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Cooling the City? A Scientometric Study on Urban Green and Blue Infrastructure and Climate Change-Induced Public Health Effects

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Abstract: Climate change causes global effects on multiple levels. The anthropogenic input of greenhouse gases increases the atmospheric mean temperature. It furthermore leads to a higher probability of extreme weather events (e.g., heat waves, floods) and thus strongly impacts the habitats of humans, animals, and plants. Against this background, research and innovation activities are increasingly focusing on potential health-related aspects and feasible adaptation and mitigation strategies. Progressing urbanization and demographic change paired with the climate change-induced heat island effect exposes humans living in urban habitats to increasing health risks. By employing scientometric methods, this scoping study provides a systematic bird's eye view on the epistemic landscapes of climate change, its health-related effects, and possible technological and nature-based interventions and strategies in order to make urban areas climate proof. Based on a literature corpus consisting of 2614 research articles collected in SCOPUS, we applied network-based analysis and visualization techniques to map the different scientific communities, discourses and their interrelations. From a public health perspective, the results demonstrate the range of either direct or indirect health effects of climate change. Furthermore, the results indicate that a public health-related scientific discourse is converging with an urban planning and building science driven discourse oriented towards urban blue and green infrastructure. We conclude that this development might mirror the socio-political demand to tackle emerging climate change-induced challenges by transgressing disciplinary boundaries.

Keywords: climate change; urban heat island; health effects; urban blue green infrastructure; scientometric analysis

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1. Introduction

The consequences of climate change are some of the most pressing issues our world is facing at present and into the future. Scientists from a wide range of disciplines are repeatedly warning policy makers and the broader public about the emergency of curbing global climate change and its disastrous effects on the biosphere [1]. Nevertheless, measures to prevent increasing greenhouse gas emissions (GHG) lack global and profound commitment. Since the first IPCC report in 1990, GHG-emissions have been steadily rising. At present they are even 60% higher than in 1990 [2]. Therefore, it is not surprising that weather extremes are increasing year by year. According to projections, the frequencies of heat waves will further increase during the rest of the 21st century [3]. This poses new health-related challenges worldwide, as it causes not only an increase in physical health effects (e.g., through temperature and pollution related illnesses) but also leads to mental health effects due to potential climate change-induced population displacement, the increase in vector-borne diseases, and threats to food and water security [4–9].

Since 2009 "The Lancet Countdown on health and climate change" has contributed to increasing knowledge on climate change by monitoring adverse health effects. According to a conservative estimate, the repercussions of climate change may be directly or indirectly responsible for 5.5 million disability adjusted life years (DALYs) lost in 2000. This figure relates only to deaths caused by cardiovascular diseases, diarrhea, malaria, accidents caused by floods or landslides, and malnutrition [10]. Regarding the scale and size of detrimental health effects, it seems evident that strategies to counter ongoing climate change need to become a core topic for political action in this century [11].

Such strategies and related measures will undoubtedly be of particular importance in urban areas for two reasons: (1) Cities are densely populated regions. The level of urbanization, i.e., people living in urban areas, is expected to increase in the coming decades [12,13]. Moreover, cities and their supply chains are major contributors of GHG emissions. On a global scale, cities are responsible for nearly three quarters of fossil fuel related GHG emissions [14]. (2) Cities are hot spots of climate change effects. Due to grey infrastructure, they are highly vulnerable to the adverse effects of heat waves, since under these conditions, heat stress lasts longer not only during the day but also during night hours as buildings and sealed surfaces store heat. Vulnerable population groups, such as young children and the elderly, suffer particularly from climate change-induced alterations of human living conditions. In light of demographic change (i.e., ageing societies), the health burden will further increase in the coming decades [15].

In this context, technological measures and nature-based interventions to improve the climate in urban spaces are gaining popularity. Scientific disciplines such as urban planning and architecture are thus becoming increasingly important to safeguard the well-being of urban populations as they are key to building up, expanding, and improving urban blue and green infrastructure. In contrast to grey infrastructure, which primarily consists of concrete, glass, and metal structures, green and blue infrastructure refers to natural and semi-natural landscape elements such as parks, trees, green facades, pools, or ponds. In recent decades, medicine-related disciplines including public health research also gained additional traction against this backdrop. The COVID-19 crisis has further increased the relevance of urban green infrastructure for human well-being in the public discourse. During COVID related lockdowns, green spaces in urban areas have been heavily used for recreational purposes, which has partly led to overcrowding [16]. Different scientific disciplines (urban planning, architecture, public health, etc.) attempt to contribute with their specific forms of knowledge and epistemic practices to tackle the climate change induced challenges in urban spaces.

In general, scientific disciplines are organized as so-called epistemic communities. According to Haas, an epistemic community is "*a network of professionals with recognized expertise and competence in a particular domain and an authoritative claim to policy-relevant knowledge within that domain or issue-area*" [17], p. 3. Haas' understanding of epistemic communities is oriented towards policy change and advice. In light of climate change, epistemic communities are fundamental for conceptualizing, planning, and implementing effective mitigation and adaptation measures. The role epistemic communities play for policy change and advice is reflected by four criteria of epistemic communities Haas has identified. First of all, epistemic communities have a "*shared set of normative and principled beliefs which provide a value-based rationale for the social action of community members*". Secondly, epistemic communities display "*shared causal beliefs which are derived from their analysis of practices leading or contributing to a central set of problems in their domain and which then serve as the basis for elucidating the multiple linkages between possible policy actions and desired outcomes*". The third characteristic of epistemic communities are "*shared notions of validity,* i.e., *intersubjective, internally defined criteria for weighing and validating knowledge in the domain of their expertise*"; while according to the fourth criteria, an epistemic community is "*a* *common policy enterprise—that is a set of common practices associated with a set of problems to which their professional competence is directed, presumably out of the conviction that human welfare will be enhanced as a consequence*".

Since C.P. Snow's work *The Two Cultures and the Scientific Revolution* spoke of the dichotomy between "science" and "humanities", the paradigms of different scientific cultures have been analyzed more closely [18]. With regard to the discourses in the philosophy of science that have emerged following Snow's analysis, P. Feyerabend's "anything goes" could be mentioned here as an example [19]. Ultimately, these postmodern analytical considerations lead to the discussion of the social relevance of science in general. Here, too, we would only like to refer to the discussion initiated by S. Funtowicz and J. Ravetz regarding the concept of "post normal science" [20].

