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Delphi-based future scenarios: A bibliometric analysis of climate change case studies

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ABSTRACT

In the Future Studies context, the scenario development process is an established method for the identification of future projections, useful to avoid future threats and take different actions in the present. The development of future scenarios is often combined with different participatory approaches, one among many is the Delphi method, widely adopted for its systematic and interactive nature. In this context, the recent climate challenges lead society to an exponential growth of uncertainty about the future where Delphi-based scenarios (DBS) could be helpful to identify interesting mid and long-term projections. For the purpose of conducting a systematic review of Delphi-based future scenarios applied to climate change context, we used a quantitative bibliometric analysis aimed at investigating the scientific literature path, implementing it with a multiple correspondence analysis and a semantic network analysis. We illustrate the results of the case studies focusing on the combination of methods, rounds of the process, panellists' sampling, time horizon, and techniques used, to establish new guidelines for future Delphi-based climate research projects.

1. Introduction

The development and application of future scenarios is a multidisciplinary approach used to create possible hypotheses on the long-term future to constitute effective planning (Becker, 1983). They cannot be thought of as objective facts, but rather as innovative objects of study to outline possible or plausible future alternatives (Berkhout, Hertin, & Jordan, 2002). In the framework of scenario planning, different participative methods are adopted, one among many is the Delphi, a popular and empirical approach in the scientific literature (Dalkey & Helmer, 1963; Linstone & Turoff, 1975; Bishop et al. 2007) useful for the development of future scenarios in uncertainty situations (Kosow & Gaßner, 2008). From a historical point of view, the Delphi method was developed in the 1950s in the RAND Corporation (Santa Monica, California) by Olaf Helmar, Norman Dalkey, and Nicholas Rescher (Gordon, 1994), to fill several forecasting gaps, and overcome the quantitative-deterministic approach, considered limited by the creators. Initially, the purpose of the study (Sossa, Halal, & Zarta, 2019) was to estimate the impacts of the Cold War (Rowe & Wright, 1999), to better understand the vulnerability of the United States and the possible future implementations of the technology in the US Army (Linstone & Turoff, 1975), becoming one of the most used approaches in decision-making and forecasting research. In our context, the Delphi method is assumed as an important iterative method (Di Zio, Rosas, & Lamelza, 2017) and "a way of using collective human intelligence" (Rodríguez Parisca, 1995), most of the time preferable to face-to-face traditional meetings in as much as feedbacks are

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expressed by professional experts along with their degree of expertise (Baláž, Dokupilová, & Filčák, 2021).

In general, the Delphi method is developed according to a systematic and organized approach of questions and feedback involving experts and their judgments (Martino, 1983; Benarie, 1988), with the application of different qualitative/quantitative techniques during the process. The approach consists of various steps, Belton, MacDonald, Wright, and Hamlin (2019) found that the Delphi-based scenario (DBS) process, can be divided into four phases: i) a clear definition of the study object; ii) an overview of the information basis (e.g., problems areas, key factors, trends, social visions); iii) Delphi rounds (generally two, but it can vary in relation to the convergence obtained), with the analysis of the results and the scenario workshops indiction; and iv) final policy recommendations (scenario transfer). In these terms, the application of the Delphi method becomes useful to develop new projections, immediate advice, and new visions of futures, providing an essential contribution to today's policies in the decision-making context. The frameworks of application of the Delphi method are numerous, and many case studies have been carried out for the construction of scenarios on economic, political, social, and medical aspects (Toppinen, Pätäri, Tuppura, & Jantunen, 2017; Bijl, 1992; Lee, Cho, Hong, & Yoon, 2016) and since the 1950s, new techniques have been changed with new implementations, providing important methodological insights. From the existing literature, in the climate change context, different quantitative forecasting techniques (Pulido-Velazquez, Collados-Lara, & Fernandez-Chacon, 2022) are normally used (e.g., trend analysis or historical series), and with the spread and recognition of Future Studies as a discipline (Urry, 2016), Delphi-based scenarios (DBS) are currently receiving growing interest from climate researchers (see Mearns et al. 2001; Puma & Gold, 2011; Pielke & Ritchie, 2021).

In the context of climate change adaptation and mitigation strategies, with ever-increasing climatic challenges (Rahman, 2013), we need more long-term future projections and policies to be adopted in the present, and the adoption of the Delphi method in scenario planning could be a useful implementation. Currently, our planet is facing different threats such as environmental degradation, urban pollution, rising temperatures, heatwaves, and storms (IPCC, 2014) where anticipating the future becomes essential. In relation to what was previously stated, this paper aims to provide a systematic overview of the Delphi-based future scenarios applications in scientific research for climate change adaptation and mitigation strategies.

To pursue our research objective, we applied a quantitative analysis of the scientific production with a combination of statistical techniques aimed at understanding the overall contributions to the field. Specifically, this paper proposes: i) to show the annual production of scientific studies during the last twenty-five years; ii) to show the scientific production of individual countries and the collaborations between them; iii) to use a multiple correspondence analysis (MCA), a hierarchical clustering and a co-occurrence analysis to understand the topic clusters in the studies; iv) to discuss the extracted case studies, specifically about the combination of the two methods, rounds, panellists, time horizon and techniques used, outlining guidelines for future research projects. This paper is organised into the following sections: Section 1 is introducing the work; Section 2 describes the theoretical framework of the Delphi method (see 2.1.) and scenario planning (see 2.2.), focusing on the origin, the process, and the open questions; Section 3 provides an overview of Delphi-based scenarios; in Section 4 the methodology used and the data gathering are outlined; Section 5 illustrates the results of the bibliometric analysis; in Section 6 we focus on the discussion of the results, analysing different variables including the combination of the two methods, number of rounds, panellists selection, time horizon and the techniques used in the case studies; finally in Section 7 conclusions will be outlined.

The innovative contribution of the paper is to establish guidelines for future DBS in the climate change adaptation and mitigation field improving case studies, with new potential techniques.

2. Theoretical framework

2.1. The Delphi method

For Dalkey (Dalkey, 1967, Delphi, Santa Monica, The Rand Corporation), the Delphi method "is a process of knowledge that allows structuring the communication of a group of privileged witnesses (or experts), in order to coagulate subjective judgments regarding the reality, forecasts of events and decision-making". We can assume here that group decisions are much more accurate than individual judgments (Galton, 1907), in fact, Gordon (2009b) and Justo (2005), state that Delphi meetings are valid because they are composed of specialists from different areas of competence, and study a specific topic, by sharing opinions, in order to build common possible scenarios. In these terms, the anonymity of the privileged witnesses constitutes a value within the procedure, Lindeman (1975) points out that this method combines different opinions from separate experts, through the use of a series of questions to produce consensus or dissensus in the majority of cases (e.g., Cuhls, 2015; De Loë, Melnychuk, Murray, & Plummer, 2016) and eliminate any conflicting situations that could arise from an in-person meeting. The Delphi method can be the ideal method for cases without predictive means of confirmation (as in the case of environmental challenges) and for identifying breaks or innovations in a specific field of knowledge, specifically considered to be appropriate for studies lacking in historical data and that require the gathering of experts' opinions (Peffers & Tuunanen, 2005; Rowe & Wright, 1999, 2001; Ewton, 2003; Scott and Walter, 2002). According to Linstone (1978), the Delphi method is appropriate to use when the research question cannot be answered with precise technical analysis but through collective judgments, specifically when "individuals who need to interact cannot be brought together in a face-to-face exchange because of time or cost constraints" (Linstone, 1978 p. 275). On the other hand, Dalkey (1969) and Uhl (1983) agree that this method is not optimal only in these circumstances, it is also useful when a face-to-face group is not available due to individual or subgroup dominance, where possible bias could occur.

For Woudenberg (1991) and Rowe and Wright (1999), Delphi is characterised by four fundamental aspects: i) anonymity; ii) iteration; iii) controlled feedback; and iv) statistical aggregation, and according to Martino (1983), to the previous characteristics, we should add v) the opinions and vi) the judgments of the panellists, fundamental during the process. The Delphi process plans to build and administer a series of questionnaires with specific questions to defined panellists (Fitch, Bernstein, Aguilar, Burnand, & LaCalle, 2001), however, in the scientific literature different open challenges remain, and for these reasons, new implementations can be analysed and proposed. Based on what emerged from our review, conducting a Delphi study can be time-consuming (Schmalz, Spinler, & Ringbeck, 2021), due to four practical main problems, the planning of the questionnaires and the rounds, the decision on the number and the selection of experts, the assessment of the degree of expertise, and the difficulty in receiving responses in as much as experts are most of the time, occupied. Specifically, since the Delphi approach consists of detailed and numerous questions, as well as several rounds, the experts will have to dedicate significant time to fill in the questionnaires, in fact, a minimum of 45 days is required to conduct a Delphi study (Delbecq, Van de Ven, & Gustafson, 1975; Ludwig, 1997; Ulschak, 1983).

In this context, one of the main open questions is what characteristics an expert should have and how to identify a significant sample size in the process, where most of the time, non-probability or purposive sampling is adopted (Devaney & Henchion, 2018). For Beech (2001) and Sharkey and Sharples (2001), an expert is someone who provides detailed information based on their degree of expertise (Rowe, Horlick-Jones, Walls, & Pidgeon, 2005) in order to obtain valid opinions. Since the experts are the fulcrum of the process, they should be “very knowledgeable about or skilful in a particular area” (Soanes & Stevenson, 2003). However, these definitions may appear very generic, Sackman (1975) states that the previous definitions are unconvincing because they are not sufficiently detailed, in fact, in this context, “there is no magic formula to help researchers decide on who are the experts and how many there should be” where “this decision is often based on funding, logistics, and rigorous inclusion and exclusion criteria” (Keeney, Hasson, & McKenna, 2006).

Recently, Devaney and Henchion (2018) proposed an interesting contribution aimed to understand who a Delphi expert is, adopting a conceptual continuum of “closeness” to the bio-economy topic, in order to consider different types of expertise (e.g., academics, stakeholders, local authorities, etc.). Nevertheless, as better defined in the next section, the main challenge is the real and objective quantification of the expertise degree, where self-assessment methods are currently used, and different cognitive biases could occur (such as overestimation or underestimation).

