Complex interlinkages between the SDGs and their importance to African development

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Abstract

A decade of research since the adoption of the Sustainable Development Goals (SDGs) argues that accurately measuring the relations between SDGs allows the identification of systemic leverage points that would unlock the achievement of the SDG agenda as a whole. While the literature on sustainable development linkages has evolved rapidly, regional variations tend to be overlooked. And yet, we have identified important differences between the SDG interlinkages in Africa and Sub-Saharan Africa in comparison to the World as a whole. The accurate identification of these links and regional differences between them hold important consequences for Africa achieving its development goals. We found that the observed significant interlinkages, more central SDGs, and nexuses between certain SDGs showed different patterns of variation between sub-Saharan Africa, Africa as a whole and the World. Leveraging significant interlinkages through policy, planning and practice can contribute to unlocking systemic advances to achieve the full SDG agenda. If regional differences in leverage points are not accurately identified, any policy and practice will be neither effective nor cost-efficient. Our findings also indicate that existing evidence on sustainable development that may be appropriate in the Global North may not be directly applicable in Africa, and therefore support contemporary calls for improving knowledge equity and evidence production between Global South and North.

Key words: SDGs, Africa, development, complexity, interlinkages, systems approach, network analysis

Introduction

Sustainability encompasses a system of tightly interlinked biophysical, economic, environmental, and social interactions. The text of the Sustainable Development Goals (SDGs) recognises these "deep interconnections and many cross-cutting elements across the new Goals and targets" (UNGA, 2015, §17). A decade of research since the adoption of the SDGs in 2015 consistently argues that the accurate detection of the relations between SDGs would allow the identification of systemic leverage points that would unlock the achievement of all SDGs. Research to date has tended to focus on either global or national levels, which may overlook certain regional features that may be better understood, advocated for, and addressed through collective regional responses. And yet, leveraging meaningful SDG interlinkages through policy, planning and practice can contribute to unlocking systemic advances to achieve the full SDG agenda. If regional differences in leverage points are not accurately identified, any policy and practice will be neither effective nor cost-efficient.

This paper uses complexity-informed mathematical analyses to identify the SDG interactions that matter in and for Africa: (1) the SDGs that are most central to achieving all other SDGs on the African continent, (2) the specific patterns of interlinkages between the SDGs in Africa, and (3) the particular clusters (or nexuses) of SDGs with strong interdependencies in Africa. Our analysis compared SDG interlinkages in sub-Saharan Africa and Africa as a whole to the results for the whole World, identifying significant differences between all three axes of analysis. In so doing, we detected key systemic leverage points for Africa and sub-Saharan Africa as regions (while recognising national and local variations within these diverse regions) which do not follow the same pattern as worldwide. The contribution of this article lies in identifying the interlinkages between Agenda 2030 goals, and specific goals and goal clusters that hold the highest potential to leverage systemic effects across the full range of sustainability targets specifically in Africa. Despite the specificity of the pattern of Agenda 2030 interlinkages in Africa, so-called "global" research continues to be considered appropriate to answer Africa's challenges. In contrast, we argue that our findings support calls for greater epistemic justice (Mbembe, 2015; Odora Hoppers, 2002) in order that

African researchers might develop relevant responses to these African challenges.

Literature

The interlinkages between sustainability issue areas and goals were introduced onto the global stage in the Brundtland report (WCED, 1987), which argued that different issue areas were not separate domains of expertise and practice but rather were systemically interconnected. While the literature on sustainable development linkages has evolved rapidly, analyses of data for the whole world dominate alongside some studies of national contexts. For example, Nilsson et al.'s (2016) 7-point scale has been deployed to provide analyses of the world (UNSG ISG 2019, 2023) and national contexts (e.g. Bisaga et al., 2021 in Rwanda; Zhang et al., 2022 in China). This literature also encompasses studies of sub-national regions (e.g. Eliasson & Grönlund (2023) in Sweden or Wu et al. (2022) in China).