With these developments in the theory of science, the re-evaluations of the meaning of epistemic landscapes can at least be represented in a rudimentary way. Particularly, research dealing with the consequences of anthropogenic climate change is also called "problem driven science" [21]. Not least because of this assessment, the hypothesis arises logically, according to which this research should precisely show a higher "interweaving" of classical epistemic landscapes. The present scientometric study attempts to test this hypothesis.

Problem-specific and solution-oriented research activities of epistemic communities such as public health, architecture, and urban planning can be better understood within this framework. Despite addressing the effects of climate change from different disciplinary backgrounds and with different epistemic practices, the normative guiding principles and the professional ethos of the various disciplines are very similar. They also share the intention to provide new knowledge and suggest potential policies or measures in order to improve human health and well-being. Research on the effects of climate change is not isolated from existing policy environments. They are in fact embedded within a dynamic and evolving political landscape, which requires constant knowledge transfer between scientific and political worlds. One of the main challenges is the knowledge transfer from scientific evidence of climate change impacts on human health and its implementation into mitigation and adaptation policies. In order for this to work, an engagement process between different actors is necessary. This allows the involved actors to develop a certain degree of ownership, which consequently increases the successful policy implementation [22].

Our study intends to facilitate this process by providing a systematic bird's eye view on the epistemic landscapes on climate change, health, and blue and green infrastructure by means of citation and keyword network analysis. Scientific documents constitute the common knowledge base of an epistemic community. Besides expressing a shared set of normative and causal beliefs, they also represent the common policy enterprise of the related epistemic community. Research articles furthermore provide a variety of additional data which can be used to analyze the development of research fields, the emergence of ideas, themes, and institutions, and the socio-epistemic structure of knowledge [23]. By applying scientometric methods based on the principles of network analysis, this data can be used to explore the epistemic landscape of blue and green infrastructure in scientific discourses. In this way we want to shed light on different disciplinary embeddings, the interrelations between them, and their historical dynamics.

Scientometrics is defined as the application of different statistical, mathematical, and algorithmic methods to bibliographic data [24]. The mapping and visualization of bibliographic data is part of scientometrics. It is used to visually explore the data and develop reasoning upon them. The bibliographic data used in this study is derived from SCOPUS and consists of information from peer reviewed documents (articles and reviews). These documents underwent a quality check by the respective epistemic community in a highly formalized process. According to Haas, this refers to the third criteria of epistemic communities, which involves the publication of studies based on established scientific practice, journal submission routines, editor selection standards, review procedures, including potential revision or refinement of manuscripts, and publishing these as articles accessible to the scientific community [17]. These documents can be conceptualized as knowledge artefacts. Their analysis with scientometric methods sheds light on the structure of the overall knowledge repository within a respective scientific field and its corresponding epistemic community. In this understanding, the bibliographic data are standardized and codified information on knowledge artefacts.

We utilize mapping and clustering techniques provided by the VOSviewer tool to analyze and study the created networks based on bibliographic data [25]. The analysis of scientific literature networks is a widely applied method in scientometrics to identify emerging topics and research fields of scientific domains [26–29]. It can also be used to analyze the historical developments of topics and research fields, thus allowing insights into the historically evolved structure of research related networks [30]. The aim of our study is to provide insights into the epistemic landscapes dealing with climate change-induced health effects and possible technological and nature-based interventions to cope with these. Our guiding research questions are:

(1) What is the structure and what are the main topics of the epistemic landscape on climate change induced health effects and urban blue and green infrastructure?
(2) What inter-connections can be identified between different disciplines (e.g., urban planning, architecture and public health, medicine) concerning the emerging health burden induced by climate change for urban settlements?
(3) What implications can be derived from the results for underlying research activities and policy making?

2. Methods

We mapped networks based on bibliographic data retrieved from documents in SCOPUS. We used this data to create a keyword co-occurrence network and a citation network. The keyword co-occurrence network was used to gain insights into the topics and their underlying evolutionary dynamics. The citation network was used as a proxy to identify epistemic communities producing and using these documents and their interrelations. Mapping and clustering procedures incorporated in VOSviewer were applied in order to provide insights into the structure of the epistemic landscapes (i.e., networks). These clustering algorithms create a two-dimensional map in which the nodes with high association strengths have a shorter distance to each other. In VOSviewer this shorter distance is an indication for the relatedness of the nodes. This leads to areas in the overall network that are denser than others (clusters). The mathematical foundations for the clustering algorithms in VOSviewer are described in detail in Waltman, van Eck, and Noyons [30]. However, a variety of different clustering methodologies exist, as this is a highly dynamic field of research in scientometrics [31]. Thus, the application of different clustering techniques to the same dataset may yield different clustering results. As VOSviewer is a commonly used tool for scientometrics and furthermore is constantly updated by its developers, we decided to choose it for this study.

However, the study not only relies on quantitative results produced by VOSviewer. These results allowed us to identify central documents and topics by means of centrality-based network measures (citations, occurrences, co-occurrences). In the next step, the identified documents and topics were used as a starting point for a more in depth qualitative analysis. In contrast to other scientometric studies, the combination of quantitative and qualitative analysis allowed us to gain more in-depth insight. Besides that, the authors of this article have dedicated expertise concerning the topics of urban green infrastructure, health, urban planning, and sustainability sciences. This expertise was used not only to validate the results but also to widen the scope of the discussion. The validation of bibliometric networks by experts is something that is neglected too often, although it is a very important aspect, as highlighted by Noyons [32].

2.1. Keyword Co-Occurrence Networks

Keyword co-occurrences are an important type of relational bibliographic data as they contextualize different documents according to their thematic content. Keywords are not always restricted to individual words. Usually, they contain multiple words or key terms. For example, if in two documents the keywords "climate-change" and "heat stress" appear in the keyword section, then these two documents are related to each other and the two keywords are connected by a relation with the value 2, because the keywords co-occur in 2 documents [25,33]. In keyword co-occurrence networks, the size of the nodes reflects the number of their occurrences. This is an indication of the overall relevance of the respective keyword in the dataset. As keywords represent the content of a document in the most condensed form possible, a network of co-occurring keywords indicates the thematic landscape. We used the constructed keyword co-occurrence map in combination with a qualitative review of central documents to identify the research themes represented within the bibliographic dataset.

