Understanding the role of biodiversity in the climate, food, water, energy, transport and health nexus in Europe

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Abstract

Biodiversity underpins the functioning of ecosystems and the diverse benefits that nature provides to people, yet is being lost at an unprecedented rate. To halt or reverse biodiversity loss, it is critical to understand the complex interdependencies between biodiversity and key drivers and sectors to inform the development of holistic policies and action. We conducted a literature review on the interlinkages between biodiversity and climate change, food, water, energy, transport and health ("the biodiversity nexus"). Evidence extracted from 194 peer-reviewed articles was analysed to assess how biodiversity is being influenced by and is influencing climate, food, water, energy, transport and health. Out of the 354 interlinkages evidenced between biodiversity and other nexus elements in the review, 53% were negative, 29% were positive and 18% contained both positive and negative influences. Most studies provide evidence of the negative influence of the nexus elements on biodiversity, highlighting the substantial damage being inflicted on nature from human activities. The main types of negative impacts were related to land or water use/change, land or water degradation, direct species fatalities through collisions with infrastructure, and climate change. Alternatively, evidence of biodiversity having a negative influence on the other nexus elements is mainly limited to the effects of invasive alien species and vector-borne disease. Furthermore, a range of studies provided evidence of how co-benefits could be achieved between biodiversity and other nexus elements, such as through agroecological practices, green and blue infrastructure, nature-based solutions, ecosystem restoration and sustainable diets. The review highlighted the complexity and context-dependency of interlinkages within the biodiversity nexus, but clearly demonstrates the importance of biodiversity in underpinning human well-being and ensuring a sustainable future for people and the planet.

Key Messages

- Biodiversity plays a critical underpinning role in nexus interlinkages among climate, food, water, energy, transport and health.
- Previous research focused heavily on negative impacts of the nexus elements on biodiversity and there is much less evidence of negative impacts of biodiversity on the other nexus elements.
- There is evidence that biodiversity has positive impacts on these nexus elements, but more studies are needed.
- Evidence from nexus studies can inform the development of holistic policy and management options that aim to promote co-benefits between biodiversity and the other nexus elements.
- Biodiversity nexus evidence needs to be contexualized in the local context where it is being used given different ecosystems, environmental conditions, pressures and drivers at play.

Keywords: biodiversity, nexus, conservation, sustainability, policy coherence, Europe

1. Introduction

Biodiversity supports and sustains life on Earth and underpins the functioning of ecosystems and the diverse benefits that nature provides to people (Brauman et al., 2020; Cardinale et al., 2012; IPBES, 2019). It plays a crucial role in the achievement of sustainability outcomes related to food and water security, health and wellbeing, and climate change mitigation and adaptation, among others (Moreno Vargas et al., 2023; Newell, 2023; Ortiz et al., 2021; Sietz & Neudert, 2022; Stoy et al., 2018). Ranging in organismal levels from genes to species and ecosystems, biodiversity contributes directly or indirectly to the achievement of all 17 Sustainable Development Goals (SDGs), encompassing a broad range of ecological and societal wellbeing ambitions set to be achieved by 2030 (Blicharska et al., 2019; Liu et al., 2018; Petersson & Stoett, 2022; Robinson, 2017). Yet, biodiversity is being lost worldwide at unprecedented rates due to human activities, with more than one million species threatened by extinction (Bellard et al., 2022; Hochkirch et al., 2023; IPBES, 2019).

The Intergovernmental science-policy Platform on Biodiversity and Ecosystem Services (IPBES), established in 2010, has raised attention to the importance of biodiversity and the urgent need to halt and reverse biodiversity loss. However, although the biodiversity crisis is now widely known, policy has been unable to arrest the decline, with much of this failure being attributed to a lack of mainstreaming of biodiversity in public policy across sectors (Rounsevell et al. 2020). Recent assessments and workshop reports from IPBES – Global Assessment (IPBES 2019), Biodiversity and Pandemics report (IPBES 2020), and Biodiversity and Climate Change report (IPBES 2021) – all point to the importance of holistic policy and governance that addresses challenges across sectors in an integrated way to identify opportunities for synergistic action that benefits both nature and people (IPBES, 2019, 2020; Pörtner et al., 2021). This has been recognised by IPBES in the initiation of the Nexus Assessment focusing on the interlinkages among biodiversity, water, food, health and climate change, which is planned to be published in 2024. In addition, a cross-sectoral approach for achieving conservation and sustainability is being increasingly embedded in regional and global policy frameworks, e.g. the SDGs (refs); the Kunming-Montreal Global Biodiversity Framework (CBD Secretariat, 2022; Leadley et al., 2022) and the European Green Deal (European Commission DG Environment, 2021; Paleari, 2024).

Nexus studies provide evidence that is essential for transforming governance away from typically siloed decision-making, where single sector policies are developed and implemented in isolation, towards holistic decision-making that aims to foster synergies and co-benefits across sectors, whilst minimizing or avoiding trade-offs or unintended consequences (Müller et al., 2015; Pascual et al., 2022). Recognising and understanding the underpinning role of biodiversity in nexus studies is key to mainstreaming biodiversity across policies and improving policy coherence so that "*biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people"*, in line with the vision of the Kunming-Montreal Global Biodiversity Framework of living in harmony with nature (Moreno Vargas et al., 2023; Stoy et al., 2018; Subedi et al., 2020). To do this, nexus research and practice need to be diversified to provide evidence on how policies and actions oriented towards biodiversity restoration and conservation can provide co-benefits for other sectors, and whether policies and actions in other sectors impact on biodiversity positively or negatively (Gomez-Echeverri, 2018; Kim et al., 2021; Pascual et al., 2022; Sietz & Neudert, 2022).

The scientific literature on nexus studies has grown rapidly over the last few decades (Estoque, 2023). Many previous nexus studies focused on two-way nexus studies, such as food-energy (Sachs & Silk, 1990) or water-energy (Malik, 2002) or on three-way nexus studies, with the water-energy-food nexus being particularly dominant (Bian & Liu, 2021; Carvalho et al., 2022; Lucca et al., 2023). However, the complexity and diversity of applications of the nexus approach has recently expanded (Estoque, 2023). These studies tend to expand upon the water-energy-food nexus by adding new elements, including climate change (Adeola et al., 2022; Hirwa et al., 2021; Ioannou & Laspidou, 2022), land use (Jaroenkietkajorn & Gheewala, 2021; Kati et al., 2021; Laspidou et al., 2019; Sietz & Neudert, 2022), and health (Astell-Burt et al., 2022; Hirwa et al., 2021; Newell, 2023; OHHLEP et al., 2022). The inclusion of biodiversity and its interlinkages with other sectors (i.e., the biodiversity nexus) has also started to gain traction more recently in terms of studies focused on the water-energy-food-ecosystem nexus (Carmona-Moreno et al., 2021; Cristiano et al., 2021; UNECE, 2015), the water-energy-food-biodiversity nexus (Moreno Vargas et al., 2023; Stoy et al., 2018; Subedi et al., 2020) or more broadly in terms of the water-energy-food-environment nexus (Hellegers et al., 2008). Despite these recent extensions of nexus applications, studies covering greater than three-way nexus interactions, and studies focusing on three-way nexuses other than water-energy-food, remain relatively rare.

The nexus studies to date that incorporate some consideration of biodiversity review evidence using diverse frameworks, approaches, methods and sources from a broad range of disciplines. These include studies with a specific focus on a country (e.g., pressure of the marine system on food-energy-water nexus in China, Zhu et al., 2021), a region (e.g., water-energy-food-ecosystem nexus in the Mediterranean, Lucca et al., 2023), a system (e.g. water-energy-food nexus in biodiversity conservation for transition in the agriculture system, Moreno Vargas et al., 2023) or a topic (e.g. urban greenroofs in water-energy-food nexus, Cristiano et al., 2021). These reviews show the new and emerging research on the biodiversity nexus, but also highlight that it is currently limited to a few regions, systems and topics, and highly focused on slight augmentations or interpretations of the water-food-energy nexus. In addition, other nexus studies have focused on negative sectoral impacts on biodiversity (Green et al., 2019; Sonter et al., 2020) and negative climate impacts on a range of sectors, including biodiversity (Adeola et al., 2022; Ioannou & Laspidou, 2022). However, few studies demonstrate the potential of the nexus approach for understanding the positive influence of biodiversity on other sectors, which will be vital for mainstreaming biodiversity considerations across sectors and providing evidence on how biodiversity can support transformative pathways towards sustainable futures.

Amid growing attention to nexus thinking in research and policy, there is a need for more comprehensive and integrated evidence on the biodiversity nexus to understand the role biodiversity plays in nexus interactions across sectors or domains of relevance to conservation, climate change, sustainability and human wellbeing. This review responds to this research gap and aims to synthesize evidence on the current state of knowledge on the nexus between biodiversity and six other elements – climate, food, water, energy, transport and health – focusing on Europe. It poses the research question: how is biodiversity influencing and influenced by climate, food, water, energy, transport and health? The review synthesises information on multiple directions and types of influences (i.e., influencing and influenced, positive and negative) across the seven nexus elements to improve understanding of the complex system dynamics represented by higher-order interlinkages (i.e. beyond two-way) within the biodiversity nexus.

2. Methods

2.1 The literature review database

A literature review was conducted to identify peer-reviewed studies that considers three-way interlinkages between biodiversity and at least two other nexus elements, with a focus on literature regarding the European continent. This included ten combinations of three-way nexus interlinkages with biodiversity: Biodiversity-Energy-Food (BEF), Biodiversity-Energy-Health (BEH), Biodiversity-Energy-Transport (BET), Biodiversity-Energy-Water (BEW), Biodiversity-Food-Health (BFH), Biodiversity-Food-Transport (BFT), Biodiversity-Food-Water (BFW), Biodiversity-Health-Transport (BHT), Biodiversity-Health-Water (BHW), and Biodiversity-Transport-Water (BTW).

We used the Web of Science online literature search engine and the R package LitsearchR to identify potentially relevant key terms for each of the seven nexus elements (biodiversity, climate change, energy, food, health, transport, water) and for terms related to "nexus". These were subsequently ranked using expert elicitation by the author team and combined with terms representing the geographical region (i.e., Europe) to derive a set of search strings (see Supplementary Material A, Tables S1, S2). Climate change was not explicitly included in the searches associated with the ten three-way nexus interlinkages as it was anticipated that climate change would be included in many of the articles identified. This was found to be the case, with climate change being part of about half (49%) of the 194 studies included in the review.

The search revealed 2,633 articles from the Web of Science, of which 1,185 articles passed an initial screening focused on title and abstract and 122 passed a second screening of the full articles. Criteria for both screenings were that the study should contain a clear link to biodiversity and between biodiversity and the two nexus elements, as well as information on the direction and magnitude of the interlinkages. We aimed to identify 20 articles per three-way nexus interlinkage to ensure consistent coverage of the ten three-way nexuses. Hence, additional refined searches were undertaken for those three-way interlinkages for which less than 20 eligible articles were found from the standard search (see Supplementary Material A). The final literature database included 200 studies; 20 for each nexus, with exceptions of 22 for Biodiversity-Health-Water and 18 for Biodiversity-Transport-Water. The former was due to over-submission and the latter due to lack of literature. The 200 reviews were based on 194 articles with six articles that were relevant for two of the three-way nexus interlinkages and hence are counted twice in the total (see Supplementary Materal A Figure S1 and Table S1 for details on the literature count, the eligibility steps and selection criteria). In addition, we searched for literature that integrates Indigenous knowledge through both standard search on the Web of Science and refined search using additional sources (see Additional literature searches section of the Supplementary Materal A. Methodology).

The selected articles were reviewed using a common template (see Supplementary Materal B for review questionnaire, Supplementary Materal C for the list of literature). An annotated Causal Loop Diagram was drawn for each article to provide an overview of all nexus interlinkages covered in the study under consideration, including and beyond the three-way interlinkage (i.e., biodiversity and two other nexus elements). In addition, the following information was captured for each article: 1) spatial scale of the nexus described in the study, 2) temporal scale over which the impacts from the nexus interlinkages manifested, 3) realm (i.e., freshwater, marine, terrestrial), 4) species group, 5) ecosystems, 6) inclusion of climate in the study, 7) additional nexus elements, drivers or intermediaries beyond biodiversity, food, water, health, energy, transport and climate (e.g., pollution), 8) direct or indirect bi-directional impacts between two nexus elements, 9) positive or negative direction of these impacts, 10) magnitude of these impacts (scale of 1 to 5), 11) indicators used to assess these impact relationships, 12) overall outcome of the nexus interlinkages including synergies and trade-offs, 13) drivers mentioned in the study, 14) engagement of stakeholders and indigenous knowledge, 15) mention of policy goals including the Sustainable Development Goals

(SDGs), the Kunming-Montreal Global Biodiversity Framework, the Paris Agreement and others, and 16) strength of evidence (scale of 1 to 5). Items (8) to (11) were repeated for all bi-directional impacts specified in the Causal Loop Diagram to capture the complexity of higher-order (beyond two-way) interactions. Detailed methodological steps, including the quality assurance of the review, are described in the Supplementary Material A.

2.2 Analysing the literature database

2.2.1 Three-way interlinkages

The impact relations between the three nexus elements were analysed in terms of the direction and magnitude of bi-directional impacts and visualised in a 3-dimensional space, which we refer to as a triplet. Ten triplets were created by plotting the information from the approximately 20 articles as triangles, with biodiversity and two nexus elements at each vertex (see Figures 4-6). In addition, five triplets were produced that highlighted interlinkages between biodiversity, climate and one other nexus element. The triplets show the influence of biodiversity on the other two nexus elements as well as their influence on biodiversity. The magnitude of bi-directional impact is plotted on the sides of the triangle, separately for positive (blue) and negative values (red) on a scale of 0 to 5. The geometric centroid is calculated and plotted in the 3-dimensional triangular space. The position and magnitude of the centroid indicates the predominance in influenced strength among the three interlinked elements: (i) position—the closest it is to one of the corners, the more this element is influenced by the other elements; (ii) magnitude—the size of the circle where the centroid is marked indicates the strength of influence. The size of the centroid is calculated by taking an average of all values (absolute values). This visual presentation of the three-way interlinkage was used in analyzing the impact relations across the three nexus elements and their estimated cascading and reinforcing effects based on the selected 20 articles.

2.2.2 Synthetic network pathways

The evidence from all the articles in the review database was used to create synthetic higher-order nexus pathways (i.e., beyond three-way interlinkages). This used the information on bi-directional linkage (direction and magnitude of impact) to identify all possible pathways between biodiversity and the six nexus elements using the “all_simple_paths()” function in the “igraph” package (Csardi and Nepusz, 2006) in R (Version: R Core Team, 2022). The pathways were created either using only positive or negative interlinkages and influencing or influenced by biodiversity. This gave the four path groups: positive from biodiversity, negative from biodiversity, positive to biodiversity and negative to biodiversity. Each path group consisted of six start and end element combinations. For example, the pathway group positive from biodiversity consists of the following six start and end element combinations: Biodiversity to Climate, Biodiversity to Energy, Biodiversity to Food, Biodiversity to Health, Biodiversity to Transport, Biodiversity to Water. Impact was generated by calculating the means of the bi-directional magnitudes that make up each pathway from biodiversity to the nexus element and then summing these means (see Supplementary Material A, Data Visualization and Analysis for more details on the calculation methods).

3. Results

3.1 Descriptive statistics

The majority of studies were at sub-national scale (between local and national; 28%), national (22%) or global (22%) scales. Local scale studies (single land parcel, farm, sub-catchment or city) made up

18% of the database with continental and sub-continental studies making up the rest (4% and 6%, respectively). The studies covered all realms with the largest number of studies focusing on the terrestrial realm (50%), followed by freshwater (34%) then marine (16%). In total, 45 countries in Europe were covered in the review with Germany, United Kingdom, Europe and Italy with the most coverage (over 6% each). Five countries in Eastern Europe and Central Asia had no studies included in this review: Armenia, Azerbaijan, Kazakhstan, Kosovo and Moldova (Figure 1).

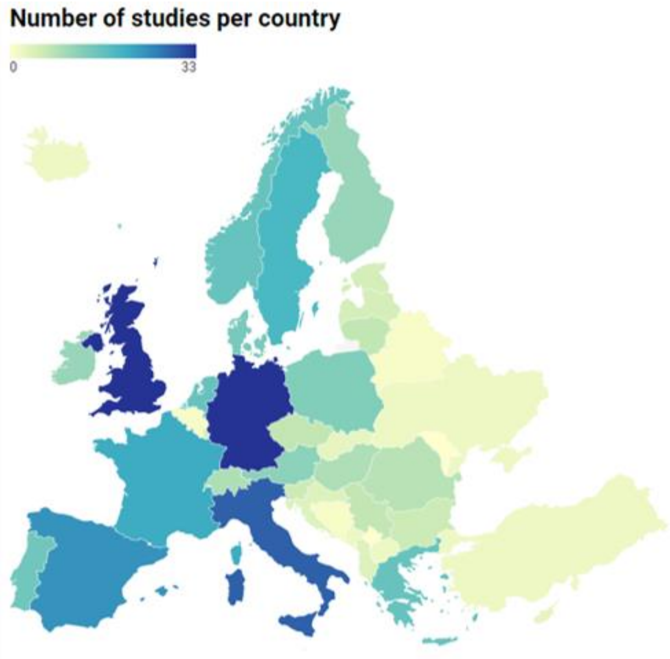


Figure 1. Number of studies included in this review per country.

Information on biodiversity was captured in terms of species and ecosystem type (Figure 2). Plants were the most frequently represented species type (26%) with birds, mammals, fish, and invertebrates similarly represented (11-12%) and amphibians slightly lower (6%). Invertebrates is obviously a broad category to describe many different taxa and a considerable portion was undefined (15%). Rivers and lakes, cropland, urban/peri-urban, grassland, woodland and forest were the most frequently recorded ecosystem types (10-13%). Wetland, coastal, heathland, open ocean, marine inlet and transitional waters, and sparsely vegetated land were also studied but in a lower proportion of the sample (<7%).

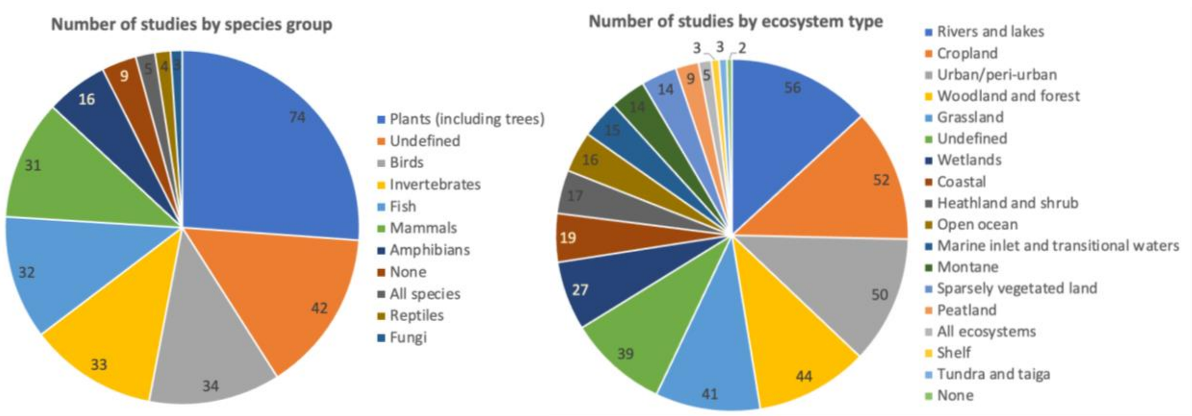


Figure 2. Number of studies by species group and ecosystem type

The estimated timeframe of impacts in the nexus studies tended to be short term (1-5 years 47%, < 1 year 27%) with studies using longer time frames ranging from 6 to 20 years less common (24%). Land use (18.6%), climate change (13%), economy (11.9%), pollution (10.6%), policy, institutions and governance (8.6%), direct exploitation (8.5%), technology (7.2%), health (6%), sociocultural (4.6%), invasive alien species (3.4%), sea use (3.3%), and conflict (2.5%) were direct or indirect drivers impacting nexus interlinkages.

The most frequently used method of research was indicator/data analysis (26%), then literature review (17%), modelling/simulation/computation (16%), observation (10%), experiment (6%), meta-analysis (5%), synthesis (5%), survey (4%), focus group/workshop (4%), interview (4%) and other (4%). Stakeholder knowledge was included in 19% of the studies with barely 1% on Indigenous knowledge. Concerning policy and legal frameworks, the Paris Agreement was mentioned in 15% of the studies while 10% mentioned the SDGs and 8% biodiversity goals, more broadly. In terms of strength of evidence[1], 42% of the studies were rated as very strong, 9% strong, 38% reasonably supported, 11% weak and 0.5% very weak evidence.

3.2 Bi-directional impact score

Bi-directional impacts between nexus elements are shown in Figure 3. The heatmaps show the relatively large number of studies evidencing a negative impact on biodiversity. The largest number of studies describe the negative impacts of transport, energy and water on biodiversity, but the highest mean magnitude of impact is from energy and climate change. Conversely, there are far fewer studies showing negative influences from biodiversity to the other nexus elements and the mean magnitude of impact is also lower. Fewer studies describe positive bi-directional impacts than negative across the nexus elements. From the studies that were found, a relatively high proportion provides evidence of the positive influence of biodiversity on the other nexus elements, particularly on health and energy. The highest mean magnitude of influence from biodiversity to the other nexus elements was found for climate and food. Positive impacts on biodiversity were also found in the literature database, with most studies highlighting the influence from water and food, whilst the highest mean magnitude was from climate (based on a single study only) and health.

Looking at bi-directional interlinkages among all the nexus elements based on the total sum of the mean magnitudes of impact (first column in Figure 3), we find that biodiversity and energy had the highest positive influence on the other nexus elements, whilst energy and transport has the highest negative influence. Alternatively, the greatest positive impacts from nexus elements was on health, whilst by far the greatest negative impact was on biodiversity (final row in Figure 3). The heatmaps shows the complexity of interlinkages among the nexus elements, with evidence showing that one element can provide both positive and negative impacts on another element. This is reflected in differences in the indicators used in each study to represent the nexus elements, which we elaborate below using specific examples from the literature database for some of the key bi-directional linkages.

[1] Definition of evidence strength: Very strong evidence based on well-designed empirical research and on synthesis (e.g., systematic review, meta-analysis); agrees with stakeholder knowledge or findings of other studies; Strong evidence based on multiple observations, well-designed experiments, modelling, indicator analysis or systematic literature review; with hypothesis and conclusion of the paper, well supported by stakeholder knowledge or findings of other studies; Reasonably supported evidence based on observations, experiment, modelling, indicator analysis or literature review, supported by stakeholder knowledge or findings of other studies; Weak evidence based on single observation, experiment, modelling, limited stakeholder engagement, indicator analysis or literature review, not as rigorously supported by findings of other studies; Very weak evidence based on author's expert or stakeholder opinion only, with no further corroboration by other citations in the discussion.

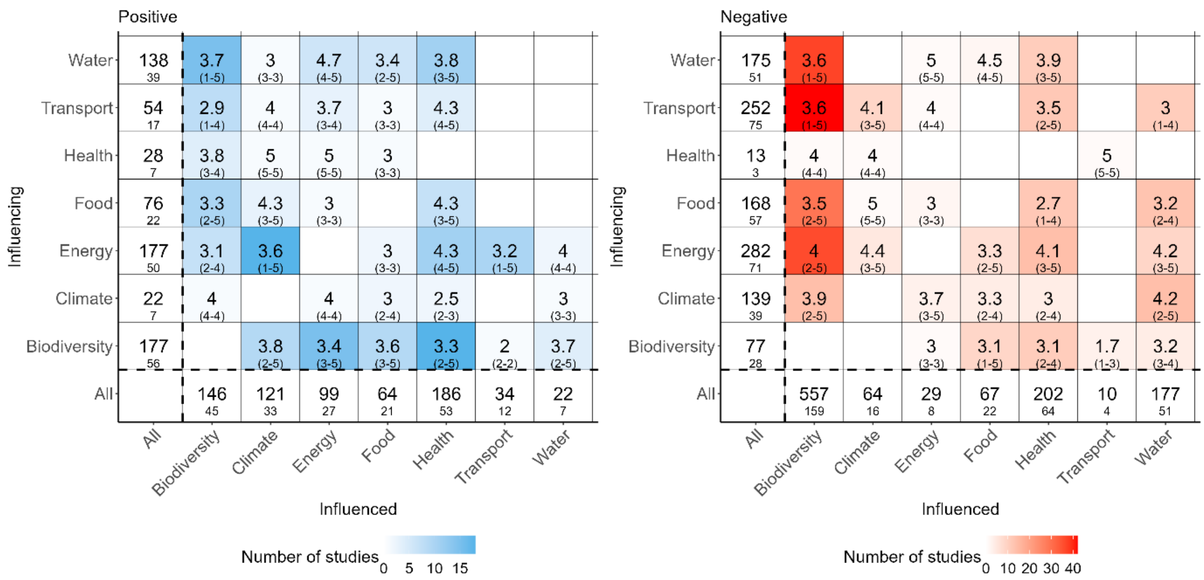


Figure 3. Heatmaps of positive (left) and negative (right) impact scores between the seven nexus elements where the nexus element in the row direction is influencing the nexus element in the column. The colour intensity indicates the number of studies evidencing each linkage, ranging from 1 to 37. The large number in each coloured cell refers to the mean magnitude of each bidirectional impact, with the range across the studies shown in brackets underneath. The total sum of the mean magnitude of impact across all other nexus elements is shown in the first column and the last row, with the count of studies upon which this is based shown underneath.

The positive bi-directional linkages with the highest numbers of studies were between water influencing biodiversity, energy influencing climate, biodiversity influencing energy, and biodiversity influencing health. The mean magnitude of these links was 3-4, i.e., between moderate and substantial, although the magnitude could range from 1 to 5 within each category. Demonstrative examples of these interlinkages include water quality positively influencing the functioning of local unique biotopes rich in biodiversity (Kropf et al., 2021); renewable energy replacing fossil fuels positively influencing climate by reducing greenhouse gas emissions (Livingstone et al., 2021); biodiversity positively influencing energy through the sustainable harvesting of above ground biomass in riparian ecosystems as a fuel source (Cartisano et al., 2013); and biodiversity positively influencing health in terms of forest walks promoting cardiovascular relaxation compared to walks in urban environments (Zorić et al., 2022); and natural ecosystems absorbing atmospheric pollutants, which improves air quality and benefits health (Barrios-Crespo et al., 2021).

The negative bi-directional linkages with the highest numbers of studies were for transport, energy, water and food all influencing biodiversity. The mean magnitude of these links was 3-4, i.e., between moderate and substantial, although the magnitude could range from 1 to 5 within each category. Demonstrative examples of these interlinkages include negative impact of roads on species mortality, movement and genetic diversity (Johansson et al., 2005; Mayer et al., 2023); ballast water for shipping transport negatively impacting biodiversity through the release of non-native species (Barrios-Crespo et al., 2021); dam construction for hydropower generation causing loss of biodiversity (Donadi et al., 2021; Göthe et al., 2019; Yoshida et al., 2020); poor water quality due to energy-producing peat extraction negatively influencing habitat quality and biodiversity (Juutinen et al., 2020); acidification of freshwater resulting in loss of fish populations (A. J. Wright et al., 2017); and negative impacts of food crops on ecosystem quality (Todorović et al., 2018) and habitat loss (Eiter & Potthoff, 2007).

3.3 Three-way nexus interlinkage

The analysis of three-way interlinkages (triplets) offers insight into more complex interactions within the biodiversity nexus. Results for Biodiversity-Energy-Water (BEF), Biodiversity-Health-Transport (BHT) and Biodiversity-Climate-Food (BCF) are shown in Figures 4 to 6, respectively. Results for the eight other triplets focused on biodiversity and four other triplets focused on biodiversity-climate are provided in the Supplementary Material D and E. Looking across all 15 sets of three-way interlinkages, the evidence from the review indicates that biodiversity receives overall positive influences from the other two nexus elements within the BFT, BFW and BTW triplets. In contrast, biodiversity receives overall negative influences from the other two nexus elements within the BEF, BET, BEW, BFT, BCE and BCT triplets. Biodiversity plays a more active role in other interlinkages, exerting negative influences on the other two nexus elements within the BFH and BCH triplets and positive influences within the BEF, BET, BCE and BCH triplets.

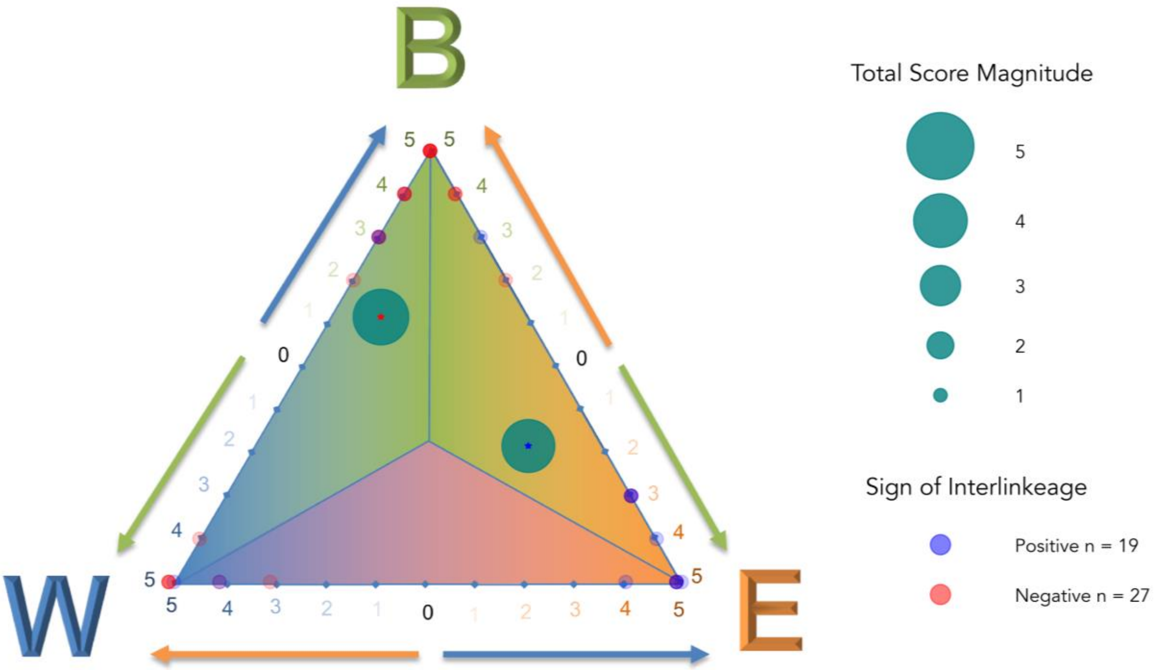


Figure 4. Three-way interlinkages between biodiversity (B), energy (E) and water (W). The locations of the centroids (positive (blue) and negative (red)) in the triangular space indicate the degree to which one nexus element is influencing or influenced by another nexus element (i.e., the closer it is to one of the corners, the more this element is influenced by the other elements). The larger the centroid, the stronger the average magnitude of the interlinkage (i.e., on a scale of 1 to 5). The number of studies reporting positive or negative influences is indicated in the bottom right of each diagram (i.e., n=X).

The location and size of the centroids in the Biodiversity-Energy-Water (BEW) triplet (Figure 4) show that biodiversity and water have a positive influencing role on energy, and energy has a negative influencing role on water and biodiversity. Our evidence indicates that the magnitude of these influences is scored relatively high at about 4.

Biodiversity is negatively impacted by energy and water in the case of energy-producing peat extraction, resulting in eutrophication and brownification (Juutinen et al., 2020). This can affect fisheries in nearby freshwater bodies causing a negative impact on the longitudinal dispersal of fish species which hinders the colonization of migrating species (Göthe et al., 2019) and leads to significant decline in the abundance of trouts, diatoms, seagrass and rhodophytes (Donadi et al., 2021). Water infrastructure for energy production, such as dams and hydropower, causes river fragmentation and alters river flow significantly (Dopico et al., 2022; Pittock, 2011; Yoshida et al., 2020) and creates stressors on river regulation and excess loadings of nutrients and sediments (Bakanos & Katsifarakis, 2019; Donadi et al., 2021). This in turn impacts water quality, aquatic life and habitat conditions, resulting in loss of biodiversity. In addition, dams can alter biophysical attributes like water depth which can have a direct effect, for example, on the abundance of diatoms, seagrass and rhodophytes (Leiva-Dueñas et al., 2020).

Water is shown to affect biodiversity positively with higher water availability improving vegetation (Eriksson et al., 2018; Irabien & Darton, 2016) and the ecological status of rivers with benefits for local ecosystems (Comino et al., 2020). Water is also shown to affect energy positively with water directly contributing to forest bioenergy generation (Comino et al., 2020; Eriksson et al., 2018; Franzaring et al., 2015), higher yields of bioenergy plants (Cartisano et al., 2013; Franzaring et al., 2015) and hydropower plants as a renewable energy source (Comino et al., 2020; Dopico et al., 2022). In turn, bioenergy production can positively impact biodiversity when delivered using a variety of tree species which has the knock-on effect of reducing carbon emissions and climate change. In addition, forest residue and other forms of woody above ground biomass can be used as a natural source of energy (Cartisano et al., 2013), such as in district heating systems (Sacchelli et al., 2013). However, bioenergy production can have negative consequences on water and biodiversity if undertaken in a way that increases irrigation use and risks to ecosystem integrity and resilience, for example, support for bioenergy production has been shown to have strong negative effects on the habitat suitability for farmland birds (Glemnitz et al., 2015).