Nevertheless, Nilsson et al. (2016) also indicated the importance of regional variability in SDG interlinkages, since contextual factors structure these interlinkages and affect how they play out (Nilsson et al., 2018). However, regional analyses and variability tend to be overlooked. Some regional analyses exist, usefully focusing on a subset of Agenda 2030 concerns. For example, in Africa, Mpofu (2022) conducts analyses on green taxes as a policy response to implement Agenda 2030, while Müller et al. (2021) examine energy justice and transitions (SDG7). What is missing are analyses that examine the different *regional* patterns of systemic interlinkages between the different goals in the broader Agenda 2030 (the SDGs and Paris Agreement on Climate Change).

Methodologically, this relational perspective has been translated into research through (1) conceptualising relations between economic, environmental and social aspects of sustainability (such as Raworth's (2017) Doughnut Economics), (2) quantifying linear links between two SDGs (for example, Nilsson et al.'s (2016) 7-point scale of identifying synergies and trade-offs between the goals), (3) examining variable rates of change between several sustainability goals simultaneously (e.g., Anderson et al., 2021), and (4) complexity-informed research that simultaneously detects variability in both rates and directions of change within the system of sustainability goals (Laumann et al., 2022).

The findings associated with the latter three empirical approaches differ regarding regional analyses. Pradhan et al. (2017) note that individual countries may show a pattern of SDG interlinkages that differ from the global picture. Anderson et al. (2021) used their SDG systems model to carry out regional analyses of nonlinear interlinkages between the SDGs to examine the contribution of different continents to the three targets that they found provided most synergies or hurdles to other SDG targets. However, they found only small variations in regional contributions to the global picture: Africa contributes slightly less to making these targets the most synergistic or antagonistic for other SDG targets, while Europe and North America contribute comparatively more. By contrast, Laumann et al. (2022) found significant differences between regional groupings, which we examine further in this article.

Methods

Like Laumann et al. (2022), we used nonparametric measures of dependence (distance correlation) to analyse pairwise dependencies to detect complex interrelations, examining changes in both the rate and direction of variation (that is, nonlinear and nonmonotonic relationships). In nonlinear nonmonotonic relations, the *direction* of change can vary as well as the *rate* of change. An example of a nonmonotonic relationship is eating chocolate, which generates a positive feeling at first that can change to a negative feeling if you continue eating too much, with different individuals having different tipping points regarding amount and time. Relations between SDGs may follow similar dynamics, where – rather than always being either synergistic or antagonistic – they may tip from positive to negative (or vice versa). The methods we use allow the detection of how the relationship between SDGs may be both reinforcing and counteracting, changing over time and/or depending on the region of operation.

We also remove spurious dependencies by factoring out confounding variables. For example, in Sub-Saharan Africa, SDG8 and SDG9 are frequently incorrectly identified to have a direct relationship (Swain & Ranganathan, 2021), whereas this relationship is actually explained away by the links between SDG4 and SDG8, and SDG4 and SDG9 (Laumann et al., 2022). Once SDG4 is taken into consideration as driving the relationship between SDG8 and SDG9, the direct relationship between these two SDGs is erased. Thus, in sub-Saharan Africa, SDG4 is a confounding, or lurking, variable, in the supposed interactions between SDG8 and SDG9.

In addition, we utilise network theoretical analysis (informed by mathematical graph theory) to simultaneously consider the dependencies between the 17 SDGs and global temperature (an indicator of progress on the 2015 UNFCCC Paris Agreement on Climate Change). This analysis allows the detection of the most important dependencies and clusters (or nexuses) of strongly related SDGs

Our dataset of time series data measuring progress on the SDGs is sourced from the World Bank (2020) and comprises 400 indicators tracking the progress of the 17 SDGs from 2000 to 2019 across 181 countries. The time period for our observations covers years in which the UN focused on the MDGs (from 2000 to 2015) and the SDGs (from 2015 to 2019). Hence, progress on the selected indicators of our study might be accredited to policies addressing both the MDGs and SDGs. However, the observed variables are the indicators which were subsequently defined by the World Bank for every goal and target of the SDGs, so we measure progress towards the SDGs when observing how these indicators have changed over time.

