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Harnessing Insights from Social-Ecological Systems Research for Monitoring Sustainable Development

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Abstract: The United Nations' Agenda 2030 marks significant progress towards sustainable development by making explicit the intention to integrate previously separate social, economic and environmental agendas. Despite this intention, the Sustainable Development Goals (SDGs) which were adopted to implement the agenda, are fragmented in their formulation and largely sectoral. We contend that while the design of the SDG monitoring is based on a systems approach, it still misses most of the dynamics and complexity relevant to sustainability outcomes. We propose that insights from the study of social-ecological systems offer a more integrated approach to the implementation of Agenda 2030, particularly the monitoring of progress towards sustainable development outcomes. Using five key features highlighted by the study of social-ecological systems (SESs) relevant to sustainable development: (1) social-ecological feedbacks, (2) resilience, (3) heterogeneity, (4) nonlinearity, and (5) cross-scale dynamics. We analyze the current set of SDG indicators based on these features to explore current progress in making them operational. Our analysis finds that 59% of the indicators account for heterogeneity, 33% for cross-scale dynamics, 23% for nonlinearities, and 18% and 17%, respectively, for social-ecological feedbacks and resilience. Our findings suggest limited use of complex SES science in the current design of SDG monitoring, but combining our findings with recent studies of methods to operationalize SES features suggests future directions for sustainable development monitoring for the current as well as post 2030 set of indicators.

Keywords: human wellbeing; sustainability; equity; complex adaptive systems; indicators

1. Introduction

The major challenges currently facing the world, including persistent poverty, rising inequalities, biodiversity loss, and climate change, are increasingly recognized as the emergent outcomes of complex social and ecological interactions [1–4]. Climate change, for example, is recognized as one of the major threats to global health because it affects disease patterns, water and nutrition security, and the severity and frequency of extreme weather events [5,6]. Similarly, movements of resources through international trade and consumption patterns have been shown to affect biodiversity negatively by contributing to habitat destruction [7,8]. These examples are far from unique, as more and more

interconnections between social and ecological systems and development challenges are emerging in this more hyper-connected era [1,9].

Importantly, social-ecological connections are not static, but change dynamically over time, and the consequences of changes in these connections are frequently non-linear and uncertain. In some cases, changes can accrue invisibly until a threshold or tipping point is reached [10,11]. In other cases, they are connected in space [12,13], with impacts appearing in seemingly unconnected distant areas, as shown more recently by studies of telecoupling [14–18]. These non-linear dynamics, which connect social and ecological systems across space and time, are key to efforts to achieve sustainable development, and neglecting them could result in recurring or new problem challenges for development.

The increased connectivity between social and ecological systems, and the dynamism associated with these interlinkages, presents two types of challenges to efforts in measuring and tracking progress towards sustainable development goals (SDGs). The first involves the need to more accurately represent the interconnections between social, economic, and ecological systems [19–22]. Failing to connect these has often resulted in undesirable trade-offs—many current ecological problems result from the neglect of the environment in economic and other measurement efforts [23,24]. The second involves understanding that these connections are not static, but dynamic, requiring the design of monitoring systems to be able to capture these dynamics including spatial, temporal, and cross-sectoral changes [25–27].

The first challenge is at the forefront of current efforts to implement Agenda 2030 of the United Nations, which highlights the interlinkages between social, environmental, and economic aspects of sustainable development. Declaration 18 aptly captures this intent: "We are announcing today 17 Sustainable Development Goals with 169 associated targets which are integrated and indivisible . . . " [28]. In response to this recognition of interlinked systems of nature, society, and economy, several "systems approaches" have been proposed to account for, monitor, and analyze trade-offs between these sub-systems in the implementation of the SDGs [29]. These system approaches highlight the need to capture and relate social, economic, and ecological components in order to assess and monitor progress to sustainable development [29–31] and are the main focus of several studies exploring sustainable development trade-offs [32–36].

However, sustainability outcomes are more than the sum of the ecological, economic, and the social "parts" of a system and are in fact also the result of complex interactions, feedbacks, and dynamics within and between systems. The study of complex adaptive systems has highlighted that interactions between individual and diverse components or actors results in emergent behavior or properties at a macro-level that cannot be predicted from micro-level components or properties [37–39]. This challenges the assumption underlying many system approaches, that micro-level monitoring of separate social, economic, and ecological variables can then be reconstructed to understand sustainability outcomes including trade-offs or possible future scenarios.

The second challenge can be addressed by broadening from a "systems" to a "complex adaptive systems" approach to monitor and analyze sustainable development, which has the potential to more adequately understand and track sustainability outcomes [22,40]. In an effort to explore what such broadening to a more dynamic and complex approach to sustainable development monitoring might entail, we interrogate the literature on complex social-ecological system (SES) approaches to sustainable development. SES is defined as complex adaptive systems, with strong interdependence and irreducibility between social and ecological systems across multiple scales. Recent reviews of this literature have highlighted key features that constitute complex SES relevant to sustainable development, including the importance of social-ecological interactions and feedbacks, non-linear dynamics, cross-scale (spatial and temporal) dynamics, diversity, and resilience [22,27,41]. Here we explore these key features of SES and evaluate their implications for sustainable development monitoring. We do so by first analyzing the current set of SDG indicators [42] using these features to explore current directions and gauge progress in making the features operational. Using these findings, as well as recent studies on complex SES and sustainable development, we then provide

recommendations for sustainable development monitoring for the current set of indicators, as well as future improvements post-2030.

2. Materials and Methods

The core features of complex SES identified in previous reviews [22,27,41,43,44] are: (1) social-ecological feedbacks, (2) resilience, (3) heterogeneity, (4) nonlinearity, and (5) spatial and temporal cross-scale dynamics. We begin by analyzing the current set of SDG indicators in terms of the extent to which they include these core features. We do this using examples from existing SES research on measurable variables, or measurement methods aligned with the core features, and assess the extent to which each proposed SDG indicator uses such variables. We evaluated all 243 indicators from the 17 SDGs (See Appendix A). Below, we clarify the core features and explain how we applied each feature to evaluate the SDG indicators. Through this analysis of current indicators, we present a set of recommendations to harness the potential value that may be added by an SES perspective.

2.1. Social-Ecological Feedbacks

In addition to the components in a system, i.e., social factors (e.g., food security), ecological factors (e.g., forest health), and economic factors (e.g., market prices), interactions between these are also important for understanding and dealing with change. Interactions capture the flow of materials, energy, and waste between components of a system [45], and they create feedbacks when stimuli are fed back to their origin through one or a series of interactions [46,47]. For a feedback to occur, there first has to be an 'initial' trigger, represented by a unidirectional interaction from one phenomenon to another. This process can potentially involve a long string of components and interactions. Studies of feedbacks typically include 'process-impact' relationships, where, for example, agricultural activity results in land degradation, which results in reduced agricultural activity, which in turn may result in further land degradation [48]. There are many similar examples showing different processes and impacts [49–53]. Our analysis of the SDG indicators showed few that account for feedbacks, and thus, we also included any indicators capturing interactions between social and ecological systems, e.g., ecosystem service use or governance of ecosystems [54].

2.2. Resilience

Resilience encompasses three elements: absorptive, adaptive, and transformative capacities [55], which sometimes overlap with one another. Many variables have been suggested to capture these capacities, including diversity of assets [56,57], social and demographic characteristics [58], and also the ability to self-organize, learn, and govern adaptively [59–61]. For this purpose, we adopt three of the seven principles of resilience [43], following [62], in which they split the seven principles into those focusing on the resilience of a system itself or its governance. The three principles chosen in this study are about the governance of a system, and the remaining four principles, which are left out, are dealt with in the other features. The three principles are: (1) encourage learning, which is a multifaceted phenomenon, including acquisition of information, skills, and interpreting knowledge differently [63], (2) broaden participation, which refers to the active engagement of relevant stakeholders in the management process [64], and (3) promote polycentric governance systems, which means governance system consisting of multiple governing authorities that interact across different levels of the policy process [65]. In evaluating the indicators, we identified those that mention or imply these three principles in their formulations by looking for mention of the words "learning", "education", "governance", "management", and "research" in the indicators.

2.3. Heterogeneity

Heterogeneity refers to the differentiation of system components [66]. System differentiation has previously been measured through indices of system diversity [67,68], socioeconomic or geographic characteristics [69–71], and indices showing multidimensionality of concepts such

as bundles of ecosystem services [72–75]. Diversity comprises variety, disparity, and balance between system components [76]. This may include biodiversity [77,78], diversity of knowledge systems [79–81], diversity of livelihoods [82,83], and diversity or options for response to change [66,84]. Socioeconomic and geographic heterogeneity can be assessed by disaggregation of phenomena according to some criteria. In other studies, social differentiation is depicted through gender, poverty, or income classes [69,71,85–87], or through the intersections of such characteristics [88,89]. Finally, multidimensionality has been used to illustrate system components with multiple dimensions not adequately portrayed through single metrics, e.g., poverty, human wellbeing, or ecosystem health [73,90,91]. We identify indicators that capture any of these aspects of heterogeneity by looking for those indicators that are disaggregated by socioeconomic criteria (e.g., gender, sector, etc.), biological diversity (e.g., genetic diversity), or indicators that highlight multiple dimensions (e.g., human wellbeing outcomes). Studies have shown that more diversity is not always good—given that too much diversity could reduce efficiency, and too little could reduce resilience—which emphasizes the need to capture this feature in indicator sets to determine whether or not there is too much, or too little, diversity.