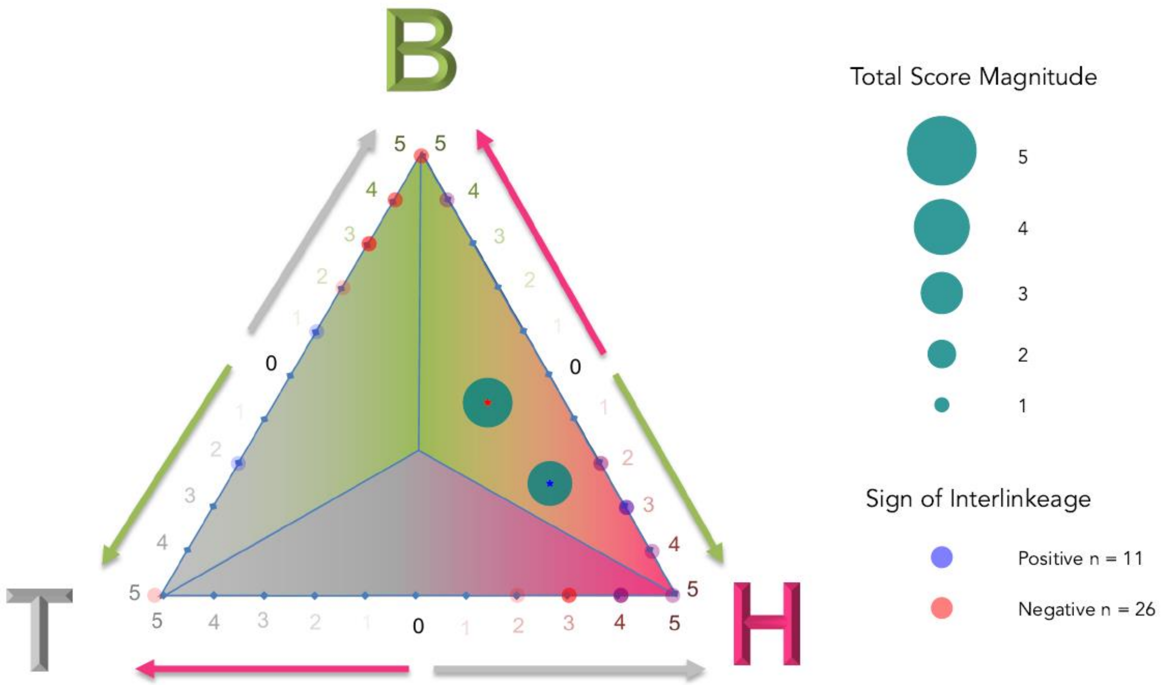


Figure 5. Three-way interlinkage between biodiversity (B), health (H) and transport (T). See caption of Figure 4 for an explanation of the structure of the figure.

The Biodiversity-Health-Transport (BHT) triplet depicted in Figure 5 offers a contrasting example. The negative centroid shows how transport has a negative influencing role on biodiversity and health. Conversely, the positive centroid shows that transport also has a strong positive influence on biodiversity and health.

Transport negatively influences biodiversity through species killed by vehicles (Seddon et al., 2021) and habitat loss and degradation from transport infrastructure (Di Giulio et al., 2009; Hunter et al., 2019; Khreis et al., 2016; Puodziukas et al., 2016). Transport negatively influences health through road accidents, air pollution from fossil fuel transport (Buekers et al., 2014; Khreis et al., 2016; Pallozzi et al., 2020; Weerakkody et al., 2017) and traffic-related noise (Khreis et al., 2016; Puodziukas et al., 2016). Transport has been shown to facilitate the spread of invasive species, pathogens, parasites and disease vectors (e.g. mosquitoes) causing zoonotic diseases that negatively influence health and biodiversity. Control measures may also damage non-target species. Biodiversity, through wildlife and provision of habitat, enables the reproduction and spread of vectors, invasive species and pathogens that can impact directly on human health or indirectly through damage to food supplies (Bax et al., 2003; Hulme, 2020; Medlock et al., 2012; Peyton et al., 2019). The production of electric vehicles negatively influences biodiversity through resource use and the manufacturing footprint (Dall-Orsoletta et al., 2022).

However, transport through green infrastructure can enhance local biodiversity (Buekers et al., 2014; Hunter et al., 2019), mitigate air and noise pollution (Toffolo et al., 2021) and positively influence mental and physical health (Hunter et al., 2019; Khreis et al., 2016; Zijlema et al., 2018; Zorić et al., 2022). Raymond et al. (2023) shows that as a result of the global health pandemic, the reduction in transport was so profound that a global 'quietening' was detected, called the 'anthropause'. Although usually the interlinkage between transport and biodiversity is negative, the pause in transport reduced wildlife vehicle collisions, having a positive effect on biodiversity (Raymond et al., 2023). There are mixed effects of transport on health because battery powered electric vehicles can cause pollution and human health issues (cobalt mining, respiratory hazards of Li ion battery particles), yet there are improvements in human health in urban environments (Buekers et al., 2014; Dall-Orsoletta et al., 2022). This has mixed effects on the climate as although electric vehicles have the potential to positively influence climate, this is dependent on electricity production methods and greenhouse gas emissions throughout the whole lifecycle being less than the fossil fuel counterpart. This study also suggested disparity in impact geographically by, for example, global south vs. north (Dall-Orsoletta et al., 2022).

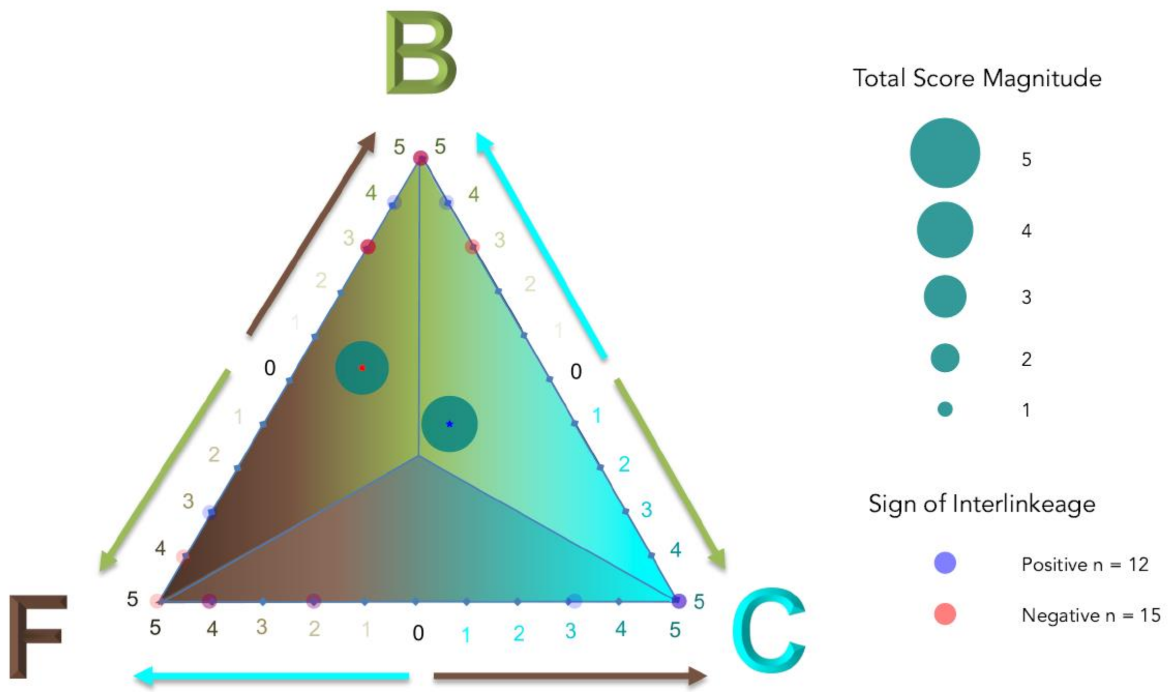


Figure 6. Interlinkages between biodiversity (B), climate (C) and food (F). See caption of Figure 4 for an explanation of the structure of the figure.

Figure 6 shows an example of the triplets focused on three-way interlinkages involving biodiversity and climate change for for Biodiversity-Climate-Food (BCF) nexus. The location and size of the negative centroid shows that climate change has a strong negative influence on both biodiversity and food. For example, climate change impacts like aridification can negatively impact amphibian and reptile reproductive sites and habitats, which reduces food availability for other species in the food web (Crnobrnja-Isailović et al., 2021). Climate change can exacerbate other negative influences on biodiversity within food systems, such as agricultural intensification, further contributing to a loss of species richness and abundance (Andriamanantena et al., 2022; Bourke et al., 2014; Wagner, 2020). Climate change can also reduce the productivity of food production, for example, making the rainfed cultivation of olive crops no longer economically feasible due to the increasing demand for water (Fotia et al., 2021). In addition, more frequent and severe flood events related to climate change can affect the recovery phase of microbenthic assemblages from eutrophication, which in turn impacts bivalves for fishers who rely on estuarine resources (Cardoso et al., 2008).

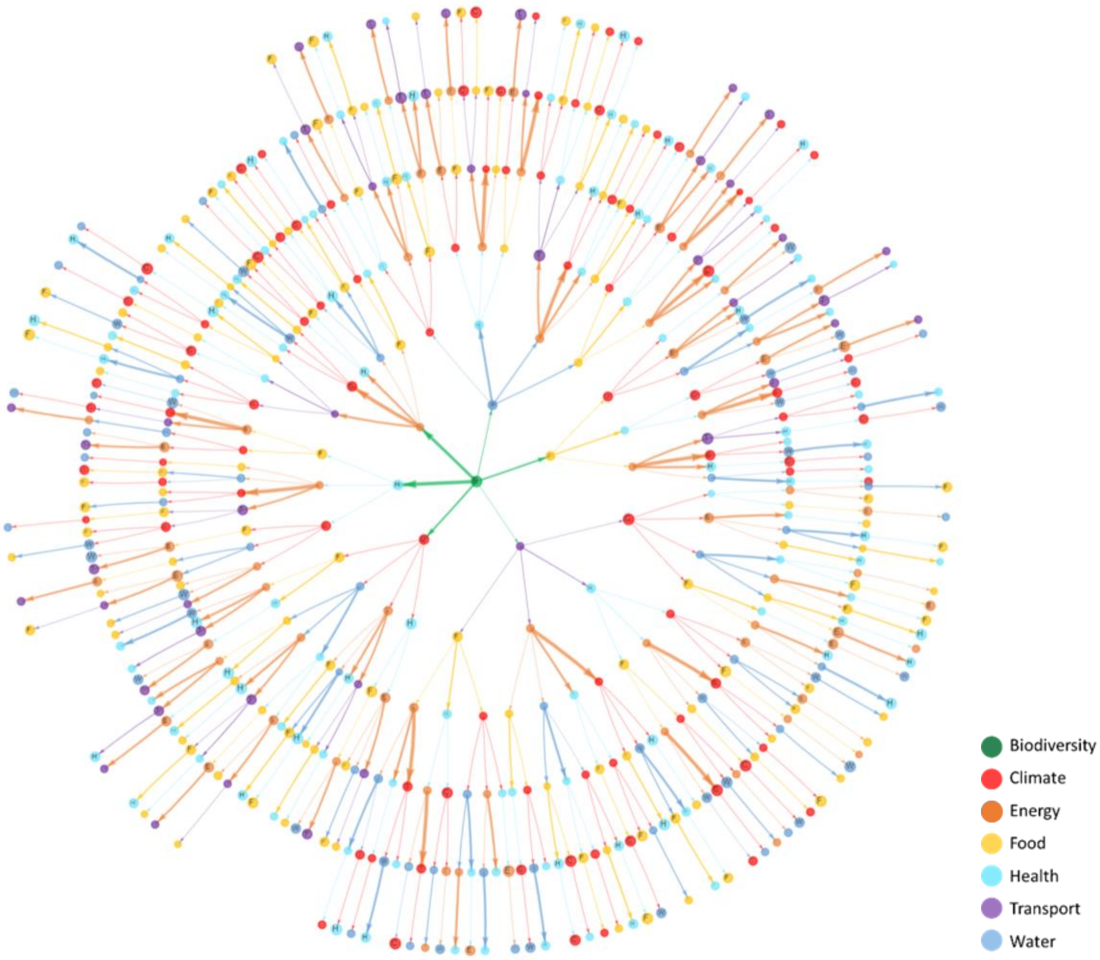
In contrast, the location and size of the positive centroid shows that the positive influences between these three nexus elements are relatively balanced and moderate. Biodiversity influences climate change as forest restoration and other biodiversity conservation measures contribute to carbon storage and climate mitigation (Eriksson et al., 2018; Schulze, 2006). The food system can positively influence biodiversity and climate change. Changing agricultural practices such as reducing livestock production reduces greenhouse gas emissions from the agricultural sector (Westhoek et al., 2014), and agronomic management of grasslands can serve to maintain habitats for grassland species and prevent the encroachment of other species like shrubs (Giubilato et al., 2016). Similarly, conversion from monocropping to alley cropping systems increases plant diversity (Tsonkova et al., 2012) and provides enhanced niche space for multiple speces. In some regions, changing climate conditions can have a positive influence on biodiversity vulnerability and food production, such as in northern Europe (Harrison et al., 2015).

3.4 Evidence on the biodiversity nexus from Indigenous knowledge

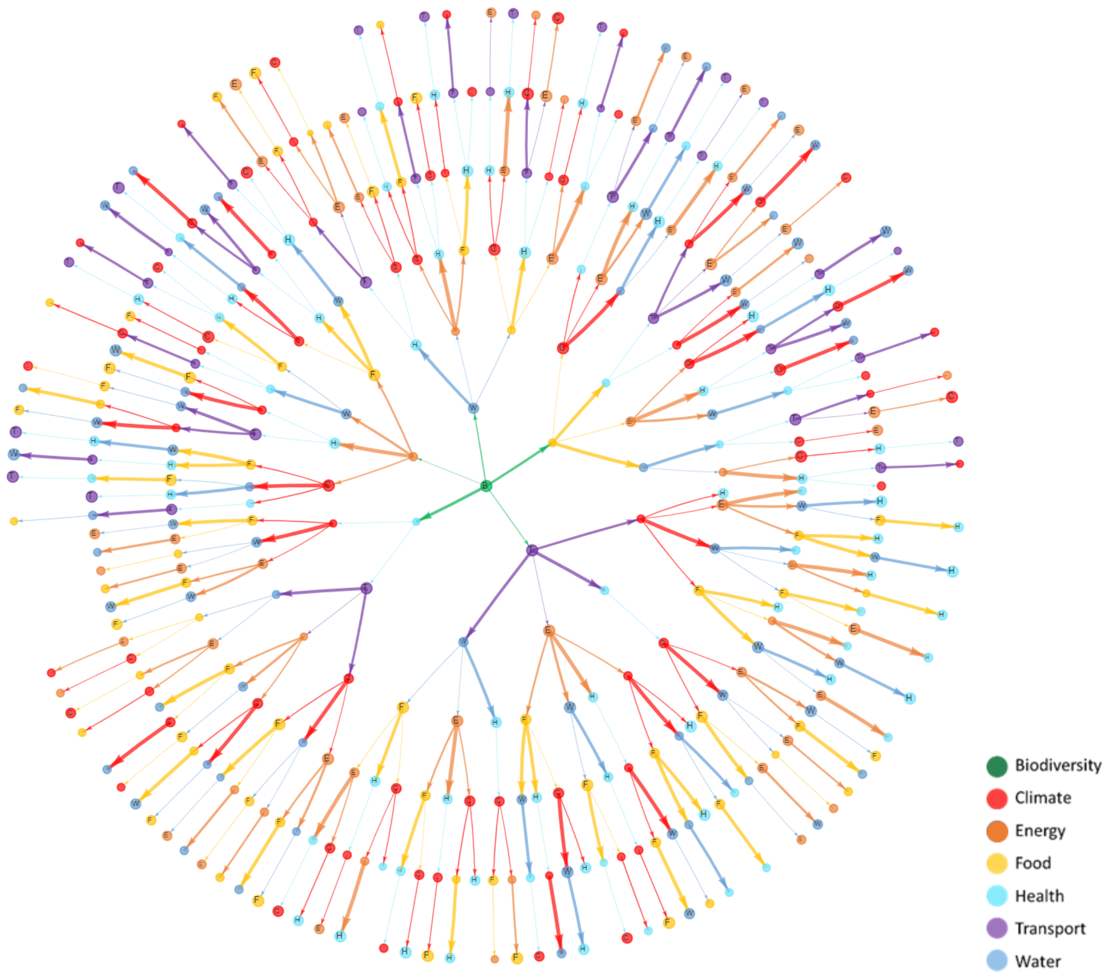
The additional literature search on how Indigenous People have perceived biodiversity nexus issues found that indigenous food systems are often intimately linked to biodiversity and climatic conditions. This means that changes in these nexus elements can disproportionately impact Indigenous People's access to food, high-quality nutrition and livelihood, especially in the Arctic regions of Europe where the Sámi and Greenlandic Inuit live (IWGIA, 2023). Reindeer herding is an important livelihood activity and a food source for the Sámi and reindeers are semi-domesticated and rely on the availability of natural forage, especially lichens which act as the primary food source during winter (Jaakkola et al., 2018). Climate change is projected to lead to a decline in lichen ecosystems in high latitudes (Jaakkola et al., 2018; Ocobock et al., 2023). This decrease in lichen availability is associated with reduced reindeer meat production, nutritional quality and changes in traditional herding practices (Jaakkola et al., 2018; Ocobock et al., 2023). Furthermore, the Sámi and Greenlandic Inuit rely on wild food sources, which includes wild plants, game and fish (Bjerregaard et al., 2021; Nilsson, 2018). For these groups, declines in biodiversity can negatively affect food security and health, since many of these food sources are key sources of vitamins and minerals. The reliance on wild fish also increases the vulnerability of these communities to the negative impacts of environmental pollutants on fish and human health, risking food security (Bjerregaard et al., 2021; Nilsson, 2018).

3.5 Synthetic network pathways

Synthetic network diagrams showing the full complexity of the interlinkages represented in our review database are shown in Figure 7 for all pathways by which biodiversity can positively or negatively influence the other six nexus elements. These pathways represent the number of studies that evidence the pathway as well as the magnitude of the pathway. Our review database shows that there are 526 possible positive paths and 388 possible negative paths by which biodiversity can influence the six nexus elements. See Supplementary Material F for the pathway figures showing the influence of the other nexus elements on each other.



(a) Positive pathways from biodiversity



(b) Negative pathways from biodiversity

Figure 7. Synthetic network trees showing (a) 526 positive pathways between biodiversity and all other nexus elements and (b) 388 negative pathways between biodiversity and all other nexus elements. The thickness of the links is proportional to the number of studies evidencing the link and the size of each nexus element is proportional to the mean magnitude of its incoming link.

The complexity and magnitude of the influence of biodiversity on the six nexus elements (as visualised in Figure 7) is summarised in Table 1(a), whilst the influence of the six nexus elements on biodiversity is summarised in Table 1(b).

(a) Overall influence of biodiversity on the six nexus elements

Nexus element	Positive		Negative		Overall	
	Complexity	Impact	Complexity	Impact	Complexity	Impact
Climate	92	340.8	75	281.7	167	5.7
Energy	70	252.2	60	220.6	130	3.7
Food	122	429.0	64	236.5	186	9.7
Health	122	427.0	79	276.4	201	9.4
Transport	44	157.5	39	152.6	83	-2.3
Water	76	270.8	71	255.7	147	0.2
All	**526**	**1877.4**	**388**	**1423.5**	**914**	**26.5**

(b) Overall influence of the six nexus elements on biodiversity

Nexus element	Positive		Negative		Overall	
	Complexity	Impact	Complexity	Impact	Complexity	Impact
Climate	65	228.7	70	268.7	135	-6.1
Energy	70	253.3	69	270.7	139	-4.4
Food	57	214.8	78	308.8	135	-9.6
Health	57	212.1	58	234.4	115	-5.2
Transport	163	603.8	120	459.5	283	4.8
Water	114	417.4	63	255.0	177	4.7
All	**526**	**1930.1**	**458**	**1797.1**	**984**	**-15.7**

Table 1. Summary of the (a) positive, negative and overall influence of biodiversity on the six nexus elements and (b) positive, negative and overall influence of the six nexus elements on biodiversity. The "Complexity" metric is calculated as the number of pathways from biodiversity to the nexus element. The "Impact" metric is generated by calculating the means of the bi-directional magnitudes that make up each pathway that goes from biodiversity to the nexus element and then summing these means. The "Overall" columns in the table show the total complexity (sum of the number of positive and negative pathways) and the overall impact (calculated by subtracting the negative impact from the positive impact indicator). The coloured bar within each cell indicates the numeric value proportional to the maximum value for each metric. These are indicative measures of the complexity and impact of nexus pathways.

The high complexities displayed in Table 1 highlight the central role biodiversity plays in the nexus with 914 paths involving biodiversity having an influence on at least one of the other nexus elements, and 984 paths involving biodiversity being influenced by the other nexus elements. These are split between positive and negative impacts, with a similar number of positive influences from and to biodiversity, but a greater number of negative influences of nexus elements on biodiversity than from biodiversity to other nexus elements (458 vs 388). Overall, biodiversity is shown to have a higher positive than negative impact on the other nexus elements (1877 vs 1424).

Complexity and impact are closely linked in Table 1 as we have assumed that the magnitude of impact is passed through all connected links in a pathway without diminishing in strength. Table 1 shows that food, health and climate stand out as being most positively impacted by biodiversity (through various paths), followed by water and energy, then finally transport as the least positively impacted by biodiversity. Biodiversity supports ecosystem services crucial to various dimensions of human health and biodiversity has positive impacts on food systems such as the importance of conserving wild food plants (Quave & Pieroni, 2015), wild game (Flis, 2012) and landraces (Scartazza et al., 2020) to ensure long-term food security. Negative influences by biodiversity are more even (but lower impact) across climate, health, water, food and energy with transport again being the least impacted. For example, there are nature related health risks such as infectious diseases and allergies (Johnson et al., 2015; Ostfeld, 2017).

Impacts on biodiversity are almost the opposite with transport standing out as having comparatively both stronger negative and positive impacts than the other nexus elements. Negative impacts of transport on biodiversity include roadkill and habitat fragmentation and loss (Hunter et al., 2019; Khreis et al., 2016; Quave & Pieroni, 2015) whereas positive impacts of transport are cited where green infrastructure has been promoted (Buekers et al., 2014; Hunter et al., 2019) or where the form of transport presented is 'active' such as cycling and walking (Hunter et al., 2019; Khreis et al., 2016; Zijlema et al., 2018). After transport, food has the largest negative impact on biodiversity, for example, through land clearance for food and intensive agriculture causing biodiversity loss.

Alternatively, water has the second largest positive impact on biodiversity, such as where streams act as humid dispersal corridors (Haugen et al., 2020) and studies highlighting the hydroperiod as one of the most important drivers of species richness (Couto et al., 2017).

4. Discussion and Conclusions

This review aimed to enhance the scientific literature on nexus studies by synthesising evidence on interlinkages between seven nexus elements: biodiversity, climate change, food, water, energy, transport and health . It particularly focused on the role that biodiversity plays in these interlinkages by capturing evidence on the direction and magnitude of interlinkages involving biodiversity and the other six nexus elements. The results show an intricate set of relationships by which biodiversity influences and is influenced by climate change, food, water, energy, transport and health . Overall, our results add weight to other studies that highlight how biodiversity plays a critical role in nexus interlinkages as it underpins ecosystem functioning and condition, which are essential for the delivery of nature's contributions to people and human well-being (Brauman et al., 2020; Cardinale et al., 2012; IPBES, 2019).

The analyses demonstrate the immense complexity of the interdependencies between biodiversity and climate change, food, water, energy, transport and health. Nevertheless, some dominant trends emerge in the impact relationships between biodiversity and the other six nexus elements (Figure 8). Out of the 354 interlinkages evidenced between biodiversity and other nexus elements in the review, 53% were negative, 29% were positive and 18% contained both positive and negative influences. 260 of these interlinkages provided evidence for how biodiversity is influenced by the other nexus elements, with 61% representing negative, 17% positive, and 21% both positive and negative impacts on biodiversity (see Figure 8(a)). The remaining 94 interlinkages provided evidence for how biodiversity is influencing the other nexus elements, with 30% representing negative, 60% positive, and 10% both positive and negative impacts (see Figure 8(b)).

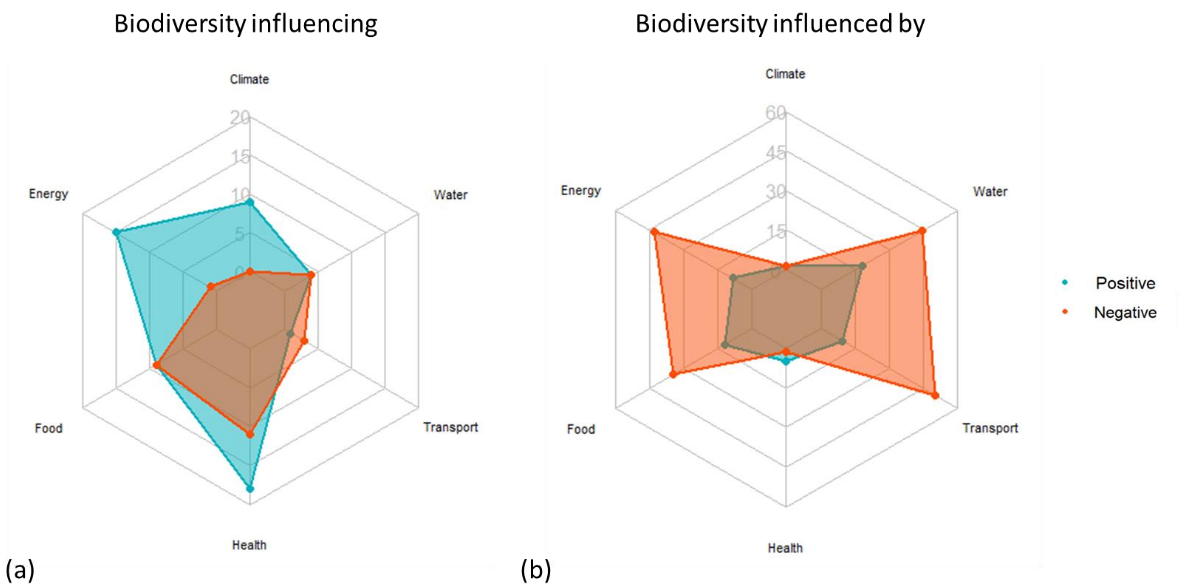


Figure 8. Number of studies demonstrating positive or negative interlinkages of (a) the influence of biodiversity on the other nexus elements and (b) the influence of the other nexus elements on biodiversity.

Thus, about half of the interlinkages involving biodiversity in the database were negative influences of other nexus elements on biodiversity, highlighting the substantial damage being inflicted on nature from human activities in these sectors. This evidence can be classified into six main types of negative influences on biodiversity and ecosystems related to (i) land use/land use alteration, such as habitat destruction for expansion of food production (Andriamanantena et al., 2022), competition for land from land-based renewable energy (bioenergy, solar, wind) (Perišić et al., 2022), and habitat fragmentation from transport and energy infrastructure (Simkins et al., 2023); (ii) water use/water course alteration, such as alteration of water flows and river fragmentation due to dams and reservoirs related to hydropower, water demand for energy and irrigation reducing environmental flows, and dredging affecting coastal and marine ecosystems (Bakanos & Katsifarakis, 2019); (iii) land degradation affecting habitat quality and species diversity and richness, such as from agricultural intensification (Glemnitz et al., 2015), peat extraction for energy (Juutinen et al., 2020), and mining for renewable energy (Elshout et al., 2019); (iv) degradation of water quality affecting freshwater, coastal and marine ecosystems and species, such as through euthrophication, acidification, brownification and sedimentation (Klante et al., 2021); (v) direct species fatalities, such as collisions with wind turbines and traffic (road, rail, shipping) (Schulze, 2006); and (vi) climate change impacts on species and ecosystems, such as through changes in heat or water stress, seasonality and floods (Cardoso et al., 2008).

By contrast, the review found only limited evidence of the negative influence of biodiversity on other nexus elements through impacts related to (i) competition for land (Eiter & Potthoff, 2007); (ii) disease transmission from a small set of species triggered by habitat loss or climate change (Hulme, 2020; Milićević et al., 2016; Sula et al., 2020); or (iii) the introduction and expansion of invasive alien species (Bax et al., 2003; Medlock et al., 2012) .

Alternatively, about one third of studies in the database demonstrate positive interlinkages to or from biodiversity and the other nexus elements. Many of these studies focus on policies or management actions that aim to deliver co-benefits between the nexus elements and biodiversity. For example, evidence of positive impacts from the nexus elements on biodiversity could be classified into studies related to (i) biodiversity-friendly management of the nexus elements, such as through agroecological practices, sustainable management of bioenergy cropping systems (Tsonkova et al., 2012), integrated management of water landscapes (Eriksson et al., 2018), and management of habitats on road verges and railway embankments (Galantinho et al., 2020); (ii) urban green and blue infrastructure, including nature-based solutions, such as green roofs for improving energy performance in buildings (Pasimeni et al., 2019)and greening of transport infrastructure for pollution control through promotion of active transport (walking, cycling) (Hunter et al., 2021); (iii) restoration of ecosystems, such as forest (Perišić et al., 2022) and peatland (Pullens et al., 2018) for climate mitigation, riparian forests for flood control (Cartisano et al., 2013), and remediation of water courses for improving water quality (Comino et al., 2020); and (iv) dietary change involving lower meat consumption to reduce livestock for climate mitigation (Westhoek et al., 2014).

Similar types of relationships were evidenced for how biodiversity positively influences the other nexus elements. This included positive influences related to (i) forests (Perišić et al., 2022), peatlands (Pullens et al., 2018) and the rewilding of urban spaces (R. F. Wright et al., 2017) on climate mitigation; (ii) biomass potential for biofuel from forests (Sacchelli et al., 2013), peatlands (Pullens et al., 2018) and other vegetation (Voortman et al., 2015) for energy; (iii) agro-biodiversity for supporting food production (Fischer et al., 2019) (Kropf et al., 2021) and wild plants for food consumption; (iv) green space (Khreis et al., 2016) and horticultural activities (Scartazza et al., 2020) on health; and (v) protected areas (Urban & Hametner, 2022), specific species such as mussels

(Dolmer & Frandsen, 2002) and specific ecosystems such as dunes (Voortman et al., 2015) for water filteration and retainment, respectively. The studies providing evidence of positive interlinkages to and from biodiversity, although fewer in number, provide valuable information on how the nexus approach can support the mainstreaming of biodiversity in other policy sectors for realising multiple co-benefits.

When interpreting these dominant trends in interlinkages, it should be borne in mind that the study, for practical reasons, was limited to evidence sourced from 194 peer-reviewed articles written in English. Hence, it does not capture knowledge from other regional and local languages, including Indigenous and local knowledge, which can provide diverse framings and unique insights on the biodiversity nexus (IPBES, 2021). In addition, there was considerably less literature on eastern Europe and Central Asia (IPBES, 2018) and for the marine realm (Zhu et al., 2021). To help attain sufficient literature for each of the ten three-way interlinkages, biodiversity was defined broadly, but in line with the IPBES glossary (Díaz et al., 2015) as "...living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part". Thus, some studies discuss specific species or habitats, whilst others discuss the role of nature or green infrastructure more generally. Finally, the direction and magnitude of nexus interlinkages are often context-dependent and thus can vary depending on the ecosystem type, spatial and temporal scale, geographical location and study method (Linney et al., 2020). Thus, caution is required when interpreting and applying findings in different contexts.

Despite these limitations and uncertainties, we believe the broad findings of the review are robust and clearly demonstrate the importance of biodiversity in underpinning human well-being and ensuring a sustainable future for people and the planet. The review database consolidates and extends the nascent and fragmented evidence base on the role of biodiversity in complex, higher-order (i.e. three-way and beyond) nexus studies. This is particularly important for supporting the growing number of policies that are embracing a nexus (or systems) approach, such as the European Green Deal (European Environment Agency., 2022). Such policies urgently need a better understanding of the cascading and compounding impacts of multi-order nexus interlinkages to prevent trade-offs and maximise synergies across sectors going forward (Arneth et al., 2023; Habibullah et al., 2022). This includes evidence on how conservation and restoration of biodiversity can contribute to the goals and targets of policies across sectors by delivering nexus-wide benefits (Kim et al., 2021; Paleari, 2024). For example, nature-based solutions such as afforestation can have multiple benefits but these often depend on the manner of implementation in practice, e.g., monoculture forest plantations may contribute to climate change mitigation by sequestering carbon but may exacerbate biodiversity loss (Santangeli et al., 2016; Seddon et al., 2021; R. F. Wright et al., 2017), whilst agroforestry that integrates tree planting, shrubs and hedges in farming systems may enhance wildlife, mitigate climate change, improve soil health, control water flow, boost livestock welfare and increase farm productivity (Mbow et al., 2014; Tsonkova et al., 2012).

Identifying appropriate holistic interventions and actions for specific contexts may require evidence from nexus studies to be filtered and analysed in more detail with local practitioners and experts to inform the design, planning and implementation of decision processes (Sutherland et al., 2004; Walsh et al., 2015). Further research is also needed on quantifying positive interlinkages between biodiversity and other nexus elements to inform future decisions on conservation and sustainable development (Clark et al., 2014; Rook, 2013; Sandifer et al., 2015). This is particularly critical given the current dominance in the literature on negative interlinkages among biodiversity and other nexus elements, reflecting past and current trends. Integrative and systemic approaches are needed to address the underlying causes of biodiversity loss as represented in these negative nexus interlinkages. Evidence from comprehensive nexus studies demonstrate the urgent need for policy coherence across sectors to foster synergistic interlinkages across nexus elements. Such evidence is critical for moving towards sustainable futures where biodiversity is valued, conserved, restored and wisely used while sustaining a healthy planet and delivering benefits essential for all people, in line with the 2050 Vision of the Convention for Biological Diversity.

