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SPECIAL FEATURE: EDITORIAL

Synergies and Trade-offs between Sustainable Development Goals and Targets

Synergies and trade-offs between sustainable development goals and targets: innovative approaches and new perspectives

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The sustainable development goals (SDGs) were adopted by the United Nations on 25th September 2015 and are now mid-way to the target implementation deadline of 2030. A set of 17 goals with 169 targets are being used to guide all UN Member States in implementing the challenging 2030 Agenda for Sustainable Development. From the beginning, it was recognised that the goals and targets were interlinked and integrated (UN 2015) and that this had to be considered for SDG implementation to ensure policy coherence. However, while addressing this agenda, countries may lose sight of the synergies and trade-offs between goals and their targets. Reasons for this are linked to the complexity of monitoring a large number of indicators (232), the lack of methods, data, and/or means to quantify some of the indicators, the lack of a definitive framework to address synergies and trade-offs, and gaps in our knowledge on how goals and targets influence each other. Yet, understanding how these interactions take place remains essential to minimise trade-offs and maximise synergies, and in the process, ensure we are making progress towards achieving the SDGs and avoid wasting resources when doing so. The issue is, therefore, complex, and in the past few years approaches have been developed to identify and quantify synergies and trade-offs between goals and between targets, particularly at the national scale at which countries report to. Less work is underway on synergies and trade-offs at the global or sub-national scales, even though these scales are also relevant to ensure equitable development ('leaving no one behind' as prioritised by the UN-CEB 2017) internationally, nationally, and within countries (Nilsson et al. 2016a).

Approaches used for the analysis of SDG synergies and trade-offs have been reviewed to various degrees of detail (e.g. Breuer et al. 2019; Scharlemann et al. 2020; Zhou and Moinuddin 2017; Zhou et al. 2022). Approaches range from relatively simple assessments (e.g. based on literature reviews) focusing on a few targets, to much more complex assessments focusing on all targets and with methods requiring large databases and specific analytical skills (Alcamo et al. 2020). Breuer et al. (2019) identified groups of approaches that have evolved with increasing knowledge generation including (1) clustering SDGs around their intended outcomes and systemic roles, but without necessarily establishing the causal links between them; (2) considering networks of SDG targets through network and data analyses, but without necessarily providing empirical insights or directionality as to the connections; and (3) empirical analyses of synergies and trade-offs, e.g. complex systems modelling, scales of interactions to characterise positive, neutral or negative interactions, which can be based on statistical analysis where data are available, cross-impact matrices, and cluster analysis.

There is, therefore, a variety of approaches used for the assessment of SDG synergies and trade-offs, with a clear evolution towards more system-level thinking and reliance on methods ranging from stakeholder consultations and literature reviews to complex statistical or modelling analyses. The work on this issue, however, remains limited (Alcamo et al. 2020), relative to its importance given the ambitions of the SDGs, while remaining a very dynamic field

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of investigation. With this in mind, the aim of this Special Feature of Sustainability Science is to take stock of recent progress made in understanding synergies and trade-offs between goals and between targets, from new theoretical and conceptual frameworks stemming from different disciplinary and geographic perspectives to new comprehensive approaches and tools that allow for a direct or an indirect analysis of synergies and trade-offs. Following Breuer et al. (2019), synergies are considered when achievements on one goal contributes towards progress on other goals, and when progress achieved on one goal produces detrimental effects to other goals, the relationship is considered a trade-off. The objective of the Special Feature is not only to present tools developed specifically for synergy and trade-off analyses but also to present studies that allow quantifying human–environment processes that can then be used within these tools or assessment frameworks.

The human–environment link is particularly relevant in the SDG context as the environment is integral to many SDGs (Scharlemann et al. 2020). The idea for the Special Feature stems from our participation in a project funded under the multi-agency call 'Towards a Sustainable Earth (TaSE)' which focussed on 'Human–Environment Interactions and the Sustainable Development Goals'. Following an open call for papers, this Special Feature comprises 20 original and review papers, as well as case- and technical reports. Seven of the papers emanate from projects funded under the TaSE call.

