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# Measuring the sustainable development goals: A poset analysis

Tadashi Hirai [a,*], Flavio Comim [b]

[a] Centre of Development Studies, Department of Politics and International Studies, University of Cambridge, 7 West Road, Cambridge CB3 9DT, United Kingdom
[b] IQS School of Management, Ramon Llull University; Department of Land Economy, University of Cambridge, Via Augusta 390, Barcelona 08017, Spain

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ABSTRACT

Sustainability requires balanced development. The economy, society and the environment all need to be pursued simultaneously. In this context, the issue of incomparabilities among different dimensions of indices is at the heart of the discussion. However, this crucial issue is not fully addressed in the existing literature. Whereas dashboards leave to the readers the difficult task of making sense of a complex array of symbols indicating distinct goal levels and trends, composite indices sidestep the issue altogether. To overcome this state of affairs and provide a structural picture of sustainability, we introduce a poset (i.e. partially ordered set) analysis as a middle ground between the two extreme techniques used in assessing progress towards SDGs. By doing so, it aims to improve the use of SDG indicators. Our study finds that partial ordering offers a more transparent, simpler and more intuitive approach than the alternatives. It not only corrects any imbalance in the joint performance of different dimensions but also accords the environment the highest impact upon the overall SDGs. In this it is unlike the existing composite indices, which accord the economy the highest impact. The poset analysis is thus an appropriate technique for the pursuit of sustainable development.

## 1. Introduction

Sustainable development is a nested concept. It reflects inseparable links between different dimensions of development and thus necessitates a comprehensive view of the progress made by each of them. This means that all economic, social and environmental dimensions need to be developed in a balanced manner: a logical precondition for assessing progress towards the Sustainable Development Goals (SDGs). Simply put, "Success in any of these three categories (or subcategories within them) will almost surely depend on success of all three" (Sachs, 2012: 2208). By contrast with the disciplinary breakdown used for the Millennium Development Goals, the validity of this self-evident claim was endorsed during the early stages of SDG construction (Griggs et al., 2013; Elmqvist et al., 2014; Norström et al., 2014).

To date, progress towards the SDGs has been assessed either with dashboards with a series of indicators or with composite indices. There are arguments for and against each strategy. Work with a large number of indicators is data-rich. It permits an examination of unbalanced progress between goals and their potential interactions (Sen, 1985; Griggs et al., 2014; Nilsson et al., 2016), but it is more difficult to interpret them together (Hopkins, 1991; Aturupane et al., 1994; Pongiglione, 2015). By contrast, the use of composite indices can attract attention and be useful in displaying a summary of overall progress, facilitating international comparisons (Streeten, 1994; Haq, 1995; Costanza et al., 2016). Even so, it risks concealing the relationship between goals, which is particularly problematic given the potential extent of imbalance between economy, society, and environment (Desai, 1991; Ravallion, 1997; Sagar and Najam, 1998; Elmqvist et al., 2014). Similar lines of argument have recently been made extensively in the context of the SDGs (Hák et al., 2016; Gan et al., 2017; Bacchini et al., 2020; Kwatra et al., 2020; Drees et al., 2021). The debate seems to take place between two extremes in which either one is condemned to use 'hyper-aggregated' indicators (that collapses complexity into composite scores) or is dumped with tens or hundreds of elementary indicators, putting the burden of selecting suitable indicators to users (Arcagni et al., 2021). Moreover, the use of composite indices implicitly prioritises the economy over both society and the environment in SDGs (Le Blanc, 2015; Waage et al., 2015; Diaz-Sarachaga et al., 2018; Jain & Jain, 2019; Hirai, 2022). Some reports, such as those published by the Bertelsmann Stiftung and the Sustainable Development Solutions Network, seek to overcome this problem by including both a dashboard and a composite index (Kroll, 2015; Sachs et al., 2016-2021).

Given the current state of affairs, the purpose of this article is to offer a middle ground between current dashboard and aggregation techniques

* Corresponding author.
*E-mail addresses:* hirai.tadashi@gmail.com (T. Hirai), fvc1001@cam.ac.uk (F. Comim).

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in order to improve the use of SDG indicators. Instead of making a complete ordering by means of a composite index, it offers partial orderings by categorising countries into similar patterns of progress, to reflect the overall level of development discounted by the degree of unbalanced development. Because it acknowledges incomparabilities, partial ordering is not so attractive as a composite index, but it offers more coherent results and a more informative instrument than a dashboard with a series of indicators. More importantly, in the pursuit of balanced development it provides more accurate information than provided by a composite index. The poset analysis thus occupies the middle ground between two extremes in the progress assessment of SDGs. Whereas the published evidence based on complete rankings suggests that economic elements have a greater impact on SDGs, we argue here that when partial ordering is used the environmental goals become more decisive in defining the SDG ordering between countries. It can offer a more coherent structural picture of the sustainability phenomena.

This article is structured as follows. It first reviews the composite indices of the SDGs and justifies the need for a partial ordering approach. It then introduces the poset analysis and conducts an empirical study to demonstrate an alternative assessment of the current SDG statistics. It concludes by discussing the key findings.