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Understanding the role of biodiversity in the climate, food, water, energy, transport and health nexus in Europe

Supplementary Materials

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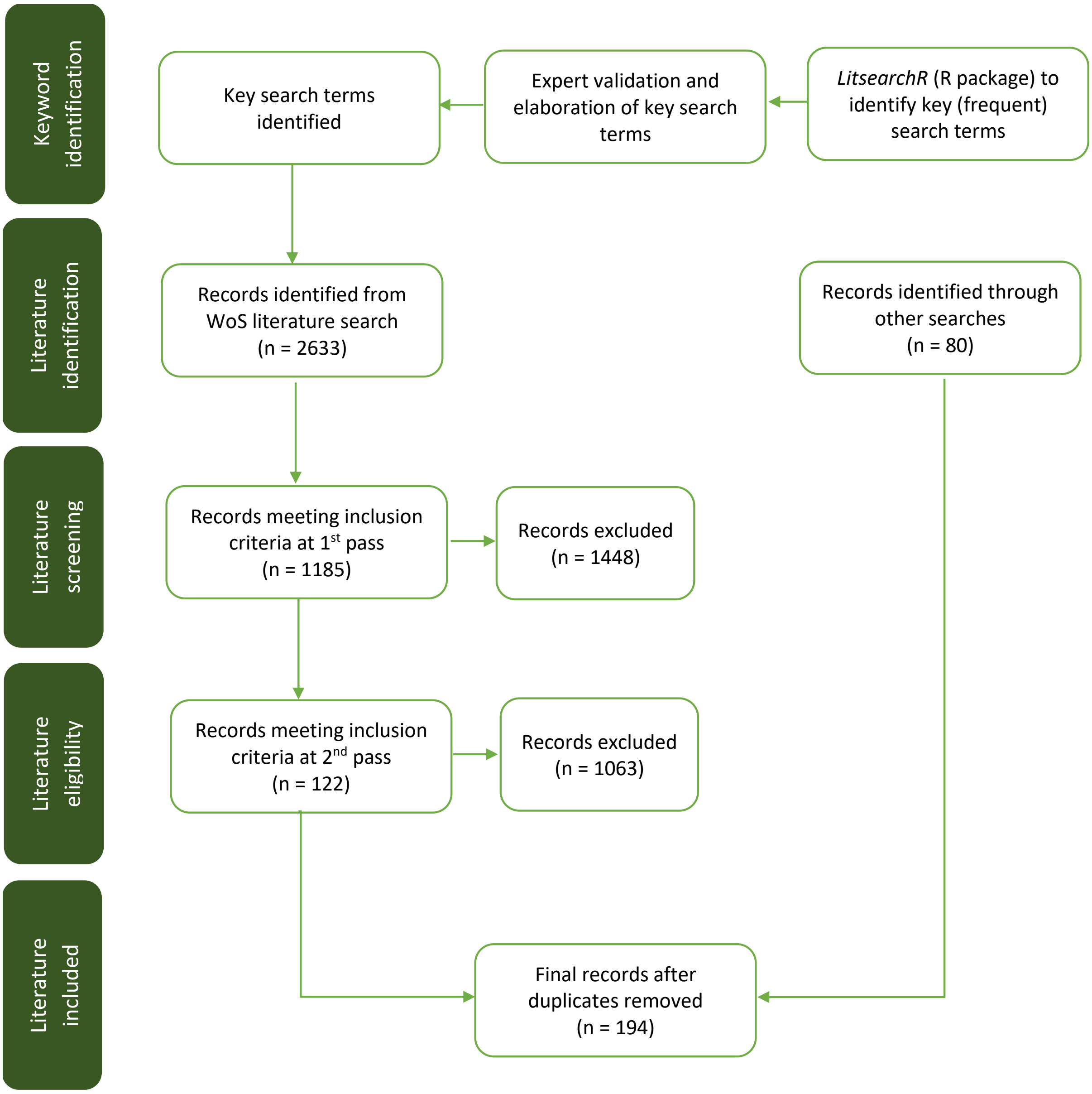
A. Methodology

Overall process of the review

Figure S1. BIONEXT biodiversity-nexus literature review process and literature counts



Identification of key search terms

Key search terms were identified in a two-step process. First, the R package LitsearchR was used to provide a list of terms frequently cited in literature associated with each of the nexus elements (i.e., biodiversity, climate, energy, food, health, transport, water). This involved undertaking a simple query on Web of Science using the following terms: biodiversity, nexus (*nexus, interlinkage, integrat*, interact*, tradeoff*, trade-off*, synerg*, cross-sect*, multifunction*, interdependenc*, influenc*, cobenefit, co-benefit*) and two of the nexus elements, making a total of 10 queries. The countries in Europe (including Europe as a region) and publications since 2013 (i.e. in the last 20 years) were included as regional and temporal scope in the search string. The query results were imported and run on LitsearchR to extract a pool of frequency terms.

Second, the most frequent and relevant 10-15 terms (Table S1) were provided to a team of experts (12) with expertise in the seven nexus elements. Experts were asked to rank the top five key terms per nexus element and for the term “nexus” using a scale of 1 (highest) to 5 (lowest). These scores were then aggregated across individual experts. Experts could also add additional relevant terms that did not appear in the LitsearchR results. Based on the ranked scores and the additional suggested terms, approximately seven key terms were selected for each nexus element to be used in the literature search (Table S2).

Table S1. List of frequency terms on nexus element from LitsearchR

Biodiversity	Climate	Energy	Food	Health	Transport	Water
biodiversity	climate change	energy	food	health	transport	water
conservation	carbon storage	renewable*	land use (land-use)	human health	infrastructure	water quality
protected area*	climate regulation	bioenergy	agricultur*	human well-being	rail*	water quantity
habitat	carbon sequestration	biomass	livestock	human wellbeing	linear	water provision
species	climate change mitigation	fossil fuels	feedstock	physical health	road	flood regulation
ecolog*	climate mitigation	energy demand	fodder	public health	ship*	river basin
nature	global warming	energy security	crop*	disease	air*	water regulation
ecosystem	climate adaptation	solar	farm*	clean water	transport network	water supply
ecosystem service*	climate change adaptation	wind	food	mental health	passenger	water pollution
natural capital	nationally determined contribution	hydropower	organic		freight	wetland*
ecosystem function	paris agreement	biofuel	agroecolog*		boat	water management
invasive species			agrobiodiversity		bike	water purification
alien species			Sustainable agric*		electric transport	water availability
pollinator*			land sparing		hydropower transport	irrigation
			land sharing			water demand
			diet			catchment*
			nutrition			water footprint
						water framework directive

Table S2. List of search terms ranked and suggested by experts.

Nexus	Biodiversity	Climate	Energy	Food	Health	Transport	Water
Nexus Interlink* Interact* Trade$off* Synerg* Cross-sect* Inter$de-penden* Coupled	Biodiversity Habitat Species Nature Ecosystem	"Climate change" "Climate regulation" "Climate mitigation" "Climate adaptation" "Carbon sequestration" "GHG" "Greenhouse gas emission"	Energy Renewable* Bioenergy "Fossil fuel*" Solar Wind Hydropower "Wave energy" "Nuclear power" "Hydrogen energy"	Food Land$use Agricultur* Crop* Farm* "Food production" "Food consumption"	"Human health" "Public health" "Physical health" "Mental health" "One health" "Infectious disease" "Zoonotic disease" "health AND well$being"	Transport Infrastructure Rail* Road Ship* Automobile "Electric vehicle" Aviation Cycling Walk "Hydropower transport"	"Water quality" "Water quantity" "Flood regulation" Irrigation Catchment* Drought "Water security"

Literature identification from Web of Science

The Web of Science (WoS) Advanced Search was used to query the literature pool. Ten searches were undertaken for each of the 3-way nexus interlinkages considered in the review: (1) Biodiversity-Energy-Food, (2) Biodiversity-Energy-Health, (3) Biodiversity-Energy-Transport, (4) Biodiversity-Energy-Water, (5) Biodiversity-Food-Health, (6) Biodiversity-Food-Transport, (7) Biodiversity-Food-Water, (8) Biodiversity-Health-Transport, (9) Biodiversity-Health-Water, (10) Biodiversity-Transport-Water. Each search combined terms for "nexus" and "biodiversity" and the two other nexus elements with "geographical region" (see example below for the search string for the Biodiversity-Food-Health nexus). Climate was not included in the search string as we did not wish to restrict the search to only papers including climate change and it was anticipated (and later checked) that climate change would be included in the many of the articles identified. The search results on WoS were ordered by relevance that accounts for the title (more weight), abstract, keywords (more weight), and keywords plus and outputted as CSV files.

<u>Example search string on Biodiversity-Food-Health</u>

*AB = ((**nexus** OR trade$off* OR synerg* OR cross-sect* OR interlink* OR interact* OR inter$dependen* OR coupled) AND (**biodiversity** OR ecosystem OR nature OR species OR habitat) AND (**food** OR land$use OR agricultur* OR crop OR farm OR "food production" OR "food consumption") AND ("human **health**" OR "public health" OR "physical health" OR "mental health" OR "one health" OR "infectious disease" OR "zoonotic disease" OR [health AND well$being]) AND (**Europe** OR Albania OR Andorra OR Austria OR Belgium OR "Bosnia and Herzegovina" OR Bulgaria OR Croatia OR Cyprus OR Czech Republic OR Denmark OR Estonia OR Finland OR France OR Germany OR Greece OR Hungary OR Iceland OR Ireland OR Italy OR Latvia OR Liechtenstein OR Lithuania OR Luxembourg OR Macedonia OR Malta OR Monaco OR Montenegro OR Netherlands OR Norway OR*

Poland OR Portugal OR Romania OR San Marino OR Serbia OR Slovakia OR Slovenia OR Spain OR Sweden OR Switzerland OR "United Kingdom" OR "Great Britain"))

For four nexus interlinkages that did not provide sufficient literature, additional terms were used for "biodiversity", "health" and "transport" to expand the pool of literature. This was the case for (1) Biodiversity-Energy-Health, (2) Biodiversity-Energy-Transport, (3) Biodiversity-Health-Transport and (4) Biodiversity-Transport-Water. Below the additional search terms used are listed.

Biodiversity *(only used for the biodiversity-energy-health nexus)*

"green space" OR "green space" OR greenspace OR forest OR garden OR "green roof" OR "green wall" OR wetland OR pond OR "blue space" OR "green infrastructure" OR "urban green" OR "urban blue space" OR "natural environment" OR "green views" OR greenery OR NDVI OR trees OR vegetation OR diversity OR "species diversity" OR "species composition" OR biodivers OR "species richness" OR biome OR ecotone*

Transport *(used for the biodiversity-energy-transport nexus and biodiversity-health-transport nexus)*

traffic OR mobility OR logistic OR airport OR car* OR ballast OR port* OR canal*

Health *(used for the biodiversity-energy-health nexus and biodiversity-health-transport nexus)*

"Nature based care" OR "nature-based care" OR "nature-based intervention" OR "nature based intervention*" OR "nature therap*" OR "nature-based therap*" OR "nature based therap*" OR "nature-based practice*" OR "nature based practice*" OR "nature-based program*" OR "nature based program*" OR "nature practice*" OR ecotherap* OR "nature-based health promotion*" OR "nature based health promotion*" OR "wilderness therap*" OR "nature-assisted therap*" OR "nature assisted therap*" OR "nature-assisted care*" OR "nature assisted care*" OR "nature-based approach*" OR "nature based approach*" OR "garden therap*" OR "horticultur* therap*" OR "green therap*" OR "environmental therap*" OR "outdoor therap*" OR "green prescription*" OR [rehab* AND garden*] OR "nature-based rehab*" OR "nature based rehab*" OR "walk and talk*" OR "health walk*" OR "nature-based social prescribing" OR "nature based social prescri*" OR "green care" OR "care farm*"*

The Web of Science Advanced Search identified 2633 articles in total (Figure S1). The distribution of these articles across the ten 3-way nexus interlinkages is shown in row (1) of Table S3.

<u>Additional searches for indigenous knowledge</u>

We refined all of the WoS standard search strings with additional search terms (*Indigenous OR sami OR Sámi OR tradition*)* to identify the literature that integrates Indigenous knowledge.

Literature screening

The first 100 articles per 3-way nexus interlinkage, in the order of relevance from the WoS query, went through an initial screening of the title, keywords and abstracts, and in some cases the full text of the article. The aim of the screening was to identify 50 relevant articles according to three inclusion criteria: 1) study has a clear link to biodiversity; 2) study has a clear link between biodiversity and the two nexus elements; and 3) study has information on direction and magnitude of the interlinkage (quantitative or qualitative if clear information on direction or strength). In addition, the screening checked if there was an equitable distribution of realms (freshwater, marine, terrestrial) across the pool of articles. Each article was assessed as “yes”, “no”, or “maybe/unclear” for the inclusion criteria, the latter category covering articles where the interlinkage across the three nexus elements or the availability of impact information were not always clearly discernible from the abstract. The screening was undertaken by two reviewers based at the same organisation to enable rapid co-learning and frequent consistency checks across the ten 3-way nexus interlinkages.

Where 50 articles per 3-way nexus interlinkage were assessed as “yes” these were extracted into a Zotero database. Where there was less than 50 articles assessed as “yes”, articles classified as “maybe/unclear” were included in the database. If there was less than 50 articles after including “maybe/unclear” then additional articles were screened beyond the first 100 articles from the WoS to increase the pool of literature in the database.

In this first screening of literature duplicate articles were not screened or filtered across the ten databases. This was decided as articles could be potentially relevant to more than one of the 3-way nexus interlinkages. However, during the screening some articles were judged to be a better fit for a different 3-way nexus interlinkage. In such cases, articles were reassigned to the database associated with that nexus interlinkage. This was the case for 42 articles across eight nexus interlinkages.

Following the screening, 1185 articles passed the inclusion criteria and 1448 articles were excluded (Figure S1). Table S3 shows the number of articles screened and that passed the inclusion criteria for each of the ten 3-way nexus interlinkages. These included a reasonable balance across the three realms (terrestrial, freshwater and marine).

Literature eligibility

The ten Zotero databases produced following the literature screening were passed to 12 reviewers from the six main partners in the work package of the project to undertake a second screening by reading the full text of each article in the database. The aim of this second screening was to identify 20 articles per 3-way nexus interlinkage that were considered eligible for the review. This screening was supported by a protocol and training session to ensure consistency across reviewers. The protocol stated that reviewers should first scan all the articles in the database for a 3-way nexus linkage to obtain an overview of the diversity of articles (e.g., study methods and focus, realms, countries, outcome of nexus, inclusion of climate change). Reviewers were then requested to screen the literature against the following inclusion criteria, similarly to the first screening process, but based on a thorough read of the full article to assess their relevance and sufficiency of information: 1) study describes the interlinkage between two sectors and biodiversity; 2) study has some information on direction and magnitude of the interlinkage (quantitative or qualitative if direction or strength is indicated); and 3) there is information on the outcome of the interlinkages. Biweekly study group meetings were held throughout this phase of the review so that challenges and questions could be discussed to enable peer-to-peer learning and to refine the protocol where necessary.

Following the second screening, 122 articles passed the inclusion criteria and 1063 articles were excluded (Figure S1). Table S3 breaks down the number of articles that passed the inclusion criteria for each of the ten 3-way nexus interlinkages (row 4). These included a reasonable balance across the three realms (terrestrial 71%, freshwater 38%, and marine 22%) and about half of the studies (49%) incorporated climate change.

Table S3. Details of the article records per ten 3-way nexus interlinkages for each stage of the literature review

	BEF	**BEH**	**BET**	**BEW**	**BFH**	**BFT**	**BFW**	**BHT**	**BHW**	**BTW**	**Total**
(1) Records from WoS query with standard search terms (first row) and with additional search terms (second row)	300	20 47	294 652	91	130	381	268	78 316	31	190 417	2633
(2) Records from WoS 1st screening	100	47	207	89	127	100	100	161	30	220	1185
(3) Records passed WoS 1st screening and provided in Zotero databases	54	19	41	57	55	32	61	32	32	11	394
(4) Records passed WoS 2nd screening and evidence extracted to review template	20	5	7	20	16	10	20	6	16	2	122
(5) Records from additional literature search	1	15	13	1	4	10		14	6	16	80
(6) Duplicate counts	2			4	3		3		4		16
(7) QA counts	3	1	3	2	2	3	1	3	1	2	21
(8) Final records after duplicates removed and QA	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**22**	**18**	**200 (194 w/o duplicates)**

Standard review protocol and template

Once articles had been identified as eligible, their information was extracted into a review template. The review template was co-developed by the review team and was tested on 1-2 articles across each of the six main partners in the work package of the project that took part in this review to improve the consistency of responses and to refine the template. The template consisted of questions related to: 1) the spatial scale of the nexus described in the study; 2) the temporal scale over which the impact from the nexus interlinkages manifested; 3) realm (i.e., freshwater, marine, terrestrial); 4) species group; 5) ecosystems; 6) inclusion of climate in the study; 7) additional nexus elements beyond biodiversity, food, water, health, energy, transport and climate; 8) direct or indirect bi-directional impacts between two elements; 9) positive or negative direction of these impacts; 10) magnitude of these impacts (scale of 1 to 5); 11) indicators used to assess these impact relationships; 12) overall outcome of nexus interlinkages including synergies and trade-offs; 13) drivers mentioned in the study; 14) engagement of stakeholders and indigenous knowledge; 15) mention of policy goals including SDGs, biodiversity, Paris agreement and others; 16) strength of evidence (scale of 1 to 5). In addition, an annotated Causal Loop Diagram was drawn for each study to provide an overview of all nexus interlinkages covered. The detailed review template is provided in SM II.

The testing of the review template revealed that many papers across the ten 3-way nexus interlinkages cover more than the nexus elements of focus (i.e., beyond biodiversity and two elements). To capture all aspects of the nexus studied in each article comprehensively and accurately, it was agreed that the review of each article would record all nexus elements and their interlinkages, including those that were not the core elements (e.g. climate, pollution), both in the causal loop diagram and the review form. For this reason, the review of each paper went beyond the originally designed ten 3-way nexus interlinkages. It was also agreed that some elements (e.g. direct and indirect drivers) that do not have substantial information or evidence but were part of the causal loop diagram would be recorded to inform on critical gaps in nexus research.

The final review template was implemented in Google Forms for consistent recording, digitalization, and instant analysis of submissions. Excel files of review submissions were downloaded from Google Forms every 2-3 weeks and made available on the MS Teams working space for any corrections to be made to improve the accuracy and consistency of entries.

Additional literature searches

For six of the ten 3-way nexus interlinkages, the WoS screened literature database did not provide sufficient literature pool that met the inclusion criteria. For these nexus interlinkages, additional literature searches were undertaken using a range of methods. A protocol was developed to guide this process in order to foster consistency across review teams and reduce potential biases in the selection of literature. Reviewers were instructed to use the following approaches for the refined search in any order: 1) snowball backwards (citations used in the study) and forwards (studies that cited the study) from the selected set of literature from WoS databases; 2) add well-known or well-cited literature not identified on WoS; 3) search literature sources (e.g. targeted topical journals) that are not in WoS or other search engines (e.g. google scholar, Scopus); and 4) further search on WoS with additional key terms refined/contextualized for each 3-way nexus interlinkage. As additional support, the Research Rabbit network analysis tool was provided on ten nexus interlinkages with selected literature for the first six nexus and the literature database for the remaining four nexus interlinkages. This tool allowed reviewers to see the references used in the selected literature to identify potentially relevant references across the publication timeline with the network of author pools analysed. The key search terms and search strings were also provided for further searches on WoS, other search engines or targeted journals.

Each review team used different approaches for the additional searches as they needed to be refined to the specific 3-way nexus interlinkage. Tools and methods used by each team were shared during bi-weekly study group meetings to foster co-learning. The total count of articles submitted from the refined search of additional literature was 80, which is shown in terms of the ten 3-way nexus interlinkages in row (5) of Table S3. The additional searches of the literature are described in more detail below per 3-way nexus interlinkage.

<u>Biodiversity-Energy-Health</u>

Reviewer expert knowledge was used to search in Google Scholar using the following topical areas: 1) Energy biodiversity human health, 2) Energy healthcare, 3) Energy One Health, 4) Green energy – biodiversity, 5) Green energy biodiversity human health, and 6) Planetary health energy. In addition, several seminal papers and high quality medical and other journals in this area were identified and checked. These searches resulted in several relevant papers, from which the 15 most relevant were selected to add to the database.

<u>Biodiversity-Energy-Transport</u>

First, a refined search was undertaken in the research databases of WoS, Scopus, Science Direct and UNAM's Digital Library (bidi.unam.mx) using the additional keywords: *vessels, traffic, offshore, wind farms, infrastructure, fishing (useful), shale, micromobility, bikes, cyclo-, scooters, planes, aeroplanes, airplanes, agrovoltaic, agrivoltaics (not useful), route, vehicle, automobile, airplane, container, train, ship*. The search yielded many articles, although subsequent screening proved that most of them were of no use from the nexus perspective. Second, Research Rabbit was used to find additional articles based on the sources in the original WoS database for this nexus interlinkage. No additional articles were found. Third, the reference lists of already reviewed articles in the WoS database were screened (backwards snowballing), again without success. Fourth, articles were searched using Elicit (<u>https://elicit.org/</u>), an open-source AI tool, by entering the following requests: (1) "provide a list of research articles that investigate biodiversity, energy and transport at the same time"; (2) "provide a list of research articles that study the biodiversity, energy and transport NEXUS"; and (3) "find research articles that explore topics related to transport or traffic and the links with biodiversity (or ecosystems or nature) and with the energy sector". Elicit yielded several articles of which a few were included in the database. The subsequent review proved that not all added articles were of relevance, but 13 articles were added to the database.

<u>Biodiversity-Food-Health</u>

Additional search terms were added to the initial search string in Web of Science. This included health impacts of animal products, including terms "chronic$disease", "health" and "ecosystem$services". The first 200 papers were screened quickly and papers were chosen that were not in the initial database with seeming relevance from the titles. Through this method 3 additional papers were identified. However, one final paper was identified by using the key search terms "biodiversity", "health" and "food" into google scholar.

Biodiversity-Food-Transport

First, the reference lists and citations from those articles included in the WoS database for this nexus interlinkage were screened (forwards and backwards snowballing). Second, these references were entered into the Research Rabbit tool and articles citing them scanned. This found 10 promising articles, which were added to the database. Some articles were found to be more relevant for Biodiversity-Water-Transport nexus interlinkage and were transferred to that database.

Biodiversity-Health-Transport

First, the citations in the articles in the WoS database for this nexus interlinkage were examined (backwards snowballing), avoiding papers on green areas in urban spaces and walking as these were incredibly frequent in the database already. Second, the Research Rabbit tool was applied to the database articles to find further papers. Third, additional key words and key words previously searched were used in different combinations to search in Google Scholar (up to 3 pages in) and Web of Science (1st page). Finally, specific journals relevant to the topic were searched, such as the journal Transport and Health, using the terms "biodiversity" and "species". All these additional searches found 14 relevant articles which were added to the database.

Biodiversity-Health-Water

The same approach was used as described for the Biodiversity-Energy-Health nexus, but using the search term 'blue space biodiversity health'. This found six additional articles that were added to the database.

Biodiversity-Transport-Water

First, snowballing was undertaken from the two articles of which results were submitted to the google form from the initial database. The list of references was scanned and the papers citing them were found using the Research Rabbit tool. This identified 17 articles, however, none of those papers fulfilled the inclusion criteria. Second, snowballing was undertaken using those articles in the Biodiversity-Food-Transport WoS database that appeared relevant for the Biodiversity-Transport-Water nexus. This identified 14 articles, of which 11 fulfilled the criteria and reviews were submitted for. Then, without knowing if these 14 papers would fulfill the inclusion criteria, their list of references were scanned and entered into Research Rabbit to check citations. This identified seven further articles of which five were included in the database.

Indigenous Knowledge

We conducted an additional literature search to identify articles that substantially included Indigenous knowledge or Indigenous perspectives through consultations with Indigenous stakeholders (e.g., interviews, surveys, focus groups, primary sources) as the Web of Science search alone found very few articles that met the criteria. This search was undertaken using a range of other sources, including Google Scholar, and UNESCO and IPBES reports. Six peer-reviewed and grey literature articles were identified.

Quality assurance

A quality assurance (QA) procedure was conducted to evaluate the quality and consistency of the reviews. Three investigators who were not involved in the reviews randomly selected one review per reviewer per nexus interlinkage. From this procedure, twenty-one reviews were selected (n=21 reviews of 200). The independent investigators referred to the original article to evaluate the quality and consistency of each of the reviewer responses. In cases where the reviewer's responses were in question, investigators corrected or consolidated the existing reviews in the database and made note of general findings. Further, to reinforce the QA, two investigators who were not involved in the reviews independently compared reviews of the same manuscript by two different reviewers (i.e., duplicate reviews). Eight duplicate articles were selected and reviewed by two reviewers across five nexus interlinkages (n=16 reviews). The two investigators made note of discrepancies or inconsistencies and merged the duplicate reviews into one overarching review for each article for inclusion in the final database. In cases of clear disagreement, the investigators referred to the article to inform their expert judgment. The number of duplicate reviews of the eight articles across nexuses is shown on row (6) of Table S3 and the number of articles for which a QA was conducted is shown on row (7) of the same table. *In total, 37 entries in the review template were QAed; 18.5% of the final database.*

Overall, the results revealed strong consistency and similarity across the reviews, with minor differences that could in most cases be attributed to the complexity of the topic and the subjective nature of certain aspects of the response options in the review template. For example, the 'magnitude of the impact' between nexus elements or the 'overall strength of evidence' for a review was evaluated on a scale of 1 to 5, which was clearly defined but still required reviewer interpretation. The QA affirmed that subjectivity (e.g. prior knowledge of the subject) likely had negligible impacts on the results. For instance, of all the 'magnitude of impacts' recorded in the first phase of the QA (n=21 reviews), only 6 of the 68 scores (9 percent) were noted as potentially subjectively affected by the reviewer. The duplicate QA process reinforced that this subjectivity had negligible implications, as 13 of the 15 direct discrepancies between two reviewers evaluating the same impact differed by only one point on the scoring scale. Other direct discrepancies, such as in the descriptive data captured for the literature (e.g., scale, ecosystem, and species) or the level of detail provided in causal loop diagrams, were considered to be an inevitable outcome of a review of this complexity and would not significantly influence the findings.

Data Visualization and Analysis

<u>Databasing bidirectional linkages across the literature</u>

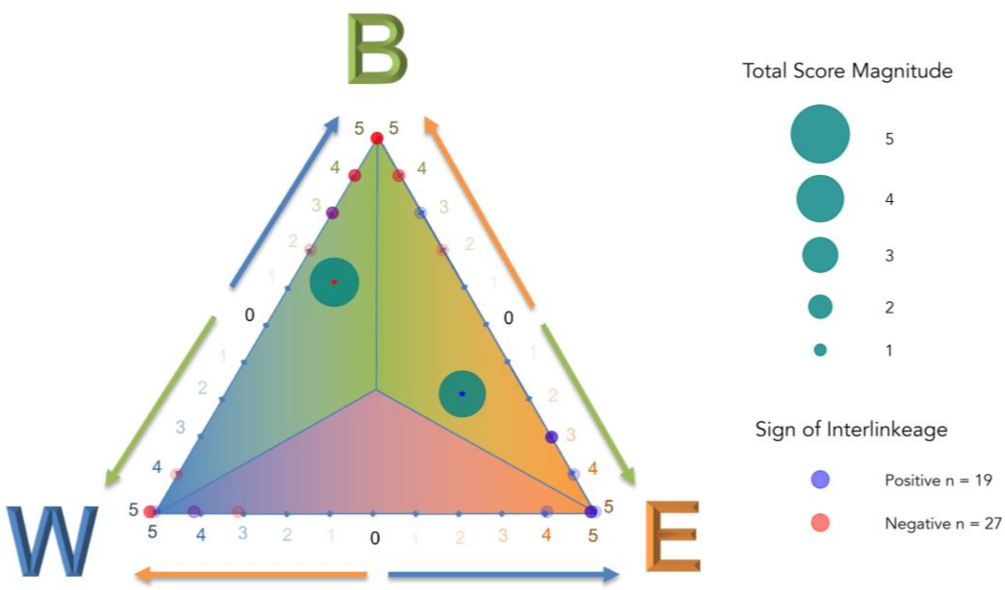
The bidirectional interlinkages (e.g. Biodiversity – Food) evidenced by each article were identified and the following information was recorded: a) Influencing nexus element, b) Influenced nexus element, c) whether the information on the interlinkage is quantitative or qualitative, d) whether the information on the interlinkage is based on direct indicators or inferred indirectly through proxies/surrogates, e) indicator(s) used for the influencing nexus element, f) indicator(s) use for the influenced nexus element, g) direction (Positive, Negative, Both (i.e., change over time)), h) description of the direction of impact, i) magnitude scale of 1-5 with 1 being negligible and 5 being substantial, j) description of the magnitude of impact.

As mentioned above, each article was reviewed for a three-way nexus interlinkage, yet many articles recorded additional links to nexus elements outside of their three-way nexus interlinkage, e.g. an article representing the Biodiversity-Energy-Food three-way interlinkage also identified an interlinkage with Health. The above information was also recorded for bidirectional interlinkages evidenced by the article that were outside of the three-way interlinkage it was initially chosen to represent. We synthesized all of these bidirectional interlinkages, removing any interlinkage that was blank and any interlinkage that linked to the same nexus element (e.g. Health – Health). The positive and negative bi-directional impact scores are presented in Figure 3 of the manuscript.

<u>Triplets of three-way nexus interlinkage</u>

A triangular space is set up. We represent each nexus element in each one of its corners. As an example, in the Figure below, the top corner represents Biodiversity (B), while Water (W) and Energy (E) are shown in the bottom two corners. Each triangle side has a scale of 0 to 5 bidirectionally, signifying the "influencing" and "influenced by" dependencies. In the W-B side, the scale increasing from 0 to 5 towards Biodiversity shows how Water influences Biodiversity with 5 being the highest score for this interlinkage. Similarly, going from 0 to 5 towards Water indicates that Biodiversity increasingly influences Water. This is shown by the arrows that are colored to match the element that exerts influence—green for Biodiversity, blue for Water and orange for Energy. Points are depicted separately for positive and negative values (blue dots are used for positive interlinkages and red dots for negative interlinkages). The dots are initially transparent, so if there are multiple dots on the same point, it appears darker. The darker the color, the more occurrences we have on the same score. All interlinkage values are plotted on the axes.

Next, the **geometric centroid** of all points that are plotted on all three axes is calculated and is shown in the triangular space. The triangle is split in 3 spaces that signify the bilateral relationships (the B-W space, the W-E space, and the B-E space). The centroid ends up in one of the three spaces indicating the predominance in influenced strength among the three interlinked elements. The centroid has three properties: (i) its position—the closest it is to one of the corners, the more this element is influenced by the other elements; (ii) its magnitude—the size of the circle where the centroid is marked is related to the strength of this interlinkage. The size of the centroid is calculated by taking an average of all values (absolute values); (iii) its center, which is either red (for negative interlinkages), or blue (for positive interlinkages). Finally, the number of interlinkage scores used to obtain the centroid is listed, separately for positive and negative scores. Naturally, the higher the number of points, the lower the uncertainty of the score reported.



Identifying pathways from biodiversity to the six nexus elements

Using the information on the collated bidirectional interlinkages from all 194 articles we can identify possible pathways, showing how one nexus element can influence another. For example, we can investigate the positive impact of biodiversity on food by identifying all pathways starting from biodiversity and ending in food that consist of positive bidirectional interlinkages between nexus elements. Pathways were identified using the "all_simple_paths()" function in the "igraph" package (Csardi and Nepusz, 2006) in R (Version: R Core Team, 2022).

The main aim of this review was to investigate the influence of biodiversity on the six nexus elements and the influence of the six nexus elements on biodiversity. We identified all the possible positive and negative pathways to and from biodiversity. This gave the four path groups positive from biodiversity, negative from biodiversity, positive to biodiversity and negative to biodiversity. Each path group consisted of 6 start and end element combinations. For example, the pathway group positive from biodiversity consists of 6 start and end element combinations Biodiversity to Climate, Biodiversity to Energy, Biodiversity to Food, Biodiversity to Health, Biodiversity to transport, Biodiversity to Water. These pathways are visually represented in Figure 7 in the manuscript.

Scoring the pathways

There can be many possible pathways between nexus elements with up to 7 nexus elements making up a pathway. For example, there are 526 positive pathways from biodiversity to all nexus elements.

We scored the pathways to identify which pathways have the most impact on the nexus element at the end of the pathway. To score the pathways we first calculated the weighted magnitude (wm) for each 2-way interlinkage as: frequency of studies evidencing the interlinkage * median magnitude of the interlinkage. We then scaled the weighted magnitude (swm) all of the 2-way interlinkages that are involved in the pathways between the start nexus element and the destination nexus element by the 2-way nexus element with the maximum weighted magnitude. Each 2-way interlinkage now has a weighted magnitude between 0 and 1. To calculate the score of a pathway we take the product of the scaled weighted magnitudes of all the 2-way interlinkages that make up the pathway. For example, the score for the pathway B-W-H-F is calculated as $B\text{-}H_{swm}$ * $W\text{-}H_{swm}$ * $H\text{-}F_{swm}$. Table 2a and 2b in the manuscript summarises the impact and complexity of all the pathways going from biodiversity to the 6 nexus elements.

B. Review questionnaire

BIONEXT WP1.1 Literature Review

1. Reference

Reviewer's Name *

Literature ID *

2. Spatial scale and location

Please select the spatial scale of the study. *

Mark only one oval.

- Local (single land parcel, farm or sub-catchment, city)
- Sub-national (anything in between local and national)
- National (countries in Europe)
- Sub-continental (anything in between national and continental)
- Continental (Europe)
- Global (European countries as part of the study)

Please select all countries included in the study. *

Tick all that apply.

- Albania
- Andorra
- Armenia
- Austria
- Azerbaijan
- Belarus
- Belgium
- Bosnia and Herzegovina
- Bulgaria
- Croatia
- Cyprus
- Czechia
- Denmark
- Estonia
- Finland
- France
- Georgia
- Germany
- Greece
- Hungary

- [ ] Iceland
- [ ] Ireland
- [ ] Italy
- [ ] Kazakhstan
- [ ] Kosovo
- [ ] Latvia
- [ ] Liechtenstein
- [ ] Lithuania
- [ ] Luxembourg
- [ ] Malta
- [ ] Moldova
- [ ] Monaco
- [ ] Montenegro
- [ ] Netherlands
- [ ] North Macedonia
- [ ] Norway
- [ ] Poland
- [ ] Portugal
- [ ] Romania
- [ ] Russia
- [ ] San Marino
- [ ] Serbia
- [ ] Slovakia
- [ ] Slovenia
- [ ] Spain
- [ ] Sweden
- [ ] Switzerland
- [ ] Turkey
- [ ] Ukraine
- [ ] United Kingdom (UK)
- [ ] Europe
- [ ] European Union (EU)

Please name the specific location of the study. *

3. Temporal scale

Please enter the duration of the study (e.g., measurement, assessment, experiments)
[YYYY to YYYY]

Please enter the estimated timeframe of impacts in the nexus (e.g., time taken for impacts on the influenced nexus element to manifest)

Mark only one oval.

