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Uncovering SDG Interlinkages: interconnection at the core of the 2030 Agenda

An analysis of the state of the art on SDG Interlinkages and an update of the JRC tool to foster policy coherence for sustainable development in EU policymaking

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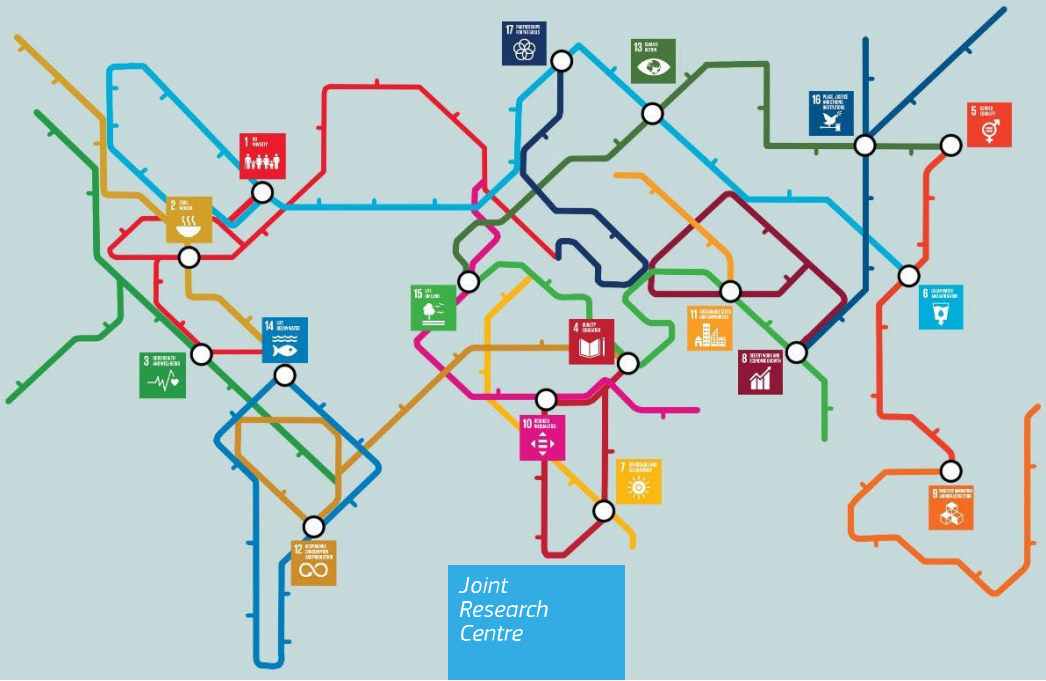

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Contents

Abstract

The 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs) are the plan of action to secure peace and prosperity for people and the planet. The SDGs are designed to be integrated and indivisible. In this context, the concept of SDG interlinkages refers to the **complex network of interactions existing within and between SDGs**. This study presents an in-depth review of the growing body of literature providing evidence of positive and negative interlinkages in different contexts.

The goal is two-fold. On the one hand, the report discusses **the state of the art on SDG interlinkages research**, looking at the frequency of pairwise interaction, their type, description and geography, as well as the methodologies used to capture interlinkages and their limitations. On the other hand, the study highlights the importance of **understanding SDG interlinkages for shaping coherent policies** that maximize synergies and minimize trade-offs in SDG implementation.

The review shows that authors apply a mix of methods to capture interlinkages, with data analysis becoming increasingly relevant while semantic analysis decreases in popularity. Similarly, as SDGs become increasingly operationalized, research, which initially focused on the global level, begins to contextualize interactions at lower geographical scales.

Most of the interlinkages collected are synergies (positive interlinkage), with SDG 6 appearing with overwhelming frequency, which highlights both the synergistic nature of the goal on water and a possible bias in the literature towards collecting synergies and focusing on specific goals. On the contrary, SDG 2 and its targets have the most negative interlinkages (trade-off), confirming the complexity of the goal on ending hunger. SDG 7 on energy is also frequent, both in terms of synergies and trade-offs, whereas less interactions are recorded for more overarching SDGs like 16 and 17.

At the same time, the report shows how the data collected can be used to analyse interlinkages from different perspectives and for specific policy areas. In this way, the study bridges interlinkages analysis with real-life policymaking. Indeed, the information collected feeds into the update of the **JRC SDG Interlinkages Tool**, which allows users to visualize and understand interaction existing between specific goals and targets. In this way, the Tool can support policymakers to approach the complex network of SDG interactions and **enhance policy coherence for sustainable development**.

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A first literature review was carried out at the JRC in 2019 by Miola A., Borchardt S., Neher F., Buscaglia D. (2019). Following up on this exercise, the authors updated and expanded the methodological approach and the analysis of all the relevant scientific and grey literature on SDG interlinkages. The work of (Miola et al., 2019) is acknowledged.

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1 Introduction

The adoption of the 2030 Agenda and its underlying Sustainable Development Goals (SDGs) constitutes a milestone in the debate on sustainability and sustainable development (United Nations General Assembly, 2015). The comprehensiveness and ambitiousness of the 2015 objectives favoured their embracing, practice, and review from different sectors and at various levels (Allen et al., 2019). Not only in policymaking, but also in research and business, the Sustainable Development Goals (SDGs) have become a common benchmark to frame the discourse and action around sustainability (van der Hel & Biermann, 2017; Van Tulder et al., 2021). Hence, it is of fundamental importance to understand how the implementation of the SDGs should be carried out to achieve their potential for sustainable development while reducing trade-offs among goals to a minimum.

With this in mind, a well-rounded assessment of SDG interactions becomes the necessary premise to achieve the 2030 Agenda while fully comprehending its implications, spillovers, and positive and negative feedbacks. The following section will first outline the relevance of the 2030 Agenda and its universal and integrated nature. Secondly, it will delve deeper into SDG interlinkages to finally discuss the scope and objective of this exercise: allow policymakers to visualise and understand sustainability interlinkages to support them in their decision-making process – from agenda setting, to creating and monitoring intended and unintended effects of new policies, in order to orient policymaking toward the pursuit of sustainable development trajectories.

1.1 The 2030 Agenda and the Sustainable Development Goals

In 2015, the United Nations Member States adopted the resolution *"Transforming our world: the 2030 Agenda for Sustainable Development"*, a global plan of action to secure peace and prosperity for people and the planet while leaving no one behind (United Nations General Assembly, 2015). With 17 SDGs and 169 associated targets at its core, the 2030 Agenda can be seen as a major political achievement because it anchors sustainable development as a comprehensive concept within international and national policymaking (McCollum et al., 2018). Balancing the three dimensions of sustainability - economic, social, and environmental - through a comprehensive and holistic set of sustainable development objectives to be achieved by 2030, the Agenda builds upon and improves the preceding eight Millennium Development Goals (MDGs) signed in 2000, which primarily focused on social and economic development and presented shortfalls and limitations in how they were designed and unevenly implemented (Fehling et al., 2013; Kanie & Biermann, 2017).

Conceived as "integrated and indivisible" (Costanza et al., 2016), the SDGs, their targets, and indicators, have an interconnected nature enshrined by design. The network of 17 goals, focusing on issues ranging from poverty to energy, infrastructure, and climate, highlights that social justice and economic wellbeing cannot be achieved without the support of healthy ecosystems, and that, vice versa, addressing social and economic inequalities is fundamental to environmental preservation, restoration, and enhancement. The strong interconnection existing among the SDGs is also the fruit of the consultations and negotiations across a broad range of actors through the years and is shown by the partial overlap between some of the SDG targets, which rely on the same indicators to monitor progress in their respect (ICSU, 2017; Tosun & Leininger, 2017).

The novelty of the 2030 Agenda compared to previous international agreements on development lies also in the vision it proposes by calling for the implementation of all the SDGs in a universal, indivisible, and consistent manner, leaving no one behind (Breuer et al., 2019). Firstly, universality implies that no goal is more important than the others are, and that all SDGs must be simultaneously achieved at a global scale to attain sustainable development (UNEP, 2021b). At the same time, the focus on indivisibility in SDGs implementation implies a complex network of interdependent and interconnected interactions. In light of a universal and interdependent SDG framework, the third fundamental ingredient for a successful progress on its achievement is the principle of Policy Coherence for Sustainable Development (PCSD), also embedded into one of the targets of the Agenda (target 14 of SDG 17 on global partnership), to be achieved vertically and horizontally, including all relevant actors at all scales (Breuer et al., 2019).

1.2 SDG Interlinkages, at the core of interconnectedness

When looking at this framework from such a holistic perspective, it becomes clear that the interconnections present in the 2030 Agenda go beyond the three-pillared conception of sustainable development, encompassing a more ramified and complex set of interactions - the SDG interlinkages. Already in 2016, this was a recognised reality, and the Interlinkages Working Group was established within the United Nations Inter-Agency and Expert Group on Sustainable Development Goal Indicators (IAEG-SDG), the group in charge of monitoring and reporting on the complex interactions across SDGs (UN IAEG-SDG, 2020). Additionally, the need for addressing SDGs as a network of interacting elements has been further stressed in academia (Alcamo, 2019; Bennich et al., 2020; Pham-Truffert et al., 2020). As a result, interlinkages have been analysed by a relatively new but increasingly wider body of literature, looking at the 2030 Agenda in an integrative way. This research provides evidence on existing and potential interlinkages between and within SDGs, across spatial and temporal scales, with or without specific thematic focus and data disaggregation (see, for example, Kroll et al., 2019; Pradhan et al., 2017).

SDGs interlinkages are here identified as the interaction between two distinct SDGs or respective targets and indicators, although the literature has also identified interlinkages within the same goal (see, for example, Kroll et al., 2019), as well as interactions across SDGs clusters of multiple goals (see, for example, Hutton et al., 2018). Interlinkages between SDGs can occur at goal-, target- or indicator-level, including distinct levels at the same time, for example, in the case of an SDG target impacting a goal and vice versa. These relations are usually characterised as either synergies or trade-offs. On the one hand, **synergies** represent positive interactions where progress of an SDG goal/target/indicator (from this point forward, SDG) promotes, contributes, or enables progress on another one. On the other hand, **trade-offs** are negative interactions where progress of an SDG deteriorates progress towards another one. It must be stressed that, given what has been discussed so far, the multidimensional approach of the 2030 Agenda creates the possibility for both synergetic and conflicting effects to occur at the same time.

These interlinkages can be further characterised by **directionality**, determining which SDG is the source of the interlinkage and which one is impacted. Additionally, the **strength** of interlinkages can also be studied, meaning that some analyses are able to capture stronger and weaker interactions. Another type of categorisation looks at the **order** of interlinkages. In this context, first order interlinkages represent direct influences between SDGs, while further orders (e.g., second order interactions) indicate indirect influences mediated by other goals, targets, or indicators. It must be noted that the interactions across SDGs are highly **context-dependent** and thus influenced by geographical settings, resource endowment, economic and technological factors, governance and legislation in force, as well as the time-horizon adopted for their evaluation (Nilsson, 2017; UN-Water, 2016).

For what concerns geographical and temporal scales, two particular types of interlinkages are transboundary and intergenerational spillovers. A **transboundary spillover** occurs when the progress or deterioration of an SDG in a certain country affects the advancement on sustainable development of other countries, while an **intergenerational spillover** is the impact of today's actions on future generations (EUROSTAT, 2021). This kind of intergenerational effect can happen when the spillover arises with considerable time lags. As an illustrative example, climate action implies both transboundary and intergenerational spillovers, as the greenhouse gas emissions from one country have negative effects (externalities) beyond national frontiers and will have impacts for generations to come, well beyond the generation responsible for the emissions. The consideration of all specificities and contextual dependencies of SDG interlinkages is useful to better comprehend them and to determine under which conditions and in which contexts they can arise.

1.3 A review of interlinkages in the 2030 Agenda

The presence of SDG interconnections shows potential for both virtuous progress and drawbacks for SDGs and their targets, which leads to the necessity to identify and understand the different interlinkages existing in the 2030 Agenda. Uncovering how SDGs link to each other would support policy makers striving to achieve holistic sustainable development in the challenge of designing and adopting policies that maximise progress across the 17 goals and avoid the unintended deterioration of any of those (Allen et al., 2019; Fu et al., 2019). In other words, implemented policies and actions directed to the promotion of one goal should foster synergetic relations

with the other objectives, while reducing conflicts and trade-offs that could happen simultaneously. This is key for targeting policy coherence for sustainable development – a cornerstone for advancing a sustainability transition in which no one is left behind.

For this reason, the SDG team at the Joint Research Centre (JRC) carried out an analysis of interactions in the 2030 Agenda by systematically revising the most relevant scientific and grey literature available on the topic. The aim of this exercise is to strengthen collective knowledge on SDG interlinkages and on the methods to assess them by detecting their existence and frequency and collecting information on their characteristics. The review builds on a similar exercise, more limited in scope, conducted by the JRC in the past years (Miola et al, 2019), and expands on its methodology and results, as, since then, further literature has been produced, requiring a new and more comprehensive assessment.

The ultimate goal of this assessment is to consolidate a comprehensive and robust knowledge base of SDG interlinkages that can support policy makers in coherently and effectively advancing the SDGs by anticipating interactions and identifying leverages and entry points. At the same time, the exercise intends to promote and enhance stakeholders' awareness of the 2030 Agenda. Providing information to contextualise and interpret the interlinkages data is an essential aspect, and for this purpose the database resulting from this extensive review feeds into the Interlinkages section hosted at the JRC KnowSDGs Platform[1]. Indeed, this review updates and expands the tool through which users, be them policy makers, academics, citizens or other stakeholders can access, filter, and retrieve the collected data, learn more about positive and negative SDG interlinkages, their contexts and descriptions, and build visualisation illustrating the interconnected nature of SDGs.

[1] https://knowsdgs.jrc.ec.europa.eu

2 Methodology: an exhaustive literature review

The assessment of SDG Interlinkages requires the identification of the interactions along with their varying characteristics. This section will describe in detail the literature consulted and methods applied to reach these objectives: firstly, the review process carried out to collect available information on SDG interlinkages; secondly, the organisation of the data in a detailed database; finally, the database processing and preparation for the analysis.

2.1 Literature search and collection

In order to identify and retrieve relevant SDG interlinkages, a structured literature review was conducted in Scopus and Google Scholar to collect both grey literature and peer-reviewed publications as a source of information. The review started in May 2021 and focused on the documents published from 2015, the year of the adoption of the 2030 Agenda, onwards, whereas the second search aimed at updating the pool of publications from May 2021 until August 2022. To retrieve the material, for both databases a keyword string was used, combining the alternative terms "sustainable development goals" and "SDGs" with alternative terms referring to interlinkages (such as "interactions," "trade-offs," "synergies," and more)[2]. The keywords were selected based on qualitative inputs from experts in the domains of sustainable development and interlinkages.

To ensure topic relevance of the retrieved publications, the keyword string in Scopus was only applied to title and paper keywords to ensure that the topic of SDG interlinkages is central in the publication, rather than a mere mention in the text or abstract. Similarly, the grey literature collected from Google Scholar was limited to the first pages of results meeting the inclusion criteria retrieved through Google Scholar's advanced search engine. Given that the search algorithm of Google ranks results accounting for their relevance with respect to the keywords searched, the first pages of results contain the most pertinent material. For what concerns the peer-reviewed resources, only journal articles, reviews, and books chapters were collected. Reports, policy briefs, working papers and further non-peer-reviewed studies were selected with reference to the grey literature. Additionally, a few documents were added to the pool of retrieved publications based on the suggestion of experts and backward snowballing in the documents' bibliography.

Once the resources were collected from Scopus and Google Scholar, a first manual screening ranked them according to their thematic relevance, to consolidate a pool of key publications. A five-point relevance score elaborated by the authors, ranging from 0 to 4, was used to indicate the degree of correspondence of each publication to the ideal case of a study illustrating the interlinkages among SDGs (for further details, see Table 1). The pool of key publications analysed in the framework of the present review contains documents obtaining the maximum relevance score of 4, as well as a limited number of journal articles with a score of 3[3].

Table 1. Relevance scores used to rank the literature collected

Relevance scores	Description
4	focusing on SDG interlinkages
3	focusing on interlinkages between SDGs and topics clearly associable with SDGs
2	focusing on topics clearly associable with SDGs but not on interlinkages
1	focusing on interlinkages between (SDGs and) topics not clearly associable with SDGs
0	not relevant (e.g., publications illustrating none or unclear interlinkages data, or mentioning interlinkages data exclusively from other publications)

[2] The full query is as follows: "sustainable AND development AND goals" OR "SDGs" AND "inter-linkages" OR interlinkages OR interconnections OR interactions OR "trade-offs" OR trade-offs OR conflicts OR synergies OR "co-benefits" OR benefits OR externalities.

[3] Publications with a score of 3 were considered in the case that the study analysed SDG interlinkages with a very explicitly SDG-linked topic, for example, the interlinkages between SDGs and climate action, mitigation, and adaptation, which is almost the description of SDG 13.

The pool of key publications identified through the literature search was further integrated with additional literature meeting the criteria of maximum relevance. These further publications were retrieved in three ways: either advised by SDG experts from the JRC and the Sustainable Development Solutions Network (SDSN); identified through bibliographic references from the publications reviewed; or were included in the resources reviewed in the context of the exercise mentioned above (see Miola et al., 2019).

The exercise globally considered a total of 454 documents published from 2015 to August 2022. Of these documents, 92 were selected as relevant for review and constitute the final pool of key publications included in the database and from which interlinkages were retrieved (see the full list in the Annex).

2.2 Review process

For each publication reviewed, an extensive set of information was recorded in an Excel database, as detailed in Table 2. This information focuses on the features and methods of the publication.

Table 2. List of methodological information collected for each selected document

Variable	Description
Type of document	Type of publication reviewed (article, review, report, conference paper, grey literature)
Bibliographic details	Authors, Title, Year, Journal, Link, Abstract, Keywords
Source	indicates the source from which the paper was retrieved (Scopus, Google, expert identification, bibliographic reference)
SDGs considered	List of the SDGs analysed in the document
Thematic focus	Present when the publication focuses on interlinkages for a particular SDG/a group of thematic SDGs
Analytical scale	The level at which SDG interlinkages are assessed ("goal", "target", "indicator" levels, or combinations of the previous).
ESTAT indicators	Present when EUROSTAT's SDG indicators are considered
Clear directionality	If the assessment considers the directionality of the interlinkages (Yes / No).
Geographical scale	The geographical scale of the SDG interlinkages assessment (global, multinational, regional, national, subnational, local, "n.a." when no specification is provided or can be deducted).
Geographical context	Further specification of the geographical context, e.g., which region, country, city if applicable.
Time scale	The time scale (reference years) of the data or the assessment, if specified
Method type	The methodology used ("modelling", "expert judgement", "literature review", "data analysis", "semantic analysis", or "mixed" to label combinations of the methods)
Method description	Brief text description of the methodology
Method limitations	If any, it summarizes the observed method limitations described in the publication
Key results	Record key results of the publication, as described in the text
Transboundary spillovers	If the study mentions the presence of transboundary spillover effects (Yes / No).
Intergenerational spillovers	If the study mentions intergenerational spillover effects (Yes / No).
Second-order interlinkages	If the study assesses second order (indirect) interlinkages (Yes / No).[4]

[4] Non-first order interlinkages were not recorded in the database of interlinkages as they represent an indirect relation.