## 2. Existing composite indices of the SDGs[1]

Soon after the SDGs were announced, Costanza et al. (2016) recommended a composite measure to assess and monitor overall progress. For this purpose, the authors proposed a Sustainable Wellbeing Index, covering all 17 SDG goals under the heads of economy, society and environment, in such a way as to reflect an overarching goal. This conceptual proposal was developed with the creation of the SDG Index, using actual data with an annual update, on the initiative of the Bertelsmann Stiftung and the Sustainable Development Solutions Network.[2] While initially consisting of 34 indicators (two indicators per goal) targeting 34 industrialised countries (Kroll, 2015), the SDG Index has since extended its coverage in terms of indicators and targeting countries. The latest SDG Index consists of 91 indicators (+30 for OECD countries) under 17 goals targeting 165 countries (Sachs et al., 2021).[3] Subsequently, alternative composite indices were proposed by Campagnolo et al. (2018), with 26 indicators under 15 goals targeting 139 countries; by Guijarro & Poyatos (2018), with 154 indicators under 17 goals targeting 28 EU countries; and by Biggeri et al. (2019), with 88 (+23) indicators under 17 goals targeting 156 countries, with reference to the data composing the SDG Index (Sachs et al., 2018). As will be examined later in this subsection, the proposers take data-driven criteria, or normative criteria, or a combination of both in the process of constructing a composite index (involving for instance the processes of normalisation and aggregation). This categorisation of weighting schemes in multidimensional indices was suggested by Decancq & Lugo (2013). The data-driven approach is characterised by classifications that follow the frequency or statistical distributions of observable achievements. Alternatively, the normative approach produces a classification according to value judgements (e.g. equal or arbitrary, expert decision). Finally, the hybrid approach uses empirical and normative criteria to provide a classification. The specification and method of each index is summarised in the following table (Table 1).

Three indices cover all 17 goals. The exception is that by Campagnolo et al. (2018) which excludes two goals: goal 5 on account of the lack of data, and goal 17 on account of its nature as the main vehicle of implementation for all the other goals.[4] The selection of indicators is affected by data availability and by the statistical standard set up by each index. Guijarro & Poyatos (2018) exclude indicators where more than three countries have no data. While Campagnolo et al. (2018) require indicators to have discriminatory power (by excluding indicators uncorrelated with macro-economic variables), the SDG Index selects indicators that satisfy global relevance, statistical adequacy, timeliness and data quality (Sachs et al., 2016), which are criteria also adopted by Biggeri et al (2019). At the same time, in order to cover as many indicators as possible under the above conditions, the SDG Index includes data available for at least 80 per cent of countries with a population greater than one million. This also corresponds to the country coverage: while Campagnolo et al. (2018) exclude countries even with single missing data-points, the SDG Index (for wider coverage) includes countries with missing data so long as they have at least 80 % of the indicators used in the index. On the whole, the SDG Index sets more demanding statistical standards for indicator selection but has more flexibility to accommodate as many indicators (91 + 30) and countries (165) as possible. By contrast, Campagnolo et al. (2018) intentionally remove indicators lacking correlation with economic data, ending up with only 26 indicators, which ensures that the coverage of countries remains relatively high (139). Focusing on the EU countries for which more data are available, Guijarro & Poyatos (2018) work with a high number of indicators (154).

For normalisation, all indices rescale each variable between the upper and lower bounds (i.e. by using maximum and minimum goalposts). The SDG Index denotes, for each indicator, upper bounds by absolute thresholds or averages of the five best performers, and lower bounds by removing the data for the worst 2.5 % performers (Sachs et al., 2016), while Campagnolo et al. (2018) demarcate upper and lower bounds by target values outlined in the 2030 Agenda for Sustainable Development, or by EU policies, or by the average indicator scores of the best and worst 5 % performers. In their turn, Guijarro & Poyatos (2018) use the values marked by the best and the worst performers as the ends of the range. Thus, data-driven criteria are used by Guijarro & Poyato (2018); normative criteria are used by Campagnolo et al. (2018), and a mixture of both is used by the SDG Index (followed by Biggeri et al., 2019).

To calculate a composite index, the SDG Index gives equal weight to each indicator within a goal and to each goal across the SDGs. It then uses the arithmetic mean for the aggregation of each indicator within a goal and for each goal so as to create a composite index (Sachs et al., 2016). Equal weight, both across indicators and across goals, corresponds to the normative claim for the SDGs that all targets and goals are equally important in pursuit of sustainable development (UN, 2015). While using the arithmetic mean for the aggregation of indicators in a dimensional index, Campagnolo et al. (2018) employ fuzzy measures and the Choquet integral for the aggregation of three dimensional

[1] This section reviews the existing composite indices covering the SDGs comprehensively and thus excludes those focusing on particular goals (e.g. Nhemachena et al. (2018) on agriculture, Horan (2020) on marine resources).

[2] The report has changed its title over time: *SDG Index Report* in 2015, *SDG Index and Dashboards* in 2016–2018, *Sustainable Development Report* in 2019–2021. In this article, the composite index in this report is called "the SDG Index", given its pioneering status and influence, while the indices proposed by others are called by the names of the authors.

[3] In the past, the SDG Index consisted of 63 indicators (+14 for OECD countries) targeting 149 countries (Sachs et al., 2016); 83 indicators (+16 for OECD countries) targeting 157 countries (Sachs et al., 2017); 88 indicators (+23 for OECD countries) targeting 156 countries (Sachs et al., 2018); 85 indicators (+29 for OECD countries) targeting 162 countries (Sachs et al., 2019); and 85 indicators (+30 for OECD countries) targeting 166 countries (Sachs et al., 2020).

[4] Given that Campagnolo et al. (2018) exclude indicators not correlated with macro-economic data (as will be explained in the next paragraph), the lack of data in goal 5 can be read as the lack of data correlated with macro-economic data.