We first identified central and interconnected keywords in the network, based on their occurrences and co-occurrences. In the second step, we used this information in combination with a reference manager to retrieve the documents from which they were drawn. This reverse engineering process allowed us to embed the identified central and interconnected keywords in their initial document context (prototypical or representative documents). These documents were qualitatively analyzed in order to obtain an understanding of the underlying topics. It furthermore enabled us to investigate the thematic structure of the research fields and to identify major research topics and trends within scientific domains [34]. Prior to creating the term co-occurrence maps with VOSviewer, a terminological thesaurus was constructed, based on certain standards [35,36]. Words may have different spelling or common stems but different variations in terms of affixes (or associated words). Furthermore, there is a high level of variation concerning words and concepts used to describe the same phenomena (i.e., synonymous expressions). In such cases, words were merged under the same conceptual umbrella in order to generate a more reliable co-occurrence map.

2.2. Citation Networks

Citations are another important type of relational bibliographic data as they contextualize different documents across a temporal dimension. The citations authors make are regarded to be the branches of their intellectual pedigree. Thus, citation networks have a temporal dimension—meaning that a citation can only refer to a (cited) document, which is older than the citing document. A citation network is a representation of the citations that occur between the documents, and it thus relates them to each other. Two documents are connected if a citation has occurred between them. We utilized citation networks in order to identify document-based epistemic communities (i.e., publication clusters) and the relatedness of these communities to each other.

Besides that, citations represent a formalized and codified form of communication, which allows researchers to be more precise in their argumentation [37]. Citations also have the potential to connect different, otherwise isolated, epistemic communities. This may be especially relevant for interdisciplinary work as different knowledge bases and epistemic practices are connected through citations [23,38]. Citations can also be used to assess the scientific importance of a document. In general, articles with a higher number of citations are more visible within a certain research field and thus are often perceived to be more important. The authors of a research article refer to theories, results, and conclusions of former works and use them as a frame of reference in their own publication.

A frame of reference can have different qualities. In some cases, it is attesting (i.e., supporting the cited work) in other cases it is objecting (i.e., not supporting the cited work). Therefore, citations are a valuable resource for the analysis of the scientific development paths and epistemic communities [39]. The citation network analysis of collected bibliographic data is central to our study. The citation network served to identify key publications within the collected bibliographic dataset (in terms of citations), groups of articles that are linked by citations (clusters), and articles that act as a bridge between different scientific subfields.

Keyword co-occurrence and citation analysis were performed to review and map the literature landscape related to climate change-induced health effects and possible technological and nature-based interventions to cope with these. Further methodological details of the VOSviewer layout and clustering techniques can be found in Van Eck, Waltman, Dekker and van den Berg [40] Waltman, van Eck and Noyons [30], Waltman and Van Eck [41], and Van Eck and Waltman [42].

2.3. Search Strategy and Search Query Definition

A well-known challenge in any study involving scientometric methods is the collection of relevant data with a predefined search query. The development of the search query is an iterative process, in which the retrieved results are constantly checked for their relevance. Thus, it takes time to identify unambiguous and relevant search terms and to combine them in a meaningful way. The search query needs to represent and describe the research field in such a way that the results of the search produce a bibliographic literature corpus with a high degree of completeness, ensuring that relevant literature is covered by the search query whereas non-relevant literature ("noise") is reduced to a minimum.

The final search query consisted of different components. Each of these components has specific functions for the identification of relevant literature. The search query for SCOPUS consisted of three different components:

- COMP_CC: Component consisting of terms related to climate change issues (e.g., urban heat island, climate change, urban sustainability, etc.);
- COMP_HE: Component consisting of terms related to health effects (e.g., heat stress, cardiovascular, etc.);
- COMP_UGI: Component consisting of terms related to mitigation and adaptation strategies and technological and nature-based interventions with urban green and blue infrastructure (e.g., green roofing, green facading, street greenery, etc.).

The search components aimed to retrieve documents on these three topics (Table 1). The search components were combined with each other in order to reflect all possible thematic contexts. A combination of COMP_CC with COMP_UGI retrieved relevant documents dealing with health-related aspects and urban blue and green infrastructure interventions. Similarly, the combination of the COMP_UGI with COMP_CC captured documents providing insights into urban blue and green infrastructure interventions in the context of climate change. In total, four searches were performed (COMP_CC+COMP_HE+COMP_UGI/COMP_CC+COMP_HE/COMP_HE+COMP_UGI/COMP_CC+COMP_UGI). The results of all possible combinations of the three search term components were merged into one bibliographic dataset. The search query was directed towards the title, abstract, and keywords of the respective documents. However, the search performed with the combination COMP_CC+COMP_HE was restricted to only provide results if the defined search phrases were present in the title of the documents, otherwise the search phrase would have retrieved a very high amount of false positive documents. The manual relevance screening of the documents would not have been possible in this case.

Further limiting conditions of the search strategy concern the time period (1990–2020) and the document types, i.e., only research articles and reviews were collected. The broad time frame reflects the historical development of climate change discourse and the debate of its potential implications for health emerging in the 1990s (UNFCC signed in 1992 by 154 states). The year 2020 was defined as upper limit. Restricting the search query to articles and reviews ensured consistency of bibliographic data. Contrary to book chapters and conference proceedings, scientific articles and reviews are more consistent (e.g., more complete data, dedicated reference lists, etc.). Language was limited to English. Data gathering and screening were finalized on 1 September 2021.

Table 1. Search term components of the SCOPUS query (* is a wildcard symbol e.g., for plural).

Search Term Component	Terms and Phrases within Component
COMP_CC	"climate change" OR "greenhouse effect" OR "changing climate" OR "global warming" OR "extreme weather" OR "climate variability" OR "greenhouse gas" OR "rising temperature" OR "heat wave *" OR "urban heat island" OR "urban sustainab *"
COMP_HE	"heat stress" OR "health" OR "health risk" OR "health effect *" OR "mental" OR "mental health" OR "disease *" OR "chronic disease *" OR "cardiovasc *" OR "cardiac" OR "heart" OR "mood"
COMP_UGI	"urban green infrastr *" OR "urban blue green infrastr *" OR "urban blue-green infrastr *" OR "urban blue infrastr *" OR "green roof *" OR "climate-proof urban" OR "climate proof urban" OR "climate-proof city" OR "climate proof city" OR "climate-proof cities" OR "climate proof cities" OR "green façad *" OR "street green *" OR "open space green *" OR "climate-adapted hous *" OR "climate adapted hous *" OR "climate-adapted build *" OR "climate adapted build *"

2.4. Relevance Screening

Although the search query was developed iteratively, still some false positives (i.e., not relevant articles or reviews) were part of the search results using SCOPUS. Therefore, a qualitative relevance screening evaluated titles and abstracts in a second step. The criteria applied were that an article should either reflect on the direct and indirect climate change induced health effects or on technical and/or nature-based interventions (urban green or blue infrastructure) in view of coping with climate change effects. The screening process also served as validation. The number of false positives was <5% of the total number of results retrieved. False positives were removed from the dataset.