The first five papers are from a TaSE-funded project entitled 'River basins as "living laboratories" for achieving sustainable development goals across national and sub-national scales'. This project focussed on the analysis of the synergies and trade-offs between the SDGs at the sub-national scale, namely in the Luanhe river basin (LRB) in China. The rational for a sub-national assessment was that, at the time when the research was developed, there had been limited focus of SDG analysis at the sub-national scale particularly regarding synergies and trade-offs. From a development perspective, this poses several inter-related problems, including (1) some development targets can only be addressed at the sub-national scale or at a more regional level, for example, in the case of ecosystems or landforms which are location-specific (e.g. Szabo et al. 2016); (2) some regions could be targeted to achieve specific SDGs at the national scale, and so receive large investments, at the expense of other regions or by locally compromising other goals (such as increasing agricultural productivity in river deltas to reach national-level food security targets at the expense of environmental targets locally); and (3) some regions could be negatively affected by actions taken elsewhere in the landscape in view of achieving specific national-level goals or targets, for example, the building of dams and reservoirs for energy production and/or to increase water availability regionally that in the process regulates water and sediment flows that subsequently negatively affects the development or even the physical integrity of downstream regions. These problems can ultimately lead to important development inequalities within a country, or between countries in the case of transboundary systems, as inferred by Nilsson et al. (2016a). In this context, river basins are a relevant geography for the analyses of human–environment interactions at the sub-national scale because they provide natural boundaries where upstream–downstream processes can be analysed precisely.

Four papers from this project quantified aspects of human–environment interactions relevant to the SDGs. In their first paper, Xu et al. (2022a) indirectly analyse trade-offs and synergies between five goals through a socio-ecological affected land system evolution scenario analysis. The land system approach, which provides comprehensive information on socio-ecological factors, was used to explore the potential land system changes of the LRB by 2030, which represents valuable information for policy and planning purposes in the pursuance of the SDGs at the sub-national scale.

In their second paper, Xu et al. (2022b) investigated both ecosystem services (ES) and ecosystem disservices (EDS) using the stakeholder participatory capacity matrix approach for exploring the human–environment interactions in the LRB. The research allowed identifying hotspots of critical ES and EDS and understanding the relationship between ES and EDS and river basin management under past, current and future land use scenarios.

Zhao et al. (2022) present a new framework to systematically analyse basin-wide flood risk in connection to different development and climate scenarios in the LRB. The framework consists of models of the design rainfall under changing climates, a numerical model for flood inundation simulation, and a flood impact/risk assessment. This framework evaluates the potential flood risk under different development, climate, and infrastructure change scenarios for the LRB.

Wei et al. (2022) compiled data related to water quality and aquatic community structure in the Panjiakou Reservoir located in the LRB, as well as the reservoir's various functions and operation modes, and social and economic development of the reservoir's surroundings for the period 1984 to 2019. The evolution of the reservoir's water quality and changes in aquatic community structure and functions were linked to adjacent social and economic development, clearly indicating different synergies and trade-offs between SDGs. This study suggests that it is essential to consider comprehensively the individual needs of communities in the vicinity of the reservoir as well as those of upstream and downstream communities to minimise trade-offs and maximise synergies.

Zhou et al. (2022) combined the analytical results generated by these four papers with additional data collection,

a systematic literature review and expert consultations to identify key elements of the SDG interlinkage system and map their interactions. A generic SDG interlinkage model was developed (accessible at https://sdginterlinkages.iges.jp/luanhe/SDGInterlinkagesAnalysis.html) based on an existing SDG interlinkages tool (Zhou et al. 2019). SDG interlinkages were subsequently quantified for 27 counties in the LRB and are further demonstrated for three selected counties located in the upstream, midstream and downstream regions of the basin. The tool can be used to explore and visualise the synergies and trade-offs among various development objectives, covering the social, economic and environmental dimensions, and support integrated solutions towards sustainable river basin development.

A group of four papers proposes new or improved approaches for the analyses of SDG synergies and trade-offs. Dawes et al. (2022) apply recently developed quantitative methods from network science to examples of interlinkage networks to draw system-level conclusions using the SDG interlinkages tool of Zhou et al. (2019). The paper discusses two country-specific matrices for Bangladesh and Indonesia that combine country-level SDG indicator data with the generic framework matrix. The paper suggests that SDGs 1–3 (No Poverty, Zero Hunger, and Good Health and Wellbeing, respectively) are much more likely to be achieved than the environmentally related SDGs 13–15 (Climate Action, Life below Water, and Life on Land, respectively) and highlights the continuing tensions within the policy landscape between the human development and environmental preservation aspects of the SDG agenda.

To analyse SDG synergies and trade-offs, Anderson et al. (2022) created a systems model based on the results of a correlation analysis of SDG indicator data. The model captures complex indirect effects among SDG connections. Their global analysis finds more synergies than trade-offs among the SDGs and their targets, highlighting SDGs 5 (Gender Equality) and 17 (Partnerships for the Goals) as levers for progress.