2.4. Nonlinearity

Nonlinearity is defined by the disproportionality between inputs and outputs, unexpected outcomes, or multiple equilibria [92–94]. Studies have linked the outcome of feedbacks between variables [95,96] and other factors, including emergence [97,98]. These nonlinear outcomes can result in sharp transitions over thresholds, and ultimately regime shifts (i.e., large, abrupt, and persistent changes in the structure and function of a system) [99–101]. Despite this understanding, the underlying assumptions behind most sustainable development indicators are that the phenomena they are measuring are linear.

Measurements or indicators currently used to observe nonlinearity include flickering (i.e., a period of instability before a regime shift occurs [102]), critical slowing down or increasing variance and autocorrelation, and recovery or return rate [103–105]. Because these variables generally require complex modelling, long term data, or both, and are therefore not immediately operable, we focused on the presence of stated or known thresholds in proposed indicators. These thresholds included any indicators with a defined limit or thresholds, as well as indicators for which we know existing approaches to define thresholds, e.g., the planetary boundary framework, ecological reserves, and limits [106–108]. We also use approaches that define minimum societal or individual requirements for development, such as the safe and just operating space [73,109,110].

2.5. Cross-Scales Dynamics

Recognizing the critical importance of feedbacks between social and ecological systems, SES research also highlights the multi- and cross-scale nature of these intertwined SES connections and feedbacks across time and space [41,111,112]. Studies on these dynamics have highlighted the importance of biophysical teleconnections and social-ecological telecouplings that link transboundary as well as far distant systems to each other [15,113,114]. Similarly, temporal links such as legacy effects, path dependencies, and time lags are the impact of prior actions, processes, natural phenomena, or other circumstances on later conditions and the (often delayed) time it takes for that impact to manifest [41,115]. Determining these cross-scale impacts is a difficult, but essential, task for sustainable development monitoring [12]. Such monitoring requires multi-scalar and multi-decadal data, or models where data are not available [105,116]. As the current indicator set is proposed for national and global reporting (although problematic for capturing cross-scale feedbacks), we focus here on the temporal cross-scale aspects of monitoring and come back to spatial scale in the recommendations. From a review of SDG indicators, little is mentioned regarding temporal dynamics, and so we rather focus on exploring whether indicators are based on time series data, with more than 10 years of data available. While most of the temporal dynamics can be modelled in cases where relationships between

variables are known [105,117], time series data can be used to establish relationships, which were previously unknown, by observing how variables vary together.

3. Results

Figure 1 summarizes the proportion of the 243 indicators assessed in our analysis. Appendix A provides the details about how each individual indicator scored across each feature. The feature of heterogeneity was found to be best represented by the SDG indicators assessed (59% of indicators). Indicators included those that track differences in social groups, differences in economic sectors, and diversity of components (e.g., genetic diversity). We found 33% indicators that have the potential to monitor the cross-scale (temporal) feature based on data availability for 10 or more years. The remaining SES features were accounted for in roughly the same percentages of indicators, with 23% of the indicators capturing nonlinearities through some form of thresholds, and 18% and 17% depicting social-ecological interactions and resilience, respectively. Apart from the indicators of social-ecological feedbacks (18%), the majority of the indicators aligning with the remaining four features were social indicators. Overall, more than 70% of the SDG indicators are social indicators. The five different features were not captured equally across goals (Figure 2). Resilience was missing in five goals (1, 3, 7, 8, and 9), and feedbacks were missing in four goals (5, 10, 16, and 17). The rest of the features were represented across almost all the goals, and heterogeneity was captured in all goals. Below we expand on the findings for each of the features.

Social-ecological feedbacks. Indicators of potential social-ecological feedbacks are featured in most goals (Figure 2), and cover the topics of land use, natural disasters, and expenditure on conservation, waste management, and sustainable use of natural resources, among other areas. They included a mix of ecosystem-to-society and society-to-ecosystem flows, such as changes in water use efficiency (Goal 6, indicator 6.4.1) and material footprint per capita (Goal 8, indicators 8.4.1 and 8.4.2). They also included both material and nonmaterial flows, such as collection of waste in cities (Goal 11, indicator 11.6.1) and total expenditure on conservation (Goal 11, indicator 11.4.1). There were also indicators that captured actual feedbacks, e.g., mortality rate attributed to household and ambient air pollution (Goal 3, indicator 3.9.1).

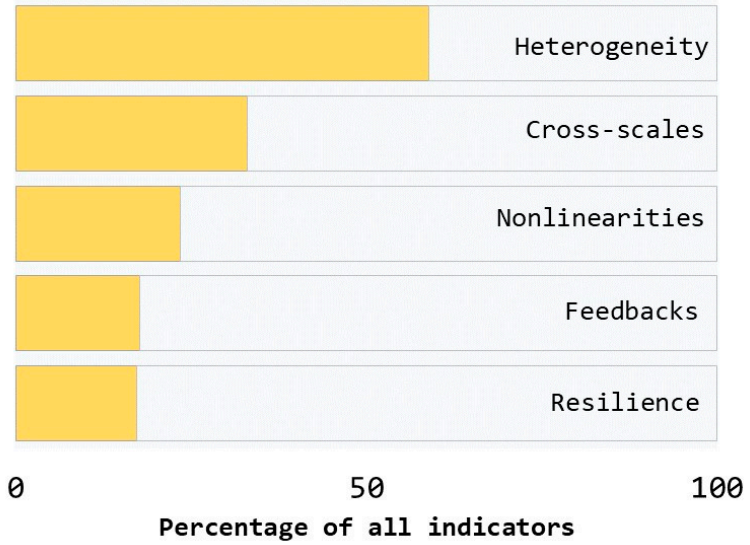

Figure 1. The percentage of SDG indicators analyzed that captured each of the five social-ecological features evaluated in this paper.

Resilience. Indicators of resilience capacities were in 12 of the 17 goals. All but 2 of the 42 indicators that captured resilience capacities were social indicators. They were mainly concerned with laws and policies to increase the enforcement of national and international laws, to increase public participation

in decision making, and to coordinate development assistance. For example, the number of countries reported progress in multi-stakeholder development effectiveness (e.g., Goal 13, indicator 13.3.1), monitoring frameworks that support the achievement of the sustainable development goals (Goal 17, indicator 17.16.1), or the proportion of transboundary basin area with an operational arrangement for water cooperation (Goal 6, indicator 6.5.2). Overall, governance aspects of resilience were spread across all but 5 goals (Figure 2). Most of the governance indicators come from Goal 17, which is about commitment to global partnership and cooperation.

Heterogeneity. Indicators that captured the feature of heterogeneity were related to indicators in 12 goals that differentiated between a phenomenon by type or proportion. The bulk of these (81%, 117 indicators) comprised social indicators (e.g., Goal 1, indicator 1.1.1: Proportion of population below the international poverty line by sex, age, employment status, and geographical location) primarily used by development agencies, where it is important to specify the targeted beneficiaries of different interventions. Of the remaining indicators, 15% were social-ecological indicators (e.g., Goal 11, indicator 11.3.1: Ratio of land consumption rate to population growth rate), and fewer still (4%) were ecological indicators (e.g., Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type).

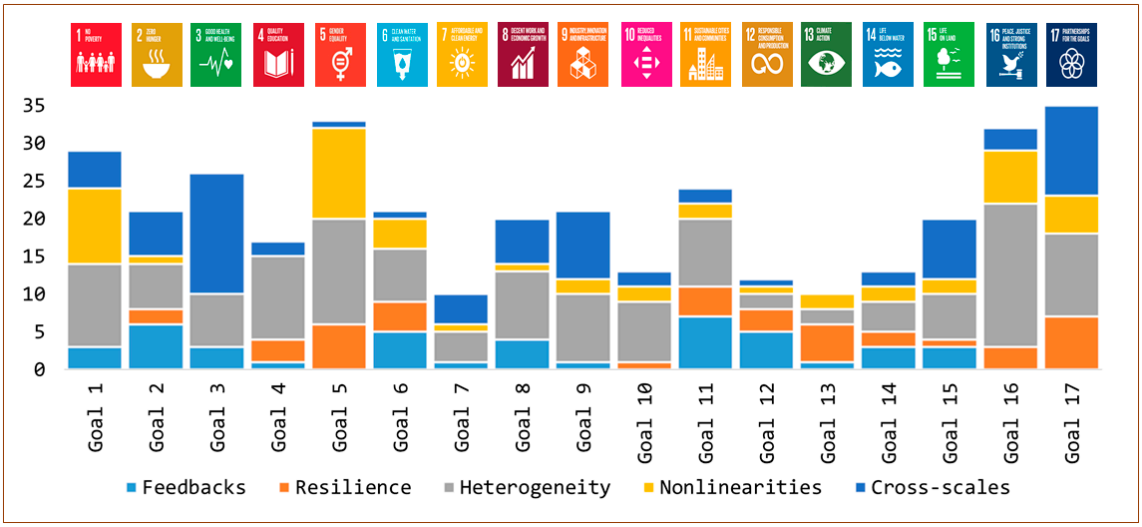

Figure 2. Degree to which indicators under each of the 17 SDGs capture each of the five key features of social-ecological systems dynamics assessed in this paper.

