and max *respectively* the minimum and the maximum values. CI_d^c is the composite indicator for country c, where w_d is the weight. D is the number of dimensions.

2.4. Objectives of this research work

As it emerges from the above discussion, the primary goal of this research is to enhance the empirical validation of Doughnut Economics by refining how one can assess whether countries are operating within the 'safe and just space'. Doughnut Economics defines this space as achieving basic social standards while staying within ecological limits to prevent environmental degradation. Previous analyses have been based on binary metrics that overlook variations in performance and proximity to the ideal state. To address these limitations, our research employs composite indicators that integrate multiple dimensions of social and environmental data, as described in detail in Section 2.3. By adopting an uncertainty approach, we apply various normalisation, weighting, and aggregation techniques to create diverse composite indicators that provide a more refined assessment of country performance. This approach aims to provide a more flexible and accurate assessment of countries' alignment with the "safe and just space" while acknowledging the inherent uncertainties in sustainability metrics.

Our methodology strikes a balance between the benefits of composite indicators and the need to preserve detailed information about country's performance. It contributes to a more accurate, comprehensive, and practical evaluation of how well countries align with sustainability goals. This method not only enhances the accuracy of the results

Table 4
A hypothetical example of our approach: rankings from 6 different composite indicators. This table shows the ranks for each country based on the example introduced in Table 1, normalised using the distance from the boundary, from the best, and Borda rule, and aggregated both linearly and geometrically.

	Dist. from boundary, AM	Dist. from boundary, GM	Borda, AM	Borda, GM	Dist. from best, AM	Dist. from best, GM
Portugal	**1**	4	**2**	4	**3**	4
Germany	**2**	**1**	4	**3**	**2**	**1**
France	5	5	4	5	5	5
Spain	**3**	3	**1**	**1**	**1**	3
THR	*4*	*2*	*2*	*2*	*4*	*2*

[7] There are 16 combinations and not 20 (the product of 5 normalisation, 2 weighting, and 2 aggregation techniques) because the geometric mean is not applicable for negative or zero values that are obtainable using z-score and min–max normalisation techniques.

[8] Principal component analysis / factor analysis (PCA-FA) decreases the dimensionality of the initial dataset to a collection of appropriate components without significantly losing original information.

[9] The linear additive technique is compensatory, enabling excellent (poor) performance in one indicator to compensate for poor (excellent) performance in another. On the other hand, the geometric technique is beneficial to lessen the compensability of poor performance in certain indicators by high values in others owing to the 'geometric-arithmetic means inequality' in return for a slightly more complex calculation process (usually the weighted geometric mean) (Beliakov et al., 2007).

[10] In the case of the environmental domain, the minimum identifies the lower side of the rank's domain, i.e. worst performance, while the maximum identifies the upper side of the ranks' domain, i.e. best performance.

Table 5
Our assessment proposal. This table reports the median, worst, and best ranks of the distribution of ranks derived from the six composite indicators of our hypothetical example. The assessment based on our proposal is in column 5, while column 6 report the percentages of met boundaries.

	Best	Worst	Median rank	In the Doughnut	n. indicators > thresholds
Portugal	1	4	3.5	No	33 %
Germany	1	4	**2.0**	**Broadly**	33 %
France	4	5	5.0	No	67 %
Spain	1	3	**2.0**	**Broadly**	67 %
THR	*2*	*4*	*2.0*		

but also offers valuable insights for policymakers, enabling international comparisons and more informed decisions. By refining the empirical assessment of Doughnut Economics, our research contributes to the broader understanding of sustainability and the global effort to guide countries toward achieving a more equitable, resilient, and sustainable world.

3. Data

Our analysis uses the database made publicly available by Fanning et al. (2022) in the supplementary materials. The database contains data for more than 140 countries from 1992 to 2015 on 17 indicators.[11] The environmental ceilings are defined by six indicators,[12] namely (i) CO2 emissions, (ii) phosphorus, (iii) nitrogen, (iv) land use change, (v) ecological footprint, and (vi) material footprint. The first four indicators refer to planetary boundaries (climate, geophysical, and land-related), while the remaining two refer to a country-scale environmental footprint. The social foundations are defined by 11 indicators built based on the UN Sustainable Development Goals and cover (i) life satisfaction, (ii) healthy life expectancy, (iii) nutrition, (iv) sanitation, (v) income, (vi) access to energy, (vii) education, (viii) social support, (ix) democratic quality, (x) equality, (xi) employment. An important reason for referring to Agenda 2030 is that the UN reached a consensus on some minimum levels of basic and social needs that should be guaranteed to all people on the planet. Data are fully available (i.e., without missing values) for a subset of 81 countries for the latest available year, 2015.[13] We restricted our analysis to this subset to avoid the imputation of missing values, which would add uncertainty.[14]

4. Results

The next two subsections present, respectively for the social and environmental macro-themes, the best, the worst, and the median of the ranks for each country as calculated by using our 16 composite indicators. Such values are compared with the respective values of the hypothetical country named 'Threshold' (THR), which is built using the threshold values identified by Fanning et al. (2022). As mentioned above, there is a direct correspondence between ranks and threshold values.

We used three alternative criteria for judging whether a country is above the aggregated social foundations or below the aggregated environmental ceilings, indicated respectively with 'strictly', 'yes', and 'broadly'. The stricter one is when the worst rank of a country is at least equal to the best rank of the 'threshold country'. A weaker criterion is when the country's worst rank is at least equal to the median rank of the 'threshold country'. An even weaker criterion is when the previous criterion is not met but the median rank of the country is at least equal to the median of the 'threshold country'.

4.1. Social foundations

The results for our 'Social Foundations' composite indicators are shown in Fig. 1 and Table 6. In Fig. 1, the range of ranks for each country is shown with a vertical bar, while the median rank with a black dot. For instance, Belgium has the second median rank, and its range goes from rank 1 to 11. The horizontal line indicates the 'threshold country' (THR). Its value is 27, while its range goes from rank 21 to rank 33.

Table 6 focuses on the 28 countries that reached the threshold in at least 7 out of 11 indicators. It reports the number of social foundation thresholds met, the median rank, the range, and the assessment given by our composite ('Just Area'). If the worst country rank is compared with the best rank of the range of the threshold 'country' (that is, 21), then 16 countries are classified as 'just' (from Norway to France in Fig. 1 and Table 6). This is indicated by the label 'strictly' in the last column ('Just'). If one checks whether the worst country rank is at least equal to the median of the 'threshold country' (27), then seven other countries are considered 'just', labelled with 'yes' in the last column of Table 6. If this criterion is not met but the median rank is equal to, or better than the median rank of the 'threshold country', then also the three countries labelled as 'broadly' are assessed as 'just'. Hence, under the latter perspective, 26 (32 %) countries reach the threshold and fall within the just space, while the remaining 55 (68 %) are below it. Such results are in line with the findings of O'Neill et al. (2018), Moyer and Hedden (2020), and Fanning et al. (2022) who found that few countries respect the social foundations.

At the same time, according to our metric, achieving approximately 80 % of the threshold is enough to fulfil the social foundations. The reason is that we allow for some compensation among dimensions at the aggregate level. For the same reason the median rank of the threshold hypothetical country (27), which respects all thresholds exactly, is worse than the rank of several countries which do not reach some of the social foundations but perform better than the 'threshold country' in many respects.