In this regard, Ludwig (1997), affirms that the number of experts identified in a Delphi study generally should be a representative sample that can elaborate judgments and information held by the research group and most studies use between 15 and 20 experts. However, there is no narrow range of consensus in the literature therefore the size of Delphi is subject to the personal judgment of the researchers. Witkin, Altschuld, and Altschuld (1995) affirm that a Delphi panel under 50 experts could be sufficient, but on the other hand, Delbecq et al. (1975) suggest that in conditions of homogeneity, 10–15 experts are enough.

Recently, Belton et al. (2019) provide a systematic guideline for the design and administration of a Delphi survey, showing that the number of expert panel members can vary in relation to the specific aims and context of the study. If there is a small number of experts, we could have a representative set of judgments that are not sufficiently valid, if, on the other hand, the sample size is too large, we could obtain fewer responses compared to the number of invitations sent, not producing significant results in terms of responses (Hsu & Sandford, 2007).

2.2. *Future scenarios development*

Being a participatory decision-making approach, the Delphi method is used in different application contexts. In this paper we focus on its combination within scenario planning, one of the major approaches adopted for the study of different futures, demonstrating its usefulness in the context of climate change adaptation and mitigation. In 1985 (Porter, 1985) Michael Porter defined future scenarios as: “an internally consistent view of what the future might turn out to be – not a forecast, but one possible future outcome”. Scenario planning is an important part of strategic planning for understanding the tools and technologies for managing future uncertainties (Ringland, 1998; Schwartz, 1991). As described by Kosow and Gaßner (2008), scenario development is not a conceptual methodology, it does not describe mere facts, but it describes the developments, the dynamics, and the driving forces of a specific conceptual future result (Greeuw et al. 2000; Götze, 2006). In this case, the future is unpredictable and is made up of sudden turns, and hidden changes, where a simple action or a simple shift can change the pre-set scenario (Kosow & Gaßner, 2008), for this reason, we should refer here to the term “futures”, as the future trajectories will be multiple and there will be no univocal projection of the future perspectives (Chermack, Lynham, & Ruona, 2001; Fritschy & Spinler, 2019; Schoemaker, 1995).

The main purpose of scenario planning is therefore to represent a hypothetical future through the observation of certain influence factors; we do not have an exact view of the future, but rather different projections of the futures. In fact, for Kahn and Wiener (1967), “scenarios are hypothetical sequences of events constructed in order to focus attention on causal processes and decision points”. In the scenario development process, all the key factors should be analysed, precisely because the final aim is not to elaborate a detailed idea of the future, but rather to “orient towards the future” (NURMI, 1989). In these terms, driving forces can be considered relevant or irrelevant to the extent that they are brought into play within the procedure in a correlation context, where specific methodologies are required (Van Der Heijden, 2000). In sum, we can now affirm that the future has three essential characteristics: i) in the first instance, it is predictable; ii) it is evolutionary; iii) and finally, it is malleable (Kosow & Gaßner, 2008) where the more the future becomes uncertain the more there is the need to analyse it.

In our context, there is no single methodology for the development of future scenarios, as it varies according to the final purpose of the research project. A widespread approach is proposed by Bishop, Hines, and Collins (2007) in strategic foresight, but is also useful for the development of future scenarios (e.g., Nowack, Endrikat, & Guenther, 2011; Hines and Bishop, 2015; Di Zio, Bolzan, & Marozzi, 2021). The authors identify six main phases in the process: i) Framing, where efforts are made to identify the study environment, objectives, and the work team; ii) Scanning, which retraces the history of the object of study, scanning the information of the present to identify future issues later; iii) Forecasting, identifies the uncertainties and the drivers, the tools, the approaches, and the different alternatives; iv) Visioning, outlines forecasts and future outcomes; v) Planning, manages possible policies and actions to be taken based on previous visions; and vi) Acting, communicate results, developing actions in the present and thinking strategically.

Generally, the six phases of the scenario planning process are not always followed chronologically and many scholars after the Framing phase might omit the Scanning and Forecasting phases and proceed into the Visioning phase (Hines, 2006).

In the environmental and climate context, the analysis of the different futures becomes increasingly fundamental, since future studies can support decision-making for the identification of opportunities and threats that could arise in the coming years or decades (Hines & Bishop, 2015). For this reason, the Delphi method is recommendable as it can be used in one or more phases of scenario planning (Di Zio et al. 2021).

3. Delphi-based scenarios

Delphi-based scenarios follow a well-indicated procedure, which may vary in relation to the questions and research objectives. Following a temporal order, the outputs of the scenarios can be used as inputs for the Delphi study, or the Delphi rounds can be of support for the development of different scenarios (Heiko & Darkow, 2010; Di Zio et al. 2021). This second approach is known as Delphi-based scenarios (Heiko and Darkow, 2010) and is particularly useful as the Delphi method is ideal for identifying and evaluating key variables and trends. Nowack et al. (2011) proposed an interesting review of DBS applications, investigating how the Delphi method can be integrated into scenario planning, focusing on three principal criteria: creativity, credibility, and objectivity. Starting from the line of research suggested by Bishop et al. (2007), the authors identified three phases where the Delphi techniques could be implemented: i) Scanning; ii) Forecasting and iii) Visioning phase.

In the Scanning phase, all the information about the system, history, and context of the study should be reviewed. In a long-term planning horizon, experts are required to identify possible future trends and challenges, starting from the study of the existing literature, providing greater creativity to the process. Also, the inclusion of the Delphi method at this stage solves some cognitive and communication biases that may occur, in fact, anonymity can reduce communicative obstacles for the participants and can solidify the iteration and feedback during the rounds. For the authors, in the Scanning phase, the combination of the two methods can enhance the creativity, objectivity, and credibility of the drivers. However, since in this phase, the experts are required to review the literature, referring to a large corpus of documents on the topic of interest or participating in different workshops, one of the main challenges is to reduce the time consumed by the process. In recent years, to overcome this challenge and simplify the process, new methods have been proposed, Kayser and Shala (2020) developed a new approach, starting from the extraction of a dataset of tweets in the technology context, adopting a concept mapping and a topic modelling approach to permit an easy overview of the literature on the topic, providing the experts with valuable starting points. In fact, Calleo and Di Zio (2021), studying the future of Covid-19, developed an implementation of the previous method, extracting a corpus of tweets that included the geographic location, adopting an unsupervised spatial data mining and topic modelling to acquire more information on the topic, including spatial distribution of the users' opinions. These methods could be useful at the first stages of the DBS process, as they can reduce the time to acquire the literature or to indict multiple workshops, where the experts could already have significant elements at their disposal and decide only which ones take into consideration.

Based on the Nowack et al. (2011) approach, the Delphi method can be adopted also in the Forecasting phase, where experts can be of support for the identification and the evaluation of key factors and uncertainties avoiding the possibility of postponing the decision on the selection of drivers to the research team (with a consequent increase in objectivity). However, as stated by Nowack et al. (2011), creativity and credibility here play a minor role, as the objective of the participants is to identify significant trends, prioritizing the drivers. Finally, in the Visioning phase, after a set of scenarios have been developed, experts can evaluate the plausibility, and prepare possible actions. In this regard, there is an enhancement of creativity, credibility, and objectivity.

In recent years, several authors proposed different case studies, generally adopting the following approach: i) in the first phase, the projections are formulated; ii) the panel of experts is identified; iii) the previous projections are evaluated in the Delphi rounds and iv) the scenarios are developed. Culot, Orzes, Sartor, and Nassimbeni (2020), studying the future of manufacturing, adopted a DBS, dividing the research into four stages, the authors started with the development of projections by applying a conceptual model technique to then select a panel of experts. The selection of experts, started here from the analysis of the Scopus database, understanding possible personal networking, and for non-academic experts, they took into account "individuals with at least manager-level responsibility in the industries in scope or their employment with digital players, technology providers, digital advisory boutiques as well as management consultants". In this case, the Delphi survey was applied in phase three, conducting two rounds to obtain convergence and identify drivers and trends. Peppel, Ringbeck, and Spinler (2022), studied the last-mile delivery in 2040 by developing Delphi-based scenarios, starting from the development of future projections, with the execution of a literature review, formulating a set of projections and validating them with an expert workshop. The Delphi survey was administrated in order to obtain convergence of opinions in two rounds to then develop future scenarios adopting a narrative-descriptive analysis and a clustering process, identifying two different variables: plausibility and consistency. Finally, Beiderbeck, Frevel, Heiko, Schmidt, and Schweitzer (2021), studied the impact of Covid-19 on the European football ecosystem, developing DBS, starting from the Roßmann, Canzaniello, von der Gracht, and Hartmann (2018) approach. The authors divided the study into three phases: i) projections development, with different workshops, desk research, expert interviews, and formulation sessions with a draft list of the projections; ii) expert selection based on a heterogeneous set of experts, including participants with different backgrounds and from different countries with a variety of gender and age; iii) analysis, with descriptive statistics, including qualitative (i.e., content analysis) and quantitative analysis (mode, arithmetic mean values, interquartile ranges, cross-impact analysis etc.). Also, the authors introduced computational analysis such as a "dissent analysis" and a sentiment analysis to then apply a Fuzzy c-means algorithm for the development of future scenarios.

Table 1
Open questions in the Delphi-based scenario process.