- Less than 1 year
- 1-5 years
- 6-10 years
- 11-20 years
- More than 20 years

4. Biodiversity

Please select all of the realms studied. *

Tick all that apply.

- [ ] Freshwater
- [ ] Marine
- [ ] Terrestrial

Please select all species groups studied. *

Tick all that apply.

- [ ] Amphibians
- [ ] Birds
- [ ] Fish
- [ ] Fungi
- [ ] Invertebrates
- [ ] Mammals
- [ ] Plants (including trees)
- [ ] Reptiles
- [ ] All species
- [ ] None
- [ ] Undefined

. Enter specific information on the species groups studied or used to study the interlinkage.

Please select all ecosystems studied. *

Tick all that apply.

- [ ] Coastal
- [ ] Cropland
- [ ] Grassland
- [ ] Heathland and shrub
- [ ] Marine inlet and transitional waters
- [ ] Montane
- [ ] Open ocean
- [ ] Peatland
- [ ] Rivers and lakes
- [ ] Shelf
- [ ] Sparsely vegetated land
- [ ] Tundra and taiga
- [ ] Urban/peri-urban
- [ ] Wetlands
- [ ] Woodland and forest
- [ ] All ecosystems
- [ ] None
- [ ] Undefined

Enter specific information on the ecosystems studied or used to study the interlinkage.

5. Nexus interlinkage

Please select the interlinkage being reviewed. *

Mark only one oval.

- biodiversity-energy-health
- biodiversity-energy-transport
- biodiversity-energy-water
- biodiversity-food-energy
- biodiversity-food-health
- biodiversity-food-transport
- biodiversity-food-water
- biodiversity-health-water
- biodiversity-health-transport
- biodiversity-transport-water

Does the study include climate, i.e., interlinkages between the 3 sectors in the context of climate change or their impact on climate. In other words, is there sufficient information in the paper to add climate change as an additional node in your causal loop diagram? *

Mark only one oval.

- Yes
- No
- Unclear

If there are elements of nexus beyond those listed above, please list them (e.g. pollution).

6. Impact information on the interlinkage

Please answer this section on each sub-interlinkage separately (i.e., nexus element 1 and 2, nexus element 2 and 3, nexus element 1 and 3) in the following sub-sections A, B, C, D, E, F, G, and H.

Please provide a causal loop diagram of the nexus interlinkage in the study with two-way interactions labeled as A, B, C, D, E, F, G, and H in correspondence to the sub-interlinkage information provided in this section. (file format: please use the powerpoint template provided in the email).

Files submitted:

Interlinkage A

A1. Working through all the interlinkages in the study, what is the influencing nexus element? *

Mark only one oval.

- Biodiversity (influencing)
- Climate (influencing)
- Energy (influencing)
- Health (influencing)
- Food (influencing)
- Transport (influencing)
- Water (influencing)

A2. Working through all the interlinkages in the study, what is the influenced nexus element? *

Mark only one oval.

- Biodiversity (influenced)
- Climate (influenced)
- Energy (influenced)
- Health (influenced)
- Food (influenced)
- Transport (influenced)
- Water (influenced)

A3. Is the information on the interlinkage quantitative or qualitative? *

Mark only one oval.

- Quantitative
- Qualitative
- Mixed

A4. Is the information on the interlinkage based on direct indicators or inferred indirectly through proxies/surrogates? *

Mark only one oval.

- ⬭ Direct
- ⬭ Indirect
- ⬭ Both
- ⬭ Unknown

A5. If direct, please name the indicators or variables used for influencing nexus element.

A6. If direct, please name the indicators or variables used for influenced nexus element.

A7. If indirect, please provide more information on proxies/surrogates used on influencing nexus element.

A8. If indirect, please provide more information on proxies/surrogates used on influenced nexus element.

A9. What is the direction of impact of element 1 (influencing) on element 2 (influenced) of the nexus? *

Mark only one oval.

- Positive
- Negative
- Both (i.e., change over time)

A10. If both, please describe the pattern of the positive impact.

A11. If both, please describe the pattern of the negative impact.

A12. What is the magnitude of the impact of the interlinkage? *

Mark only one oval.

- 1 - Negligible: There is evidence that change in the first variable leads to a negligible change in the second variable and/or on balance, the change is not expected to be a concern and does not need to be a priority for action.
- 2 - Between negligible and moderate
- 3 - Moderate: There is evidence that change in the first variable leads to a moderate change in the second variable and/or on balance, the change is not highlighted as a major concern and/or priority for action but rather as a watching brief.
- 4 - Between moderate and substantial
- 5 - Substantial: There is evidence that change in the first variable leads to a substantial change in the second variable and/or the change is highlighted as a major concern, or is a priority for action.
- Unclear: There is no evidence on the magnitude of the change and its likely level of priority for action.

A13. Please describe further, including the scale of the impact of the nexus interlinkages if it is different from the scale of the study.

Please describe the overall impact and or outcome of the nexus interlinkage, including synergies and trade-offs, as well as indirect and additional nexus elements. *

7. Drivers of change

Please select all drivers being considered in the paper (whether positive or negative or mixed).

Tick all that apply.

- [ ] Land use
- [ ] Sea use
- [ ] Climate change
- [ ] Direct exploitation
- [ ] Invasive alien species
- [ ] Pollution
- [ ] Demographic
- [ ] Economic
- [ ] Policy, institutions and governance
- [ ] Sociocultural
- [ ] Technological
- [ ] Conflict
- [ ] Health
- [ ] Other: ______________________

Please describe those drivers in more detail.

8. Methods

Please select the methods being used in the paper. *

Tick all that apply.

- [ ] Experiment
- [ ] Focus group / workshop
- [ ] Indicator / data analysis
- [ ] Interview
- [ ] Literature review
- [ ] Modelling / simulation / computation
- [ ] Observation
- [ ] Survey
- [ ] Synthesis (e.g., meta-analysis, systematic review)
- [ ] Other: ______________________

Please describe further.

9. Inclusion of stakeholder knowledge

Does the study include knowledge from stakeholders? *

Mark only one oval.

- ( ) Yes
- ( ) No

If yes, which group? *

Tick all that apply.

- [ ] Businesses
- [ ] Minority groups
- [ ] Non-governmental or civil society organizations (NGOs, CSOs)
- [ ] Policy/governments
- [ ] Research
- [ ] Undefined
- [ ] Other: ____________________

Does the study include Indigenous knowledge? *

Mark only one oval.

- ( ) Yes
- ( ) No
- ( ) Unclear

Does the study engage Indigenous People? *

Mark only one oval.

- ( ) Yes
- ( ) No
- ( ) Unclear

Please describe any stakeholder knowledge used in the study further.

10. Global/multiscale policies and goals

Are any Sustainable Development Goals (SDGs) mentioned in the study? *

Mark only one oval.

- Yes
- No

Are any biodiversity (e.g., CBD) goals mentioned in the study? *

Mark only one oval.

- Yes
- No

Are any climate (e.g., Paris Agreement, 1.5 degree) goals mentioned in the study? *

Mark only one oval.

- Yes
- No

Please name specific (SDGs, biodiversity, climate) or another policies or goals mentioned in the study.

11. Evidence rating

Please rate the evidence on a scale of 1 (very weak) to 5 (very strong). *

Mark only one oval.

- 1 - Very weak evidence based on author's expert or stakeholder opinion only, with no further corroboration by other citations in the discussion
- 2 - Weak evidence based on single observation, experiment, modelling, limited stakeholder engagement, indicator analysis or literature review, not as rigorously supported by findings of other studies
- 3 - Reasonably supported evidence based on observations, experiment, modelling, indicator analysis or literature review, supported by stakeholder knowledge or findings of other studies
- 4 - Strong evidence based on multiple observations, well-designed experiments, modelling, indicator analysis or systematic literature review; with hypothesis and conclusion of the paper, well supported by stakeholder knowledge or findings of other studies
- 5 - Very strong evidence based on well-design empirical research and on synthesis (e.g., systematic review, meta-analysis); agrees with stakeholder knowledge or findings of other studies

Please describe the rationale for your rating.

12. Comments

Please provide any comments that are important to note in describing, analysing, and generalizing the relationships of the interlinkages for the BIONEXT project that are not covered in previous questions.

C. List of literature by three-way nexus interlinkage

Nexus Interlinkage	Title	Publication Year	Publication Title	DOI
BEF	Barbastelle bats in a wind farm: are they at risk?	2018	European Journal of Wildlife Research	10.1007/s10344-018-1202-1
BEF	Bioenergy crops and farmland biodiversity: benefits and limitations are scale-dependant for a declining mammal, the brown hare	2017	European Journal of Wildlife Research	10.1007/s10344-017-1106-5
BEF	Biological control of the terrestrial carbon sink	2006	Biogeosciences	10.5194/bg-3-147-2006
BEF	Conceptualising multi-regime interactions: The role of the agriculture sector in renewable energy transitions	2015	Research Policy	10.1016/j.respol.2015.05.013
BEF	Confronting governance challenges of the resource nexus through reflexivity: A cross-case comparison of biofuels policies in Germany and Brazil	2020	Energy Research & Social Science	10.1016/j.erss.2020.101464
BEF	Consequences of a cumulative perspective on marine environmental impacts: Offshore wind farming and seabirds at North Sea scale in context of the EU Marine Strategy Framework Directive	2013	Ocean & Coastal Management	10.1016/j.ocecoaman.2012.10.016
BEF	Diet analysis of bats killed at wind turbines suggests large-scale losses of trophic interactions	2022	Conservation Science and Practice	10.1111/csp2.12744
BEF	Environmental Issues as Drivers for Food Choice: Study from a Multinational Framework	2021	Sustainability	10.3390/su13052869
BEF	Fate of unproductive and unattractive habitats: recent changes in Iberian steppes and their effects on endangered avifauna	2006	Environmental Conservation	10.1017/S0376892906003146
BEF	Identifying leverage points for shifting Water-Energy-Food nexus cases towards sustainability through the Networks of Action Situations approach combined with systems thinking	2023	Sustainability Science	10.1007/s11625-022-01170-7
BEF	Insect Declines in the Anthropocene	2020	Annual Review of Entomology	10.1146/annurev-ento-011019-025151
BEF	Linking biomass production in short rotation coppice with soil protection and nature conservation	2014	iForest - Biogeosciences and Forestry	10.3832/ifor1168-007
BEF	Local effects of blue mussels around turbine foundations in an ecosystem model of Nysted off-shore wind farm, Denmark	2009	Journal of Sea Research	10.1016/j.seares.2009.01.008

BEF	Modeling Small Scale Impacts of Multi-Purpose Platforms: An Ecosystem Approach	2021	Frontiers in Marine Science	10.3389/fmars.2021.694013
BEF	Monitoring and evaluating the sustainability of Italian agricultural system. An emergy decomposition analysis	2014	Ecological Modelling	10.1016/j.ecolmodel.2013.02.014
BEF	Multi-step cognitive mapping of perceived nexus relationships in the Seewinkel region in Austria	2021	Environmental Science & Policy	10.1016/j.envsci.2021.08.004
BEF	Response of farmland biodiversity to the introduction of bioenergy crops: effects of local factors and surrounding landscape context	2014	GCB Bioenergy	10.1111/gcbb.12089
BEF	Small Hydropower Plants' Proliferation Would Negatively Affect Local Herpetofauna	2021	Frontiers in Ecology and Evolution	10.3389/fevo.2021.610325
BEF	The potential of Miscanthus to harbour known cereal pathogens	2015	European Journal of Plant Pathology	10.1007/s10658-014-0519-1
BEF	Willow coppice in intensive agricultural applications to reduce strain on the food-energy-water nexus	2021	Biomass and Bioenergy	10.1016/j.biombioe.2020.105903
BEH	A global perspective on energy: health effects and injustices	2007	The Lancet	10.1016/S0140-6736(07)61252-5
BEH	A sixteen-year reduction in the concentrations of aquatic PAHs corresponding to source shifts in the Elbe River, Germany	2019	Journal of Cleaner Production	10.1016/j.jclepro.2019.03.159
BEH	Build Healthier: Post-COVID-19 Urban Requirements for Healthy and Sustainable Living	2022	Sustainability	10.3390/su14159274
BEH	Combined heat and power as a platform for clean energy systems	2021	Applied Energy	10.1016/j.apenergy.2021.117686
BEH	Environmental impacts and risks of the national renewable energy targets – A review and a qualitative case study from Finland	2018	Renewable and Sustainable Energy Reviews	10.1016/j.rser.2017.05.146
BEH	Environmental impacts of utility-scale solar energy	2014	Renewable and Sustainable Energy Reviews	10.1016/j.rser.2013.08.041
BEH	Helping to heal nature and ourselves through human-rights-based and gender-responsive One Health	2020	One Health Outlook	10.1186/s42522-020-00029-0
BEH	How fossil fuel-derived pesticides and plastics harm health, biodiversity, and the climate	2020	The Lancet Diabetes & Endocrinology	10.1016/S2213-8587(20)30116-9

BEH	Impacts of renewable energy atlas: Reaping the benefits of renewables and biodiversity threats	2020	International Journal of Hydrogen Energy	10.1016/j.ijhydene.2020.05.195
BEH	International comparison of health care carbon footprints	2019	Environmental Research Letters	10.1088/1748-9326/ab19e1
BEH	Planetary Health and the Role of Nursing: A Call to Action: Planetary Health and Nursing	2017	Journal of Nursing Scholarship	10.1111/jnu.12343
BEH	Policies for accelerating access to clean energy, improving health, advancing development, and mitigating climate change	2007	The Lancet	10.1016/S0140-6736(07)61257-4
BEH	Pollution and health: a progress update	2022	The Lancet Planetary Health	10.1016/S2542-5196(22)00090-0
BEH	Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation–Lancet Commission on planetary health	2015	The Lancet	10.1016/S0140-6736(15)60901-1
BEH	Synergies and trade-offs between renewable energy expansion and biodiversity conservation – a cross-national multifactor analysis	2016	GCB Bioenergy	10.1111/gcbb.12337
BEH	The 2022 report of the Lancet Countdown on health and climate change: health at the mercy of fossil fuels	2022	The Lancet	10.1016/S0140-6736(22)01540-9
BEH	The environmental footprint of health care: a global assessment	2020	The Lancet Planetary Health	10.1016/S2542-5196(20)30121-2
BEH	The externalities of energy production in the context of development of clean energy generation	2020	Environmental Science and Pollution Research	10.1007/s11356-020-07625-7
BEH	The Nexus between the Austrian Forestry Sector and the Sustainable Development Goals: A Review of the Interlinkages	2019	Forests	10.3390/f10030205
BEH	Trends of European research and development in district heating technologies	2017	Renewable and Sustainable Energy Reviews	10.1016/j.rser.2016.02.023
BET	A global assessment of the prevalence of current and potential future infrastructure in Key Biodiversity Areas	2023	Biological Conservation	10.1016/j.biocon.2023.109953
BET	A Ship Traffic Disturbance Vulnerability Index for Northwest European Seabirds as a Tool for Marine Spatial Planning	2019	Frontiers in Marine Science	10.3389/fmars.2019.00192

BET	An indicator for assessing the status of marine-bird habitats affected by multiple human activities: A novel statistical approach	2021	Ecological Indicators	10.1016/j.ecolind.2021.108036
BET	Cautious but Committed: Moving Toward Adaptive Planning and Operation Strategies for Renewable Energy's Wildlife Implications	2014	Environmental Management	10.1007/s00267-014-0333-8
BET	Could future electric vehicle energy storage be used for hydropeaking mitigation? An eight-country viability analysis	2019	Resources, Conservation and Recycling	10.1016/j.resconrec.2019.04.032
BET	Decarbonising UK transport: Implications for electricity generation, land use and policy	2023	Transportation Research Interdisciplinary Perspectives	10.1016/j.trip.2022.100736
BET	Designing Sustainable Cold Chains for Long-Range Food Distribution: Energy-Effective Corridors on the Silk Road Belt	2017	Sustainability	10.3390/su9112044
BET	Ecology and environment of the Belt and Road under global climate change: A systematic review of spatial patterns, cost efficiency, and ecological footprints	2021	Ecological Indicators	10.1016/j.ecolind.2021.108237
BET	Global relative species loss due to first-generation biofuel production for the transport sector	2019	GCB Bioenergy	10.1111/gcbb.12597
BET	Operational offshore wind farms and associated ship traffic cause profound changes in distribution patterns of Loons (Gavia spp.)	2019	Journal of Environmental Management	10.1016/j.jenvman.2018.10.053
BET	Power lines and impacts on biodiversity: A systematic review	2018	Environmental Impact Assessment Review	10.1016/j.eiar.2018.04.010
BET	Renewable energy and biodiversity: Implications for transitioning to a Green Economy	2017	Renewable and Sustainable Energy Reviews	10.1016/j.rser.2016.08.030
BET	Synthetic fuel production costs by means of solid oxide electrolysis cells	2014	Energy	10.1016/j.energy.2014.04.002
BET	The contributory capacity of natural capital to energy transition in the European Union	2022	Renewable Energy	10.1016/j.renene.2022.03.142
BET	The EU–Africa Energy Partnership: Towards a mutually beneficial renewable transport energy alliance?	2009	Energy Policy	10.1016/j.enpol.2009.08.016

BET	The hidden costs of energy and mobility: A global meta-analysis and research synthesis of electricity and transport externalities	2021	Energy Research & Social Science	10.1016/j.erss.2020.101885
BET	The interplay between urban mitigation and adaptation strategies to face climate change in two European countries	2019	Environmental Science & Policy	10.1016/j.envsci.2019.02.002
BET	The quest for sustainable forest bioenergy: win-win solutions for climate and biodiversity	2022	Renewable and Sustainable Energy Reviews	10.1016/j.rser.2022.112180
BET	The Role of Bioeconomy in the Future Energy Scenario: A State-of-the-Art Review	2022	Sustainability	10.3390/su14010560
BET	Unravelling the ecological impacts of large-scale offshore wind farms in the Mediterranean Sea	2022	Science of The Total Environment	10.1016/j.scitotenv.2022.153803
BEW	Assessing and mapping biomass potential productivity from poplar-dominated riparian forests: A case study	2013	Biomass and Bioenergy	10.1016/j.biombioe.2012.10.023
BEW	Assessment of the water and energy budget in a peatland catchment of the Alps using the process based GEOtop hydrological model	2018	Journal of Hydrology	10.1016/j.jhydrol.2018.05.041
BEW	Bioenergy production and forest multifunctionality: A trade-off analysis using multiscale GIS model in a case study in Italy	2013	Applied Energy	10.1016/j.apenergy.2012.11.038
BEW	Brownification in Lake Bolmen, Sweden, and its relationship to natural and human-induced changes	2021	Journal of Hydrology: Regional Studies	10.1016/j.ejrh.2021.100863
BEW	Controlling biodiversity impacts of future global hydropower reservoirs by strategic site selection	2020	Scientific Reports	10.1038/s41598-020-78444-6
BEW	Cost-effective land-use options of drained peatlands– integrated biophysical-economic modeling approach	2020	Ecological Economics	10.1016/j.ecolecon.2020.106704
BEW	Effects of multiple stresses hydropower, acid deposition and climate change on water chemistry and salmon populations in the River Otra, Norway	2017	Science of The Total Environment	10.1016/j.scitotenv.2016.09.044
BEW	Energy–water–food nexus in the Spanish greenhouse tomato production	2016	Clean Technologies and Environmental Policy	10.1007/s10098-015-1076-9
BEW	Factors regulating primary producers' assemblages in Posidonia oceanica (L.) Delile ecosystems over the past 1800 years	2020	Science of The Total Environment	10.1016/j.scitotenv.2020.137163
BEW	Flow restoration and the impacts of multiple stressors on fish communities in regulated rivers	2019	Journal of Applied Ecology	10.1111/1365-2664.13413

BEW	Impacts of Mainstream Hydropower Dams on Fisheries and Agriculture in Lower Mekong Basin	2020	Sustainability	10.3390/su12062408
BEW	Interactive effects of land use, river regulation, and climate on a key recreational fishing species in temperate and boreal streams	2021	Freshwater Biology	10.1111/fwb.13799
BEW	Mini-hydro power plant for the improvement of urban water-energy nexus toward sustainability - A case study	2020	Journal of Cleaner Production	10.1016/j.jclepro.2019.119416
BEW	National Climate Change Policies and Sustainable Water Management: Conflicts and Synergies	2011	Ecology and Society	10.5751/ES-04037-160225
BEW	Optimizing operation of a large-scale pumped storage hydropower system coordinated with wind farm by means of genetic algorithms	2019	Global NEST Journal	10.30955/gnj.002978
BEW	Quantifying energy and water fluxes in dry dune ecosystems of the Netherlands	2015	Hydrology and Earth System Sciences	10.5194/hess-19-3787-2015
BEW	Regionalizing land use impacts on farmland birds	2015	Environmental Monitoring and Assessment	10.1007/s10661-015-4448-z
BEW	Responses of the novel bioenergy plant species Sida hermaphrodita (L.) Rusby and Silphium perfoliatum L. to CO 2 fertilization at different temperatures and water supply	2015	Biomass and Bioenergy	10.1016/j.biombioe.2015.07.031
BEW	Water security determines social attitudes about dams and reservoirs in South Europe	2022	Scientific Reports	10.1038/s41598-022-10170-7
BEW	Water, Forests, People: The Swedish Experience in Building Resilient Landscapes	2018	Environmental Management	10.1007/s00267-018-1066-x
BFH	A reservoir of ethnobotanical knowledge informs resilient food security and health strategies in the Balkans	2015	Nature Plants	10.1038/nplants.2014.21
BFH	Antimicrobial resistance (AMR) and marine plastics: Can food packaging litter act as a dispersal mechanism for AMR in oceanic environments?	2020	Marine Pollution Bulletin	10.1016/j.marpolbul.2019.110702
BFH	Assessment of water quality in the Alqueva Reservoir (Portugal) using bioassays	2010	Environmental Science and Pollution Research	10.1007/s11356-009-0174-9
BFH	Bats actively prey on mosquitoes and other deleterious insects in rice paddies: Potential impact on human health and agriculture	2020	Pest Management Science	10.1002/ps.5925

BFH	Biodiverse edible schools: Linking healthy food, school gardens and local urban biodiversity	2019	Urban Forestry & Urban Greening	10.1016/j.ufug.2018.02.015
BFH	Caring local biodiversity in a healing garden: Therapeutic benefits in young subjects with autism	2020	Urban Forestry & Urban Greening	10.1016/j.ufug.2019.126511
BFH	Constant Hepatitis E Virus (HEV) Circulation in Wild Boar and Red Deer in Spain: An Increasing Concern Source of HEV Zoonotic Transmission	2016	Transboundary and Emerging Diseases	10.1111/tbed.12311
BFH	Environmental and health impacts of using food waste as animal feed: a comparative analysis of food waste management options	2016	Journal of Cleaner Production	10.1016/j.jclepro.2016.05.049
BFH	Food choices, health and environment: Effects of cutting Europe's meat and dairy intake	2014	Global Environmental Change	10.1016/j.gloenvcha.2014.02.004
BFH	Modelling ecological and human exposure to POPs in Venice lagoon. Part I — Application of MERLIN-Expo tool for integrated exposure assessment	2016	Science of The Total Environment	10.1016/j.scitotenv.2016.04.146
BFH	Mycotoxin in the food supply chain—implications for public health program	2016	Journal of Environmental Science and Health, Part C	10.1080/10590501.2016.1236607
BFH	pp´DDT and pp´DDE Accumulation in a Food Chain of Lake Maggiore (Northern Italy): Testing Steady-State Condition	2006	Environmental Science and Pollution Research - International	10.1065/espr2006.01.010
BFH	Reducing overall herbicide use may reduce risks to humans but increase toxic loads to honeybees, earthworms and birds	2022	Environmental Sciences Europe	10.1186/s12302-022-00622-2
BFH	Risk of Malaria Reemergence in Southern France: Testing Scenarios with a Multiagent Simulation Model	2009	EcoHealth	10.1007/s10393-009-0236-y
BFH	Spatio-temporal models of bovine tuberculosis in the Irish cattle population, 2012-2019	2021	Spatial and Spatio-temporal Epidemiology	10.1016/j.sste.2021.100441
BFH	Systematic Review on Crimean–Congo Hemorrhagic Fever Enzootic Cycle and Factors Favoring Virus Transmission: Special Focus on France, an Apparently Free-Disease Area in Europe	2022	Frontiers in Veterinary Science	10.3389/fvets.2022.932304
BFH	TRACE ELEMENTS IN FISH TISSUE WITH COMMERCIAL VALUE OF THE DANUBE DELTA BIOSPHERE RESERVE	2017	Environmental Engineering and Management Journal	10.30638/eemj.2017.075

BFH	Trichinosis in Lublin Province in 2003-2010 on a Background of Wild Boar`S Population Dynamics	2012	Bulletin of the Veterinary Institute in Pulawy	10.2478/v10213-012-0008-2
BFT	Abundance of red-listed species in infrastructure habitats – ”responsibility species” as a priority-setting tool for transportation agencies´ conservation action	2015	Nature Conservation	10.3897/natureconservation.11.4433
BFT	Alien flora of Europe: Species diversity, temporal trends, geographical patterns and research needs	2008	Preslia -Praha	
BFT	Do all roads lead to resistance? State road density is the main impediment to gene flow in a flagship species inhabiting a severely fragmented anthropogenic landscape	2021	Ecology and Evolution	10.1002/ece3.7635
BFT	Fragmented dry grasslands preserve unique components of plant species and phylogenetic diversity in agricultural landscapes	2020	Biodiversity and Conservation	10.1007/s10531-020-02066-7
BFT	Habitat use and selection patterns inform habitat conservation priorities of an endangered large carnivore in southern Europe	2021	Endangered Species Research	10.3354/esr01105
BFT	Highways associated with expansion of boreal scavengers into the alpine tundra of Fennoscandia	2020	Journal of Applied Ecology	10.1111/1365-2664.13668
BFT	How Effective Are the Protected Areas of the Natura 2000 Network in Halting Biological Invasions? A Case Study in Greece	2021	Plants	10.3390/plants10102113
BFT	Improving the factual knowledge of landscapes: Following up the European Landscape Convention with a comparative historical analysis of forces of landscape change in the Sjodalen and St∅lsheimen mountain areas, Norway	2007	Norsk Geografisk Tidsskrift - Norwegian Journal of Geography	10.1080/00291950701709127
BFT	Influence of roads on space use by European hares in different landscapes	2023	Landscape Ecology	10.1007/s10980-022-01552-3
BFT	Plant Species Diversity of Highway Roadsides in Southern New England	2012	Northeastern Naturalist	10.1656/045.019.0102
BFT	Plant species richness in midfield islets and road verges – The effect of landscape fragmentation	2006	Biological Conservation	10.1016/j.biocon.2005.09.009
BFT	Principal threats to the conservation of freshwater habitats in the continental biogeographical region of Central Europe	2019	Biodiversity and Conservation	10.1007/s10531-019-01865-x

BFT	Rapid linear transport infrastructure development in the Carpathians: A major threat to the integrity of ecological connectivity for large carnivores	2022	Nature Conservation	10.3897/natureconservation.47.71807
BFT	Road verges provide connectivity for small mammals: A case study with wood mice (Apodemus sylvaticus) in an agro-silvo pastoral system	2020	Journal of Environmental Management	10.1016/j.jenvman.2019.110033
BFT	Roads and supplemental feeding affect home-range size of Slovenian red deer more than natural factors	2012	Journal of Mammalogy	10.1644/11-MAMM-A-136.1
BFT	Roadside diversity in relation to age and surrounding source habitat: evidence for long time lags in valuable green infrastructure	2020	Ecological Solutions and Evidence	10.1002/2688-8319.12005
BFT	Species co-occurrence networks of ground beetles in managed grasslands	2021	Community Ecology	10.1007/s42974-020-00034-3
BFT	The effect of railways on bird diversity in farmland	2019	Environmental Science and Pollution Research	10.1007/s11356-019-06245-0
BFT	The geomorphologic forcing of wild boars	2019	Earth Surface Processes and Landforms	10.1002/esp.4623
BFT	The influence of landscape structure on occurrence, abundance and genetic diversity of the common frog, Rana temporaria	2005	Global Change Biology	10.1111/j.1365-2486.2005.1005.x
BFW	A global synthesis of ecosystem services provided and disrupted by freshwater bivalve molluscs	2022	Biological Reviews	10.1111/brv.12878
BFW	A Qualitative Ecosystem Assessment for Different Shrublands in Western Europe under Impact of Climate Change	2004	Ecosystems	10.1007/s10021-004-0219-3
BFW	Assessing multiple goods and services derived from livestock farming on a nation-wide gradient	2017	Animal	10.1017/S1751731117000829
BFW	Assessing the effectiveness of regulatory controls on farm pollution using chemical and biological indices of water quality and pollution statistics	2001	Water Research	10.1016/S0043-1354(00)00587-X
BFW	Biodiversity and distribution patterns of freshwater invertebrates in farm ponds of a south-western French agricultural landscape	2008	Hydrobiologia	10.1007/s10750-007-9219-6
BFW	Biodiversity on the waves of history: Conservation in a changing social and institutional environment in Hungary, a post-soviet EU member state	2017	Biological Conservation	10.1016/j.biocon.2017.05.005

BFW	Can agriculture and conservation be compatible in a coastal wetland? Balancing stakeholders' narratives and interactions in the management of El Hondo Natural Park, Spain	2022	Agriculture and Human Values	10.1007/s10460-021-10271-5
BFW	Climate change impacts on the Alpine, Continental and Mediterranean grassland systems of Italy: A review	2021	Italian Journal of Agronomy	10.4081/ija.2021.1843
BFW	Climate-dependent scenarios of land use for biodiversity and ecosystem services in the New Aquitaine region	2022	Regional Environmental Change	10.1007/s10113-022-01964-6
BFW	Cross-sectoral impacts of climate change and socio-economic change for multiple, European land- and water-based sectors	2015	Climatic Change	10.1007/s10584-014-1239-4
BFW	Ecological benefits provided by alley cropping systems for production of woody biomass in the temperate region: a review	2012	Agroforestry Systems	10.1007/s10457-012-9494-8
BFW	Evaluation of the Danish mussel fishery: suggestions for an ecosystem management approach	2002	Helgoland Marine Research	10.1007/s10152-001-0095-6
BFW	Exploring the ecological constraints to multiple ecosystem service delivery and biodiversity	2013	Journal of Applied Ecology	10.1111/1365-2664.12085
BFW	Groundwater nitrogen and the distribution of groundwater-dependent vegetation in riparian areas in agricultural catchments	2014	Ecological Engineering	10.1016/j.ecoleng.2013.07.047
BFW	The Economy–Environment Nexus: Sustainable Development Goals Interlinkages in Austria	2022	Sustainability	10.3390/su141912281
BFW	The impact of extreme flooding events and anthropogenic stressors on the macrobenthic communities' dynamics	2008	Estuarine, Coastal and Shelf Science	10.1016/j.ecss.2007.07.026
BFW	Trophic niche but not abundance of Collembola and Oribatida changes with drought and farming system	2022	PeerJ	10.7717/peerj.12777
BHT	A Review of the Invasive Mosquitoes in Europe: Ecology, Public Health Risks, and Control Options	2012	Vector-Borne and Zoonotic Diseases	10.1089/vbz.2011.0814
BHT	Active commuting through natural environments is associated with better mental health: Results from the PHENOTYPE project	2018	Environment International	10.1016/j.envint.2018.10.002
BHT	Developing a Dynamic Model for Assessing Green Infrastructure Investments in Urban Areas	2021	International Journal of Environmental Research and Public Health	10.3390/ijerph182010994

BHT	Developing Forest Therapy Programmes Based on the Health Benefits of Terpenes in Dominant Tree Species in Tara National Park (Serbia)	2022	International Journal of Environmental Research and Public Health	10.3390/ijerph19095504
BHT	Effects of habitat and landscape fragmentation on humans and biodiversity in densely populated landscapes	2009	Journal of Environmental Management	10.1016/j.jenvman.2009.05.002
BHT	Environmental impacts in the civil aviation sector: Current state and guidance	2023	Transportation Research Part D: Transport and Environment	10.1016/j.trd.2023.103717
BHT	Environmental, health, wellbeing, social and equity effects of urban green space interventions: A meta-narrative evidence synthesis	2019	Environment International	10.1016/j.envint.2019.104923
BHT	Health and environmental benefits related to electric vehicle introduction in EU countries	2014	Transportation Research Part D: Transport and Environment	10.1016/j.trd.2014.09.002
BHT	Horizon scanning for invasive alien species with the potential to threaten biodiversity and human health on a Mediterranean island	2019	Biological Invasions	10.1007/s10530-019-01961-7
BHT	Invading European Seas: Assessing pathways of introduction of marine aliens	2013	Ocean & Coastal Management	10.1016/j.ocecoaman.2013.02.024
BHT	Investigating the physical activity, health, wellbeing, social and environmental effects of a new urban greenway: a natural experiment (the PARC study)	2021	International Journal of Behavioral Nutrition and Physical Activity	10.1186/s12966-021-01213-9
BHT	Low-carbon technologies and just energy transition: Prospects for electric vehicles	2022	Energy Conversion and Management: X	10.1016/j.ecmx.2022.100271
BHT	Marine invasive alien species: a threat to global biodiversity	2003	Marine Policy	10.1016/S0308-597X(03)00041-1
BHT	Measures for Sustainable Development of Road Network	2016	Transportation Research Procedia	10.1016/j.trpro.2016.05.076
BHT	One Biosecurity: a unified concept to integrate human, animal, plant, and environmental health	2020	Emerging Topics in Life Sciences	10.1042/ETLS20200067
BHT	Particulate matter concentrations and fluxes within an urban park in Naples	2020	Environmental Pollution	10.1016/j.envpol.2020.115134
BHT	Particulate matter pollution capture by leaves of seventeen living wall species with special reference to rail-traffic at a metropolitan station	2017	Urban Forestry & Urban Greening	10.1016/j.ufug.2017.07.005