Nonlinearities. Goals 3 and 4 are the only two of the 17 goals which did not have indicators with thresholds in them. These indicators primarily captured social, ecological, and social-ecological thresholds. While there were indicators with clear thresholds, such as the poverty line, other indicators did not explicitly state thresholds, but alluded to those defined elsewhere (e.g., the just space and the planetary boundary frameworks, which are threshold based frameworks) [107,109]. Others still, such as Indicator 12.3.1: Global food loss index, do not have a clearly defined threshold, but clearly alludes to undesired outcomes in the food system and were included.

Cross-scale dynamics (temporal). Of the 80 indicators with more than 10 years of reported data, over half have more than 25 years of reported data. These are mostly social indicators that have been reported for decades, such as the proportion of population below the poverty line. However, there were several ecological and social-ecological indicators too. Long term ecological indicators were primarily linked to protection and protected areas—e.g., Goal 15, Indicator 15.5.1: Red List Index, which is available for 37 years. There were also social-ecological indicators, e.g., Level of water stress: Freshwater withdrawal as a proportion of available freshwater resources (Goal 6, Indicator 6.4.2), which has been reported for the last 56 years. While these indicators did not convey information about

temporal feedbacks, they fulfilled the minimum requirements to achieve this goal by existing over long periods, and therefore were available for temporal analyses and reporting.

4. Discussion

Moving from systems to complex adaptive systems approaches to account for the current hyper-connected, complex, and uncertain global context is proving popular across a number of domains, including sustainable development [22,40]. Complex social-ecological system research provides a useful lens for analysis in moving towards more dynamic and systemic monitoring systems. Key features of social-ecological systems such as feedbacks, non-linearities, and resilience are not easy to operationalize [118,119]. However, our findings highlight that there are areas of progress in making these features practical for sustainability monitoring. They also point to areas of sustainable development with relatively few current indicators capturing the key SES features, where future focus in SES theory development and their approaches could assist (Figures 1 and 2). Below we explore areas of progress, as well as areas where progress is not apparent, to provide recommendations for SDG monitoring with a focus on current indicators, as well as future iterations of the SDGs.

4.1. Social-Ecological System (SES) Dynamic Features: Current Progress, Gaps, and Future Directions

4.1.1. Heterogeneity

Our evaluation suggests that some of the features of SES are easier to operationalize for monitoring than others. Heterogeneity, which we analyze using diversity, multidimensionality, and disaggregation measures, was captured by most indicators (59%). Almost all of these indicators particularly captured disaggregation aspects of heterogeneity, which mostly differentiates between age groups, gender, income, type of sector, and other socioeconomic differentiations, and have been highlighted as essential in Agenda 2030 to "leave no one behind" [71,120–122]. Progress in methods for disaggregation of data has been rapid and serves a strong foundation for a complex systems approach to monitoring at local to global scales (e.g., [27]). These approaches have been found to highlight power relations, conflicts, and trade-offs, as well as impacts that can potentially reinforce poverty [83,123]. Multidimensionality was not very prevalent, but an increasing focus in research on poverty, equity, and human wellbeing as multidimensional could help to address the lack of such indicators currently proposed in the SDGs [73,91]. However, the paucity of ecological indicators, and especially indicators of ecological diversity in the SDG indicator set, is a limitation. The wide range of research and data on this topic offers potential to rapidly close this gap [67,124,125]. Considering the evidence of the role of enhanced diversity in sustainability and resilience outcomes, a key recommendation would be to focus indicator development on capturing diversity in social, ecological, and social-ecological variables. Research on functional and response diversity highlights this importance and provides examples of potential indicators for use in current SDG monitoring, as well as future indicator development [126,127].

4.1.2. Cross-Scale Dynamics

Many indicators showed potential for capturing temporal dynamics due to the presence of time series data for those indicators (33% have at least 10-year time series). Most SDG indicators have existed for long periods of time, with some already starting in the 1940s following the formalization of international development and the subsequent establishment of institutions such as the United Nations, the World Bank, and the Food and Agriculture Organization. However, the existence of time series data does not mean that temporal dynamics will indeed be captured. This would require interactions between two or more factors to be established (for attribution), after which the relationship between them can be tracked overtime. It is also complicated by questions of what length of time is 'long enough' to capture effects [128] and assumptions of how to capture impacts [129]. This raises questions around the fit-for-purpose nature of the time series data available, suggesting the need for new datasets as well as new technologies able to model such data where it is missing. The focus on capturing and avoiding

or negotiating trade-offs between SDGs is a major focus of current attention. Complex SES approaches emphasize the need to be able to make such trade-offs clear, not just between SDGs, but also over time and space to reveal hidden trade-offs. The availability of time series data, combined with recent advances in modelling, is increasingly making it possible to reveal temporal dynamics such as legacy effects and time lags [10,105,117,130]. When combined with scenario models and assessments, these indicators also provide an opportunity of exploring future consequences and dynamics and should be a focus of future monitoring efforts. While not explored in this analysis, the challenge of spatial cross-scale dynamics must also be highlighted. Currently, the focus is on national and global indicators, which will not be sufficient to highlight important cross-scale feedbacks and trade-offs within and between SDGs. This is especially important to explore important aspects, including teleconnections, surprise, and cascading effects that tend to dominate in poverty contexts [1,100,131]. New techniques and datasets present opportunities to capture this interplay between ecosystems and societies at multiple scales (see review in [22,132]).

4.1.3. Nonlinearities

Not many current SDG indicators captured nonlinearities, which we assessed by evaluating the presence of thresholds relating to social, ecological, and social-ecological systems within the indicators. Those that did capture thresholds focused primarily on social thresholds as minimum standards, above which people should be lifted [133]. Even within these indicators, and across all SDG indicators, lie assumptions of linear (and infinite) improvements (Figure 1), a major gap in SDG monitoring efforts. Furthermore, while the research and datasets for thresholds and non-linear effects are still relatively new and under development [99,106,107], some potential for improvement lies in several SDG indicators that use data, or variables, in which thresholds are known or predicted [106,107]—for example, use of nitrogen and phosphorus in agricultural systems [52,53]. This presents an opportunity to link these indicators to thresholds in the monitoring and reporting processes. Wilcock et al., 2016 in their review of the non-linear aspects of complex systems also highlight the challenges posed by current global indicators and the lack of early warning systems [134]. They point to hybrid models as a way to generate understanding of system trade-offs associated with non-linearities, an avenue that could be explored to prepare for post-2030 monitoring systems.

4.1.4. Social-Ecological Feedbacks

The paucity of SDG indicators that capture social-ecological feedbacks (18%) is a cause for concern. Advances in capturing them are already available from multiple areas of study, including ecosystem services [135–138], social-ecological metabolism [45,139,140], and many other human-nature frameworks [141,142], highlighting their importance to many fields of study [47,143,144]. It is a key requirement to capture the effects of ecosystem change on human wellbeing, and the resultant consequences of changes in wellbeing for ecosystems. Feedbacks are at the core of an SES approach to monitoring—both as a cause of features, such as non-linearities, temporal dynamics, and resilience capacities, and also as a consequence of system changes with strong roles in trade-offs, especially important in spatial and temporal cross-scale trade-offs [145]. An SDG monitoring system needs to, therefore, be designed to capture key feedbacks, as well as be able to account for unknown and unpredictable feedbacks as they emerge. New approaches that are able to conceptualize and analyze the system in a more integrated fashion, or at a macro-level scale, offer some promise (e.g., [146,147]).

4.1.5. Resilience

The topic of resilience and resilience indicators are a focus of much research and policy efforts. However, fewer efforts are targeted at the notion of resilience as a system property shaped by, and shaping, the SES features [148]. Our analysis here focused mostly on resilience as it related to system governance and management, while resilience of the system has been shown to be strongly reliant on the other features listed here, e.g., feedbacks and diversity. The low numbers of indicators

capturing resilience of governance and management of systems is possibly due to the challenge of quantifying these factors [56,62] and their context-specific nature. However, progress in the monitoring of management effectiveness and governance suggest indicators for use [56]. Research on resilience has especially highlighted the need to foster complex systems approaches and learning [43,63,149] within the governance and management of social-ecological systems. This extends to their use in the development of SDG monitoring systems and could well prove useful as nation states implement and tailor the SDGs and their indicators for use in their contexts [150–152]. Furthermore, new research on absorptive, adaptive, and especially transformative capacities [153–155] offer useful avenues for indicator development. This research has also highlighted the differences between these capacities, suggesting the need for indicators that track each separately rather than assuming that higher levels of adaptive capacity are also good for transformative change [153–155].

4.2. Moving towards Dynamic System Indicators for Sustainable Development

For sustainability to be truly achieved, systems need to be understood not only in terms of the connections among the different components within them, but also the dynamic character of these connections [44](). In addition to biophysical feedbacks and thresholds [106,107], social feedbacks and thresholds [73,156], it is also important to understand thresholds resulting from the interactions between social and ecological systems [157,158]. It is crucial to distil how social and economic targets (such as ending poverty or increasing GDP) primarily affect, and are affected by, ecological targets (such as life on land and life under water). This is akin to observing 'shadow effects' where social indicators have 'ecological shadows' and vice versa. With limited social-ecological feedbacks and nonlinearities captured in the SDG (Figure 2), there is a possibility that warning of important tipping points will be missed that could have profound consequences. A future focus on the social-ecological nature of systems and systems changes, as well as an acknowledgement of the importance of heterogeneity within and between systems, is key to future efforts to track and adaptively manage sustainable development.