Id	Question	References
1	How do reduce time-consuming and increase high participant motivation?	Rowe and Wright (1999); Gordon (2007);Geist (2010);Schmalz et al. (2021)
2	What new methods can be adopted to extract the key drivers while avoiding time-consuming?	Nowack et al. (2011);Kayser and Shala (2020); Calleo and Di Zio (2021)
3	How many experts should be selected for the construction of a panel?	Linstone and Turoff (1975);Baker, Lovell, and Harris (2006);Belton et al. (2019)
4	What is the new method for the identification and selection of experts?	Culot et al. (2020);Di Zio et al. (2021);Peppel et al. (2022)
5	What approaches can be used for the measurement of the expertise degree?	(Bedard, 1989); Barroso Osuna and Cabero Almenara (2013);Devaney and Henchion (2018);Bonaccorsi, Apreda, and Fantoni (2020)
6	What is the best time horizon in which to investigate the future? And how is it selected by researchers?	Kosow and Gaßner (2008);Amer, Daim, and Jetter (2013)
7	What additional techniques and indicators can be implemented in the process?	Kayser and Blind (2017);Sossa et al. (2019);Di Zio et al. (2021)

As seen above, although the methods of application are different, the process requires different efforts, and some new approaches can be used to minimize these impacts. For example, the Real-Time Delphi (Gordon, 2009a), is a useful implementation, frequently applied in future studies contexts for the development of future scenarios. With this approach, the experts can see in real-time the trend of responses without waiting for the analysis of the results by the research team. Starting from that, in our climatic framework, a spatial implementation has been proposed by Di Zio et al. (2017) with the Real-Time Spatial Delphi technique, adopted in a few studies, due to the lack of dedicated platforms. From what emerged, in the Future Studies context, the adoption of the two methods can be combined in different ways (Kosow & Gaßner, 2008), producing an enhancement of the quality of the final outputs (Nowack et al. 2011). However, this combination leads to different open questions coming from each of the two methods. We summarise some of the open questions in the Delphi-based scenario method in the table below (Table 1). The previous questions are addressed and analysed in Section 4 as part of the bibliometric study and in the results section (Section 5).

4. Method and data gathering

4.1. Bibliographic data

To pursue the aim of this paper, we adopt a bibliometric analysis in order to understand the production of scientific case studies related to climate change Delphi-based scenarios. In our context, the bibliometric analysis allows us to explore and analyse large volumes of scientific data and cumulative scientific knowledge, to understand more about research trends, citations, collaboration networks, major countries, institutions, exploring the intellectual structure in the existing literature (Verma & Gustafsson, 2020; Aria & Cuccurullo, 2017).

For our study, we want to first compare the number of studies adopting scenario planning for the development of future scenarios in the climate change context, taking into account the following terms as keywords: “scenario planning”, “future scenarios” and “climate change”. However, to pursue our research objectives, once we obtain the results, we filter the papers with the term “Delphi” and “Delphi-based” to obtain only the study, adopting the Delphi method in the process. In this case, each topic will be identified in the abstract, the title, and/or the keywords of the contribution, by entering the word “AND” to obtain all the terms in the same paper. The decision to use these keywords rather than others was made by the research team, in order to encompass a broad spectrum of the research topic.

To extract relevant statistical information, we first compared two scientific databases widely used in the scientific literature: Scopus and Web of Science (we decided to exclude Google Scholar since it also offers results not published in scientific journals (e.g., online newspapers, non-index journals, etc.), for then decided to use the Web of Science database in August 2021, because it provided more contributions compared to Scopus (49 contributions against 37). Web of Science is produced by Clarivate Analytics and the multidisciplinary coverage encompasses 12.000 high-impact journals and 160,000 conference proceedings (the last update is 24 February 2017) with over 12 million articles.

Normally, the available data on the scientific databases are numerous, sometimes exceeding thousands of contributions, in our case, we apply the analysis to the case studies, and for this reason, we have a low presence of papers. However, this technique becomes equally useful in our context because it provides through quantitative analyses and statistical techniques a systematic overview of the framework of the case studies.

Once we extracted the general information, we have available specific details for each contribution (e.g., title, abstract, authors, etc.), in BibText format. To extract relevant data from our matrix, we use the Bibliometrix R package (Aria & Cuccurullo, 2017), an open-source tool for quantitative data that can include all the main bibliometric methods, performing bibliometric analysis, and building data matrices for co-citation, coupling, scientific collaboration analysis, country collaborations, and co-word analysis.

4.2. Multiple correspondence analysis and document scanning

To perform our research, we apply a multiple correspondence analysis (MCA) (Greenacre & Blasius, 2006). Multiple correspondence analysis is based on a correspondence analysis (CA), a multivariate statistical technique useful to summarize and visualize data in a multidimensional plot. In the CA logic, when there are K nominal variables, each of it correspond to a J_k levels, and the sum of all J_k levels are equal to J. Specifically, in the MCA, the original data are represented in a Euclidean low dimensional representation, plotting the keywords of the documents, in a two-dimensional map. The words are plotted onto a two-dimensional map where in the distribution among the different documents, the closest words are identified based on their distance.

We implement here a hierarchical clustering analysis to obtain clusters of contributions related by common terms, combining it with a semantic network analysis based on the abstracts to understand the co-occurrence of the terms. Starting from this point, we proceed with a specific scanning of the case studies, investigating the methodologies used in the Delphi study, including the combination of the two methods, rounds, the number of panellists and the identification of them, the time horizon, and the techniques used.

5. Results

In this section, the results of the bibliometric analysis will be illustrated, divided into three sections: i) in the first section, we describe a general analysis of the scientific production, showing the annual research activity and the citations information; ii) in the second section we analyse the scientific production rate for each country and the country links; iii) finally, we propose a multidimensional plot with an analysis of the principal topics, adopting the multiple correspondence analysis (MCA) and hierarchical clustering, illustrating the semantic relations between close keywords in a network. In Section 5, in order to scan all the documents and to have a detailed vision of the contributions, we proceed with the discussion of the results obtained.

5.1. Annual research activity

From the first results obtained, the papers discussing scenario planning in the climate change context are 5.027, with 943 case studies, demonstrating a strong interest in the development of future scenarios in the climate change context. However, only 49 adopted the Delphi in one or more phases, leading to several insights. (Table 2).

From what has been described before, 49 case studies were identified, in a time span of 25 years (from 1997 to 2022). The majority are articles ($n = 45$), book chapters ($n = 2$), and proceeding papers ($n = 2$). A total of 198 authors were found, with an average of authors per document of $\overline{x}= 4$. The single-authored contributions were written by 4 different authors, with an average of documents per author of$\overline{x} = 0.251$.

From a general perspective of the annual research activity of the Web of Science database, it is evident a fluctuant trend during the years which seems to be improving only in recent years. As represented in Fig. 1, the first case study was published in 1997, in fact, before this date, any contribution was published and until 2005, there are no new contributions. Starting from 2005 we have a fluctuant situation that starts with the publication of 1 article in 2005, with a stable situation until 2012 ($n = 4$). However, from 2013, the publication of contributions decreased with 3 articles in 2013 then falling again in 2014. After 2014, the overall situation seems to improve, with a steady increase in the linear forecast, in fact in 2017 we have a high peak of 7 articles for then decrease again in 2019 with 4 publications and increase with 6 articles published in 2020. In sum, the trend over time is not homogeneous and it turns out to be fluctuating, but it is constantly increasing with an annual growth rate of $x = 7.43$ % and with an average year of publication equal to 5.59.

After a first analysis of the principal information of the annual production, from Fig. 2 it is possible to understand the annual citations per year, this analysis is interesting because allows us to understand how many contributions are cited in further scientific papers, which is useful for our literature review. The results obtained demonstrate different perspectives, starting from 2005 we can see a slowly increasing trend, but fluctuant over the years, that starts with a mean of 1 citation and have different peaks, in 2008, 2011, 2013, 2015 and in 2019 with a MeanTCperYear = 8.67, where TC = total citations. Overall, as the annual productivity here we have an increasing fluctuant scenario.

Table 2
Scientific contributions adopting scenario planning or Delphi-based scenario process.

Method	Frequency	Time span	Authors	Articles	Conference proceedings	Book chapters
Scenario planning	943	1995–2022	450	880	55	8
Delphi-based scenarios	49	1997–2022	198	45	2	2

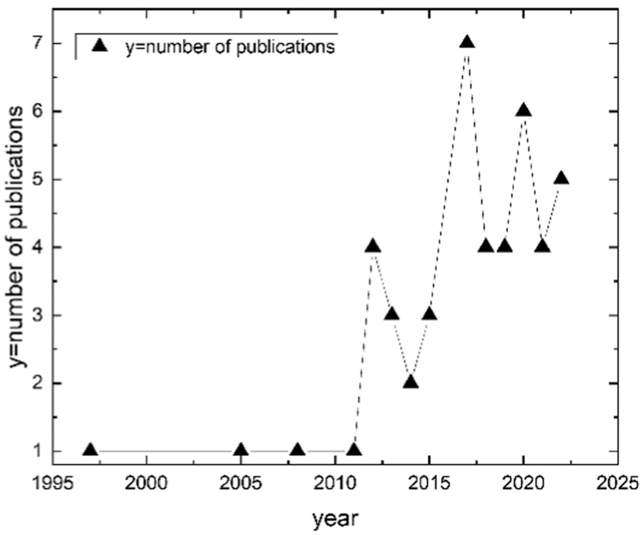

Fig. 1. Annual scientific production.

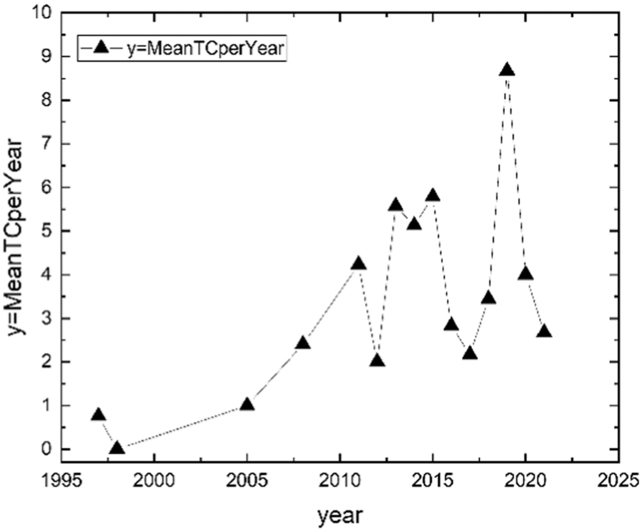

Fig. 2. Average citation per year.

5.2. Country activity

After a first overview of the annual scientific literature, we proceed in this section with the representation of the results of the most productive countries and the collaboration links between them using an analysis of the absolute frequencies. The application of this technique allows us to obtain important information about the involvement of some countries in future climate themes compared to others and the collaborations developed between different countries located on different continents. From the results obtained, we will proceed with the discussion of the top five most productive countries by investigating the motivations and topics of discussion.