**Table 1**
SDG composite indices: features and methods.

| | Number of Goals | Number of Indicators | Normalisation | Aggregation | | Country coverage (number of countries) |
|---|---|---|---|---|---|---|
| | | | | Indicators to goal indices | Goal indices to composite index | |
| Sachs et al. (2021) "the SDG Index" | 17 | 91 + 30 | Goalpost *data-driven & normative* | Arithmetic (equal weight) *normative* | | 165 |
| Campagnolo et al. (2018) | 15 | 26 | Goalpost *normative* | Arithmetic (equal weight) *normative* | Fuzzy measures & Choquet integral *normative* | 139 |
| Guijarro & Poyatos (2018) | 17 | 154 | Goalpost *data-driven* | Goal Programming (GP) model *data-driven* | | 28 |
| Biggeri et al. (2019) | 17 | 88 + 23 | Goalpost *normative & data-driven* | Multidimensional Synthesis of Indicators (MSI) approach *data-driven* | | 156 |

Source: Authors.

indices (economy, society, and environment) in a composite index, to reflect potential interactions between dimensions.[5] Weights used in these aggregative formulations are based on expert evaluations of the relative importance of each sustainability element (i.e. higher weight on society and environment over economy) and are thus in line with strong rather than weak sustainability criteria.

Alternatively, Guijarro & Poyatos (2018) use a Goal Programming (GP) model for first producing goal indices based on an aggregation of individual indicators and then using these indices to produce the final composite index. The model allows the composite index with 101 different weights to be shaped by the extent of correlation, synergies and trade-offs among all indicators and goals - "favouring the majority or favouring the most conflicting SDGs" (Guijarro & Poyatos, 2018: 11). It attaches higher weights to indicators that are either most synergetic or most in conflict with others.[6] The aim is to overcome the arbitrary selection implied by the use of equal weighting (i.e. perfect substitutability) with the arithmetic aggregation used in the SDG Index. This strategy would also address the over-correction imposed on worst performers with the use of the geometric and Leontief aggregation formulations. For their part, Biggeri et al. (2019) replace the arithmetic mean used in the SDG Index with an alternative aggregative form based on the Multidimensional Synthesis of Indicators (MSI). In this way, a different degree of substitution can be assigned more flexibly to each unit in the analysis, reflecting the extent of unbalanced development. This replacement is intended to correct unbalanced development between the indicators and goals associated with arithmetic aggregation. At the same time it is intended to avoid over-correction associated with the geometric mean, and also to take into account the synergies and trade-offs between indicators and goals. Unlike the SDG Index and Campagnolo et al. (2018), both Guijarro & Poyatos (2018) and Biggeri et al. (2019) adopt data-driven criteria for their aggregative formulations.

Overall, all four composite indices discussed above provide a single SDG value for each country, permitting international comparisons with complete orderings. However, although this is a recommendable empirical strategy it is not free from shortcomings. For this reason, the four existing composite indices should be analysed from a conceptual, methodological, and empirical perspective. We chose specific indices to illustrate certain limitations in their approaches.

From a conceptual perspective, Biggeri et al. (2019) are unable to distinguish between heterogeneity (understood as an unbalanced development between SDGs) and the degree of interaction between variables (i.e. synergies and trade-offs), because their arguments equate low heterogeneity with more synergies and high heterogeneity with more trade-offs between variables. Nevertheless, these are different issues.[7] In fact, heterogeneity could be smoothed by synergies while being increased by trade-offs, but measurement of progress reflecting unbalanced development cannot be undertaken at the same time as measurement of the extent of interaction. For example, a goal associated with the economy (e.g. economic growth) could be reached in parallel with a goal associated with the environment (e.g. clean water and sanitation). Such a similar performance (i.e. low heterogeneity) is, however, not necessarily due to strong synergies since they could move independently at different levels of performance. Indeed, some goals are powerfully connected with each other while others are not, irrespective of their level of performance, as shown by numerous studies (e.g. Nilsson et al., 2016; von Stechow et al., 2016; Pradhan et al., 2017; Banerjee et al., 2019; Barbier & Burgess, 2019). Simply put, the performance of each goal (i.e. low/high heterogeneity) needs to be considered separately from the dynamics of interaction between specific goals (low/high synergies and trade-offs). In this respect, the indices proposed by Biggeri et al. (2019) reflect imbalance in development but not any degree of interaction between particular goals.

From a methodological perspective, the SDG Index fails to reflect imbalance in development across indicators and goals by using the arithmetic mean as an aggregative formulation (as noted by Biggeri et al., 2019). Although justified by ease of interpretation and practicality (Sachs et al., 2016), the index violates the fundamental concept of the SDGs as a nested concept, which thus calls for further research into alternatives (as in the present article). In turn, the index by Campagnolo et al. (2018) is inconsistent in applying a double standard: one standard favouring economic achievement in selecting indicators (by excluding indicators lacking correlation with macro-economic variables) and the other standard favouring sustainability in determining weights across dimensions (by employing the aggregative formulation based on expert evaluations that prioritise the categories of society and environment over the economy). On top of the shortcomings attributable to the limited coverage of indicators in the SDGs (Drees et al., 2021), this results in making the index less intuitive.

From an empirical perspective, Guijarro & Poyatos (2018) propose

[5] Bypassing a discussion about the categorisation of goals in the SDGs, Campagnolo et al. (2018) classify the indicators into groups such as economy, society, and the environment.

[6] "Depending on the norm used in the GP model, the solution can be interpreted either as one in which the consensus between all the indicators is maximised (penalising the more conflicting indicator in favour of those that are more representative of the majority trend in the corresponding SDG) or as one where preference is given to the most conflicting indicators (thereby penalising the indicators that share the most information with the rest in the common SDG)" (Guijarro & Poyatos, 2018: 5).

