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Decision-making fitness of methods to understand Sustainable Development Goal interactions

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The integrated nature of the Sustainable Development Goals (SDGs) presents a challenge to implementing the 2030 Agenda. Analytical methods to support decision-makers are often developed without explicitly incorporating decision-makers' views and experience. Here, we investigate whether existing methods are fit-for-purpose in supporting decision-makers at national and subnational levels. We identify prominent methods for SDG interaction analysis, which we then evaluate by engaging directly (via a survey and interviews) with method developers and decision-makers in Sweden. We find that decision-makers prioritize methods that are simple and flexible to apply and able to provide directly actionable and understandable results. They are less concerned with the accuracy, precision, completeness or quantitative nature of the knowledge. Prominent categories of methods include self-assessment, expert judgement, literature-based, statistical analyses and modelling. Interviewed decision-makers consider these methods in line with the features prioritized in the survey but highlight low performance on features they value highly, such as the extent to which results are actionable and overall ease of use. Methods developers have limited awareness of decision-makers' priorities and requirements, so hindering methodological advancement. They should focus on the practical value of applications to support decision-makers, resource-constrained organizations and those seeking to evaluate multiple cases.

The Sustainable Development Goals (SDGs), adopted by the United Nations (UN) in 2015, are the most recent expression of a shared global vision that is designed to be a blueprint to achieve a better and more sustainable future for all[1]. Achieving the 17 SDGs at once, however, requires the ability to plan and make decisions that identify and harness positive interactions (synergies) and limit negative interactions (trade-offs) between the goals and their 169 targets[2]. Synergies occur when efforts in pursuit of one goal contribute towards progress on other goals, while trade-offs occur in situations where efforts to progress on one goal are detrimental to other goals. To ensure plans to implement the SDGs, the UN 2030 Agenda for Sustainable Development calls for integrated planning methods, tools and models to support the appraisal of alternatives.

Since the adoption of the UN Agenda, a growing number of methodological approaches have been developed or adapted to provide an integrated understanding of the SDGs. Recent studies highlight that, despite a common objective, the outcomes of interaction analyses differ considerably depending on the methods used and this has important implications for decision-making[3–9]. These studies suggest that limitations, such as the inability to address all SDGs accounting also for transboundary effects[4] or to provide context relevant ranking of goals[3], are features of current methods that hinder integrated planning and, thus, the realization of the UN Agenda. However, these conclusions are reached without explicitly accounting for the views and experience of the organizations using the methods and the results of the analyses to guide decision-making.

This paper asks whether existing methods for analysing the interactions between SDGs are fit-for-purpose in supporting decision-makers with the implementation of the UN Agenda at national and subnational level. To achieve the aim, we ask: (1) what methods have been used so far; (2) what methodological features are prioritized by decision-makers; (3) how current methods perform against the requirements of decision-makers; and (4) to what extent the performance matches the views of developers of methods. The analysis is based on direct engagement of knowledge producers and knowledge users in organizations committed to the implementation of the UN Agenda in Sweden (based on a survey of 107 organizations, 11 interviews with decision-makers and 11 interviews with developers of methods for SDG interaction analysis), together with a review of the scientific literature and practice of SDG interaction research. Sweden is selected for the study to represent the state of play in countries where progress on implementing the 17 SDGs is most advanced[10]. It provides a case relevant also to other countries expecting to reach that level of progress in the near future.

Results

Our study found that decision-makers prioritize methods that are simple and flexible to apply and able to provide directly actionable and understandable results. They are less concerned with detail. Furthermore, decision-makers consider existing methods largely in line with their priorities but highlight low performance on critical features such as the actionability of results and the overall ease of use of the methods.

Six methodological approaches to SDG interaction analysis. Since the adoption of the UN Agenda, a small number of methodological approaches have had a prominent role in the analysis of SDG interactions. Our search of the scientific literature returned 359 scientific publications containing an analysis of trade-offs and/or synergies between two or more SDGs (Methods and Supplementary Data). We classified these studies on the basis of the methodological stance applied for the analysis of interactions and identified four methodological approaches (statistical analyses, literature-based, expert

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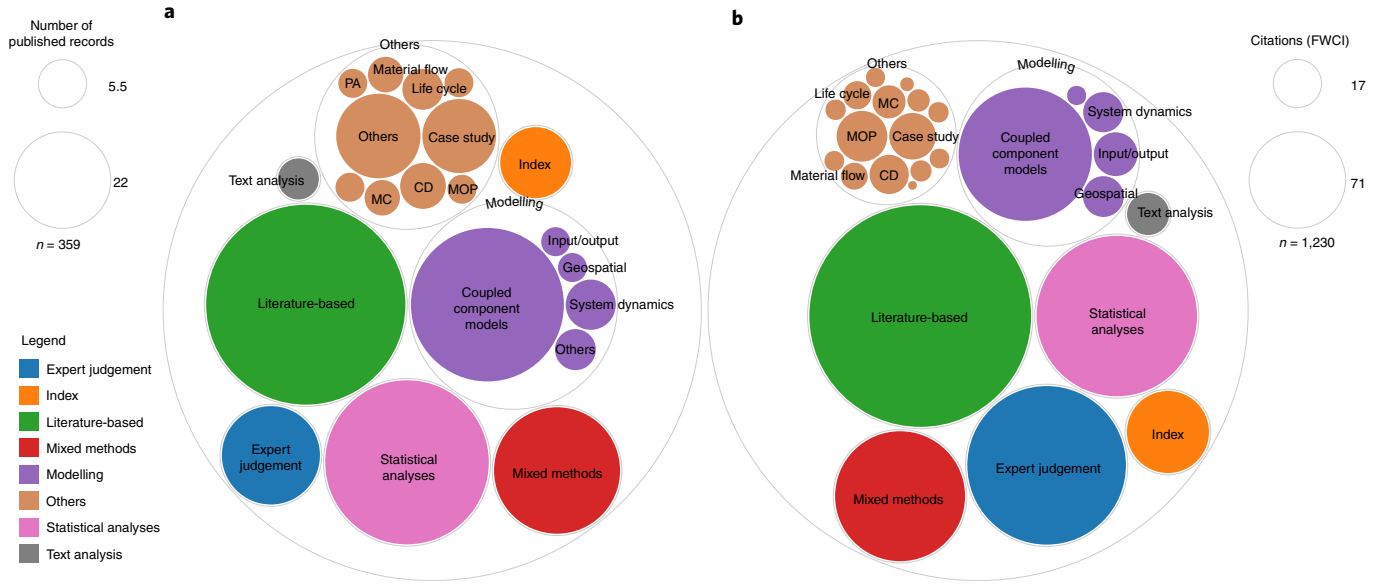