The country that produced the most case studies is the United Kingdom with 36 case studies. In fact, in the UK precipitation, temperatures, and sunshine increased as a result of climate change. Some scientists claim that over the 30-year time horizon, the UK became 0.9° warmer, and 6 % wetter, it is estimated that 3400 people died due to high temperatures in the years 2016–2019 (Cotton & Stevens, 2019).

South Korea proposed 30 papers and from what is emerging, more and more challenges are spreading due to climate change, and many countries are developing future planning projects to fight it. Climate change is one of the major threats in South Korea which has led to various weather events with social, economic, productive, and cultural consequences. Several parameters have been studied, including the annual temperature and the amount of precipitation and according to the Environmental Performance Index, South Korea ranks 173rd out of 180 nations in terms of quality in the area, where more than 50 % of the population is exposed to heavy inhalation of fine dust. We in fact know that South Korea has numerous environmental laws, with different restrictions on both green belts and emissions, however, it is actually one of the most polluted countries in the world in terms of air quality (Lim et al. 2019) and for these reasons, many studies involved experts to prevent future disasters.

Moving to the northern European part, Finland contributes to the debate on climate change with 25 studies. We know from the scientific community the research interests of Finland in the climate change context (Carter & Kankaanpää, 2003), in fact, there is a substantial environmental focus, with the development of new strategies and policies to fight climate problems since the advent of the Act which entered into force on 1 June 2015. In these terms, according to scientists (Forsius et al. 2013; Nerem et al. 2018), Finland should reduce its greenhouse gas emissions by at least 80 % by 2050 compared to 1990 levels, otherwise, temperatures and rainfall will rise and sea levels in the Baltic Sea will rise resulting in reduced winter ice cover.

In terms of production, Spain contributes with 19 studies, developing interesting output scenarios in environmental and climatic frameworks, as we will see later in the analysis of the collaborations. In fact, of particular concern, as stated by the European Union, in 2020 the average temperature in Spain was 1.7 degrees Celsius, which increased exponentially over the years and was much higher than at the end of '900. The European Environment Agency (EEA) and the Joint Research Center (JRC), say that Spain is one of the countries in Europe most vulnerable to climate change where the rate of warming has accelerated in recent decades, increasing by a cumulative 1.3 degrees. in 60 years.

The fifth country in terms of contributions is Japan with 12 contributions. Since Japan is hardly fighting against climate change, where temperatures and precipitation drastically increased before 2020, many studies have been published. Some forecasts affirm that in the future, Japan's temperature will increase by about 4 degrees leading to plausible environmental disasters. (Fig. 3).

After a first analysis, we proceed with an analysis of the collaborations between countries to understand more about the link between the principal country and the affiliate country. From what emerged, most of the links are between Spain and Portugal, with $n = 4$ contributions. Finland and Germany, Finland and Spain, the United Kingdom and New Zealand, and the United Kingdom and Spain, contributed with 2 works on the topic. The remaining countries have collaborated only 1 time with other countries. On the other hand, if we look at the general collaboration links, we can see some different results, illustrated in Table 3.

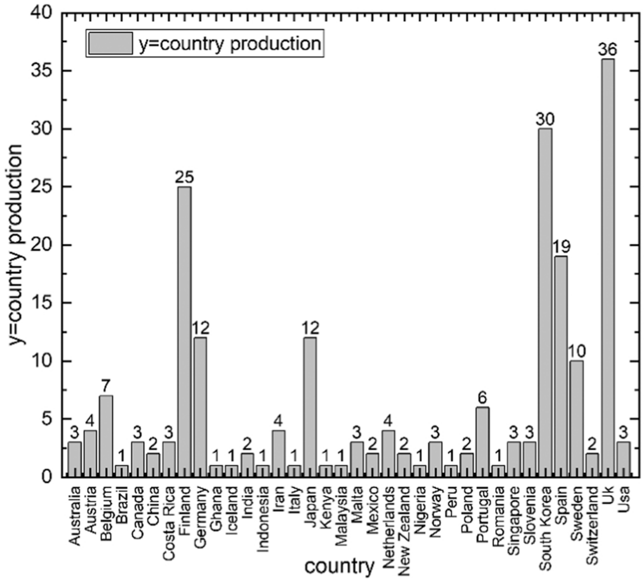

Fig. 3. Country activity.

Table 3
Country collaborations.

Country	N
Australia, Iceland, Korea, Mexico, Netherlands, Slovenia, United States	1
Costa Rica, Iran, Italy, Malta, New Zealand, Portugal, Romania, Sweden	2
Belgium	4
Kenya	12
Austria, Brazil, Germany, Ghana, Indonesia, Japan, Malaysia, Norway, Peru, Singapore	14
Canada, Finland	15
Spain	17
United Kingdom	22

The country that collaborates more frequently with at least one other country, is the United Kingdom, with $n = 22$ collaborations, for than found Spain with $n = 17$ collaborations, Canada, and Finland with $n = 15$, and Austria, Brazil, Germany, Ghana, Indonesia, Japan, Malaysia, Norway, Peru and Singapore with $n = 14$ contributions.

5.3. Factorial analysis and thematic plot

After a first overview at the research activity, the aim of this paragraph is to cluster the major themes of the documents in order to have a general – and immediate – perspective of the studied framework. To pursue our aim, we applied here a factorial analysis and a co-occurrence network. To depict the conceptual structure map, we decided to rely on the authors' abstracts, and the results are represented on the two-dimensional plane of the multiple correspondence analysis (MCA). We have decided to apply the technique to the abstract excluding the authors' keywords because with this approach the keywords used for the preliminary extraction do not appear in the results, producing more detailed results.

The results obtained are significant, from a general point of view, the horizontal dimension separated terms related to future scenarios and its method, to energy words, with a variability of 34.58 %, on the other hand, the second-dimension separate policy and decisions making context to assessment and adaption (see Fig. 4).

From the hierarchical clustering, important clusters emerge, that we can identify by the colour (red, green, blue, violet, and yellow). In the red cluster, we can depict different terms, on the first quadrant we have words related to the decision-making context,

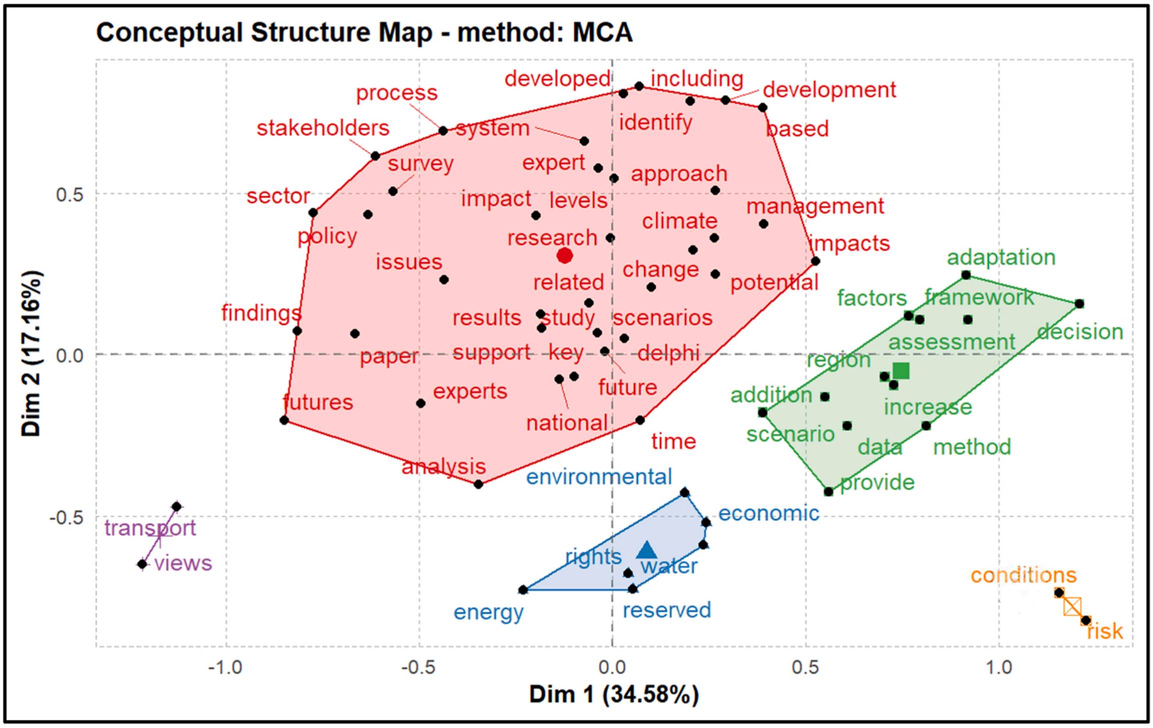

Fig. 4. Multiple correspondence analysis outputs.