At the time of analysis, SDG13 focused entirely on inputs and procedures, such as the integration of climate change into national policies (indicator 13.2.1), but no SDG indicator actually measured the *results* of the implementation of such inputs and procedures. They describe which *actions* are taken against climate change. The text of the SDG agenda acknowledges "that the United Nations Framework Convention on Climate Change is the primary international, intergovernmental forum for negotiating the global response to climate change." We use rising temperatures as a better proxy for climate change than the SDG13 targets, since other climate change indicators are correlated with, or caused by temperature rise. By including our 18th variable (temperature), we measure actual temperature changes, that is, outcomes and impacts of the actions taken in SDG 13 and the other SDGs. For annual country-level average temperatures, we utilised data from the Climatic Research Unit (2020). Each indicator corresponds to one of the 18 objectives (the 17 SDGs plus climate change).

For a given grouping of n countries, we treat the countries as independent samples of the grouping (e.g., the World, Africa, sub-Saharan Africa); hence, the sample size of a grouping is n. Let X represent one of our 18 variables (SDGs and climate change). Each variable X has an associated set of indicators I_X, and each indicator $i \in I_X$ has 20 observations over time

(from 2000 to 2019). Thus, the dimensionality for each variable X is $d_X = 20 \, |I_X|$.

The distance correlation $R^2(X,Y)$ between X and Y is a measure of dependence between these variables with the following properties: $0 \leq R^2(X,Y) \leq 1$, indicating it is a normalised quantity, with $R^2(X,Y) = 0$ only if X and Y are independent. This makes it a non-parametric measure capable of detecting nonmonotonic as well as nonlinear dependencies, unlike Pearson or Spearman correlation (Faul et al., n.d.). Moreover, $R^2(X,Y)$ is well-defined for $d_X \neq d_Y$. This latter property is particularly advantageous in our context since the dimensionality varies significantly between variables due to the differing numbers of indicators per SDG. Given two variables X and Y, another variable (or a set of variables) is considered a confounder if it causally influences both X and Y. Our method therefore enables the detection of this causal influence that can induce a statistical association between X and Y even if there is no direct causal link between them. Thus, pairwise dependence between X and Y may arise due to the influences of the other 16 nodes.

To determine the direct strength of dependence between any pair of nodes (X, Y), we controlled for the shared effects from other nodes by conditioning on any subset of the remaining nodes: $Z \subseteq V \setminus \{X,Y\}$, where V represents the set of 18 nodes. As a measure of the direct dependence between X and Y, we use the minimal partial distance correlation over all possible subsets:

$$R_n^*(X,Y) \; = \; min_{Z \subseteq V \setminus \{X,Y\}} \, R_n^*(X, Y \mid Z)$$

This measure reflects the strength of the dependence between X and Y that cannot be explained away by the subset Z that may influence both X and Y. In our study, we analysed 153 unique pairs of the 18 variables (SDGs and climate change). For each variable pair, we computed the partial distance correlation by minimising over the 65,535 conditional sets Z formed by the remaining 16 variables. This process was conducted for each of the country groupings to obtain a contextualised description of the dependencies among SDGs and climate change.

For any given grouping of countries (we analyse sub-Saharan Africa, Africa, and the World), the described procedure yielded a set of significant interlinkages among the 18 variables, with strengths as previously detailed. To further analyse these interdependencies, we employed a network representation, where the variables are depicted as nodes and the significant minimal partial distance correlations constitute weighted edges. Having

constructed an undirected, weighted network for each country grouping, we conducted two additional analyses. Firstly, we quantified the relative importance of each of the 18 nodes (variables) using eigenvector centrality, a network-theoretic measure that assigns high ranks to nodes with strong connections to other highly ranked nodes. Secondly, we applied community detection by modularity maximisation to group nodes into nexuses, which are clusters of variables with strong interdependencies.