The relationship between the number of thresholds reached and the median position of a country is confirmed by a negative (−0.952) and significant (p-value: 0.00) linear OLS regression. This relation is shown in Fig. 3, which on the x-axis reports the number of indicators for which the threshold is met, while on the y-axis the individual country's median rank.

This statistical finding indicates that our composite measure of social foundations effectively integrates performance across various dimensions. Although the'blurred doughnut approach introduces some epistemological weaknesses, it pragmatically synthesises complex, multidimensional data into a coherent assessment. This enables a broad yet practical evaluation of a country's alignment with social sustainability goals within the Doughnut Economics framework. Thus, despite its limitations, our approach provides a useful tool for policymakers to improve social sustainability.

4.2. Environmental ceilings

Following the same pattern as the previous subsection, the results for the environmental ceilings are illustrated in Fig. 2 and Table 7, which have to be read similarly to those of Fig. 1 and Table 6 but for the fact that the threshold is not a minimum to be reached, rather a maximum

[11] The detailed explanation and discussion of how the database was build is in the "Supplementary information" available at this link:https://static-content.springer.com/esm/art%3A10.1038%2Fs41893-021-00799-z/MediaObjects/41893_2021_799_MOESM1_ESM.pdfSince the available data are standardised with respect to the thresholds, we obtained the raw data by multiplying the standardised data by the thresholds.
[12] Indicators are consumption-based footprints that take account of international trade and population.
[13] We should also acknowledge that data gaps in sustainability measurement were found to be a relevant predictor of poor sustainability performance and the strengthening of related measurement systems is crucial to get a full picture of this global phenomenon (Jacob, 2017).
[14] Table A.1 in the Annex provides descriptive statistics for the 17 dimensions.

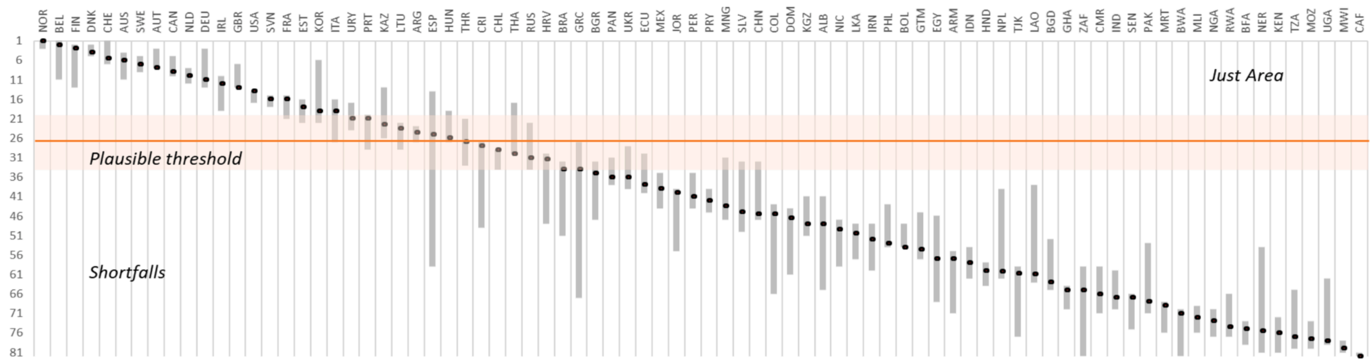

Fig. 1. Social foundation ranks by country and just area. This figure shows the range of ranks for each country in social foundations. Black dots mark the median rank, while the grey band spans from the minimum (best) to the maximum (worst) rank.

Table 6
Social foundation threshold of high-ranked countries. This table focuses on 28 countries that have met the thresholds in at least 7 out of the 11 social indicators. It reports the number of unmet thresholds, the median rank, and range of ranks. The last column contains our assessment proposal that classifies countries as 'strictly', 'yes', or 'broadly' just, depending on their rank relative to the benchmark (THR). 'Strictly' is when the country's worst rank is better than or equal to the best rank of the threshold country (21); 'Yes' if the country's worst rank is at least equal to the threshold country's median rank (27); 'Broadly' if the country's worst rank does not meet the 'Yes' criteria, but its median rank is equal to or better than the threshold country's median rank; 'No', otherwise.

Country	Unmet thresholds	Median rank	Range	Just
Norway	0	1	1–3	Strictly
Switzerland	0	6	1–7	Strictly
Austria	0	8	3–8	Strictly
Germany	0	11	3–13	Strictly
Finland	1	3	2–13	Strictly
Denmark	1	4	2–5	Strictly
Sweden	1	7	5–9	Strictly
United Kingdom	1	13	7–13	Strictly
United States	1	14	14–17	Strictly
Belgium	2	2	1–11	Strictly
Australia	2	6	4–11	Strictly
Canada	2	9	5–10	Strictly
Netherlands	2	10	8–12	Strictly
Ireland	2	12	10–19	Strictly
Slovenia	3	16	15–18	Strictly
France	3	16	15–21	Strictly
Estonia	3	18	16–22	Yes
Italy	3	19	16–27	Yes
Uruguay	3	21	17–24	Yes
Spain	3	25	14–59	Broadly
Hungary	3	26	19–27	Yes
Korea, Rep.	4	19	6–22	Yes
Portugal	4	21	20–29	Broadly
Kazakhstan	4	23	13–26	Yes
Lithuania	4	24	22–29	Broadly
Argentina	4	25	23–27	Yes
Chile	4	29	29–34	No
Croatia	4	32	30–48	No
THR	–	*27*	*21–33*	–

not to be exceeded. The median rank of the 'threshold country' (horizontal line) is 31, while it ranges from rank 27 to 35.

Under the stricter assessment criterion, the worst rank in the country range must be at least equal to the best rank of the range of the 'threshold country' (that is, 27). In this case, 21 countries are classified as being in the 'safe' area. This is indicated by the label 'strictly' in the last column of Table 7. If one checks whether the worst rank in the country range is at least equal to the median of the 'threshold country' (31), then seven other countries are considered 'safe', labelled with 'yes' in the last column of Table 7. If this criterion is not met but the median country rank is at least equal to, or better than the median of the 'threshold country', then also two other countries, labelled as 'broadly', are assessed as lying within the 'safe' area. Hence, under the more indulgent perspective, 30 countries (37 %) live within the safe area, while the remaining 51 (63 %) overshoot the environmental ceilings.

Hence, following our approach, an albeit limited number of countries can be considered in the environmentally safe area. Again, this result is in line with O'Neill et al. (2018), who concluded that only 16 countries did not exceed the environmental constraints. Table 7 compares, for each country, the number of thresholds met individually and the attainment or non-attainment of the environmentally safe area according to our 'blurred' doughnut approach.

How does our assessment compare with the number of individual thresholds reached by each country? Again, the answer is found in Table 7. First, no country with more than three overshoots can be considered in the safe area. The nine countries that do not overshoot any planetary limit are within the aggregate environmentally safe area. However, when compared with the social foundations, there is a lower correspondence between the assessment based on the composite indicator and that based on overshooting in the six environmental dimensions. For instance, Nicaragua and Armenia exceed in three dimensions while resulting 'safe', while Mali exceeds only in one but is borderline when considering the aggregate assessment; or the Dominican Republic is within the limits for all environmental dimensions while performing rather badly compared to other environmentally virtuous countries. This suggests that, for some countries, overshooting in one dimension might be enough to generate a considerable effect on the aggregate assessment. Similarly, other countries exceeding two or three environmental boundaries by a limited amount can be considered within the environmental limits in aggregate terms.