[7] As they argue, "The difference between the arithmetic mean and the I-SDI [Integrated Sustainable Development Index] can be regarded as a measure of heterogeneity. The lower the absolute value of this difference is for a country, the more synergies among SDGs are expected to be achieved" (Biggeri et al., 2019: 639, words in brackets added).

an alternative aggregative formulation with 101 possibilities for weighting, but performance by country is largely unchanged regardless of weights. Although the authors justify this result as illustrating the robustness of the model, it would be of no practical use without differentiation according to the strength of correlation. At the very least, it does not reflect the scale of interactions between goals (i.e. high and low synergies and trade-offs depending on the combination of goals) so widely claimed in recent years (e.g. Pradhan et al., 2017; Banerjee et al., 2019; Barbier & Burgess, 2019).

More fundamentally, as pointed out by Diaz-Sarachaga et al. (2018), Jain & Jain (2019) and Hirai (2022), the SDG Index implicitly prioritises economic goals over environmental goals. Indeed, the ranking in the SDG Index relates inversely to that of ecological footprint per capita.[8] This outcome challenges the rationale of the SDGs as a nested concept. This priority of the economy might arise from a biased selection of indicators attributable to data availability (Schmidt-Traub et al., 2017) or from the implicit bias inherent in the SDGs. Indeed, if the wording of targets in each goal is examined by network analysis techniques (Le Blanc, 2015), goals associated with the economy have a far greater impact on the SDGs as a whole than do those associated with society and environment. Nevertheless, we note that these findings are parametric on the use of complete orderings and that they might not necessarily apply to partial orderings, as examined below. To be fair, the SDG reports include not only the SDG Index but also the dashboards, with a series of indicators to analyse progress in a more nuanced manner. Nonetheless, to the extent that the composite index is a powerful communicative tool, this unfavourable tendency misrepresents the reality of progress in the SDGs.

Tackling the problem of perfect substitutability among different SDG goals is the principal motive behind all indices examined here. Campagnolo et al. (2018) take a normative route by adjusting weights depending on the degree of interaction based on expert evaluations in favour of environmental goals. However, the value judgements in those evaluations are not made explicit, despite their significance for the elaboration of a composite index (Foster & Sen, 1997; Sen, 1997), so to this extent it is difficult to interpret their results. They thus need to explain several steps, such as the process of deciding the extent of interaction employed in the index (i.e. which field of experts will take part, how they make their decisions, and how their decisions are reconciled). On the other hand, the indices by Guijarro & Poyatos (2018) and Biggeri et al. (2019) take a data-driven route, by adjusting weights depending on empirical association of the extent of either interaction or heterogeneity between indicators and goals. While Guijarro & Poyatos (2018) failed to justify the practical significance of their work, Biggeri et al. (2019) succeeded in reflecting unbalanced development despite their similar treatment of the categories of heterogeneity and interaction.

The SDG Index is undoubtedly simple and easy to interpret. Nonetheless, it fails (both methodologically and empirically) to reflect the imbalance in performance resulting from lumping together several potential incomparabilities produced by different indicators (and thereby missing the nested nature of sustainable development, as argued above). On the other hand, the results provided by alternatives to the SDG Index fail to ensure accuracy for the evaluation of sustainable development, owing to either conceptual, methodological or empirical problems with the construction of a composite index. With this in mind, a different possibility explored in this article is to take the middle ground between a composite index and a dashboard approach, by creating partial orderings which make incomparabilities and unbalanced development explicit in a more intuitive manner. This is significant all the more given the normative nature of the concept of sustainability (Rametsteiner et al., 2011; Steffen et al., 2015). As will be examined below, this not only corrects imbalance in the joint performance of different dimensions but also reveals the higher impact of environmental goals than economic and social ones.

The use of partial orderings can be conceptually based on Amartya Sen's capability approach (Sen, 2009; Sen, 2017), which has been influential in shaping the Human Development perspective. In simple terms, its justification derives from the argument that there is no *a priori* reason to assume that all interpersonal comparisons (between individuals or countries) should result in complete orderings (or rankings) at all times. Partial orderings articulate the informational pluralism required for comparative analysis and reasoned scrutiny that Sen advocates. They offer an operational tool that takes seriously the problem of incomparabilities resulting from the use of assorted criteria (pointing in different directions) as a basis for reasoned social judgements.

## 3. Poset analysis

A poset (partially ordered set) is an analytical tool used to represent an ordering relation. If one attribute can be evaluated as better or worse than, or equal to another, they are said to be comparable; otherwise, they are classified as incomparable (or showing incomparabilities). In other words, the first scenario makes an ordering relation complete, while the second one makes the ordering incomplete and thus partial. Complete ordering, in which all attributes can be arranged in a simple sequence, is thus regarded as a particular case of partial ordering (Bruggemann & Patil, 2011; Fattore et al., 2017). It is only in the case of complete ordering that composite indices (such as those reviewed above) can be constructed. In so doing, their elaboration involves a series of methodological decisions about, for example, weighting and methods of aggregation (e.g. arithmetic and geometric means), which in turn conceal potential incomparabilities between dimensions in exchange for an eye-catching feature with a single number. This is a serious difficulty in the context of SDGs, which are expected to involve balanced development. Being both metric-free and parametric-free (Annoni & Bruggemann, 2009), a poset can reveal the existence and extent of incomparability while ordering comparable attributes.

With respect to SDGs, a poset categorises elements (such as countries) and attributes (such as goals or dimensions) in two ways: a *chain* or a linear order for comparables and an *antichain* or a non-linear order for incomparables (Bruggemann & Patil, 2011; Fattore et al., 2012). The *height* of the poset is determined by the number of elements in the longest chain; the *width* of the poset is determined by the number of elements in the largest antichain, which represents the level of incomparability among attributes. To represent a poset visually, a Hasse diagram is used (Caperna & Boccuzzo, 2018). In this diagram, only those elements that are connected are deemed comparable. The following figure (Fig. 1) represents a simple Hasse diagram with five elements.