Fig. 1 | Methodological approaches to analysing SDG synergies and trade-offs in the scientific literature. a,**b**, Size of circles represents number of published records (**a**) and total citations as FWCI (**b**). PA, participatory assessment; CD, causal diagrams; MC, multi criteria; and MOP, multi objective programming. A full list of published records is available in the Supplementary Data.

judgement and modelling) which show a prominent position in the field, on the basis of the total number of publications and total citations received compared to the average citations received by similar publications as field-weighted citation impact (FWCI)[11] (Fig. 1).

To identify studies with a central role in the body of literature, we developed a set of citation networks (Fig. 2). Here, the modelling approach is shown as two separate networks (coupled component models (CCM) and system dynamics (SD) models), in consideration of the variety of modelling methodologies. From the networks, studies with a central role were identified considering the number of citations received (size of circles) and the distribution of those citations among the studies in the sample (connecting edges) (Methods).

We also searched the grey literature for methodological approaches developed by practitioners experienced in the practice of SDG decision-making. In this literature, we identified nine approaches, two of which (guidelines and self-assessment) have currently no or limited representation in the scientific literature (Supplementary Data). Among these, self-assessment was selected for evaluation in this study due to its broad application in Sweden.

Table 1 illustrates the six categories of methodological approaches analysed in the study (details in section 1 of the Supplementary Information).

Methodological features prioritized by decision-makers. A broad range of private and public organizations have been actively working to realize the SDGs in Sweden. Our survey of decision-makers' opinions on the methods for SDG interaction analysis included representatives of businesses, civil society organizations, public agencies and governments at local, regional and national level. The results show that these organizations prioritize methods that support practical initiatives on the UN Agenda (section 2 of the Supplementary Information). Respondents across all categories highlight the importance of methods that provide results that are actionable; that is, able to inform evidence-based decisions (17.1% of preferences) and understandable without specialist knowledge (16.5% of preferences), while being easy to apply (16.2% of preferences) and adapt (14.9% of preferences) considering the human resources and time required. Transparency with regard to the methods' logic, assumptions, uncertainties and limitations is a feature of medium importance (12.6% of preferences). Among the features of least importance is the ability to generate results expressed in quantitative units such as tons, jobs or hectares (8.7% of preferences), to provide complete knowledge of interactions considering the range of SDGs and geographical scales covered by the analysis (7.1% of preferences) and to ensure the results' accuracy and precision (6.8% of preferences).

Developers' assessment of methods. The experts who contributed to the development of the methods listed in Table 1 consider the approaches largely suited to support decision-making (Fig. 3a and section 3 of the Supplementary Information). They regard most approaches as sufficiently easy to apply and flexible, while being able to generate understandable and complete knowledge of SDG interactions. A notable exception is modelling with CCM which is considered by developers as underperforming on all these criteria due, primarily, to the complexity, data intensity and level of expertise required. Meanwhile, the developers' assessment shows that transparency is largely regarded as being addressed by all methods.

Among the limitations of current methods, developers highlight the challenge of generating actionable knowledge to support decision-making. With the exception of modelling and literature-based methods, developers consider current approaches are unable to generate the type of knowledge they believe is required to inform evidence-based decisions. This limitation is seen, mainly, as a consequence of the inability to analyse alternative initiatives, policies or scenarios. Concerning the least prioritized features of methods (completeness, relevance and accuracy and precision), performance appears mixed. Most methods are able to analyse multiple SDGs at various geographical scales (that is, results are complete), while only model-based methods provide results in quantitative units (that is, results are relevant) and, with the addition of statistical analyses, generate results that are considered sufficiently accurate and precise (section 3 of the Supplementary Information).

Decision-makers' interpretation of what is fit-for-purpose. The results of the interviews with decision-makers show that they distinguish between methods that are always acceptable and methods that