BHT	The health impacts of traffic-related exposures in urban areas: Understanding real effects, underlying driving forces and co-producing future directions	2016	Journal of Transport & Health	10.1016/j.jth.2016.07.002
BHT	The impact of the COVID-19 lockdowns on wildlife–vehicle collisions in the UK	2023	Journal of Animal Ecology	10.1111/1365-2656.13913
BHT	Urban plant assemblages by land use type in Milan: Floristic, ecological and functional diversities and refugium role of railway areas	2021	Urban Forestry & Urban Greening	10.1016/j.ufug.2021.127175
BHW	Bio-Physical Controls on Wave Transformation in Coastal Reed Beds: Insights From the Razelm-Sinoe Lagoon System, Romania	2022	Frontiers in Marine Science	10.3389/fmars.2022.813474
BHW	Blue space, health and well-being: A narrative overview and synthesis of potential benefits	2020	Environmental Research	10.1016/j.envres.2020.110169
BHW	Blue-space availability, environmental quality and amenity use across contrasting socioeconomic contexts	2022	Applied Geography	10.1016/j.apgeog.2022.102716
BHW	Combined effects of moderate hypoxia, pesticides and PCBs upon crucian carp fish, Carassius carassius, from a freshwater lake- in situ ecophysiological approach	2020	Aquatic Toxicology	10.1016/j.aquatox.2020.105644
BHW	Fishing in the city for food—a paradigmatic case of sustainability in urban blue space	2021	npj Urban Sustainability	10.1038/s42949-021-00043-9
BHW	Global Perspective of Drought Impacts on Ozone Pollution Episodes	2022	Environmental Science & Technology	10.1021/acs.est.1c07260
BHW	Impact of different water and nitrogen inputs on the eco-efficiency of durum wheat cultivation in Mediterranean environments	2018	Journal of Cleaner Production	10.1016/j.jclepro.2018.02.200
BHW	Innovative actions in oceans and human health for Europe	2021	Health Promotion International	10.1093/heapro/daab203
BHW	Integrated urban stormwater management: Evolution and multidisciplinary perspective	2021	Journal of Hydro-environment Research	10.1016/j.jher.2020.11.003
BHW	LCA-Based Environmental Performance of Olive Cultivation in Northwestern Greece: From Rainfed to Irrigated through Conventional and Smart Crop Management Practices	2021	Water	10.3390/w13141954
BHW	Mechanisms underlying childhood exposure to blue spaces and adult subjective well-being: An 18-country analysis	2022	Journal of Environmental Psychology	10.1016/j.jenvp.2022.101876

BHW	Nonlinear and threshold-dominated runoff generation controls DOC export in a small peat catchment: NONLINEAR FLOW PATHS CONTROL DOC EXPORT	2017	Journal of Geophysical Research: Biogeosciences	10.1002/2016JG003621
BHW	Olive mill waste water risk assessment based on GIS techniques in Crete, Greece	2017	Global Nest Journal	
BHW	Proximity to blue spaces and risk of infection with Pseudomonas aeruginosa in cystic fibrosis: A case–control analysis	2015	Journal of Cystic Fibrosis	10.1016/j.jcf.2015.04.004
BHW	Researches in Castelporziano test site: ecophysiological studies on Mediterranean vegetation in a changing environment	2015	Rendiconti Lincei	10.1007/s12210-014-0374-1
BHW	Risk assessment of cyanobacteria toxic metabolites on freshwater ecosystems applying molecular methods	2023	Environmental Science and Pollution Research	10.1007/s11356-022-21814-6
BHW	Science-Narrative Explorations of “Drought Thresholds” in the Maritime Eden Catchment, Scotland: Implications for Local Drought Risk Management	2021	Frontiers in Environmental Science	10.3389/fenvs.2021.589980
BHW	Socio-economic and environmental vulnerability to heat-related phenomena in Bucharest metropolitan area	2021	Environmental Research	10.1016/j.envres.2020.110268
BHW	Swimming in Ireland: Immersions in therapeutic blue space	2015	Health & Place	10.1016/j.healthplace.2014.09.015
BHW	The seasons’ length in 21st century CMIP5 projections over the eastern Mediterranean	2018	International Journal of Climatology	10.1002/joc.5448
BHW	Vegetation feedbacks during drought exacerbate ozone air pollution extremes in Europe	2020	Nature Climate Change	10.1038/s41558-020-0743-y
BTW	A comparative study of macroinvertebrate biodiversity in highway stormwater ponds and natural ponds	2020	Science of The Total Environment	10.1016/j.scitotenv.2020.140029
BTW	Aquatic biodiversity in sedimentation ponds receiving road runoff – What are the key drivers?	2018	Science of The Total Environment	10.1016/j.scitotenv.2017.06.080
BTW	Can road stormwater ponds be successfully exploited by the European green frog (Pelophylax sp.)?	2022	Urban Ecosystems	10.1007/s11252-021-01129-z
BTW	Chloride Balance in Freshwater System of a Highly Anthropized Subalpine Area: Load and Source Quantification Through a Watershed Approach	2020	Water Resources Research	10.1029/2019WR026024

BTW	Constrained by aliens, shifting landscape, or poor water quality? Factors affecting the persistence of amphibians in an urban pond network	2020	Aquatic Conservation: Marine and Freshwater Ecosystems	10.1002/aqc.3309
BTW	DNA metabarcoding adds valuable information for management of biodiversity in roadside stormwater ponds	2019	Ecology and Evolution	10.1002/ece3.5503
BTW	Drought tolerance differs between urban tree species but is not affected by the intensity of traffic pollution	2023	Trees	10.1007/s00468-022-02294-0
BTW	Fine scale genetic structure in fire salamanders (Salamandra salamandra) along a rural-to-urban gradient	2021	Conservation Genetics	10.1007/s10592-021-01335-4
BTW	Highway stormwater ponds as islands of Odonata diversity in an agricultural landscape	2022	Science of The Total Environment	10.1016/j.scitotenv.2022.155774
BTW	Impact of environmental factors on aquatic biodiversity in roadside stormwater ponds	2019	Scientific Reports	10.1038/s41598-019-42497-z
BTW	Landscape connectivity and spatial prioritization in an urbanising world: A network analysis approach for a threatened amphibian	2019	Biological Conservation	10.1016/j.biocon.2019.06.035
BTW	Landscape genetics of northern crested newt Triturus cristatus populations in a contrasting natural and human-impacted boreal forest	2020	Conservation Genetics	10.1007/s10592-020-01266-6
BTW	Local and Landscape Drivers of Pond-Breeding Amphibian Diversity at the Northern Edge of the Mediterranean	2017	Herpetologica	
BTW	Multiple stressors in small streams in the forestry context of Fennoscandia: The effects in time and space	2021	Science of The Total Environment	10.1016/j.scitotenv.2020.143521
BTW	Occurrence and trophic transport of organic compounds in sedimentation ponds for road runoff	2021	Science of The Total Environment	10.1016/j.scitotenv.2020.141808
BTW	Road related pollutants induced DNA damage in dragonfly nymphs (Odonata, Anisoptera) living in highway sedimentation ponds	2019	Scientific Reports	10.1038/s41598-019-52207-4
BTW	Salinization of Alpine rivers during winter months	2021	Environmental Science and Pollution Research International	10.1007/s11356-020-11077-4
BTW	The impact of environmental factors on benthos communities and freshwater gastropod diversity in urban sinkhole ponds in roadside and forest contexts	2019	Landscape Research	10.1080/01426397.2018.1441387

D. Triplets analysis of ten three-way biodiversity nexus interlinkages

Biodiversity-Energy-Food Nexus

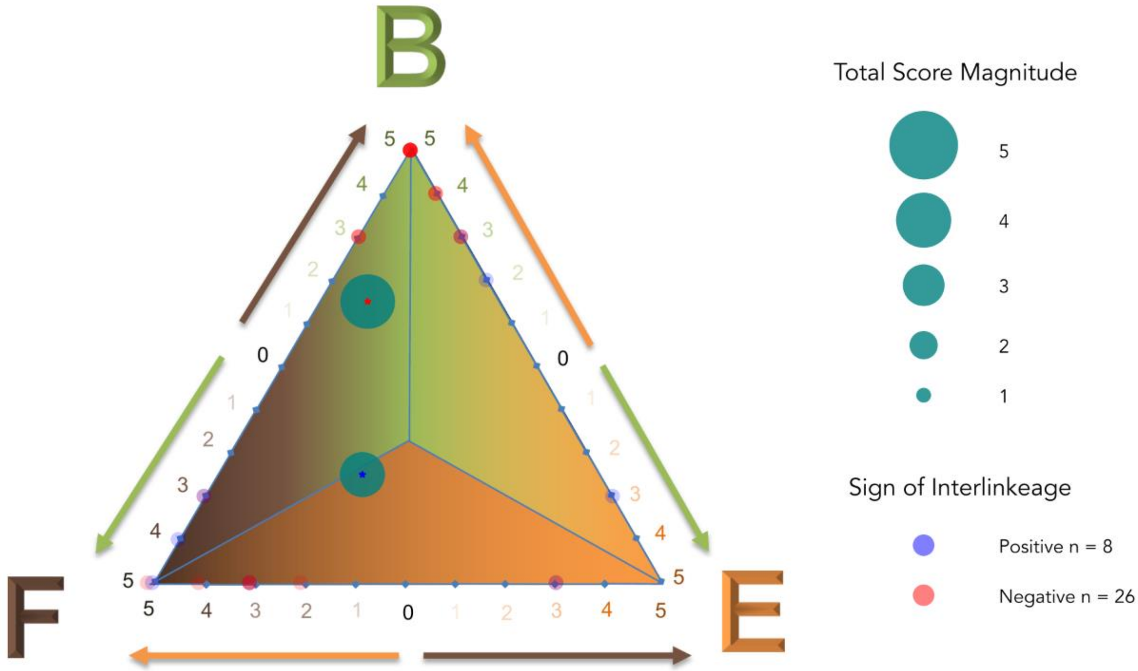


Figure S2. Triplet of the Biodiversity-Energy-Food Nexus interlinkage with positive and negative centroids

*Interpretation of the position and size of the **negative** centroid:*

In the Biodiversity-Energy-Food nexus interlinkage, food and energy both have a strong negative impact on biodiversity. For instance, (Wagner, 2020) stresses that agricultural intensification leads to loss of insects (loss of bees, bumblebees, moths, specifically a threat to Lepidoptera and monarch) and the avifauna of farmlands (specifically insectivorous birds). Deforestation and agriculture, taken together, account for the greatest annual losses of habitat and biodiversity (Wagner, 2020). In terms of energy, fossil fuel burning and fuelwood use lead to deforestation and biodiversity loss (Wagner, 2020). Renewable energy production, on the other hand, requires additional space, which leads to extensive land use change, creating pressure on ecosystems (e.g., Serpetti et al., 2021), as well as to the intensification of agriculture (Santos & Dekker, 2020) and the spread of monocultures (Sutherland et al., 2015a).

*Evidence for the **negative** bi-directional influence between the nexus elements (red):*

Biodiversity is the most clearly affected element of the nexus. It is often highlighted in the literature how the development of renewable energies, and the associated land-use change, will affect biodiversity negatively. The most common effects in this relationship are ecosystem degradation and ecosystem services loss (Serpetti et al., 2021), individuals or species loss (Scholz & Voigt, 2022), and competition between nature conservation and other uses (Busch et al., 2013). The interconnections between biodiversity, biofuels, and food have also been addressed under the banner “Food, Energy, and Environment Trilemma” (Santos & Dekker, 2020). Fossil fuel energy also has detrimental effects on biodiversity (Schulze, 2006; Wagner, 2020), including indirect effects through wood fuel use which leads to deforestation and biodiversity loss. Also, agricultural intensification leads to biodiversity loss (Wagner, 2020). The avifaunas of farmlands have been decreasing in both species richness and abundance, with insectivorous birds among those showing the greatest population declines.

The literature also mentions the importance of competition for land between energy use and food production, particularly concerning energy crops (Petzold et al., 2014; Sutherland et al., 2015a) and wind farming (Busch et al., 2013). The negative change in food chains as a collateral effect of land-use change for energy development and its operation is also mentioned (Crnobrnja-Isailović et al., 2021).

*Interpretation of the position and size of the **positive** centroid:*

The location of the positive centroid signifies that both biodiversity and energy have a considerable influence on food production. This corresponds to the understanding that in order to provide food, input from the energy sector as well as biodiversity is needed. At the same time, environmentally conscious consumers may opt for local food choices, having in mind that locally produced food may be less energy-intensive and have a lower negative impact on biodiversity (Guiné et al., 2021). In a multi-regime interaction, the agriculture regime may be supported by the electricity regime (in regards to technological anchoring, for example) (Guiné et al., 2021b).

*Evidence for the **positive** bi-directional influence between the nexus elements (blue):*

The positive impacts in the nexus concern mainly food production. Bioenergy crops and adequate farming practices can have a positive impact on both the food system and local ecosystems (Bourke et al., 2014; Petrovan et al., 2017a). For instance, short rotation coppice can improve both renewable energy production and biodiversity conservation (Petzold et al., 2014). Regarding energy production, a study by (Maar et al., 2009) shows a positive effect of offshore wind farms on blue mussel populations. Focusing on policies, (Sutherland et al., 2015a) show that agriculture and electricity regimes may create a symbiosis, reaping benefits from each other's existence in terms of policy anchoring, technical spill-over effects. In relation to food choices, both energy and biodiversity may act as an environmental issue that influences behaviour. Guiné et al. (2021b) showed that the notion of biodiversity protection and the necessity to use less energy may motivate people to consume local fresh food. On the other hand, Santos & Dekker (2020) mention that potential biodiversity loss and conflicts with local food production is an issue that deserves attention.

Biodiversity-Energy-Health Nexus

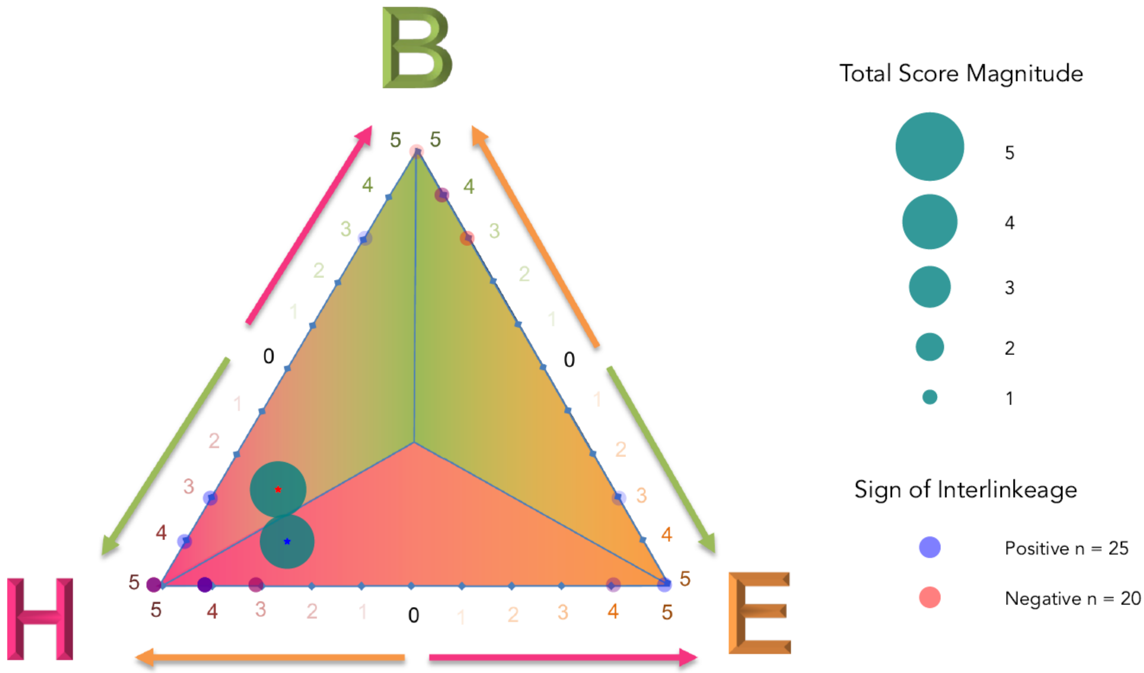


Figure S5. Triplet of the Biodiversity-Energy-Health Nexus interlinkage with positive and negative centroids

*Interpretation of the position and size of the **negative** centroid:*

Both Biodiversity and Energy have positive and negative influence on Health according to the location of the centroids. It is however important to clarify that health should be considered as both an outcome (health impact) and a sector (environmental impact); the fact that this distinction was not clearly taken into account in the analytical approach, may explain the dominance of the other two sectors to health.

*Evidence for the **negative** bi-directional influence between the nexus elements (red):*

The negative impact of biodiversity on health can be explained by nature related health risks such as infectious diseases and allergies. Regarding these two, health impacting of biodiversity dynamics can occur. Under the dilution effect hypothesis, the transmission and burden of infectious diseases are expected to be lower in animal species-rich, natural environments through lower infection prevalence in vectors (Kreuder Johnson et al., 2015; Ostfeld & Keesing, 2017), even when higher species richness indicating higher pathogen richness (Dunn et al., 2010). The amplification effect, in which the infection prevalence in vectors increases following an environmental change affecting biodiversity, has also been observed (Faust et al., 2017). The conditions in which dilution or amplification will be observed are still being investigated (Hurst, 2018; Kilpatrick et al., 2017; Kreuder Johnson et al., 2015). However, it has been established that the risk of disease spread appears higher in human-dominated and simplified habitats (Hurst, 2018).

However, the negative impact of the health sector on biodiversity need not be underestimated when we consider the high energy use in the health sector, negatively impacting both the environment (biodiversity) and health (Lenzen et al., 2020; Pichler et al., 2019). This may even be the main explanation for the complicated linkage of biodiversity, health and energy.

The negative impact of energy on health can be largely explained by negative health impact from fossil fuel energy production in general (particulate matter pollution, climate change) (Romanello et al., 2022) with substantial injustice effects (Wilkinson et al., 2007) and the high energy use in the health sector (Lenzen et al., 2020; Pichler et al., 2019). As such, the health sector itself contributes to the negative health impacts from energy, demanding even more energy, which can be a downward spiral. Simultaneously, the negative impact of this high energy demand in the health sector also negatively impacts health of the ecosystem. Turning towards renewable energy production would contribute to a lower environmental and health impact. Yet, renewable energy production may have negative externalities including the impact on biodiversity (Nazir et al., 2020; Santangeli et al., 2016). Finally, potentially recreation and physical activity in nature, apart from having health benefits, may also put pressure on ecosystem health, which became more obvious in the lockdowns during COVID (Ferguson et al., 2023).

*Interpretation of the position and size of the **positive** centroid:*

The most influential seems to be the combination of energy and biodiversity towards health. However, it is important to clarify that health should be considered as both an outcome (health impact) and a sector (environmental impact); the fact that this distinction was not clearly taken into account in the analytical approach, may explain the dominance of the other two sectors to health.

*Evidence for the **positive** bi-directional influence between the nexus elements (red):*

The natural living environment, including both green and blue space, can have many contributions to health, with potentially a bigger positive impact with higher biodiversity, even if the evidence in relation to human health is still scarce (Beute et al., 2023; Marselle et al., 2021). Prominent in this respect is the Biodiversity Hypothesis (Hanski et al., 2012), which emphasizes that contact with natural environments enriches the human microbiome and is necessary for promoting immune balance (Haahtela, 2019). While recent research highlights the potential transfer of diverse microbial communities from the environment to humans (Roslund et al., 2020, 2021; Selway et al., 2020), additional research is required to validate causality. Consequently, preventative healthcare may benefit from promoting contact with nature, e.g. nature on prescription (Astell-Burt et al., 2022), as such intervention eventually lowers the environmental impact on the health sector. In conjunction, the health sector may also have an advocacy role towards environmental care and nature conservation, which can be seen as an upward spiral (Kurth, 2017).

Biodiversity-Energy-Transport Nexus

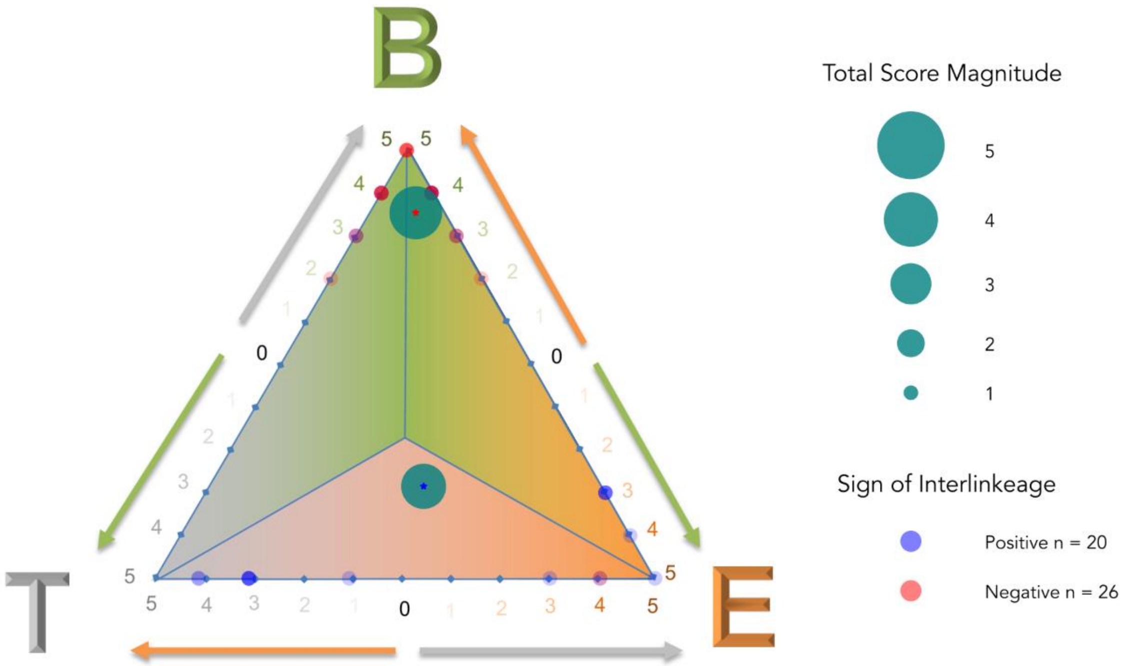


Figure S7. Triplet of the Biodiversity-Energy-Transport Nexus interlinkage with positive and negative centroids

*Interpretation of the position and size of the **negative** centroid:*

Energy production from both non-renewable and renewable sources can have a variety of negative impacts on biodiversity, including through land transformation, emissions and nutrient loads, or infrastructure that creates barriers to wildlife. The negative impacts of transport on biodiversity are intertwined with the energy sector, as the transport sector has high energy demands or as energy facilities require transport for maintenance and operation. Based on the review of Gasparatos et al. (2017), the renewable energy pathways include solar, wind, hydro, bioenergy, ocean, and geothermal energy, and they all have direct negative impacts on biodiversity by disrupting ecosystem services. Also, increased vessel traffic due to the development of ocean projects, could have a negative impact on various marine animals, fish stocks, and bird populations.

*Evidence for the **negative** bi-directional influence between the nexus elements (red):*

Most of the literature reviewed consider the negative impact of energy or transport on biodiversity; either by describing the impact of unsustainable transport (mainly powered by fossil fuels; e.g. Gallo et al. (2017)), or due to the infrastructure (Simkins et al. (2023)), or by revealing the negative impacts that renewable energy production can have on biodiversity and ecosystems, e.g. through the operation of hydroelectric plants (Román et al., 2019), unsustainable forestry and biomass harvest (Giuntoli et al., 2022), or mass production of biofuels for transport (Elshout et al., 2019). In the latter case, the papers mainly discuss the chemical inputs that energy crops may require and that may harm their surroundings (Charles et al., 2009) or the land competition between energy crop production and other uses (Perišić et al., 2022). Offshore wind farms development may enhance ship traffic and, in turn, affect seabird species and their habitats (Fliessbach et al., 2019). Several studies observed adverse biodiversity effects if wind energy facilities (Köppel et al., 2014; Lloret et al., 2022) or power lines (Biasotto & Kindel, 2018) are placed without caution in wildlife areas. Gasparatos et al. (2017) provides a literature review identifying the relatively complex positive and negative impacts of different renewable energy pathways on biodiversity and ecosystems, and its implications for transitioning to a Green Economy. Based on this review, the actual mechanisms of biodiversity loss and ecosystem change are found to be very diverse, depending on the renewable technology, operational characteristics, and the environmental context.

Interpretation of the position and size of the ***positive*** *centroid:*

The symbiotic relationship between transport and energy is quite self-explanatory. As mentioned above, the energy sector fuels the transport sector while increasing traffic increases energy demands. This is a reinforcing loop, although the important differences are in what technology and resources are being implemented in these sectors. Biodiversity is also positively influenced by energy and transport due to green measures in these and infrastructure sectors. However, in comparison to the symbiotic relationship between transport and energy, the positive impact is not as strong.

Evidence for the ***positive*** *bi-directional influence between the nexus elements (blue):*

Energy is the nexus element that receives most of the positive impact in the nexus. Most of the positive impacts have to do with biodiversity or biomass as a main input for the development of renewable energies (Perišić et al., 2022; Ridjan et al., 2014). Energy and transport are in symbiotic relationship in terms of carbon policies and enhanced public transport, where transition in the transport sector aims at use of cleaner energy, which in turn boosts renewable energy production (Logan et al., 2023). The Belt and Road initiative is another example, where shipping of goods and energy demand and sources of transportation, are intertwined. There are also positive impacts o that renewable energy development can bring to the transport sector (Ridjan et al., 2014), which could diminish the sector's reliance on fossil fuels. Some of the positive impacts of energy on transport can be explained by the logical increase in transportation during the construction and maintenance of offshore wind farms (Fliessbach et al., 2019). Further, (Pasimeni et al., 2019) shows that green measures in the transport and infrastructure as well as in the energy sector can positively influence biodiversity. Based on Gasparatos et al. (2017), all the technologies for renewable energy sources, except for geothermal, can have a positive impact on biodiversity.

Biodiversity-Energy-Water Nexus

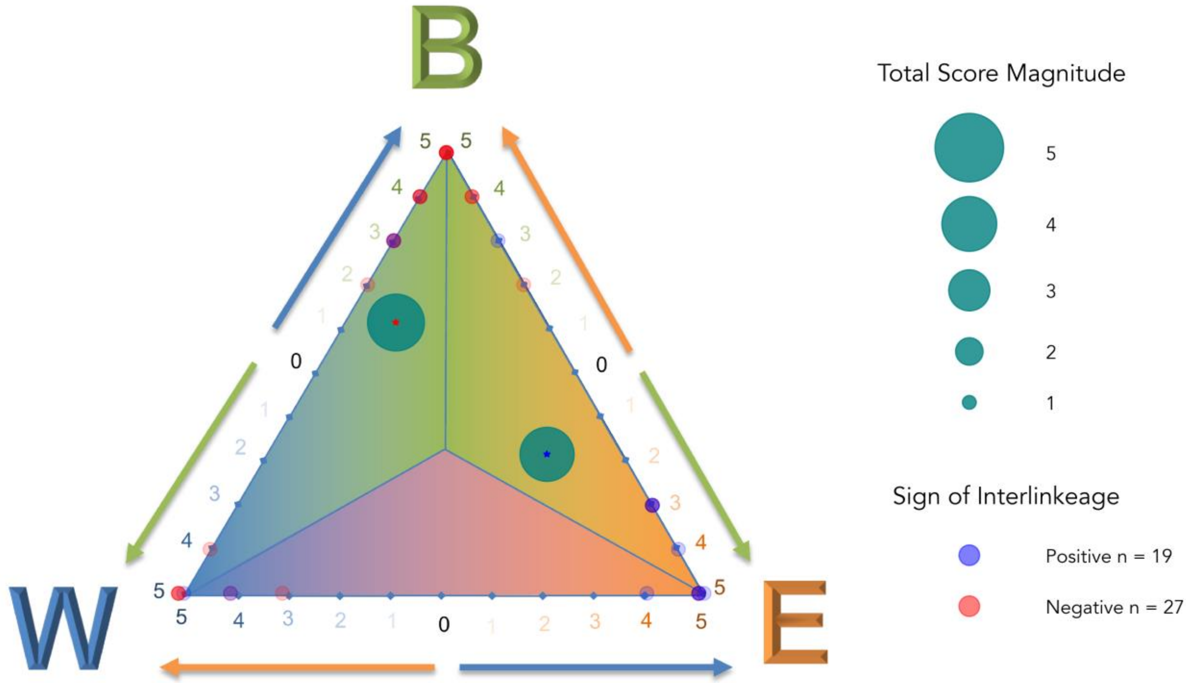


Figure S3. Triplet of the Biodiversity-Energy-Water Nexus interlinkage with positive and negative centroids

*Interpretation of the position and size of the **negative** centroid:*

The negative influences in the Biodiversity-Energy-Water nexus triplet is recorded in the Biodiversity-Water space. Overall, out of the three nexus elements, biodiversity is being most negatively affected by water and energy, as shown by the centroid location approaching the Biodiversity corner. Generally, energy seems to receive less negative influences from biodiversity and water. The magnitude of the influence is high, with a centroid size of 4/5; the high number of interlinkages being reported in the literature (n=27) enhances the confidence in this interlinkage assessment.

*Evidence for the **negative** bi-directional influence between the nexus elements (red):*

Biodiversity is negatively impacted by water in the case of peat extraction (Juutinen et al., 2020), while water, in terms of depth, has a direct and quantitative effect on the abundance of diatoms, seagrass, and rhodophytes (Leiva-Dueñas et al., 2020). Water infrastructure, such as dams and reservoirs, cause river fragmentation and alter river flow significantly impacting ecosystems and causing loss of biodiversity, particularly affecting aquatic life and habitats (Dopico et al., 2022; Pittock, 2011; Yoshida et al., 2020). Fisheries are greatly affected, with a negative impact on the longitudinal dispersal of fish species, hindering the colonization of migrating species (Göthe et al., 2019) and leading to significant declines in trout abundance (Donadi et al., 2021). Acidification of freshwaters has damaged fish populations in acid-sensitive regions, including southern Norway (R. F. Wright et al., 2017). Furthermore, brownification negatively affects water quality, its aesthetic value and ecosystems, with negative effect on live expectancy of fish species, productivity and composition of the community, negatively influencing ecosystems and leading to long-term changes (Klante et al., 2021). The reverse relationship can also be negative, i.e. biodiversity negatively affects water, mainly in coniferous forest areas, that have significant influence on the carbon cycle, with higher amounts of biomass and increased brownification (Klante et al., 2021), that in turn affects biodiversity in a feedback loop.

Probably the most important way that energy impacts water is through hydropower, which requires massive amounts of water and affects ecological flows (Pittock, 2011). Hydropower operations directly alter river water temperature and discharge, which in turn directly affect water quality (R. F. Wright et al., 2017). Energy production via hydropower creates stressors such as river regulation, and excess loadings of nutrients and sediments impacting its quality and habitat conditions (Bakanos & Katsifarakis, 2019; Donadi et al., 2021). Another way that energy impacts water is through negatively impacting water quality through emissions (TN, TP and TOC) under the energy-producing peat extraction, causing eutrophication and brownification (Juutinen et al., 2020). At the same time, irrigation improves yields and profit margins for energy crops; thus, it is expected to intensify in the near future (Glemnitz et al., 2015). Finally, energy biomass extraction can have negative impacts on soil and water protection, depending on factors like slope, soil bearing capacity, soil depth, and soil compaction risk (Sacchelli et al., 2013). Energy negatively affects biodiversity through peat extraction (Juutinen et al., 2020), and through energy production via hydropower (Bakanos & Katsifarakis, 2019), which specifically affects the salmon life cycle (A. J. Wright et al., 2017), and reduces fish species diversity, while favoring opportunistic species with traits that allow them to persist in unpredictable environments (Göthe et al., 2019). Finally, energy farming directly affects farmland birds, with changes in cropping patterns impacting the population densities of these birds (Glemnitz et al., 2015). Similarly, the decrease in crop diversity can also contribute to the homogenization of landscapes, which can negatively affect biodiversity (Glemnitz et al., 2015). Overall, the negative effect of energy on biodiversity overpowers the one on water and ends up moving the negative centroid closer to the energy corner.

*Interpretation of the position and size of the **positive** centroid:*

Positive influence on the Biodiversity-Energy-Water nexus triplet is recorded in the Biodiversity-Energy space. Overall, out of the three nexus elements, energy is being most positively affected, shown by the centroid location that approaches the energy corner. The magnitude of the influence is relatively high, with a centroid size of 4/5; the relatively high number of interlinkages being reported in the literature (n=19) enhances the confidence in this interlinkage assessment.

*Evidence for the **positive** bi-directional influence between the nexus elements (blue):*

Energy is affected positively by biodiversity due to the growth of variable tree species, thereby creating a strong forest bioenergy potential (Cartisano et al., 2013). Forest residue, or other forms of woody above ground biomass can be used as an energy source (Cartisano et al., 2013), with district heating being such an example (Sacchelli et al., 2013). Also, water impacts the carbon balance of peatlands that are important energy sources (Pullens et al., 2018). In dry dune ecosystems, (Voortman et al., 2015), moss vegetation can play an important role in increasing groundwater recharge due to energy requirements and emitted radiation that plays a role in evapotranspiration dynamics. At the same time, the inverse interlinkage also exists, i.e. biodiversity is affected positively by energy, but at a lesser degree, pulling the centroid more towards the energy corner; harvesting practices for using wood as an energy source can increase the regeneration capacity for forests (Cartisano et al., 2013). Water affects energy positively, since it is either needed for forest bioenergy generation (Comino et al., 2020; Eriksson et al., 2018; Franzaring et al., 2015), but is also used in hydropower plants for renewable energy production (Comino et al., 2020; Dopico et al., 2022). Water is shown to affect biodiversity in a positive way, since abundant water availability results in higher yields for bioenergy plants and forest and riparian vegetation (Cartisano et al., 2013;

Franzaring et al., 2015), while on top of water availability, high water quality and chemistry have a positive impact on vegetation and biodiversity (Eriksson et al., 2018; Irabien & Darton, 2016) and may improve the ecological status of rivers with benefits for local ecosystems (Comino et al., 2020). Even though there is evidence that water positively affects biodiversity, this influence is overpowered by the overall positive influence on energy, thus placing the centroid closer to the energy corner.