Lastly, we estimated (OLS) the correlation between the number of environmental ceilings exceeded and the median rank (see Fig. 4). We found a positive (0.922) and significant linear correlation (p-value: 0.00), confirming that nations that attained lower ranks in environmental sustainability also exceeded more thresholds on average. This finding, which reveals that countries with lower environmental sustainability ranks exceed more thresholds, aligns with our results at the social level. It underscores the robustness of our methodology by validating that the aggregate measures accurately capture the underlying data, reinforcing the reliability of our composite indicators in assessing both social and environmental dimensions.

4.3. Countries in the doughnut

Despite our synthetic approach based on composites, few countries manage to respect either the social foundations or the planetary boundaries. Under a rather weak assessment, about one-third of the countries in our sample have an appropriate level of social foundations, while 37 % operate within planetary boundaries. At the same time, the

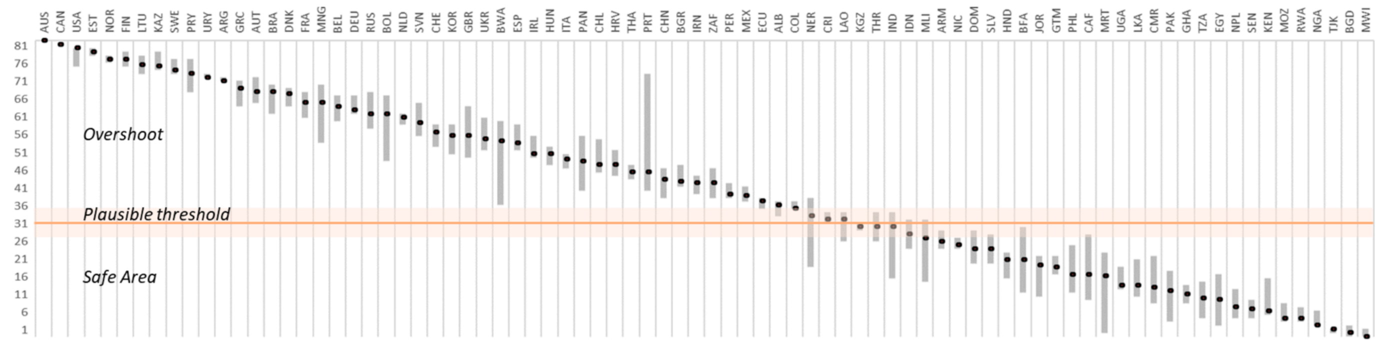

Fig. 2. Environmental ceiling ranking by country and safe area. This figure shows the range of ranks for each country in environmental ceilings. Black dots mark the median rank, while the grey band spans from the minimum (worst) to the maximum (best) rank.

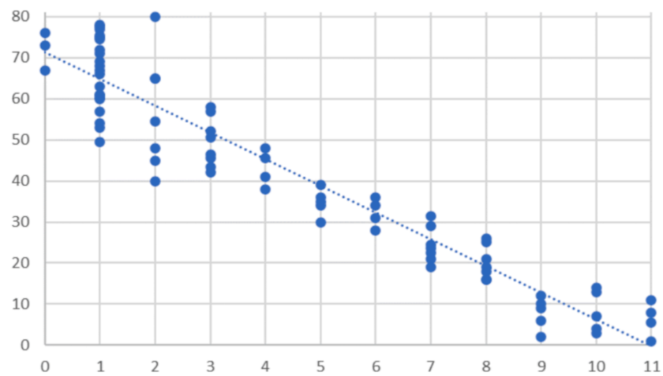

Fig. 3. Linear regression of the median country ranking on the number of social thresholds reached. This figure illustrates the results of an OLS estimation between the number of social foundation thresholds a country meets and its median rank. The x-axis represents the number of indicators for which the threshold is met, while the y-axis shows the median rank of each country.

two sets do not overlap: no country respects both constraints, as summarised in Fig. 5.

It is also interesting to see a quantitative representation of the distance of each of the 81 investigated countries vis-à-vis the 'threshold country'. Fig. 6 plots the difference between the median rank of each country and that of the 'threshold country'. By construction the median rank is positioned at the origin of the cartesian axes; a positive (negative) difference means that the country does not (does) meet the threshold. The distances to the medians of the social foundation (planetary boundaries) are reported on the horizontal (vertical) axis. Ideally, countries living in the doughnut should be placed in the bottom-left quadrant when none of the two composite thresholds are transgressed. Conversely, countries that transgress both the social and environmental composites are placed in the top-right quadrant. Lastly, countries that achieve the social threshold while overshooting the planetary boundaries are situated in the top-left quadrant, and countries that are compliant with the planetary boundaries while not reaching the social boundaries are in the bottom-right quadrant.

As an example, Australia (AUS) is the country that is better positioned with respect to the social threshold, while being one of the worst positioned with respect to the planetary threshold. Conversely, Malawi (MWI) is the country that is better placed vis-à-vis the environmental threshold, while being the second worst placed in terms of social foundations. Lastly, although no country ranks within the doughnut, similar patterns can still be observed across countries. For instance, countries in

Table 7
Environmental thresholds of high-ranked countries. This table focuses on the 32 countries for which thresholds are met in more than 14 out of the 17 environmental indicators. It reports the number of exceeded thresholds, the median rank, and the range of ranks. Our assessment proposal is in the 5th column ('Environmentally Safe') and classifies countries as 'strictly', 'yes', or 'broadly' Environmentally safe, depending on their rank relative to the benchmark (THR). 'Strictly' is if the country's worst rank is better than or equal to the best rank of the threshold country (27); 'Yes' if the country's worst rank is at least equal to the threshold country's median rank (31); 'Broadly' if the country does not meet the 'Yes' criteria, but its median rank is equal to or better than the threshold country's median rank; 'No', otherwise.

Country	Exceeded thresholds	Median rank	Range	Environmentally Safe
Malawi	0	1	1–3	Strictly
Bangladesh	0	2	1–4	Strictly
Tajikistan	0	3	2–3	Strictly
Nigeria	0	4	4–8	Strictly
Mozambique	0	6	5–10	Strictly
Rwanda	0	6	5–9	Strictly
Senegal	0	8	6–11	Strictly
Kenya	0	8	7–17	Strictly
Dominican Republic	0	25	21–30	Yes
Nepal	1	9	6–14	Strictly
Tanzania	1	11	6–16	Strictly
Egypt, Arab Rep.	1	11	4–18	Strictly
Cameroon	1	14	10–23	Strictly
Sri Lanka	1	15	12–22	Strictly
Uganda	1	15	14–20	Strictly
Central African Rep.	1	18	11–29	Yes
Burkina Faso	1	22	13–31	Yes
Honduras	1	22	17–24	Strictly
Mali	1	28	16–33	Broadly
Ghana	2	12	10–15	Strictly
Pakistan	2	13	5–19	Strictly
Mauritania	2	17	2–24	Strictly
Philippines	2	18	13–26	Strictly
Jordan	2	20	12–23	Strictly
Guatemala	2	20	18–23	Strictly
El Salvador	2	25	21–29	Yes
Indonesia	2	29	25–33	Broadly
India	2	31	17–35	Yes
Niger	2	34	20–39	No
Nicaragua	3	26	25–28	Yes
Armenia	3	27	25–30	Yes
Costa Rica	3	33	32–35	No
THR	–	31	27–35	–