Analyses

We represented the obtained dependencies among the 18 interrelated objectives (17 SDGs and mean annual temperature rise) as a network, which was analysed to compute the (1) *centrality* (that is, the relative importance) of each goal individually, (2) *most strongly linked pairs* of goals, and to which we applied community detection to find (3) *nexuses* (or groups of most strongly interconnected variables). We report our analysis at increasing levels of complexity: first individual goals, then pairs of goals, and finally groups of goals. It is critical to note, however, that these results arise from the analysis of *all linkages* between all goals in the whole Agenda 2030. Thus, the results of the importance of individual goals are ranked as they affect the whole system of SDG goals and temperatures; so are the results of the importance of pairs of goals, and then significant clusters. Our findings show strong discrepancies between country groupings Africa, sub-Saharan Africa, and the World (global results), highlighting the importance of regional analyses and solutions produced in and for the regions in preference to so-called "global" prescriptions.

Eigenvector Centralities of Agenda 2030 Goals in sub-Saharan Africa, Africa, and the World

Table 1 summarises the relative importance of the top ranked, most central Agenda 2030 goals in the networks of interlinkages studied. The more central the goal, the more important its achievement is to achieving the remainder of the goals. The means of implementation and partnerships (SDG17) and infrastructure and innovation (SDG9) appear as central in the World and Africa but do not appear in the top three leverage point goals in sub-Saharan Africa. In contrast, sub-Saharan Africa shares no leverageable goals with either Africa or the World, prioritising instead sustainable communities and cities (SDG11), education (SDG4) and equalities (SDG10) as most important to bring about systemic change across the full Agenda 2030. Rising global temperatures (T) are seen to be second most important in Africa, a country grouping already among the worst affected by climate

breakdown, while affordable, sustainable energy (SDG7) is most important in the data for the World. These analyses therefore show the importance of regional and sub-regional analyses for identifying the key goals to leverage in order to bring about systemic change across all Agenda 2030 goals.

Table 1. Most central Agenda 2030 goals with their eigenvector centralities in Africa, Sub-Saharan Africa, and the World

Country Grouping	1st most central Agenda 2030 goal	2nd most central Agenda 2030 goal	3rd most central Agenda 2030 goal
Sub-Saharan Africa	11 (0.35)	4 (0.33)	10 (0.33)
Africa	17 (0.38)	T (0.34)	9 (0.33)
World	7 (0.46)	17 (0.43)	9 (0.34)

Figure 1.a shows that in sub-Saharan Africa, mean annual temperature rise (T), the means of implementation and partnerships (SDG17) and infrastructure and innovation (SDG9) (the top three in Africa as a whole (Figure 1.b) are close behind the top three reported in Table 1. In the World (Figure 1.c), improving hunger and nutrition ranked fourth, whereas this ranked much lower in Africa and sub-Saharan Africa.