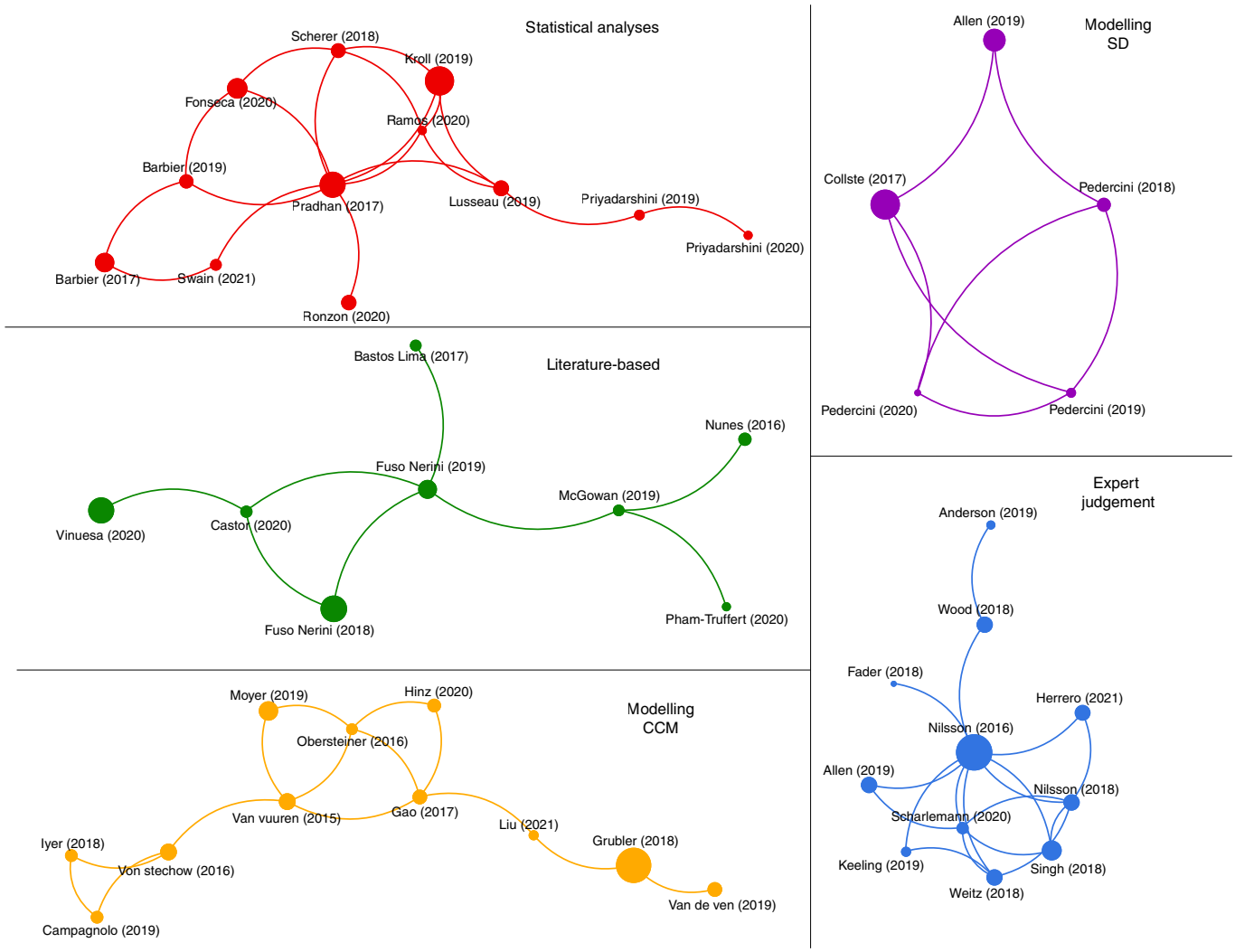

Fig. 2 | Citation networks of the categories of prominent methods identified in the scientific literature. Size of circle represents the number of times a paper has been cited; connecting edges represent networks of citations; and the distance between papers along the connecting lines represents the number of times papers reference each other (the higher the number of times two papers reference each other, the closer the papers are located). A full list of references is available in the Supplementary Data.

are only acceptable for certain categories of users or under specific circumstances. Table 2 provides selected quotations pertaining to the appraisal of methods by the different groups of decision-makers.

Decision-makers prioritize methods that provide actionable knowledge. They consider always acceptable results that are sufficiently contextual, concrete and specific to inform the design of practical initiatives to realize the SDGs. However, results that do not have such features may still be acceptable, especially for organizations at an early stage of SDG implementation and/or with less resources available, as long as the knowledge broadly contributes to their work on the SDGs (quote A).

Decision-makers consider results understandable when they do not require specialist knowledge to be interpreted. This quality is seen as largely dependent on the skills and previous experience of individual users, including their involvement in the analysis. However, while complete reliance on (external) experts is consistently rejected, a certain level of reliance may be acceptable, especially for organizations used to relying on external experts for their core activities (quote B).

Methods are regarded as easy to use when their application requires a maximum of 4–6 weeks (quote C) and no expertise external to the organization (quote D). Overall, decision-makers prioritize simpler methods that can be applied more often (quote E). Methods whose application requires extended periods of time and/or external expertise may be more acceptable within larger organizations (quote F) and/or to evaluate more important decisions (quote G).

Considering flexibility, decision-makers consistently regard methods as acceptable when method adaptation requires minor additional investments in time or resources, broadly <10% of the original investment. Although full flexibility (that is, no additional investments) is not necessary, flexibility is of great importance, primarily for organizations interested in the analysis of numerous decisions (quote H). However, lower levels of flexibility may be acceptable for organizations interested in evaluating fewer decisions.

Concerning transparency, users consider acceptable methods for which the overall logic of the analysis can be directly understood and explained to others (quote I). Overall, transparency is advanced by the availability of supporting evidence and the direct participation of users, while it is hindered by an increase in the complexity of the analysis or the post-processing of the results. Lower levels of transparency may be acceptable within organizations where there is

Table 1 | Categories of methods analysed in the study, including examples of central applications

Methods	Analysis of interactions	Purpose of the analysis	Selected applications
Self-assessment	Interactions are characterized exclusively on the basis of pre-existing knowledge of users	•Scoping (problems and objectives)	SDG Impact Assessment Tool[7,19,30]
Expert judgement	Systematic judgement by a group of experts is used to characterize relations between pairs of SDG targets	•Scoping (problems and objectives) •Prioritization (objectives)	Scientific studies[31–33] and SDG Synergies tool[34]
Literature-based	Evidence from the scientific literature is used to qualify interactions between SDGs	•Scoping (problems and objectives) •Prioritization (objectives) •Search for alternative actions	Scientific studies[35–38] and SDG-IAEA framework[39,40]
Statistical analyses	Statistical techniques are applied to analyse the relationship between pairs of SDG targets on the basis of historic data	•Prioritization (objectives) •Monitoring	Scientific studies[41,42]
Modelling SD	System thinking and stock and flows models are used to simulate impacts of interventions on SDGs over time	•Scoping (problems and objectives) •Prioritization (objectives) •Search for alternative actions •Evaluation of alternative actions	Scientific studies[43,44] and iSDG model[45]
Modelling CCM	Computer models from different disciplines are combined to simulate the impacts of scenarios on a set of SDGs over time	•Evaluation of alternative actions •Monitoring	IMAGE model[46] applied at regional/global scale[8,47] and CLEWs framework[48] applied at local level[49]

an internal agreement on the purpose of the analysis and the use of the results (quote J).