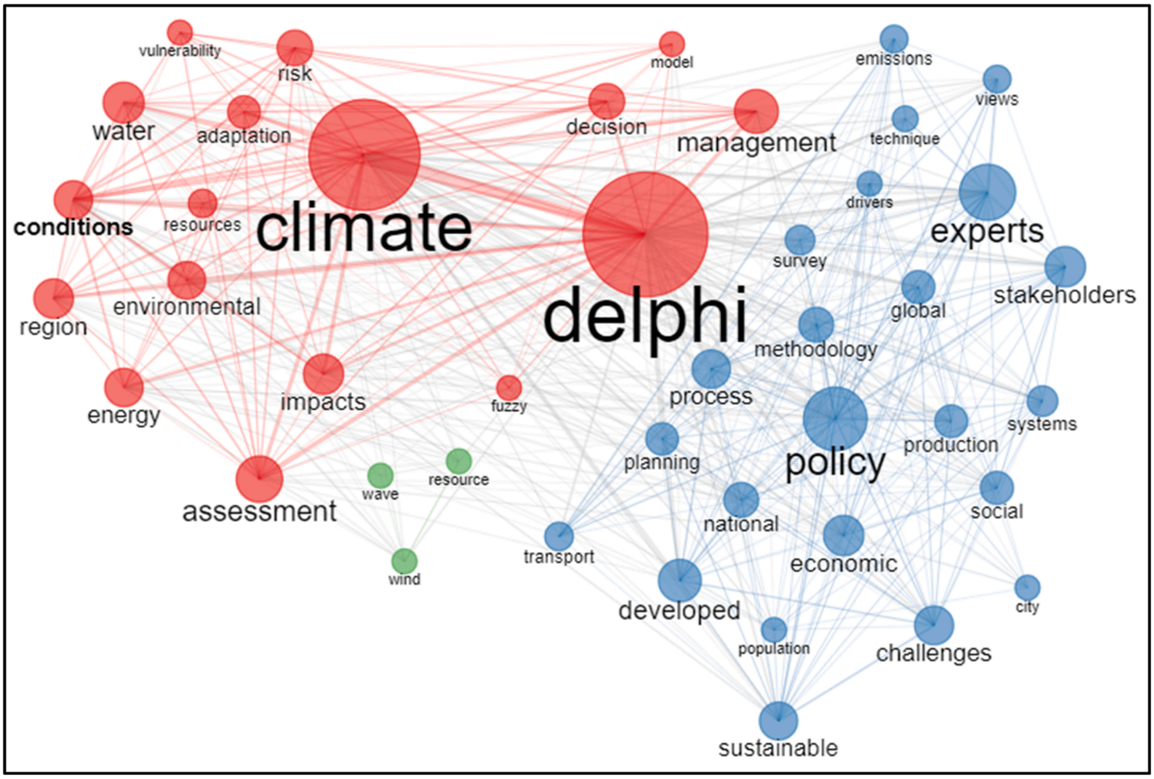

Fig. 5. Semantic network of abstracts.

particularly referring to the Delphi method, the engagement of experts and the administration of surveys (see the keywords: “stakeholders”, “expert”, “policy”, “survey”), topics that are important and discussed extensively in the scientific literature of Delphi-based scenarios. On the second quadrant, we have terms related to climate change scenarios and the management of long-term impacts (see “climate”, “change”, “impacts”, “management”, “Delphi”, and “scenarios”), important in the anticipation of the future in environmental contexts. On the other hand, in the third and fourth quadrants, different terms are related to the national future and its analysis.

In the second cluster (green), the area is delimited to quadrants 3 and 4, in the first one we have themes related to the decision-making context focusing more on the assessment and the adaption (“assessment”, “adaptation” and “decision”), on the other hand, on the fourth quadrant, more terms related to the methodology and data (see the words “method”, “data”, “increase”) are discussed.

The blue cluster that involves the 3 and 4 quadrants are related to the economic, environmental, and energy fields, demonstrating, as we will see below, an important interest in the development of future scenarios regarding water levels and the risk of flooding. Finally, the analysis produced two small clusters, one of them is related to the risk conditions (see yellow cluster), and the other one concern the transport theme (see the violet cluster).

The co-occurrence network is based on the abstracts shown in Fig. 5 and highlights the links and relationships between keywords. As it is possible to see, 3 clusters are connected, the red cluster depicts different themes linked: i) the central node “Delphi”, is connected to different keywords, including “decision”, “management”, “model” and “fuzzy”; ii) on the other hand, the node “climate” is related to different environmental themes, including the energy and impacts, the water sustainability and the risk and vulnerability.

The blue cluster depicts two different themes: i) the development of policies, with different sub-variables such as economic, social, transportation, demographic, and sustainability; ii) the experts’ node is linked to different keywords, including stakeholders, the identification of drivers in the survey and the implementation of views and techniques in the process. The third cluster (green one) is related to environmental keywords including “wind”, “wave” and “resource”, and is linked to the impacts of climate change, and the planning of different policies to avoid future threats.

6. Discussion

The results obtained previously allowed us to have a general overview of the scientific production, understanding the main topics covered by scholars in order to have a first overview of the scientific literature. In this section, we focused on the Delphi-based process administration, proposing a review of the stages of our study cases, with a particular interest in the methodologies and approaches used. Specifically, we analysed the combination of the two methods, understanding where the Delphi method is adopted in the development of future scenarios and the techniques used on the various rounds, then, we discussed the selection of experts and the sample size. Furthermore, a particular attention has been placed on the choice of the time horizon and the technique used to perform the final scenario outputs. The output of this analysis is aimed at producing an overview of best practices that can be used for future Delphi-based scenarios in climate change contexts.

6.1. *Combination of the methods*

The combination of the two methods is flexible because it generally allows the Delphi method to be applied in one or more stages of scenario planning. In our context of application, most authors have applied the Delphi method in the first phases of the process, for the first identification of projections and trends. For example, in the work of Rikkonen (2005), the Delphi was useful to develop “mini-scenarios” for future agriculture in Finland, taking into account climate historical data, to then proceed with Delphi rounds, describing the utopia and dystopia of the topic.

In 2012, Biloslavo and Grebenc, integrated group Delphi, analytic hierarchy process, and dynamic fuzzy cognitive maps, for the development of a climate warning scenario. The model is based on a cognitive mapping of 28 factors, with 2 independents (namely human consciousness and living standard), useful for the development of future scenarios carried out with the implementation of a fuzzy and dynamic fuzzy method (Chen, Ming, Zhou, & Chang, 2020), integrated the Delphi survey into scenario planning for China’s renewable energy, first understanding the main projections from the rounds, using a conceptual chart of the possible causal relationship, and then describing the scenarios using an intuitive logic. The authors, adopted a narrative technique, describing 5 scenarios: i) the best scenario optimal for the country; ii) the better scenario, optimal for renewable industry; iii) the moderate scenario for a positive economic cycle; iv) the worse scenario with a policy-based dependence and v) the worst scenario. D’agostino et al. (2020), provided an interesting case study, adopting a “three-staged stakeholder-driven approach”. In the first phase, the Delphi analysis is used to identify the “key constraints” on water management to then apply a fuzzy cognitive mapping to exploit stakeholders’ mental models formalising the conceptual and causal relationship of the projections. In this case, the scenarios are formulated by adopting a backcasting exercise. (Liimatainen et al. 2014), developed future scenarios of the carbon emissions of Finnish road freight transport, using the Delphi methods to collect factors and indicators, to then use cluster analysis to create six scenarios using a narrative approach. Melander, Dubois, Hedvall, and Lind (2019) used a Delphi-based scenario analysis for future goods transport in Sweden, administrating a Delphi survey based on the probability and impact and the probability and desirability of different pre-established key drivers.

In the combination of the two methods, different authors took into account open data in the process. (Jun, Chung, Kim, & Kim, 2013) quantified the flood risk vulnerability in South Korea, in this case, the Delphi projections were used to determine all proxy variables, objectively in the first round, to then weigh the values in the second and the third phase. After, the data were standardized using the min-max method, to then weight the values with a triangular fuzzy number (TFN). Furthermore, they quantify the flood risk with a Fuzzy TOPSIS, comparing the rankings using MCDM techniques in order to develop four-time scenarios. (Kim et al. 2016) applied a Delphi survey in the acquisition of variables list, actual data, and weights, assessing the vulnerability based on quantitative data databases. Finally, (Bailey et al. 2012) adopted a methodology starting from the estimation of 2005 local emissions, using climate databases, in order to apply a forecasting approach and a backcast with a workshop. In this case, after three rounds Delphi, the scenarios are developed only after the validation in a workshop.

In our dataset, the Delphi method has been also adopted in the last phases, for the development of policies (scenario transfer). In an interesting recent work published by Antonelli, Basile, Gagliardi, and Isernia (2022), the scholars, used Delphi as an “examiner” of what trends will shape the future of the Mediterranean agri-food system. In the second part of the study, they adopted a Boston Consulting Group (BCG) matrix, to understand the policy interventions, understanding the desirability and the feasibility based on Delphi rounds judgments. In this context, Alizadeh, Lund, Beynaghi, Abolghasemi, and Maknoon (2016), depict the “axes of uncertainty” that emerged from the rounds in order to use the experts’ feedback from the panel to extract scenarios using the GBN Approach: i) orient; ii) explore; iii) synthesize; iv) act.

6.2. Number of rounds

From a general perspective, most of the analysed case studies mentioned the number of rounds in the process. The total average of our sample reached a consensus in two rounds of Delphi, however, not all cases found consensus in two rounds and for this reason, a further round was applied (Table 4).

Begemann et al. (2021), provided an interesting study about the future of deforestation and forest degradation as a result of climate change, wondering about which methodology to use for the selection of a panel of experts. In these terms, for the identification of experts, the first round is dedicated to structured interviews and six interview pre-tests in order to collect and systematise expert knowledge and their expertise degree. Soria-Lara and Banister (2017) adopted a traditional Delphi in order to extract future projections about the transport sector in Andalusia (Spain), round one is characterized by an anonymous exchange of views between participants, and in round two, participants could revise the initial views based on the first-round feedback.

In the Alizadeh et al. (2016) case study, which aimed to develop specific policies for energy industries, they used two rounds of Delphi, implementing different techniques and an email administration of the questionnaires. For the development of future scenarios, the identification of “uncertainty criteria” was applied in round one in order to extract relevant driving forces, and in round two, a Cross-Impact Analysis (CIA) was adopted to deepen the driving forces found, in order to understand the influence degree of them. As mentioned before, some studies applied a three-round Delphi for two main reasons, the first one is that most of the time a consensus was not reached, otherwise, in other cases the last round was useful to optimize the process and to develop future policies. In these terms, D’agostino et al. (2020), proposed a Delphi study to improve agricultural water management policy and practice in Malta, starting from a fuzzy cognitive mapping and an online anonymous questionnaire, involving a workshop with the stakeholders for new future policies.

From what emerged, the choice of the rounds was made in the early stages, in fact, Saito et al. (2019) developed future scenarios assessing the natural capital and ecosystem services of Japan in 2050, applying two rounds of Delphi and a workshop. On the other hand, Tapio, Rintamäki, Rikkonen, and Ruotsalainen (2017) explored the energy futures of farms in 2030 within a two-round Delphi, first with anonymous questionnaires and interviews, then, with the administration of an online questionnaire, and finally with a stakeholder seminar aimed to develop possible policies.