Figure 1. Mapping eigenvector centrality against SDGs and temperature

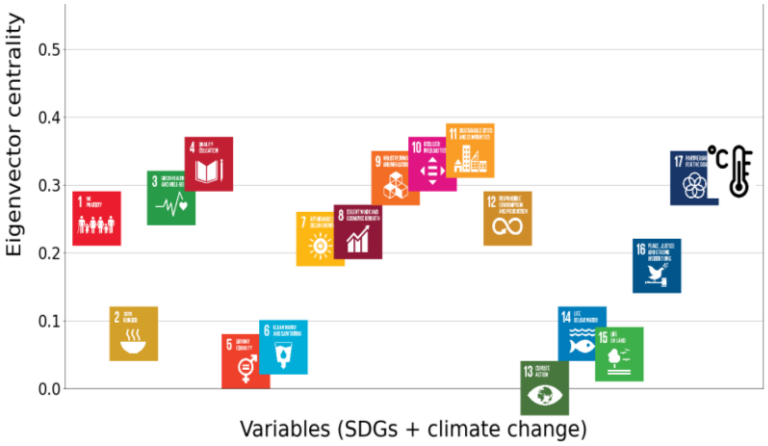

Figure 1.a. Sub-Saharan Africa

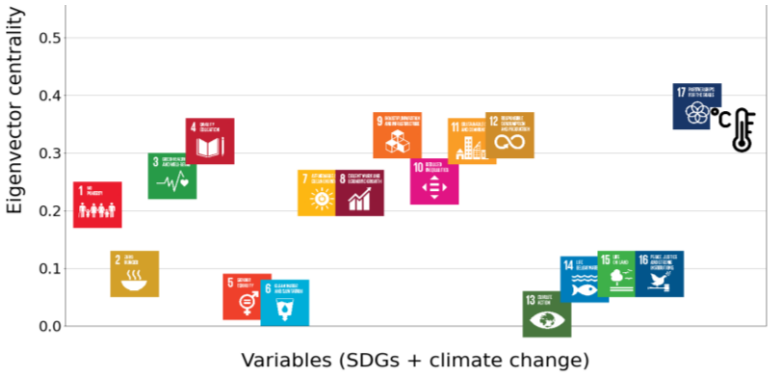

Figure 1.b. Africa

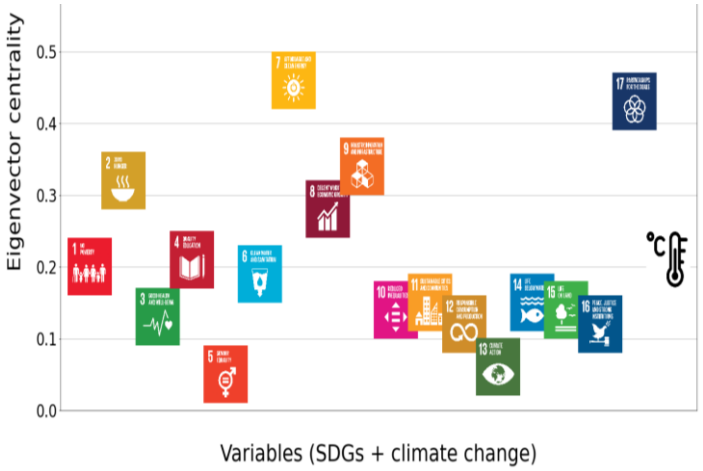

Figure 1.c. The World

Networks of Agenda 2030 Goals' Linkages in sub-Saharan Africa, Africa, and the World

Network maps illustrating the strength of the partial distance correlation in the weight of the lines linking the goals reveal strong differences between the analysis for the World (Figure 2.c.) in comparison to sub-Saharan Africa (Figure 2.a) and Africa (Figure 2.b), which are relatively similar to each other.

Figure 2: Network maps of simultaneous analysis of interlinkages between Agenda 2030 goals

Figure 2.a. Sub-Saharan Africa

Figure 2.b. Africa

Figure 2.c. The World

The three strongest of all interlinkages in each of these three groupings $[R_n{}^*(X,Y)]$ are reported in Table 2. These are the strongest pairwise interlinkages as detected within the enmeshed system of Agenda 2030 goals, not as if they were independent variables (Laumann, 2022). The connection between decent work and strong economy (SDG8) and the means of implementation and partnerships (SDG17) appears in all three country groupings (and all other regional groupings except North and Central America). The link between sustainable communities and cities (SDG11) and rising global temperatures (T) holds prime position in both Africa and sub-Saharan Africa but does not appear in global results for the World. The important links between the Agenda 2030 goals in Africa and sub-Saharan Africa have more in common than the links calculated to be important for the World as a whole. Again, the differences between these results reveals the importance of regional and sub-regional analyses for identifying the most leverageable links to bring about systemic change across all Agenda 2030 goals.

Table 2: The Three Strongest Pairwise Interlinkages with their Minimal Partial Distance Correlation in sub-Saharan Africa, Africa, and the World

Country Grouping	1st strongest interlinkage	2nd strongest interlinkage	3rd strongest interlinkage
Sub-Saharan Africa	11 – T (0.24)	1 – 16 (0.15)	8 – 17 (0.14)
Africa	11 – T (0.24)	8 – 17 (0.13)	1 – 8 (0.12)
World	7 – 9 (0.30)	8 – 17 (0.25)	7 – 17 (0.25)

Nexuses of Interconnected Agenda 2030 Goals in sub-Saharan Africa, Africa, and the World

In this section we report on results of nexuses of interconnected SDGs with strong interdependencies to each other, detected through network analyses identifying clusters of interlinkages. Action on these clusters of goals is widely theorised to leverage the achievement of the wider system of goals. None of these clusters follows the conventional sustainability heuristic "economy, environment, society", showing that this categorisation does not necessarily support strategic decision making for sustainability.