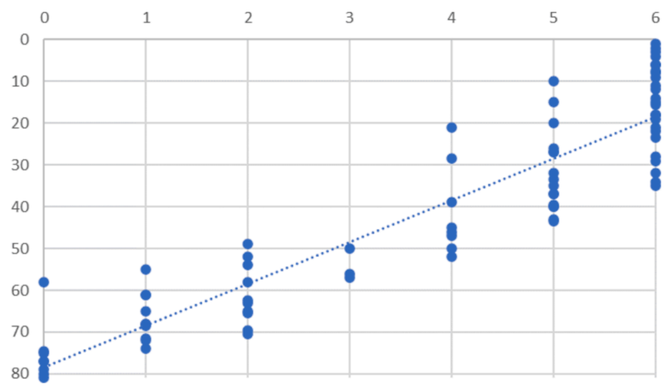

Fig. 4. Linear regression of the median country ranking on the number of environmental thresholds exceeded. This figure illustrates the results of an OLS estimation between the number of a country's environmental thresholds exceeded and its median rank. The *x*-axis represents the number of indicators for which the threshold is exceeded, while the *y*-axis shows the median rank of each country.

the top-left quadrant need to enhance their social performance to be considered within the doughnut, whereas those in the bottom-right quadrant need to focus on improving their environmental behaviour. Moreover, countries represented within the dotted black box in the top-right quadrant are the closest to aligning with the doughnut, yet they still need to take policy action on both environmental and social aspects to be above the social foundations and below the environmental ceilings.

5. How far from the doughnuts?

Although no country falls within our 'blurred' doughnut, it is nevertheless interesting to quantify how far countries are from reaching the safe and just area. Fig. 6 in the previous section provided a measure of distance merely in terms of countries' rank with respect to the 'threshold country', but it does not appraise how far a country is from the boundaries of the doughnut.

A possible solution is to measure the improvement that a country would need to enter our 'blurred' doughnut. Here, for simplicity, we measure such an improvement by using the composite built with min–max normalisation, equal weight, and linear aggregation. The reason for choosing this composite is that the ranking that it generates is the closest[15] to the median ranking[16]; furthermore, it has an easy-to-interpret scale.

Let us first focus on the subset of 20 countries that meet our social threshold and are represented in Fig. 7. The dotted vertical line indicates the value for the threshold of the environmental ceilings. The darkest bar shows Ireland, which is closest to the environmental 'threshold country'. To reach it, Ireland should decrease its overshoot by a factor of about 2.3 (i.e. from 0.300 to 0.128). The medium dark bars identify the values of the social composite of the top 10 per cent of countries. One can observe that countries like the Republic of Korea, the UK, Switzerland, Slovenia, the Netherlands, Germany, and Belgium should decrease their environmental composite value by a factor close to 3 to enter the safe area (i.e., from 0.384 to 0.128). Finally, if one wanted all 20 countries that meet the social foundations to also respect the environmental ceilings, it would be necessary to reduce the environmental composite by a factor of up to 6.4. If one applies the decrease linearly for all the dimensions, this will require a decrease by a factor between 2 and 6 of countries' environmental impact. This would require, for instance, a reduction of annual per capita phosphorus production by as much as 5 kg (to fit the threshold of 0.8 kg), and a reduction in current annual per capita nitrogen production by up to 45 kg (to fit the threshold of 8.4 kg).[17]

A similar analysis is replicated for the 25 countries lying within the safe area but not in the just one, which is reported in Fig. 8. Jordan is the country that comes closest to the social threshold while being about 15 % lower. Moreover, the social composite should increase by up to approximately 25 % (i.e., from 0.582 to 0.771) to allow eight countries to be in the doughnut (Armenia, is the eighth country). Lastly, to make all 25 countries compliant with the environmental ceilings, the country's social composite should increase by about 85 %.

Following the same assumption on the linearity of the movement of the threshold, these changes would entail, for instance, an increase in social standards of at least 15 % just to get one country within the safe and just space, which would imply an 11-year increase in life expectancy (from 63 to 74), and a 15 % decrease in people without access to electricity (from 95 % to 80 %).

Overall, it emerges clearly that not only does no country lie within the doughnut, even in this 'weak' version, but that the effort needed to allow at least one country to lie within the doughnut in terms of reduced environmental impact (x2.3) or increase in livelihood and social conditions (x15%) looks high and difficult to attain.

6. Discussion

This section will discuss in more detail some of the assumptions we adopted and clarify issues subject to possible misunderstandings or criticism. A possible objection to our approach concerns the relevance of proximity, which depends on the nature of the thresholds. If thresholds are interpreted as tipping points, which cannot be surpassed without causing serious and irreversible harm to society or even humanity, the distance from meeting them is not very relevant to the assessment: countries need to meet them. This is, however, not in the spirit of the planetary boundaries approach. As the authors that developed the approach highlighted, it is a misinterpretation of seeing the boundaries as tipping points (see Rockström et al. (2018) and the website at Stockholm Resilience Institute[18]). They are rather values that keep humanity in a safe space, beyond which we enter an uncertainty in which the risk of abrupt and irreversible changes increases. This implies that it is wise not to surpass them, but not that surpassing them by a small amount will automatically generate a collapse, as it would be for tipping points. Kate Raworth, who proposed the Doughnut approach, while using the term tipping points, also emphasises the uncertainty issue. For instance, she wrote "… tipping Earth into an unknown state in which novel and unexpected changes are likely to happen. The catch, of course, is that it is not possible to pinpoint exactly where danger lies" (Raworth 2017, 42). If the environmental boundaries in the Doughnut are technically not tipping points, the same applies with more strength to social foundations, which are mainly established out of ethical reasons.

A second possible issue is about the techniques we used to build composite indicators. We took as a major reference point the authoritative handbook developed by JRC-OECD (2008) on composite indicators, although we are aware that there are many more alternatives in the existing literature for standardising/weighting/ aggregating indicators. We do not claim that our choice is the best one; rather, we emphasise that the specific techniques used are not of paramount importance. What is important is to use a wide set of composite indicators to convey the inherent uncertainty in the outcomes.

A third and related consideration is the impact of our compensatory

[15] The sum of squares of the difference between its ranks and the median ranks is the lowest compared with the other composites.

[16] It is worth emphasising that the median rank of one country can be any of the 16 composites.

[17] Based on the thresholds produced by Fanning et al. (2022).

[18] https://www.stockholmresilience.org/research/research-news/2017–11-20-a-fundamental-misrepresentation-of-the-planetary-boundaries-framework.html.