Toth et al. (2022) demonstrate how to adopt the multi-criteria analysis technique Analytic Network Process (ANP) for prioritising SDG targets through consideration of all positive and possible indirect SDG target interactions at once. The ANP allows the evaluation and ranking of SDG targets according to their synergistic potential as well as their progress controllability. The paper suggests that the application of a combination of analytical methods with their inherent advantages and limitations can improve the overall quality of the formulated policy advice regarding its scope and methodological strength.

Coenen et al. (2022) used content and network analysis techniques to examine the interlinkages between the climate actions of 72 transnational (non-state actor) initiatives and the 169 targets of the 17 SDGs. Transnational initiatives on climate are shown to contribute towards achieving 16 of the 17 SDGs, in particular SDG 7 (Affordable and Clean Energy), 9 (Industry, Innovation and Infrastructure), 12 (Responsible Consumption and Production), 13, and 17, while SDG 5 is not addressed by these initiatives. SDG 9 is highly synergistic with many other SDGs.

Working with a broad range of stakeholders is essential to increase SDG implementation and integration, and to maximise synergies between SDGs and between their targets. Five papers introduce tools, frameworks and approaches to allow capturing perceptions of different stakeholders and encourage knowledge uptake and participation.

Maher et al. (2022) present a new graphical tool, MetaMAP, to support an integrated approach to achieve the SDGs, to design integrated sustainability initiatives, and to manage synergies and trade-offs in achieving multiple development objectives jointly with stakeholders. The tool integrates components of the natural environment, built environment, and society across multiple spatial and temporal scales. Maher et al. apply it to a case study of an Ecovillage in which a multidisciplinary team analysed the tool's impacts across scales and designed synergetic initiatives.

Eppinga et al. (2022) developed an interactive online tool and asked a target audience from three small island states to use the Q-sort technique to rank SDGs according to their subjective valuation of importance of various SDG domains: Economy, Governance, Planet and Society. The aim was to determine if people's perception of the relative importance of the SDGs translates into prioritisation across domains, or whether this perception is based on different valuations of the domains themselves. Identified subjective synergies and trade-offs can inform the delivery and increase the effectiveness of Education for Sustainable Development programmes at the local level.

To translate systemic knowledge on SDG interactions into practice, Barquet et al. (2022) investigated determinants of knowledge uptake and capacity building in real-world decision-making processes and how this can support more systemic thinking. For this, they use a decision-support approach called SDG Synergies, which is based on systems analysis, and apply it to Mongolia, Colombia, and Sri Lanka, where they identified three important sets of mechanisms that enable more systemic thinking.

Horan (2022) focused on the importance of broad-based partnerships and proposed a framework that 'lead actors' can use to help harness collaborative SDG implementation and account for synergies and trade-offs across goals and targets based on a specific 'entry point' to the interactions (see Alcamo et al. 2020; Alcamo 2019). The six-step analytic partnership-building framework is discussed and applied to policy coordination across a range of stakeholders involved with the implementation of SDG 13 and SDG 7, and to integrated multilateral responses to crises. The paper

acknowledges that mapping these responsibilities is a major challenge and that not enough attention has been given to roles and responsibilities of different stakeholder groups for integrated implementation. The issues of how to select entry points, how to institutionalise and incentivise participation and how to bring relevant actors on board are other important challenges.

Agusdinata (2022) uses a human-centred design (HCD) and shared-action learning (SAL) model for a university-led design and engagement process to co-create SDG solutions. The model allows capturing inherent synergies across SDGs, determining modes of solution identification, design, and implementation, and optimizing stakeholder involvement and interactions. Using the model, synergies within SDGs 1, 2, 5 and 7 were leveraged in North Lombok (West Nusa Tenggara province) and Mimika (Papua province) in Indonesia.

Various approaches, frameworks, conceptual models and tools are used to characterise issue-related and scale-specific synergies and trade-offs between SDGs and between their targets. Su et al. (2022) investigated the role of contextual factors in analysing the synergies and trade-offs between SDG 2 and SDG 6 (Clean Water and Sanitation). Both qualitative and quantitative approaches were explored to identify and explain the interlinkages at the target level and at the national scale. The qualitative analysis was conducted through a text analysis of the Voluntary National Reviews of 159 countries and a synthesis of the existing studies. The quantitative analysis was conducted using a correlation analysis. By comparing previous qualitative studies with their quantitative correlation analysis, Su et al. (2022) were able to highlight significant differences between the number and nature of linkages identified, induced by methodological considerations and contextual factors, such as project design, technology application, phase of interventions, and project scale.