Normally, a Delphi study does not exceed three rounds, some authors included workshops and final interviews as a round of the process, however, in this study, we refer to the rounds as “iterative rounds” (e.g., the first iteration of a questionnaire, interim analysis and second iteration of the questionnaire). In fact, Stephenson, Spector, Hopkins, and McCarthy (2018) studied the potential future of New Zealand’s transport system, with 3 rounds of Delphi, in round one, the Delphi participants were asked a series of open-ended

Table 4
Number of iterative rounds.

Number of rounds	N
2	38
3	11

questions in order to explore their trends' view, in round two, participants were asked to state the likelihood of the previous trends, innovations and changes that can occur in News Zealand's transport system in the long term. In round three, panellists were asked to answer on a Likert scale their level of agreement with selected free-text statements from round two. In round three they also invited the Delphi panel to nominate three trends, innovations and step changes for the interventions already considered. Finally, the experts selected the ten top priority areas and described possible interventions previously considered.

Also, Hopkins, Bailey, and Potts (2018) developed a further perspective, in fact, the authors adopted three rounds of Delphi in order to develop future scenarios in the climate change marine ecosystems context adding a fourth focus group round in order to encourage participants to produce group contributions instead of individual ideas. From what has been described so far, the case studies of the extracted literature are homogeneous with 38 contributions that have adopted two Delphi rounds, 11 contributions that have instead adopted three rounds.

6.3. *Panellists: identification of a significant sample*

In the Delphi-based scenarios, experts play a key role, they can be academics, stakeholders, and experts on the topic, and as adopted in some studies, also citizens can be involved in the process. From the above, the experts' identification becomes essential, insofar as the scenario outputs will depend on the panellists' expertise degree. In these terms, the scientific literature, produced different opinions regarding the number of experts to involve and their characteristics, in this paragraph, we investigate the choice of scholars from the sample of selected experts and the evaluation of their expertise. (Table 5).

From a first overview, the results demonstrate different decisions in the choice of experts, where each contribution adopted different methods in identifying the sample size. (Rikkonen, Lauttamäki, Parkkinen, Varho, & Tapio, 2021) proposed a two-round panel in order to identify transition pathways to renewable energy futures, involving 67 stakeholders for the first round. In the second round the presence rate lowered, the author affirms that on 100 emails only 21 answers have been received. As described by the authors, the first open challenge in the DBS, but in all the participative processes, is the lack of time of the experts, because they do not have the material timing to answer interviews or questionnaires, and very often, they leave the process in the second round. Begemann et al. (2021) studying the possible future directions of the global forest governance assessment in 2030, involved 38 practitioners and researchers for the first round, and 32 for the second round.

D'agostino et al. (2020) included different figures, the panel was composed of policymakers, environmentalists, farmers, water regulators, and academic researchers. For the whole process, a total of 40 stakeholders, in particular, 22 stakeholders for the first round, for the second 44 stakeholders, and 24 for the final round.

Proceeding with our review, some studies provided interesting methods for the experts' selection, for example, Kattirtzi and Winskel (2020), proposed a new innovation to avoid excessive time-consuming with a detailed selection. The case study aimed to develop scenario outputs on UK energy with a two-round Delphi recruiting 127 panellists from three communities: i) the UKERC; ii) representatives from government and parliamentary bodies and industry and iii) non-governmental organizations. Similarly, Godínez-Zamora et al. (2020) proposed a case study aimed to understand the impacts of decarbonised transport and energy sector in Costa Rica, composing a large-scale panel, with 154 panellists for the first round and 192 for the second one, very often the construction of large panels can imply a greater degree of experience but requires a strong capacity of administration of the process. In the research and selection of experts, various techniques are used, among the most used, when the task is difficult to identify, a non-probabilistic approach called "snowball sampling" is adopted. This approach is widely used in the scenario development process and requires a first expert identification by the scholars, after that, the same experts will be asked to identify – based on their knowledge – further figures with the same traits until the sample is significant. In these terms, most of the time, for the administration of a Delphi survey, researchers select many more experts than needed, since they probably could refuse at the last second, not answer, or ask for a high fee.

Table 5
Panellists involved.

Number of experts	N
N/A	8
0–20	11
21–40	13
41–60	4
61–70	2
71–80	1
81–90	3
91–100	2
100+	5

This problem is exposed in detail by Saito et al. (2019), that involved 27 experts, including 21 researchers, 3 environmental consultants, and for the first workshop, 3 policymakers from the Ministry of the Environment in Japan. Assumed that, for the first round Delphi, they invited 104 experts, but they received only 94 answers, and for the final round they invited 94 experts, receiving 86 answers.

In the selection of experts, some scholars developed interests in the measurement of experts' competences with new coefficients (e.g., Barroso Osuna & Cabero Almenara, 2013), in our case, no real measurement of the experience was made by coefficients, however, Gorn, Kleemann, and Fürst (2018), applied an interesting approach. In the experts' identification, the scholars divided the expertise competence into two categories: i) expert type A; ii) expert type B. Type A is an expert who has specific competence and practical experience in regional planning and ecosystem services (8 panellists involved), type B is an expert with theoretical knowledge of spatial and environmental planning, regional geography, and ecosystem services (39 experts involved).

From the above, in general, the figures involved in participatory research are mostly people with expertise in a certain field of study. However, sometimes, it is possible to integrate individual citizens who do not have a very high degree of experience into the scenario planning process but contributing to offering a valuable knowledge resource. In the climate change context, it becomes essential to delineate the vision of citizens, to understand their thoughts, perceptions, concerns, and uncertainties about the future. For this purpose, Soria-Lara and Banister (2017) in order to study the Andalusian transport sector in 2050 proposed a different participatory method, involving three categories of participants: i) the public; ii) practitioners and decision-makers; iii) academics and theorists. The first category includes citizens with "social backgrounds", in particular, as stated by the authors, young people (14–16 years old), are involved for their open and creative minds (Tuominen, Tapio, Varho, Järvi, & Banister, 2014). In order to recruit these categories, they referred to a mailing list from Andalusian citizen associations and high schools. The practitioners and decision-makers figures were identified in a mail list from professional associations and include environmental and urban planners, experts in engineering, geographers, and politicians. Finally, academics and theorists were identified from a mailing list of the main universities and research centres, involving professors of geography, civil engineering, architecture, etc. In sum, interesting new approaches emerged from what was revised, proposing new implementations for future climate professionals.

6.4. *Time horizon*

In order to understand the future, becomes fundamental to establish the time horizon, to the extent that the outputs refer to a specific period. In these terms, it is not possible to find a univocal methodology for the decision of the time horizon, however, Kosow and Gaßner (2008) affirm that we could apply accurate probabilistic reasoning, in fact, in the choice of the time horizon, the further our future vision of the study in question is, the less will be the knowledge of the future and of the predictions themselves of the prognostic possibilities. From the results of our review, almost all authors cited the selected time horizon, however, some studies did not report the period chosen because the aim of the case study was the development of general future perspectives that did not apply any time horizon. Coleman, Sosa-Rodriguez, Mortsch, and Deadman (2016), in order to individuate the impacts of water-level reductions in Trent-Severn, administered a two-round Delphi. In the final outputs, one present scenario plus two general future scenarios have been identified without an established time horizon. (Table 6).

Generally, in the reviewed cases, most of the scholars (e.g., Begemann et al. 2021) applied mid-term scenario planning. For example, Kattirtzi and Winskel (2020) analysed the future of heating in buildings and the future of personal transport in a time horizon of 20 years (2040). Other scholars' contributions provided a contribution with 30-year time horizon scenarios (Melander et al. 2019), to understand the transport systems in Sweden and derive the future output of 2050. In conclusion, Ribeiro et al. (2021), proposed a different approach to evaluate the viability of a wave energy farm focusing on the exploitation of the present, the near future, and the far future. They applied a two-round Delphi with 15 experts in wave energy and engineers in the following time horizon: 1979–2005, 2026–2045, and 2081–2100.

Table 6
Time horizon.

Time horizon	Frequency
N/A	9
2025	3
2030	13
2040	3
2050	10
Multiple time horizon	11

Table 7
Quantitative statistical techniques.

Techniques used	Frequency
Statistical indicators	48
Time-series	4
Monte Carlo method (CTMC)	1
Cross-respondent analysis	1
Analytic hierarchy process (AHP)	1
Fuzzy techniques (DFCM, TFN, TOPSIS, VIKOR)	5
GIS Analysis	7
MCDM Technique	2
Q^2 scenario technique	1
Cross-Impact Analysis (CIA)	1
PEST analysis	1
Entropy analysis	1

6.5. Techniques used

In order to have meaningful results, in the Delphi-based scenarios process, different quantitative and qualitative statistical indicators and techniques are used in order to evaluate experts' answers. In our case, many of the contributions reported information on the statistical indicators used (e.g., mean, median, quartiles, etc.), however not all results are often integrated into papers.

Some of the case studies adopted a cluster analysis in the rounds process. For example, (Rikkonen, Lauttamäki, Parkkinen, Varho, & Tapio, 2021), to perform their research, used a hierarchical cluster analysis. Cluster analysis is an exploratory data analysis with the aim of grouping objects within clusters, to measure the similarity between them. In scenario planning, hierarchical cluster analysis is based on the idea that the correlation of nearby objects is greater than the correlation of distant objects and according to the authors, it is useful in the Delphi rounds because the views of the experts are organized into distinct outputs (clusters) through a multi-theoretical approach. Nygren, Tapio, and Qi (2017), proposed a two-round Delphi to study lake management in 2030, applying cluster analysis, affirming that "it is important to keep in mind that cluster analysis does not decide how many clusters there are in the data, but it only shows how the units are divided to any number of clusters".

Introduced by Bart Kosko (1986), the fuzzy cognitive map becomes relevant in order to calculate the "strength of impact" of mental elements, in our case, D'agostino et al. (2020), applied a semi-qualitative fuzzy cognitive mapping (FCM), to gather information regarding stakeholder perceptions and sentiment on the water-related problems and risks facing the irrigated agricultural sector. (Table 7)

An interesting new approach is used by Cairns, Wright, Fairbrother, and Phillips (2017), developing the "branching scenario" approach, useful in complex participatory contexts. According to the scholars, several expert figures in the object of study were involved in the process and the new approach could enter the scenarios' generation phase, in fact in the second round of the process, the branching scenario presented the "best" and "worst" future output.