Indicators. Just under 40% of the indicators are conceptually clear, have internationally established methodology and standards, and data regularly produced by countries (UN 2017). The reliance on existing conventional data and indicators will not be sufficient to effectively monitor sustainable development [159]. There are too many individual indicators with no clear indication of what the 'combined outcome' of all SDGs will look like [33,36]. This will likely result in uncoordinated and disparate monitoring of indicators, which creates a monitoring burden and often results in silos of implementation [160,161]. To deal with this proliferation problem, it has been suggested to focus on 'essential' variables for SDGs that are indispensable and capture the system's essence, coordination areas, and system transformation [21]. Such forms of indicators focus on the macro level, where sustainability and other system outcomes are realized, rather than the reductionist separation at the micro level, from which such emergence will not be visible. Systems level indicators will be integral to wider monitoring efforts, and in combination with other indicators, should give an indication of the general trajectory of the system as a whole [162].

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Appendix A

Table A1. Sustainable Development Goal indicators and classification across Social-Ecological System features.

		Feedbacks			Resilience			Heterogeneity		Nonlinearity		Cross-Scale Dynamics
Goal	**Indicators**	**Social**	**Ecological**	**Social Ecological**	**Learning**	**Governance**	**Participation**	**Diversity**	**Disaggregation**	**Multi-Dimension**	**Ecological Thresholds**	**Social Thresholds**	**Years**
1	1.1.1. Proportion of population below the international poverty line, by sex, age, employment status, and geographical location (urban/rural)	1	0	0	0	0	0	0	1	0	0	1	27
1	1.2.1. Proportion of population living below the national poverty line, by sex and age	1	0	0	0	0	0	0	1	0	0	1	32
1	1.2.2. Proportion of men, women, and children of all ages living in poverty in all its dimensions according to national definitions	1	0	0	0	0	0	0	1	0	0	1	0
1	1.3.1. Proportion of population covered by social protection floors/systems, by sex, distinguishing children, unemployed persons, older persons, persons with disabilities, pregnant women, newborns, work-injury victims, and the poor and the vulnerable	1	0	0	0	0	0	0	1	0	0	1	0
1	1.4.1. Proportion of population living in households with access to basic services	1	0	0	0	0	0	0	1	1	0	1	0
1	1.4.2. Proportion of total adult population with secure tenure rights to land, with legally recognized documentation and who perceive their rights to land as secure, by sex and by type of tenure	0	0	1	0	0	0	0	1	0	0	1	0
1	1.5.1. Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population	0	0	1	0	0	0	0	0	0	0	0	0
1	1.5.2. Direct economic loss attributed to disasters in relation to global gross domestic product (GDP)	0	0	1	0	0	0	0	0	0	0	0	0
1	1.5.3. Number of countries that adopt and implement national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015–2030	1	0	0	0	0	0	0	0	0	0	0	10
1	1.5.4. Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies	1	0	0	0	0	0	0	1	0	0	0	0

Table A1. *Cont.*

		Feedbacks			Resilience			Heterogeneity			Nonlinearity		Cross-Scale Dynamics
Goal	**Indicators**	**Social**	**Ecological**	**Social Ecological**	**Learning**	**Governance**	**Participation**	**Diversity**	**Disaggregation**	**Multi-Dimension**	**Ecological Thresholds**	**Social Thresholds**	**Years**
1	1.a.1. Proportion of domestically generated resources allocated by the government directly to poverty reduction programs	1	0	0	0	0	0	0	1	0	0	1	0
1	1.a.2. Proportion of total government spending on essential services (education, health, and social protection)	1	0	0	0	0	0	0	1	0	0	1	0
1	1.a.3. Sum of total grants and non-debt-creating inflows directly allocated to poverty reduction programs as a proportion of GDP	1	0	0	0	0	0	0	1	0	0	1	0
1	1.b.1. Proportion of government recurrent and capital spending to sectors that disproportionately benefit women, the poor, and vulnerable groups	1	0	0	0	0	0	0	1	0	0	1	0
2	2.1.1. Prevalence of undernourishment	1	0	0	0	0	0	0	0	0	0	0	18
2	2.1.2. Prevalence of moderate or severe food insecurity in the population, based on the Food Insecurity Experience Scale (FIES)	1	0	0	0	0	0	0	0	1	0	1	3
2	2.2.1. Prevalence of stunting (height for age <−2 standard deviations from the median of the World Health Organization (WHO) Child Growth Standards) among children under 5 years of age	1	0	0	0	0	0	0	0	0	0	0	27
2	2.2.2. Prevalence of malnutrition (weight for height >+2 or <−2 standard deviation from the median of the WHO Child Growth Standards) among children under 5 years of age, by type (wasting and overweight)	1	0	0	0	0	0	0	1	0	0	0	27
2	2.3.1. Volume of production per labor unit by classes of farming/pastoral/forestry enterprise size	0	0	1	0	0	0	0	1	0	0	0	0
2	2.3.2. Average income of small-scale food producers, by sex and indigenous status	0	0	1	0	0	0	0	1	0	0	0	0
2	2.4.1. Proportion of agricultural area under productive and sustainable agriculture	0	0	1	0	0	0	0	1	0	0	0	0
2	2.5.1. Number of plant and animal genetic resources for food and agriculture secured in either medium- or long-term conservation facilities	0	0	1	1	0	0	0	1	0	0	0	3
2	2.5.2. Proportion of local breeds classified as being at risk, not at risk, or at unknown level of risk of extinction	0	0	1	0	0	0	1	1	0	0	0	24

Table A1. *Cont.*

		Feedbacks			Resilience			Heterogeneity			Nonlinearity		Cross-Scale Dynamics
Goal	**Indicators**	**Social**	**Ecological**	**Social Ecological**	**Learning**	**Governance**	**Participation**	**Diversity**	**Disaggregation**	**Multi-Dimension**	**Ecological Thresholds**	**Social Thresholds**	**Years**
2	2.a.1. The agriculture orientation index for government expenditures	1	0	0	1	0	0	0	0	0	0	0	0
2	2.a.2. Total official flows (official development assistance plus other official flows) to the agriculture sector	1	0	0	0	0	0	0	0	0	0	0	44
2	2.b.1. Agricultural export subsidies	0	0	1	0	0	0	0	0	0	0	0	22
2	2.c.1. Indicator of food price anomalies	1	0	0	0	0	0	0	0	0	0	0	0
3	3.1.1. Maternal mortality ratio	1	0	0	0	0	0	0	0	0	0	0	27
3	3.1.2. Proportion of births attended by skilled health personnel	1	0	0	0	0	0	0	1	0	0	0	27
3	3.2.1. Under-5 mortality rate	1	0	0	0	0	0	0	0	0	0	0	27
3	3.2.2 Neonatal mortality rate	1	0	0	0	0	0	0	0	0	0	0	27
3	3.3.1 Number of new HIV infections per 1000 uninfected population, by sex, age, and key populations	1	0	0	0	0	0	0	1	0	0	0	0
3	3.3.2. Tuberculosis incidence per 100,000 population	1	0	0	0	0	0	0	0	0	0	0	17
3	3.3.3. Malaria incidence per 1000 population	0	0	1	0	0	0	0	0	0	0	0	17
3	3.3.4. Hepatitis B incidence per 100,000 population	1	0	0	0	0	0	0	0	0	0	0	0
3	3.3.5. Number of people requiring interventions against neglected tropical diseases	1	0	0	0	0	0	0	0	0	0	0	17
3	3.4.1. Mortality rate attributed to cardiovascular disease, cancer, diabetes, or chronic respiratory disease	1	0	0	0	0	0	0	0	0	0	0	17
3	3.4.2. Suicide mortality rate	1	0	0	0	0	0	0	0	0	0	0	17
3	3.5.1. Coverage of treatment interventions (pharmacological, psychosocial and rehabilitation and aftercare services) for substance use disorders	1	0	0	0	0	0	0	0	0	0	0	0
3	3.5.2. Harmful use of alcohol, defined according to the national context as alcohol per capita consumption (aged 15 years and older) within a calendar year in liters of pure alcohol	1	0	0	0	0	0	0	0	0	0	0	12
3	3.6.1. Death rate due to road traffic injuries	1	0	0	0	0	0	0	0	0	0	0	17

Table A1. *Cont.*

		Feedbacks			Resilience			Heterogeneity			Nonlinearity		Cross-Scale Dynamics
Goal	**Indicators**	**Social**	**Ecological**	**Social Ecological**	**Learning**	**Governance**	**Participation**	**Diversity**	**Disaggregation**	**Multi-Dimension**	**Ecological Thresholds**	**Social Thresholds**	**Years**
3	3.7.1. Proportion of women of reproductive age (aged 15–49 years) who have their need for family planning satisfied with modern methods	1	0	0	0	0	0	0	1	0	0	0	17
3	3.7.2. Adolescent birth rate (aged 10–14 years; aged 15–19 years) per 1000 women in that age group	1	0	0	0	0	0	0	1	0	0	0	0
3	3.8.1. Coverage of essential health services (defined as the average coverage of essential services based on tracer interventions that include reproductive, maternal, newborn and child health, infectious diseases, non-communicable diseases and service capacity and access, among the general and the most disadvantaged population)	1	0	0	0	0	0	0	0	1	0	0	0
3	3.8.2. Proportion of population with large household expenditures on health as a share of total household expenditure or income	1	0	0	0	0	0	0	1	0	0	0	0
3	3.9.1. Mortality rate attributed to household and ambient air pollution	0	0	1	0	0	0	0	0	0	0	0	27
3	3.9.2. Mortality rate attributed to unsafe water, unsafe sanitation and lack of hygiene (exposure to unsafe Water, Sanitation and Hygiene for All (WASH) services)	0	0	1	0	0	0	0	0	0	0	0	5
3	3.9.3. Mortality rate attributed to unintentional poisoning	1	0	0	0	0	0	0	0	0	0	0	5
3	3.a.1. Age-standardized prevalence of current tobacco use among persons aged 15 years and older	1	0	0	0	0	0	0	0	0	0	0	17
3	3.b.1. Proportion of the target population covered by all vaccines included in their national program	1	0	0	0	0	0	0	1	0	0	0	0
3	3.b.2. Total net official development assistance to medical research and basic health sectors	1	0	0	0	0	0	0	0	0	0	0	44
3	3.b.3. Proportion of health facilities that have a core set of relevant essential medicines available and affordable on a sustainable basis	1	0	0	0	0	0	0	1	0	0	0	0
3	3.c.1. Health worker density and distribution	1	0	0	0	0	0	0	0	0	0	0	17
3	3.d.1. International Health Regulations (IHR) capacity and health emergency preparedness	1	0	0	0	0	0	0	0	0	0	0	1