To illustrate this point, we might think about a case with five countries (Ireland, UK, Germany Poland, Uruguay) with three attributes/variables (GNI per capita, life expectancy, and ecological footprint).[9] Ireland is the top achiever in all three attributes (GNI per capita: 68,371 USD, life expectancy: 82.3 years, ecological footprint: 21.5). Next comes either the UK (GNI per capita: 46,071 USD, life expectancy: 81.3 years, ecological footprint: 22.7) or Germany (GNI per capita: 55,314 USD, life expectancy: 81.3 years, ecological footprint: 23.0), but

[8] Schmidt-Traub et al. (2017: 551) give reasons for excluding the material footprint from the SDG Index: "First, with the exception of fossil fuels, which are covered under SDG 13, it is not clear how *per capita* consumption of specific materials (biomass, construction minerals and metal ores) relates to local and global environmental impact. Second, the Material Footprint Index aggregates consumption across a broad range of different materials on a per kilogram basis even though one kilogram of biomass might have a different environmental impact than one kilogram of iron ore or building stone". However, those reasons relate to the representative nature of the material footprint indicator and are not persuasive enough to exclude it from the SDG Index.

[9] Data source: *Human Development Report 2020*.

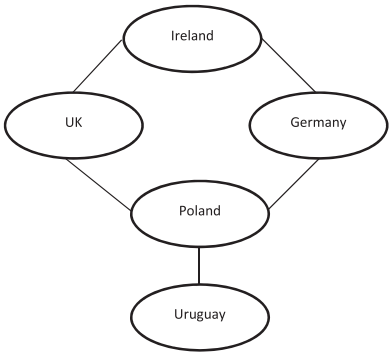


**Fig. 1.** An example of a Hasse diagram.

they cannot be ranked because of the incomparability between their overall attributes: Germany leads in terms of GNI per capita; the UK leads in terms of its ecological footprint. Thus they are incomparable in the aggregate and are not connected by a line. They are then followed by Poland (GNI per capita: 31,623 USD, life expectancy: 78.7 years, ecological footprint: 24.5) and lastly by Uruguay (GNI per capita: 20,064 USD, life expectancy: 77.9 years, ecological footprint: 37.7). These countries can be ordered in sequence, because they are fully comparable in all the attributes (with all attributes the second worst in Poland and the worst in Uruguay, out of the five countries).

In this example, the height of the poset (representing the number of elements in the longest chain) is 4 and the width of the poset (representing the number of elements in the largest antichain) is 2. In this way, the Hasse diagram provides an overall (albeit incomplete) ranking, taking comparability and incomparability into account.

## 4. Findings: Framing SDG incomparabilities

All of the SDG indices reviewed above dismiss the problem of incomparabilities between different goals. This is not a minor point for sustainability debates, which often struggle against substitutability/trade-offs between different goals. It should be noted that the use of SDG dashboards (with their higher levels of disaggregation) seeks to compensate for the limitations of composite indices. However, dashboards take the analysis to the other extreme, treating all goals as separate objectives and leaving readers to make sense of a compleX array of symbols indicating distinct goal levels and trends.

Given this context, the poset analysis of the 165 countries forming part of the SDG Index suggested a middle ground between the two alternatives above. Goals were classified according to their distinctive sustainability dimensions, namely the social dimension (with goals 1, 2, 3, 4, 5, 11 and 16), the environmental dimension (with goals 6, 7, 13, 14 and 15) and the economic dimension (with goals 8, 9, 10 and 12).[10] In addition, we included data for Gross National Income (GNI) per capita for all countries, to control for the effect of income upon SDGs. The calculations were made using the PyHasse programme.[11] As a result, we could observe the extent of incomparabilities between different dimensions. Fig. 2 displays all posets for all the countries (represented by their 3-digit ISO abbreviations) in a Hasse diagram. It shows how countries might be ordered, taking into account the existing incomparabilities among different criteria used to rank them.

The first important finding to emerge from this Hasse diagram is that countries can be classified not on a continuum (as in the case of complete orderings) but into 11 discrete levels of development (the height of the poset), so far as SDGs are concerned. The 'level information' can be useful to add some structure to the SDGs debate because up until now the standard analyses, as discussed above, are restricted to either regional or income groups without directly taking performance by countries into account. In a poset, levels relate to the relative advantage of a given country, taking into account all incomparabilities between the relevant dimensions. Secondly, we can also observe that certain levels exhibit a higher level of incomparabilities (the width of the poset) than others. For instance, at the highest level of SDG achievement we find countries such as Austria, Switzerland, and the Czech Republic. Overall, 14 countries that are not fully comparable (either because one scores higher on environmental goals or another on social or economic goals) constitute the top of the partial rankings derived from their data. It is also possible to see that the greatest frequency of incomparabilities appears at the fourth and fifth levels, where 23 and 30 countries respectively can be found. In their turn, the countries that can be considered 'left behind' (i.e. those at the bottom of the poset) are Madagascar, Somalia and Yemen. These countries fall to the bottom of every partial ranking analysis as a result of poor achievement in almost all of the SDGs, although it is important to acknowledge that among them there are also some incomparabilities. Whereas Madagascar is the highest relative achiever for SDGs 2, 5, 8 and 12, Somalia has the highest relative performance on SDGs 6, 10, 11, 13 and 15, and Yemen is highest on SDGs 3, 7, 9, 14 and 17. By looking at specific partial rankings inside Hasse diagrams, we can see the distinct incomplete ordering relations that emerge when we take seriously the problem of incomparabilities among different sustainability dimensions.