Momblanch et al. (2022) investigated how alternative conservation strategies in the Beas River in India affect the likelihood of survival of the endangered Indus River Dolphins using a water resource systems model linked with a forecast extinction model that allows accounting for potential trade-offs between related SDGs. Freshwater ecosystems and endangered aquatic species are not explicitly addressed in the SDGs, but only nested as targets within SDG 6 and SDG 15, and there is a high risk that decisions to advance other SDGs may overlook impacts on them. Momblanch et al. show that modifying the management of water supply infrastructure to support the protection of rare and endangered aquatic species need not be at the expense of human sustainable development and the status of other relevant SDGs.

Mohd Hanafiah et al. (2022) conducted a literature review to determine the impact of palm oil on multiple SDGs in the Malaysian context. Benefits and concerns linked to palm oil are systematically documented across social, economic, health, and environmental dimensions. Through the identification of benefits, adverse effects, mitigation measures, challenges and knowledge gaps, a series of recommendations are put forward to balance mitigation of negative impacts with building on positive aspects of palm oil on multiple SDGs.

Otsuki et al. (2022) explored the synergies between the 17 SDGs and existing involuntary resettlement guidelines by drawing on the case of Mozambique's liquefied natural gas project. Their analysis highlights the misalignment between how SDGs are used to evaluate a development project and how involuntary resettlement guidelines are applied to the same project. They propose that the SDGs and involuntary resettlement guidelines need to be realigned by integrating SDG-induced displacement and resettlement into SDG 10 (Reduced Inequalities) with a focus on migration and inequality, into SDG 16 (Peace, Justice and Strong Institutions) with a focus on conflicts, and into SDG 17.

To support sustainable management and development of landscapes surrounding rivers, Grabowski et al. (2022) propose an interdisciplinary conceptual framework of river-land process interactions, the 'land–river interface' (LRI). The framework draws together concepts from hydrology, geomorphology, and ecology to explain how impacts of development propagate through river systems to affect people and the environment. Using the LRI, they demonstrate how activities related to development, which occur at different locations and scales in the landscape, namely urbanisation, dam construction, and aggregate mining, affect riverine processes, causing impacts both locally and throughout the landscape.

Vercruysse et al. (2022) build on the work of Grabowski et al. (2022) and observe that existing approaches to scale up or down SDG targets and link them to natural capital are insufficient for the two-way human–environment interactions that exist in the LRI. They propose a place-based approach to interpret the SDG framework to support sustainable land/water management through a normative content analysis of the SDG targets. They identify key priorities for sustainable development and subsequently illustrate these priorities through three case studies of human–environment interactions (urbanisation, dam construction, and aggregate mining). Their study presents a practical framework that can be used to assess context-specific impacts of such interactions which can be used to help achieve the SDGs without compromising the functions and services of the land–river interface.

This Special Feature highlights the diversity of available assessments to characterise SDG synergies and trade-offs and the range of innovative approaches and models that have been developed or improved upon to support this. This is in recognition that understanding these synergies and trade-offs

at multiple spatial and temporal scales is essential to deliver on the 2030 Agenda. The multiplicity of approaches reinforces the diagnostic made by Alcamo et al. (2020) that convergence on a single method and methodology has not yet happened; and that a 'perfect methodology' does not yet exist (Breuer et al. 2019: 13). The implication is that results of SDG synergy and trade-off analyses may lead to very different results depending on the method used, which can be deemed as problematic in terms of informing policies and developing concrete actions on the ground. Although efforts to reach method convergence might be desirable, it is also important to recognise that synergies and trade-offs between SDGs are context and case specific (Nilsson et al. 2016a, b; Breuer et al. 2019), and that having multiple, tested models and tools available at hand to characterise these might bring flexibility (e.g. to overcome monitoring costs, data availability, and/or capacity bottlenecks) and still allow for robust assessments to be carried out. Furthermore, many of the available approaches are complementary to each other as they can allow to overcome limitations of each individual approach in addressing the huge gaps in data and knowledge. From the viewpoint of their practical applications, it is suggested to discuss the limitations and differences from other approaches in future research on SDG synergies and trade-offs.

As we are mid-way through the implementation of the SDGs, scepticism could emerge as to the relevance of developing tools to track their interactions. However, we believe that the more we address complex human–environment relationships that can inform our understanding of SDG interactions at various spatial and temporal scales, the more likely we are to provide solid evidence to prioritise and integrate development policies in the future.

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