Methods' relevance, interpreted as the provision of results expressed in quantitative units, is considered important, or even necessary, within organizations seeking to monitor progress, often on a narrow range of SDGs (quotes K and L). However, organizations interested in a broad range of SDGs, and often at an early stage with the work on the UN Agenda, consider acceptable and sometimes even preferable the provision of qualitative or semiquantitative results (quote M).

Methods are considered complete when the scope of the analysis matches the interests of users, concerning both the range of SDGs and the geographical areas covered (quote N). Consequently, methods addressing a fixed set of SDGs or geographical areas are seen as less suitable. However, organizations with a broader range of interests and, often, more experience with the UN Agenda may accept, or even demand, the inclusion of most or all SDGs (quote O).

Considering the accuracy and precision of the results, decision-makers express a variety of views. They interpret accuracy in relation to the validity of the findings or whether they are representative of the real system and tend not to question it. When they do, they favour methods that promote validity (quote P). Meanwhile, precision is interpreted in relation to the level of resolution and details of the findings. Consistently, decision-makers do not question the level of precision and mention the high level of complexity and the long-time frame of decisions about the SDGs to consider the level of precision always adequate.

Decision-makers' views on the performance of methods. Existing methods to study SDG interactions show substantially different levels of alignment with the requirements of decision-makers (Fig. 3b). The following examination relies exclusively on the views of the decision-makers engaged (details in section 5 of the Supplementary Information).

Self-assessment contributes to decision-making supporting the scoping process, primarily by exposing the knowledge gaps of users. The strengths of this method derive from an approach that is transparent and easy to apply and adapt, while being able to provide results that are complete, understandable and sufficiently precise. All these advantages derive essentially from the simplicity of an analysis that uses, exclusively, the pre-existing knowledge of users. Decision-makers, however, also point to weaknesses including the qualitative nature of the knowledge generated and the lack of actionable results, mainly due to the inability to explore alternative initiatives.

Expert judgement supports decision-making by providing guidance on the prioritization of actions and goals in consideration of systemic trade-offs and synergies. Decision-makers appreciate this method's flexibility and ability to generate understandable and sufficiently precise knowledge of interactions. They also highlight the potential transparency and completeness of the method which, however, hinge on conditions such as access to the evidence used by the experts and the effective engagement of suitable experts. Regarding the method's weaknesses, decision-makers highlight problems with its practical application, which requires external experts to lead the exercise and the inability to generate actionable knowledge of interactions expressed in quantitative units.

Literature-based methodology is praised for the ability to provide general characterizations of the interactions between SDGs grounded in the body of scientific evidence. The results can support goal prioritization and the search for alternative actions. The high level of flexibility and the ability to generate understandable and sufficiently precise results are considered key strengths. Other advantages, including the completeness and transparency of the analysis, are however only potential because dependent on the existence of relevant literature and the provision of plain-language summaries. The method's weaknesses include the level of investments required for application, in particular to hire external experts, and the limited actionability of the results due to the inability to analyse alternative scenarios and to provide contextual knowledge.

Statistical analyses provide decision-makers with systemic knowledge of theoretical interactions between SDGs which can guide goal prioritization and the search for actions. The method is generally perceived as flexible and sufficiently accurate and precise. In addition, users with (basic) knowledge of statistics consider it also transparent, understandable and easy to apply. However, the potential ease of use and completeness of the method require available data and limited need for data preprocessing. Among the method's weaknesses, decision-makers highlight the inability to generate knowledge in quantitative units such as tons, jobs or hectares, and to inform evidence-based actions, primarily due to a limited capacity to explain causality and to evaluate alternative scenarios.

a Views of developers

	Self-assessment	Expert judgement	Literature-based	Statistical analyses	Modelling (SD)	Modelling (CCM)
Actionable	–	–	+	–	+	+/–
Understandable	++	+	+	+	+	–
Easy to use	++	+	+	+	+/–	–
Flexible	++	+	++	++	+	–
Transparent	++	++	+	+	++	+
Relevant	–	–	–	–	++	++
Complete	++	+	++	++	+	–
Accurate and precise	–	–	–	+	+/–	+/–

b Views of decision-makers

	Self-assessment	Expert judgement	Literature-based	Statistical analyses	Modelling (SD)	Modelling (CCM)
Actionable	–	–	–	–	+	+/–
Understandable	++	+	+	+/–	+	–
Easy to use	++	+/–	–	+*	–	–
Flexible	++	++	++	++	+/–	–
Transparent	++	+*	+*	+/–	+*	–
Relevant	–	–	–	–	++	++
Complete	++	+*	+*	+*	+/–	–
Accurate and precise	+	+	+	++	++	++

c Misaligned perspectives

	Self-assessment	Expert judgement	Literature-based	Statistical analyses	Modelling (SD)	Modelling (CCM)
Actionable	0	0	2	0	0	0
Understandable	0	0	0	1	0	0
Easy to use	0	1	2	1	1	0
Flexible	0	–1	0	0	1	0
Transparent	0	2	1	1	2	0
Relevant	0	0	0	0	0	0
Complete	0	1	2	2	1	0
Accurate and precise	–2	–2	–2	–1	–2	–2

Fig. 3 | Developers' and decision-makers' views on the performance of methodological approaches to SDG interaction analysis. a, Views of developers on the performance of methodological approaches (++ highly suitable, + suitable, +/– partly suitable, – not suitable). **b**, Views of decision-makers on the performance of methodological approaches (++ highly suitable, + suitable, +/– partly suitable, – not suitable, +* potentially suitable). **c**, Misalignment between the views of developers and decision-makers on the performance of current methods; numerical values calculated as the difference between the values of developers (**a**) and the values of decision-makers (**b**) using the following conversion of the four-point scale: highly suitable (2), suitable (1), partly suitable and potentially suitable (0) and not suitable (–1). Negative values (green colours) indicate instances where developers' opinions are more positive than those of decision-makers, while positive values (yellow colours) indicate instances where decision-makers' opinions are more positive. Zero values identify cases of alignment between the two groups.