3. Results

The search query resulted in 2713 documents (2150 articles and 563 reviews). During the relevance screening, 99 documents were removed, as they were identified as false positives. This resulted in a final dataset consisting of 2614 documents (2058 articles and 556 reviews) published in the time period from 1990 to 2020. This dataset was used to create a keyword co-occurrence network (generating a thematic landscape) and a citation network (reflecting epistemic communities constructed through documents). In the following section, the results of the analysis of these two network analyses are presented.

3.1. Keyword Co-Occurrence Network Analysis

Figure 1 shows the keyword co-occurrence network based on author and index keywords. The minimum occurrence (i.e., the number of documents in which a keyword occurs) was set to 10. This resulted in a keyword co-occurrence map consisting of 747 items in which five different topics were identified based on the clustering algorithms of VOSviewer.

Topic 1 (red) can be subsumed as "Urban Blue & Green Infrastructure". In general, it contains terms related to urban planning and measures to address climate change effects in urban spaces (i.e., urban heat islands). The top ten keywords within the topic "Urban Blue & Green Infrastructure" according to their occurrences are listed in Table 2. Results show that nature-based urban planning and architectural interventions, e.g., through green roofs or green spaces, are widely seen to be important for adaption to and mitigation of urban heat island effects. Furthermore, urban green infrastructure is also contextualized with water related aspects, e.g., "rainfall", "precipitation", "runoff", "water management", "water supply", or "water pollution". Scientific discourse accordingly highlights the potential influence of urban green infrastructure on water flows in cities. Topic 1 also contains several countries or city names as keywords. This indicates that some of the underlying studies within the topic "Urban Blue & Green Infrastructure" are case studies with a precise regional reference. Representative examples for topic 1 are the articles by Tabatabaee et al. [43] and Versini et al. [44] who conducted an analysis of green roof implementations in European cities. One of their key findings is that different degrees of progress on urban greening initiatives and in situ implementation exist across the analyzed cities. Another example is Skala et al. [45], who assessed different green roof layer designs concerning their drainage and urban heat island mitigation effects. According to their research, depth of substrate of a green roof layer design influences root water uptake, which increases with substrate depth. They furthermore observed a reduction in the maximum temperature in correspondence with substrate depth. Santi et al. [46] explore strategies and technical solutions for the building envelopes needed to implement integrated green systems for Italy.

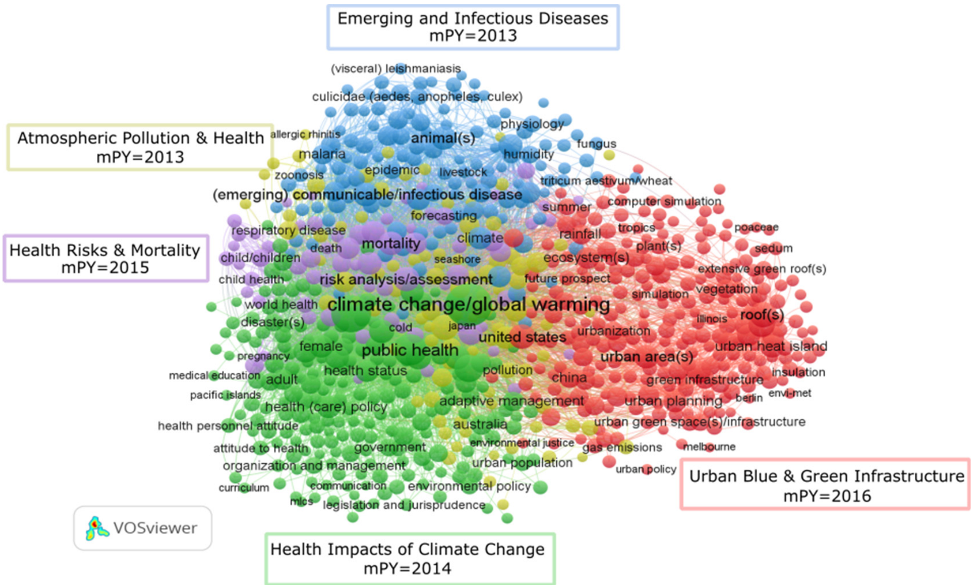

Figure 1. Keyword co-occurrence network (n = 747 terms) based on bibliographic data retrieved from the search query described in Table 1 (time period = 1990–2020). Five topics were identified: Topic 1 (red) = "Urban Blue & Green Infrastructure", Topic 2 (green) = "Health Impacts of Climate Change", Topic 3 (blue) = "Emerging and Infectious Diseases", Topic 4 (yellow) = "Atmospheric Pollution and Health", Topic 5 (purple) = "Health Risks and Mortality"; mPY = mean publication year.

Table 2. Top 10 keywords according to number of occurrences in topic 1 "Urban Blue & Green Infrastructure".

Keyword	Occurrences	Keyword	Occurrences
roof(s)	259	green space(s)	177
green roof(s)	253	urban planning	150
united states	248	ecosystem(s)	144
urban area(s)	194	heat island (effect)	141
urban heat island	180	atmospheric temperature	136

The top 10 keywords of topic 2 (green) are depicted in Table 3. This topic is about "Health Impacts of Climate Change", containing keywords, which are related to the human health and climate change discourse, indicated by the high number of occurrences of keywords such as "public health", "humans", "health impact", "adaptation", or "health (care) policy". The review article by Arbuthnott and Hajat [47] is a prototypical example of this cluster. They show that heat related mortality is increasing in the UK, especially for vulnerable population groups like the elderly. The future increase in this demographic group will also aggravate such climate change induced health burdens. The nexus between health, climate change, governance, and the adaptive capacity of different social entities (individuals, communities, institutions, nations, etc.) is another important discursive element within this topic, as for instance elaborated by Bowen et al. [48]. They identify key concerns related to health, climate change, and governance and analyze the interrelation between these components, which according to the authors is fundamental for developing or strengthening policies effectively reducing negative health effects of climate change.