Biodiversity-Food-Health Nexus

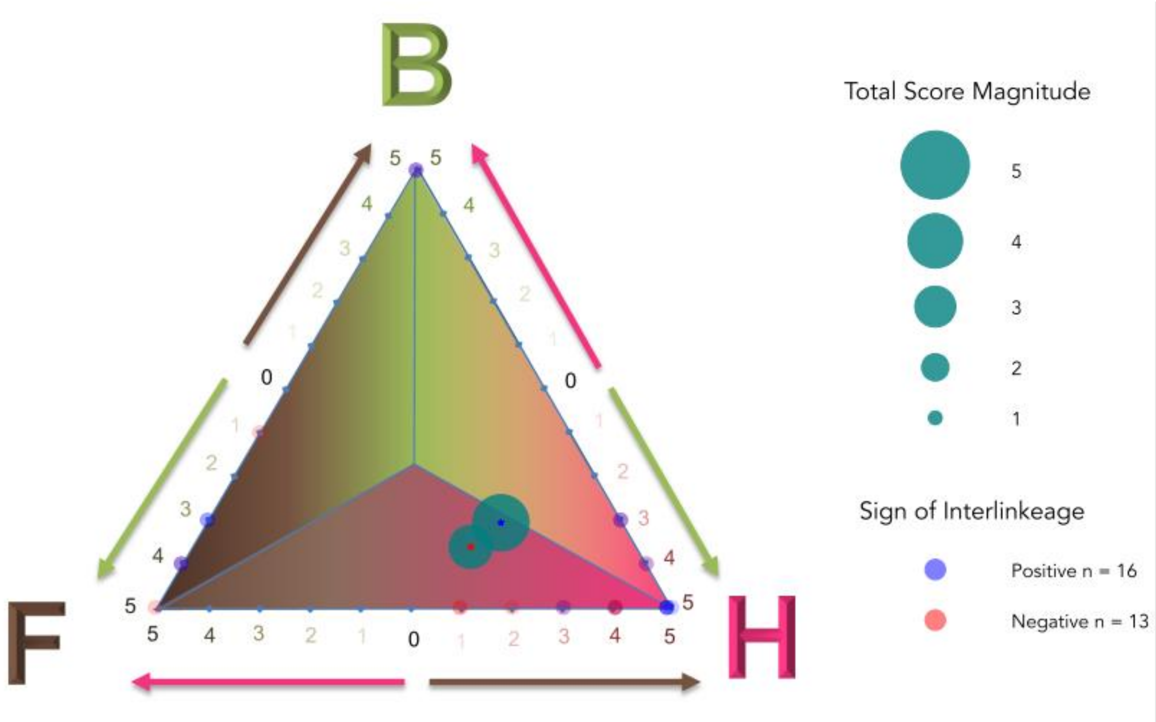


Figure S4. Triplet of the Biodiversity-Food-Health Nexus interlinkage with positive and negative centroids

Figure S4 shows both positive and negative influence biodiversity and food have on health based on the location of the centroids. The effects of food systems and biodiversity on health are well documented. The risks to human health from agricultural pollution, food-borne diseases and livestock disease transmission, as well as the opportunities to reduce these, have been widely explored in the literature. Growing interest in understanding the way in which biodiversity impacts human food and health systems has led to a substantial body of literature on these topics. However, the influence of the health sector on food and biodiversity remains poorly documented, potentially downplaying its impact in this nexus area.

*Interpretation of the position and size of the **negative** centroid:*

There is a significant body of literature exploring the different relationships between biodiversity, food and health. Agricultural production is seen to be highly impactful to the health sector, mainly due to disease transmission and pesticides. Biodiversity seems to cause an indirect negative impact through food production as a vector to the health sector.

Biodiversity and food are shown to be the more influencing within the interlinkage which resulted in higher magnitudes resulting in the centroids negative position. While health was the influenced variable within the nexus, biodiversity and food seem to be quite interlinked.

*Evidence for the **negative** bi-directional influence between the nexus elements (red):*

There is a high frequency of negative impacts from biodiversity and food on health. Biodiversity can impact the health of humans and animals through the infiltration of the food production system. This can be seen in studies on dangerous fungal species and mycotoxins which are harmful to human and farm animal health through consumption (Milićević et al., 2016). Wild boar populations have been shown to cause cases of trichinosis in humans due to its consumption of meat (Flis, 2012). Biodiversity can be a source of disease transmission. Various animals can be hosts of ticks, which is hazardous to human health and livestock (Bernard et al., 2022), for example, the mosquito can pose a serious health risk to humans as a potential vector for the malaria parasite (Linard et al., 2009).

Food production and agriculture have been documented to have negative implications for the health sector. Food production systems are linked to human health and can be the source of disease, bacteria and pollutants. Disease transmission through livestock is also an example of human health being impacted by the biodiversity in the surrounding area, with the transmission of hepatitis E from wild boar to humans (Kukielka et al., 2016). Pollutants from food production can have detrimental effects on human health, with organic pollutants altering local biodiversity including numerous aquatic species consumed by humans. This results in negative organ function impact from the pollutant exposure in humans (Giubilato et al., 2016). Antibiotic resistant bacteria can harbour in plastic produced in food production, which has a risk of being introduced to other ecosystems and food chains (Moore et al., 2020).

Biodiversity can indirectly have negative impacts on human health through the food production sector. This can be seen where fungal species can contaminate food production and be harmful to human health (Milićević et al., 2016) and cause diseases from wild boar meat consumption (Flis, 2012) and insect hosts (Bernard et al., 2022).

*Interpretation of the position and size of the **positive** centroid:*

All stages of activities in the food system, from production to consumption and waste management, are intimately linked to human health, so changing approaches to agriculture and food production can produce significant positive health outcomes. Similarly, biodiversity supports ecosystem services crucial to various dimensions of human health, so conserving and enhancing biodiversity can provide important health benefits, explaining the strong magnitude of the positive interlinkages in this nexus. Health is more positively influenced by biodiversity and food than it influences these two sectors.

*Evidence for the **positive** bi-directional influence between the nexus elements (red):*

There was a high frequency of positive impacts on health by both biodiversity and food. Biodiversity underlies many ecosystem services which are crucial for human health, providing a source of nutrition and medicines (Quave & Pieroni, 2015), mental health benefits through interactions with nature (Scartazza et al., 2020) and regulating the risk of infectious disease outbreaks (Linard et al., 2009).

Food systems are closely linked to human health, and therefore, changing how food is produced, consumed and how waste is managed, can have a large influence on health outcomes. Changing food production practices, such as reducing pesticide inputs (Cech et al., 2022) and switching to smart irrigation systems (Fotia et al., 2021) can decrease human health risks from agricultural pollution. Changing consumption practices, through reducing meat and dairy consumption can lead to lower health risks from cardiovascular diseases and strokes (Westhoek et al., 2014). Management of food waste can also have important implications for human health, for instance, (Salemdeeb et al., 2017) found that recycling food waste as pig feed, rather than through conventional disposal methods, can reduce health risks to humans, through a reduction in levels of zinc in pig feed.

There were also a few examples of positive impacts biodiversity has on food systems, such as the importance of conserving wild food plants (Quave & Pieroni, 2015), wild game (Flis, 2012) and landraces (Scartazza et al., 2020) to ensure long-term food security.

Biodiversity-Food-Transport Nexus

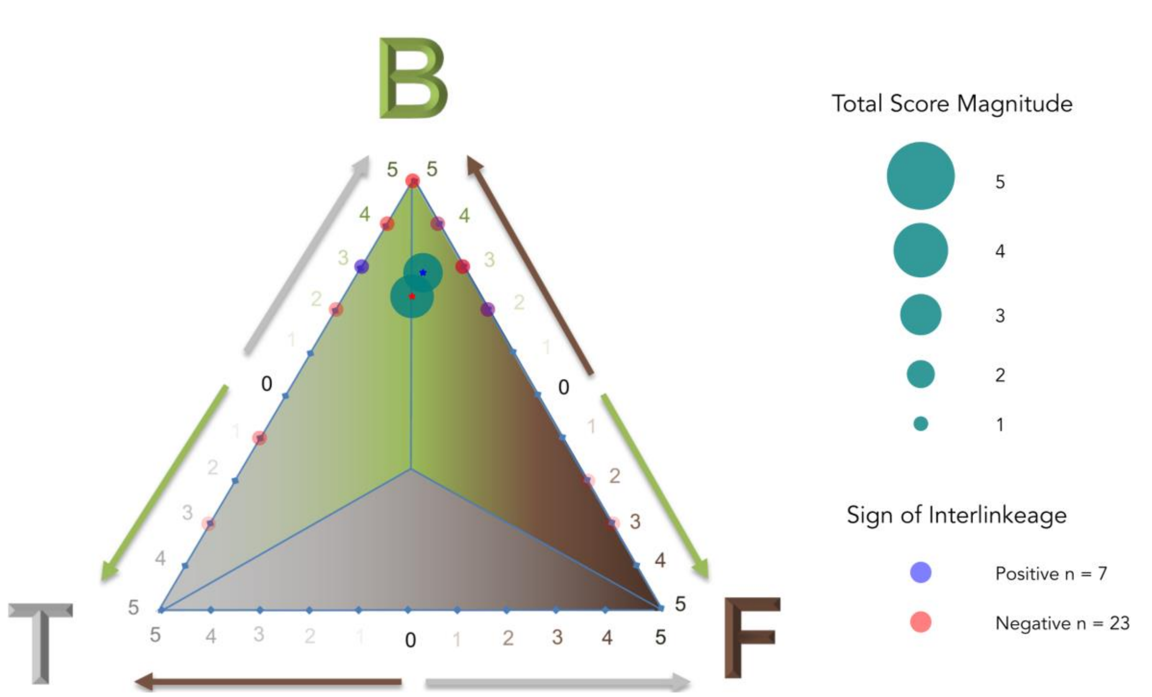


Figure S11. Triplet of the Biodiversity-Food-Transport Nexus interlinkage with positive and negative centroids

Interpretation of the position and size of the ***negative*** *centroid:*

The negative centroid is located close to the biodiversity corner of the triangle, meaning that the governing negative influences are of transport and food negatively influencing biodiversity. The size of the centroid is relatively small, so these influences are of approximately of a magnitude of 3.

Evidence for the ***negative*** *bi-directional influence between the nexus elements (red):*

The negative influence of transport on biodiversity relates to the presence of infrastructure. For example, roads are not absolute barriers for red deer, but proximity to roads can affect the shape and size of their home ranges (Jerina, 2012). Hares avoided establishing home ranges in areas with higher road densities (Mayer et al., 2023) and roads are a significant landscape variable impeding the gene flow of wildcats (Westekemper et al., 2021). Transportation and service corridors have negative impacts on the conservation status of some habitats (Grzybowski & Glińska-Lewczuk, 2019) and rapidly increasing linear transport infrastructure (e.g., roads and railways) can contribute to habitat fragmentation, for example those of large carnivores (Papp et al., 2022). Transport also influences biodiversity through the transfer of alien species. For example, alien species are assumed to have arrived as stowaways (Lambdon et al., 2008) and highly disturbed habitats like grasslands with close proximity to transportation networks experience more propagule pressure (Christopoulou et al., 2021). The negative influence of biodiversity on transport include damage from wild boars that cause local erosion in areas connected to roads (Mauri et al., 2019) and the protection of natural areas preventing further development of transport infrastructure (Eiter & Potthoff, 2007).

Food has various negative influences on biodiversity. Agricultural and horticultural pathways of introduction account for 488 and 1018 alien plant species respectively in Europe (Lambdon et al., 2008). Agriculture negatively affects biodiversity due to pesticide use and soil scarification (Helldin et al., 2015). Simple landscapes with seasonally varying resource availability (large agricultural fields, crop growth and harvest seasons) increase space use requirements (Mayer et al., 2023), which, for example, contribute to the reduction of large carnivore habitats (Papp et al., 2022). Agricultural fields and dry meadows were found to decrease bird diversity (Kajzer-Bonk et al., 2019). Agriculture also has various negative impacts on freshwater habitats, such as eutrophication and chemical pollution (Grzybowski & Glińska-Lewczuk, 2019). These impacts can also be indirect, where supplemental feeding of red deer to reduce their damage on farm crops can reduce the size of their home range and increase competition for food, facilitating transmission of parasites and diseases (Jerina, 2012). Conversely, negative influences of biodiversity on food relate to damage in agricultural fields by animals like wild boars (Mauri et al., 2019) or red deer (Jerina, 2012).

*Interpretation of the position and size of the **positive** centroid:*

The positive centroid is also located close to the biodiversity corner of the triangle, meaning that biodiversity receives positive influences from both food and transport. The size of the positive centroid is slightly smaller than the negative centroid, meaning the average magnitude of the positive influences are slightly smaller than the negative influences.

*Evidence for the **positive** bi-directional influence between the nexus elements (blue):*

The positive influence of transport on biodiversity relates to the habitat created next to transport corridors. For example, railway embankments can support diversity of birds, possibly through the higher variance in the landscape and available habitats (Kajzer-Bonk et al., 2019) and road verges providing habitat for grassland carabids and other species (Elo et al., 2021). The positive influence of food on biodiversity relates to the suitability of some agricultural landscapes as habitat. For example, grasslands and rural biotopes like meadows and pastures maintained by traditional agricultural practices host high species diversity (Elo et al., 2021). Similarly, bear species used areas closer to natural habitat during the day and areas closer to human-related habitat (including intensive and naturalized crops) at night (De Gabriel Hernando et al., 2021).

Biodiversity-Food-Water Nexus

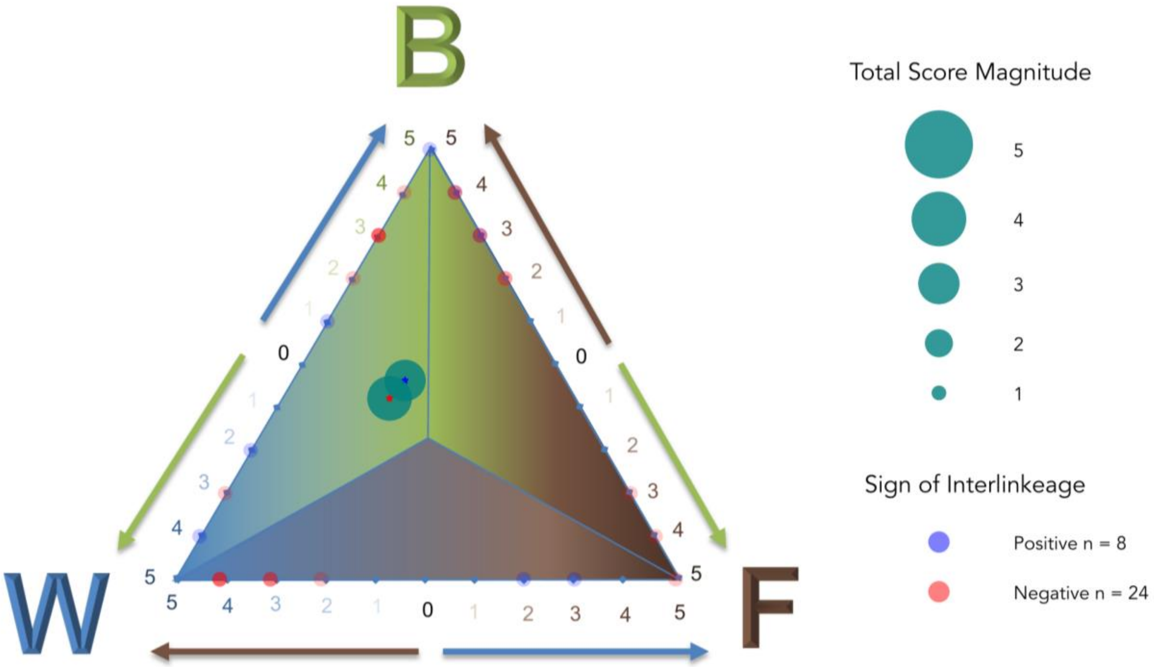


Figure S8. Triplet of the Biodiversity-Food-Water Nexus interlinkage with positive and negative centroids

The food has both positive and negative influence on biodiversity and water, and stronger than the biodiversity and water influences on food. The average magnitude of impact is around 3/5 and is smaller for positive than the negative influence with eight studies for the positive linkage and 24 studies for the negative linkage.

*Interpretation of the position and size of the **negative** centroid:*

Food is influencing both water and biodiversity negatively more than it is being influenced by the other elements. Both direct and indirect effects of food on water and biodiversity are well-known and widely acknowledged. Production of food can pollute water and irrigation demands can result in water over-extraction. Land clearance for food and intensive agriculture can cause drastic biodiversity loss, hence the negative relationships observed here. Fewer studies explored the impact of biodiversity on food and water, hence fewer dots in the figure for this direction of impact.

*Evidence for the **negative** bi-directional influence between the nexus elements (red):*

There was a high frequency of negative influences of food on biodiversity and water. For example, Kurth (2017) showed that more agriculture is associated with more water pollution and poorer water quality and that agricultural intensification contributes to habitat disturbances on birds and reduces bird biodiversity.

There were also several records of water influencing biodiversity negatively. Whilst some of these associations were strong, such as the installation of water infrastructure, e.g. hydrological power plant leading to restriction of movement of fish contributing to the extinction of freshwater species e.g. beluga sturgeon (Mihók et al., 2017), Foy et al. (2001) was limited by the strength of evidence. Discrepancies between the speed of biological recovery after farm pollution events, and the short length of the study and sampling period made it difficult to assess the influence of water quality and regulatory controls on biodiversity (in this case benthic invertebrates), hence the magnitude of 2 is allocated here.

*Interpretation of the position and size of the **positive** centroid:*

The location of positive centroid seems to reflect the spread of positive points across the B-W side in both directions and water influencing food on the B-F side, possibly balancing the total effect at the centre, but closer on the B-W side with more data.

*Evidence for the **positive** bi-directional influence between the nexus elements (blue):*

There were fewer positive linkages than the negative linkages. There were studies with positive impacts of water on food, such as the building of two large interconnected ponds of freshwater service as water reservoirs to irrigate croplands (Ricart & Rico-Amorós, 2022). The positive influences of food on water focused on how improvements/changes in agriculture and food production benefit biodiversity, e.g. conversion from monocropping to alley cropping systems incorporating trees (Tsonkova et al., 2012), can increase plant diversity and pollinators. (Dolmer & Frandsen, 2002) also found that strategic farming of mussels can be used to remove excess nutrients from agro-production, improving the water quality.

Biodiversity-Health-Transport Nexus

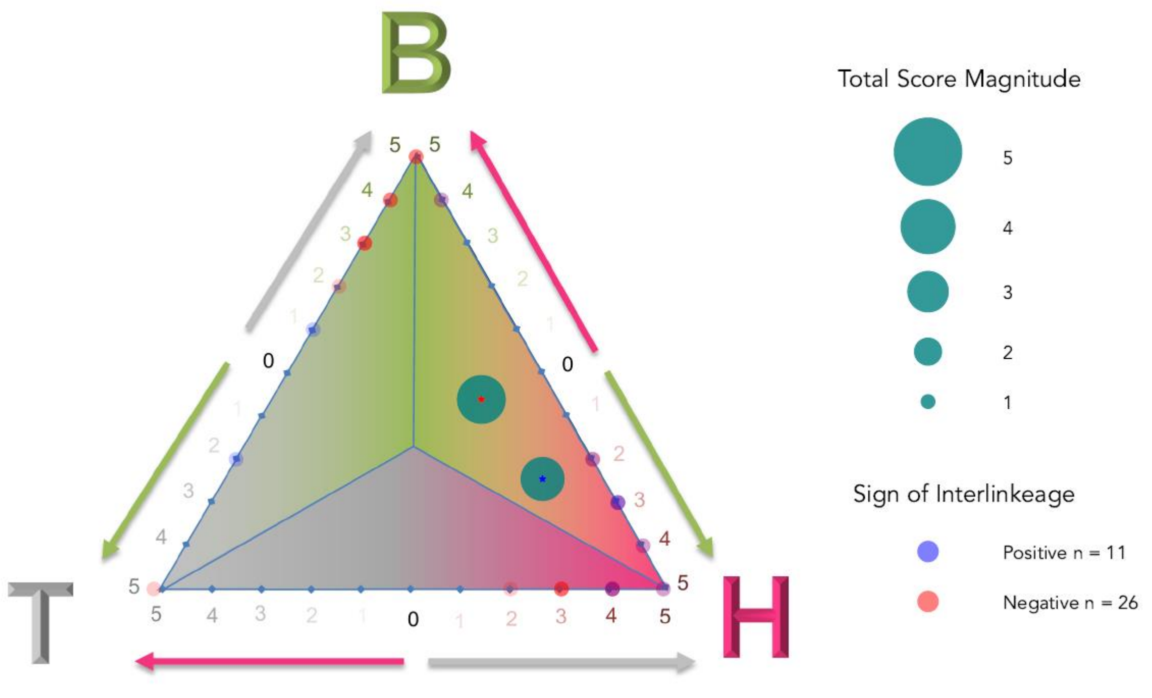


Figure S6. Triplet of the Biodiversity-Health-Transport Nexus interlinkage with positive and negative centroids

Overall, transport is the most influential element in the BHT nexus, either positively and negatively, while health is the most positively influenced by biodiversity and transport and the negative influence of transport balancing between the health and biodiversity element.

*Interpretation of the position and size of the **negative** centroid:*

Most of the influences in this nexus resulted negative, principally on biodiversity and health. The relationships are not bi-directional in most of the cases, and transport is the most influential element but the less influenced. When the influence exists, the magnitude mostly ranges from 3 to 5 (medium to high). Therefore, the medium-high influence of transport on biodiversity and health allocated the centroid of size 4 in the BH side of the triangle in a position of magnitude zero, because of the balance generated between the impacts of transport on those two elements and the absence of a large number of influences on transport.

*Evidence for the **negative** bi-directional influence between the nexus elements (red):*

Transport has medium-high impacts on biodiversity (magnitude between 3 and 5). The main impacts found are related to species killed by vehicles (Di Giulio et al., 2009; Puodziukas et al., 2016; Raymond et al., 2023), the production of battery-powered electric vehicles impact local biodiversity in different stages of their life cycle (Dall-Orsoletta et al., 2022), transporting invasive/alien species (Barrios-Crespo et al., 2021; Bax et al., 2003; Hulme, 2020; Katsanevakis et al., 2013; Medlock et al., 2012; Peyton et al., 2019), destruction or intervention of wildlife habitats due to transport infrastructure and traffic (Di Giulio et al., 2009; Hunter et al., 2019; Khreis et al., 2016; Puodziukas et al., 2016). There is no evidence of negative influences of biodiversity on transport.

Transport also affects health negatively, mainly with a medium to high magnitude (3 to 5), for example through air pollution from terrestrial fossil fuel transport (Buekers et al., 2014; Khreis et al., 2016; Pallozzi et al., 2020; Weerakkody et al., 2017) and aerial (Rupcic et al., 2023), as well as other types of pollutants emitted in the production of electric vehicles in rural areas (Dall-Orsoletta et al., 2022). Viruses and bacteria from human mobility, international trade, and biological invasions in general may affect humans directly (Medlock et al., 2012; Peyton et al., 2019) and risk water and food security (Bax et al., 2003; Hulme, 2020) due to increased tree canopy cover (Hunter et al., 2019). The only negative impact reported of health on biodiversity is the use of insecticides to control invasive mosquitoes, which can affect other fauna, with a magnitude of 4 (Medlock et al., 2012).

*Interpretation of the position and size of the **positive** centroid:*

Health is the most positively influenced element, mainly due to biodiversity, which located the centroid on the BH side of the triangle and closer to health. Positive influences, either from biodiversity and transport are medium with the size of the centroid 3 as a result of averaging low to high magnitudes.

*Evidence for the **positive** bi-directional influence between the nexus elements (blue):*

Most of the evidence analysed reveals the benefits of biodiversity on human health thanks to the use of green spaces. For example, active transport (walking, cycling) through natural environments, forests, or green infrastructure increases mental health (Hunter et al., 2019, 2021; Khreis et al., 2016; Zijlema et al., 2018) and physical health. Physical health is benefited, for example, by incrementing the number and the activity of natural killer cells to fight cancerous cells and virus-infected cells (Zorić et al., 2022), promoting cardiovascular relaxation (Khreis et al., 2016; Zorić et al., 2022), improving sleep patterns, skin microbiota and reducing chronic diseases (Khreis et al., 2016), and enhancing physical activities in general (Di Giulio et al., 2009). Additionally, interventions on biodiversity as a greenway improves social networks (Hunter et al., 2021) and brings other social benefits such as reduction in crime (Hunter et al., 2019). Urban biodiversity and natural ecosystems capture atmospheric pollutants (Barrios-Crespo et al., 2021; Pallozzi et al., 2020; Weerakkody et al., 2017) and also help with noise mitigation (Toffolo et al., 2021). On the other hand, only one study reported an indirect positive impact of health on biodiversity, due to the global Covid-19 pandemic in which it was possible to study species trait vulnerability to vehicle collisions, thanks to the reduction in transport (Raymond et al., 2023).

The positive impacts of transport on health are, in most of the cases, connected to biodiversity or natural/green spaces and have a high magnitude of 4 or 5. For example, mental health is increased when the daily commuting occurs through nature (Zijlema et al., 2018), as well as physical health due to the production of terpenes and BVOCs in mixed forests (Zorić et al., 2022). Similarly, spaces between tram and railways tracks and adjacent habitats facilitate green areas for flora that mitigate air and noise pollution (Toffolo et al., 2021). Air pollutants also decrease in urban areas due to the use of electric vehicles (Buekers et al., 2014; Dall-Orsoletta et al., 2022) and to road engineering, e.g., bypasses, which also reduce noise pollution in cities (Puodziukas et al., 2016). Transport policies also represent benefits for health, for example, traffic policies to reduce the number of vehicles and over emissions reducing air pollution and associated mortalities (Barrios-Crespo et al., 2021). There are no evidences of negative influences of health on transport.

Transport's positive impacts on biodiversity are mostly related to opportunities and are very low with a magnitude of 1. For example, active transport (cycling, walking) and green infrastructure interventions, particularly those associated with roads, rails and cycleways enhance local biodiversity (Hunter et al., 2019, 2021), which in turns improve the perception of the environment for attraction (Hunter et al., 2021). More direct benefits are related to railways, which represent a reservoir and refuge for many native species incorporating microhabitats not present in other city landscapes (Toffolo et al., 2021). Policies may also contribute positively, for example, doubling of the price of car usage would reduce pressure on the environment and improve nature/biodiversity (De Groot & Steg, 2006). Finally, there is only one evidence of biodiversity affecting transport positively in this review, in which protected area provides space for safe hiking routes (Zorić et al., 2022).

Biodiversity-Health-Water Nexus

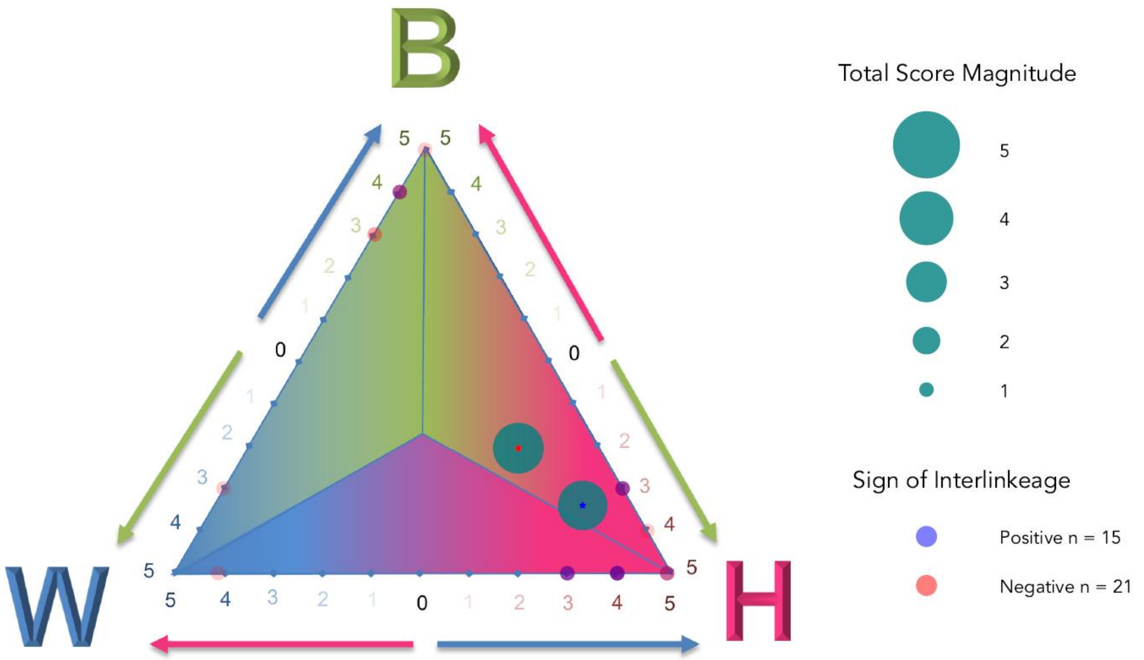


Figure S9. Triplet of the Biodiversity-Health-Water Nexus interlinkage with positive and negative centroids

*Interpretation of the position and size of the **negative** centroid:*

There are more negative influences between the nexus element than positive influences. The most influential seems to be the combination of water and biodiversity towards health. However, it is important to clarify that health is considered both an outcome (health impact) and a sector (environmental impact). The fact that this distinction was not clearly accounted for in the analytical approach may explain the dominance of the other two sectors to health.

*Evidence for the **negative** bi-directional influence between the nexus elements (red):*

The negative impact of biodiversity on health can be explained by nature related health risks such as infectious disease, drowning, natural disasters, pollution or even the lack of water due to climate change driven drought. (Goeminne et al., 2015) show how P. aeruginosa infection, due to living close to natural blue space for patients suffering from cystic fibrosis (CF), can represent a turning point in their disease. This is associated with lower survival, decreased lung function, worse radiological scores, increased pulmonary exacerbations and a reduced nutritional status. Mycotoxins are a group of naturally occurring toxic chemical substances, produced mainly by microscopic filamentous fungal species. In Serbia, recent drought and then flooding confirmed that mycotoxins are one of the foodborne hazards most susceptible to climate change (Milićević et al., 2016).

The risk of water related natural disasters makes the need for urban stormwater management for human well-being more important (Bertrand-Krajewski, 2021). Furthermore, water may transport particles with potential environmental health risks, e.g. soluble heavy metals and other pollutants in peatlands (Birkel et al., 2017), or olive mill waste water. Grigorescu et al. (2021) shows how droughts and heat waves can have a devastating effect on human health and the ecosystem and (Lei et al., 2022) on how O_3 pollution decreases greatly following the reductions in anthropogenic emissions with increased heatwaves and droughts.

In addition, we should not underestimate the negative impact of the health sector on biodiversity when we consider the high production of waste (both materials in general and medicines) negatively impacting water quality, which also negatively affects the ecosystem (Lenzen et al., 2020; Seppänen & Or, 2023). This may be the main explanation for the complicated linkage between biodiversity and health. As such, the health sector contributes to the negative health impacts they have to deal with (e.g. anti-microbial resistance), demanding more materials and medicines, resulting in a downward spiral. Further, recreation and physical activity in blue space, apart from having health benefits, may also put pressure on ecosystems.

*Interpretation of the position and size of the **positive** centroid:*

There are fewer positive influences between the nexus element than negative influences. The most influential seems to be the combination of water and biodiversity towards health. However, it is important to clarify that health should be considered both an outcome (health impact) and a sector (environmental impact). The fact that this distinction was not clearly accounted for in the analytical approach may explain the dominance of the other two sectors to health.

*Evidence for the **positive** bi-directional influence between the nexus elements (blue):*

Wetlands are an effective buffer against coastal erosion and flooding, enhancing the water quality, human health and wellbeing (Möller et al., 2022). Contact with blue space may have several benefits to health (White et al., 2020), through different forms of water contact, e.g. swimming as a healthy body-water engagement in blue space (Foley, 2015), or urban blue space as a food source, e.g. fishing in the city for food (Joosse et al., 2021). Pellens et al. (2023) created an overview of innovative actions by citizens and organizations in Europe to promote both health of ocean and humans, with plastic pollution and biodiversity loss as the most targeted environmental issues, and tourism, recréation and wellbeing as ecosystem services. Vitale et al. (2022) shows how contact with blue space in childhood can lead to blue space contact in the adult life. (White et al., 2020) also incorporates being good for the environment and nature connectedness in their framework, linking human health with ecosystem health. Thornhill et al. (2022) shows how urban blue spaces are critical for biodiversity, providing a range of ecosystem services, and can promote human health and wellbeing. The study also indicates that the access to blue space is often unequally distributed across socioeconomic gradients and the availability of quality blue space could extend to environmental justice issues.

Beneficial contact with blue spaces contributes to preventative healthcare, and as such, lowers the need for healthcare, lowering environmental impact of the health sector in terms of waste and energy use. In conjunction, the health sector may also have an advocacy role towards nature conservation, which can be seen as an upward spiral.