Table A1. *Cont.*

		Feedbacks			Resilience			Heterogeneity			Nonlinearity		Cross-Scale Dynamics
Goal	**Indicators**	**Social**	**Ecological**	**Social Ecological**	**Learning**	**Governance**	**Participation**	**Diversity**	**Disaggregation**	**Multi-Dimension**	**Ecological Thresholds**	**Social Thresholds**	**Years**
4	4.1.1. Proportion of children and young people (a) in grades 2/3; (b) at the end of primary; and (c) at the end of lower secondary achieving at least a minimum proficiency level in (i) reading and (ii) mathematics, by sex	1	0	0	0	0	0	0	1	0	0	0	7
4	4.2.1. Proportion of children under 5 years of age who are developmentally on track in health, learning and psychosocial well-being, by sex	1	0	0	0	0	0	0	1	0	0	0	0
4	4.2.2. Participation rate in organized learning (one year before the official primary entry age), by sex	1	0	0	0	0	0	0	1	0	0	0	19
4	4.3.1 Participation rate of youth and adults in formal and non-formal education and training in the previous 12 months, by sex	1	0	0	0	0	0	0	1	0	0	0	0
4	4.4.1. Proportion of youth and adults with information and communications technology (ICT) skills, by type of skill	1	0	0	0	0	0	0	1	1	0	0	0
4	4.5.1. Parity indices (female/male, rural/urban, bottom/top wealth quintile and others such as disability status, indigenous peoples and conflict-affected, as data become available) for all education indicators on this list that can be disaggregated	1	0	0	0	0	0	0	1	0	0	0	0
4	4.6.1. Proportion of population in a given age group achieving at least a fixed level of proficiency in functional (a) literacy and (b) numeracy skills, by sex	1	0	0	0	0	0	0	1	0	0	0	0
4	4.7.1. Extent to which (i) global citizenship education and (ii) education for sustainable development, including gender equality and human rights, are mainstreamed at all levels in (a) national education policies; (b) curricula; (c) teacher education; and (d) student assessment	1	0	0	1	0	0	0	1	0	0	0	0
4	4.a.1. Proportion of schools with access to (a) electricity; (b) the Internet for pedagogical purposes; (c) computers for pedagogical purposes; (d) adapted infrastructure and materials for students with disabilities; (e) basic drinking water; (f) single-sex basic sanitation facilities; and (g) basic handwashing facilities (as per the WASH indicator definitions)	0	0	1	0	0	0	0	1	1	0	0	0

Table A1. *Cont.*

		Feedbacks			Resilience			Heterogeneity			Nonlinearity		Cross-Scale Dynamics
Goal	**Indicators**	**Social**	**Ecological**	**Social Ecological**	**Learning**	**Governance**	**Participation**	**Diversity**	**Disaggregation**	**Multi-Dimension**	**Ecological Thresholds**	**Social Thresholds**	**Years**
4	4.b.1. Volume of official development assistance flows for scholarships by sector and type of study	1	0	0	1	0	0	0	1	1	0	0	7
4	4.c.1. Proportion of teachers in: (a) pre-primary; (b) primary; (c) lower secondary; and (d) upper secondary education who have received at least the minimum organized teacher training (e.g., pedagogical training), pre-service or in-service, required for teaching at the relevant level in a given country	1	0	0	1	0	0	0	1	0	0	0	0
5	5.1.1. Whether or not legal frameworks are in place to promote, enforce, and monitor equality and non-discrimination on the basis of sex	1	0	0	0	1	0	0	1	0	0	1	0
5	5.2.1. Proportion of ever-partnered women and girls aged 15 years and older subjected to physical, sexual, or psychological violence by a current or former intimate partner in the previous 12 months, by form of violence and by age	1	0	0	0	0	0	1	1	1	0	1	0
5	5.2.2. Proportion of women and girls aged 15 years and older subjected to sexual violence by persons other than an intimate partner in the previous 12 months, by age and place of occurrence	1	0	0	0	0	0	0	1	0	0	1	0
5	5.3.1. Proportion of women aged 20–24 years who were married or in a union before age 15 and before age 18	1	0	0	0	0	0	0	1	0	0	1	0
5	5.3.2. Proportion of girls and women aged 15–49 years who have undergone female genital mutilation/cutting, by age	1	0	0	0	0	0	0	1	0	0	1	0
5	5.4.1. Proportion of time spent on unpaid domestic and care work, by sex, age, and location	1	0	0	0	0	0	0	1	0	0	0	0
5	5.5.1. Proportion of seats held by women in (a) national parliaments and (b) local governments	1	0	0	0	1	1	0	1	0	0	1	0
5	5.5.2. Proportion of women in managerial positions	1	0	0	0	1	1	0	1	0	0	1	12
5	5.6.1. Proportion of women aged 15–49 years who make their own informed decisions regarding sexual relations, contraceptive use, and reproductive health care	1	0	0	0	0	0	0	1	0	0	1	0

Table A1. *Cont.*

		Feedbacks			Resilience			Heterogeneity			Nonlinearity		Cross-Scale Dynamics
Goal	**Indicators**	**Social**	**Ecological**	**Social Ecological**	**Learning**	**Governance**	**Participation**	**Diversity**	**Disaggregation**	**Multi-Dimension**	**Ecological Thresholds**	**Social Thresholds**	**Years**
5	5.6.2 Number of countries with laws and regulations that guarantee full and equal access to women and men aged 15 years and older to sexual and reproductive health care, information, and education	1	0	0	0	1	0	0	1	0	0	1	0
5	5.a.1. (a) Proportion of total agricultural population with ownership or secure rights over agricultural land, by sex; and (b) share of women among owners or rights-bearers of agricultural land, by type of tenure	1	0	0	0	0	0	0	1	0	0	1	0
5	5.a.2. Proportion of countries where the legal framework (including customary law) guarantees women's equal rights to land ownership and/or control	1	0	0	0	1	1	0	1	0	0	1	0
5	5.b.1. Proportion of individuals who own a mobile telephone, by sex	1	0	0	0	0	0	0	1	0	0	0	4
5	5.c.1. Proportion of countries with systems to track and make public allocations for gender equality and women's empowerment	1	0	0	0	1	0	0	1	0	0	1	0
6	6.1.1. Proportion of population using safely managed drinking water services	0	0	1	0	0	0	0	1	0	0	1	0
6	6.2.1. Proportion of population using safely managed sanitation services, including a hand-washing facility with soap and water	0	0	1	0	0	0	0	1	0	0	1	0
6	6.3.1. Proportion of wastewater safely treated	0	0	1	0	0	0	0	1	0	0	0	0
6	6.3.2. Proportion of bodies of water with good ambient water quality	0	1	0	0	0	0	0	1	0	1	0	0
6	6.4.1. Change in water-use efficiency over time	0	0	1	0	0	0	0	0	0	1	0	0
6	6.4.2. Level of water stress: freshwater withdrawal as a proportion of available freshwater resources	0	0	1	0	0	0	0	1	0	1	0	56
6	6.5.1. Degree of integrated water resources management implementation (0–100)	1	0	0	0	1	0	0	0	0	0	0	9
6	6.5.2. Proportion of transboundary basin area with an operational arrangement for water cooperation	1	0	0	0	1	0	0	1	0	0	0	0
6	6.6.1. Change in the extent of water-related ecosystems over time	0	1	0	0	0	0	0	0	0	1	0	0
6	6.a.1. Amount of water- and sanitation-related official development assistance that is part of a government-coordinated spending plan	1	0	0	0	1	0	0	0	0	0	0	9