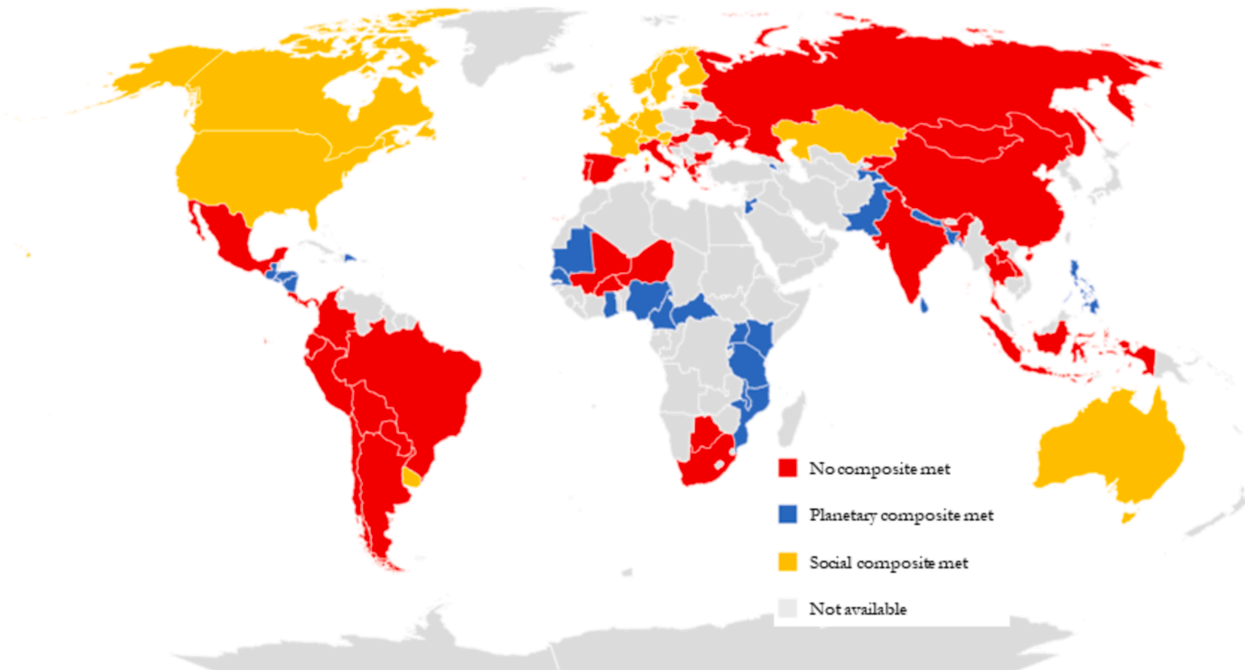

Fig. 5. Country-specific behaviour with respect to social and environmental boundaries. This figure shows countries that (1) are not exceeding planetary boundaries (blue), (2) are meeting social boundaries (yellow), and (3) are both exceeding environmental boundaries and not meeting social boundaries (red). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

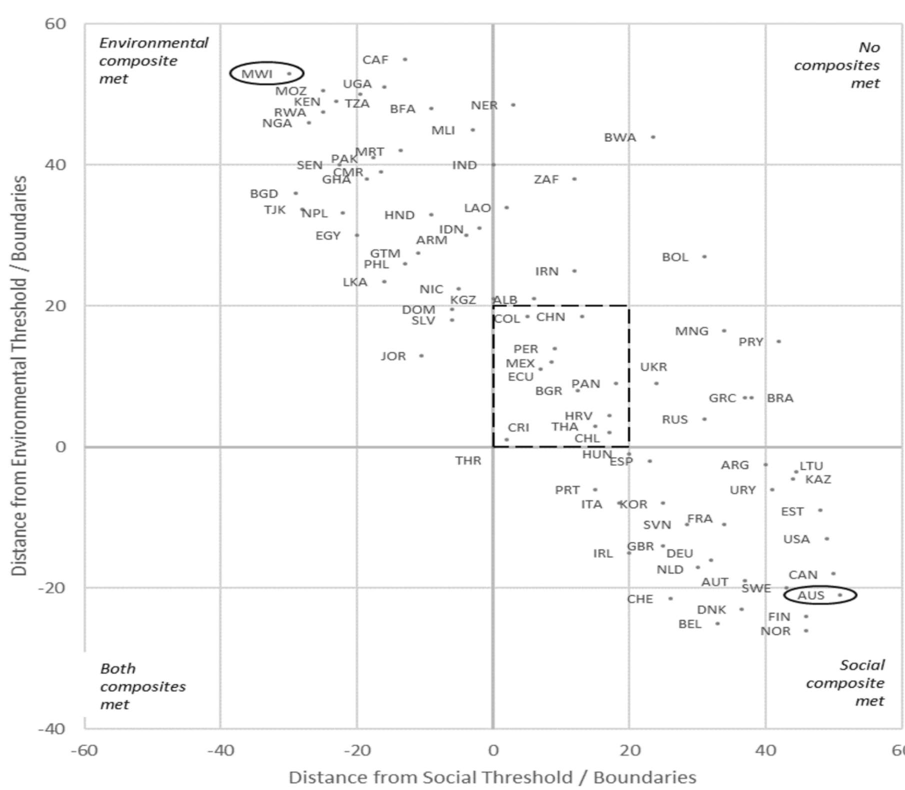

Fig. 6. Distance between the median rank of each country and the rank of the threshold 'country'. This figure plots the difference of each country's median rank from that of the threshold country. The horizontal axis reports the difference from the social foundation median, while the vertical axis the difference from the planetary boundaries.

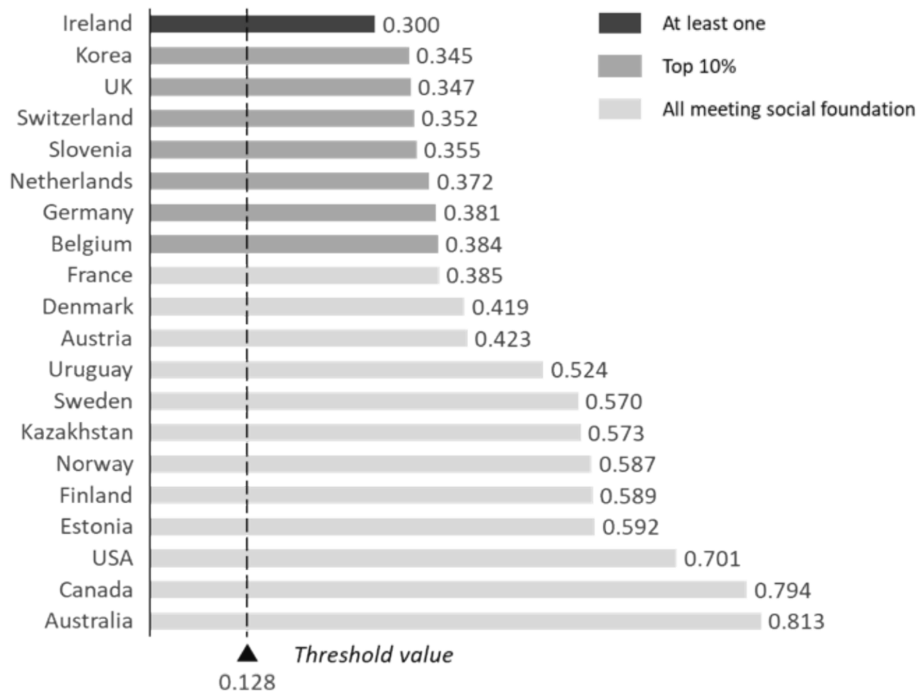

Fig. 7. Distance from the environmental ceilings. This figure shows the distance from the environmental threshold for countries that meet social foundations. 'At least one' indicates the country closest to the threshold; 'Top 10%' indicates the first 10% of countries closest to the threshold based on the distribution of social scores; 'All meeting social threshold' indicates all remaining countries meeting the social foundations. The figures at the right end of the bars are the values of one specific composite.