The general analysis of each publication was followed by a specific investigation of the SDG interlinkages contained in-text. For each interlinkage indicated by the literature, the data was recorded only when the relationship between a pair of SDG goals, targets or indicators was clearly identifiable. As portrayed in Table 3, the information[5] registered includes the directionality, the two SDG goals/target/indicators involved in the interlinkage (source and objective in case of clear direction), the type of interaction, the specification of its strength, the geographical and temporal scales of the interlinkages (when available). Finally, the database records the textual description of the interlinkage, in the publication, which contextualises and provides more information regarding the nature of the registered interactions.

Table 3. List of information collected for interlinkage in each document

Variable	Description
SDG A	First SDG goal/target/indicator of the pair interlinkage as indicated in the publication. In case of clear directionality, it is the source from which the interlinkage stems.
SDG B	Second SDG goal/target/indicator of the pair interlinkage, as indicated in the publication. In case of clear directionality, it is the one affected by the source
Clear direction	If it is possible to identify a clear direction of the interlinkages (Yes/No). If not, the distinction between source and objective does not exist.
Interlinkage type	Synergy, trade-off, mixed or not specified (if not explicitly specified)
Interlinkage strength	Quantification/specification of the strength of the interlinkage, if available.
Interlinkage description	Text explanation of the interlinkage, as indicated in the publication, if available.
Interlinkage geographical scale	The geographical scale/context at which the interlinkage arises, if available.
Interlinkage time scale	The years considered by the analysis, if available.

As mentioned, recorded interlinkages display a clearly identifiable relationship between a pair of two different SDG goals, targets, or indicators. On the contrary, unclear interlinkages, for example, those illustrated by vague graphical representations, were not recorded[6]. Similarly, interlinkages featuring the exact same SDG as both the source and objective of the link, for instance, interlinkages within target 1.2 and target 1.2, were not registered, as they were considered not meaningful. In general, the interlinkages recorded were always the results of the analysis conducted in reviewed publication except for "review" papers – in this case, interlinkages stemming from other sources mentioned by these papers were also recorded if they were not already included in the database of publications selected.

For what concerns the type of interaction, when the information was available in the publication, interlinkages were recorded as either positive (synergies), negative (trade-offs), or mixed, when displaying both positive and negative relations. Each interlinkage was further characterised in terms of directionality, specifically, whether the effect of the relation was clearly directed from one SDG to the other. All descriptions regarding interlinkages concerning the same pair of SDGs with the same direction at the same geographical scale was recorded as a single entry. On the contrary, an interlinkage indicated by a study as presenting bi-directionality, i.e., having clear twofold direction, was recorded as two different interlinkages (A → B and B → A). Similarly, one interlinkage presented at different geographical scales, for example, for two or more European countries, was registered separately.

In case of inconsistencies between the figures, tables and text, data was recorded according to the figures and tables, or the authors were contacted for further information. In case of clear unintentional typos from the authors, the reviewer corrected the inaccuracy.

[5] It must be noted that all the mentioned information was recorded only when available, which was not always the case for all publications.

[6] In the cases where figures portraying interlinkages were presented in a document but the representation was not clear enough, the authors of the publications were contacted to obtain the datasets behind the figures. If the data was made available, the related information was recorded in the database of this study, otherwise the data was not recorded.

Further interventions from the reviewer were as following. As mentioned, the present exercise attempted to capture first-order interlinkages only. For this reason, all those interlinkages presented as first-order but, based on the description provided, rather appear as second or third order, were left out from the database. Secondly, when needed, the sign of an interlinkage was adjusted to avoid biases in the interpretation of the type of interaction (if synergy or trade-off). The adjustment happened, for instance, for some of the publications containing interlinkages at the indicator-level. With indicators, it can be that a negative relation is portraying a synergy with the objective of the related target or goal, and vice versa. For example, indicators that measure poverty (SDG 1) or malnutrition rates (SDG 2) must decrease to progress towards the respective goals of ending poverty and hunger. For this reason, it is important to correctly classify a negative or positive interlinkage involving an SDG indicator based on progress towards sustainable development to guarantee a coherent interpretation of interaction. In most cases, studies adjust their methodology to account for this aspect, to ensure that their results can be correctly interpreted. However, when a study under review did not consider this element or did not do it in a consistent manner, the interlinkage type was corrected to avoid bias and mistake in the analysis of the data. Finally, when the interlinkage type and directionality of an interlinkage was not specified in the publication but was clearly deducible, for example, from the text description, this information was also added to the database to retain more meaningful information.

2.3 Data cleaning and processing

As data on the specific interlinkages was collected manually, the resulting database was processed for further data cleaning and harmonisation in Python and SPSS. For the processing, the individual sheets for each publication were merged to facilitate subsequent data analysis. Empty rows were removed along with duplicated rows and additional metadata like information on geographical scales and methods used within each publication was added to each interlinkage. The source SDGs and the objective SDGs were processed and cleaned to ensure that only rows with valid SDG labels on both goal- and target-level were considered in the later aggregations (this included removal of whitespaces, replacing of commas with periods, double checking target and indicator labels against official SDG labels, converting indicators to targets). Similarly, the columns on directionality and interlinkage type were harmonised to retain only binary values for directionality ('yes' or 'no') and unique descriptors for interlinkage types ('+': synergies, '-': trade-offs, '-/+': mixed, 'n.a.': non-specified). Columns containing information on the interlinkages, such as its description, geographical and temporal scales, were also processed to harmonise the text (capitalisation, punctuation, whitespaces removal, etc.) and facilitate spotting duplicates and subsequent data aggregation. To summarise the information on the vast number of interlinkages collected the same strategy was adopted for both the report and the KnowSDGs platform. The cleaned data was further processed to enable additional analyses and data visualisations. In the case of undirected links, interlinkages were untangled, duplicating them and swapping the source and objective for the duplicated link to retain the information for both SDGs (for example, for a recorded undirected interlinkage SDG 2 ←→ SDG 3, the link is repeated twice, both stemming from SDG 2 to SDG 3 and vice versa). Similarly, to ease the understanding and use of the platform, mixed interlinkages were also untangled as two different links: one synergy and one trade-off, as mixed link refers precisely to a case where the interaction can be both positive and negative. Any duplicate emerging from these operations was dropped. Moreover, univocal pairs of interlinkages with the same source and objective, type and directionality but considered multiple times by the same publication because of different geographical contexts were retained only once by aggregating interlinkages descriptions, strength temporal and geographical scales. For goal-level visualisations, univocal interlinkages in the same publication were further merged by type and direction at the goal level, aggregating the relevant information.

For analytical purposes, the resulting database of interlinkages was processed to identify goals and targets with the highest number of links by type, as well as specific pairs of goals and targets that were most prominently addressed by the reviewed publications, counting univocal links (same publication, SDG source and objective, type and direction) without considering non specified interaction. The above-mentioned aggregations were also applied to subsets of the data representing various focal points of the analysis. The first is a dataset on interlinkages within an EU context (only retaining links identified in the context of an EU country, multiple EU countries or at the European Union level in general). The other two datasets were created to facilitate methods comparison by retaining only links identified through expert judgment and data analysis.

3 Results of the review

This section presents and discusses the results of the analysis of the collected literature. As a first step, the methodological information is provided and reflected upon, including a breakdown of results based on the different variables recorded through the literature review. Emerging trends and gaps are highlighted. As a second step, interlinkages are more explicitly analysed with respect to their occurrence, frequency, and characteristics, also focusing on the various variables at play.

3.1 Main methods for SDG interlinkages assessment

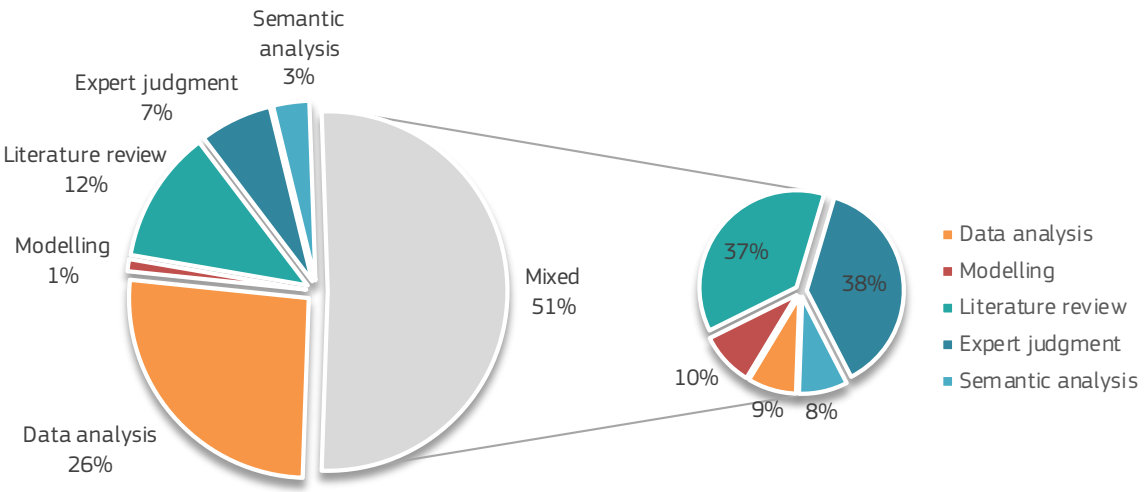
Following the antecedent JRC exercise on SDGs Interlinkages (Miola et al., 2019), the methods used to assess the interlinkages within the final set of 92 publications were grouped under five major domains:

1. Data Analysis, i.e., establishing interlinkages between SDGs based on a qualitative or quantitative analysis, for example, using correlation and covariation analysis.
2. Expert Judgement, i.e., evaluating SDGs interrelation based on the argumentations and judgements of a set of selected experts, which can be collected using surveys, interviews, group discussions, amongst others.
3. Semantic Analysis, i.e., linking SDGs based on their wording and what they mean, for example, through a keyword search or text analysis.
4. Modelling, i.e., using models pertaining to different policy sectors, such as Integrated Assessment Model (IAMs) or future scenarios based on emission pathways, to evaluate SDGs interactions.
5. Literature Review, i.e., carrying out an exhaustive document search to identify interlinkages previously established in the literature, and discussing them.

In the database created through this review, more than half of the papers (47 out of 92) applied a mixed approach including two or more of the methodologies presented above. In 37 cases, authors combined literature review and expert judgment. Sometimes, literature review and expert judgement were applied together with semantic analysis (7 documents), data analysis, or modelling (4 documents respectively).

Figure 1 provides methodological details. Among the collected documents, 45 publications applied one single methodology: 24 used data analysis (mostly correlation), and 11 used a literature review approach, with these two methods representing the most adopted single methodologies. Expert judgment was used in 6 papers as a stand-alone method, whereas semantic analysis three times and modelling just once.

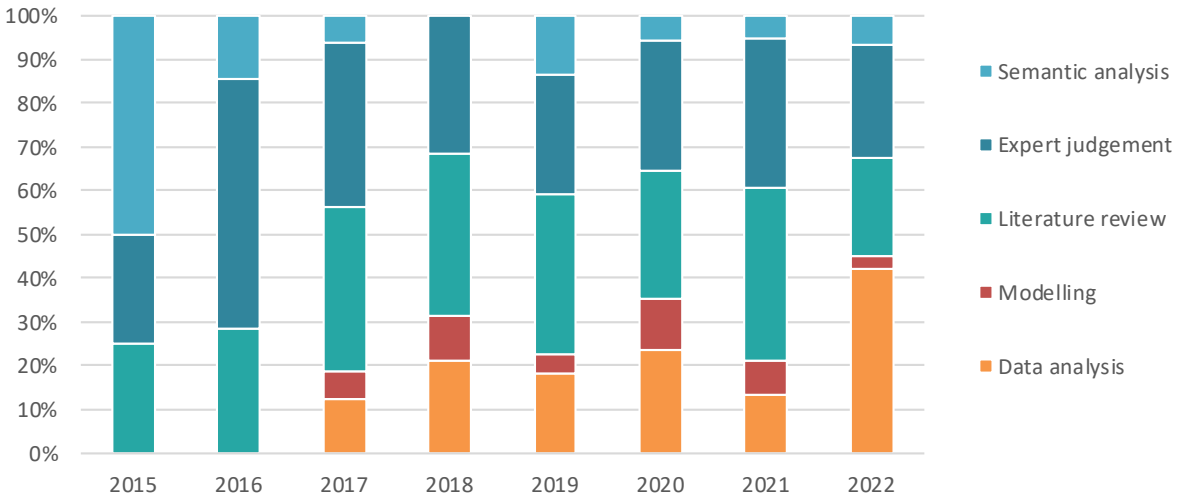
Figure 1. Methodologies applied in the reviewed publications and detail for mixed approaches



Source: Authors' elaboration.

Figure 2 below illustrates the trend of methodologies applied to identify and analyse interlinkages over time. At the beginning - with the adoption of the 2030 Agenda - most studies applied semantic analysis in response to the need of gaining a better understanding of the framework, its goals, and targets. Additionally, qualitative methods like expert judgments and literature reviews were applied to tackle the complexity of such a holistic sustainable development agenda. Hence, both qualitative appraisal experts and qualitative coding of SDG descriptions provided an entry point to understating pairwise interactions. After a shared understanding of the SDGs and their interlinkages was established, the ongoing operationalisation and progress monitoring of the SDGs led to new datasets and available data sources, opening the door for the application of more quantitative methodologies to analyse SDG interlinkages (e.g., correlation analysis). While qualitative approaches still play a crucial role in the studies of SDG interlinkages, more elaborated methods like modelling and network analysis complement the pool of literature over time.

Figure 2. Trend over time of the methodologies applied in the reviewed publications



Source: Authors' elaboration.

The results above suggest that data analysis and literature reviews are the preferred standalone methodologies to assess SDG interlinkages, although they are rarely used in combination with each other. A broad uptake of data analysis and literature review is not surprising: as stated in Bennich et al. (2020), the main data sources for mapping SDG interlinkages are scientific literature and official databases. The trend may owe to online data availability and the relative approachability of the two methods, especially when it comes to literature review and document analysis.

The above can also suggest why, in the database, expert judgement is not applied extensively as the unique method in a publication. Expert elicitation requires careful planning, organisation, the provision of external knowledge and its interpretation by harmonising contributions written in different formats and tones through rigorous and fine-tuned qualitative analysis (see for example, the methods for Hutton et al., 2018; McCollum et al., 2018). However, this methodology is widely applied in SDG interlinkages studies to better interpret interactions and to understand them in context and make up for lacking data and literature (Bennich et al., 2020; Ospina-Forero et al., 2022).

In the database, expert judgment appears more often in combination with other methodologies, especially literature review, which facilitates deliberation by grounding the discussion in existing evidence. It is also interesting to note that in many cases, papers using expert judgment apply the scale first developed by Nilsson et al. (2016), which consists of a 7-point scale scoring negative, neutral, and positive SDGs interactions ranging from "cancelling" (-3) to "indivisible" (+3).

Semantic analysis and modelling are both scarcely represented in the database. On the one hand, when it comes to semantic analysis, its limited use might have a temporal explanation: the publications analysing interlinkages based solely on semantic analysis are written between 2015 and 2017 (Le Blanc, 2015; Tosun & Leininger, 2017) when the 2030 Agenda was still relatively new and not much ad-hoc data was available to assess it. In

that period, SDG wording was the most accessible way to understand interlinkages. However, as SDGs specific data is collected, researchers have been increasingly able to use this data to examine SDG interactions, for instance, using progress on indicators, rather than only the links emerging from the text of each SDG.

On the other hand, the limited application of modelling can have both a general and a contextual explanation. First, in general, a model requires a deep understanding of a system to evaluate interactions in a meaningful way (Ospina-Forero et al., 2022), and it is common knowledge that the SDG network of 17 goals and 231 indicators is rather complex (for example, Allen et al., 2019; Bali Swain & Ranganathan, 2021). Few models specifically address SDGs interlinkages (a recent example is found in Anderson et al., 2022), thus, most of the analyses are based on the association of SDGs with model's indicators and/or on the adaptation of existing models designed for other policy fields, with all the limitations implied (Barbero Vignola et al., 2020). Integrated assessment modelling (IAMs) approaches, originally developed to study the interrelations among energy, the economy, climate, and land, and are most used. IAMs are applied to explore future developments of complex socio-ecological relations or scenarios of change based on SDG trade-offs and synergies (Hutton et al., 2018; Marcinko et al., 2021), and existing models are also linked to SDGs (e.g., MAGNET model in Philippidis et al., 2020).

Finally, interestingly, network visualisation techniques are often implemented across papers to represent interlinkages obtained through other analytical methods like expert judgement. Moreover, network analysis is used to examine the characteristics of the SDGs network. The application of this kind of analysis is rather self-explanatory: as underlined in the introduction, the SDGs form a network of feedbacking interactions. While network analysis measures like closeness and centrality can provide useful insights on the role of SDGs (network nodes) inside their network, measures like network density and transitivity allow insights on the interconnectedness of the network and the nature of the connections (edges) between SDGs. Network visualisation techniques can support those insights by providing a visual representation of this network through nodes and edges showing the degree of connectedness of each SDG and SDG clusters, their centrality in the network and the direction and strength of the interactions (see, for example, Allen et al., 2019; Bennich et al, 2020). However, with increasing complexity in the network due to increasing numbers of nodes and edges, visual interpretations can be hampered and limit the readability of those visualisations.

3.2 Literature in focus: trends and gaps for selected variables

Besides the methods used in the publications, the papers were analysed for an extensive set of variables. For what concerns the analytical scale, one-third of the publications looked at interactions both at goal- and target-level, one quarter focused on goal level only, another quarter on target-level, and 7 publications are present for indicators only and for analyses of all three levels (Figure 3).

Figure 3. Venn diagram: analytical scale of the reviewed publications

Source: Authors' elaboration.