As we include other variables, such as GNI, the number of levels in the Hasse diagram, shown in Fig. 3, rises from 11 to 14. This means that the introduction of an additional variable produces more incomparabilities, reducing the number of countries at the top of the diagram to 5. There is also an increase in the number of countries occupying intermediate levels in the Hasse diagram. This additional information indeed allows us to understand how the SDG Index does not differentiate much between countries such as Qatar and Sweden (both at the top tier of Fig. 2). When the incomparabilities between GNIpc and the SDG variables are highlighted, Qatar drops to the sixth level of the Hasse diagram significantly increasing its distance to Sweden that stays at the second level of the Hasse diagram as it can be seen from Fig. 3.

A first attempt to understand the relationships between different dimensions of the SDG Index would consider an analysis of its correlation matrix: indeed, with the introduction of GNI we can see that there are very high Spearman correlations between GNIpc and the social (0.894) and economic (0.674) dimensions. However, the correlation between GNIpc and the environmental dimension is weak and negative (-0.081). As a consequence, the overall correlation between GNIpc and the SDG Index is 0.838, which could suggest *prima facie* that there are no tensions between GNIpc and the SDGs. However, nothing could be further from the truth.

In order to assess the claim, we carried out a sensitivity analysis using PyHasse. A sensitivity analysis allowed us to quantify the importance of a dimension in country ranking, by comparing distances between posets originating from the inclusion of different dimensions. Without entering into technical details, we note that Fig. 4 shows a sensitivity analysis for the key dimensions of the SDG Index. It shows that the goals which comprise the environmental dimension are the most influential in deciding the country ranking. These findings are obtained by counting the number of ordinal changes caused by deleting any given variable. Those with higher numbers of changes are considered more decisive in defining the shape of the Hasse diagrams. As we can see from Fig. 4, some outcomes provide evidence to challenge the simple correlation analysis presented above, given that the environmental goals have a

[10] This categorisation follows that by the Stockholm Resilience Centre (https://www. stockholmresilience.org/research/research-news/2017–02-28-contributions-to-agenda-2030.html), apart from goal 7, which we categorised as mostly environmental. Having said that, we accept the argument offered by one of our reviewers that these classifications are to a certain extent unavoidably subjective once SDGs are intrinsically multidimensional.

[11] We used the 'pro version' developed by Rainer Bruggemann, and more specifically the modules mHDC17_3.py and sensitivity 24_5.py, to produce respectively, the Hasse diagrams and the corresponding similarity analysis.

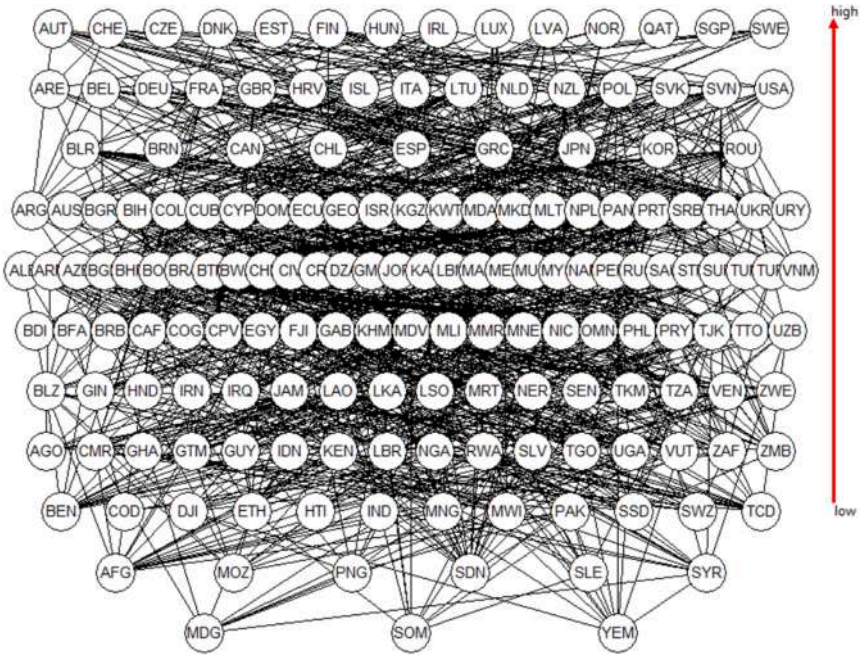


**Fig. 2.** Hasse diagram for SDG dimensions. The right arrow indicates that higher ranked countries are towards the top of the Hasse diagram whereas lower ranked countries are towards the bottom. Black lines represent ordering relations.