Modelling with SD contributes to decision-making, primarily by supporting the evaluation of alternative actions providing credible and contextual knowledge of the systemic effects on the SDGs over time. Decision-makers praise the method for using a modelling technique that is potentially transparent and suitable to produce knowledge that is actionable due to the use of contextual data and the ability to evaluate alternative actions and scenarios, understandable as conventionally codeveloped with users but also accurate and relevant, since results are provided in quantitative units. The method's weaknesses are, in particular, the low ease of use and flexibility since application requires external experts and periods of time up to 3 months.

Modelling with CCM is suitable to support the evaluation of alternative actions, primarily due to the ability to supply high-level insights on the effects of human activities on the SDGs over time. The quantitative knowledge of impacts and processes is considered sufficiently accurate and partly actionable, even though results may provide only limited descriptions of how to achieve the goals. However, users question the value of the method in consideration of the investments required to apply and adapt CCMs, the lack of transparency and the inability to directly understand the results.

Misalignment between the views of developers and decision-makers. The opinions of users do not align well with those of developers. The opinions of the two groups differ in 40% of the instances and in 63% of such cases developers show a more positive stance (Fig. 3c). The misalignment between the views of the two groups is most pronounced regarding the methods' accuracy and precision, which are substantially under-appreciate by the developers. Meanwhile, developers tend to overappreciate the methods' ease of use, transparency and completeness. At the root to the problem with developers' optimistic views appears to be a

Table 2 | Quotations from the interviews with decision-makers

Actionable results
A. "When we started working with the Agenda it was sufficient to point at the SDGs on which we were claiming to have a positive impact. Today we have matured, and our ambitions are higher. This requires different knowledge." (Civil organizations)
Understandable results
B. "The world today is too complex to have almost any issue open [...] where you don't have experts to help." (Civil organizations)
Easy to use
C. "No, not months. We don't have this time." (Civil organizations)
D. "Employing somebody [external to the organization] requires a strong justification for the task." (City governments)
E. "To analyse also daily decisions and more decisions, not only big ones." (City governments)
F. "It is a whole different universe if you are a big company. You have the resources to invest." (Businesses)
G. "If it is a bigger assignment, we can put in more than a year." (National public agency)
Flexible
H. "All our projects are different that is why I want it to be flexible." (Businesses)
Transparent
I. "Unless you can explain the logic of what they [decision-makers] are going to decide, any model is useless because you will not instil the trust to make the decision." (Businesses)
J. "Many of my colleagues are sceptical towards the opportunity of employing the SDGs. I have to be able to explain to somebody else how the tool works, well enough that makes it believable. If I don't know I cannot explain and rebuke critiques." (Civil organizations)
Relevant results
K. "Quantities which can be monetized will be needed." (City governments)
L. "Trends would not satisfy me. I would like to know kroner and pieces." (Civil organizations)
M. "SDGs are very complex to take into consideration in decisions. Results should indicate where [the organization] could make an improvement in a sustainable direction." (Businesses)
Complete results
N. "The right thing to do would be to look at them all [SDGs], but that is not feasible for my work. Our members are very interested in some SDGs and not so in others." (Civil organizations)
O. "Many Swedish municipalities [...] are going from having an overall knowledge of the SDGs, and having perhaps worked in depth with a few, to begin thinking of them in a broader holistic framework." (City governments)
Accurate and precise results
P. "Information is not useful but actually dangerous if it is not correct." (Civil organizations)

Quotes are organized by the methodological features evaluated in the study. For each quote, the group affiliation of the decision-maker that made the statement is noted in parentheses.

limited understanding of decision-makers' requirements (for example, limited awareness of the users' time and resource constraints) and a set of misleading assumptions (for example, that method transparency concerns primarily other experts, not final users, or that methods with a broader scope are more complete, while decision-makers prioritize those that more accurately match the breath of their interests).

Discussion

This exploratory study reveals that existing methodologies for evaluating SDG interactions meet many of the requirements articulated by decision-makers but show critically low performance on the requirements decision-makers prioritize most. These shortcomings are expected to hinder the adoption and reach of these methods and limit their value in proving insight into SDG synergies and trade-offs for decision-making support.

Decision-makers in Sweden seek a broad understanding of what can support, or hinder, progress on the SDGs and are less concerned with detail. They prioritize methods that are simple and flexible to apply and able to provide directly actionable and understandable results, while maintaining a minimum level of transparency. Meanwhile, they appear less concerned with the details of this knowledge including its accuracy, precision, completeness or quantitative nature. This confirms a general awareness of the complexity and uncertainties involved in the analysis of SDG interactions[9].

Against these priorities, no method does it all but some are more fit-for-purpose than others. Self-assessment methods are easy to use and perform well on most requirements. Their qualitative nature and low actionability are not major limitations due to a focus on the initial scoping of problems and objectives. Several methodologies, including expert judgement, literature-based and statistical analyses, targeting the prioritization of objectives, show adequate performance if diligently applied; the lack of actionable results, however, is an important limitation. Modelling with SD models represent the method most suited to provide actionable results, a key priority for users. However, their application is often considered too demanding.

The level of resources available within organizations and their experience with the SDG affects how the fitness of methods is perceived. In Sweden, organizations with no or little experience with the Agenda often seek a general understanding of where they are contributing to, or hindering, progress and where they have a gap of knowledge. Self-assessment is well suited to support this scoping process. Organizations that focus their attention on a small set of SDGs often require a quantification of the impacts to support target-setting, monitoring and reporting. Modelling methods, and especially simpler applications of CCM, for example the CLEWs framework[12], can provide this knowledge. Organizations that have more recently expanded their interest on the SDGs prioritize a qualitative or semi-quantitative understanding of the overall systemic effects, which can be provided by several methodologies. Finally, organizations with more experience on a broad set of SDGs often prioritize a quantitative understanding of the systemic impacts of specific actions. Modelling with SD is regarded by decision-makers as a suitable method for the quantitative evaluation of alternatives to inform decisions.