In the scenario development process, a useful analysis is a Cross-Impact Analysis (CIA), developed by Theodore Jay Gordon and Olaf Helmer, in 1966. Cross-Impact Analysis is often used to define the causal probability relationships (better defined here as "plausibility") of future events, and consists of the following steps: i) the first step is to determine possible values of the key factors (here called events); ii) then, the probability of every single event is calculated independently of the other events; iii) a cross-impact matrix of conditional probabilities is formed, based on the probability of event A in case event B occurs or event A and event B will occur. Alizadeh et al. (2016), applied a Cross-Impact Analysis (CIA) using the MICMAC foresight software and integrated it with a PEST (political, economic, social, and technological) analysis as a "tool to describe a framework of macro-level factors".

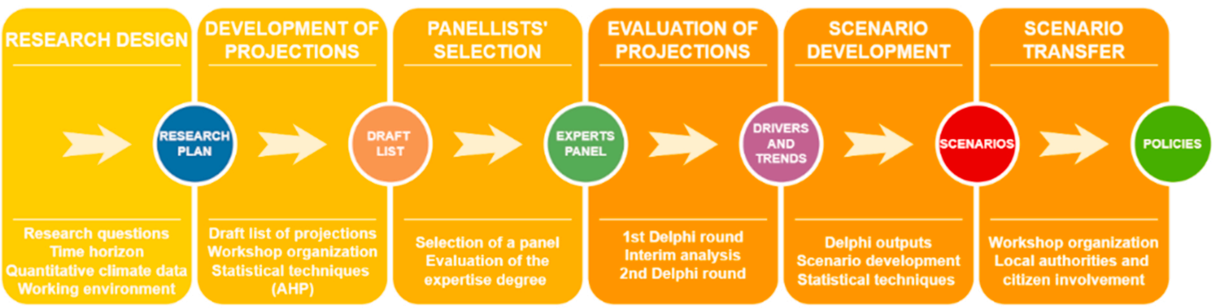

Fig. 6. Delphi-based climate scenarios approach.

6.6. Guidelines for climate scenarios research projects

In the Future Studies context, the development of Delphi-based scenarios refers to well-defined methodologies and for this reason, is important to have adequate knowledge about the two methods. In the climate change context, the adoption of this approach for the development of future scenarios is a useful implementation and to pursue the aim of this paper, in this final paragraph, guidelines will be established for the development of climate scenarios using the Delphi method in one or more stages of the scenario planning. In this guideline, we define 6 phases for the construction of a Delphi-based scenario, as depicted in Fig. 6.

6.6.1. Phase 1: research design

The first step is preliminary and aims to develop a valid and optimized research project following guidelines typical of a good scientific research model. Generally, studies or guidelines tend not to include this phase in their own approaches' guidelines, but we believe it is essential for the good construction of Delphi-based climate scenarios. In fact, in this phase, researchers should study in depth the two methods (scenario planning and Delphi method) and their combination to avoid possible errors and to adopt possible and useful implementations in the process.

All information must be taken into account; the topic of interest, the research questions, and the objectives are established according to a well-organised research plan. The formulation of the research questions is at the discretion of the research team, in fact, the questions could be formulated differently (e.g.: "How will climate change affect the future in 2030?", or from a plausibility point of view: "How plausible is that in 2030 floods will be increasingly present in our territories?"). The purpose of the project should be carefully analysed, understanding the relevancy and the boundaries of the study, avoiding touching other fields of application but understanding which external contexts may or may not influence the topic under consideration. In this context, in relation to the research objectives, the selection of a time horizon should be carefully evaluated, taking into account that "the farther distant the point in time selected for study lies in the future, the smaller will be the extent of available hard knowledge of the future" (Kosow & Gaßner, 2008).

Scholars should evaluate the working environment (e.g., meeting rooms for workshops, conference rooms, computer laboratories, etc.), the prior notification and request to participate in the study for local and governmental bodies, and the possibility – based on the research project – to implement possible environmental data for the development of time series, or trend analysis as a support to the DBS. In climate scenarios, even with the Delphi method, the implementation of quantitative data within the process becomes fundamental and could be of support in the retracement of the literature and in the development of scenarios with quantitative methods (e.g., trend analysis) in order to compare the results obtained with participatory methods (DBS). Finally, the decision of which Delphi method to use is left to the research team, using the classic Delphi method, the times will be greater, however by applying the Real-Time Delphi (Di Zio et al. 2017) the times are reduced more. In the climatic context, we recommend the application of the Spatial Delphi and Real-Time Spatial Delphi (Di Zio & Pacinelli, 2011), if the main aim is to develop spatial scenarios.

6.6.2. Phase 2: development of projections

In this phase, projections or "descriptors" are acquired, in order to understand the variables and trends, having an impact on the object of study. In this phase, the present and the past of the topic should be evaluated, with the retracement of the literature and a careful analysis of the corpus of documents. In fact, two main approaches can be classified: i) the projections, should be listed by the research teams based on their expertise, in this case, the research team should conduct an intensive preliminary period of empirical and theoretical analysis (desk research), based mainly on data from official databases, including Google Scholar, Web of Science or Scopus, but also from climate database, reports and policies (e.g., IPCC reports). In this phase, we recommend analysing any data acquired previously, including quantitative trend data to understand the long-term prospects of the data held and help experts; or ii) a general draft list could be generated in a participatory process through workshops or surveys, in this case, experts should be involved administering preliminary questionnaires (some scholars administer argumentative Delphi at this stage).

However, since this phase involves specific efforts and the experts should retrace the history and the present of the topic, different approaches can be implemented to better acquire and classify the projections. The approach proposed by Kayser and Shala (2020) and Calleo and Di Zio (2021) for this Scanning phase, should be a useful implementation to acquire a list of projections and trends, adopting Text-Mining techniques in order to extract topics from a dataset of textual data (in our case, scientific papers, climate reports, policies etc.).

Since most of the time the first draft list is composed of multiple projections, before validating and sending to the experts for the Delphi rounds, a refinement of the projections must be carried out: i) the researchers could refine the projections based on their expertise, in this case, the research team must have an important knowledge in the context of application; ii) however, we recommend the organization of workshops, for the refinement of the projections. In this case, different experts could be selected from academics, local authorities, stakeholders, and citizens; iii) to speed up the process and avoid organizing a workshop, an interesting statistical technique can be used, namely the Analytic Hierarchy Process (AHP) technique (see this interesting online tool: https://bpmsg.com/ahp/, proposed by Goepel (2018).

6.6.3. Phase 3: selection of panellists

Before identifying panellists for the Delphi study, some pre-criteria should be evaluated and since the Delphi method is a creative process, different expertise and background should be taken into account. We can consider, academic experts, stakeholders from industries and companies, climate activists, and local and government authorities, taking into account gender equality, geographic origin and the type of expertise.

With regard to the size of the sample, 15–30 experts should be adequate, but we recommend identifying a larger sample of experts, as not all of them could participate in the study or some may drop out over the course of the rounds. For the selection of a panel, generally, non-probabilistic approaches are used (e.g., snowball sampling), from what emerged, we recommend the use of computational methods in order to make the process less time-consuming and more efficient. Online social networks are a suitable channel for the identification of the experts (Facebook pages, LinkedIn, ResearchGate etc.), the experts could in fact be identified and contacted via email. Also, a useful implementation would be a bibliometric analysis extracting authors with more expertise in a topic starting from scientific databases (e.g., Scopus, Web of Science, Google Scholar).

Once the experts have been identified, we obtain a potential list (or draft list) of panellists, in this case, most of the time, researchers evaluate the degree of expertise with a self-assessment approach (Barroso Osuna & Cabero Almenara, 2013) by administering a questionnaire asking possible participants to evaluate their expertise in a given topic (e.g., adopting a Likert scale). However, the self-assessment could lead to various cognitive biases, such as the overestimation and underestimation of the expertise degree, and for this reason, we suggest selecting the experts based on different variables of interests (h-index, publications, projects, policies, conference speech etc.) and to evaluate them based on these variables (e.g., how many publications does this expert have on this topic? How many policies has this expert developed on this topic?).

6.6.4. Phase 4: evaluation of projections (Delphi-rounds)

This phase includes the administration of Delphi-rounds, where drivers and uncertainties are evaluated. Delphi rounds, defined here as iterative rounds, can be 2 or more rounds, where the questionnaires can be set up differently depending on the research objectives. The authors should take into account that conducting a Delphi study is a slow process, for that we suggest using the Real-Time Delphi (e.g., The Millennium Project suggest these platform https://www.realtimedelphi.com/ or https://4cf.pl/en/halnyx/), or Spatial Delphi and Real-Time Spatial Delphi (see the platform http://rtgscs.com/).

Quite often, the questionnaires mainly investigate the probability, impact, plausibility, and desirability of an event over a certain time horizon. For example, a 5-point Likert scale, based on the above variables, could be used, asking experts to answer the question set and to justify their feedback in open comments. Regardless of the approach used, researchers must take into account that time is important, considering the times of the year (for example, it could be avoided to send a questionnaire during a holiday period of the year).

After the first round, different analyses can be performed through descriptive statistics (interim analysis), such as, for example, mean, median, standard deviation, interquartile range, IQR, x^2-test. etc. for then administer a second round of Delphi, where experts can receive the responses of the first rounds, including graphs, estimations, a summary of the group response etc. We recommend using statistical software such as R to analyse textual data derived from the open questions.

6.6.5. Phase 5: scenario development

In the climate change context, this phase involves specific efforts since it can vary in relation to the research objectives. In these terms, there is no consensus among experts on the number of scenarios to develop, nevertheless, we suggest proceeding with sorting the scenarios, with a range of 4–5 scenarios (Velte et al. 2004).