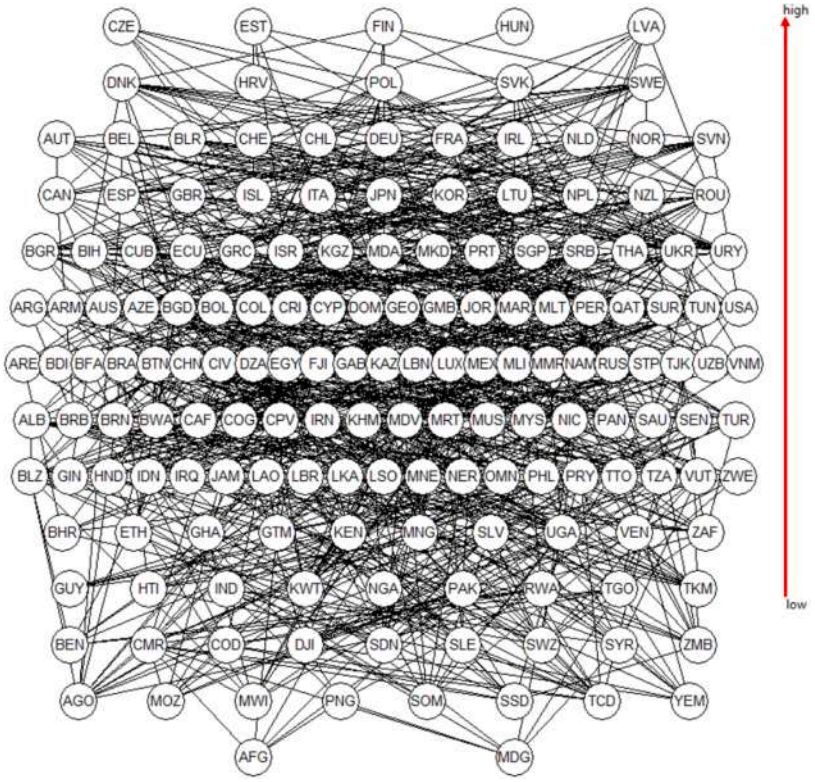


**Fig. 3.** Hasse diagram for SDGs for social, environment, economic goals and GNI.

higher impact than the social or economic goals.

It is also interesting to carry out a sensitivity analysis when income (which differs from economic SDG goals) is added, given that we saw above how the structure of the Hasse diagram changes when GNIpc is included. The main findings, shown in Fig. 5, confirm the robustness of the environmental dimension as the most relevant attribute to explain the partial ordering of countries in the Hasse SDG. As expected, other dimensions such as the social and the economic have lower discriminatory power, given their high correlations, in determining the partial rankings when GNIpc is introduced. Fig. 5 also includes the aggregate SDG Index (sdg) as a way of controlling for composition effects but, as can be seen, its aggregate impact is not significant.

The message conveyed by these findings suggests that environmental goals are the most important in defining the place that countries occupy

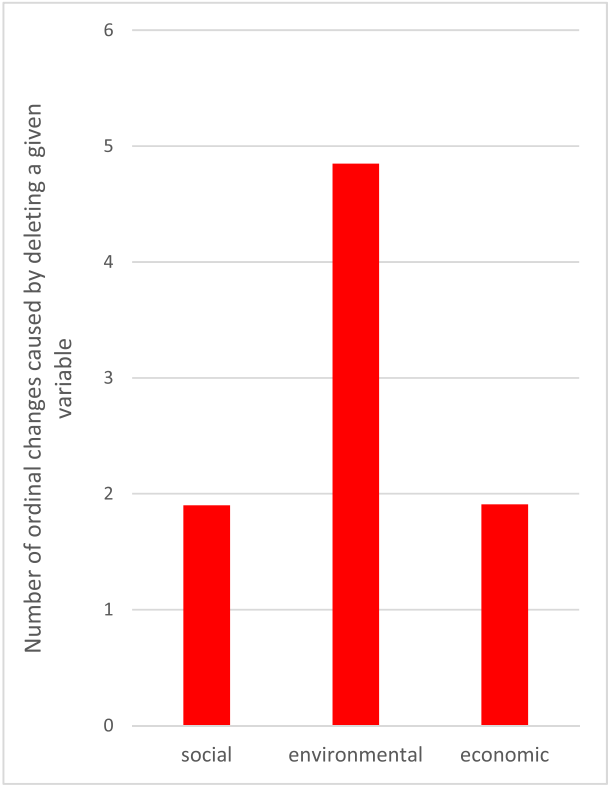


**Fig. 4.** Sensitivity analysis for SDG dimensions.

in the SDG Index partial ranking. However, this happens only if we attach proper weight to the problem of incomparabilities between different goals. This point is overlooked by composite indices, and it remains to be determined whether dashboards can indicate with equal clarity the role of different types of goal in determining the country rankings.

## 5. Discussion and conclusions

The issue of incomparabilities is at the heart of discussions about sustainable development. This is because sustainable development seeks to realise a harmonic/nested view of development that promotes economic growth without compromising the environment, that strengthens environmental policies without the cost of undermining the livelihoods of the poor, and that promotes social inclusion without harming economic growth. The SDGs provide a unique evaluation framework for promoting sustainability. But the main issues related to incomparabilities are not fully addressed by the most widely used measurement strategies in the literature, namely the use of dashboards and the elaboration of composite indices.

On the one hand, SDG dashboards provide accurate information about the progress of each individual indicator/goal and their differences, albeit at the expense of increasing complexity and interpretative looseness in providing an overall picture of some of their findings. On the other hand, current SDG composite indices show the overall progress of each indicator or goal and the differences between them. Nevertheless, as we found in the analysis above, they conceal conceptual, methodological and empirical difficulties. The concept of incomparability is at the centre of the respective shortcomings of these approaches. Whereas dashboards recognise the existence of incomparabilities between dimensions, they do not do anything about them. In their turn, composite indices do something, but without regard to their incomparabilities.