To ensure progress on the UN Agenda, decision-makers' ability to understand interactions between SDGs must be improved[13]. One option to achieve that is to combine existing methods to expand the purpose of the analysis of interactions (for example, expert judgement for prioritization and CCM for the evaluation of alternative actions). This may, however, generate trade-offs; for example, greater actionability at the expenses of decreased ease of use and/or transparency. Evaluating the opportunity of mixed methods is not a simple task and merits further research. To increase the reach and application of SDG interaction methods in decision-making, we suggest that research could also focus on supporting organizations not effectively assisted by current methods. In the case of Sweden, these include the multitude of (small) organizations with limited resources available for the SDGs and those interested in assessing numerous decisions.

A critical challenge for improving the quality of the methods available is the misalignment between the views of developers and users on the performance of methods. Unaware of such misalignment, developers may fail to identify issues that require

urgent attention (for example, the ease of use, transparency and completeness of methods). Communication (or lack of it) between these two groups is at the root of the problem here. Decision-makers' participation in method codevelopment, although challenging[14], can be an effective way to provide a deeper mutual understanding and more usable science[15,16]. More attention must be paid to increasing communication and participation from current practice in which users are often relegated to testing the final output[3]. To address such challenges, the growing field of sustainability science has adopted a variety of useful approaches, including coproduction of knowledge[17] and hands-on experimentation with stakeholders[13]. Dedicated funding for research and development could accelerate the process of adopting these approaches[13] also for the methodological development of SDG interaction analysis.

With increasing experience and ambition, decision-makers' priorities and requirements can be expected to evolve and become more demanding[18]. Decision-makers' familiarity with the SDGs in industrializing, least-developed and rapidly industrializing countries is also expected to increase. These decision-makers' priorities and requirements may differ markedly from those identified in this study and this would be an important area for further research.

Methods

The evaluation of the fitness of methodologies to support decision-making consists of three broad steps: (1) we identify what methods have been used so far by conducting a review of the scientific literature and practice of SDG decision-making; (2) we identify and rank the methodological features prioritized by decision-makers by conducting a survey of organizations committed to the implementation of the UN Agenda in Sweden; and (3) we evaluate the performance of methods for SDG interaction analysis against the priorities of decision-makers by interviewing a sample of method developers and decision-makers in Sweden.

Search and identification of prominent methods. Relevant scientific studies were identified through a systematic search of the scientific literature available in two major repositories—Web of Science and Scopus. We searched for journal articles published in the period 2015 (January) to 2021 (February) using the Boolean query presented in section 1 of the Supplementary Information. The search resulted in a total of 3,247 entries (1,278 from Web of Science and 1,969 from Scopus) from which we removed duplicates and publications that did not address the analysis of interactions between or across SDGs. In total, 359 entries were considered relevant for this study and were classified on the basis of the method applied to analyse interactions. Seven main categories emerged from the classification including statistical analyses, literature-based, modelling, expert judgement, text analysis, indexes and mixed. The remaining publications were allocated to the category of 'others' (Supplementary Table 1).

From the dataset, we selected categories with a prominent position in the scientific literature considering the number of published studies in the literature and the total citations received as FWCI. FWCI, provided by Scopus[11], was used to represent data independently of publication year, type and discipline. From this exercise, we identified five categories of prominent methods: statistical analyses, literature-based, expert judgement and modelling, represented by modelling with CCM and modelling with SD models.

Meanwhile, our selection of the methods used in the practice of SDG interaction analysis was based on a review of the grey literature complemented with direct observations and suggestions from informants such as network managers and government officials in Sweden (details in section 1 of the Supplementary Information and Supplementary Data).

Identification of central applications of the methods. To facilitate the operationalization and evaluation of the methods for SDG interaction analysis, each category of prominent methods was matched with one or more examples of practical application. For methods identified in the scientific literature, the applications were selected for their central role in the field of studies based on the citation networks displayed in Fig. 2. Developed using a visualization tool, VOSviewer software, these citation networks show the total number of citations received by each publication as FWCI[11] (size of circles) and the distribution of citations among the sample of publications (connecting edges). We selected publications considering the size of circles and the number of connecting edges in each network. Regarding the methods identified in the practice of SDG decision-making, of the two categories (self-assessment and guidelines) for which we found limited evidence in the scientific literature, self-assessment emerged as the prominent category due to its broad application in Sweden. The SDG Integrated Assessment Tool[19] was used to represent the category (details available in section 1 of the Supplementary Information).

Survey of the priorities of decision-makers in Sweden. To rank the priorities of decision-makers with regard to the features of methods for SDG interaction analysis, we surveyed a sample of private and public organizations active in Sweden. Organizations were selected for their formal commitment to the implementation of the SDGs evidenced by their membership of a network connected to the UN Agenda, including: GD forum—Joint collaboration of Swedish government agencies for 2030 Agenda[20]; Glokala Sweden—Agenda 2030 in municipalities and regions[21]; CONCORD Sweden—platform of civil society organizations[22]; UN Global Compact[23]; Swedish Investors for Sustainable Development[24]; and Swedish Association of Local Authorities and Regions[25,26].

The online survey was distributed via email to representatives of 497 organizations, including 179 businesses (large and small–medium enterprises), 59 civil society organizations (religious groups and NGOs), six for the national government, 46 public agencies as well as 161 city governments and 46 regional governments. We received 107 complete responses (23 from businesses, 14 from civil organizations, 32 from the national government and/or public agencies and 38 from city and/or regional governments) (Supplementary Fig. 2).