Topic 2 also hosts a variety of health care related keywords, e.g., "health care cost(s)", "health care access", "health care delivery", "health care organization", "health care personnel/professionals", "health care quality", or "health care system". This illustrates the diversity of perspectives articulated within the topic.

Table 3. Top 10 keywords according to number of occurrences in topic 2 "Health Impacts of Climate Change".

Keyword	Occurrences	Keyword	Occurrences
climate change/global warming	1858	adaptation	211
human(s)	1106	health hazard(s)	195
public health	612	female	182
Health	354	environmental health	170
health impact(s)	217	health (care) policy	169

Topic 3 (blue) is about "Emerging and Infectious Diseases". The top 10 keywords are depicted in Table 4. This topic reflects the indirect effects climate change has on human health through the emergence of communicable and infectious diseases. Taxonomic classes of microorganisms (bacteria, and animals such as ticks or other arthropods) as well as names of viruses are relevant keywords, which indicate the research topics represented within this thematic cluster. The diseases mentioned in this context are, e.g., "malaria", "chikungunya", "dengue (fever, virus)", "(visceral) leishmaniasis", or "zika virus (infection)" to name some of them. The cluster mainly contains research regarding nonhuman effects of climate change. These effects may have epidemiological implications (i.e., through communicable diseases and disease vectors) for human health in the second place. Prototypical examples covering infectious disease risks due to climate change are Akin et al. [49], Cissé [50], or Wu et al. [51].

Table 4. Top 10 keywords according to number of occurrences in topic 3 "Emerging and Infectious Diseases".

Keyword	Occurrences	Keyword	Occurrences
(emerging) communicable/infectious disease	199	environmental temperature	143
animal(s)	193	climate effect	140
Climate	187	Infection	111
Nonhuman	168	Malaria	108
temperature	162	disease/virus transmission	103

Table 5 shows the top 10 keywords for Topic 4 (yellow), which is about "Atmospheric Pollution and Health" as it represents research documents covering air and atmospheric pollution and related health effects. Respiratory diseases such as "asthma" and "chronic obstructive lung disease" are relevant keywords. They often co-occur with emission related terms such as "vehicle emissions", "particulate matter", "pollen", or "exhaust gas". A representative document within this topic is the review article by Kinney [52], which deals with the interactions of climate change, air pollution, and human health. The author concludes that higher ambient temperatures lead to increasing concentrations of ozone and $PM_{2.5}$ precursors. Thereby human exposure risk increases and may consequently cause various (respiratory) diseases. This topic seems to be transversal as it overlaps with the other topics. A possible reason for this could be the focus on atmospheric phenomena. The topic contains keywords such as "greenhouse gas(es)" and "carbon dioxide/monoxide", which are also generic terms in the broader context of climate change and therefore connect different topics with each other. It is thus less discriminate than the other topics.

Table 5. Top 10 keywords according to number of occurrences in topic 4 "Atmospheric Pollution and Health".

Keyword	Occurrences	Keyword	Occurrences
air/atmospheric pollution/pollutant	281	environmental impact	120
greenhouse gas(es)	186	Ozone	92
air quality	138	environmental monitoring	83
carbon dioxide/monoxide	129	respiratory disease	83
environmental exposure	127	carbon footprint	82

The last topic identified is about "Health Risks and Mortality" (purple). It refers to a risk and mortality related document base. Dominant terms are for instance "risk analysis/assessment", "health risk(s)", "risk factor(s)", or "mortality risk". It also contains age related keywords such as "infant, newborn", "child health", "child", or "preschool child/children" and heat related terms such as "heat", "heat wave(s)", "temperature/thermal/heat stress", "high temperature", or "heat shock response" (see Table 6). Although its similarly dispersed as topic 4 "Atmospheric Pollution and Health", it can be more clearly delimited. It primarily revolves around heat with regard to vulnerable population groups and their specific risk factors. This is confirmed by several prototypical articles addressing the effects and risks of climate change regarding child health [53–55].

Table 6. Top 10 keywords according to number of occurrences in topic 5 "Health Risks and Mortality".

Keyword	Occurrences	Keyword	Occurrences
risk analysis/assessment	238	risk factor(s)	148
Mortality	194	high temperature	145
health risk(s)	182	temperature/thermal/heat stress	127
Heat	167	heat wave(s)	123
Weather	153	controlled study	109

Evolutionary Dynamics of the Thematic Landscape

The temporal analysis of the five topics reveals the evolutionary dynamics of the thematic landscape. For each of the five topics, the mean value of the publication year of all the keywords represented within the topic was calculated. According to that, "Urban Blue & Green Infrastructure" represents the most recent topic within the dataset (mean publication year mPY = 2016), closely followed by "Health Risks and Mortality" (mPY = 2015). The mPY of the keywords for "Health Impacts of Climate Change" is 2014, followed by "Emerging and Infectious Diseases" and "Atmospheric Pollution and Health", which both have mPY 2013. This allows one to hypothesize that the evolution of the thematic landscape represented in Figure 1 started from the top left topic of "Emerging and Infectious Diseases", following an L-shape to the bottom right topic of "Urban Blue & Green Infrastructure". This indicates that nature and technology-based greening interventions in urban spaces are an emerging field of research.

3.2. Citation Network Analysis

The minimum number of overall citations a document needed for inclusion in the citation network was set to 10. This limit was set in order to achieve a better granularity and to allow the identification of highly cited and thus "visible" documents in the citation network. However, it needs to be pointed out that this represents the citation network at a certain point of time, i.e., the day at which the bibliographic data were collected. As the overall citation counts are increasing over time in SCOPUS, the resulting citation networks may also change. A citation network derived from bibliographic data collected with the same search query in a year from now will probably look different and include more documents than it does currently, but the citation network shown in Figure 2 would still be a central part of it. The figure shows a citation network consisting of 999 documents. The sizes of the vertices represent normalized citation weights, which are defined as the number of citations of a document divided by the average number of citations of all documents published in the same year. Thus, the normalization procedure corrects for the potentially unequal distribution of citation scores, which over-represents older publications in comparison with newer publications. The citation network consists of four clusters. The proximity of documents and clusters indicates how closely respective clusters or documents are related to each other. From a macrostructural point of view, the cluster on the right (green) and the cluster on the top (yellow) occupy a relatively distinct position, whereas the red and blue clusters on the bottom left corner are more tightly connected to each other. The top five documents of each cluster are represented in Table 7.