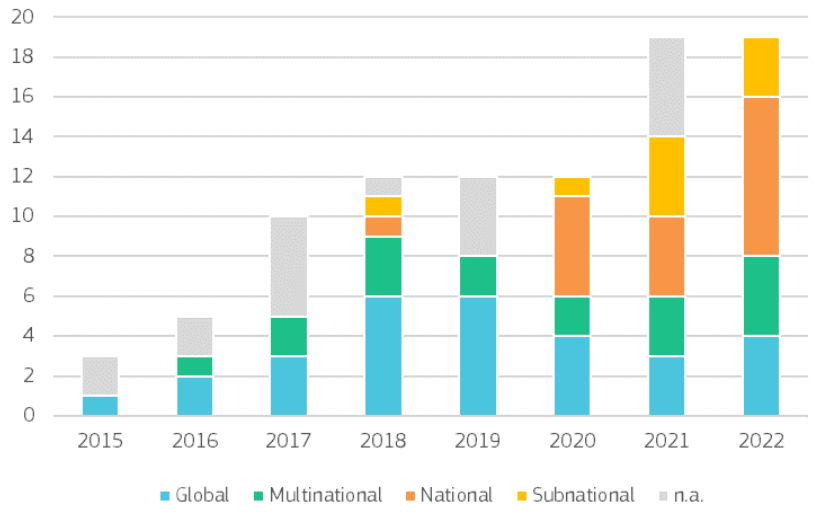
Looking at the geographical scales considered in the papers, 73 documents had a clear geographical focus (Figure 4). Of these, 29 papers provided a global outlook, whereas 17 adopted a multinational[7] scale (more than one country considered at the same time). The national and subnational[8] scales count 19 and 9 documents, respectively.

Figure 4. Geographical scale of the reviewed publications (number and percentages on the total of publications with specified geographical scale)

Source: Authors' elaboration.

There is a visible trend over time: publications initially focused on the global and multinational scale before researchers progressively narrowed their view towards the national and subnational level (Figure 5). This trend aligns with the general process of operationalising the SDGs: while research strives to establish a general understanding of the framework in the beginning, ongoing research focuses increasingly on specific contexts in which the more general knowledge can be specifically applied and translated to ultimately support the operationalisation and implementation of the SDGs.

Figure 5. Trend over the time of the geographical scale

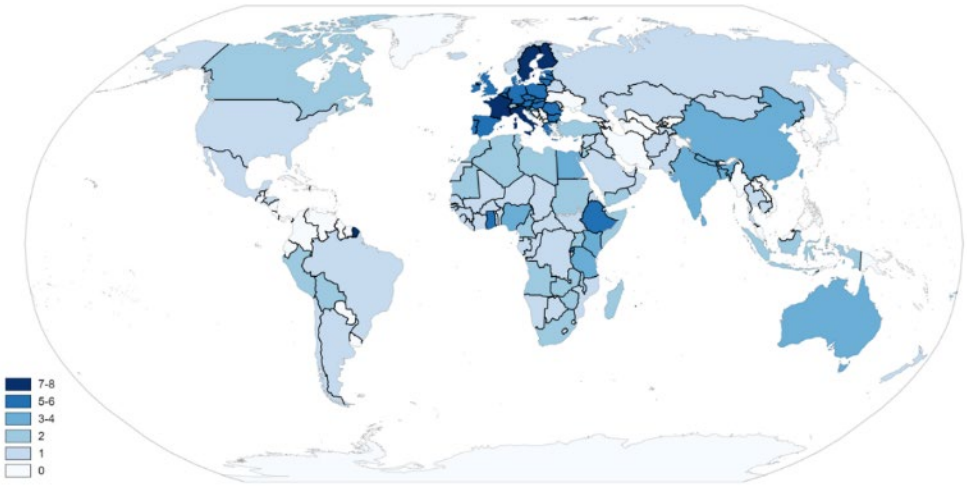


Source: Authors' elaboration.

[7] Multinational here includes both macro geographic areas (e.g., Africa, European Union) and other types of socio-economic aggregations (e.g., low income countries).
[8] Subnational here refers to a combination of "subnational" (e.g., Northern Canada) and "local" scales (e.g., Norrkoping municipality, Sweden).

For the subset of publications where a geographical scale is specified, both at national, sub or multi-national levels, the map in Figure 6 show the country coverage of the interlinkages analysed in the reviewed publications. Every country is counted once when there is a publication referring to that country or a geographical area including it (e.g. East Africa, South Asia, EU). The highest frequency of the European countries is explained by the fact that five papers focus specifically on EU Member States' data.

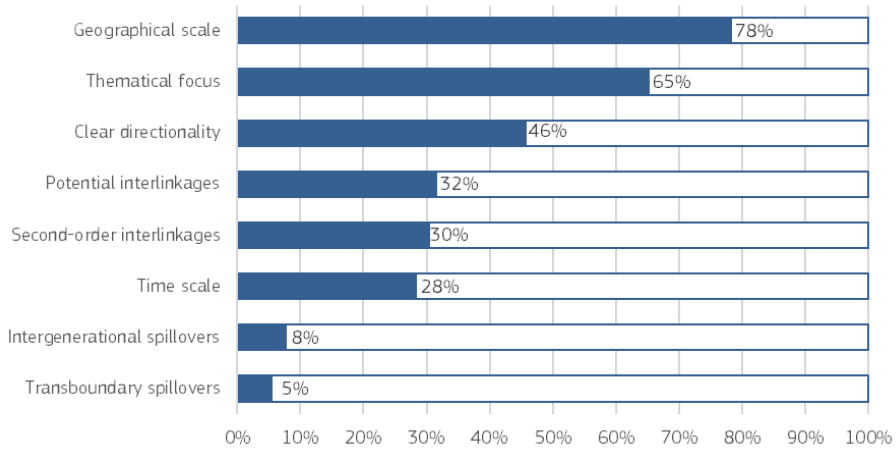
Figure 6. World map with the number of publications by country



Source: Authors' elaboration, using IMAGE (Interactive map generator) © European Union.

Other information collected is available only for a subset of publications, and could be utilised for further analysis, comparison or focus on specific topics. As seen in Figure 7, for example, the geographical scale was a feature present in many of the reviewed publications, on the contrary, only one-fourth of the papers mentioned a time scale, even though a substantial number of publications discussed interlinkages based on potential time-dependent relations, i.e., interactions based on forecasts rather than existing data. Moreover, two-thirds of the publications presented some sort of thematic focus, for example, analysing the interlinkages between a specific SDG and all the others. Documents paid special attention to SDG 6 on water; SDG 7 and its targets; SDG 14; SDG 3 at the goal or target-level. Paper also discussed interlinkages across a specific set of SDGs (e.g., SDGs 2, 6, and 7 representing the WEF, Water – Energy – Food -Nexus). Transboundary and intergenerational spillovers were mostly absent, while a higher share of the publications (30%) mentioned second-order interlinkages. Finally, as mentioned before, almost half the publications captured clear directionality.

Figure 7. Percentage of information available in the reviewed publications



Source: Authors' elaboration.

The overview provided confirms the challenging task of capturing and characterising SDG interlinkages in a consistent manner. This is a multifaceted challenge. SDG data consist inherently of short time-series (10-20 years) and a limited number of observations, thus hampering certain types of statistical analysis (Ospina-Forero et al., 2022). Moreover, there is limited availability of consistent data when it comes to monitoring and measuring the achievement toward SDGs because data collection capacities vary from country to country, also due to varying degrees of countries' commitment, attitude, engagement with the SDGs as well as research attention towards the SDGs around the world. Consequentially, gaps exist for specific years, countries, and indicators (Breuer et al., 2019) – possibly skewing analysis toward certain indicators and geographical areas *vis* à *vis* others.

At the same time, the more data is made available, the more difficult it is to make sense of it in a coherent way to capture interlinkages, requiring further processing and aggregation (Hegre et al., 2020). Small data samples with consistent gaps explain why the methodological limitations flagged by most authors of the papers in the database is the lack of coherent data to capture SDG interlinkages. It is self-understanding that these gaps limit the scope of the analysis and the lessons learnt from it, as well as its replicability and transferability in other studies since the faulty data requires authors to make assumptions that can potentially bias the results (Breuer et al., 2019; Requejo-Castro et al., 2020; Santika et al., 2019).

For example, lacking temporal data is reflected in the collected literature, which mostly does not place interlinkages in time. From what is highlighted by the reviewed papers, this trend may owe not only to data unavailability but also the challenges in accounting for the time lags in the manifestation of SDG interlinkages and their consequences (for example, GHG emissions generated today can manifest their impact later in the future). The more consistent inclusion of the geographical scale can also be explained in these terms: the geographical reference is easier to retrieve, both using data (because UN SDG data is recorded by country) and using a case study approach (because case studies are bound to specific geography). However, general SDG analysis without a clear geographical scale or looking at interlinkages globally can continue to overlook the importance of contextualising SDG interlinkages (Pham-Truffert et al., 2020).

Moreover, as shown, geographical coverage does not lead to examining transboundary spillovers These interlinkages refer to the impact that SDG interactions in one location have in another location and are harder to qualify and quantify, not easily captured in datasets and, consequentially, in analysis. The same can be argued for intergenerational spillovers because determining the impact of an interlinkage for future generations implies predicting with great degrees of uncertainty, which is even further aggravated by faulty datasets. The challenges of capturing spillovers can explain why the task is not widely embraced by researchers.

It is also interesting to note that the choice of methods is reflected in the variables discussed by a publication. For example, potential interlinkages are usually based on modelling and expert judgment. Network analysis allows to capture and quantify indirect interlinkages through the edges connecting more or less distant nodes. In its absence, second-order interlinkages are normally just mentioned but not analysed. Methodological challenges can also explain why most publications cannot conclude on the directionality of an interlinkage. Establishing the directionality of impact requires determining causation, which is substantially more challenging than producing correlation analysis, the most adopted approach for data analysis in the set of reviewed publications.

3.3 SDG interlinkages in the literature: an overview

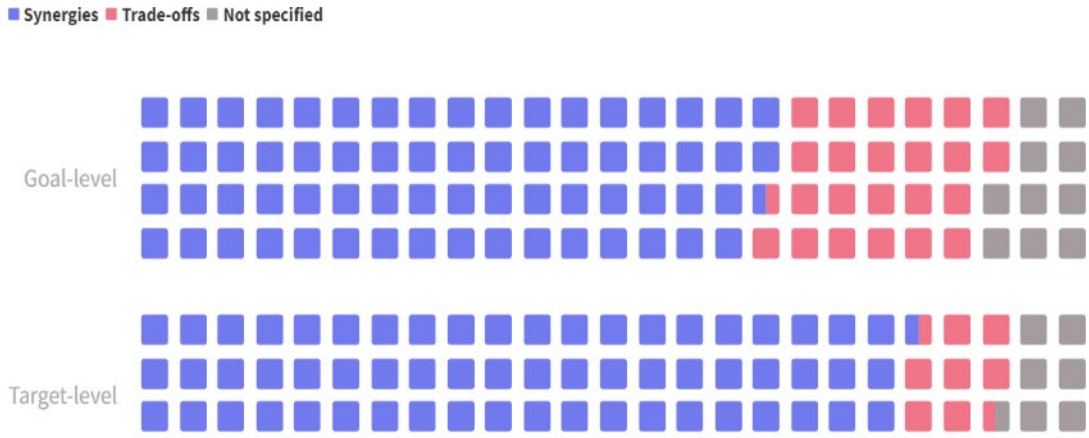
The following paragraphs describe the number and type of interlinkages collected from the publications through the literature review, providing information at goal and target-level in terms of positive and negative interactions and focusing on interlinkages identified by specific methods and at the European level.

The final database after the update of the review consists of 18780 interlinkages. Of these, 7323 represent univocal links[9] at the goal-level and 9447 univocal links at the target-level. The number of synergies detected is clearly higher than the trade-offs. At the goal-level aggregation, there are 66.5% synergies, 23.5% trade-offs and 10% not specified links. At the target-level, there are 80.5% synergies, 10% trade-offs and 9.5% not specified. The proportion of synergies and trade-offs differs because, as explained in chapter 2, at goal level

[9] Links with the same publication, SDG source and objective, type and direction.

the information has been summarized considering all the interlinkages at target level inside the same goal only once (univocal by type, pair of goals and publication). Figure 8 provides a general overview.

Figure 8. Types of interlinkages collected through the literature review (as a percentage of the total)

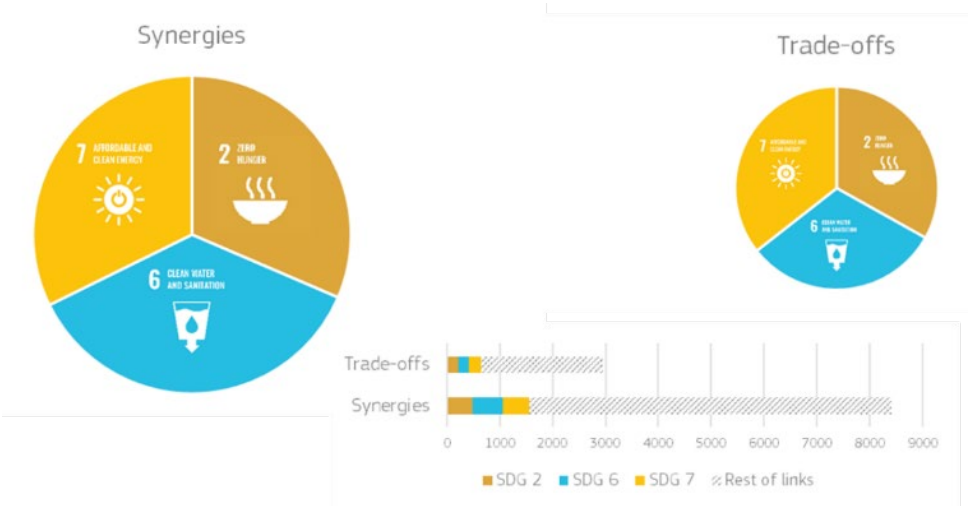


Source: Authors' elaboration, created with flourish.studio.

3.4 Goal-level interlinkages

Figure 9 shows the top three[10] goals by number of links for positive and negative interaction. The sizes of the pie charts reflect the fact that overall, synergies outnumber trade-offs. Although SDG 6 on water and sanitation is the most synergistic (present in 8.5% of all recorded synergies) and SDG 7 on affordable and clean energy records the highest share of trade-offs (present in 10% of all recorded trade-offs), for both synergies and trade-offs these SDGs are the most identified, together with SDG 2 on ending hunger – they cover at least one-fourth of all recorded interlinkages for each type of interaction, as shown in the bar graph. These results may in part reflect the abundance of publications focusing on SDG 6 and SDG 7, as well as those discussing the WEF-Nexus, i.e., the strong interconnections existing between food systems, water management and energy provision. However, the results also highlight the relevance of these goals in the SDGs network.

Figure 9. Top 3 goals by interlinkage type (pie charts) and as percentages of total interlinkages by type (bar chart).

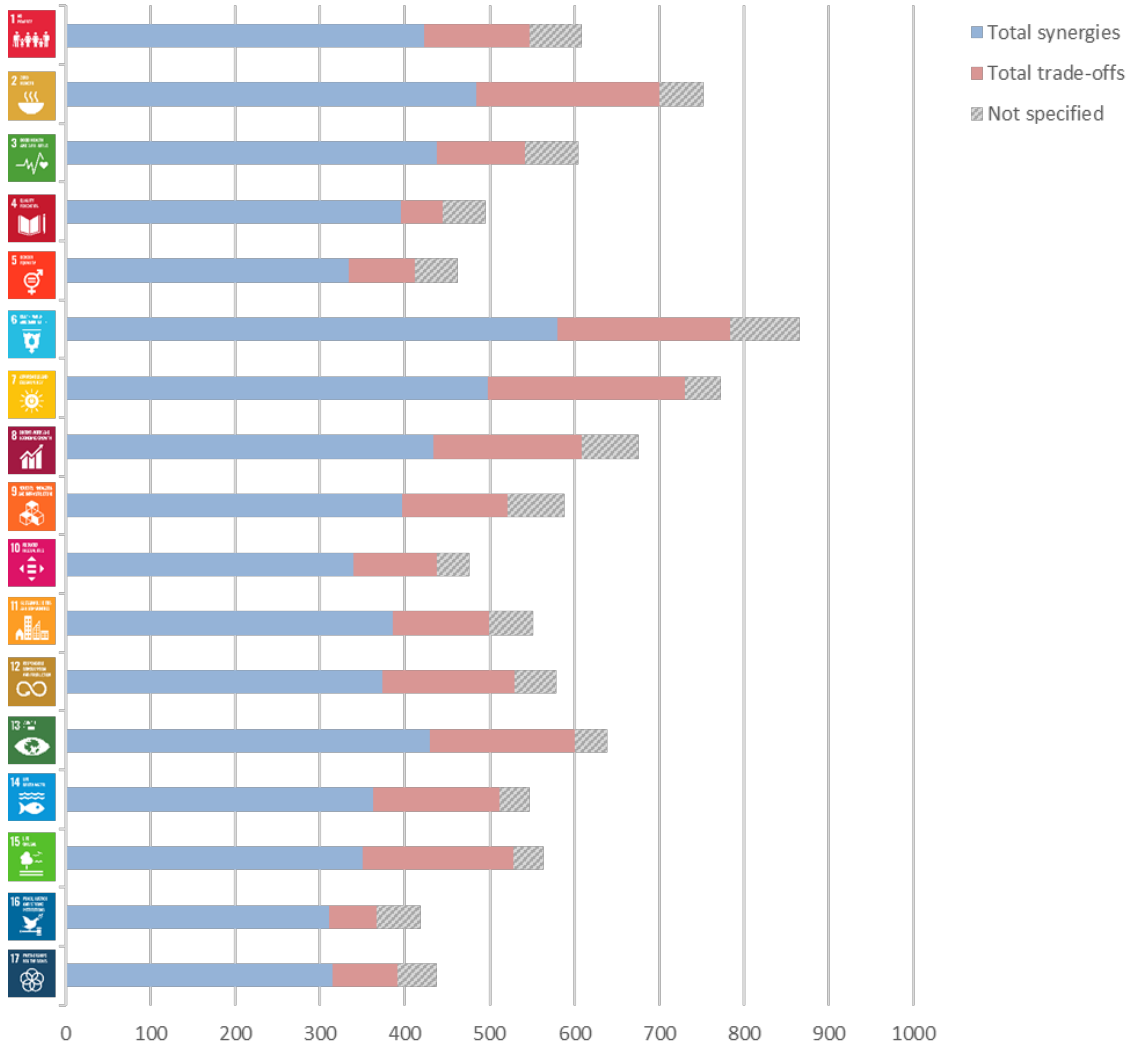


Source: Authors' elaboration. Note: The size of the charts reflects the highest number of synergies compared to trade-offs.

[10] For the analysis of the top goals and targets identified (for the entire database, by methods, at the EU level), SDGs and targets are counted only in the source of the interaction when there is no clear directionality since those links have been duplicated (SDG A, for example in the case of the interaction 2 --> 6, the source is SDG 2). They are also counted in the objective (SDG B) when the interlinkages have clear directionality.