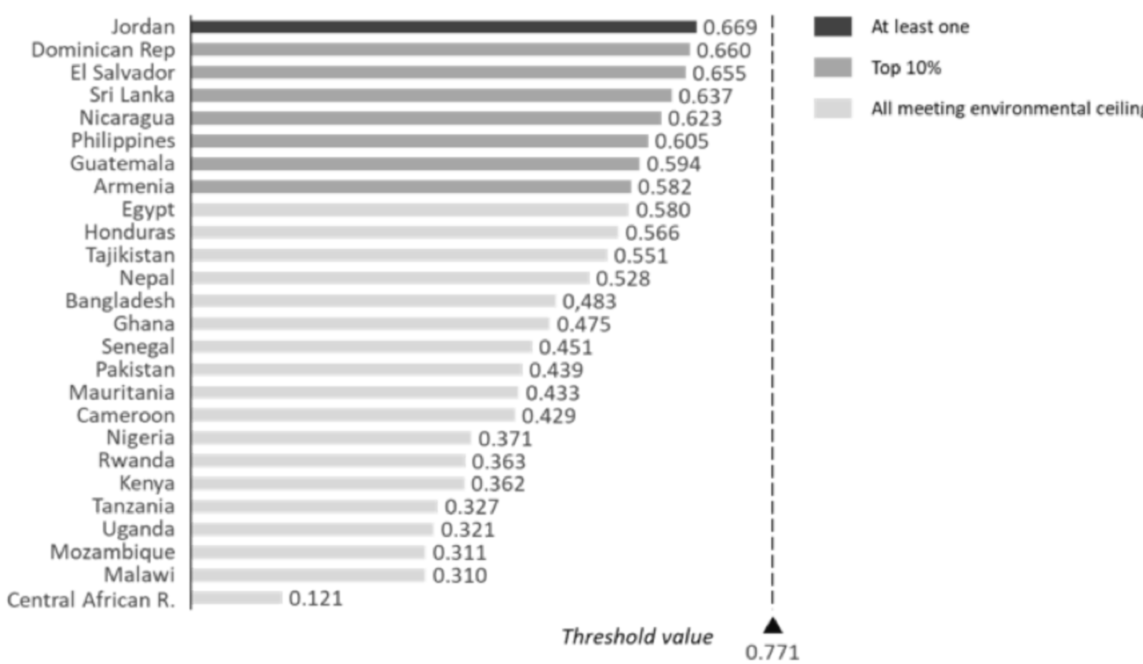

Fig. 8. Distance from the social foundations. This figure shows the distance from the social threshold for countries that do not exceed environmental boundaries. At least one' indicates the country closest to the threshold; 'Top 10%' indicates the first 10% of countries closest to the threshold based on the distribution of environmental scores; 'All meeting social threshold' indicates all remaining countries not exceeding environmental boundaries. The figures at the right-end of the bars are the values of one specific composite.

approach on the interpretation of countries' positions relative to the Doughnut. The compensatory approach allows for trade-offs between different dimensions of social and environmental performance. This means that a country could achieve a high overall score even if it performs poorly in some areas if it excels in others. While this flexibility accommodates the complexity of sustainability metrics, it also presents some challenges. Specifically, the compensatory nature can obscure significant deficiencies in certain areas, leading to a potentially misleading view of how well a country truly aligns with the Doughnut criteria. For example, a country that is weak in critical areas such as climate stability or social equity might still score relatively high if it performs exceptionally well in other dimensions like economic stability or education. This could mask urgent problems that need immediate attention.

Additionally, the use of composite indicators inherently involves decisions about which dimensions to include and how to weight them. While we have taken steps to mitigate the problem of arbitrariness by employing a variety of methodological approaches including less compensatory aggregation techniques like the geometric mean, these decisions can still introduce subjectivity and affect the results. For instance, if the weights assigned to different dimensions do not accurately reflect their relative importance, the overall assessment might be skewed. This could result in an inaccurate representation of how close or far a country is from achieving the "safe and just space". Therefore, users of this approach need to be aware of these limitations and understand that while composite indicators provide a broad overview, they may not fully capture the complexity and severity of sustainability issues.

A fourth issue might relate to the interpretation of Figs. 1 and 2. It might be counterintuitive that the median rank of the theoretical country that meets all criteria ranks respectively 27th and 31st, while none of the countries is found to live within the doughnut. This is the effect of the aggregation. Some countries largely meet some (or all) criteria within a given domain (social or environmental), while the hypothetical 'threshold country' meets them exactly, hence getting an aggregate score lower than other countries. Of course, this is based on our compensatory metric, which in turn rests on the idea that thresholds are not technical tipping points but blurred boundaries. Otherwise, it would not be admissible, for instance, that Guatemala exceeds 2 environmental dimensions and ranks 20th (range 18–23), ahead of the boundary country at position 31 (range 27–35).

A fifth consideration relates to the specific contribution of our study as compared with the existing literature. To the best of our knowledge, this paper is the first to use a robustness approach based on composite indicators to assess whether countries lie within the doughnut at the global level. Only one recently published paper, Gómez-Alvarez Díaz et al. (2024), uses composite indicators to investigate whether countries belong to the doughnut framework, focusing on 26 European countries. While our paper aligns with it in terms of findings, our research addresses some of their limitations. First, their analysis is limited to European countries, which generally have similar social and environmental performance. In contrast, our study takes a global perspective, examining over 80 countries with far greater diversity in both social and environmental outcomes, providing broader and more varied insights. Second, while Gómez-Alvarez Díaz et al. (2024) made a significant contribution by employing composite indicators to assess the doughnut framework, the variables that they used are partially different from those used in earlier empirical studies. Conversely, by using the same variables as those in previous research, we ensure that our results remain directly comparable with the established literature, enhancing continuity and clarity in understanding how countries perform within the 'safe and just space'. Lastly, they used only two composite indicators, while our 8 + 8 different composites offer a more robust and flexible framework. This approach reduces potential biases and uncertainties, providing richer insights into how close countries are to meeting the doughnut criteria.

A final consideration is that the present analysis is entirely based on the data used by Fanning et al. (2022), as the empirical purpose was to perform a robustness check on their results. The proposed method can be used for future empirical assessments of the 'Doughnut' model at the country level, using updated or new indicators.

7. Concluding remarks

According to Doughnut Economics, a 'safe and just space' can be identified for a country to live in, by both achieving recognized social standards and not exceeding some planetary physical boundaries that bring the state of the natural environment in an uncertain and dangerous area. Of course, scaling down the concept of a 'safe space' to the country level should involve not using the term 'safe', as most issues are global in nature. For example, many countries that are indicated here as being in the environmentally safe space are dramatically affected by the consequences of climate change. At the same time, the country not exceeding the environmental limits does not contribute to exacerbating the environmental crises.

Previous analyses aiming to empirically identify such space found that no country positions itself within the doughnut. However, the metric used so far assesses countries with overshoots or shortfalls of minor severity as not lying in the doughnut, thereby overlooking the matter of proximity. To take this into account, one might look at the overall performance in each of the two macro-areas, the social and environmental, and allow for some compensation between poor and good performance. Would such an approach allow one or more countries to lie within the doughnut?