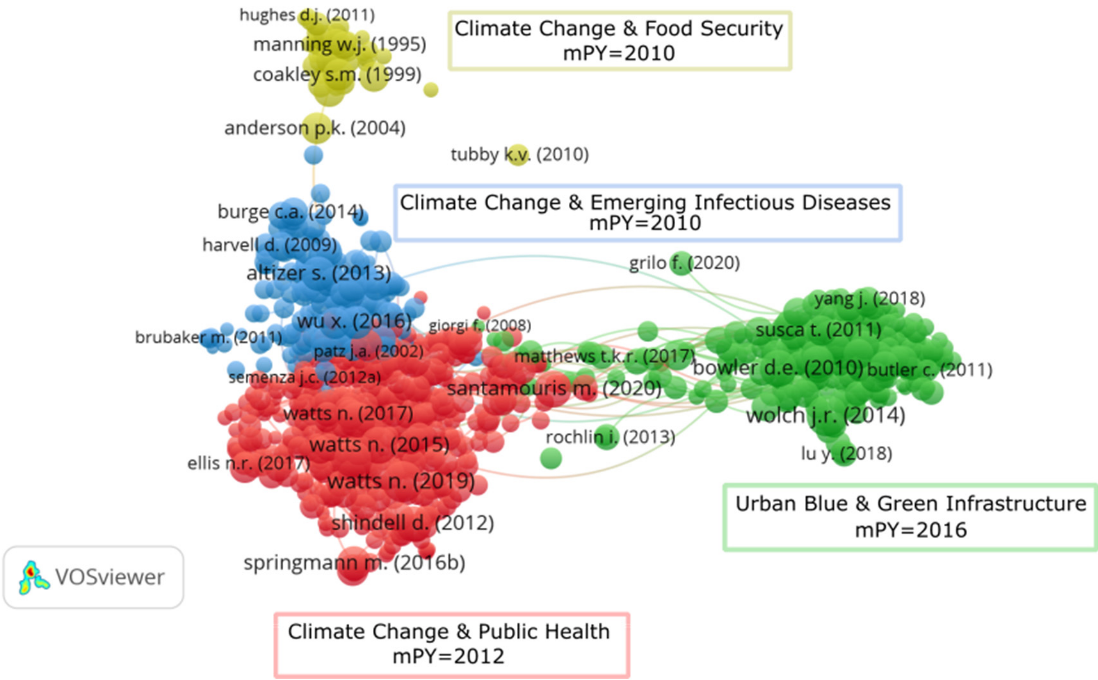

Figure 2. The citation network shows 4 clusters (n = 999). The size of the vertices represents normalized citation weights. Four different clusters were identified. These represent document-based epistemic communities. Cluster 1 (red) = Climate Change & Public Health; Cluster 2 (green) = Urban Blue & Green Infrastructure; Cluster 3 (blue) = Climate Change and Emerging Infectious Diseases; Cluster 4 (yellow) = Climate Change and Food Security.

Cluster 1 (red) represents a document-based epistemic community subsumed under "Climate Change & Public Health". The major research theme of this community covers the broader scientific discourse on the effects climate change has on public health. Documents published by the Lancet Countdown have the highest normative citation weights within this cluster [56,57]. These documents occupy central positions within Cluster 1. Research activities addressing adequate public health policies on a global and regional scale are one of its central topics. Besides that, other thematic foci concern mental health, indigenous health, and health and climate change mitigation co-benefits through dietary change and emission reduction. Food security in relation with human well-being is also being addressed within this cluster. This cluster is dominated by journals used by medical and health-related disciplines. Examples of prominent journals are *International Journal of Environmental Research and Public Health*, *Environmental Health Perspectives*, *The Lancet*, *Asia-Pacific Journal of Public Health*, and *The American Journal of Preventive Medicine*.

Table 7. Most central documents of the four clusters according to normalized citation weights.

Document (Label in Map)	Title	Norm. Citation Weight
Cluster 1: "Climate Change & Public Health"		
Watts N. (2019)	The 2019 report of The Lancet Countdown on health and climate change: ensuring that the health of a child born today is not defined by a changing climate	29.86
Watts N. (2018b)	The Lancet Countdown on health and climate change: from 25 years of inaction to a global transformation for public health	20.14
Watts N. (2015)	Health and climate change: policy responses to protect public health	19.73
Santamouris M. (2020)	Recent progress on urban overheating and heat island research. Integrated assessment of the energy, environmental, vulnerability and health impact. Synergies with the global climate change	17.88
Costello A. (2009)	Managing the health effects of climate change: Lancet and University College London Institute for Global Health Commission	17.12
Cluster 2: "Urban Blue & Green Infrastructure"		
Wolch J.R. (2014)	Urban green space, public health, and environmental justice: The challenge of making cities "just green enough"	28.71
Bowler D.E. (2010)	Urban greening to cool towns and cities: A systematic review of the empirical evidence	17.74
Norton B.A. (2015)	Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes	10.44
Susca T. (2011)	Positive effects of vegetation: Urban heat island and green roofs	8.22
Oberndorfer E. (2007)	Green Roofs as Urban Ecosystems: Ecological Structures, Functions, and Services	7.79
Cluster 3: "Climate Change and Emerging Infectious Diseases"		
Altizer S. (2013)	Climate Change and Infectious Diseases: From Evidence to a Predictive Framework	12.82
Wu X. (2016)	Impact of climate change on human infectious diseases: Empirical evidence and human adaptation	11.59
Ellwanger J.H. (2020)	Beyond diversity loss and climate change: Impacts of Amazon deforestation on infectious diseases and public health	9.52
Pounds J.A. (2006)	Widespread amphibian extinctions from epidemic disease driven by global warming	6.75
Caminade C. (2019)	Impact of recent and future climate change on vector-borne diseases	6.58
Cluster 4: "Climate Change and Food Security"		
Coakley S.M. (1999)	Climate change and plant disease management	9.65
Chakraborty S. (2011)	Climate change, plant diseases and food security: an overview	9.40
Anderson P.K. (2004)	Emerging infectious diseases of plants: pathogen pollution, climate change and agrotechnology drivers	8.71
Sturrock R.N. (2011)	Climate change and forest diseases	7.45
Manning W.J. (1995)	Climate change: Potential effects of increased atmospheric Carbon dioxide (CO_2), ozone (O_3), and ultraviolet-B (UV-B) radiation on plant diseases	5.09