Further breaking down this overview, Figure 10 provides a summary for each goal, divided by the type of interlinkage. This overview allows to identify the goals with the highest number of interlinkages detected (SDG 6, 7 and 2) and the ones with the lowest frequency (SDG 16, 17 and 3). It also shows the goals that present an overwhelming majority of synergies (like SDG 4, 16, 3 and 5) or a bigger share of negative links (e.g., SDG 15, 7, 2, 12 and 13), indicating potential areas where action could kick-start the most positive change or require the most caution within the SDG framework.

Figure 10 Number of interlinkages, by goal and type (synergy, trade-off or not specified)



Source: Authors' elaboration.

As it emerges from Figure 11, the interactions between SDGs 6, 2 and 7 are the most recorded in the database[11]. For example, interlinkages between SDG 2 and SDG 6 are the most identified in total and for trade-offs, whereas those between SDG 6 and 2 record the most synergies – suggesting that more synergies stem from SDG 6 towards SDG 2, whereas SDG 2 is the source of a higher share of negative impacts. Zero hunger and water and sanitation are inextricable: access to water is essential for crops irrigation; yet nutrient run-off can irremediably pollute water resources, causing eutrophication and decreasing water quality, which is why sustainable food production can help in addressing water scarcity and pollution (Mainali et al., 2018; Alcamo, 2019). The

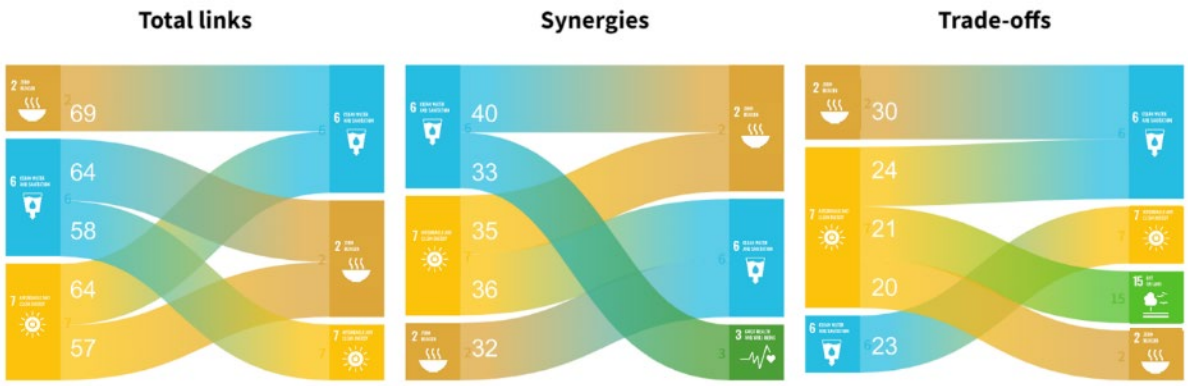
[11] For the analysis of top interlinkages, interlinkages are counted as in the platform (number of univocal links per publication going from SDG A to SDG B).

relevance of interaction between those goals is also well-reflected in the academic literature focusing on the water-energy-food (WEF) nexus.

SDG 6 and 7 interlinkages rank high for synergies and trade-offs. For example, energy infrastructure helps in the provision of water resources, but it can also impact the quality and availability of water when used in energy production processes, such as coal conversion into electricity (Fader et al., 2018). In this light, switching to some types of renewable energy (e.g., non-thermal) can support the protection of water ecosystems, whereas other renewables like hydropower can be detrimental to aquatic ecosystems (Fuso Nerini et al., 2018). Similarly, increased demand for safe and affordable freshwater supplies can constrain the deployment of certain types of renewables (McCollum et al., 2018). Interlinkages between SDG 7 and 2 are also prominent, for example, concerning trade-offs, there can be competition between food security and energy production in terms of land and water resources (Ehrensperger et al., 2019; ICSU, 2017). However, looking at the top five most identified pairwise interlinkages also highlight other relevant interactions. In term of synergies, there are many links between SDG 6 and SDG 3 on health and wellbeing. As described, run off from industrial and agricultural activities can pollute water environments, and contaminated waters feedback negatively to health (Alcamo, 2019). Thus, good quality water and improved treatment of wastewater can contribute to progress on SDG 3 objectives. The proliferation and transmission of neglected tropical diseases is also facilitated by contaminated freshwater and poorly managed sanitation facilities (Dziubaniuk et al., 2022). Reductions in (child) mortality and overall health are therefore indivisible from access to safe water and sanitation and hygiene (Mathematics, 2016). At the same time, the implementation of health frameworks, such as that on Tobacco Control, can support the achievement of SDG 6 targets – for example, as it regards the water intensity of tobacco production and the possible leaking of chemicals to nearby water sources (UN IAEG-SDGs, 2020).

In terms of trade-offs, SDG 15 reports many negative links with SDG 7 (as well as SDG 2), for instance in the context of land use conversion. The links between food production (cattle ranching, crops) and deforestation, biodiversity loss and other adverse impacts to terrestrial ecosystems are evident and prominently addressed in the reviewed publications (Bandari et al., 2022; Ehrensperger et al., 2019). Reversing those links, forest protection projects can also undermine food production (Zhang et al., 2022); for many years, deforestation and agricultural production have been closely interlinked, however, their decoupling is essential for transitioning towards sustainable food systems (UNEP, 2021b). As said, the production of renewables like biofuels and hydropower can also negatively affect ecosystem conservation, for instance, leading to flooding of forested areas (ICSU, 2017), and infrastructure development can cause biodiversity deterioration when it becomes the entry point for invasive species, or it alters the habitats of native species (Mantlana & Maoela, 2020).

Figure 11. Sankey of most identified interlinkages at goal-level with breakdown by type of interlinkage. The numbers refer to the n° of links recorded.



Source: Authors' elaboration, created with flourish.studio. Note: The sankey for Total links includes not specified interlinkages.

Beyond the top 5 interactions, there are other pairs of goals that share many interlinkages, regardless of direction. For example, there is a considerable number of positive links from SDG 7 towards SDG 3. Access to energy and electricity is necessary for medical equipment and the delivery of healthcare (Fuso Nerini et al., 2018). At the same time, the development of cleaner energy technologies (SDG 7) links to better indoor air quality, diminishing premature deaths, as well as the control of the spread of diseases (Bangert et al., 2017;

ICSU, 2017; Blair et al., 2021). Hence, energy access policies should promote the use of less-polluting, cleaner energy sources. Moreover, a sustainable and decarbonised energy system can support the efforts towards mitigating global warning, as GHG emissions are correlated with primary energy consumption (Diaz et al., 2020; EUROSTAT, 2021), which indicates the many existing synergies between SDG 7 and 13 on climate action. SDG 7 also has several benefits on SDG 1 on poverty eradication because access to energy services helps reducing chronic poverty (McCollum et al., 2018). The supply of energy from renewable sources is a key enabler for developing economic activities, modern infrastructures, and increased living standards (Fuso Nerini et al., 2018; Kroll et al., 2019; Agusdinata et al., 2022).

There are also synergies between SDG 6 and the "no poverty" goal (SDG 1). Lack of access to basic services like adequate sanitation and hygiene is a driver of poverty (Parikh et al., 2021). Proper sanitation and access to safe and affordable water, as well as good quality water-related ecosystems, are factors that contribute to poverty eradication, resilience-building, and reduced poverty traps, i.e., self-reinforcing mechanisms that perpetuate poverty, such as lack of education, low social mobility, high burden of diseases (Mainali et al., 2018). Moreover, drought risk reduction and prevention strategies that provide a buffer to water scarcity, such as integrated water management, can reduce human exposure and vulnerability to water-related extreme events, as well as economic shocks (UNESCAP, 2016; UN-Water, 2016; UNEP, 2021). SDG 15 (life on land) shares many synergies with the goal on water. Freshwater ecosystems are the source of many water-related services, from the provision of drinking water to water purification. Hence, well-managed water systems are essential to avoid ecosystems alteration and contamination (Flörke et al., 2019). Moreover, together with innovation, the development of good quality infrastructure (SDG 9) in a broad sense can support the provision of basic services (Kroll et al., 2019).

There are trade-offs with the goal on "decent economic growth" (SDG 8) and environmental goals like SDG 6 and 15, because economic growth continues to exert pressures on ecosystems and natural resources (Hutton et al., 2018). Hence, increasing production, extracting material, and expanding industrial infrastructure – also linked to SDG 9, without accounting for environmental impacts can lead to ecosystem degradation, habitats destruction and biodiversity losses (UNEP, 2021; Bandari et al., 2022; Warchold et al., 2022). For example, economic activities such as those related to tourism link to fuel and nutrient discharges in waters (UNEP, 2021). On the other hand, progress on environmental goals can both support and hamper SDG 8, depending if the focus is placed on increasing production and growth per se or achieving sustainable, resource-efficient, and diversified economies.

Exploring further trade-offs, progress on SDG 2 can hinder the climate goal. If food security in its aspects of access to good quality, affordable, nutritious, and sustainable food for all is to be achieved, there is the need to maintain a healthy resource base (Ehrensperger et al., 2019). Climatic changes like rising global temperatures and fluctuating precipitation patterns negatively impact the production of food (ICSU, 2017), underlining the relevance of investments in climate change adaptation and mitigation measures. Nevertheless, such measures could limit access to land, especially for vulnerable populations, for example, as it concerns ecosystem conservation and agricultural production, generating negative interlinkages between SDG 13 and 2 (Iacobuță et al., 2021). Moreover, unsustainable food production practices may cause land use changes that significantly contribute to GHG emissions. At the same time, food consumption based on meat and dairy products further increases the burden in terms of environmental impacts and emissions (Nilsson, 2017). However, examples of methods and technologies that enable food production with reduced GHG emissions and soil erosion and desertification exist, including no-tillage agriculture, optimized fertilizer delivery, agroforestry (ICSU, 2017)[12].

Most of the pair-wise interactions report both synergies and trade-offs. For example, for SDG 7 and 8 the interaction is mixed, there are significant numbers of synergies and trade-offs. A switch to renewable energy and energy-efficient technologies can create employment and increase the demand of skilled workforce but also disrupt the job opportunities and livelihoods of those working with fossil fuels (ICSU, 2017). It is a matter of outweighing the costs of a transition to renewables with its net benefits, for example, using re-training programs for the workforce and accounting for the long-term positive impacts of decarbonising our economies

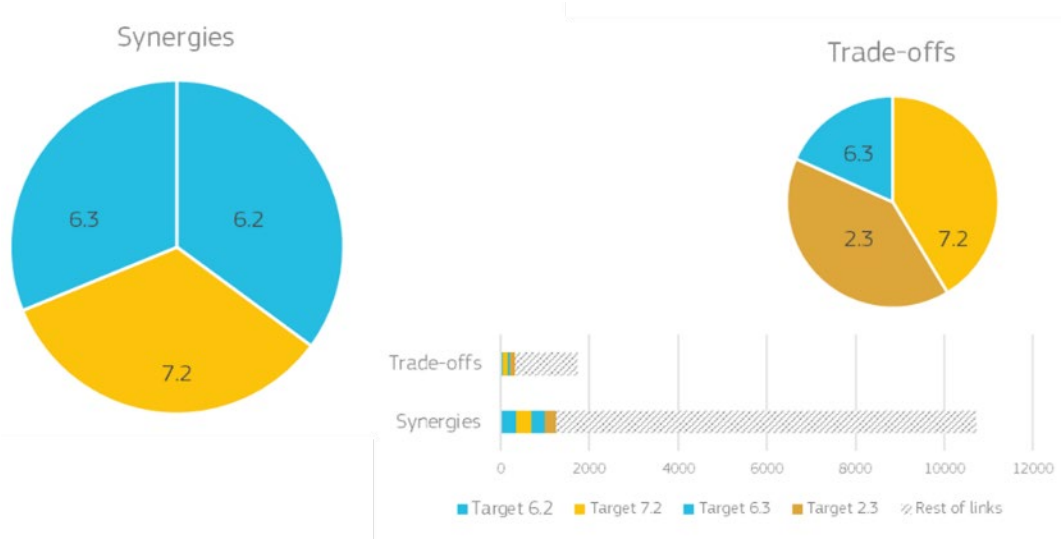
[12] It must be stressed that further trade-offs may exist between agricultural practices labeled as "sustainable" and (indirect) land use changes linked to increases in GHG emissions and pressures on habitats. For example, Seufert & Ramankutty (2017) discuss the context-dependant costs and benefits of organic farming in terms of yields, consumer prices, and biodiversity, amongst others. Hence, a balanced mix of different farming methods and technologies shall be used depending on contextual factors such as local climate and soil types, as well as the type of crop used, to achieve the most sustainable levels of food production.

(McCollum et al., 2018). Similarly, SDG 8 has both positive and negative impacts on SDG 14. A sustainable blue economy can support hunger reduction and marine protected areas could favour food security in the long term (while potentially counteracting it in the short term) (Le Blanc et al., 2017). Concerning the blue economy, oceans conservation and sustainable management, as well as capacity building and skills transfer on marine technology can favour the fisheries, aquaculture and tourism sectors, thus enabling decent economic growth (SDG 8) and youth employment. Additionally, the goal of decoupling economic growth from natural resources degradation goes hand in hand with achieving healthy marine habitats (ICSU, 2017). At the same time, trade-offs exist when economic development hampers ocean conservation.

3.5 Target-level interlinkages

The top three targets identified for synergies and trade-offs resemble the situation at the goal-level. As presented in Figure 12, targets 6.2 on access to sanitation and hygiene, 7.2 on renewable energies and 6.3 on water quality are the most synergistic targets, underlying the synergistic nature of SDG 6 and targets. Together, they represent almost 11% of total synergies at target level. Target 7.2 is also the one recording the most negative interactions, followed by target 2.3 on agricultural productivity and 6.3. These three targets with most trade-offs participate in more than 20% of all negative interlinkages recorded, as shown in the bar chart.

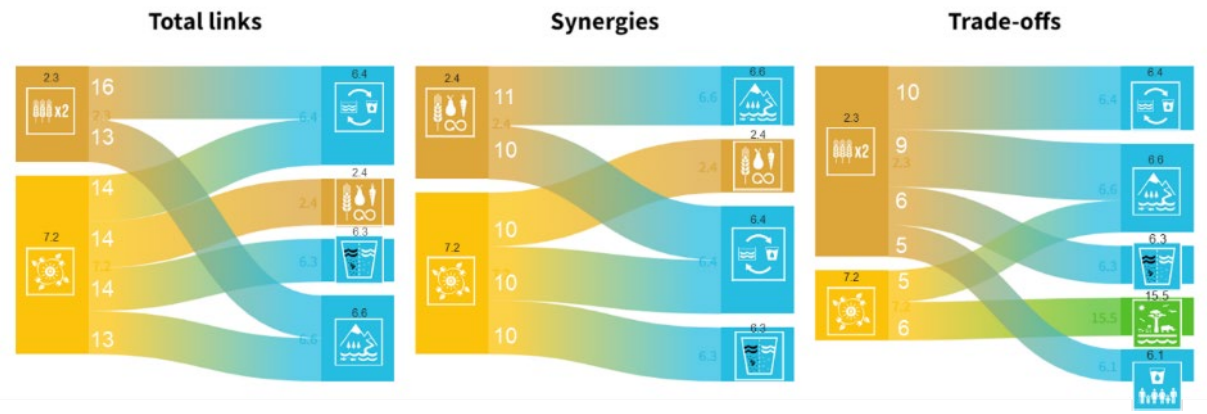
Figure 12. Top 3 targets by interlinkage type (pie charts) and as percentages of total interlinkages by type (bar chart on the right).



Source: Authors' elaboration. Note: The size of the charts reflects the highest number of synergies compared to trade-offs.

Focusing on the top five interlinkages the most recorded links regardless of the type of interaction are those between targets 2.3 and 7.2 and targets of SDG 6, as well as the links between 7.2 and 2.4 (see Figure 13 for the details). Concerning synergies, the interactions between SDG 2.4 on sustainable food systems and targets of SDG 6 on water ecosystem conservation (6.6) and water-use efficiency (6.4) are predominant. Indeed, unlike many of the interactions recorded for SDG 2, target 2.4 is highly synergistic. Many examples exist from the collected literature: sustainable agriculture allows the improvement of water quality, as well as land and soil management, thus contributing to restore the services provided by water-related ecosystems. Resilient agricultural practices, from Integrated Pest Management to drip irrigation are linked with sustainable and efficient water use as well as with diminished water contamination (Su et al., 2022). At the same time, well-preserved water resources contribute to food systems (ICSU, 2017), for example, good water management can support innovative agricultural practices, as in the case of safely treated wastewater supplying nutrient-rich organic compost (UN-Water, 2016).

Figure 13. Sankey of most identified interlinkages at target-level with breakdown by type of interlinkage. The numbers refer to the n° of links recorded.



Source: Authors' elaboration, created with flourish.studio. Note: The sankey for Total links includes not specified interlinkages.

Target 7.2 also shares many synergies with both target 2.4 and SDG targets 6.3 and 6.4. Renewable energy sources should generally benefit SDG targets concerned with increasing water and water-related ecosystem quality while reducing pollution, as these sources of energy should be comparably less polluting than fossil energy (ICSU, 2017). Hence, 7.2 should also benefit SDG 15 targets. Moreover, the water footprint of certain renewables is also lower compared to conventional fossil-fuel based sources. Conversely, water use efficiency is crucial for sustaining most forms of energy production (Mainali et al., 2018). Food production is also highly interconnected with the provision of energy. There are synergies with target 2.4, for example, regarding the use of crop residues for energy instead of turning them to waste or improving food security with lessened environmental impacts by reducing the fossil-fuel dependency in agriculture (Blair et al., 2021). Energy crops can also improve soil quality when planted on marginal or degraded land by supporting pollutants filtration, thus also contributing to water quality and ecosystem restoration and generating a virtuous cycle across SDGs 7, 6 and 2.

The trade-offs that exist between renewable energies, water access, quality and use efficiency, and habitats and biodiversity conservation(target15.5) stem from the fact that different renewable energy sources exist and, depending on the energy mix, these may increase or decrease detrimental impacts on water (e.g., water is required as an input for energy crops and a driving force for hydroelectric turbines; Requejo-Castro et al., 2020), forests and biodiversity (e.g., harvesting biomass unsustainably, turning natural landscapes into energy crops plantations; Blair et al., 2021; UNESCAP, 2016). Moreover, in terms of agriculture, using residues for energy can decrease soil quality by diminishing its nutrient content which can also increase soil erosion and run-offs of pesticides. Energy crops could also require more water for irrigation, possibly overexploiting freshwater and ground water resources (Blair et al., 2021). Energy crops may also create trade-offs in terms of land competition (Blair et al., 2021). Other significant mixed interactions beyond the most recorded links include the potential impact of energy crops on increased food prices and reduced access to food (target 2.1 on ending hunger and ensuring access to food), even though, as discussed, renewables concur in granting food security if there is no land use competition.