Biodiversity-Transport-Water Nexus

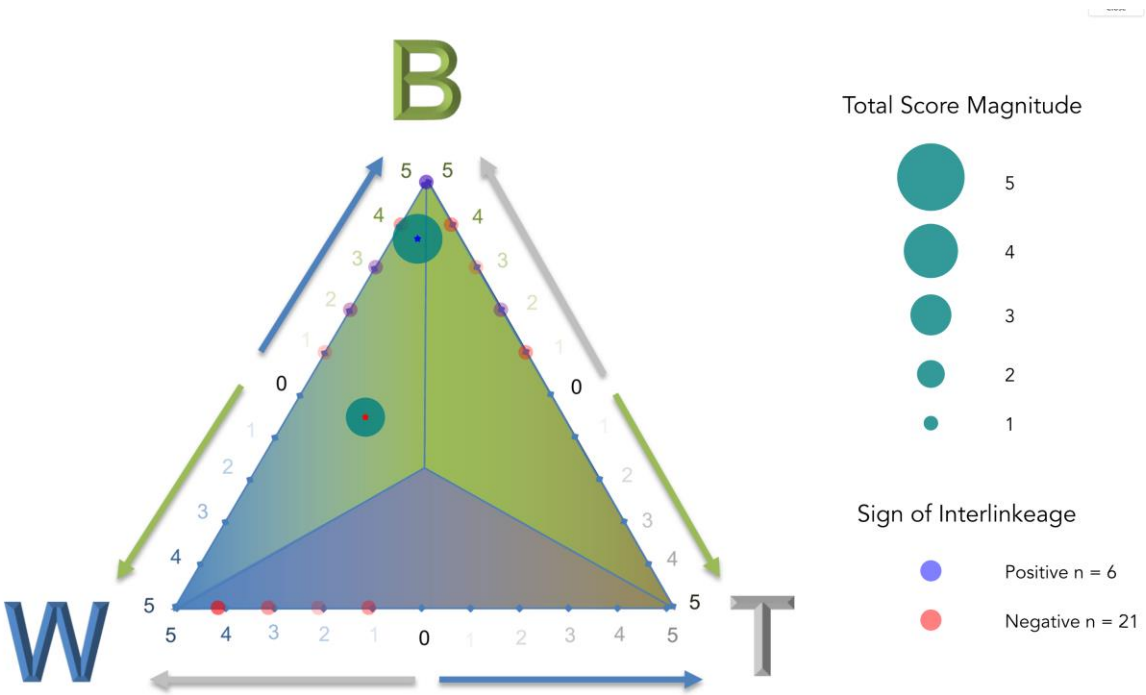


Figure S10. Triplet of the Biodiversity-Transport-Water Nexus interlinkage with positive and negative centroids

Interpretation of the position and size of the ***negative*** *centroid:*

The negative centroid is approximately in the middle of the biodiversity-water side of the triangle, meaning that the negative influence from transport is governing this three-way interlinkage. The size of the negative centroid is relatively small, meaning that these influences are scored on a lower magnitude on average.

*Evidence for the **negative** bi-directional influence between the nexus elements (red):*

The negative influences of transport on biodiversity are mainly due to the infrastructure. Roads cause habitat fragmentation and loss (Conan et al., 2022; Haugen et al., 2020) and affect species richness. Road density and proximity negatively impact amphibian species richness (Bounas et al., 2020; Couto et al., 2017). Roads and railways create linear barriers for migratory and dispersal movement of the northern crested newt (Matos et al., 2019) and gene flow of amphibians (Yannic et al., 2021).

The negative influences of transport on water are due to infrastructure and pollution. Road construction and off-road driving for forest management can increase sediment loading, stream network fragmentation, and flood frequency in water bodies nearby (Kuglerová et al., 2021). Road traffic pollutes stormwater (Conan et al., 2022; Sun et al., 2019) and nearby water bodies, for example, with de-icing salts and sediments, brake linings and tires, and runoff containing the by-products of petroleum and diesel combustion, which affect aquatic organisms (Grung et al., 2021; Nava et al., 2020; Niedrist et al., 2021; Šigutová et al., 2022; Sun et al., 2018, 2019). Sinkhole ponds along the roadsides can also contain higher salinity and concentrations of calcium and phosphates (Krodkiewska et al., 2019).

The negative influence of water on biodiversity originates from various factors. Increased sediment and flood frequency can decrease the biomass of primary producers, decomposition rate of organic matter, diversity of macroinvertebrates and microbe activity (Kuglerová et al., 2021). Chloride and other pollutants in water can have adverse effects on freshwater biota, including changes in taxa, algal food resources, DNA damage, and the spread of alien species (Grung et al., 2021; Krodkiewska et al., 2019; Meland et al., 2019; Nava et al., 2020). Drought causes stress to urban trees and diminishes their growth (Hirsch et al., 2023) and rivers can act as a barrier on gene flow for amphibians (Yannic et al., 2021).

*Interpretation of the position and size of the **positive** centroid:*

The positive centroid is located very close to the biodiversity corner of the triangle, meaning water and transport are positively influencing biodiversity. The size of the positive centroid is larger, so these influences are more significant than the negative influences.

*Evidence for the **positive** bi-directional influence between the nexus elements (blue):*

The positive influence of transport on biodiversity relates to a positive correlation between average annual daily traffic (AADT) and biological community composition of neighbouring ponds (Meland et al., 2020). This unexpected positive influence may be associated with size of the pond and their dilution capacity as the highest AADT values relate to the areas with the largest ponds.

The positive influence of water on biodiversity relates to several factors. Artificial and semi-natural ponds and high pond connectivity were found to predict the presence of the Macedonian crested newt (*T. macedonicus*) and a ray-finned fish species (*L. graecus*) (Bounas et al., 2020). Ponds providing breeding habitats for northern crested newts, and artificial ponds from former extractive industries have been quickly colonized by the amphibians and other freshwater species (Matos et al., 2019). Further, streams act as humid dispersal corridors (Haugen et al., 2020) and hydroperiod was one of the most important drivers of species richness (Couto et al., 2017).

E. Triplets analysis of five three-way biodiversity-climate nexus interlinkages

Biodiversity-Climate-Energy Nexus

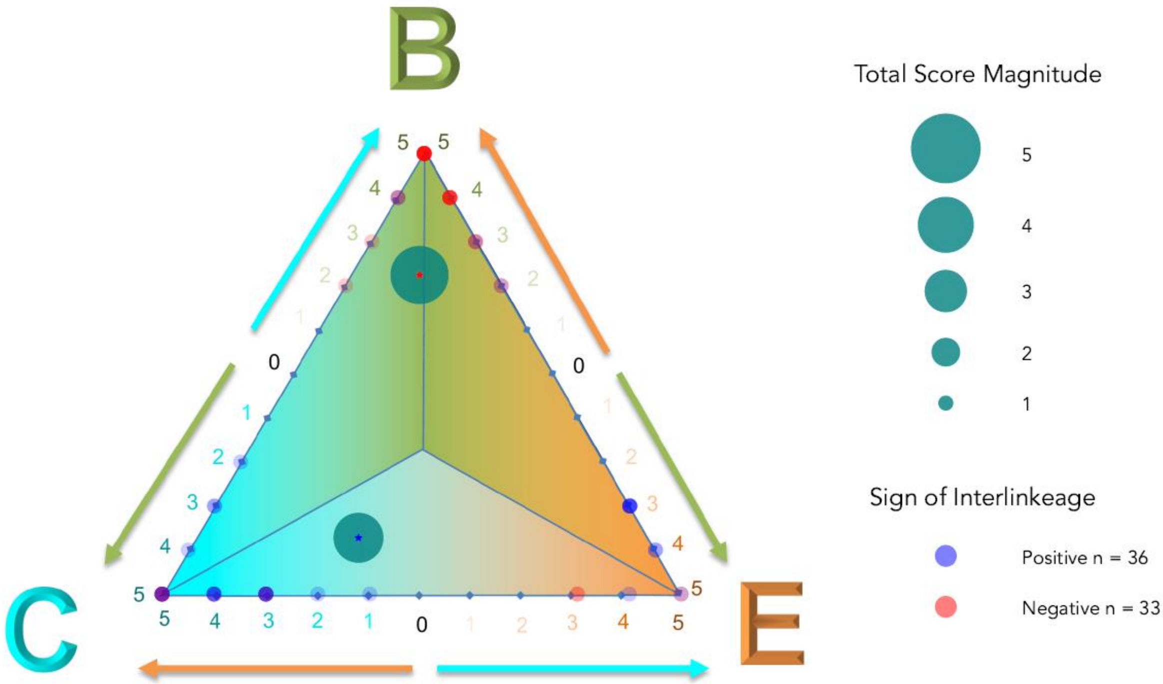


Figure S12. Triplet of the Biodiversity-Climate-Energy Nexus interlinkage with positive and negative centroids

Interpretation of the position and size of the ***negative*** *centroid:*

Energy and climate change play a negative influencing role on biodiversity in this interlinkage. The burning of fossil fuels emits greenhouse gases that cause climate change (Guiné et al., 2021; Schulze, 2006), and climate change is a direct driver of biodiversity loss (Gasparatos et al., 2017; Lloret et al., 2022). Climate change impacts such as increasing hydroclimatic variability and extreme events in turn result in changes to ecosystem structure and function, and species are pushed outside of their preferred precipitation and temperature regimes (Leiva-Dueñas et al., 2020; Serpetti et al., 2021; Wagner, 2020). Fossil fuel burning and oil and gas infrastructure also have a direct negative influence on biodiversity (Whitmee et al., 2015), for example, through the release of atmospheric nitrites that negatively impact butterflies (Wagner, 2020). Renewable energy infrastructure can impact surrounding ecosystems and create increased competition for land (Logan et al., 2023). For example, offshore wind turbines can pose environmental risks to marine ecosystems (Lloret et al., 2022), such as seabird dislocation and mortality (Busch et al., 2013; Serpetti et al., 2021). Small hydropower dam infrastructure can cause ecosystem degradation and fragmentation, resulting in a loss of amphibian and reptile habitats, which is further amplified by the aridification of their habitats due to climate change (Crnobrnja-Isailović et al., 2021). Approximately 7% of key biodiversity areas fall within areas of potential future mining activities (Simkins et al., 2023), so the supply chains for renewable energy productions (e.g., metals) can also threaten biodiversity. The cultivation of bioenergy crops can negatively impact biodiversity, for example, through the spread of monocultures (Sutherland et al., 2015a), pressure for land resources (Perišić et al., 2022), and stress on local water resources (Elshout et al., 2019), though bioenergy crops can also improve species richness compared to conventional crop types (Bourke et al., 2014) and if managed using low risk approaches (Giuntoli et al., 2022). Climate change exacerbates these risks, as it can lead to higher temperatures, higher carbon dioxide concentrations, and reduced water supply, which can result in lower yields for bioenergy plants (Franzaring et al., 2015).

*Interpretation of the position and size of the **positive** centroid:*

The positive centroid is located between climate and energy corners of the triangle, meaning that the governing positive influences are from biodiversity to the two other nexus elements. The centroid is slightly closer to the climate element, meaning that energy also positively influences climate. The size of the centroid indicates that these influences are moderate.

*Evidence for the **positive** bi-directional influence between the nexus elements (blue):*

Intact ecosystems act as carbon sinks and thus have a positive influence on climate change (Lloret et al., 2022; Perišić et al., 2022; Schulze, 2006). For example, intact peatland is an important carbon sink (Pullens et al., 2018) and extraction of woody biomass (forest residues) for energy production can positively impact climate change by reducing the risk of forest fire and associated carbon emissions (Sacchelli et al., 2013). Biodiversity can also aid in climate change adaptation, for example, the cooling effect of rewilding urban spaces (Pasimeni et al., 2019). Renewable energy production, such as with offshore wind turbines or hydropower, has a positive influence on climate change by reducing fossil fuel emissions (Busch et al., 2013; Crnobrnja-Isailović et al., 2021; Kellner, 2023; Lloret et al., 2022; Serpetti et al., 2021). Bioenergy production can have a positive greenhouse gas balance as well (Petzold et al., 2014). Renewable energy infrastructure can also positively impact biodiversity, for example, offshore wind farms can act as artificial reefs, providing new habitat (Serpetti et al., 2021). Bioenergy crops can also improve biodiversity depending on their management (Giuntoli et al., 2022), as they may favour species richness over other conventional crops (Bourke et al., 2014).

Biodiversity-Climate-Food Nexus

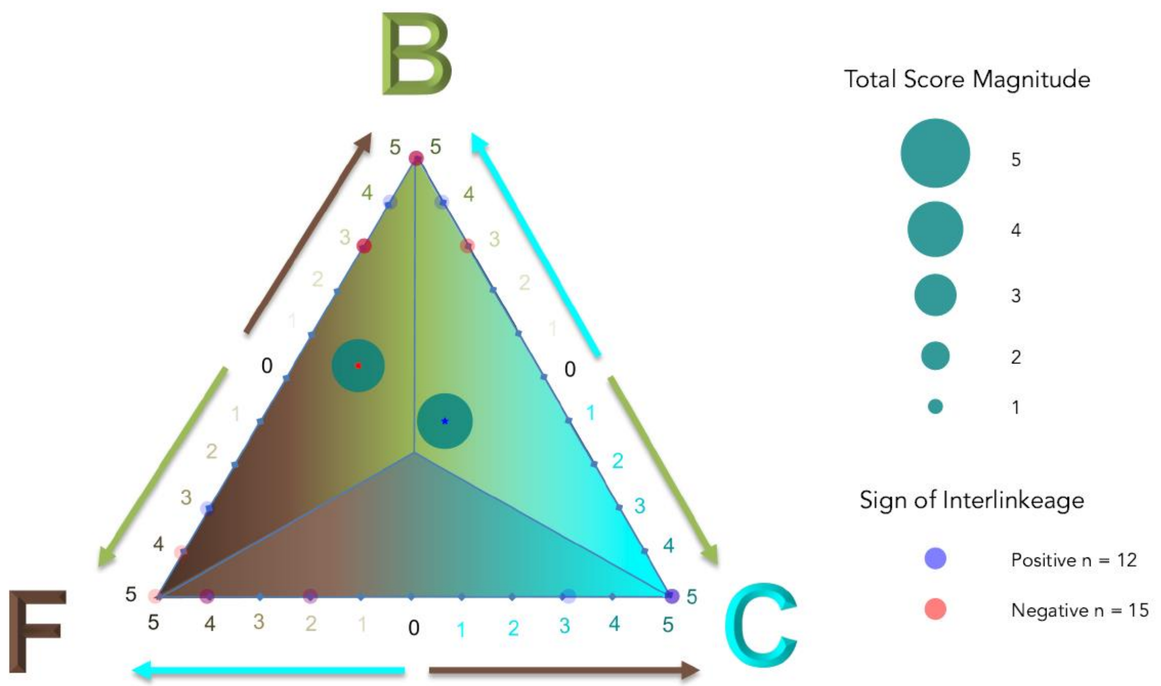


Figure S13. Triplet of the Biodiversity-Climate-Food Nexus interlinkage with positive and negative centroids

Interpretation of the position and size of the ***negative*** *centroid:*

The negative centroid is located between the biodiversity and food corners of the triangle, meaning that the governing negative influences are from climate to the two other nexus elements. The size of the centroid indicates that the magnitude of these influences is moderate.

Evidence for the ***negative*** *bi-directional influence between the nexus elements (red):*

The climate plays a strong negative influencing role in this three-way nexus interlinkage. For example, fossil fuel burning releases atmospheric nitrites that negatively impact species (e.g., butterflies), and wood fuel leads to deforestation that contributes to biodiversity loss (Wagner, 2020). Climate change impacts like aridification can negatively impact amphibian and reptile reproductive sites and habitats, which reduces food availability for other trophic levels in the food web (Crnobrnja-Isailović et al., 2021). Such negative influences from climate change can exacerbate other negative influences on biodiversity. For example, climate warming can exacerbate agricultural intensification, further contributing to a loss of species richness and abundance (Andriamanantena et al., 2022; Bourke et al., 2014; Wagner, 2020). Climate change also influences habitat condition, with ripple effects to the food system. For example, higher temperatures and relative humidity can alter the growing conditions of mycotoxin producing fungi, and changes in the abundance and distribution of mycotoxin producing fungi can infect food crops and livestock, thereby reducing agricultural and livestock productivity (Milićević et al., 2016). More frequent and severe flood events can affect the recovery phase from eutrophication of microbenthic assemblages, which in turn impacts bivalves for fishers who rely on estuarine resources (Cardoso et al., 2008). Climate change also has a direct negative influence on food production. For example, climate change can increase water demand in ways that make the rainfed cultivation of olive crops no longer economically feasible (Fotia et al., 2021) and reduce food production more generally, for example in southern Europe (Harrison et al., 2015).

Interpretation of the position and size of the ***positive*** *centroid:*

The positive centroid is located close to the centre of the triangle, but slightly closer to the biodiversity and climate elements than to food. This location means that the positive influences between these three nexus elements are relatively balanced, with food having slightly more influence on biodiversity and climate. The size of the centroid indicates that the magnitude of these influences is moderate.

Evidence for the ***positive*** *bi-directional influence between the nexus elements (blue):*

Biodiversity and food have a positive influence on climate change in this interlinkage. For example, forest restoration and other means for conserving biodiversity and ecosystems contribute to carbon storage and climate mitigation (Eriksson et al., 2018; Schulze, 2006). Changes in food production systems (e.g., reducing livestock production) can reduce greenhouse gas emissions from the agricultural sector (Westhoek et al., 2014). The food sector can also have a positive influence on biodiversity. For example, agronomic management of grasslands can serve to maintain habitats for grassland species and prevent the encroachment of other species like shrubs (Giubilato et al., 2016). Similarly, conversion from monocropping to alley cropping systems increases plant diversity (Tsonkova et al., 2012). In some cases, changing climate conditions can have a positive influence on biodiversity vulnerability and food production, for example in northern Europe (Harrison et al., 2015).

Biodiversity-Climate-Health Nexus

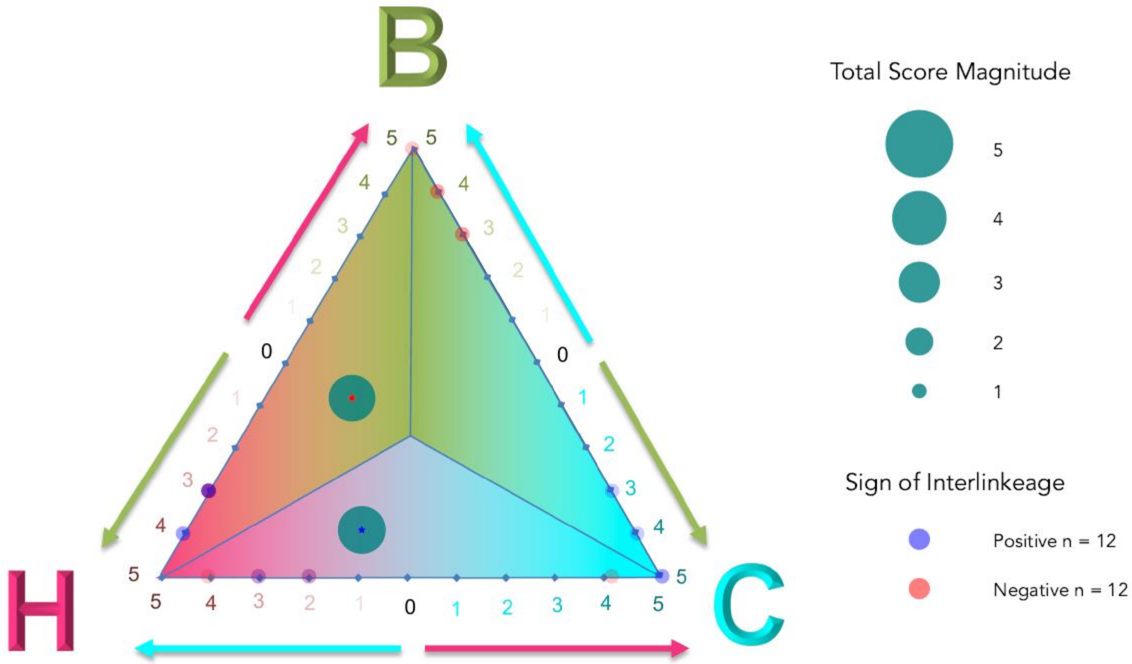


Figure S14. Triplet of the Biodiversity-Climate-Health Nexus interlinkage with positive and negative centroids

*Interpretation of the position and size of the **negative** centroid:*

The negative centroid is located between the biodiversity and health corners of the triangle, meaning that the governing negative influences are from climate to the two other nexus elements. The size of the centroid indicates that the magnitude of these influences is moderate.

*Evidence for the **negative** bi-directional influence between the nexus elements (red):*

The climate plays a strong influencing role in this three-way nexus interlinkage. Climate change has a negative impact on health, ecosystems and biodiversity (Buekers et al., 2014; Hazarika & Jandl, 2019; Lenzen et al., 2020; Whitmee et al., 2015) and can thus increase the burden on already-stressed healthcare systems (Pichler et al., 2019). For example, climate change-induced droughts have a negative impact on ecosystems (Fusaro et al., 2015), and more extreme heat phenomena can affect human health directly (Grigorescu et al., 2021). Droughts also modulate surface ozone via meteorological processes and vegetation feedbacks, and ozone pollution is a key concern for human and ecosystem health (Lin et al., 2020). The impacts of climate change can also have compounding effects with other drivers: for example, climate change and eutrophication together have effects on the depletion of bottom-water oxygen in lakes, which affects species like crucian carp (Sula et al., 2020). Climate change can also affect biodiversity in ways that reduce human access to health-related ecosystem services; for example, climate change is expected to reduce the distribution of spruce trees, which decreases the prevalence of terpenes and BVOC which benefit human health (Zorić et al., 2022) and more extreme heat events can affect agricultural crops which affects nutritional health (Grigorescu et al., 2021). Conversely, healthcare systems themselves have large environmental footprints that impact biodiversity, emit greenhouse gases, and further threaten human health (Grigorescu et al., 2021).

*Interpretation of the position and size of the **positive** centroid:*

The positive centroid is located between health and climate corners of the triangle, meaning that the governing positive influences are from biodiversity to the two other nexus elements. The centroid is slightly closer to the health element, meaning that climate also positively influences health. The size of the centroid indicates that the magnitude of these influences is moderate.

*Evidence for the **positive** bi-directional influence between the nexus elements (blue):*

Biodiversity has several positive influences on health and climate. Intact forests and ecosystems can improve human health and wellbeing (Fusaro et al., 2015; Hazarika & Jandl, 2019). For example, ecosystems absorb pollutants from the atmosphere, improving air quality in ways that can benefit human health (Barrios-Crespo et al., 2021). Forest therapy can improve cardiovascular relaxation, reducing blood pressure and possibly preventing clinical hypertension (Zorić et al., 2022). Spending time in forests can also have positive effects on chronic patients (Zorić et al., 2022). Biodiversity also helps mitigate climate change: forests (Hazarika & Jandl, 2019), wetlands and estuaries (Barrios-Crespo et al., 2021) and peat soils (Birkel et al., 2017) act as carbon sinks. Intact and healthy ecosystems and water bodies like lakes and rivers also enhance the capacity of the environment to adapt to the impacts of climate change (Grigorescu et al., 2021). Other climate mitigation actions can also positively impact health; for example, traffic policies that reduce emissions from vehicles reduce air pollution and associated mortalities (Barrios-Crespo et al., 2021).

Biodiversity-Climate-Transport Nexus

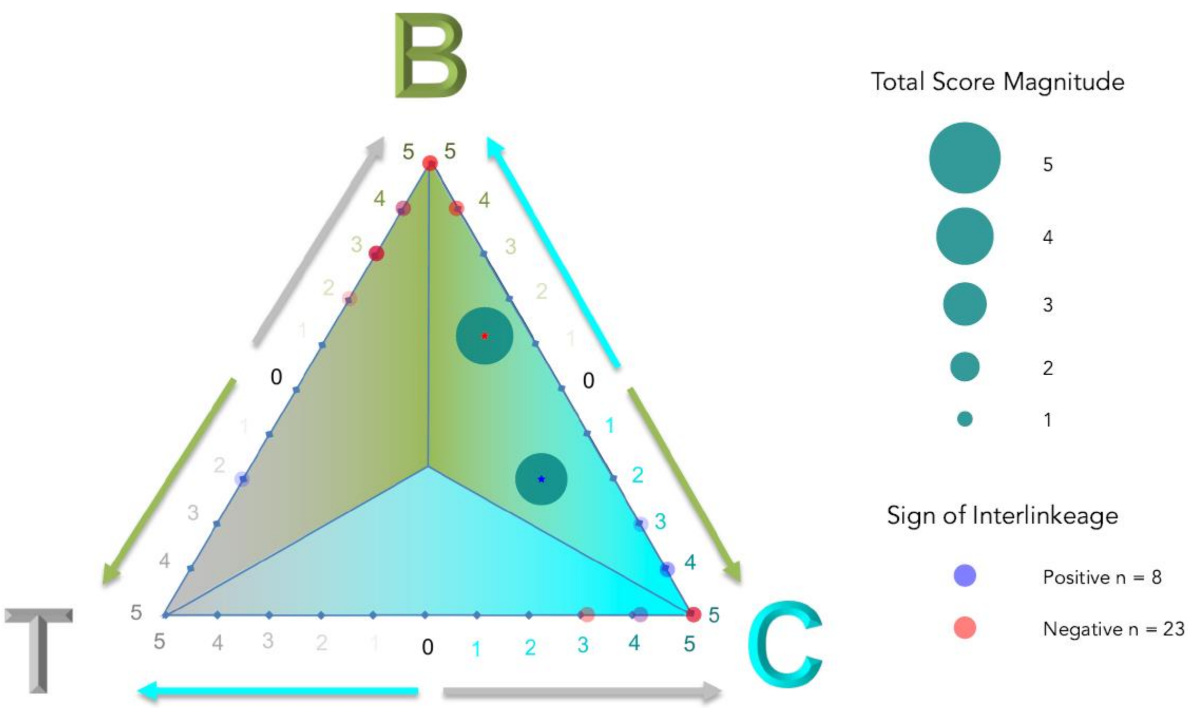


Figure S15. Triplet of the Biodiversity-Climate-Transport Nexus interlinkage with positive and negative centroids

*Interpretation of the position and size of the **negative** centroid:*

The negative centroid is located between the biodiversity and climate corners of the triangle, meaning that the governing negative influences are from transport to the two other nexus elements. The centroid is also slightly closer to the biodiversity corner, meaning that climate also negatively influences biodiversity. The size of the centroid indicates that the magnitude of these influences is moderate to significant.

*Evidence for the **negative** bi-directional influence between the nexus elements (red):*

The negative influence of transport is primarily due to the emissions of fossil fuels, including by air, land and sea (Barrios-Crespo et al., 2021; Charles et al., 2009; Dall-Orsoletta et al., 2022; Gallo et al., 2017; Kassouri et al., 2022; Puodziukas et al., 2016; Rupcic et al., 2023; Zhang et al., 2021). Transport emissions directly influence climate change, which is a major driver of biodiversity loss (Lloret et al., 2022). Transport infrastructure also threatens biodiversity directly. For example, increased vessel traffic can negatively impact marine ecosystems, exacerbating the negative impacts of climate change on marine biodiversity (Gasparatos et al., 2017). Ship collisions can lead to pollution (Lloret et al., 2022) and transport corridors can spread invasive species (Zhang et al., 2021), such as ballast water from ships (Barrios-Crespo et al., 2021). Transport infrastructure like roads and railways impact habitats through loss of territory, changes to hydrological regimes, pollution, disturbance, barriers to movement, accidents and noise (Buekers et al., 2014; Elshout et al., 2019; Puodziukas et al., 2016; Simkins et al., 2023). The removal of biomass and disturbance of soils for transport infrastructure can also induce the release of greenhouse gases (Elshout et al., 2019). There are also external transport costs on biodiversity loss and climate change, such as through fuel production and processing (Sovacool et al., 2021).

*Interpretation of the position and size of the **positive** centroid:*

The positive centroid is also located between the biodiversity and climate corners of the triangle, meaning that both the positive and negative influences are from transport to the two other nexus elements. The centroid is also slightly closer to the climate corner, meaning that biodiversity also positively influences climate. The size of the centroid indicates that the magnitude of these influences is moderate.

*Evidence for the **positive** bi-directional influence between the nexus elements (blue):*

Biodiversity positively influences climate change as intact forests and other ecosystems are important carbon sinks (Barrios-Crespo et al., 2021; Lloret et al., 2022; Perišić et al., 2022). Transport can also positively influence climate and biodiversity. Rewilding urban spaces contributes to both climate adaptation and mitigation (e.g., the cooling effect), so green transport infrastructure solutions can help improve ecological balance while also mitigating and adapting to climate change (Pasimeni et al., 2019). Efficient road infrastructure design can reduce greenhouse gas emissions, for example, using smooth bypasses and paving of gravel roads (Puodziukas et al., 2016). Forest materials contribute to biomass renewable energy production (Perišić et al., 2022) and biomass for biofuels reduces dependence of transport systems on greenhouse gas emissions (Charles et al., 2009).

Biodiversity-Climate-Water Nexus

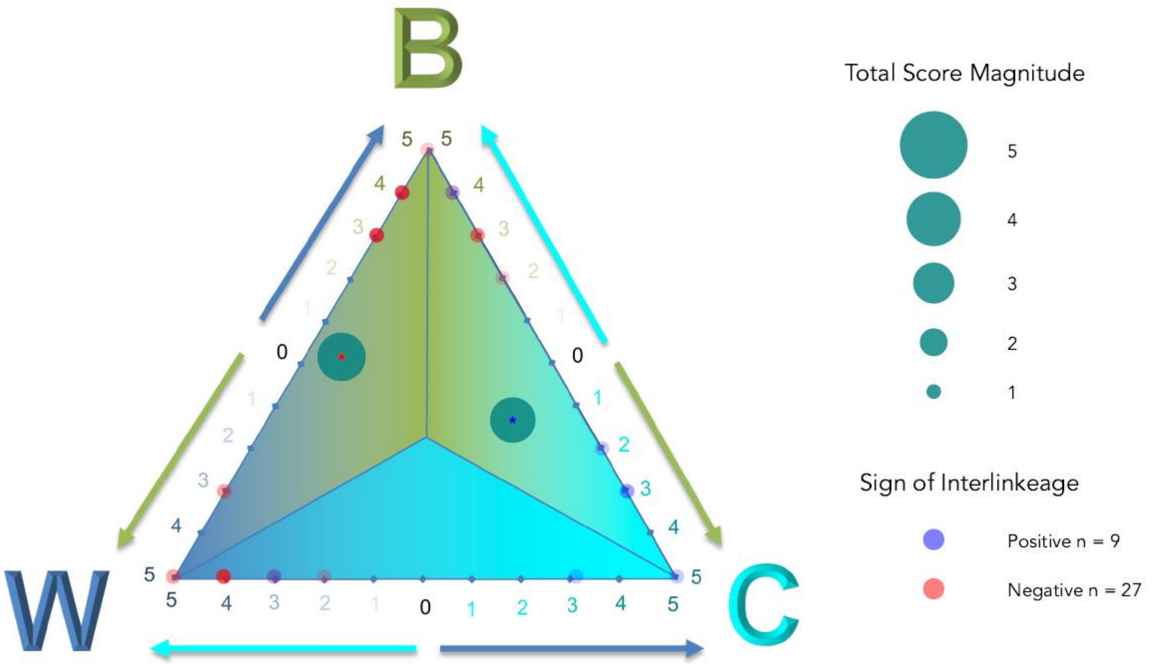


Figure S16. Triplet of the Biodiversity-Climate-Water Nexus interlinkage with positive and negative centroids

*Interpretation of the position and size of the **negative** centroid:*

The negative centroid is located between the biodiversity and water corners of the triangle, meaning that the governing negative influences are from climate to these two nexus elements. Water also slightly negatively influences biodiversity. The size of the centroid indicates that the magnitude of these influences is moderate.

*Evidence for the **negative** bi-directional influence between the nexus elements (red):*

Climate change can directly impact aquatic ecosystems, for example by increasing the abundance of dinoflagellates which outcompete seagrass (Leiva-Dueñas et al., 2020) or exacerbating existing stress on salmon rivers from hydropower and acid deposition (Wright et al., 2017). Climate change also changes the hydrological regime and seasonality (Hochman et al., 2018) in ways that may influence biodiversity (Franzaring et al., 2015; Milićević et al., 2016). For example, higher temperatures lead to higher carbon dioxide concentrations and lower water supply, which can in turn result in lower yields for bioenergy plants (Franzaring et al., 2015). Higher drought risk due to climate change (Grigorescu et al., 2021) can decrease grassland productivity and aboveground biomass (Dibari et al., 2021) and decrease biodiversity more generally (Fusaro et al., 2015), for example, through reduced soil moisture content (Wessel et al., 2004). Droughts also modulate surface ozone, and ozone is a concern for ecosystems (Lei et al., 2022, p. 20). Similarly, extreme flooding driven by climate change affects the recovery phase of microbenthic assemblages from eutrophication, and eutrophic areas in an estuary were shown to lead to habitat instability (Cardoso et al., 2008). Climate change contributes, along with eutrophication, to the depletion of bottom-water oxygen, which can affect habitat conditions for fish like crucian carp (Sula et al., 2020). Water infrastructure also has a direct influence on biodiversity. For example, dams and reservoirs significantly impact ecosystems and biodiversity, such as through the fragmentation and alteration of river flow (Dopico et al., 2022;

Mihók et al., 2017). In addition, increased irrigation (e.g., water withdrawals for bioenergy) can negatively impact the suitability of habitat (e.g., for farmland birds) (Glemnitz et al., 2015).

*Interpretation of the position and size of the **positive** centroid:*

The positive centroid is located between the biodiversity and climate corners of the triangle, meaning that the governing positive influences are from water to these two nexus elements. The centroid is also slightly closer to the climate element, meaning that biodiversity also has a slight positive influence on climate. The size of the centroid indicates that the magnitude of these influences is moderate.