The second cluster (green) is about "Urban Blue & Green Infrastructure" and represents a document-based epistemic community concerned with urban green infrastructure and nature-based solutions in view of adaption to and mitigation of negative effects of climate change in urban spaces. Table 7 lists the documents according to the highest normalized citations scores within this cluster. Other relevant themes are pollution and water retention in relation to green infrastructure (e.g., green roofs and facades). From a disciplinary perspective, this cluster is mainly attributed to non-medical or public health related research activities, namely urban and landscape planning, civil engineering, architecture, and the like. This is also confirmed by the journals represented in this cluster. *Building and Environment*, *Urban Forestry and Urban Greening*, *Landscape and Urban Planning*, *Energy and Buildings*, *Ecological Engineering*, and *Science of the Total Environment* are most abundant. The two document-based epistemic communities—"Climate Change & Public Health" (red) and "Urban Blue & Green Infrastructure" (green)—are linked to each other via 82 citations. The thematic embedding of these inter-cluster relations is primarily due to the urban heat island effect and its implications for human health. Nature-based solutions in the form of urban blue and green infrastructure are discussed as potential adaptation and mitigation strategies to cope with overheating.

Thematically, Cluster 3 (blue), "Climate Change and Emerging Infectious Diseases", is mainly concerned with infectious diseases and their relation to climate change. This cluster is thus dealing with the indirect health effects of climate change caused by pathogens that benefit from climate change. These pathogens cause communicable and vector-borne diseases. Another relevant topic is biodiversity loss, which may impact the proliferation of infectious diseases. The cluster "Climate Change and Emerging Infectious Diseases" is tightly connected to "Climate Change & Public Health". These clusters share 471 inter-cluster citations. These two document-based epistemic communities share the same disciplinary roots (health and medical sciences). This is also reflected by the journals represented within this cluster, being associated to health and medical sciences. Examples include the *International Journal of Environmental Research and Public Health, Environmental Health Perspectives, The Lancet Infectious Diseases, Trends in Parasitology*, and the *International Journal of Circumpolar Health.* The connection to "Urban Blue & Green Infrastructure" is marginal with only eight inter-cluster citations, indicating that there is not much disciplinary intersection between them.

The smallest cluster (Cluster 4) on top of the citation map is about "Climate Change and Food Security". The reason for the relatively isolated position (22 inter-cluster citations with Cluster 3) is the merely indirect relation to health. It mainly covers food security and plant related (infectious) diseases. These are often favored by climate change, with significant effects on food crops, and malnutrition is one of the potential health related consequences. The journals with highest abundances are *Plant Pathology, Canadian Journal of Plant Pathology*, and the *European Journal of Plant Pathology.*

Evolutionary Dynamics of the Document-Based Epistemic Communities

The temporal analysis provides insights into the evolutionary dynamics of document-based epistemic communities. For each of the four clusters the mean value of the publication year (mPY) was calculated. It reveals a similar picture as in the case of the keyword co-occurrence network. With an mPY of 2016, "Urban Blue & Green Infrastructure" (green) represents the most recent cluster. "Climate Change & Public Health" (red) has a mPY of 2012 and both "Climate Change and Emerging Infectious Diseases" (blue) and "Climate Change and Food Security" (yellow) have an mPY of 2010. Accordingly, the evolution of the document-based epistemic communities in Figure 2 began at the top left and evolved to the bottom right. "Urban Blue & Green Infrastructure" has a different disciplinary anchoring as compared to the older clusters, indicating a recently emerging document-based epistemic community. The citations referring to "Climate Change & Public Health" point towards cross-disciplinary boundary transgression.

4. Discussion

Climate change poses a broad variety of systemic risks for human health, well-being, and the living environment in general. With increasing urgency of counteraction, different adaptation and mitigation measures to cope with climate change-induced health risks are becoming increasingly relevant. These measures, however, must take into account a high degree of complexity. In light of ageing societies, effects may even become more severe as the vulnerable population groups increase [15]. Temperature rise and resulting heat stress not only directly affect public health but also exert indirect effects by, e.g., reducing agricultural productivity [58]. This feeds back on health and well-being due to a growing risk of malnutrition. Increasing heat stress also threatens overall economic productivity by reducing labor capacity during heat waves [59]. Emerging infectious diseases as well as mental health issues add further complexity to the respective mechanisms [60,61].

Nature-based solutions, e.g., urban blue and green infrastructure, have the potential to address several climate change induced health issues. They can positively influence the health and well-being of the urban population. Our findings show that several relevant topics emerged during the last 30 years and that they peaked at different times. The most recent topic refers to research targeting urban blue and green infrastructure as adaptation and mitigation measures. Ambient air temperature can be reduced by up to 4.0 °C through evapotranspiration [62]. Additionally, extensive green roofs enhance natural rainfall retention capacity in urban areas by up to 22% [63]. As extreme storm water events are becoming more probable because of climate change, urban sewage systems can easily be overburdened. This can paralyze cities on a large scale, causing not only economic damages but also human casualties. Urban vegetation also acts as a passive filter of urban air pollution. It has been shown that city greening can effectively filter airborne particulate matter, thus reducing adverse effects on health [64–67]. Besides these physical benefits, urban vegetation contributes to mental health [68,69].

However, existing knowledge on climate change effects and possible mitigation and adaptation measures is still fragmented across different disciplines. Our results indicate that the citation based "interaction" between documents related to health research (red and blue cluster in Figure 2) and documents related to urban and landscape planning, civil engineering, or architecture (green cluster in Figure 2) is relatively weak. The connection between these document-based epistemic communities is created via concern for the urban heat island effect and its implications on human health. In this context, nature-based interventions are discussed as potential solutions to cope with overheating.