Table A1. *Cont.*

		Feedbacks			Resilience			Heterogeneity			Nonlinearity		Cross-Scale Dynamics
Goal	**Indicators**	**Social**	**Ecological**	**Social Ecological**	**Learning**	**Governance**	**Participation**	**Diversity**	**Disaggregation**	**Multi-Dimension**	**Ecological Thresholds**	**Social Thresholds**	**Years**
6	6.b.1. Proportion of local administrative units with established and operational policies and procedures for participation of local communities in water and sanitation management	1	0	0	0	1	1	0	1	0	0	0	9
7	7.1.1. Proportion of population with access to electricity	1	0	0	0	0	0	0	1	0	0	1	27
7	7.1.2. Proportion of population with primary reliance on clean fuels and technology	1	0	0	0	0	0	0	1	0	0	0	37
7	7.2.1. Renewable energy share in the total final energy consumption	0	0	1	0	0	0	0	1	0	0	0	27
7	7.3.1. Energy intensity measured in terms of primary energy and GDP	1	0	0	0	0	0	0	0	0	0	0	27
7	7.a.1. International financial flows to developing countries in support of clean energy research and development and renewable energy production, including in hybrid systems	1	0	0	0	0	0	0	0	0	0	0	0
7	7.b.1. Investments in energy efficiency as a proportion of GDP and the amount of foreign direct investment in financial transfer for infrastructure and technology to sustainable development services	1	0	0	0	0	0	0	1	0	0	0	0
8	8.1.1. Annual growth rate of real GDP per capita	1	0	0	0	0	0	0	0	0	0	0	47
8	8.10.1. (a) Number of commercial bank branches per 100,000 adults and (b) number of automated teller machines (ATMs) per 100,000 adults	1	0	0	0	0	0	0	0	0	0	0	13
8	8.10.2. Proportion of adults (15 years and older) with an account at a bank or other financial institution or with a mobile-money-service provider	1	0	0	0	0	0	0	1	0	0	0	6
8	8.2.1. Annual growth rate of real GDP per employed person	1	0	0	0	0	0	0	0	0	0	0	26
8	8.4.1. Material footprint, material footprint per capita, and material footprint per GDP	0	0	1	0	0	0	0	0	0	0	0	0
8	8.4.2. Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP	0	0	1	0	0	0	0	0	0	0	0	47
8	8.5.1. Average hourly earnings of female and male employees, by occupation, age, and persons with disabilities	1	0	0	0	0	0	0	1	0	0	0	0

Table A1. *Cont.*

		Feedbacks			Resilience			Heterogeneity		Nonlinearity		Cross-Scale Dynamics
Goal	**Indicators**	**Social**	**Ecological**	**Social Ecological**	**Learning**	**Governance**	**Participation**	**Diversity**	**Disaggregation**	**Multi-Dimension**	**Ecological Thresholds**	**Social Thresholds**	**Years**
8	8.5.2. Unemployment rate, by sex, age, and persons with disabilities	1	0	0	0	0	0	0	1	0	0	0	8
8	8.6.1. Proportion of youth (aged 15–24 years) not in education, employment, or training	1	0	0	0	0	0	0	1	0	0	0	14
8	8.7.1. Proportion and number of children aged 5–17 years engaged in child labor, by sex and age	1	0	0	0	0	0	0	1	0	0	1	0
8	8.8.1. Frequency rates of fatal and non-fatal occupational injuries, by sex and migrant status	1	0	0	0	0	0	0	1	0	0	0	0
8	8.8.2. Level of national compliance with labor rights (freedom of association and collective bargaining) based on International Labor Organization (ILO) textual sources and national legislation, by sex and migrant status	1	0	0	0	0	0	0	1	0	0	0	0
8	8.9.1. Tourism direct GDP as a proportion of total GDP and in growth rate	0	0	1	0	0	0	0	1	0	0	0	0
8	8.9.2. Proportion of jobs in sustainable tourism industries out of total tourism jobs	0	0	1	0	0	0	0	1	0	0	0	0
8	8.a.1. Aid for Trade commitments and disbursements	1	0	0	0	0	0	0	0	0	0	0	15
8	8.b.1. Existence of a developed and operationalized national strategy for youth employment, as a distinct strategy or as part of a national employment strategy	1	0	0	0	0	0	0	0	0	0	0	0
9	9.1.1. Proportion of the rural population who live within 2 km of an all-season road	1	0	0	0	0	0	0	1	0	0	0	0
9	9.1.2. Passenger and freight volumes, by mode of transport	1	0	0	0	0	0	0	1	0	0	0	47
9	9.2.1. Manufacturing value added as a proportion of GDP and per capita	1	0	0	0	0	0	0	1	0	0	0	27
9	9.2.2. Manufacturing employment as a proportion of total employment	1	0	0	0	0	0	0	1	0	0	0	27
9	9.3.1. Proportion of small-scale industries in total industry value added	1	0	0	0	0	0	0	1	0	0	1	0
9	9.3.2. Proportion of small-scale industries with a loan or line of credit	1	0	0	0	0	0	0	1	0	0	1	0
9	9.4.1. CO_2 emission per unit of value added	0	0	1	0	0	0	0	0	0	1	0	27
9	9.5.1. Research and development expenditure as a proportion of GDP	1	0	0	0	0	0	0	1	0	0	0	36

Table A1. *Cont.*

		Feedbacks			Resilience			Heterogeneity			Nonlinearity		Cross-Scale Dynamics
Goal	**Indicators**	**Social**	**Ecological**	**Social Ecological**	**Learning**	**Governance**	**Participation**	**Diversity**	**Disaggregation**	**Multi-Dimension**	**Ecological Thresholds**	**Social Thresholds**	**Years**
9	9.5.2. Researchers (in full-time equivalent) per million inhabitants	1	0	0	0	0	0	0	0	0	0	0	36
9	9.a.1. Total official international support (official development assistance plus other official flows) to infrastructure	1	0	0	0	0	0	0	0	0	0	0	15
9	9.b.1. Proportion of medium and high-tech industry value added in total value added	1	0	0	0	0	0	0	1	0	0	0	27
9	9.c.1. Proportion of population covered by a mobile network, by technology	1	0	0	0	0	0	0	1	0	0	0	10
10	10.1.1. Growth rates of household expenditure or income per capita among the bottom 40 percent of the population and the total population	1	0	0	0	0	0	0	1	0	0	0	0
10	10.2.1. Proportion of people living below 50 percent of median income, by sex, age and persons with disabilities	1	0	0	0	0	0	0	1	0	0	0	0
10	10.3.1. Proportion of population reporting having personally felt discriminated against or harassed in the previous 12 months on the basis of a ground of discrimination prohibited under international human rights law	1	0	0	0	1	0	0	0	0	0	1	0
10	10.4.1. Labor share of GDP, comprising wages and social protection transfers	1	0	0	0	0	0	0	1	0	0	1	0
10	10.5.1. Financial Soundness Indicators	1	0	0	0	0	0	0	0	0	0	0	0
10	10.6.1. Proportion of members and voting rights of developing countries in international organizations	1	0	0	0	0	0	0	1	0	0	0	0
10	10.7.1. Recruitment cost borne by employee as a proportion of yearly income earned in country of destination	1	0	0	0	0	0	0	1	0	0	0	0
10	10.7.2. Number of countries that have implemented well-managed migration policies	1	0	0	0	0	0	0	0	0	0	0	0
10	10.a.1. Proportion of tariff lines applied to imports from least developed countries and developing countries with zero-tariff	1	0	0	0	0	0	0	1	0	0	0	12
10	10.b.1. Total resource flows for development, by recipient and donor countries and type of flow (e.g., official development assistance, foreign direct investment and other flows)	1	0	0	0	0	0	0	1	0	0	0	57
10	10.c.1. Remittance costs as a proportion of the amount remitted	1	0	0	0	0	0	0	1	0	0	0	0

Table A1. *Cont.*

		Feedbacks			Resilience			Heterogeneity			Nonlinearity		Cross-Scale Dynamics
Goal	**Indicators**	**Social**	**Ecological**	**Social Ecological**	**Learning**	**Governance**	**Participation**	**Diversity**	**Disaggregation**	**Multi-Dimension**	**Ecological Thresholds**	**Social Thresholds**	**Years**
11	11.1.1. Proportion of urban population living in slums, informal settlements, or inadequate housing	1	0	0	0	0	0	0	1	0	0	0	27
11	11.2.1. Proportion of population that has convenient access to public transport, by sex, age, and persons with disabilities	1	0	0	0	0	0	0	1	0	0	0	0
11	11.3.1. Ratio of land consumption rate to population growth rate	0	0	1	0	0	0	0	0	0	1	0	0
11	11.3.2. Proportion of cities with a direct participation structure of civil society in urban planning and management that operate regularly and democratically	1	0	0	0	1	1	0	1	0	0	0	0
11	11.4.1. Total expenditure (public and private) per capita spent on the preservation, protection, and conservation of all cultural and natural heritage, by type of heritage (cultural, natural, mixed and World Heritage Centre designation), level of government (national, regional and local/municipal), type of expenditure (operating expenditure/investment), and type of private funding (donations in kind, private non-profit sector and sponsorship)	1	0	1	0	1	0	1	0	1	0	0	0
11	11.5.1. Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population	0	0	1	0	0	0	0	0	0	0	0	0
11	11.5.2. Direct economic loss in relation to global GDP, damage to critical infrastructure and number of disruptions to basic services, attributed to disasters	0	0	1	0	0	0	0	0	0	0	0	27
11	11.6.1. Proportion of urban solid waste regularly collected and with adequate final discharge out of total urban solid waste generated, by cities	0	0	1	0	0	0	0	1	0	0	0	0
11	11.6.2. Annual mean levels of fine particulate matter (e.g., PM2.5 and PM10) in cities (population weighted)	0	0	1	0	0	0	0	0	0	1	0	9
11	11.7.1. Average share of the built-up area of cities that is open space for public use for all, by sex, age, and persons with disabilities	1	0	0	0	0	0	0	1	0	0	0	0
11	11.7.2. Proportion of persons victim of physical or sexual harassment, by sex, age, disability status, and place of occurrence, in the previous 12 months	1	0	0	0	0	0	0	1	0	0	0	0