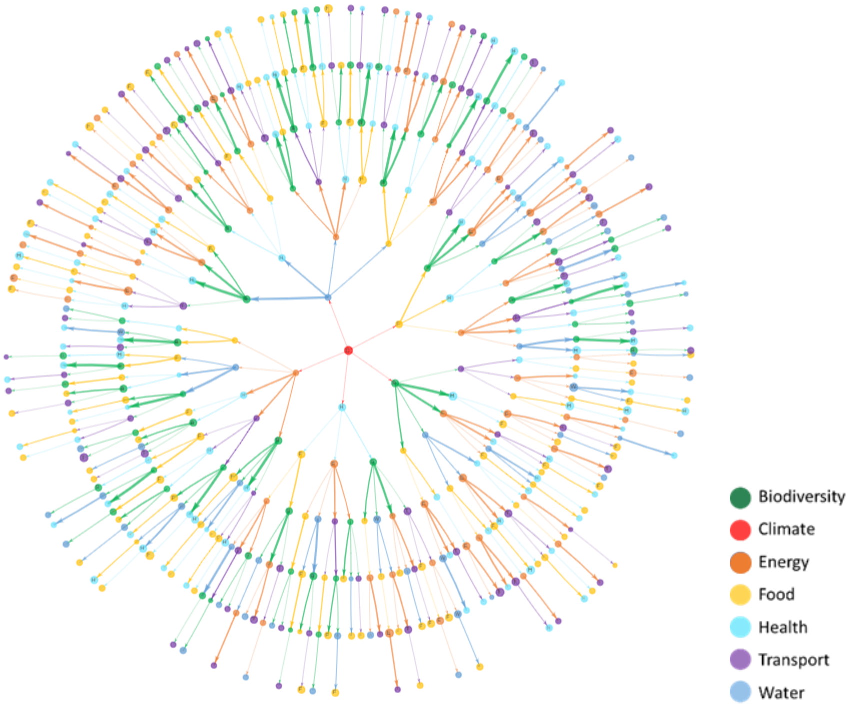
*Evidence for the **positive** bi-directional influence between the nexus elements (blue):*

Healthy water ecosystems like lakes and rivers can positively impact aquatic biodiversity as a whole (Eriksson et al., 2018), but particular biophysical factors determine exactly what type of ecosystem is established. For example, seagrass benefits from shallower water depths and more natural light while diatoms prefer well-mixed and turbulent waters (Leiva-Dueñas et al., 2020). Biodiversity contributes to both climate mitigation and helps manage water resources; for example, trees and forests are carbon sinks and act as sponges to store water and slowly release it during more hydrological extreme events (Eriksson et al., 2018). In some cases, climate change impacts can improve the state of water resources: for example, increased precipitation and altered runoff patterns can dilute strong anions, which may slightly improve the chemistry of river water (R. F. Wright et al., 2017). However, such changes can be counterbalanced by other impacts, such as mineralization of soil organic matter and increased aquatic vegetation activity (R. F. Wright et al., 2017). The ocean also plays a key role in climate regulation by producing oxygen and absorbing carbon dioxide (Pellens et al., 2023).

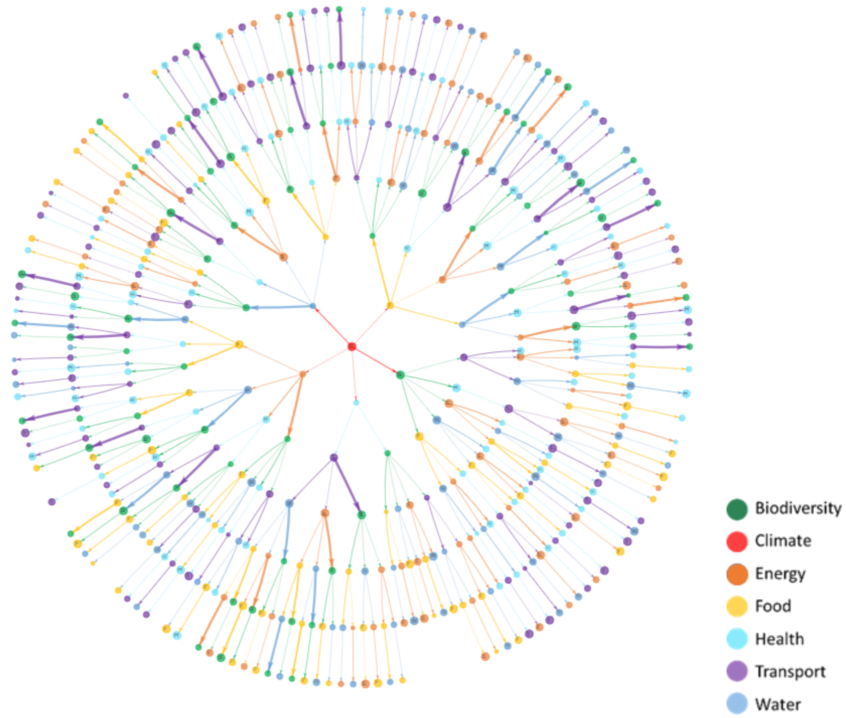
F. Synthetic network pathways for six nexus elements

Climate

Figure S17. Synthetic network trees showing (a) 499 positive pathways between climate and all other nexus elements and (b) 504 negative pathways between climate and all other nexus elements.



(a) Positive pathways from climate



(b) Negative pathways from climate

Table S4. Summary of the (a) positive, negative, and overall influence of climate on the six nexus elements and (b) positive, negative, and overall influence of the six nexus elements on climate.

(a) Overall influence of climate on the six nexus elements

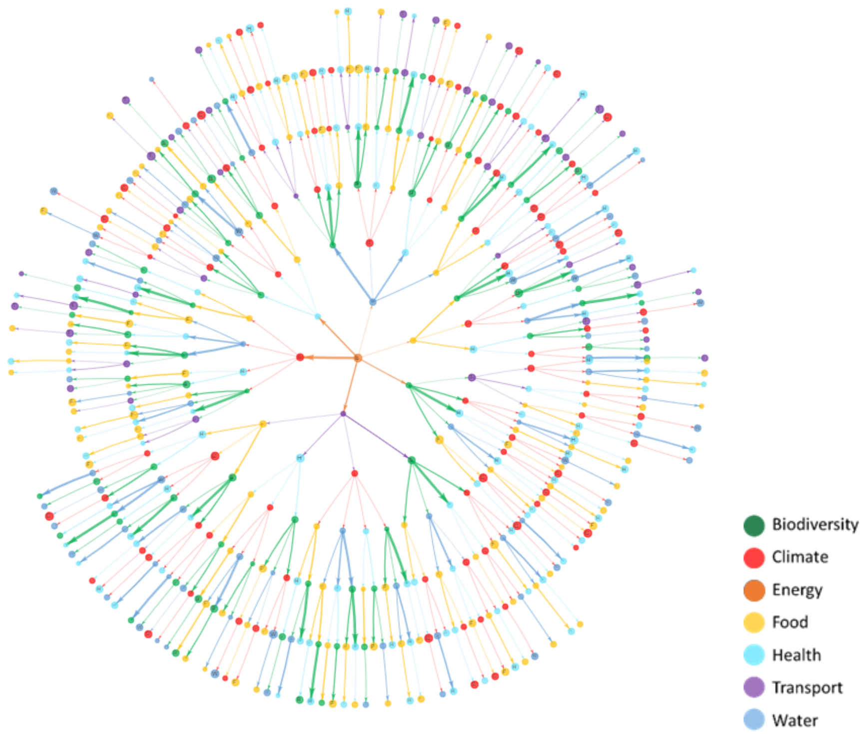
Nexus element	Positive		Negative		Overall	
	Complexity	Impact	Complexity	Impact	Complexity	Impact
Biodiversi	65	228.7	70	268.7	135	-40.0
Energy	65	225.2	81	295.5	146	-70.3
Food	114	396.7	72	269.8	186	126.9
Health	114	400.9	103	361.0	217	39.8
Transport	86	288.1	97	359.4	183	-71.3
Water	55	193.2	81	286.2	136	-93.0
All	**499**	**1732.8**	**504**	**1840.6**	**1003**	**-107.8**

(b) Overall influence of the six nexus elements on climate

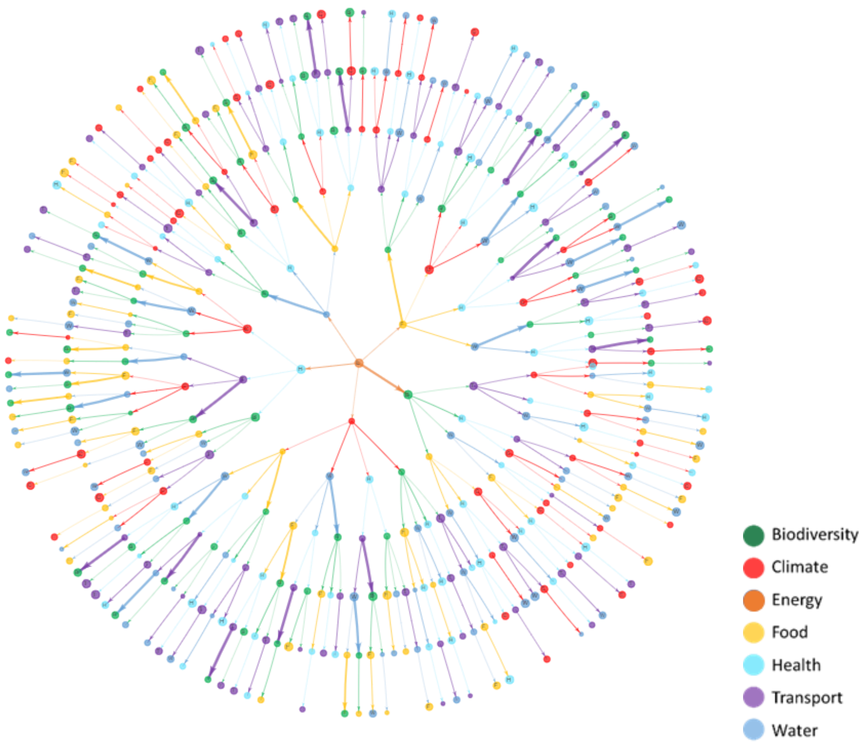
Nexus	Positive		Negative		Overall	
	Complexity	Impact	Complexity	Impact	Complexity	Impact
Biodiversi	92	340.8	75	281.7	167	59.1
Energy	92	334.9	67	252.6	159	82.3
Food	76	280.2	79	292.2	155	-12.0
Health	76	273.3	46	184.1	122	89.3
Transport	163	604.9	95	358.2	258	246.7
Water	163	600.4	86	329.4	249	271.1
All	**662**	**2434.6**	**448**	**1698.1**	**1110**	**736.5**

Energy

Figure S18. Synthetic network trees showing (a) 526 positive pathways between energy and all other nexus elements and (b) 442 negative pathways between energy and all other nexus elements.



(a) Positive pathways from energy



(b) Negative pathways from energy

Table S5. Summary of the (a) positive, negative, and overall influence of energy on the six nexus elements and (b) positive, negative, and overall influence of the six nexus elements on energy.

(a) Overall influence of energy on the six nexus elements

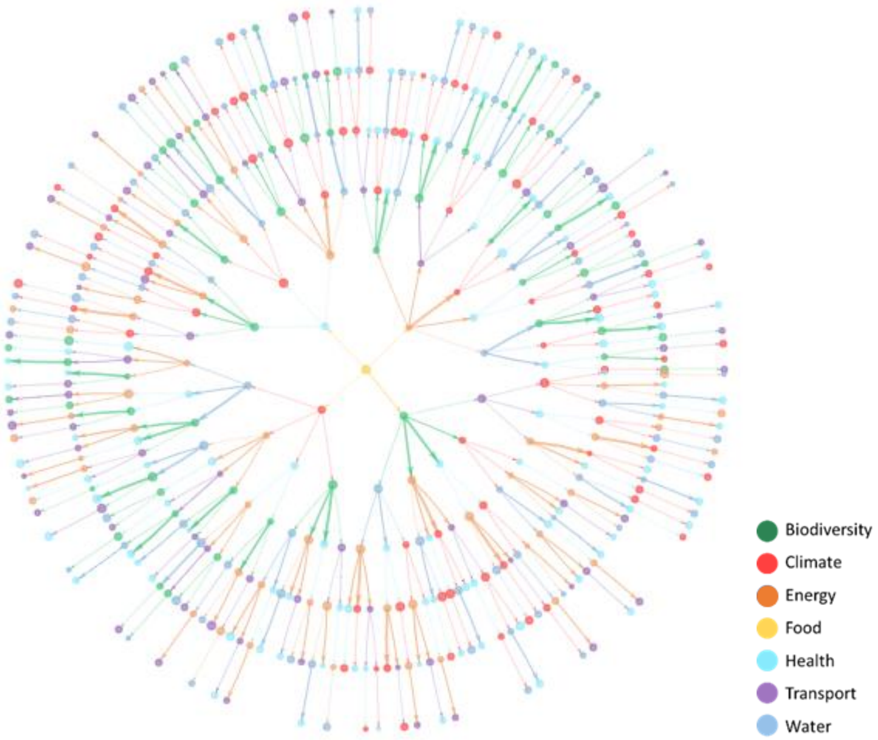
Nexus element	Positive		Negative		Overall	
	Complexity	Impact	Complexity	Impact	Complexity	Impact
Biodiversi	70	253.3	69	270.7	139	-17.3
Climate	92	334.9	67	252.6	159	82.3
Food	122	421.5	65	248.0	187	173.5
Health	122	419.8	75	267.0	197	152.8
Transport	44	144.7	80	297.1	124	-152.3
Water	76	269.4	86	313.6	162	-44.2
All	**526**	**1843.6**	**442**	**1648.9**	**968**	**194.7**

(b) Overall influence of the six nexus elements on energy

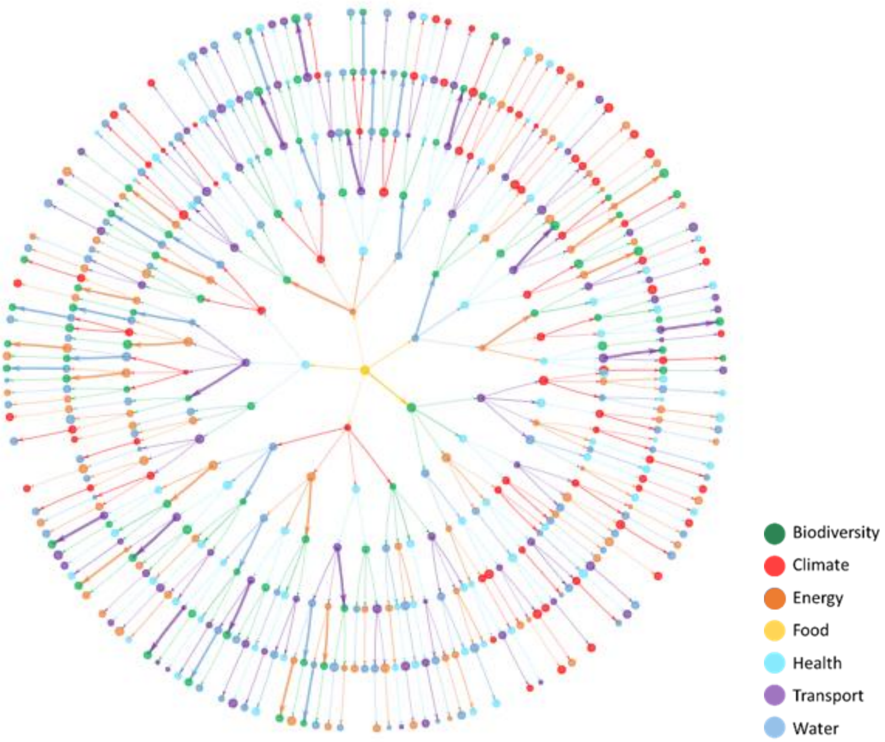
	Positive		Negative		Overall	
Nexus	Complexity	Impact	Complexity	Impact	Complexity	Impact
Biodiversi	70	252.2	60	220.6	130	31.6
Climate	65	225.2	81	295.5	146	-70.3
Food	57	214.8	86	320.5	143	-105.7
Health	57	205.5	74	281.9	131	-76.3
Transport	163	601.4	95	349.2	258	252.2
Water	114	404.7	66	245.6	180	159.1
All	**526**	**1903.9**	**462**	**1713.3**	**988**	**190.6**

Food

Figure S19. Synthetic network trees showing (a) 461 positive pathways between food and all other nexus elements and (b) 510 negative pathways between food and all other nexus elements.



(a) Positive pathways from food



(b) Negative pathways from food

Table S6. Summary of the (a) positive, negative, and overall influence of food on the six nexus elements and (b) positive, negative, and overall influence of the six nexus elements on food.

(a) Overall influence of food on the six nexus elements

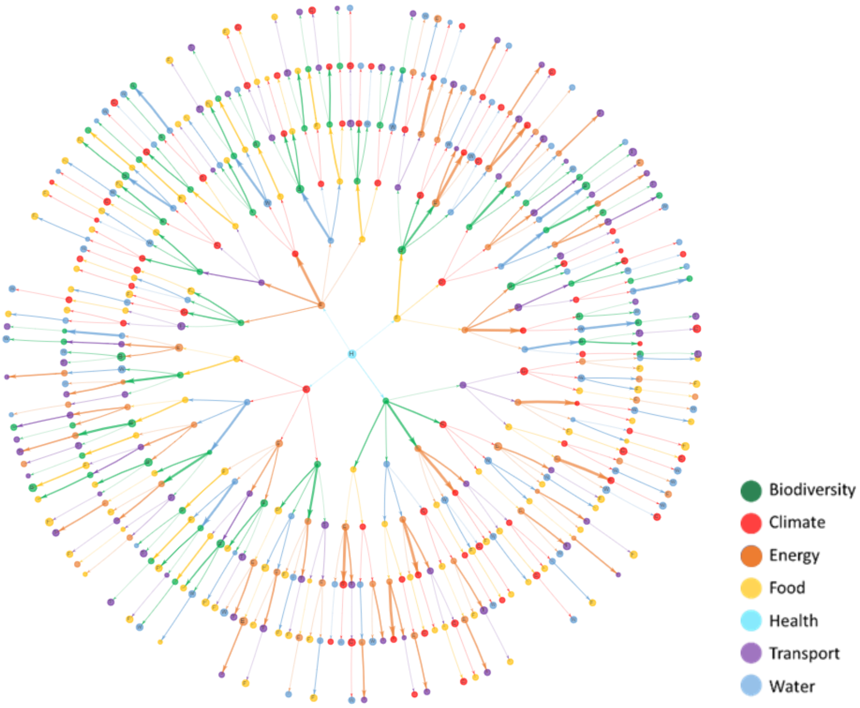
Nexus element	Positive		Negative		Overall	
	Complexity	Impact	Complexity	Impact	Complexity	Impact
Biodiversi	57	214.8	78	308.8	135	-94.0
Climate	76	280.2	79	292.2	155	-12.0
Energy	57	214.8	86	320.5	143	-105.7
Health	103	362.3	84	303.2	187	59.1
Transport	76	272.5	80	300.7	156	-28.2
Water	92	337.7	103	378.5	195	-40.9
All	**461**	**1682.4**	**510**	**1904.0**	**971**	**-221.6**

(b) Overall influence of the six nexus elements on food

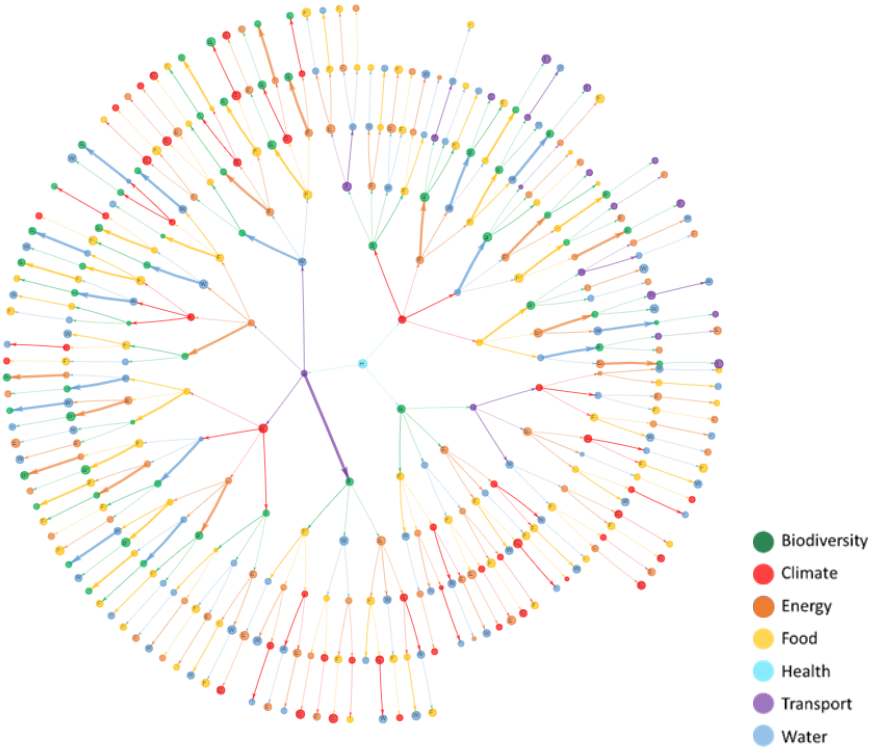
Nexus	Positive		Negative		Overall	
	Complexity	Impact	Complexity	Impact	Complexity	Impact
Biodiversi	122	429.0	64	236.5	186	192.5
Climate	114	396.7	72	269.8	186	126.9
Energy	122	421.5	65	248.0	187	173.5
Health	103	375.5	84	325.5	187	49.9
Transport	212	772.0	121	455.8	333	316.1
Water	163	576.7	61	230.3	224	346.4
All	**836**	**2971.4**	**467**	**1765.9**	**1303**	**1205.4**

Health

Figure S20. Synthetic network trees showing (a) 461 positive pathways between health and all other nexus elements and (b) 367 negative pathways between health and all other nexus elements.



(a) Positive pathways from health



(b) Negative pathways from health

Table S7. Summary of the (a) positive, negative, and overall influence of health on the six nexus elements and (b) positive, negative, and overall influence of the six nexus elements on health.

(a) Overall influence of health on the six nexus elements

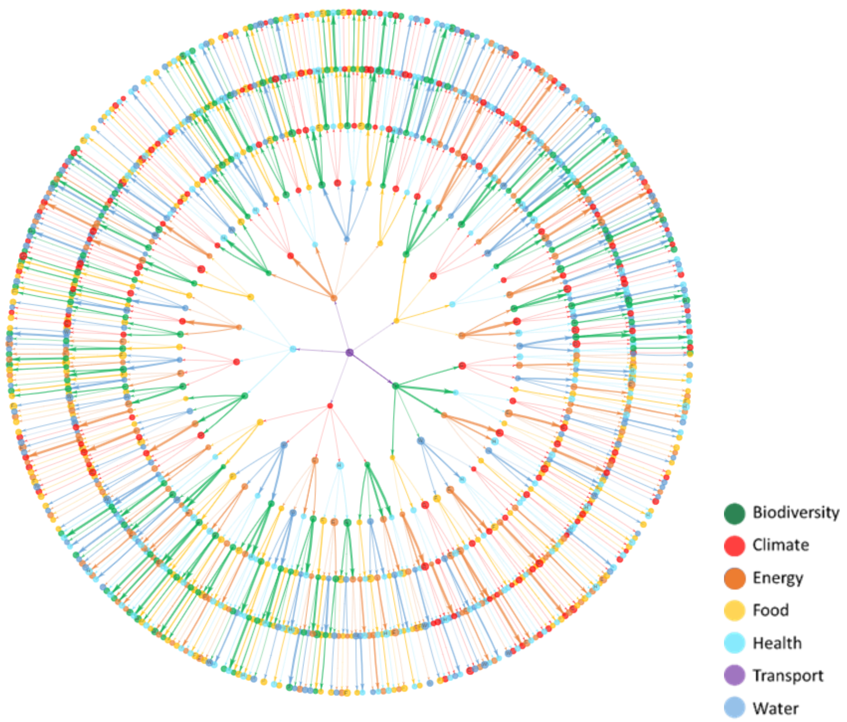
Nexus element	Positive		Negative		Overall	
	Complexity	Impact	Complexity	Impact	Complexity	Impact
Biodiversi	57	212.1	58	234.4	115	-22.3
Climate	76	273.3	46	184.1	122	89.3
Energy	57	205.5	74	281.9	131	-76.3
Food	103	375.5	84	325.5	187	49.9
Transport	76	266.0	18	62.1	94	204.0
Water	92	329.0	87	326.4	179	2.7
All	**461**	**1661.4**	**367**	**1414.3**	**828**	**247.2**

(b) Overall influence of the six nexus elements on health

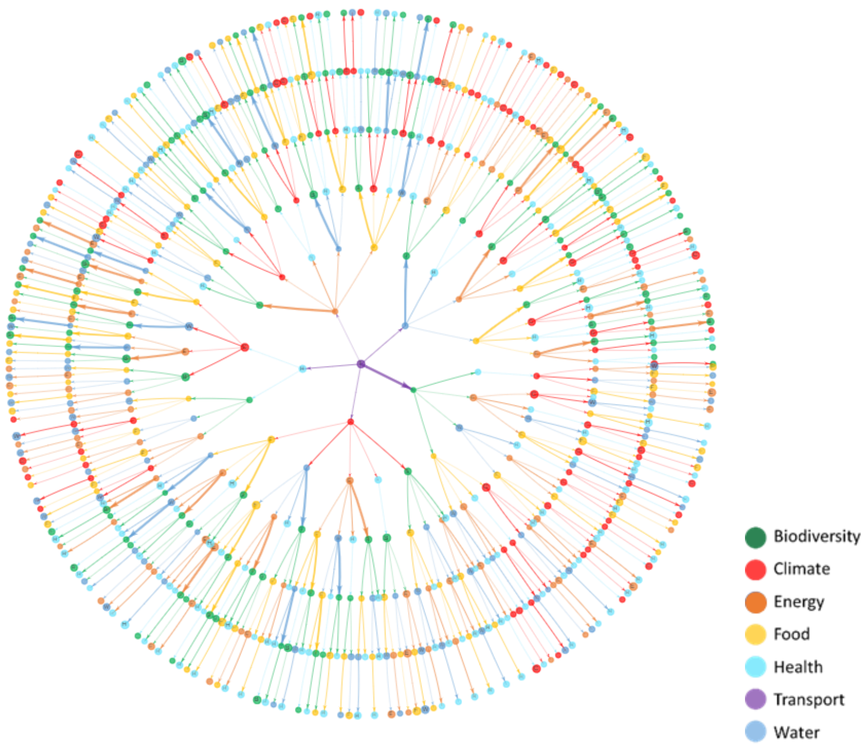
Nexus	Positive		Negative		Overall	
	Complexity	Impact	Complexity	Impact	Complexity	Impact
Biodiversi	122	427.0	79	276.4	201	150.6
Climate	114	400.9	103	361.0	217	39.8
Energy	122	419.8	75	267.0	197	152.8
Food	103	362.3	84	303.2	187	59.1
Transport	212	752.9	185	685.7	397	67.2
Water	163	570.4	68	247.0	231	323.4
All	**836**	**2933.3**	**594**	**2140.3**	**1430**	**793.0**

Transport

Figure S21. Synthetic network trees showing (a) 1108 positive pathways between transport and all other nexus elements and (b) 725 negative pathways between transport and all other nexus elements.



(a) Positive pathways from transport



(b) Negative pathways from transport

Table S8. Summary of the (a) positive, negative, and overall influence of transport on the six nexus elements and (b) positive, negative, and overall influence of the six nexus elements on transport.

(a) Overall influence of transport on the six nexus elements

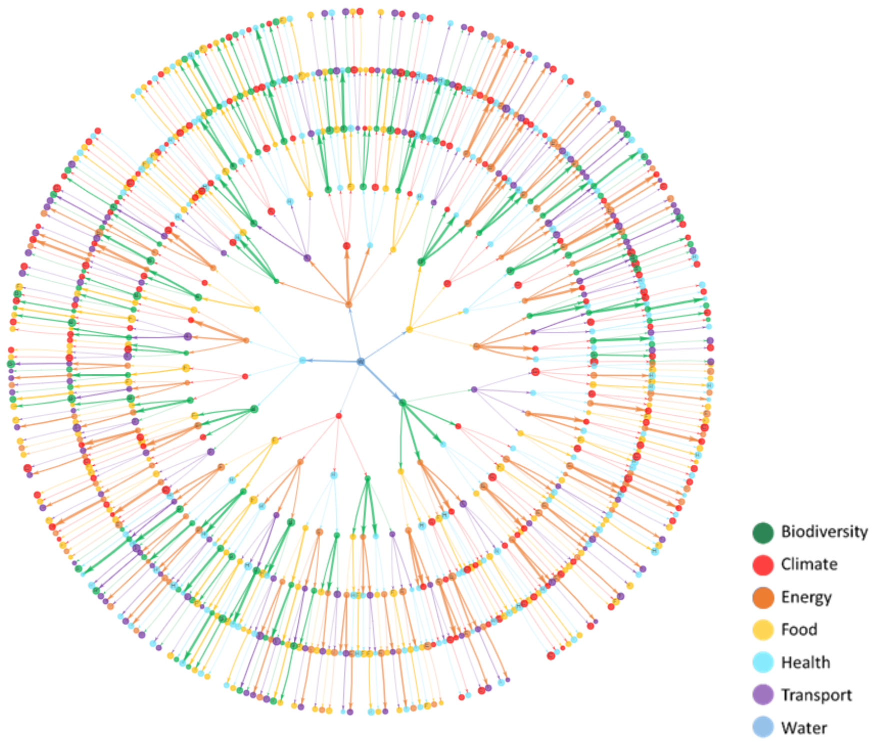
Nexus element	Positive		Negative		Overall	
	Complexity	Impact	Complexity	Impact	Complexity	Impact
Biodiversi	163	603.8	120	459.5	283	144.3
Climate	163	604.9	95	358.2	258	246.7
Energy	163	601.4	95	349.2	258	252.2
Food	212	772.0	121	455.8	333	316.1
Health	212	752.9	185	685.7	397	67.2
Water	195	715.4	109	399.6	304	315.8
All	**1108**	**4050.3**	**725**	**2708.0**	**1833**	**1342.3**

(b) Overall influence of the six nexus elements on transport

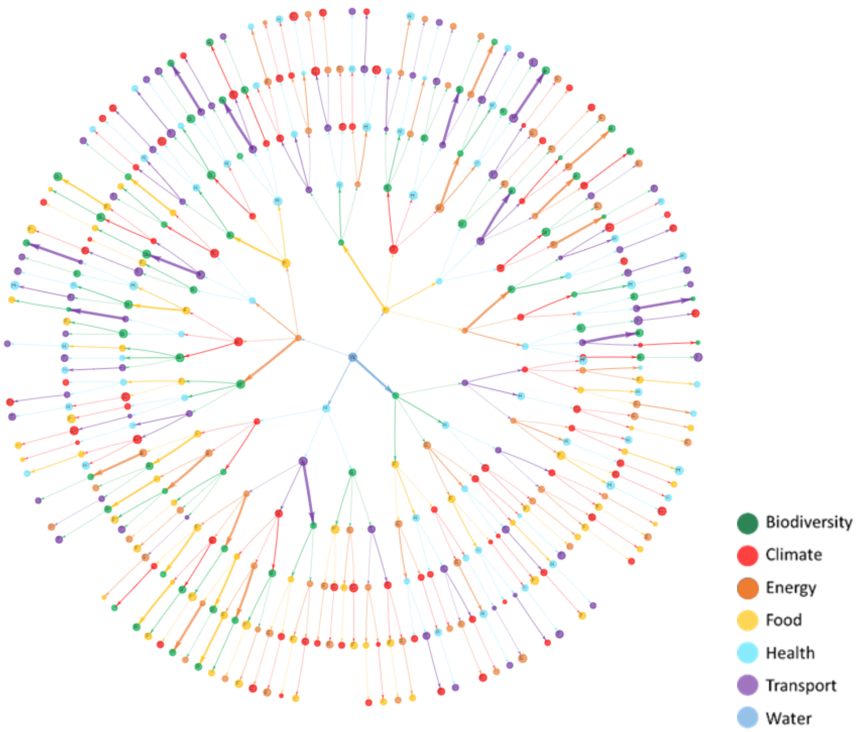
Nexus	Positive		Negative		Overall	
	Complexity	Impact	Complexity	Impact	Complexity	Impact
Biodiversi	44	157.5	39	152.6	83	4.9
Climate	86	288.1	97	359.4	183	-71.3
Energy	44	144.7	80	297.1	124	-152.3
Food	76	272.5	80	300.7	156	-28.2
Health	76	266.0	18	62.1	94	204.0
Water	130	449.3	71	269.0	201	180.3
All	**456**	**1578.2**	**385**	**1440.9**	**841**	**137.3**

Water

Figure S22. Synthetic network trees showing (a) 847 positive pathways between water and all other nexus elements and (b) 415 negative pathways between water and all other nexus elements.



(a) Positive pathways from



(b) Negative pathways from water

Table S9. Summary of the (a) positive, negative, and overall influence of water on the six nexus elements and (b) positive, negative, and overall influence of the six nexus elements on water.

(a) Overall influence of water on the six nexus elements

Nexus element	Positive		Negative		Overall	
	Complexity	Impact	Complexity	Impact	Complexity	Impact
Biodiversi	114	417.4	63	255.0	177	162.3
Climate	163	600.4	86	329.4	249	271.1
Energy	114	404.7	66	245.6	180	159.1
Food	163	576.7	61	230.3	224	346.4
Health	163	570.4	68	247.0	231	323.4
Transport	130	449.3	71	269.0	201	180.3
All	**847**	**3018.9**	**415**	**1576.2**	**1262**	**1442.7**

(b) Overall influence of the six nexus elements on water

	Positive		Negative		Overall	
Nexus	Complexity	Impact	Complexity	Impact	Complexity	Impact
Biodiversi	76	270.8	71	255.7	147	15.1
Climate	55	193.2	81	286.2	136	-93.0
Energy	76	269.4	86	313.6	162	-44.2
Food	92	337.7	103	378.5	195	-40.9
Health	92	329.0	87	326.4	179	2.7
Transport	195	715.4	109	399.6	304	315.8
All	**586**	**2115.4**	**537**	**1960.0**	**1123**	**155.5**

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