In the first part of the survey we collected demographic information, including information about the type of organization and the SDGs considered of interest, as well as the age class, gender group and role of the respondent. The second part explored respondents' preferences related to SDG interactions and decision-making, considering the relative importance of eight utility criteria (Supplementary Table 2). The selection of the utility criteria was informed by the work of Allen et al.[5] and more generally by the UK's National Audit Office 'Framework to review models'[27].

The preferences of respondents were ranked applying a pair-wise comparison method referred to as maximum difference scaling (Max-Diff)[28]. As a mathematical theory about how people make choices, Max-Diff leverages the ability of respondents to identify the best and worst option from a list. Conventionally, in Max-Diff analysis, individual preference utilities are calculated applying hierarchical Bayes analysis (HBA)[29]. However, in this study we calculated them by counting the number of preferences received by each criterion. HBA was not required since the survey was designed to cover all possible combinations of items (28) and to have each item appearing with each other item exactly an equal number of times (details in section 2 of the Supplementary Information).

Interviews with method developers. To collect information about each methodological approach selected for the analysis, we involved developers who were, at the time of the analysis, either directly involved with the development of the method or working closely with the group developing the method (details of interviewees are available in Supplementary Table 4). During the semistructured interviews (11) conducted with developers, we asked participants to rate the performance of the method on each utility criteria using a four-point scale from 'not suitable' to 'very suitable' and to provide a thorough description of the performance. To operationalize each category of methods and facilitate evaluation, during the interviews we referred to the methods and applications listed in Table 1. We received informed consent from all participants before beginning data collection.

Interviews with decision-makers in Sweden. To collect the views of decision-makers, we conducted semistructured interviews (11) with informants and representatives of civil society organizations, businesses, city and regional governments and national public agencies active in Sweden (details of participants available in section 4 of the Supplementary Information). During the interviews, participants were asked to: (1) illustrate their interpretation of each of the eight utility criteria used in the study to evaluate methodologies; and (2) identify for each criterion the minimum level of performance they required. Our approach for eliciting the views of interviewees assumed that decision-makers do not need direct experience with the application of the methods to be able to build an informed opinion. To achieve that, we developed eight multiple-choice questions, one question for each utility criterion evaluated. Each of the multiple options referred directly to the performance of the methods, informed by the developers interviewed for the study. Participants were asked to select all acceptable options, motivating their choice. In this process, the methods were only mentioned and briefly illustrated in their totality at the beginning of the interview. The results allowed us to identify minimum levels of performance required by all participants and lower levels considered acceptable only by certain groups and/or under specific circumstance. We received informed consent from all participants before beginning data collection.

Reporting Summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

Data of the review of the literature and practice of SDG interaction research are available in the Supplementary Data and the source data for Fig. 1. Source data are provided with this paper. Additional data are available from the corresponding author on reasonable request.

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Author contributions

L.D., R.S. and J.K. designed the research. L.D. collected and analysed the data and was the primary writer. All authors edited the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

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Software and code

Policy information about availability of computer code

Data collection	Qualtrics Core XM Survey Software (publicly available)
Data analysis	VOSviewer, Ver.sion 1.6.16 (publicly available); Microsoft Office 365 suite (publicly available)

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Behavioural & social sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	Mixed-method case study using quantitative and qualitative data
Research sample	The study employed multiple research samples, as illustrated in the following. 1. Regarding the review of scientific literature, we searched two major literature databases (Scopus and Web of Science) employing the Boolean query presented in Supplementary Information. The results were then sampled to select entries relevant for this analysis. The final sample is considered representative of the scientific research published on the topic of methodologies for SDG interaction analysis in the period January 2015 to February 2021. 2. Regarding the review of the practice of SDG interaction analysis, we conducted a search of major tool databases, including UNESCAP [http://sdghelpdesk.unescap.org/toolboxes], SDG Compass [https://sdgcompass.org/business-tools/], Local2030 Network [https://www.local2030.org/discover-tools] and UNDP [https://sdgintegration.undp.org/knowledge-bank?field_enablers_tid=All&field_category_name_value=All&field_tool_function_value=All&field_accelerator_tool_value=All]. The results of this search were complemented with our direct observations and suggestions from informants including national government officials in Sweden. The final sample is considered representative of the categories of methodologies for SDG interaction analysis employed by practitioners. 3. Regarding the survey of decision makers, we conducted a self-administered online survey targeting representatives of private and public organisations committed to SDG implementation at national and subnational level in Sweden. The survey population consists of all organisations committed to the implementation of the SDGs in Sweden (currently unknown). To reach the population, we individually invited 497 organisations formally committed to the implementation of the Agenda (as indicated by their membership of an SDG related network). Based on self-selection, our sample consists of 107 complete responses received. This sample is considered representative of decision makers within organisations committed to the implementation of the SDGs in Sweden. The demographics show that 75% of respondents is female and 22% male, and that the majority (45%) belong to the age group of 40-49 years old . 4. Regarding the engagement of developers of methods for SDG interaction analysis, we selected those with an in-depth knowledge of one of the six methodologies selected for the analysis. Individuals were selected because directly or indirectly involved with the development of one of the applications emerging as central from our review of the practice and scientific literature of SDG interaction analysis. For each category of methods, one or two individuals were interviewed. The sample is considered suitable to represent the views of developers of each category of methods. 5. For the interviews with decision makers, the selection of participants relied largely on a list of potential participants provide by the representative of Sweden's National coordinator for Agenda 2030, complemented with a handful of participants from the respondents of the survey of decision makers in consideration of their interest in participating in the project activities. The sample of interviewees consists of representatives of organisations with significant experience with the implementation of the UN Agenda in Sweden, and covers the four categories of potential users of methods considered important in this study (business, national government and agencies, local and regional governments, and civil organisations).
Sampling strategy	1. Scientific literature. No sample-size calculation was performed. All entries from the application of the Boolean query were used to identify the sample for the analysis. The period of reference (January 2015 to February 2021) was selected considering the year of adoption of the Agenda (2015) and the most recent datasets available in Scopus and Web of Science at the time of the analysis. 2. Practice of SDG interaction analysis. No sample-size calculation was performed. All methods identified from the search of online databases, direct observations and from informants were included in the analysis. 3. Survey of decision makers. No sample-size calculation was performed. All organisations that could be identified as committed to the implementation of the Agenda from the search of relevant networks in Sweden were included in the survey. The ability to identify the person responsible for the work on the Agenda within the organisation was required. 4. Developers of methods for SDG interaction analysis. No sample-size calculation was performed. Experts were selected based on the results of the literature review with the intention of representing central applications of each of the six prominent categories of methods identified in the study. The individuals engaged were selected based on judgment. 5. Interviews with decision makers. No sample-size calculation was performed. We targeted organisations based on a list of potential participants provide by the representative of Sweden's National coordinator for Agenda 2030. Such list was complemented with a handful of participants selected from the survey of decision makers in consideration of their interest in participating in the project activities. Not all individuals invited to participate accepted our invitation. The final sample of participant is considered representative of the four categories of decision makers employed in the study.
Data collection	1. Scientific literature review. Data were collected searching two major online databases of scientific publications (Scopus and Web of Science) employing the Boolean query provided in the Supplementary Information. 2. Review of the practice of SDG interaction analysis. We conducted a search of major tool databases, complemented with direct observations and suggestions from informants in Sweden. Informants including SDG network managers and national government officials working on the Agenda met during specialised events organised in Sweden in 2020. At these events, data were recorded using pen and paper. Informants were selected applying a judgment approach. 3. Survey of decision makers. Data were collected employing Qualtrics Core XM Survey Software (publicly available). The researcher conducting the data collection was not blind to the experimental conditions. 4. Developers of methods for SDG interaction analysis. Data were collected conducting online interviews employing video and audio