Table A1. *Cont.*

		Feedbacks			Resilience			Heterogeneity			Nonlinearity		Cross-Scale Dynamics
Goal	**Indicators**	**Social**	**Ecological**	**Social Ecological**	**Learning**	**Governance**	**Participation**	**Diversity**	**Disaggregation**	**Multi-Dimension**	**Ecological Thresholds**	**Social Thresholds**	**Years**
11	11.a.1. Proportion of population living in cities that implement urban and regional development plans integrating population projections and resource needs, by size of city	0	0	1	0	0	0	0	1	0	0	0	0
11	11.b.1. Number of countries that adopt and implement national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015–2030	1	0	0	0	1	0	0	0	0	0	0	10
11	11.b.2. Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies	1	0	0	0	1	0	0	1	0	0	0	0
11	11.c.1. Proportion of financial support to the least developed countries that is allocated to the construction and retrofitting of sustainable, resilient, and resource-efficient buildings utilizing local materials	1	0	0	0	0	0	0	1	0	0	0	0
12	12.1.1. Number of countries with sustainable consumption and production (SCP) national action plans or SCP mainstreamed as a priority or a target into national policies	1	0	0	0	1	0	0	0	0	0	0	0
12	12.2.1. Material footprint, material footprint per capita, and material footprint per GDP	0	0	1	0	0	0	0	0	0	0	0	0
12	12.2.2. Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP	0	0	1	0	0	0	0	0	0	0	0	47
12	12.3.1. Global food loss index	0	0	1	0	0	0	0	0	0	0	0	0
12	12.4.1. Number of parties to international multilateral environmental agreements on hazardous waste, and other chemicals that meet their commitments and obligations in transmitting information as required by each relevant agreement	1	0	0	0	1	0	0	0	0	0	0	7
12	12.4.2. Hazardous waste generated per capita and proportion of hazardous waste treated, by type of treatment	0	0	1	0	0	0	0	1	0	1	0	0
12	12.5.1. National recycling rate, tons of material recycled	0	0	1	0	0	0	0	0	0	0	0	0
12	12.6.1. Number of companies publishing sustainability reports	1	0	0	0	0	0	0	0	0	0	0	0
12	12.7.1. Number of countries implementing sustainable public procurement policies and action plans	1	0	0	0	0	0	0	0	0	0	0	0

Table A1. *Cont.*

		Feedbacks			Resilience			Heterogeneity			Nonlinearity		Cross-Scale Dynamics
Goal	**Indicators**	**Social**	**Ecological**	**Social Ecological**	**Learning**	**Governance**	**Participation**	**Diversity**	**Disaggregation**	**Multi-Dimension**	**Ecological Thresholds**	**Social Thresholds**	**Years**
12	12.8.1. Extent to which (i) global citizenship education and (ii) education for sustainable development (including climate change education) are mainstreamed in (a) national education policies; (b) curricula; (c) teacher education; and (d) student assessment	1	0	0	1	0	0	1	0	0	0	0	0
12	12.a.1. Amount of support to developing countries on research and development for sustainable consumption and production and environmentally sound technologies	1	0	0	0	0	0	0	0	0	0	0	0
12	12.b.1. Number of sustainable tourism strategies or policies and implemented action plans with agreed monitoring and evaluation tools	1	0	0	0	0	0	0	0	0	0	0	0
12	12.c.1. Amount of fossil-fuel subsidies per unit of GDP (production and consumption) and as a proportion of total national expenditure on fossil fuels	1	0	0	0	0	0	0	1	0	0	0	0
13	13.1.1. Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population	0	0	1	0	0	0	0	0	0	0	0	0
13	13.1.2. Number of countries that adopt and implement national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015–2030	1	0	0	0	0	0	0	0	0	0	0	10
13	13.1.3. Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies	1	0	0	0	1	0	0	1	0	0	0	0
13	13.2.1. Number of countries that have communicated the establishment or operationalization of an integrated policy/strategy/plan, which increases their ability to adapt to the adverse impacts of climate change, and foster climate resilience and low greenhouse gas emissions development in a manner that does not threaten food production (including a national adaptation plan, nationally determined contribution, national communication, biennial update report, or other)	1	0	0	0	0	0	0	0	0	0	0	0
13	13.3.1. Number of countries that have integrated mitigation, adaptation, impact reduction and early warning into primary, secondary, and tertiary curricula	1	0	0	0	1	0	0	0	0	0	0	0

Table A1. *Cont.*

		Feedbacks			Resilience			Heterogeneity			Nonlinearity		Cross-Scale Dynamics
Goal	**Indicators**	**Social**	**Ecological**	**Social Ecological**	**Learning**	**Governance**	**Participation**	**Diversity**	**Disaggregation**	**Multi-Dimension**	**Ecological Thresholds**	**Social Thresholds**	**Years**
13	13.3.2. Number of countries that have communicated the strengthening of institutional, systemic, and individual capacity-building to implement adaptation, mitigation and technology transfer, and development actions	1	0	0	0	1	0	0	0	0	0	0	0
13	13.a.1. Mobilized amount of United States dollars per year between 2020 and 2025 accountable towards the $100 billion commitment	1	0	0	0	1	0	0	0	0	0	1	0
13	13.b.1. Number of least developed countries and small island developing States that are receiving specialized support, and amount of support, including finance, technology, and capacity-building for mechanisms in raising capacities for effective climate change-related planning and management, including focusing on women, youth, and local and marginalized communities	1	0	0	0	1	0	0	1	0	0	1	0
14	14.1.1. Index of coastal eutrophication and floating plastic debris density	0	0	1	0	0	0	0	0	0	1	0	0
14	14.2.1. Proportion of national exclusive economic zones managed using ecosystem-based approaches	0	0	1	0	0	0	0	1	0	0	0	0
14	14.3.1. Average marine acidity (pH) measured at agreed suite of representative sampling stations	0	1	0	0	0	0	0	0	0	0	0	0
14	14.4.1. Proportion of fish stocks within biologically sustainable levels	0	1	0	0	0	0	0	1	0	0	0	43
14	14.5.1. Coverage of protected areas in relation to marine areas	0	1	0	0	0	0	0	0	0	0	0	117
14	14.6.1. Progress by countries in the degree of implementation of international instruments aiming to combat illegal, unreported, and unregulated fishing	1	0	0	0	0	0	0	0	0	0	0	0
14	14.7.1. Sustainable fisheries as a proportion of GDP in small island developing States, least developed countries and all countries	0	0	1	0	0	0	0	1	0	0	0	0
14	14.a.1. Proportion of total research budget allocated to research in the field of marine technology	1	0	0	0	0	0	0	1	0	0	0	0

Table A1. *Cont.*

		Feedbacks			Resilience			Heterogeneity			Nonlinearity		Cross-Scale Dynamics
Goal	**Indicators**	**Social**	**Ecological**	**Social Ecological**	**Learning**	**Governance**	**Participation**	**Diversity**	**Disaggregation**	**Multi-Dimension**	**Ecological Thresholds**	**Social Thresholds**	**Years**
14	14.b.1. Progress by countries in the degree of application of a legal/regulatory/policy/institutional framework, which recognizes and protects access rights for small-scale fisheries	1	0	0	0	1	0	0	0	0	0	1	0
14	14.c.1. Number of countries making progress in ratifying, accepting, and implementing through legal, policy, and institutional frameworks, ocean-related instruments that implement international law, as reflected in the United Nations Convention on the Law of the Sea, for the conservation and sustainable use of the oceans and their resources	1	0	0	0	1	0	0	0	0	0	0	0
15	15.1.1. Forest area as a proportion of total land area	0	1	0	0	0	0	0	1	0	0	0	27
15	15.1.2. Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type	0	1	0	0	0	0	0	1	0	0	0	117
15	15.2.1. Progress towards sustainable forest management	0	1	0	0	0	0	0	0	0	0	0	27
15	15.3.1. Proportion of land that is degraded over total land area	0	1	0	0	0	0	0	1	0	0	0	0
15	15.4.1. Coverage by protected areas of important sites for mountain biodiversity	0	1	0	0	0	0	0	0	0	0	0	117
15	15.4.2 Mountain Green Cover Index	0	1	0	0	0	0	0	0	0	0	0	17
15	15.5.1. Red List Index	0	1	0	0	0	0	0	0	0	0	0	37
15	15.6.1. Number of countries that have adopted legislative, administrative, and policy frameworks to ensure fair and equitable sharing of benefits	1	0	0	0	0	0	0	0	0	0	1	0
15	15.7.1. Proportion of traded wildlife that was poached or illicitly trafficked	0	0	1	0	0	0	0	1	0	0	0	0
15	15.8.1. Proportion of countries adopting relevant national legislation and adequately resourcing the prevention or control of invasive alien species	1	0	0	0	1	0	0	1	0	0	0	0
15	15.9.1. Progress towards national targets established in accordance with Aichi Biodiversity Target 2 of the Strategic Plan for Biodiversity 2011–2020	0	0	1	0	0	0	0	0	0	1	0	0
15	15.a.1. Official development assistance and public expenditure on conservation and sustainable use of biodiversity and ecosystems	1	0	0	0	0	0	0	0	0	0	0	15