Moreover, increasing productivity can have a range of detrimental effects on SDG 6 targets. Agricultural activity requires abundant water resources, and, in a reality of water-scarcity, it competes with access to safe drinking water and sanitation. Obtaining high yields can intensify water use to the point of unsustainability: continuous withdrawals of groundwater lead to a depletion of resources. Moreover, access to clean drinking water is further reduced by way of nutrient and chemical leaching from fertiliser and animal farming (ICSU, 2017; Fader et al, 2018; Pingali & Plavšić, 2022). It follows that intensive conventional agriculture also poses a threat to ecosystem health due to the contamination of water reservoirs and aquifers, already threatened by climatic changes, potentially causing substantial deterioration of the livelihoods of already vulnerable populations like smallholder farmers (Mainali et al., 2018). However, water is essential to food production. For example,

developing technologies and management approaches for the recycling and use of wastewater (target 6.3) can support food production while diminishing the burden on freshwater resources (UN-Water, 2016).

Beyond the five most recorded links, other prominent synergies regard (Karnib, 2019) targets 2.3 and 2.1, which are positively interconnected with each other. Indeed, improving farmers' productivity (2.3) can entail increased food availability for the undernourished people (2.1), while more modern agricultural practices can also improve land-use efficiency, increase yields, and diminish food insecurity (Mainali et al., 2018; Santika et al., 2019).

However, as discussed, an unsustainable increase of agricultural productivity has widespread negative impacts on socio-ecological systems. Productivity can also entail trade-offs for 2.1, for example, in terms on the nutritional value of certain products (Pingali & Plavšić, 2022). Other impacts of target 2.3oconcern trade-offs with target 13.1 on strengthening resilience and adaptation to climate related hazards and natural disasters and 3.9 on decreasing the number of deaths and illnesses caused by pollution. When it involves deforestation and soil degradation, intense agricultural expansion increases the probability of extreme events and aggravates their impacts. It may also lead to increased emission levels due to land use change (ICSU, 2017), as well as contamination of ecosystem due to run-offs. (Pingali & Plavšić, 2022) In turn, pollution increases exposure to dangerous chemicals and can lead to an increment in the number of illnesses and deaths associated (ibid, 2017, 2022; Singha et al., 2021).

3.6 Comparison between two methods: data analysis and expert judgement

The information collected in the database allows for a comparison of interlinkages using different variables. For instance, the database can be examined to identify if and in which way different methods can lead to the identification of different interlinkages. In this sense, it may be interesting to look at two different methods: qualitative expert judgement and data analysis. Table 4 summarises information on the different interlinkages recorded by each method.

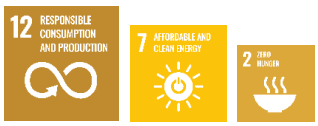
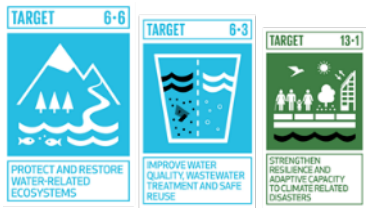
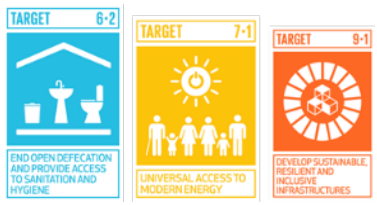
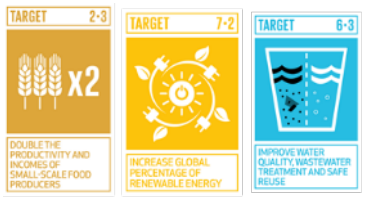
In line with the whole database, the most synergistic goal is SDG 6 for both methods and SDG 7 is also in the top three. However, differences emerge. For example, for expert judgment, SDG 13 is in the top-three goals with most synergies and SDG 14 is present for trade-offs – e.g., in terms of how marine conservation can constrain economic and urban expansion and access to resources (Singh et al., 2018)(Horan, 2020). For data analysis, SDG 9 emerges as the second most synergistic and SDG 12 reports many trade-offs with other goals and targets, for example, with social goals linked to poverty and inequality reduction and energy consumption, which can heighten resources consumption (EUROSTAT, 2021).

When it comes to targets, beyond SDG 6 targets, according to expert judgement target 13.1 is highly present and synergistic, for example, actions that strengthen socio-ecological resilience and adaptive capacity to climate change reinforce the health of coastal and marine ecosystems (SDG 14 and targets; ICSU, 2017; Weitz et al, 2019). Climate change mitigation and adaptation have also broad positive impact on public health, both physical and mental (SDG 3 targets, Stevenson et al., 2021). For data analysis, synergies exist between access to sustainable energy (target 7.1) and eliminating poverty, achieving food security and better nutrition (Mainali et al., 2018). Concerning SDG 9, target 9.1 on sustainable and resilient infrastructure presents many synergies. for instance, with access to water and sanitation facilities, enabling investments, trade, and exports, and supporting economic productivity, value chain development and resilient rural and urban livelihoods (Mantlana & Maoela, 2020); Gannon et al., 2022). At the same time, target 9.2 on sustainable industrialization shows trade-offs concerning environmentally sound management of e-waste (Liu, 2020).

Like the full database, the most recorded interlinkages concern SDGs 2, 6, and 7. For expert judgement, many links exist between goals 2 and 6 (stemming from 2 for trade-offs and from 6 for synergies). As discussed, this relationship involves water-use in agriculture, amongst others. This case also stresses how target 2.4 provides mainly positive interactions in the networks, whereas 2.3 is a source of negative impact on SDG 6 targets. The strong ties between SDG 2 and 6 appear also for data analysis, in total and for trade-offs. Also in this case, target 2.3 participates in many negative interlinkages with water use efficiency and conservation of ecosystems. The most recorded synergy is between SDG 7 and 6, including, for example, the role played by water conservancy for energy processes and how electricity is essential to guaranteeing a functioning and efficient water supply and wastewater treatment (Mainali et al., 2018; UNEP, 2021b).

This overview shows how the variables collected in the database allow approaching interlinkages from different angles based on the necessity of the user, **hence highlighting the need of proper contextualisation when discussing interlinkages**. Results in terms of the most relevant goals, targets or interlinkages detected can vary because different topics can be addressed in diverse ways. For example, there can be an abundancy of quantitative data regarding a specific argument, while other SDG targets are not easily translated quantitatively, and expert judgement is more pertinent.

Table 4. Overview of goal and target-level results for expert judgment and data analysis.

		Expert Judgement	**Data Analysis**
Top 3 goals	Synergies		
	Trade-offs		
Top 3 targets	Synergies		
	Trade-offs	 *7.2 and 6.3 have the same nº of links	
Most detected interlinkages at goal-level	Synergies	6→ 2	7 → 6
	Trade-offs	2 → 6	2 → 6
Most detected interlinkages at target-level	Synergies	2.4 → 6.4 2.4 → 6.6	Various across targets 6.1, 6.2, 6.4, 7.2, 7.2, 2.3, 2.4
	Trade-offs	2.3 → 6.4	2.3 → 6.4 2.3 → 6.6

3.7 Focus on the European Union

Besides methodological consideration, the collected information on the reviewed publications allows to better account for different geographical contexts by focusing only on a specific geographical area. Using the information available for each publication, it is possible to filter interlinkages that play out at the EU level, either considering all 27 EU Member States or a single country. Specifically, 9 of the publications collected report interactions at the EU level where, in line with the rest of the database, most of the recorded interlinkages at goal- and target-level are synergistic.

Differences from the global picture emerge in terms of the most present goals and targets. Primarily, SDGs 2 and 6 and their targets seem to lose their predominance. At the EU level, climate action (**SDG 13**) is the most present and synergistic goal, followed by sustainable industrialisation (**SDG 9**) and sustainable production, and consumption (**SDG 12**). Together these SDGs make up almost one-fourth of all interactions. For example, for SDG 9, the development of sustainable, resilient, and quality infrastructure, as well as scientific research and innovation, interact positively across the entire SDG network (UN IAEG-SDG, 2020). Moreover, in the EU, the relationship between increased share of alternatives to plastic and the potential to reduce GHG emissions associated to petrochemicals, plastic production and after-use illustrate the synergies between goals 12 and 13. Target 13.1 on climate adaptation and 15.5 on protecting habitats and biodiversity feature many positive interlinkages, starting with synergies between the two. Target 2.4 is also present in many positive interlinkages at the EU level since sustainable food systems have many beneficial impacts of different SDGs.

The limited trade-offs stem from SDGs 13, 7 and 17. Investments in climate adaptation (target 13.2) give rise to intricate relationships with SDG 8, for example. Target 17.11 on increasing the exports of developing countries is especially prominent, even though Weitz et al. (2018) suggest that this could be due to a limited capture of the benefits of trade in the 2030 Agenda. Target 7.2 also presents negative links, for example, in Finland, a broader uptake of renewable energy may increase pressures on water ecosystems linked to the more intensive use of forests in bioenergy production (Kangas et al., 2018)

Overall, the publications offer insights on a richness of topics, geographical and temporal contexts, with additional information and explanation of the synergies and trade-offs identified. Hence, this literature review and the interlinkages tool which derives from it (presented in Section 5) can serve as a roadmap to guide the users inside the dense forest of SDG interlinkages.

4 Discussion: limits and step forward

The literature review and analysis shed light on the gaps, challenges and opportunities related to achieving the Sustainable Development Goals (SDGs). Looking at the most detected goals, targets and interlinkages, SDG 6 tends to be the most synergistic and SDG 7 and 2 the most negatively interlinked. The synergistic nature of SDG 6 is discussed in the literature, as progress on water quality and sustainable management of water resources may yield positive impacts on other areas of sustainability (Alcamo, 2019). Concerning SDG 7, identified trade-offs regard mainly the possible negative impact of using specific forms of renewable energies on terrestrial and aquatic ecosystems, as well as competition for water and land (e.g., bio-based fuels), affecting social sustainability in terms of access to water and food. Trade-offs within SDG 2 and between SDG 2 and the rest of the SDGs are well-known, especially for targets linked to environmental sustainability, and can stem from the multiple and counteracting SDG 2 targets (Lipper et al., 2020), some of which have been linked to the depletion of natural resources and increased carbon, land and water footprints (Scherer et al., 2018; Fanzo, 2019). Moreover, issues of food production, food security and nutrition, central to SDG 2, are also connected to many other SDGs (Herrero et al., 2020). Finally, these three goals are prominent to two of the six transformations to achieve SDGs proposed by Sachs and colleagues (2019), namely energy decarbonization and sustainable industry, and sustainable food, land, water, and oceans – with the one on food systems potentially entailing the most trade-offs.

However, part of the explanation for the overwhelming presence of these SDGs in the database may also owe to the various thematic publications existing for these SDGs. Out of the 92 publications from which interlinkages were extracted, 11 have a thematic focus on SDG 6 on water, 7 on SDG 7 on energy, and 4 on the WEF (Water-Energy-Food) nexus.

The results of the review also allude to the various challenges related to the analysis of SDG interlinkages. These are also highlighted in the existing literature. The limitations can refer to a specific methodology applied in a study, data gaps in the SDG framework, or generally derive from the complexity of SDG interactions. Exploring the methods used to capture interlinkages and their shortcomings can be insightful not only for academics but also for professionals wishing to support evidence-based decision-making.

Concerning methods, capturing semantic relations can give a first idea of the possible connections in the SDG network and provide an entry point to a more evidence-based discussion. Nevertheless, semantic analysis alone, as suggested above, is limited to uncovering potential interlinkages based on word-matching, semantic contexts, and thematic overlap. These interlinkages may not exist in real-world interactions (Stevenson et al., 2021). This is a severe limitation because **contextualising SDG interlinkages is necessary** to understand their impact in different settings. Moreover, qualitative coding based on SDG descriptions can be influenced by the background and views of the coders (Smith et al., 2021).

Similarly, even when protocols for scientific integrity are in place, expert judgement analyses can be limited by the scarce replicability of the ways in which data is collected, analysed, and interpreted (Ospina-Forero et al, 2022). For example, the 7-point scale approach, developed by Nilsson et al. (2016) and widely embraced by other authors, is hardly replicable, as it involves teams of experts making subjective evaluations based on their values, beliefs, background, and experiences (Lyytimäki et al., 2021; Wilkins, 2003). In addition, experts can be limited by the scope of their knowledge: as underlined by Ospina-Forero and colleagues (2022), this may lead to echo chambers replicating conventional knowledge, hampering a complete estimation of the complex SDG network.

In terms of data analysis, correlation analysis is not entirely able to explain the full extent and impact of SDG interlinkages. First, correlation does not imply causation and it cannot capture the direction of the impact of an SDG, which is problematic when it comes to using interlinkages for policy advice (Ospina-Forero et al., 2022). Focusing on the simultaneous covariance in SDG indicators may limit the ability to capture lagged interdependencies such as intergenerational impact and environmental externalities.

Moreover, statistical analysis that relies on scarce data may be hampered by limited data points, for example due to the costs of monitoring indicators, and confounding variables, leading to spurious correlations and results that are conflicting with existing evidence (Smith et al., 2021; EUROSTAT, 2021; UNEP, 2021b). For example, in the EUROSTAT correlation analysis (2021), SDGs like life on land (SDG 15), zero hunger (SDG 2) and reduced inequalities (SDG 10) show few connections, even though they are crosscutting SDGs. New analysis from

Warchold and colleagues (2022) questions the robustness of quantitative analysis, showing that by using different datasets for the same variable, the resulting interlinkages vary consistently.

As suggested by Bennich and colleagues (2020), empirical models should be adopted by researchers on SDG interlinkages. However, when it comes to modelling, as discussed, models applied to SDGs often come from different study areas and are not primarily designed for the SDG framework. Besides, they tend to explore future scenarios that, depending on the factors included, give rise to different SDG interlinkages, not always consistent and sometimes counteracting (Ospina-Forero et al., 2022; Gannon et al., 2022).

On top of the methodological limitations to interlinkages analysis that have been thoroughly discussed, some cross-cutting issues appear. The operationalisation of SDG interlinkages is per se difficult due to unavailable data, especially for low-income countries: despite improvements in the last years, half the indicators lack good country coverage, cross-country comparability, standardised measurement, and even data for specific segments of the population (Dunning & Kalow, 2016).

However, being able to account for the temporal and geographical scale at which interlinkages happen matters. In terms of timescale, SDG interlinkages can change over time, with synergies turning into long-term trade-offs and vice versa, like for investments in education (Breuer et al., 2019). Being able to account for time-lags in the emergence of interlinkages can allow for more tailored policy responses (Lyytimäki et al., 2021; UNEP, 2021b).

The literature review also uncovered a shift in the geographical focus over time, a trend aligning with the general process of operationalising and implementing the SDGs. Sticking to global data exclusively can result in overlooking local interactions., which is why studies are increasingly focusing on the national and sub-national levels, ultimately emphasising the importance of considering different contexts. At the same time, this trend may lead to neglecting aspects like international spillovers, whose consideration is crucial for the global achievement of the SDGs. In addition, aggregating data from different countries has its limitations concerning the heterogeneity of interlinkages and the contextual peculiarities that can get lost in the process (Pradhan et al., 2017; Ospina-Forero et al., 2022). Indeed, contextual social, ecological, and environmental variables influence how interlinkages play out in specific places and may give rise to scale mismatches in synergies and trade-offs (Karnib, 2017; Singh et al., 2018; UNEP, 2021b).

The diverging results regarding the type of interlinkage identified further add to the complexity. As publications analyse interlinkages at different geographical and analytical scales with differing narratives, they often reach different conclusions, indicating the relevance of context in shaping the relationship between different goals and targets. While global analyses and cross-country comparisons are useful to address the universal nature of the 2030 Agenda, many authors agree that some approaches applied to analyse interlinkages do not carefully consider the context of interaction (Breuer et al., 2019). Nilsson and colleagues (2016) go as far as warning about the risks of generalisation given the dependency of interlinkages on time, geography, technology, resources, directionality, and governance. In response, some authors focus only on subsets of SDGs that are most relevant for the area under study and use them as proxies for the entire development spectrum. Moreover, the ambiguous nature of certain interlinkages is further underlined by publications identifying specific relationships as both positive and negative. This ambiguity can be attributed to how targets are conceptualized. Therefore, insights gained from one study may not always be applicable to other contexts, especially if analytical and geographical scales are significantly different.

In another paper Nilsson (2017) writes that "it is simply not possible to provide a robust, comprehensive assessment of all the important interactions in one single policy paper". However, the inability to capture and make sense of the entire network of SDGs should not be an excuse to gloss over its complex and multidimensional nature. For example, contextualisation may come at the expenses of the replicability of a study outside its location, and analyses limited to a subset of SDGs may be affected by selection biases and are less suitable to understand second-order and indirect effects (Breuer et al., 2019).

These limits are reflected in the interlinkages recorded in the database. The overview of goal- and target-level interaction shows an overwhelming presence of synergies. While this trend can stem from the integrated and self-reinforcing design of the 2030 Agenda and its SDGs, it can also allude to positive bias in the literature, where documents tend to look for and discuss synergies rather than trade-offs (Fader et al., 2018). Indeed, according to their authors, some methodologies are not designed to capture trade-offs.

However, these limitations should not discourage academics in the field, as understanding the complex web of cascading interlinkages remains key for a transition towards sustainable development now and for future generations, at the global and local scale – the overall objective of the SDGs. Yet, these challenges highlight potential gaps for future research, for example, concerning the analysis of transboundary and intergenerational spillover effects.

To respond to the limitations of current interlinkages analyses, some papers suggest interesting twists and improvements to the most adopted methodologies, as well as novel approaches able to capture the full implications of SDG interlinkages (Ospina-Forero et al., 2022). These include composite qualitative and quantitative methods (McCollum et al., 2018; Kroll et al., 2019; UNEP, 2021b; Warchold et al., 2021), data disaggregation (Kroll et al., 2019; Warchold et al., 2021), socio-ecological models and scenario analyses (Hutton et al., 2018; van Soest et al., 2019) and participatory approaches (Hutton et al., 2018; Breuer et al., 2019).

Integration may be the response to the complexity of the network of SDG interactions. Combining different methods and approaches, such as instances of social network analysis, providing distinct levels of analysis from aggregated and disaggregated data, and exploring future scenarios, all allow delving deeper into the characteristics of the interlinkages to grasp place and time components, population differences, second-order effects, and interactions across different subsystems (health, environment, society). These integrated analyses can suggest future evolutions of SDGs and their interconnections and pave the way to understanding transboundary and intergenerational spillovers. Moreover, studies focusing on the actors, behaviours and interests involved in the implementation of SDGs can provide insights on the role of active participation for systemic thinking and better link interlinkages analysis to policy uptake and outcomes (Bennich et al., 2020; Biermann et al., 2022).