We would have expected a tighter connection between these communities and disciplines. The benefits provided by urban blue and green infrastructure seem to perfectly fit in the causal relationship between climate change and health. Thus, it was surprising to see that the citation based "interaction" is not better developed so far. However, it is also necessary to remark that the academic discourse on urban blue and green infrastructure is the most recent part in the citation network. The "citation gap" between the left and right cluster in Figure 2 represents only the status quo. We may also interpret it as a condensation core for an increasing convergence between usually isolated disciplines (medicine related and urban planning and engineering related). At least this would be desirable as for a single discipline and epistemic community, it is nearly impossible to solve such a complex problem like climate change and its related health effects. Single disciplines can only provide pieces of potential solutions. Addressing complex societal problems demands contributions from a variety of disciplines and also must consider knowledge incorporated in and produced by non-scientific entities. Referencing across different epistemic communities and disciplinary boundaries indicates that research on urban greening is increasingly contextualized with medical and public health-related findings. Previously fragmented knowledge is thus put into broader context. In a recent scientometric study on climate change with a focus on infectious diseases, Sweileh showed that research activities on the health effects of climate change have been sharply increasing since 2007, but that innovations, policies. and the preparedness of the health system still need to catch up [70]. This finding points towards a shared responsibility of different actors and entities in view of tackling the problem. It furthermore shows that, although the knowledge exists, the operationalization of this knowledge in action lags behind. Literature shows that strong causal links between health, overheating, energy consumption, pollution, income, and vulnerability exist but that an integrative and holistic frame theorizing these causalities is still lacking. In order to address this shortcoming, a conceptually more extended and interdisciplinary framework is necessary [71]. Adaptation and mitigation measures need to consider the complexity of underlying cause–effect relationships. Health actors need to be involved in the discussion on the built environment and vice versa. Frameworks developed by public health professionals already exist and may be of interest for this topic [72].

Despite the emerging demand for interdisciplinary cooperation, and indications of a convergence of different disciplines addressing the same societal grand challenge, there are still gaps in research that need to be addressed properly. This includes more research on the interplay between climate change-adapted built environments and their effects and relation to health impacts [73,74]. New and adequate funding regimes as well as policy strategies are necessary for progress in this regard. They would facilitate inter- and transdisciplinary research on the nexus between health, climate change, and nature-based interventions. In order to successfully address the challenges and public health burdens created by climate change, a coordinated and holistic approach is needed, which embraces a variety of knowledge bases across different disciplines and entities.

Currently, decisions on the built environment are usually made by city planners, politicians, investors, and public service officials. Considering a health-in-all-policies perspective, this is no longer sufficient. Public policies should be designed across sectors and need to systematically take into account their health and health systems implications [75,76]. Because the built environment affects health and well-being, it is necessary to involve health professionals in respective decision-making processes [77]. Moreover, coupling climate change mitigation policies in urban space with health care related policies may increase the legitimacy of measures within both policy fields since their ultimate outcomes will be beneficial for both human well-being and the effectiveness of climate change adaptation as well as mitigation [78].

The underlying study also has limitations, which need to be pointed out. The first one is concerned with SCOPUS as a data source. Although SCOPUS is one of the largest scientific databases, including journals from a variety of disciplines, there are also journals that are not indexed in SCOPUS. This includes for instance sources of regional interest. Nevertheless, this also holds true for alternative databases such as Web of Science. Concerning the thematic coverage, SCOPUS is well positioned in areas like natural, medicine, and health sciences but also engineering and technology. Pranckutė [79] has extensively analyzed and compared SCOPUS and Web of Science. In conclusion, SCOPUS performs better according to the criteria like implemented impact indicators, coverage, and usability.

Another limitation, which needs to be pointed out, is related to the search query. In addition, the best-defined search query cannot guarantee to cover 100% of the relevant literature (i.e., to be complete). The search query is always a compromise between noise and relevance. Furthermore, SCOPUS (as well as other databases) are not immune to errors that occur in publication metadata. Our relevance screening of the dataset intended to address the issues related to relevance and potential errors.

There is also a disadvantage concerning the application of direct citation data for the construction of citation networks. Citation data are dynamic bibliographic data, meaning that during the analysis of that data at a certain point in time, there may be some documents that have no relation (i.e., citation) with other documents. During the clustering procedure, this leads to the effect that these documents cannot be assigned to a cluster. However, direct citations have been shown to produce more accurate clusters compared to other citation-based network analyses like bibliographic coupling or co-citation [80].

A further limitation is also related to the clustering procedures performed in VOSviewer. Within the research field of scientometrics, a broad variety of different clustering methodologies exists [31]. The application of different clustering techniques to the same dataset may yield different results. However, VOSviewer is a broadly used, well maintained, and renowned tool for scientometric analysis yielding highly reproducible and high-quality results.

5. Conclusions

The results of this scientometric study show that a multidisciplinary reference to blue and green urban infrastructure and health can be traced in the scientific world. These discourses can be seen as an encouraging sign of the need for intra-scientific interdisciplinary exchange. Notwithstanding this, however, several areas remain to be mentioned into which this exchange of expertise must continue.

Complex societal problems, such as the question of how to deal with climate change, must be addressed as broadly as possible. This breadth must of course also be reflected in the scientific expertise that flows into general social discourse. Our results showed that in the academic world, technological and nature-based interventions as measures to cope with climate change-induced health effects in urban spaces is an emerging field of research. The disciplinary foundation of this emerging field of research is located within urban and landscape planning, civil engineering, and architecture. To our surprise, its relation to the "older" scientific discourse on health and medicine related research on climate change is not as strong as expected or as it should be. We think that this gap needs to be addressed by, e.g., implementing specific research funds that intend to build intellectual capacity at the disciplinary intersection between health and urban planning professionals. Additional communication channels between academia, policy making, and the society in general need to be implemented in order to not only achieve integrative and holistic policy making but also to raise awareness and to mobilize society. There is still plenty of untouched potential for collaboration and knowledge exchange between different actors, e.g., scientists, politicians, urban and transportation planners, healthcare providers, and concerned individuals and citizen groups. Here, broadly understood interdisciplinary scientific expertise can make a contribution to raising awareness of the problem among social actors. The sooner this goal is achieved, the better displacement mechanisms, e.g., in the sense of cognitive dissonance of individual actors, can be broken up. Finally, this improved awareness of the problem provides the indispensable basis for the development of mitigation strategies that are widely accepted by society. This observation is not only calling for new ways of thinking, e.g., acknowledging longer time frames than usual in political decision making, strengthening systems thinking approaches instead of assuming linear causalities, but it also requires effective risk communication and appropriate actions that lead to synergistic health, environment, economic, and social benefits.

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