The Delphi outputs can be useful to develop future scenarios, including probable, extreme, and unforeseen scenarios (Heiko & Darkow, 2010). Generally, starting from the Delphi projections, most of the time qualitative methods are adopted and climate researchers could intuitively define what the experts described in their answers with an intuitive and narrative approach. However, in our case, the quantitative approach could provide interesting insights into the process, in fact, Fuzzy c-means (FCM), k-means clustering, partitioning around medoids (PAM clustering) and hierarchical clustering (HC) can be used. Also, for scenarios developed with trend analysis or historical series, TOPSIS (Jaroszweski, 2012) and VIKOR analysis could be a useful implementation. We recommend here to compare the forecasting analysis with the results of the Delphi-based scenarios to acquire an even broader overview of the study.

6.6.6. Phase 6: scenario transfer

This last optional phase provides interesting insights because the results of the process are "transferred" to the local authorities, organizations, and researchers' opinions in order to develop further policies. With the huge diffusion of atmospheric and climatic events in our world, the study of future scenarios does not claim to be certain, but rather investigates the different futures, for these reasons, this transfer is useful to take action in the present. In this phase, in relation to the objectives, a workshop with experts could be held or a survey could be administered (we do not recommend administering another Delphi survey for timing purposes). At this stage, we recommend instead that citizens also participate in the meetings, so that the results obtained are shown and explained since the process has as its ultimate goal – moreover – also communication.

7. Conclusions

This paper provided a general overview of the state of the art of Delphi-based scenario case studies in the climate change context, using bibliometric analysis. In our context, it was possible through the annual analysis of the scientific production to understand more about different aspects related to the development of future scenarios. The use of bibliometric analysis may entail some limits regarding the identification of the overall reference number of contributions and possible keyword-paper mismatches. However, the results of the bibliometric analysis constitute a preliminary view of the subject studied, but only with the individual review of the contributions and possible non-indexed contributions will it be possible to have an even more precise state-of-the-art.

From a first overview of the scientific production, 49 contributions found in the Web of Science database were reviewed, demonstrating an interest of the authors in environmental and climate issues. However, the underrepresentation of the Delphi method in the scenario planning could raise possible considerations: i) the use of quantitative methods in the climate field for long-term forecasting could be implemented through the use of participatory processes (including DBS), to optimize the process and ii) for Future Studies, low representation is a missed opportunity for the recognition and dissemination of consolidated methods for the study of challenges in our society.

From the statistical analysis, despite a fluctuating trend in publications over the years, the forecast line demonstrates in recent years an increase in applicable cases. Different countries and different scholars have contributed to enhancing future climate perspectives, in particular, the countries most involved in climate change, which we know to be particularly active in the fight against environmental threats, contributed to the studies. From the application of the multiple correspondence analysis, it is possible to have a view of the main themes represented in clusters, including i) scenario development process and methods of application; ii) adaption, assessment, and decision-making process iii) environmental and energy issues; iv) risk management v) transport context. From the case studies, we extracted particular information regarding rounds, panellists, and statistical indicators in order to contribute to a new literature review in the climate change context and offer information for future new research.

From a general overview, we implemented all processes analysing every single contribution in order to understand how the Delphi was developed and the results demonstrate, specifically in the most recent studies, interesting contributions for future studies, integrating several new approaches in the rounds, in identifying the experts and the number to be selected, in the time horizon and in the new techniques applied in the studies.

However, since in the last decade special attention is paid to climate change, from what emerged, more contributions should be produced to analyse long-term trajectories in order to implement different plans in the present. In these terms, among the themes studied in our dataset, there is a lack of research on different topics: i) firstly, the impacts of climate change on society were not addressed (e.g., how much will climate change affect citizens? What can we do to prevent it?); ii) in the contributions, no Delphi investigated the future of cities located in urban and coastal areas; iii) there are no Delphi projections or feedbacks related to future technological implementations, useful to fight climate change.

Overall, most of the studies had no particular problems in reaching a consensus among the experts, however, among the major problems encountered is the discrepancy between the panellists contacted and the answers obtained, as we know to be a weak point of participatory processes. Regarding the choice of an appropriate time horizon, the researchers do not mention how they selected that date, and this is a serious lack that should be implemented in future research plans. As discussed in paragraph 6.1., different methods have been used to develop future scenarios with interesting techniques as well. We can however affirm that in the revised literature the Delphi method has been applied for two main reasons: i) the identification of the drivers; ii) the development of policies after developing scenarios.

In future works, the identification, and the selection of the experts could be implemented, for example through the use of coefficients to measure the expertise degree (see Barroso Osuna and Cabero Almenara (2013) and new innovative methodologies (but already consolidated in the literature) could be used to conduct a Delphi-based scenario process. For example, Real-time Delphi (RTD), or Real-Time Spatial Delphi (RTSD) could be an implementation because involve sequential "rounds", avoiding long time processes (Gordon & Pease, 2006; Di Zio et al. 2017).

Finally, another important aspect regards the scenario methodology, in fact, in part of the contribution, the literature review (Scanning phase) and the extraction methods of the major trends and key driving forces have not been mentioned sufficiently. The scanning phase, in the scenario method, is an important phase, and in future works, different approaches could be used to reduce the time, such as computational methods (see Calleo and Di Zio, 2021; Kayser & Shala, 2020).

Overall, from what has been described it is possible to obtain a complete view of the studies on future scenarios combined with the Delphi method in the climatic context, useful for the next studies and for the next applications. .

Data Availability

Data will be made available on request.

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Appendix

(Table 8)

Table 8
Contributions analysed in the literature review.

Paper	Year	Rounds	Contacted panellists	Involved panellists	Time horizon	Techniques used
Alizadeh et al.	2016	2	12	12	2050	Graded statements
Almansa and Martinez-Paz	2011	2	174	112	2025	Statistical indicators
Al-Saleh et al.	2012	2	N/A	81	2050	Statistical indicators, Time series
Amman et al.	2022	2	N/A	34	Multiple time horizon	Statistical indicators, Monte Carlo approach
Antonelli	2022	3	N/A	63	2050	Statistical indicators, Cross-respondent analysis
Bailey et al.	2012	3	138	39	N/A	Statistical indicators, Analytic hierarchy process (AHP), dynamic fuzzy cognitive maps (DFCM)
Begeman et al.	2021	2	N/A	38	Multiple time horizon	Statistical indicators
Biloslavo and Grebenc	2012	3	3	3	2030	Statistical indicators, time series
Cairns et al.	2017	3	15	15	Multiple time horizon	Statistical indicators, GIS analysis, MCDM techniques, Triangular fuzzy numbers (TFN), Fuzzy TOPSIS
Camilleri et al.	2021	2	20	20	Multiple time horizon	Statistical indicators, Fuzzy VIKOR
Chen	2020	2	N/A	12	2050	Statistical indicators, Q2 technique
Coleman et al.	2016	2	262	60	2030	Statistical indicators
Costoya et al.	2019	2	N/A	N/A	N/A	Statistical indicators
Costoya et al.	2022	2	N/A	N/A	N/A	Statistical indicators
D'Agostino et al.	2020	2	N/A	22	N/A	Statistical indicators
Godinez et al.	2020	2	N/A	N/A	2025	Statistical indicators, Cross-Impact Analysis (CIA), MICMAC, PEST analysis
Gorn et al.	2018	2	N/A	47	Multiple time horizon	Statistical indicators, Time series
Hopkins et al.	2018	3	N/A	6	Multiple time horizon	Statistical indicators, GIS analysis
Jaroszweski et al.	2012	2	N/A	10	Multiple time horizon	MCDM, Entropy Analysis, TOPSIS
Jun et al.	2013	3	N/A	N/A	2030	Statistical indicators
Kattirtzi and Winskel	2020	2	N/A	127	2030	Statistical indicators
Kim and Chung	2013	3	N/A	11	2050	Statistical indicators, Expertise matrix
Kim et al.	2015	2	N/A	N/A	2030	Statistical indicators
Kim et al.	2016	2	N/A	70	2025	Statistical indicators
Kirezieva et al.	2015	2	56	31	N/A	Statistical indicator, GIS Analysis
Lee et al.	2017	2	5	5	N/A	Statistical indicators
Liimatainen	2014	2	135	24	Multiple time horizon	Statistical indicators
Liu et al.	2022	2	N/A	6	2050	Statistical indicators
Melander et al.	2019	2	N/A	27	Multiple time horizon	Statisical indicators, GIS Analysis
Mukherjee et al.	2015	2	56	32	2050	Statistical indicators
Naskar et al.	2018	2	N/A	80	2050	Statistical indicators
Nygrén et al.	2017	2	568	200	2040	Statistical indicators
O'Neill et al.	2008	3	17	11	2030	Statistical indicators, Fuzzy Cognitive mapping
Packalen et al.	2017	2	48	21	2050	Statistical indicators
Parveen	2017	2	N/A	29	2040	Statistical indicators
Ribeiro et al.	2020	2	N/A	N/A	Multiple time horizon	Statistical indicators, GIS analysis
Ribeiro et al.	2021	2	N/A	N/A	2030	Statistical indicators
Rikkonen	2005	2	167	101	2030	statistical indicators
Rikkonen et al.	2021	3	N/A	21	Multiple time horizon	Statistical indicators, GIS analysis
Saito et al.	2019	2	104	94	2050	Statistical indicators
Solnet	2014	3	72	47	N/A	Statistical indicators
Soria-Lara and Banister	2017	2	93	40	2040	Statistical indicators and GIS analysis
Stephenson et al.	2018	3	N/A	86	N/A	Statistical indicators
Tapio et al.	2017	2	N/A	30	2030	Statistical indicators and fuzzy evaluation method
Varho and Tapio	2013	2	N/A	34	2030	Statistical indicators
Vreys	2019	2	240	36	N/A	Statistical indicators
Wåhlström et al.	2022	2	N/A	N/A	2030	Statistical indicators

(*continued on next page*)

Table 8 (*continued*)

Paper	Year	Rounds	Contacted panellists	Involved panellists	Time horizon	Techniques used
Wilenius and Tirkkonen	1997	2	142	98	2030	Statistical indicators
Winskel and Kattirtzi	2020	2	N/A	127	2030	Statistical indicators

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