5 JRC Interlinkages Tool for better informed policy making

The JRC Interlinkages Tool is hosted in the KnowSDGs Platform[13] and contains all the information collected from the literature review. The tool is structured to guide users step by step from a more general overview toward an in-depth understanding of the network of selected interlinkages.

The tool shows interlinkages at the goal and target-level. As seen in Figure 14, for each level, the user can have an overview of the synergies and trade-offs in a chord diagram and further investigate the interlinkages between a specific goal/target and the rest of the SDG network in a Sankey diagram. Breakdowns are available by type of interlinkage.

Users can also read the description of the interlinkage, as collected from the publications, and find out in which geographical context it has been observed, as well as other information collected in the review (when provided). Filters allow to combine various goals or targets or to highlight only a subset of results. Users not only can explore interlinkages in the platform in an interactive way, but they can also download the results as tables and chart images.

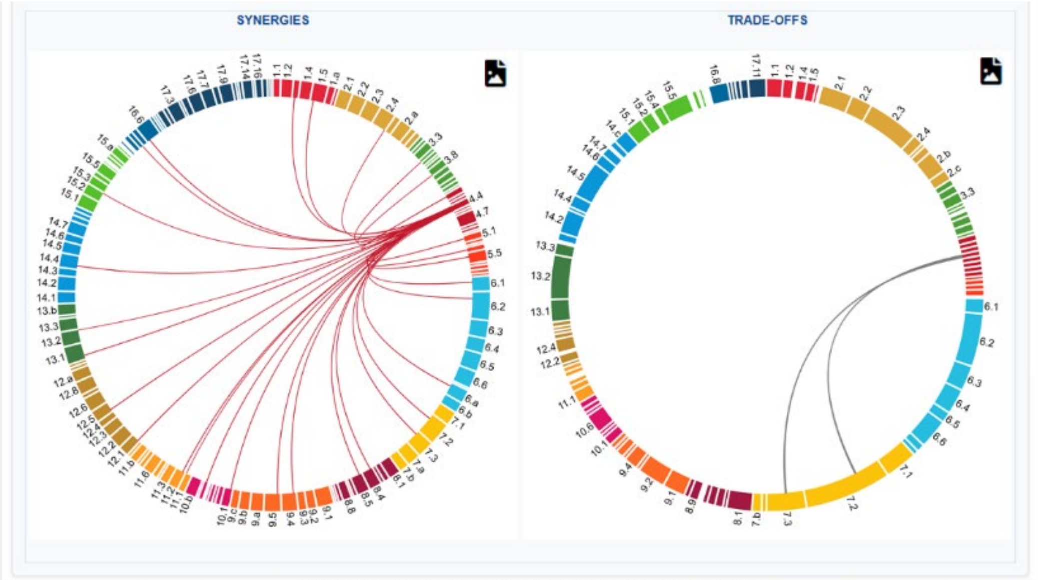
For the visualization in the platform, a slightly different approach in data aggregation has been used, compared to the results presented in the report. Specifically, here the unit of measurement is the publication: the number of links depends on the number of publications where a specific interlinkage (unique per type and pair of SDG goals/targets) has been mentioned in the text. The thickness of the line represents the number of papers where at least one interlinkage between a couple of goal/target has been mentioned in the text (not considering how many times it has been observed, disaggregated at target or indicator level, or duplicated for different geographical or temporal scales). In this way, the visualizations enable users to immediately identify the interlinkages most cited in different documents, in a sense showing for which relations the literature is most consensual.

The following sections provide two concrete examples on the application of the SDG Interlinkages Tool to harness and visualise the information on interlinkages for a better understanding of the complex interconnections across policy areas: the case of gender mainstreaming in policies and the case of food loss and waste.

[13] https://knowsdgs.jrc.ec.europa.eu/

Figure 14. Overview of the JRC SDG Interlinkage Tool. Examples of visualization for target 4.4

Chord diagrams: overview of synergies and trade-offs at target level



Sankey diagram: overview of interlinkages between selected targets

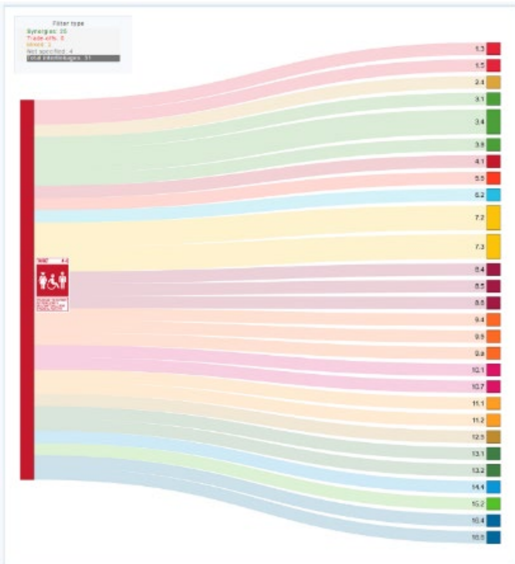


Table: description of interlinkages

Target A	Target B	Type	Geographical focus	Description	Publication
4.4	5.5	synergy	Sweden		Weitz_2018
4.4	6.2	synergy	Global	Synergies include job formations benefiting the sanitation sector (e.g. masonry); or where the sanitation sector boosts employability of individuals, for example, through provision of trainings; or where sanitation-related formations triggers behaviour change in hygiene practices	Parikh_2021

Publication ID	Method type	Geographic scale	Geographic context	Year	Title	Authors	Link
Parikh_2021	Mixed (Literature review, Expert judgement)	Global		2021	Synergies and trade-offs between sanitation and the sustainable development goals	Parikh, Priti, Loan Diep, Pascale Hofmann, Julia Tomei, Luiza Campos, T. Teh, Yacob Mulugetta, Ben Milligan, and Monica Lakhanpaul.	

Target A	Target B	Type	Geographical focus	Description	Publication
4.4	7.2	synergy	Sweden		Weitz_2018
4.4	7.2	mixed	Global	In case electricity access for providing that electricity is provided predominantly with non-renewable energy sources and inefficient energy appliances, 4.4 could have (limited) trade-offs with Targets 7.2	Fuso Nerini_2018
4.4	7.3	synergy	Sweden		Weitz_2018
4.4	7.3	mixed	Global	In case electricity access for providing that electricity is provided predominantly with non-renewable energy sources and inefficient energy appliances, 4.4 could have (limited) trade-offs with Targets 7.3.	Fuso Nerini_2018
4.4	8.4	synergy	Sweden		Weitz_2018
4.4	8.5	synergy	Sweden		Weitz_2018
4.4	8.6	not specified			Cutter_2015

5.1 A gender gap? Putting SDG 5 at the centre of the interlinkages

SDG 5 aims to achieve gender equality and empower all women and girls by "*ending all forms of discrimination, violence and any harmful practices against women and girls in the public and private spheres. It also calls for the full participation of women and equal opportunities for leadership at all levels of political and economic decision-making*" (EUROSTAT, 2022a).

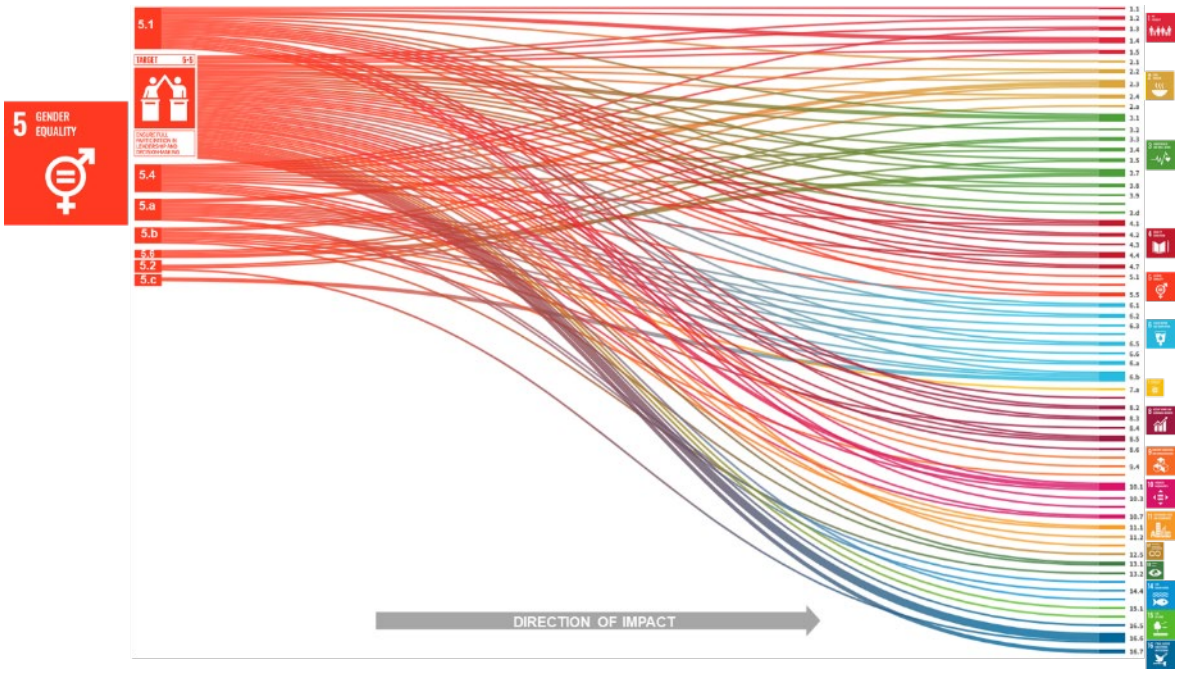
According to the last report of EUROSTAT on "Monitoring progress towards the SDGs in an EU context" (EUROSTAT, 2022b), the Union is progressing towards attaining gender equality in leadership positions and aspects related to the labour market. However, even though women perform better than men in education, the gender pay gap is still consistent. Women are less likely to be employed, they take over most of caring responsibilities and are over-represented in lower paid jobs. Additionally, one-third of European women have experienced physical or sexual violence since the age of 15. In light of this data, the political commitment exists to close existent gender gaps, enhance gender equality in decision-making, and eliminate gender-based violence (EUROSTAT, 2022a).

Yet, when mapping EU policies against the SDGs, keywords related to SDG 5 and its targets are the least detected in legal acts and policy documents (Borchardt et al., 2022). Thus, it can be inferred that the gender dimension is not so prominent in the EU policy landscape compared to other areas of sustainable development, at least semantically. However, gender equality is a cross-cutting topic, starting with the fact that the data informing SDG indicators could and should be disaggregated by gender (UN Women, 2022).

The SDG Interlinkages Tool can help to visualise the areas of connection between SDG 5 and the rest of the SDGs. Understanding the ways in which gender influences social, economic, and environmental sustainability, and is in turn affected by it, can facilitate the integration of the gender perspective and the promotion of concrete actions across policy areas.

For example, looking at recorded interlinkages with clear directionality, SDG 5 targets are well-connected across the SDG network, as sources of interactions (Figure 15). Their impact is preponderantly positive especially on targets of SDGs 3, 6, 1, 2, 4, 8: progress on gender equality is particularly relevant for health and well-being, water and sanitation improvements, reduced poverty, diminished hunger, access to education, decent growth. Out of 114 links, only one trade-off was recorded, between 5.4 and 11.1.

Figure 15. Sankey chart showing the direct interlinkages from SDG 5 targets to other SDG goals ant targets

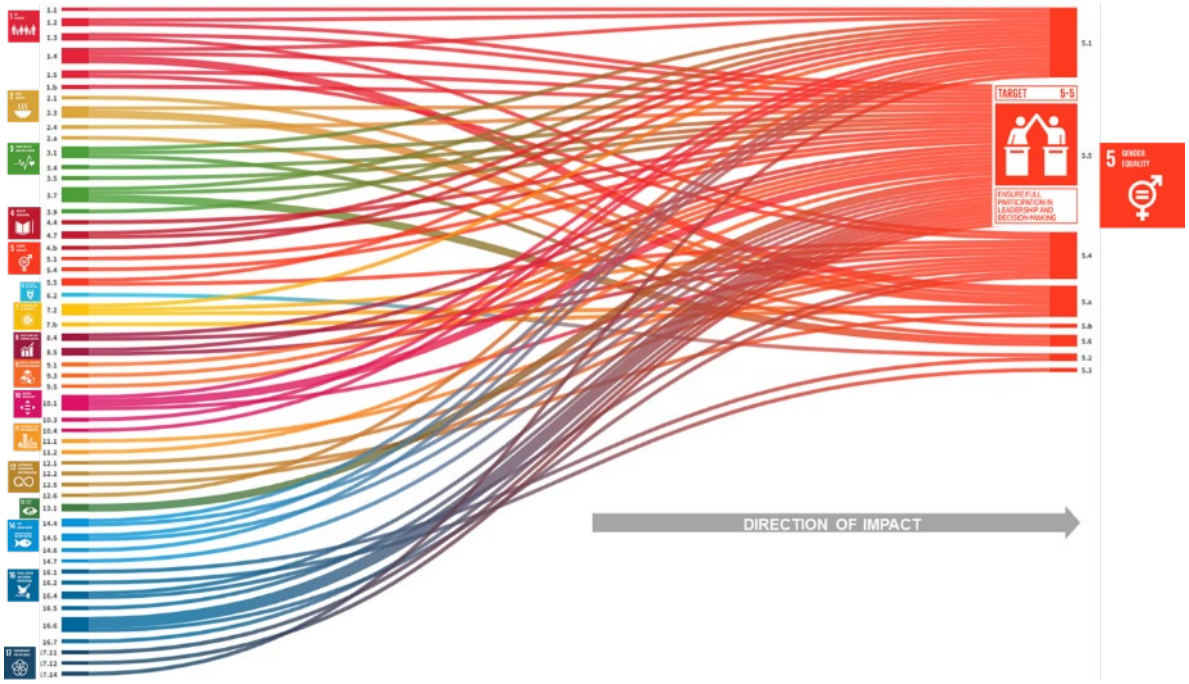


Source: Authors' elaboration, created with flourish.studio. Note: As suggested by the arrow, direction of impact is from left to right.

In the database, the most interlinked targets are the two on *"ending all forms of discrimination against all women and girls everywhere"* (5.1) and ensuring *"women's full and effective participation and equal opportunities for leadership at all levels of decision-making in political, economic and public life"* (5.5). The most impacted targets are 16.6 and 6.b, followed by 2.3, 3.1, 3.7, 10.1.

Similarly, many interlinkages stem from different sustainability areas to directly affect SDG 5 and its targets. These interlinkages are again mostly synergies with 2 trade-offs and 4. SDG 3 targets not only benefits the most from progress on gender equality but together they have significant impact on it, together with SDG 1 and SDG 16. Figure 16 gives an overview of all SDG targets that concur in affecting SDG 5.

Figure 16. Sankey chart showing the SDG targets directly affecting SDG 5, and corresponding targets.



Source: Authors' elaboration, created with flourish.studio. Note: As suggested by the arrow, direction of impact is from left to right.

The SDG Interlinkages Tool collects the descriptions of the interlinkages, which help in contextualising the opportunities to connect gender-related policy measures to different areas of policymaking.

The health-water-gender relationship is well-recognised in literature and policymaking (UNICEF, 2017; Pouramin et al., 2020). Specifically, progress on SDG 5 can benefit health and wellbeing concerning maternal, sexual, and reproductive health by leveraging women's leadership potential to push for policies more supportive of women rights. At the same time, access to these kind of health services enables women's full participation in economic and political life, thus favouring ending discrimination (Nilsson, 2017). Similarly, gender equality and women's participation in leadership and decision-making can support equitable access to safe and affordable drinking water, and improvements to WASH (Water, Sanitation and Hygiene) systems (UNESCAP, 2016).

Concerning poverty, access to resources is indivisible from ending gender-based discrimination. Indeed, discrimination can hamper women's entrepreneurship and access to trade and decent working opportunities, while women's participation can favour the creation of jobs and increase productivity (Nilsson, 2017). For example, women's empowerment can strengthen their role in agricultural production systems, with positive effects on smallholder's productivity and nutrition (ICSU, 2017). Simultaneously, diminishing poverty and improving access to resources can directly favour women (UNESCAP, 2016).

In some cases, for example in China, evidence suggests that closing the gender gap plays a role in lowering water and marine pollution levels, because granting women access to resources and services allows for increased efficiency in productivity with less contamination and more sustainable water management (Wang et al., 2022). Hence, progress on gender equality correlates with the sustainable management of natural resources. Moreover, sustainably managed sectors can increase income and job opportunities for women and grant equal rights to natural and economic resources.

In general, increased women's participation in political life is associated with lower levels of corruption (Nilsson, 2017), as well as increased equality, diversity, and sustainability in fields like energy (UNESCAP, 2017) and infrastructure development. Renewable energy can disproportionately benefit women who are most affected from the detrimental health effects of non-renewable sources (e.g., indoor air pollution) (UN Women, 2018). Better public infrastructure can favour women's participation in the labour market. Indeed, the need for gender-based transportation policies grounded on gender-disaggregated data is broadly discussed and, in some cases, acted upon (Duchene, 2011; Kronsell et al., 2015).

At the same time, improved access to technologies, knowledge and skills can support women's participation in community and political life (UNESCAP, 2016). In particular, the interaction between gender and education is fundamental. Discrimination can hinder access to education, while women as parents tend to allocate more resources to education. Hence, more empowered women can initiate long-term educational improvements (Nilsson, 2017). Better education also translates into increasingly diverse job opportunities for women, and it correlates with positive attitudes towards gender equality and women's rights (Vladimirova & Blanc, 2016).

The overview that the SDG Interlinkages Tool gives of all interconnections existing between gender and other sustainability dimensions allows to grasp the multidimensional character of gender equality objectives and the multiple and diverse opportunities to link these objectives to most, if not all, policy areas. Policymakers can tap into the evidence-based entry-points highlighted by existing interlinkages to mainstream gender equality into sustainability policymaking and thus address the gender gap starting by the gap in policies. However, it shall be mentioned that an ad-hoc and contextualized evaluation of all impacts shall precede any policy action.

5.2 The case of food loss and waste

Efficient food production and consumption play a fundamental role in the challenge to feed a growing global population in a context of resource scarcity (Caldeira et al., 2021). Reducing food loss and waste (FLW), understood as all food and inedible parts of food removed from the food supply chain (Gustavsson et al., 2014), has profound socio-ecological and economic impacts, from eradicating hunger to reducing emissions and saving money for producers and consumers.