To answer this question, rather than building two composite indicators for each macro-theme, we followed an uncertainty approach and combined several normalisations, weighting, and aggregation techniques to obtain two sets of composite indicators. This allowed us to develop a 'safe and just space' metric that is both easy to interpret and robust, but also weaker as compared to the metric hitherto used in the literature. Despite using a weaker criterion for empirically defining the doughnut, our results confirm that no countries lie within the 'just and safe space', thereby reinforcing the results obtained by previous research. Moreover, this research has shown that the 'effort' needed to allow at least one country to enter the doughnut in terms of reduced environmental impact or increase in social indicators is high and difficult to achieve.

The overall policy implication is that efforts to achieve social and environmental sustainability are urgently needed across all dimensions of the doughnut framework and in countries worldwide. This remains true even with our inherently 'cautious', which offset poor performances in some areas with stronger performances in others. While this caution methodology allows for a balanced view, it provides policymakers with valuable guidance by combining multiple aspects of performance into a unified framework. This facilitates the identification of strengths and weaknesses, informing the design of more targeted and effective policy actions. For countries that have met one area—either social or environmental—but lag in the other, efforts should be focused on addressing the shortfall in the unmet area. For example, a country excelling in environmental sustainability but lacking in social equity might focus on improving social policies, such as enhancing welfare programs, reducing inequality, and improving access to healthcare and education. Conversely, a country with strong social indicators but poor environmental performance should prioritise measures to address environmental issues, such as implementing stricter environmental regulations, investing in clean energy, and promoting sustainable resource management. Countries that are far from meeting both dimensions require more fundamental changes. Specifically, they may need to undertake broad reforms across both areas, such as overhauling economic systems to align with environmental limits and developing robust social safety nets. These efforts often require substantial investment and international support to address deep-rooted challenges and achieve meaningful progress. Finally, for countries that are close to meeting both dimensions but have not fully achieved the Doughnut criteria, a balanced approach is essential. These countries should concentrate on incremental improvements in both social and environmental areas.

From a methodological point of view, this research attempted to offer a balanced compromise between the usability advantages of synthetic representations and the need to reduce the loss of relevant information involved in composite indicators. Applying this approach to the empirical assessment of the 'Doughnut' model at the country level allows for a robustness check of the existing literature. As a result, this paper strengthens the main message, that the current situation needs strong and urgent policy interventions to move countries into a safe and just space.

CRediT authorship contribution statement

Gianluca Gucciardi: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Tommaso Luzzati:** Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We are grateful to the many colleagues who provided valuable comments during the presentations of preliminary versions of this paper at two seminars at the Universitat Autònoma de Barcelona, the US Ecological Economics Society, the 9th International Degrowth Conference in Zagreb, the XIV Biennial ESEE 2022 Conference in Pisa, the 17th Biennial ISEE 2023 Conference in Bogota, and the 2024 CISEPS Annual Workshop in Milan. We thank the anonymous reviewers for their careful reading of our manuscript. Their insightful comments significantly contributed to improving the paper. Tommaso Luzzati gratefully acknowledges the support from the University of Pisa, project 269999_2022_BIHO_DM_737.

Annex

Table A.1
Summary statistics.

Indicator	Min	Max	Mean	Std. Dev	Median
CO2 Emissions	0.05	10.79	1.89	2.11	0.99
Phosphorus	0.00	12.14	2.11	2.35	1.24
Nitrogen	0.13	8.99	2.70	2.30	2.05
Land System Change	0.18	3.35	1.29	0.71	1.12
Ecological Footprint	0.45	5.63	1.96	1.25	1.62
Material Footprint	0.18	6.26	2.05	1.64	1.55
Life Satisfaction	0.05	1.29	0.74	0.30	0.75
Life Expectancy	0.52	1.19	0.98	0.16	1.01
Nutrition	0.31	1.9	1.19	0.37	1.2
Sanitation	0.09	1.05	0.79	0.29	0.93
Income Poverty	0.03	1.05	0.68	0.36	0.8
Access to Energy	0.11	1.05	0.89	0.27	1.05
Education	0.12	1.77	0.92	0.35	1.01
Social Support	0.03	1.1	0.87	0.20	0.93
Democratic Quality	0.35	1.35	0.89	0.27	0.88
Equality	0.07	1.15	0.76	0.24	0.77
Employment	0.4	1.18	0.96	0.16	0.99

Note: Data included in this table were retrieved from the Fanning et al. (2022) public database: this paper provides (i) figures normalised to have the threshold equal to 1, and (ii) the absolute value of the threshold. In our work, we obtain the raw data by rescaling normalised figures for the value of the threshold for the 81 countries with full information for all 17 indicators.

Data availability

Data will be made available on request.

References

Barbier, E.B., Burgess, J.C., 2019. Sustainable development goal indicators: analyzing trade-offs and complementarities. *World Dev.* 122, 295–305.
Beliakov, G., Pradera, A., Calvo, T., 2007. *Aggregation Functions: A Guide for Practitioners*, Vol. 221. Springer, Heidelberg.
Biggeri, M., Clark, D.A., Ferrannini, A., Mauro, V., 2019. Tracking the SDGs in an 'integrated' manner: A proposal for a new index to capture synergies and trade-offs between and within goals. *World Dev.* 122, 628–647.
Böhringer, C., Jochem, P.E., 2007. Measuring the immeasurable—a survey of sustainability indices. *Ecol. Econ.* 63 (1), 1–8.
Brundtland, G.H., 1987. Our Common Future: Report of the World Commission on Environment and Development, available at https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf.
Buch-Hansen, H., Koch, M., 2019. Degrowth through income and wealth caps? *Ecol. Econ.* 160, 264–271.
Büchs, M., 2021. Sustainable welfare: How do universal basic income and universal basic services compare? *Ecol. Econ.* 189, 107152.
Castro, J.F.G., Evangelio, C.E.A., Saguiguit, C.A.G., Pasquin, E.G., 2022. Is the Philippines within the Doughnut?: Quantifying Doughnut Economics through Sustainability Window Method. Int. J. Res. Eng., Sci. Manage. 5 (11), 194–206.
Cook, D., Davíðsdóttir, B., 2021. An appraisal of interlinkages between macro-economic indicators of economic well-being and the sustainable development goals. *Ecol. Econ.* 184, 106996.
Cripps, E., 2021. Population ethics for an imperfect world: Basic justice, reasonable disagreement, and unavoidable value judgements. *J. Dev. Stud.* 57 (9), 1470–1482.
Dao, H., Peduzzi, P., Friot, D., 2018. National environmental limits and footprints based on the Planetary Boundaries framework: the case of Switzerland. *Glob. Environ. Chang.* 52, 49–57.
Desmoitier, N., Kolenda, M., Olsen, K.H., Ryberg, M.W., 2023. Methods for assessing social impacts of policies in relation to absolute boundaries. *Environ. Impact Assess. Rev.* 101, 107098.
Doyal, L., Gough, I., 1991. *A Theory of Human Need*. Palgrave Macmillan, Basingstoke.
Ebert, U., Welsch, H., 2004. Meaningful environmental indices: a social choice approach. *J. Environ. Econ. Manag.* 47 (2), 270–283.
Fanning, A.L., O'Neill, D.W., Hickel, J., Roux, N., 2022. The social shortfall and ecological overshoot of nations. *Nat. Sustainability* 5 (1), 26–36.
Fisch-Romito, V., 2021. Embodied carbon dioxide emissions to provide high access levels to basic infrastructure around the world. *Glob. Environ. Chang.* 70, 102362.
Fleurbaey, M., 2009. Beyond GDP: The quest for a measure of social welfare. *J. Econ. Lit.* 47 (4), 1029–1075.
Fleurbaey, M., Blanchet, D., 2013. *Beyond GDP: Measuring welfare and assessing sustainability*. Oxford University Press.
Gan, X., Fernandez, I.C., Guo, J., Wilson, M., Zhao, Y., Zhou, B., Wu, J., 2017. When to use what: Methods for weighting and aggregating sustainability indicators. *Ecol. Ind.* 81, 491–502.
Gómez-Alvarez Díaz, M.R., Perez León, V.E., Fuentes Saguar, P., 2024. How close are European countries to the doughnut-shaped safe and just space? Evidence from 26 EU countries. *Ecol. Econ.* 221, 108189.