Posets offer a more transparent approach than sophisticated aggregative schemes or formulas proposing different weighting schemes. This is because they are simpler and more intuitive, in line with the human development perspective. Their use allows the operationalisation of SDGs as a nested concept once it highlights how different dimensions are explicitly considered in ranking the countries. In addition, a simple look at the Hasse diagrams conveys information about how high levels of incomparability among different goals delay countries' sustainable and harmonic development. In this way, posets offer a clearer way forward

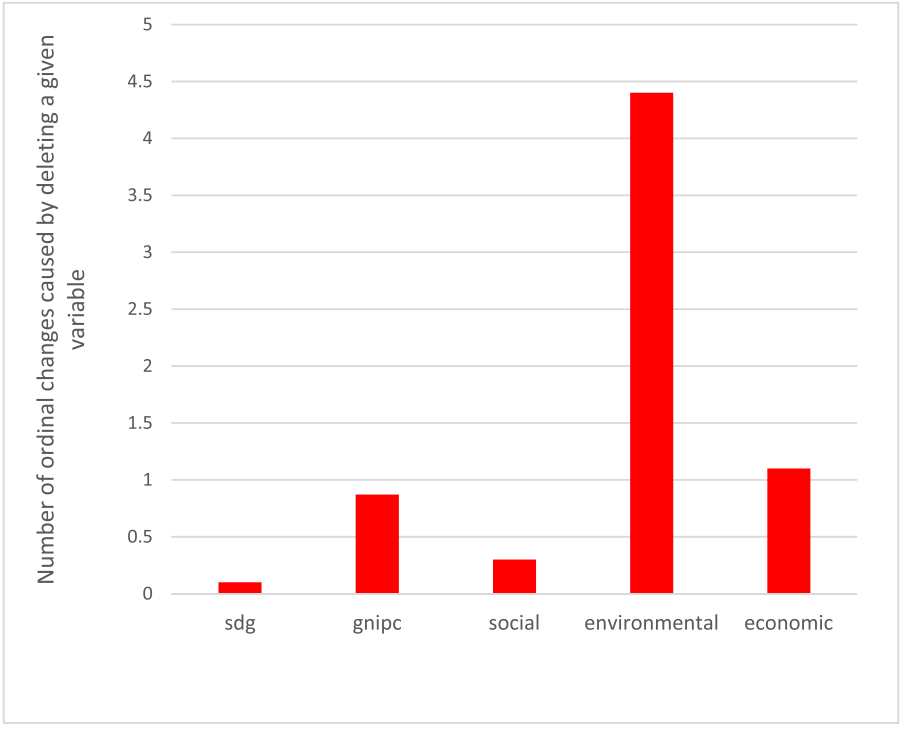


**Fig. 5.** Sensitivity analysis for SDG dimensions and GNIpc.

to tackle the problem of perfect substitutability among different SDG goals.

Although composite indices have the important attraction of simplicity by summarising information in a single number, they have the disadvantage of concealing the extent of incomparabilities across each indicator and goal. This is not a trivial point, considering that Goal 17 is strategically important for the achievement of the overall SDGs and that it needs clearer information to promote consensus and a better North-South balance of power in the implementation of key themes. Otherwise, it is unclear how global partnerships for sustainable development can be built if countries do not achieve a clear way of identifying their priorities and implementing principles such as "Leaving No One Behind" (LNOB), which is essential for the 2030 agenda. Within this context, issues of implementation imbalances and unequally distributed SDG partnerships among Northern and Southern are not minor (Blicharska et al., 2021). The challenges of integration and coordination of substantive targets surely depend on a wide range of factors including those of governance, multi-stakeholder partnerships, policy and institutional coherence, capacity building, trade, technology, finance as well as those of data, monitoring and accountability (Stafford-Smith et al., 2017). Given the current situation of lack of progress in many countries in the areas of infrastructure, climate action, biodiversity protection and sustainable consumption (Sachs et al., 2021), a clearer view of how different indicators and targets can or cannot be seen in an integrated way seems important for building fairer and more inclusive SDG global partnerships.

The problem of incomparability in the SDGs is all the more important given the claim that economic goals have greater impact on the overall SDGs than that of social and environmental goals (Le Blanc 2015). This prima facie evidence is sometimes taken for granted, leading to an underappreciation of the role of the environment in meeting the SDGs (Diaz-Sarachaga et al., 2018; Jain & Jain, 2019; Hirai, 2022). We showed above that the same misleading result can be obtained with a simple correlation analysis. The common story, as it goes, is that the SDG Index has a very high correlation with GNIpc and a weak negative correlation with the environmental dimension. It means that the environmental dimension has the least impact upon its complete ranking. This surely contradicts the raison d'être of the SDGs and thus provides a misleading signal for sustainable development. That conclusion, parametrically conditional on the use of complete rankings, is further strengthened by a high proportion of trade-offs along the economic dimension, not only against the environment (von Stechow et al., 2016; Pothen & Welsch, 2019) but also across the overall SDGs (Pradhan et al., 2017). In view of all this evidence, the poset offers an appropriate signal in favour of the environment, to the extent that it has the most powerful impact among the SDG dimensions for its partial ranking, as the sensitivity analysis has shown.

Overall, partial rankings provide a more suitable framework for SDGs than that offered by complete rankings. This is not only because of serious shortcomings in the use of composite indices leading to complete rankings, but also because these indices downplay the relevance of environmental goals – which should be central for the pursuit of sustainable development – for the SDGs. Thus, partial rankings can be used as much as complete rankings are ordinarily used (as in the case of the SDG Index or of the HDI -Human Development Index), showing how different countries stand vis-à-vis each other. In practice, policy-makers should cross-check in which particular dimensions their countries fall short relatively to other neighbour countries. For that they can benefit from the information provided by the corresponding sensitivity analysis. Furthermore, it cannot be overemphasised that the poset framework can offer a middle ground between the current options for tackling SDGs, where incomparabilities are either acknowledged but not identified (as happens with dashboards) or completely ignored (as happens with composite indices). If the 2030 Agenda for Sustainable Development is first and foremost an agenda for equality, then it is important that we neither ignore nor remain indifferent to problems with incomparability.

## 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.

## Data availability

The data used in this article are publicly available (UNDP, 2020; Sachs et al., 2021).

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