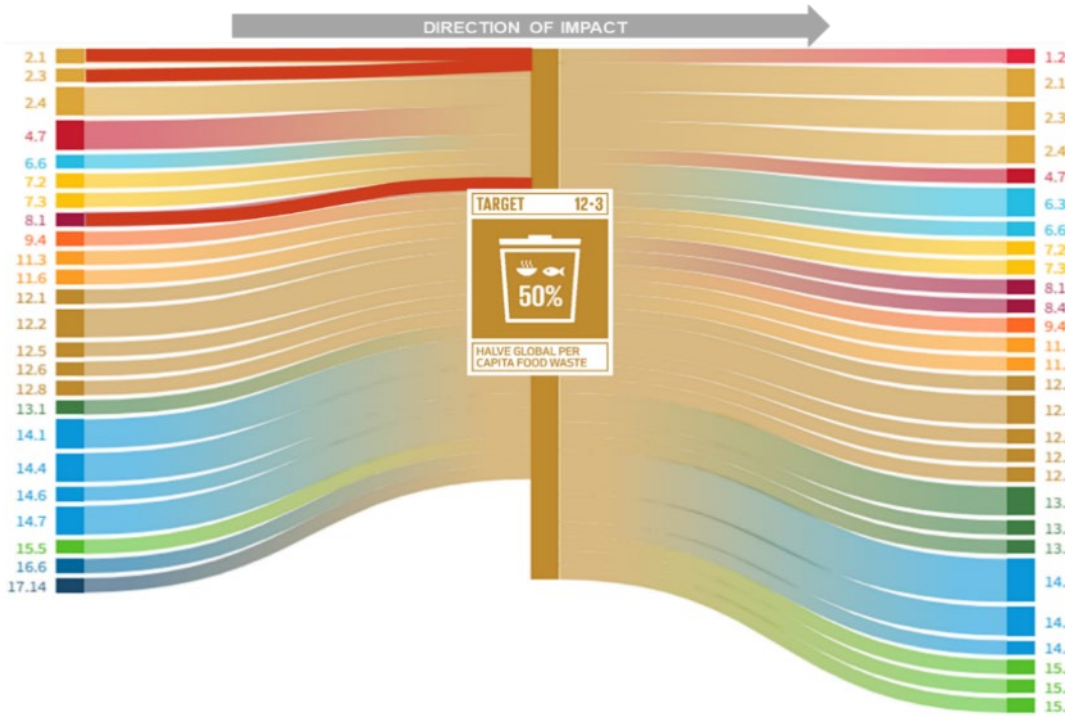
In light of its commitment to the 2030 Agenda, the European Union already implemented various actions to address FLW, including the 2018 revision of the Waste Directive and the emphasis placed on FLW reduction in the Circular Economy Action Plan and in the Farm to fork strategy (European Commission, 2021). Nevertheless, analysis (Sala et al., 2020) calculates that in 2020 nearly 59Mt of food were wasted in the EU, representing roughly 10% of food supplied to retail, food services and households. Moreover, 20% of the food produced is lost, in the face of 36.2 million people that can afford a quality meal only every other day (European Commission, 2022). According to the UNEP Food Waste Index Report (UNEP, 2021a), the estimation of GHG emissions associated with FLW is a staggering 8-10% globally. In the Union, the environmental impacts of food waste contributed to 11%-17% of the total impacts of the EU food system, depending on the impact category considered (Sala et al., 2020).

Multiple drivers affect FLW generation (Eriksson et al., 2020) and its reduction is only one of the elements contributing to another multifaceted system, that of sustainable food. Aware of this complexity, the SDG Interlinkages Tool can support policymakers in visualising the links between FLW and other policy areas to implement policies to reduce FLW and promote sustainable production and consumption patterns.

How is that possible? SDG target 12.3 aims to halve per capita food waste at the retail and consumer level by 2030 and reduce food losses along the food production and supply chains. By looking at the interlinkages with clear directionality existing between target 12.3 and all the other SDGs, the policymaker can quickly identify areas where action on FLW can leverage positive effects, and vice versa. At the same time, the tool allows to flag possible challenges in other areas.

From the information collected through the literature review, it emerges that 12.3 exhibits positive impacts on other SDG targets (Figure 17). Halving FLW will favour progress on poverty and hunger reduction; health; education for sustainable development; water and sanitation; sustainable and inclusive urban areas; sustainable and resource-efficient industrialization, economic growth, and energy; climate mitigation and adaptation; ecosystem and biodiversity conservation (Breu et al., 2021; Lyytimäki et al., 2021).

Figure 17. Sankey chart showing interlinkages of SDG 12.3 as the target (left) and source (right) of directed interlinkages



Source: Authors' elaboration, created with flourish.studio.
Note: The red lines for targets 2.1, 2.3 and 8.1 represent a trade-off and signal a negative impact of those targets on 12.3.

A reduction of FLW contributes to the achievement of SDG 12 on sustainable production and consumption, especially on the sustainable management and efficient use of natural resources, and the sound management of all waste (Coopman et al., 2016; Breu et al., 2021). FLW presents the most target-level synergies to reducing and preventing marine pollution (14.1), and it diminishes the risk of overfishing by increasing food availability, thus favouring marine conservation (14.4, 14.5). Lessening FLW will also decrease the detrimental impacts of food production on water quality (target 6.3; Lyytimäki et al., 2021) and ecosystem conservation (target 6.6, SDG 15 targets). Halving FLW also improves food security (SDG 2; Breu et al., 2021; Jacob-John et al., 2021; Pingali & Plavšić, 2022).

The strong interconnections between FLW and other areas of sustainable development are not only identified in the literature underlying the SDG Interlinkages Tool, but also in other publications. Lemaire and Limbourg (2019) review the potential of managing FLW to achieve SDGs and discuss the implications of FLW on scarce resources and the positive contributions of effectively managed FLW for reducing the economic burden on consumers and producers (Morone et al., 2019), decreasing the water and carbon footprint (Chapagain & James, 2013), improving food security (Garrone et al., 2014), amongst others.

At the same time, as mentioned, many policy areas directly impact FLW. In the database, the only negative effects recorded are those from economic growth (8.1), ending hunger and granting access to food (2.1) and agricultural productivity (2.3), probably linked to patterns of unsustainable production and consumption, such as over-production for short-term economic benefit. Yet, mostly synergistic effects are recorded. Targets from sustainable urbanization, industrialization, and energy (11.3, 11.6, 9.4, 7.2, 7.3), sustainable production and consumption (SDG 12), climate change mitigation and adaptation (SDG 13), biodiversity and ecosystems (1SDGs 6, 14, 15), and education positively affect 12.3, making the relation mutually beneficial.

The role of knowledge, skills and education for sustainable development and sustainable lifestyles (4.7) in addressing FLW is widely recognised in the literature (Neff et al., 2015; Richter & Bokelmann, 2016). Many links also emerge from the targets of SDG 14: specific measures for sustainable fisheries like discard bans or selective fishing help in reducing FLW along the supply chain (ICSU, 2017). Remarkably, institutions also play a role in shaping coherent policies for FLW management (targets 16.6 and 17.14).

This overview highlights that policies and initiatives on FLW should pay special attention to the possibility to simultaneously work on FLW and other policy areas. From what emerges, most of the positive direct impacts

address aspects of resource efficiency, like in urban areas, industries and infrastructures, production, consumption and lifestyles, energy. Sustainable management of resources contributes reducing environmental degradation and tackling climate change. Moreover, FLW goes hand-in-hand with innovative and sustainable food production and consumption practices. And education, awareness, and institutional action, including policy coherence, can concur in reducing FLW.

On the contrary, conventional strategies to increase agricultural and economic outputs regardless of sustainability objectives can still generate massive amounts of FLW: 14% of food produced is lost between post-harvest and retail supply chain stages (FAO, 2019) and 17% is wasted at the retail, food-service and consumer level (UNEP, 2021a), for a total of one-third of FLW globally.

The SDG Interlinkages Tool uncovers FLW reduction benefits, as well as possible leverages and burdens coming from the rest of the policy landscape. This example shows the relevance of making sense of SDG interlinkages, as they translate in the realm of policymaking and can guide more coherent, efficacious, and efficient policies for sustainable development.

It is important to stress that the tool offers a good entry point to understand the possible effects of action in a certain policy area by providing an overview of interlinkages coming from available literature. However, an evaluation of all effects of a specific policy action shall be performed with an ad-hoc study that, starting from the tool, is shaped along the pertinent contextual, geographical and time conditions of the action to be performed.

6 Conclusions

The 2030 Agenda and its **SDGs are designed to bring about the comprehensive fulfilment of social and ecological wellbeing**. In the reality we are currently living, threatened by climate change and socio-political crises, the achievement of these ambitious objectives is more than necessary but **it requires a policy coherence perspective focusing on a sustainable development transition**. Indeed, governance is a key cross-cutting issue identified as shaping SDG interactions (Nilsson et al., 2016; McCollum et al.; 2018). In other words, achieving the SDGs calls for the active participation of policymakers willing to design, implement and monitor policies that can support synergetic progress toward sustainable development.

Holistic transformational initiatives like the 2030 Agenda are inherently complex, not only due to the many different objectives bundled together within a single framework, but also because of the numerous direct and indirect intricate interconnections that exist between these objectives. This complexity becomes almost overwhelming when considering the different actors and governance levels involved, the varying capacities and available resources, as well as temporal and geographical spillovers that generate feedback loops across the entire system. Consequently, navigating this complexity can become challenging for policy and decision makers. The complexity also extends to the analysis of SDG interlinkages, a process in which analytical, temporal, and geographical scales, as well as data sources, may vary depending on the specific context. Lack of coherent data, limited time coverage and an abundance of different datasets can hinder the application of elaborated methods with standardised protocols, eventually impeding a proper comparison of results across different studies and looking at different countries. The recent analysis from Warchold and colleagues (2022) discusses the extent of variation and conflicting information arising when analysing the same SDGs using different datasets.

Methods to address this complexity of SDG interlinkages are constantly evolving. A well-balanced mix combining qualitative and quantitative elements seems appropriate to capture the complexity of SDG interlinkages. Indeed, as suggested by Ospina-Forero and colleagues (2022), the "best" method to understand interlinkages should account for temporal dependence, small samples, multidimensionality, and causation. In other words, it should address all the limitations inherent to interlinkages analysis: short time series with limited observations, scalability, replicability, directionality, specificity, and validity.

While taking an integrated approach into account, as seen so far, the nature of SDG interlinkages (positive, negative) and the possibilities for indirect effects and unintended consequences are highly context-dependant. As a result, policies aiming at maximising synergies and minimising trade-offs should behave accordingly, accounting for the specific context and geographical scale where they aim to intervene (Weitz et al., 2019; Breu et al., 2021).

Contextualisation is also necessary to ensure that policies can define and target those SDG interactions that are most urgent in the specific area and promote mutually reinforcing "virtuous circles" of interaction (Breu et al., 2021). Consequentially, policymakers must balance between specificity and a global outlook.

Which policies can foster coherence and the systemic change underlying the 2030 Agenda? First, working "in-silo", with each area of policymaking isolated from the other, is neither a suitable nor a recommendable option. Political decisions give rise to systemic interactions, feedback loops and spillovers in other areas. To cope with these effects, policies need to embrace integration and comprehensiveness, and policymakers need to engage in coordinated efforts across governmental sectors and levels (McCollum et al., 2018; Breuer et al., 2019; Biermann et al., 2022).

Even though the 2030 Agenda aims at "leaving no one behind", policies tend to generate winners and losers. Hence, policies striving to foster coherence on the SDGs should recognise the intrinsic costs of specific interventions for some stakeholders and reduce trade-offs to minimise them as much as possible.

Innovative, integrated, context-specific but adaptable policies that are monitored and evaluated for performance and accountability are necessary to address the SDGs within actual policymaking and deliver on the 2030 Agenda. Yet, policymaking is uncertain by design, being a future-oriented exercise with implications that are not easily accounted for beforehand (Weitz et al., 2019). Consequently, before they can design and implement policies that consider SDGs, policymakers must understand the complex set of relationships occurring across the 2030 Agenda. This aspect has also been firmly anchored in EU policymaking practices with the update of the Better Regulation guidelines requiring policy makers to assess and analyse SDGs and their

interlinkages for any new policy proposal. Particularly in these regards, the SDG Interlinkages analysis and the Interlinkages Tool derived from it can provide meaningful support to policymakers at the national and European levels during all stages of policymaking, from agenda setting to evaluation, as outlined below.

Since integrated policymaking requires engaged policymakers, the Tool can initiate the conversation on interlinkages and policy coherence (Weitz et al., 2019), by allowing users to understand what is meant by SDG interlinkages, synergies, and trade-offs whilst providing concrete examples. It shows positive and negative relations across the development spectrum and where action in one policy field can lead to positive reinforcement (synergy), drawbacks (trade-offs), or even mixed results in other areas. It enables policymakers to identify entry- and leverage-points where policy interventions can provide multiple co-benefits and support progress on various targets. At the same time, multipliers of trade-offs can be spotted and addressed.

Visualising existing SDG Interlinkages, their synergies and trade-offs, can help policymakers move past the "silo approach" to acknowledge that policy fields are interlinked, and areas of cross-contamination exist. Through interlinkages, policymakers can also understand if any policy field requires new initiatives, legislation, more resources, as well as which instruments would be more suitable to address interconnected policy areas. This exercise can promote resource-use efficiency and effectiveness in policymaking, as well as policy innovation, which is necessary to achieve SDGs.

The Tool offers further information on the geographical scale, time, and context of SDG interlinkages (when specified by authors). At the same time, it provides detailed descriptions and explanations of specific interlinkages. This deeper level of analysis helps with the contextualisation of SDG synergies and trade-offs: the same targets can have quite different outcomes under specific conditions. With this information, the Tool supports policymakers in building context-specific evaluations and policies, buffering against the scale and time lags hindering policy coherence for SDGs and supporting the prioritisation of most relevant policies (Breu et al, 2021). Future developments of the Interlinkages Tool may include linking each SDG to a set of issue areas to contextualise SDG interactions across different policy fields. In a similar fashion, the SDGs can be connected to other frameworks, like the Aichi Biodiversity Targets, the Bioeconomy Strategy or Gender Equality Indexes, the Megatrends Hub, to enhance coherence not only within the 2030 Agenda but also with other international initiatives.

Translating research on complex systems and their interactions into understandable and applicable information is essential for designing coherent policies to advance sustainable development. Bridging science and policy enables decision makers maximise sustainability benefits, rather than working on isolated components of the 2030 Agenda, which may inadvertently lead to neglecting potential side effects in other areas. This approach can help avoiding the risk of engaging in a system change gamble, where policy interventions might generate unexpected and undesired outcomes. Future research should thus capitalise on the SDG interlinkages database created along this review with the aim to integrate the information on pairwise interactions in a systemic way, moving beyond first-order effects to analyse the cumulative impact arising from the cascading interactions arising from different SDG pathways.

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List of abbreviations and definitions

EU = European Union

FLW = Food Loss and Waste

GHG = Greenhouse gases

IAEG-SDG = United Nations Inter-Agency and Expert Group on Sustainable Development Goal Indicators

IAM = Integrated assessment modelling

JRC = Joint Research Centre

MDGs = Millennium Development Goals

PCSD = Policy Coherence for Sustainable Development

SDG = sustainable Development Goals

SDSN = Sustainable Development Solutions Network

UN = United Nations

WASH = Water, Sanitation and Hygiene

WEF = Water – Food – Energy

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Annex. List of publications

Table A1. List of selected publications for the review (from 2015 to August 2022)

N	Authors	Title	Year	Method	Geographic scale	Geographic context
1	Agusdinata D.B.	The role of universities in SDGs solution co-creation and implementation: a human-centered design and shared-action learning process	2022	Literature review	Subnational	North Lombok and Mimika, Indonesia
2	Alcamo J.	Water quality and its interlinkages with the Sustainable Development Goals	2019	Literature review	n.a.	
3	Anderson C.C., Denich M., Warchold A., Kropp J.P., Pradhan P.	A systems model of SDG target influence on the 2030 Agenda for Sustainable Development	2022	Mixed (Data analysis; network analysis)	Global	*251 countries*
4	Reihaneh Bandari, Enayat A. Moallemi, Rebecca E. Lester, David Downie, Brett A. Bryan	Prioritising Sustainable Development Goals, characterising interactions, and identifying solutions for local sustainability	2022	Mixed (Semantic analysis; Literature review; Expert judgement)	Subnational	Goulburn-Murray region (Australia)
5	Bangert, M., Molyneux, D.H., Lindsay, S.W., Fitzpatrick, C., Engels, D.	The cross-cutting contribution of the end of neglected tropical diseases to the sustainable development goals	2017	Literature review	Multinational	developing countries
6	Bennich T., Belyazid S., Stjernquist I., Diemer A., Seifollahi-Aghmiuni S., Kalantari Z.	The bio-based economy, 2030 Agenda, and strong sustainability – A regional-scale assessment of sustainability goal interactions	2021	Mixed (Literature review; Expert judgement; Modelling)	Subnational	Norrkoping municipality, Sweden
7	Blair MJ, Gagnon B, Klain A, Kulišić B.	Contribution of Biomass Supply Chains for Bioenergy to Sustainable Development Goals	2021	Mixed (Literature review; Expert judgement)	Multinational 20 countries (case studies)	Australia, Austria, Brazil, Canada, China, Denmark, France, Germany, Ghana, Italy, Kenya, Netherlands, Rural China, Rwanda, South Africa, Sweden, Switzerland, Tanzania, United States, Zambia
8	Breu T., Bergöö M., Ebneter L., Pham-Truffert M., Bieri S., Messerli P., Ott C., Bader C.	Where to begin? Defining national strategies for implementing the 2030 Agenda: the case of Switzerland	2021	Literature review	National	Switzerland
9	Cling J.-P., Delecourt C.	Interlinkages between the sustainable development goals	2022	Data analysis	Global	160 countries

N	Authors	Title	Year	Method	Geographic scale	Geographic context
10	Coenen J., Glass L.-M., Sanderink L.	Two degrees and the SDGs: a network analysis of the interlinkages between transnational climate actions and the Sustainable Development Goals	2021	Mixed (Literature review; Expert judgement)	Multinational	
11	Cook D., Davíðsdóttir B.	An appraisal of interlinkages between macro-economic indicators of economic well-being and the sustainable development goals	2021	Mixed (Literature review; Modelling)	n.a.	
12	Coopman, A., Osborn, D., Ullah, F., Auckland, E. and Long, G.	Seeing the Whole: Implementing the sdgs in an Integrated and Coherent Way	2016	Expert judgement	n.a.	
13	Cutter, A., Osborn, D., Romano, J. and Ullah, F.	Sustainable Development Goals and Integration. Achieving a better balance between the economic, social and environmental dimensions	2015	Semantic analysis	n.a.	
14	de Miguel Ramos C., Laurenti R.	Towards the agenda 2030: A quantitative analysis of synergies and trade-offs between the sdgs of spain during 2000–2019	2020	Data analysis	National	Spain
15	Dörgő, G.; Sebestyén, V.; Abonyi, J.	Evaluating the Interconnectedness of the Sustainable Development Goals Based on the Causality Analysis of Sustainability Indicators	2018	Data analysis	Global	283 geographical regions
16	Dziubaniuk O., Ivanova-Gongne M., Berdysheva E.	Challenges of network interaction in managing sustainable development projects in developing countries: case of an international consulting company	2021	Mixed (Literature review; Expert judgement)	National; Subnational	Local Nepalese communities, Finland
17	Ehrensperger, A., de Bremond, A., Providoli, I., & Messerli, P.	Land system science and the 2030 agenda: Exploring knowledge that supports sustainability transformation.	2019	Mixed (Literature review; Expert judgement)	n.a.	
18	Eurostat	Sustainable development in the European Union. Monitoring report on progress towards the SDGs in an EU context. 2021 edition	2021	Data analysis	Multinational	EU 28
19	Fader M., Cranmer C., Lawford R., Engel-Cox J.	Toward an understanding of synergies and trade-offs between water, energy, and food SDG targets	2018	Data analysis	Global	
20	Floerke, M., Baerlund, I., van Viet, M.T.H., Bouwman, A.F., Wada, Y.	Analysing trade-offs between SDGs related to water quality using salinity as a marker	2019	Literature review	n.a.	