Gough, I., 2015. Climate change and sustainable welfare: the centrality of human needs. *Camb. J. Econ.* 39 (5), 1191–1214.

Greco, S., Ishizaka, A., Tasiou, M., Torrisi, G., 2019. On the methodological framework of composite indices: a review of the issues of weighting, aggregation, and robustness. *Soc. Indic. Res.* 141 (1), 61–94.

Gucciardi, G., 2022. Measuring the relative development and integration of EU countries' capital markets using composite indicators and cluster analysis. *Rev. World Econ.* 1–41.

Gupta, J., Bai, X., Liverman, D.M., Rockström, J., Qin, D., Stewart-Koster, B., Gentile, G., 2024. A just world on a safe planet: a Lancet Planetary Health–Earth Commission report on Earth-system boundaries, translations, and transformations. The Lancet Planetary Health 8 (10), e813–e873.

Hoekstra, R., 2019. *Replacing GDP by 2030: Towards a Common Language for the Well-Being and Sustainability Community*. Cambridge University Press.

Jacob, A., 2017. Mind the gap: Analyzing the impact of data gap in Millennium Development Goals'(MDGs) indicators on the progress toward MDGs. *World Dev.* 93, 260–278.

JRC-OECD (2008). *Handbook on constructing composite indicators: methodology and user guide*. OECD publishing.

Kapp, K.W., 1976. The open system character of the economy and its implications'. In: Dopfer, K. (Ed.), *Economics in the Future: towards a New Paradigm*. Macmillan, London, pp. 90–105.

Kapp, K.W., 1977. Environment and technology: new frontiers for the social and natural sciences. *J. Econ. Issues* 11 (3), 527–540.

Li, M., Wiedmann, T., Hadjikakou, M., 2019. Towards meaningful consumption-based planetary boundary indicators: the phosphorus exceedance footprint. *Glob. Environ. Chang.* 54, 227–238.

Luukkanen, J., Vehmas, J., Kaivo-oja, J., 2021. Quantification of doughnut economy with the sustainability window method: Analysis of development in Thailand. *Sustainability* 13 (2), 847.

Luzzati, T., 2010. Economic development, environment and society: rediscovering Karl William Kapp. 48-64. In: McNeill, J.R., Pádua, J.A., Rangarajan, M. (Eds.), Environmental History: as If Nature Existed. Oxford University Press.

Luzzati, T., 2023. KW Kapp: an ecological economist *ante litteram*. In: Padilla, E., Ramos, J. (Eds.), Elgar Encyclopedia of Ecological Economics. Elgar.

Luzzati, T., Gucciardi, G., 2015. A non-simplistic approach to composite indicators and rankings: an illustration by comparing the sustainability of the EU Countries. *Ecol. Econ.* 113, 25–38.

Martiskainen, M., Axon, S., Sovacool, B.K., Sareen, S., Del Rio, D.F., Axon, K., 2020. Contextualizing climate justice activism: Knowledge, emotions, motivations, and actions among climate strikers in six cities. *Glob. Environ. Chang.* 65, 102180.

Max-Neef, M.A., 1991. Human scale development: conception, application and further reflections. The Apex Press, New York, NY USA.

Mazziotta, M., Pareto, A., 2017. Synthesis of indicators: The composite indicators approach. In: Complexity in society: From Indicators Construction to their synthesis. Springer, Cham, pp. 159–191.

Moyer, J.D., Hedden, S., 2020. Are we on the right path to achieve the sustainable development goals? *World Dev.* 127, 104749.

Munda, G., 1997. Environmental economics, ecological economics, and the concept of sustainable development. *Environ. Values* 6 (2), 213–233.

Nardo, M., Saisana, M., Saltelli, A., Tarantola, S., Hoffman, A., Giovannini, E., 2005. *Handbook on Constructing Composite Indicators: Methodology and User Guide* (No. 2005/3). OECD Publishing.

O'Neill, D.W., Fanning, A.L., Lamb, W.F., Steinberger, J.K., 2018. A good life for all within planetary boundaries. *Nat. Sustainability* 1 (2), 88–95.

Paruolo, P., Saisana, M., Saltelli, A., 2013. Ratings and rankings: voodoo or science? *J. R. Statist. Soc.: Series A (Statistics in Society)* 176 (3), 609–634.

Qizilbash, M., 2001. Sustainable development: concepts and rankings. *J. Dev. Stud.* 37 (3), 134.

Raworth, K., 2017. *Doughnut Economics: Seven Ways to Think like a 21st-century Economist*. Chelsea Green Publishing.

Raworth, K., 2012. *A safe and just space for humanity: can we live within the doughnut?* Oxfam.

Richardson, K., Steffen, W., Lucht, W., Bendtsen, J., Cornell, S.E., Donges, J.F., Rockström, J., 2023. Earth beyond six of nine planetary boundaries. Sci. Adv. 9 (37), eadh2458.

Rockström, J., Richardson, K., Steffen, W., Mace, G., 2018. Planetary boundaries: separating fact from fiction. A response to Montoya et al. Trends Ecol. Evol., 33(4), 233–234.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin III, F.S., Lambin, E., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., 2009. Planetary boundaries: exploring the safe operating space for humanity. *Ecol. Soc.* 14 (2).

Rockström, J., Gupta, J., Qin, D., Lade, S.J., Abrams, J.F., Andersen, L.S., Zhang, X., 2023. Safe and just Earth system boundaries. Nature 619 (7968), 102–111.

Saltelli, A., 2007. Composite indicators between analysis and advocacy. *Soc. Indic. Res.* 81 (1), 65–77.

Saunders, A., Luukkanen, J., 2022. Sustainable development in Cuba assessed with sustainability window and doughnut economy approaches. *Int J Sust Dev World* 29 (2), 176–186.

Steffen, W., Richardson, K., Rockström, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Sörlin, S., 2015. Planetary boundaries: Guiding human development on a changing planet. *Science* 347 (6223), 1259855.

UN, 2015. *Transforming our World: the 2030 Agenda for Sustainable Development*, Resolution A/RES/70/1 adopted by the General Assembly on 25 September 2015 by 193 Nation States.

Valdés, J., 2018. Arbitrariness in multidimensional energy security indicators. *Ecol. Econ.* 145, 263–273.

Yeheyis, M., Hewage, K., Alam, M.S., Eskicioglu, C., Sadiq, R., 2013. An overview of construction and demolition waste management in Canada: a lifecycle analysis approach to sustainability. *Clean Techn. Environ. Policy* 15, 81–91.