equipment. Only the researcher and the interviewee were present during data collection. The researcher conducting the data collection was not blind to the experimental conditions.
5. Interviews with decision makers. Data were collected conducting online interviews employing video and audio equipment. Only the researcher and the interviewee(s) were present during data collection. The researcher conducting the data collection was not blind to the experimental conditions.

Timing

1. Review of scientific literature. Data were collected in three stages in April 2019, November 2020 and February 2021.
2. Review of practice of SDG interaction analysis. A first sample cohort was collected in November 2020 and a second cohort was collected in February 2021.
3. Survey of decision makers. The survey run between 8 April 2020 and 1 May 2020.
4. Developers of methods for SDG interaction analysis. Interviews with experts were conducted between 12 May 2020 and 19 April 2021.
5. Interviews with decision makers. Interviews took place between 18 November 2020 and 14 January 2021.

Data exclusions

1. Scientific literature sample. From the results of the Boolean search we excluded duplicates and entries which did not address the topic of methods for SDG interaction analysis. That exclusion was based on an assessment of the title, abstract and, in limited cases, of the main text of the article. A small number of 17 entries was excluded because we could not access the main text of the article while the title and abstract did not clearly identify the methods applied for SDG interaction analysis.
2. Practice of SDG interaction analysis. No data were excluded.
3. Survey of decision makers. We excluded 13 incomplete answers.
4. Experts of SDG interaction analysis. We excluded the data collected from one interview with the representatives of the IGES SDG Interlinkages Analysis & Visualisation Tool (V3.0) (https://sdginterlinkages.iges.jp/visualisationtool.html). The reason for such exclusion is that from the insights gained during the interview it emerged that the IGES application should not be categorised as Literature-based method, but as Mixed method, which did not emerge as a prominent category of methods.
5. Interviews with decision makers. No data was excluded.

Non-participation

In the survey of decision makers, we recorded a response rate of 21.5% (497 personal invitations submitted, 107 complete answers received, and 13 incomplete answers).
In the engagement of method developers, two experts of the SDG Synergies tool (Expert judgment category of methods) declined participation due to limited knowledge of the tool or health reasons.
Concerning the interviews with decision makers, five decision makers declined the invitation to participate providing justifications related to a lack of time or not being able to contribute to the topic.

Randomization

Participants were not allocated into experimental groups.

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

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n/a	Involved in the study	
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☒	☐	Animals and other organisms
☐	☒	Human research participants
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Methods

n/a	Involved in the study	
☒	☐	ChIP-seq
☒	☐	Flow cytometry
☒	☐	MRI-based neuroimaging

Human research participants

Policy information about studies involving human research participants

Population characteristics

In addition to what we have presented in the Study Design questions, we would like to add that regarding the survey of decision makers, 48% of respondents were responsible for providing knowledge of SDGs to their organisation, 38% were directly involved in the decision making regarding the SDGs within the organisation, 8% provided knowledge of SDGs to other organisations, 3% were involved in the development of the orginal set of SDGs at UN level, and 3% were interested in the SDGs as research topic.

Recruitment

Regarding the participants to the survey of decision makers in Sweden, we decided to analyse only organisations committed to the implementation of the Agenda since we considered organisations not committed to be unable to provide insights on the challenges connected to the implementation of the SDGs. All organisations identified as formally committed to the implementation of the SDGs were included in the survey. For each organisation, we invited the person responsible for the work on the Agenda in the organisation.
Concerning the interviews with method developers, a large majority of the experts contacted were keen to participate. Such self-selection process is not expected to impact the results of the analysis.
For the interviews with decision makers, we recruited decision makers from a list of potential participants provide by the

representative of Sweden's National coordinator for Agenda 2030, complemented with a handful of participants selected from the survey of decision makers in consideration of their interest in participating in the project activities. Not all decision makers contacted agreed to participate.

Ethics oversight	The Swedish Ethical Review Authority has adopted a policy to regulate the need for ethical oversight in research (Act Concerning the Ethical Review of Research Involving Humans). Based on such Act this research was not required to undergo ethical review.

Note that full information on the approval of the study protocol must also be provided in the manuscript.