N	Authors	Title	Year	Method	Geographic scale	Geographic context
21	Fonseca L.M., Domingues P., Dima A.M.	Mapping the sustainable development goals relationships	2020	Data analysis	Global	193 UN Member States
22	Fuso Nerini F., Tomei J., To L.S., Bisaga I., Parikh P., Black M., Borrion A., Spataru C., Castán Broto V., Anandarajah G., Milligan B., Mulugetta Y.	Mapping synergies and trade-offs between energy and the Sustainable Development Goals	2018	Mixed (Literature review; Expert judgement)	Global	
23	Gannon K.E., Pettinotti L., Conway D., Surminski S., Ndilanha E., Nyumba T.	Delivering the Sustainable Development Goals through development corridors in East Africa: A Q-Methodology approach to imagining development futures	2022	Mixed (Expert judgement; data analysis)	Multinational	East Africa
24	Gleeson H.S., Oliveras Rodriguez C.A., Hatane L., Hart D.	Ending AIDS by 2030: The importance of an interlinked approach and meaningful youth leadership: The	2018	Literature review	n.a.	
25	Grigorescu A., Ion A.-E., Lincaru C., Pirciog S.	Synergy Analysis of Knowledge Transfer for the Energy Sector within the Framework of Sustainable Development of the European Countries	2022	Data analysis	National	24 EU countries and 4 other European states
26	Guijarro F., Poyatos J.A.	Designing a sustainable development goal index through a goal programming model: The case of EU-28 countries	2018	Modelling	Multinational	EU 28
27	Hall N.L., Creamer S., Anders W., Slatyer A., Hill P.S.	Water and health interlinkages of the sustainable development goals in remote Indigenous Australia	2020	Mixed (Literature review; Expert judgement)	Subnational	Indigenous Australia
28	Hoeltl A., Brandtweiner R., Bates R., Berger T.	The interactions of sustainable development goals: The case of urban informal settlements in Ethiopia	2020	Mixed (Literature review; Expert judgement)	National	Ethiopia
29	Horan D.	National baselines for integrated implementation of an environmental sustainable development goal assessed in a new integrated SDG index	2020	Expert judgement	National	Island states
30	Hutton C.W., Nicholls R.J., Lázár A.N., Chapman A., Schaafsma M., Salehin M.	Potential trade-offs between the sustainable development goals in coastal Bangladesh	2018	Mixed (Expert judgement; Modelling)	Subnational	coastal zone of southwest Bangladesh
31	Iacobuță G.I., Höhne N., van Soest H.L., Leemans R.	Transitioning to low-carbon economies under the 2030 agenda: Minimizing trade-offs and enhancing co-benefits of climate-change action for the sdgs	2021	Mixed (Literature review; Expert judgement)	n.a.	

N	Authors	Title	Year	Method	Geographic scale	Geographic context
32	UN Inter-Agency and Expert Group on SDG Indicators (IAEG-SDGs)	Interlinkages of the 2030 Agenda for Sustainable Development	2019	Mixed (Expert judgement; Semantic analysis)	n.a.	
33	UN Inter-Agency and Expert Group on SDG Indicators (IAEG-SDGs)	Second Report of the Interlinkages Workstream	2020	Literature review	Multinational; National	France, Italy, multinational
34	Griggs, D.J., Nilsson, M., Stevance, A., McCollum, D.	A guide to SDG interactions: From science to implementation	2017	Mixed (Literature review; Expert judgement)	n.a.	
35	ICSU, ISSC	Review of the sustainable development goals: the science perspective.	2015	Mixed (Literature review; Expert judgement)	n.a.	
36	Jacob-John J., D'souza C., Marjoribanks T., Singaraju S.	Synergistic interactions of sdgs in food supply chains: A review of responsible consumption and production	2021	Mixed (Semantic analysis; Literature review; Expert judgement)	n.a.	
37	Karnib, A.	Mapping the direct and indirect interlinkages across the sustainable development goals: A qualitative nexus approach	2017	n.a.	n.a.	
38	Karnib A.	Water as Crosscutting Factor in the SDGs Under Review at the High-Level Panel Forum for Sustainable Development (HLPF) 2019 in the Arab States	2019	Mixed (Literature review; Expert judgement)	Multinational	Arab states
39	Kostetckaia M., Hametner M.	How Sustainable Development Goals interlinkages influence European Union countries' progress towards the 2030 Agenda	2022	Data analysis	Multinational	EU MS
40	Kroll C., Warchold A., Pradhan P.	Sustainable Development Goals (SDGs): Are we successful in turning trade-offs into synergies?	2019	Data analysis	Global	196 countries
41	Kunčič A.	Prioritising the sustainable development goals using a network approach: Sdg linkages and groups	2019	Data analysis	Global	
42	Langou, G.D., Florito, J., Biondi, A., Sachetti, F.C. and Petrone, L.	Leveraging synergies and tackling trade-offs among specific Goals	2020	Mixed (Semantic analysis; Literature review; Modelling)	National	Peru, Bolivia, India, Sri Lanka Ghana, Nigeria
43	Latif M.H., Amjad M., Tahir Z.U.R., Qamar A., Asim M., Mahmood W., Khalid W., Rehman A.	Nexus implementation of sustainable development goals (SDGs) for sustainable public sector buildings in Pakistan	2022	Data analysis	National	Pakistan
44	Laumann F., von Kügelgen J.,	Complex interlinkages, key objectives, and nexuses among	2022	Data analysis	Global; Multinational	180 countries

N	Authors	Title	Year	Method	Geographic scale	Geographic context
	Kanashiro Uehara T.H., Barahona M.	the Sustainable Development Goals and climate change: a network analysis				
45	Le Blanc, D.	Towards Integration at Last? The Sustainable Development Goals as a Network of Targets	2015	Semantic analysis	Global	
46	Le Blanc, D., Freire, C., Vierros, M.	Mapping the linkages between oceans and other Sustainable Development Goals: A preliminary exploration.	2017	Mixed (Literature review; Expert judgement)	Multinational	
47	Liu S.	Interactions between industrial development and environmental protection dimensions of Sustainable Development Goals (SDGs): Evidence from 40 countries with different income levels	2020	Data analysis	Multinational	40 countries
48	Lusseau D., Mancini F.	Income-based variation in Sustainable Development Goal interaction networks	2019	Data analysis	Global	World, Low-income countries
49	Lyytimäki J., Lonkila K.-M., Furman E., Korhonen-Kurki K., Lähteenoja S.	Untangling the interactions of sustainability targets: synergies and trade-offs in the Northern European context	2021	Expert judgement	National	Finland
50	Mainali B., Luukkanen J., Silveira S., Kaivo-Oja J.	Evaluating synergies and trade-offs among Sustainable Development Goals (SDGs): Explorative analyses of development paths in South Asia and Sub-Saharan Africa	2018	Mixed (Literature review; Expert judgement; Data analysis)	Multinational	Developing countries + focus on Bangladesh, Nepal, Sri Lanka, Ethiopia, Ghana and Rwanda
51	Maksymiv Y., Yakubiv V., Pylypiv N., Hryhoruk I., Piatnychuk I., Popadynets N.	Strategic challenges for sustainable governance of the bioeconomy: Preventing conflict between sdgs	2021	Literature review	n.a.	
52	Mantlana K.B., Maoela M.A.	Mapping the interlinkages between sustainable development goal 9 and other sustainable development goals: A preliminary exploration	2019	Mixed (Literature review; Data analysis)	Global	
53	Marcinko C.L.J., Nicholls R.J., Daw T.M., Hazra S., Hutton C.W., Hill C.T., Clarke D., Harfoot A., Basu O., Das I., Giri S., Pal S., Mondal P.P.	The development of a framework for the integrated assessment of sdg trade-offs in the sundarban biosphere reserve	2021	Mixed (Literature review; Expert judgement; Modelling)	Subnational	Sundarban Biosphere Reserve (SBR), India
54	McCollum D.L., Echeverri L.G., Busch S., Pachauri S., Parkinson S., Rogelj J., Krey V., Minx J.C., Nilsson M., Stevance A.-S., Riahi K.	Connecting the sustainable development goals by their energy inter-linkages	2018	Mixed (Literature review; Expert judgement)	Global	

N	Authors	Title	Year	Method	Geographic scale	Geographic context
55	Milan B.F.	Clean water and sanitation for all: interactions with other sustainable development goals	2017	Mixed (Literature review; Expert judgement; Modelling)	Global	Urban context
56	Natcher D., Ingram S.	A nexus approach to water, energy, and food security in Northern Canada	2021	Mixed (Literature review; Expert judgement)	Subnational	Northern Canada
57	Nilsson, M.	Important Interactions among the Sustainable Development Goals under Review at the High-Level Political Forum 2017	2017	Mixed (Literature review; Expert judgement)	n.a.	
58	Nunes, A.R., Lee, K., O'Riordan, T.	The importance of an integrating framework for achieving the Sustainable Development Goals: the example of health and well-being	2016	Literature review	n.a.	
59	Recuero Virto, L.	A preliminary assessment of indicators for SDG 14 on "Oceans"	2017	Mixed (Literature review; Expert judgement)	n.a.	
60	Oghenekaro R.E., Kant S.	Interactions between proposed energy-mix scenarios and non-energy Sustainable Development Goals (SDGs): A Sub-Sahara African perspective	2022	Mixed (Literature review; Expert judgement)	National	Nigeria; Ethiopia
61	Osman, A., Mensah, E.A., Mensah, C.A., Asamoah, Y., Dauda, S., Adu-Boahen, K., Adongo, C.A.	Spatial analysis of synergies and trade-offs between the Sustainable Development Goals (SDGs) in Africa	2022	Data analysis	National	African countries
62	Ospina-Forero L., Castañeda G., Guerrero O.A.	Estimating networks of sustainable development goals	2020	Mixed (Data analysis; Modelling)	National	Egypt; Indonesia; Mexico; Turkey
63	Parikh, Priti, Loan Diep, Pascale Hofmann, Julia Tomei, Luiza Campos, T. Teh, Yacob Mulugetta, Ben Milligan, and Monica Lakhanpaul.	Synergies and trade-offs between sanitation and the sustainable development goals	2021	Mixed (Literature review; Expert judgement)	Global	
64	Pham-Truffert M., Metz F., Fischer M., Rueff H., Messerli P.	Interactions among Sustainable Development Goals: Knowledge for identifying multipliers and virtuous cycles	2020	Mixed (Literature review; Expert judgement)	Global	
65	Philippidis G., Shutes L., M'Barek R., Ronzon T., Tabeau A., van Meijl H.	Snakes and ladders: World development pathways' synergies and trade-offs through the lens of the Sustainable Development Goals	2020	Mixed (Expert judgement; Modelling)	Global	

N	Authors	Title	Year	Method	Geographic scale	Geographic context
66	Pingali P., Plavšić M.	Hunger and environmental goals for Asia: Synergies and trade-offs among the SDGs	2022	Literature review	Multinational	South Asia
67	Pradhan P., Costa L., Rybski D., Lucht W., Kropp J.P.	A Systematic Study of Sustainable Development Goal (SDG) Interactions	2017	Data analysis	Global	227 countries
68	Requejo-Castro D., Giné-Garriga R., Pérez-Foguet A.	Data-driven Bayesian network modelling to explore the relationships between SDG 6 and the 2030 Agenda	2020	Data analysis	Global	179 countries
69	Rulisa A., van Kempen L., Koch D.-J.	When Local Trade-Offs between SDGs Turn Out to Be Wealth-Dependent: Interaction between Expanding Rice Cultivation and Eradicating Malaria in Rwanda	2022	Mixed (Literature review; Data analysis)	National; Subnational	Rwanda; sub-district of Ruhusa
70	Santika W.G., Anisuzzaman M., Bahri P.A., Shafiullah G.M., Rupf G.V., Urmee T.	From goals to joules: A quantitative approach of interlinkages between energy and the Sustainable Development Goals	2019	Mixed (Semantic analysis; Literature review; Expert judgement; Modelling)	Global	
71	Scherer L., Behrens P., de Koning A., Heijungs R., Sprecher B., Tukker A.	Trade-offs between social and environmental Sustainable Development Goals	2018	Data analysis	Global	166 nations of the world
72	Singh G.G., Cisneros-Montemayor A.M., Swartz W., Cheung W., Guy J.A., Kenny T.-A., McOwen C.J., Asch R., Geffert J.L., Wabnitz C.C.C., Sumaila R., Hanich Q., Ota Y.	A rapid assessment of co-benefits and trade-offs among Sustainable Development Goals	2018	Mixed (Literature review; Expert judgement)	Global	
73	Mrinal Singha, Jinwei Dong, Quansheng Ge, Graciela Metternicht, Sangeeta Sarmah, Geli Zhang, Russell Doughty, Sharachchandra Lele, Chandrashekhar Biradar, Sha Zhou, Xiangming Xiao	Satellite evidence on the trade-offs of the food-water–air quality nexus over the breadbasket of India	2021	Data analysis	Subnational	northwest India (Punjab and Haryana)
74	Samuel Stevenson, Alexandra Collins, Neil Jennings, Alexandre C. Köberle, Felix Laumann, Anthony A. Laverty, Paolo Vineis, Jeremy Woods & Ajay Gambhir	A hybrid approach to identifying and assessing interactions between climate action (SDG13) policies and a range of SDGs in a UK context	2021	Mixed (Semantic analysis; Literature review; Expert judgement)	National	UK
75	Su H., Krol M.S., Hogeboom R.J.	The role of context in identifying linkages between	2022	Mixed (Literature review; data	National	various countries and

N	Authors	Title	Year	Method	Geographic scale	Geographic context
		SDG 2 (food) and SDG 6 (water)		analysis; semantic analysis)		their aggregation
76	Taka M., Ahopelto L., Fallon A., Heino M., Kallio M., Kinnunen P., Niva V., Varis O.	The potential of water security in leveraging Agenda 2030	2021	Mixed (Literature review; Expert judgement; Data analysis)	n.a.	
77	Tosun J., Leininger J.	Governing the Interlinkages between the Sustainable Development Goals: Approaches to Attain Policy Integration	2017	Semantic analysis	n.a.	
78	UN Women	Why gender equality matters across all SDGs: An excerpt of "Turning promises into action: Gender equality in the 2030 Agenda for Sustainable Development"	2018	Literature review	Multinational	
79	UNEP	Measuring Progress: Environment and the SDGs	2021	Mixed (Literature review; Expert judgement; Data analysis)	Global	193 UN Member States
80	UNESCAP	Analytical Framework for Integration of Water and Sanitation SDGs and Targets Using Systems Thinking Approach	2016	Expert judgement	Global; Multinational	Global and Asia-Pacific region
81	UNESCAP	Integrated approaches for Sustainable Development Goals planning: The case of Goal 6 on water and sanitation	2017	Expert judgement	Global; National	Sri Lanka, Tajikistan and Fiji
82	UN-Water	Water and Sanitation Interlinkages across the 2030 Agenda for Sustainable Development	2016	Expert judgement	Multinational	
83	Van Soest, H.L., Van Vuuren, D.P., Hilaire, J., Minx, J.C., Harmsen, M.J., Krey, V., Popp, A., Riahi, K. and Luderer, G.	Analysing interactions among Sustainable Development Goals withIntegrated Assessment Models	2019	Mixed (Semantic analysis; Literature review; Expert judgement)	From global to local	
84	Vera, I., Wicke, B., Lamers, P., Cowie, A., Repo, A., Heukels, B.,... & van der Hilst, F.	Land use for bioenergy: Synergies and trade-offs between sustainable development goals.	2022	Mixed (Literature review; Expert judgement)	Multinational	
85	Vladimirova, K. and Le Blanc, D	Exploring links between education and sustainable development goals through the lens of UN Flagship Reports	2016	Mixed (Semantic analysis; Literature review; Expert judgement)	Global	
86	Wang M., Janssen A.B.G., Bazin J., Strokal M., Ma L., Kroeze C.	Accounting for interactions between Sustainable Development Goals is essential	2022	Mixed (Literature review; Expert judgement)	National	China

N	Authors	Title	Year	Method	Geographic scale	Geographic context
		for water pollution control in China				
87	Warchold A., Pradhan P., Kropp J.P.	Variations in sustainable development goal interactions: Population, regional, and income disaggregation	2021	Data analysis	Global	247 countries
88	Warchold A., Pradhan P., Thapa P., Putra M.P.I.F., Kropp J.P.	Building a unified sustainable development goal database: Why does sustainable development goal data selection matter?	2022	Data analysis	Global; Multinational	Global, income-groups countries, regions
89	Weitz, N., Carlsen, H., Nilsson, M. and Skånberg, K.	Towards systemic and contextual priority setting for implementing the 2030 Agenda	2018	Mixed (Literature review; Expert judgement)	National	Sweden
90	Weitz, N., Carlsen, H., Skånberg, K., Dzebo, A. and Viaud, V.	SDGs and the environment in the EU: A systems view to improve coherence	2019	Mixed (Literature review; Expert judgement)	Multinational	EU
91	Zhang J., Wang S., Pradhan P., Zhao W., Fu B.	Mapping the complexity of the food-energy-water nexus from the lens of Sustainable Development Goals in China	2022	Data analysis	Subnational	China
92	Zhu J., Zhai Y., Feng S., Tan Y., Wei W.	Trade-offs and synergies among air-pollution-related SDGs as well as interactions between air-pollution-related SDGs and other SDGs	2022	Data analysis	National; Subnational	China national, China provincial

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