In all groupings, a nexus between poverty eradication (SDG1), education (SDG4), and decent work and strong economies (SDG8) was detected. Peace, justice and strong institutions (SDG16) joins this triplet in sub-Saharan Africa and Africa as a whole, but are replaced by the means of implementation (SDG17) in the World analysis. Beyond the importance of certain connected goals, the remaining goals differ between regional groupings.

All three groupings we examine in this paper contain a nexus that includes sustainable communities and cities (SDG11) and mean annual temperature rise (T). These two goals form a nexus alone in Africa, whereas in sub-Saharan Africa, they are joined in the same nexus by health (SDG3), clean water and sanitation (SDG6), improving inequalities (SDG10), and sustainable consumption and production (SDG12). In the World, these two goals were also joined in the same nexus by health (SDG3), and sustainable consumption and production (SDG12) (as in sub-Saharan Africa), but also by

peace, justice and institutions (SDG16). The remainder of the nexuses are more unalike than alike.

Figure 3. Nexuses of Interconnected Agenda 2030 Goals

Figure 3.a. Sub-Saharan Africa

Figure 3.b. Africa

Figure 3.b. The World

The structure of the nexuses in Africa (in which 5 significant clusters were detected) is more complicated than in sub-Saharan Africa or the World, which have three significant clusters each. Again, the regional differences apparent in these analyses call for a more granular, regional analysis of interlinkages between Agenda 2030 goals and sensitivity to regional needs and evidence to serve them.

Discussion

Regional differences matter more than global patterns. The observed central goals, important interlinkages between two goals, and nexuses of several goals that we identify show different patterns of interlinkages between Agenda 2030 goals in sub-Saharan Africa, Africa as a whole and the World. Using partial distance correlations, we calculated nonlinear nonmonotonic dependencies between all 17 SDGs and mean annual temperature rise while discounting the effects of removing spurious dependencies originating from confounding variables. Leveraging significant interlinkages through policy, planning and practice can contribute to unlocking systemic advances to achieve the full SDG agenda. If regional differences in leverage points are not accurately identified, any policy and practice will be neither effective nor cost-efficient. Given that none of the clusters identified through these analyses follows the conventional sustainability categorisation "economy, environment, society" (Figure 3), we argue that this heuristic does not support strategic decision making for

sustainability. By contrast, systemic analysis such as ours identifies action points with the potential for more systemic effects, and the different policy action needed in different leverage points in Africa in comparison to the World.

Regional patterns are different to analyses of the "global" aggregate data of the World; addressing them requires knowledge and solutions that are locally relevant and contextually rooted. Our findings also support contemporary calls for improving knowledge equity and evidence production between Global South and North. In addition to a perspective grounded in epistemic justice to right historical wrongs in research and knowledge equity, we also emphasise the pragmatic argument that existing evidence on sustainable development produced in the Global North may not be applicable to Africa. We deliberately do not use the language of "global vs. local", since this gives the false impression that research that is denoted as global (produced in and by the Global North) is placeless and universal, in contrast to the local–contextually grounded, locally relevant–evidence from the Global South. Language that discriminates between "global and local" elides the equal "localness" of research and evidence produced in the Global South and North, and also the equal potential global usefulness of both.

Two policy implications arise from our study. First, focus more attention on region-specific interlinkages and focus policy action to those SDGs that hold the greatest potential to unlock systemic effects across the full SDG agenda. Secondly, provide more funding for African research in Africa to respond to regional needs and address region-specific concerns. Funding African research is critical to identifying solutions to the complexity of SDG interconnections in Africa at the same time as decision makers use these insights as they work towards achieving these goals and elaborating the next global development agenda.

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