Table A1. *Cont.*

		Feedbacks			Resilience			Heterogeneity			Nonlinearity		Cross-Scale Dynamics
Goal	**Indicators**	**Social**	**Ecological**	**Social Ecological**	**Learning**	**Governance**	**Participation**	**Diversity**	**Disaggregation**	**Multi-Dimension**	**Ecological Thresholds**	**Social Thresholds**	**Years**
15	15.b.1. Official development assistance and public expenditure on conservation and sustainable use of biodiversity and ecosystems	1	0	0	0	0	0	0	0	0	0	0	15
15	15.c.1. Proportion of traded wildlife that was poached or illicitly trafficked	0	0	1	0	0	0	0	1	0	0	0	0
16	16.1.1. Number of victims of intentional homicide per 100,000 population, by sex and age	1	0	0	0	0	0	0	1	0	0	1	7
16	16.1.2. Conflict-related deaths per 100,000 population, by sex, age, and cause	1	0	0	0	0	0	0	1	0	0	1	0
16	16.1.3. Proportion of population subjected to physical, psychological or sexual violence in the previous 12 months	1	0	0	0	0	0	0	1	0	0	1	0
16	16.1.4. Proportion of population that feel safe walking alone around the area they live	1	0	0	0	0	0	0	1	0	0	1	0
16	16.10.1. Number of verified cases of killing, kidnapping, enforced disappearance, arbitrary detention and torture of journalists, associated media personnel, trade unionists and human rights advocates in the previous 12 months	1	0	0	0	0	0	0	0	0	0	0	0
16	16.10.2. Number of countries that adopt and implement constitutional, statutory, and/or policy guarantees for public access to information	1	0	0	0	1	0	0	0	0	0	0	0
16	16.2.1. Proportion of children aged 1–17 years who experienced any physical punishment and/or psychological aggression by caregivers in the past month	1	0	0	0	0	0	0	1	0	0	0	0
16	16.2.2. Number of victims of human trafficking per 100,000 population, by sex, age, and form of exploitation	1	0	0	0	0	0	0	1	0	0	0	0
16	16.2.3. Proportion of young women and men aged 18–29 years who experienced sexual violence by age 18	1	0	0	0	0	0	0	1	0	0	0	0
16	16.3.1. Proportion of victims of violence in the previous 12 months who reported their victimization to competent authorities or other officially recognized conflict resolution mechanisms	1	0	0	0	0	0	0	1	0	0	0	0
16	16.3.2. Unsentenced detainees as a proportion of overall prison population	1	0	0	0	0	0	0	1	0	0	0	14

Table A1. *Cont.*

		Feedbacks			Resilience			Heterogeneity			Nonlinearity		Cross-Scale Dynamics
Goal	**Indicators**	**Social**	**Ecological**	**Social Ecological**	**Learning**	**Governance**	**Participation**	**Diversity**	**Disaggregation**	**Multi-Dimension**	**Ecological Thresholds**	**Social Thresholds**	**Years**
16	16.4.1. Total value of inward and outward illicit financial flows (in current United States dollars)	1	0	0	0	0	0	0	0	0	0	0	0
16	16.4.2. Proportion of seized, found, or surrendered arms whose illicit origin or context has been traced or established by a competent authority in line with international instruments	1	0	0	0	0	0	0	1	0	0	0	0
16	16.5.1. Proportion of persons who had at least one contact with a public official and who paid a bribe to a public official, or were asked for a bribe by those public officials, during the previous 12 months	1	0	0	0	0	0	0	1	0	0	0	0
16	16.5.2. Proportion of businesses that had at least one contact with a public official and that paid a bribe to a public official, or were asked for a bribe by those public officials during the previous 12 months	1	0	0	0	0	0	0	1	0	0	0	0
16	16.6.1 Primary government expenditures as a proportion of original approved budget, by sector (or by budget codes or similar)	1	0	0	0	0	0	0	1	0	0	0	0
16	16.6.2. Proportion of population satisfied with their last experience of public services	1	0	0	0	0	0	0	1	0	0	0	0
16	16.7.1. Proportions of positions (by sex, age, persons with disabilities, and population groups) in public institutions (national and local legislatures, public service, and judiciary) compared to national distributions	1	0	0	0	0	0	0	1	0	0	0	0
16	16.7.2. Proportion of population who believe decision-making is inclusive and responsive, by sex, age, disability, and population group	1	0	0	0	1	1	0	1	0	0	1	0
16	16.8.1. Proportion of members and voting rights of developing countries in international organizations	1	0	0	0	1	1	0	1	0	0	0	0
16	16.9.1. Proportion of children under 5 years of age whose births have been registered with a civil authority, by age	1	0	0	0	0	0	0	1	0	0	0	7
16	16.a.1. Existence of independent national human rights institutions in compliance with the Paris Principles	1	0	0	0	0	0	0	0	0	0	1	17

Table A1. *Cont.*

		Feedbacks			Resilience			Heterogeneity			Nonlinearity		Cross-Scale Dynamics
Goal	**Indicators**	**Social**	**Ecological**	**Social Ecological**	**Learning**	**Governance**	**Participation**	**Diversity**	**Disaggregation**	**Multi-Dimension**	**Ecological Thresholds**	**Social Thresholds**	**Years**
16	16.b.1. Proportion of population reporting having personally felt discriminated against or harassed in the previous 12 months on the basis of a ground of discrimination prohibited under international human rights law	1	0	0	0	0	0	0	1	0	0	1	0
17	17.1.1. Total government revenue as a proportion of GDP, by source	1	0	0	0	0	0	0	1	0	0	0	26
17	17.1.2. Proportion of domestic budget funded by domestic taxes	1	0	0	0	0	0	0	1	0	0	0	27
17	17.10.1. Worldwide weighted tariff-average	1	0	0	0	0	0	0	0	0	0	0	12
17	17.11.1. Developing countries' and least developed countries' share of global exports	1	0	0	0	0	0	0	1	0	0	0	17
17	17.12.1. Average tariffs faced by developing countries, least developed countries and small island developing States	1	0	0	0	0	0	0	0	0	0	0	12
17	17.13.1. Macroeconomic Dashboard	1	0	0	0	0	0	0	0	0	0	0	0
17	17.14.1. Number of countries with mechanisms in place to enhance policy coherence of sustainable development	1	0	0	0	1	0	0	0	0	0	0	0
17	17.15.1. Extent of use of country-owned results frameworks and planning tools by providers of development cooperation	1	0	0	0	0	0	0	0	0	0	0	0
17	17.16.1. Number of countries reporting progress in multi-stakeholder development effectiveness monitoring frameworks that support the achievement of the sustainable development goals	1	0	0	0	1	0	0	0	0	0	0	0
17	17.17.1. Amount of United States dollars committed to public–private and civil society partnerships	1	0	0	0	0	0	0	0	0	0	0	0
17	17.18.1. Proportion of sustainable development indicators produced at the national level with full disaggregation when relevant to the target, in accordance with the Fundamental Principles of Official Statistics	1	0	0	0	0	0	0	1	0	0	0	0
17	17.18.2 Number of countries that have national statistical legislation that complies with the Fundamental Principles of Official Statistics	1	0	0	0	1	0	0	0	0	0	0	0
17	17.18.3. Number of countries with a national statistical plan that is fully funded and under implementation, by source of funding	1	0	0	0	1	0	0	1	0	0	0	10

Table A1. *Cont.*

		Feedbacks			Resilience			Heterogeneity			Nonlinearity		Cross-Scale Dynamics
Goal	**Indicators**	**Social**	**Ecological**	**Social Ecological**	**Learning**	**Governance**	**Participation**	**Diversity**	**Disaggregation**	**Multi-Dimension**	**Ecological Thresholds**	**Social Thresholds**	**Years**
17	17.19.1. Dollar value of all resources made available to strengthen statistical capacity in developing countries	1	0	0	0	0	0	0	0	0	0	1	11
17	17.19.2. Proportion of countries that (a) have conducted at least one population and housing census in the last 10 years; and (b) have achieved 100 per cent birth registration and 80 percent death registration	1	0	0	1	0	0	0	1	0	0	0	0
17	17.2.1. Net official development assistance, total and to least developed countries, as a proportion of the Organization for Economic Cooperation and Development (OECD) Development Assistance Committee donors' gross national income (GNI)	1	0	0	0	1	0	0	1	0	0	1	15
17	17.3.1. Foreign direct investment (FDI), official development assistance, and South–South cooperation as a proportion of total domestic budget	1	0	0	0	1	0	0	1	0	0	0	0
17	17.3.2. Volume of remittances (in United States dollars) as a proportion of total GDP	1	0	0	0	0	0	0	1	0	0	0	27
17	17.4.1. Debt service as a proportion of exports of goods and services	1	0	0	0	0	0	0	1	0	0	0	27
17	17.5.1. Number of countries that adopt and implement investment promotion regimes for least developed countries	1	0	0	0	0	0	0	0	0	0	1	0
17	17.6.1. Number of science and/or technology cooperation agreements and programs between countries, by type of cooperation	1	0	0	0	0	0	0	0	0	0	1	0
17	17.6.2. Fixed Internet broadband subscriptions per 100 inhabitants, by speed	1	0	0	0	0	0	0	0	0	0	0	16
17	17.7.1. Total amount of approved funding for developing countries to promote the development, transfer, dissemination, and diffusion of environmentally sound technologies	1	0	0	0	0	0	0	0	0	0	0	0
17	17.8.1. Proportion of individuals using the Internet	1	0	0	0	0	0	0	1	0	0	0	22
17	17.9.1. Dollar value of financial and technical assistance (including through North–South, South–South, and triangular cooperation) committed to developing countries	1	0	0	0	1	0	0	0	0	0	1	15

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