Energy Research & Social Science 93 (2022) 102815

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Perspective

Towards participatory cross-impact balance analysis: Leveraging morphological analysis for data collection in energy transition scenario workshops

J.H. Kurniawan [a,*], M. Apergi [a], L. Eicke [a,b], A. Goldthau [a,b], A. Lazurko [d], E. Nordemann [c], E. Schuch [a], A. Sharma [e], N. Siddhantakar [f], K. Veit [a], S. Weko [a,b]

[a] Institute for Advanced Sustainability Studies e.V. (IASS), Germany
[b] University of Erfurt, Willy Brandt School of Public Policy, Germany
[c] University of Waterloo, Department of Knowledge Integration, Canada
[d] University of Waterloo, School of Environment, Resources, and Sustainability, Canada
[e] University of Waterloo, Department of Systems Design Engineering, Canada
[f] University of Waterloo, School of Environment, Enterprise, and Development, Canada

ARTICLE INFO

Keywords:
Cross-impact balance analysis
Morphological analysis
Transdisciplinary research
Energy transition
Scenarios

ABSTRACT

This Perspective article presents a novel, participatory scenario development method for studying the energy transition. It shows how moving towards transdisciplinarity can inform formal scenario analysis and enhance modelling by engaging stakeholders and scientific communities to co-develop energy transition scenarios. The innovative approach combines participatory elements of morphological analysis with formal cross-impact balance analysis (CIB), and it was tested at a series of energy transition scenario workshops held in 2021 both virtually and in person. Focusing on the first workshop of the series, we present the resulting data collection strategy and critically reflect on the analytical potential of the approach. We highlight the advantage of CIB in grasping the complexity and the multi-scale nature of the energy transition, as it enables computing of how different driving forces interact. We also demonstrate that leveraging morphological analysis for data collection in participatory scenario workshops yields a more participatory approach to CIB. Some limitations notwithstanding, the insights from the scenario workshops following the novel approach suggest further avenues for improving the process of online participatory scenario methods. This holds significant potential for empirical research under the conditions of a global pandemic and for scenario analysis more generally.

1. Introduction

The clean energy transition depends on multiple and interdependent driving forces, including normative goals, public policies, technology, societal factors, and economics [1–8]. The resulting complex interdependencies call for a holistic, systems-level approach to studying energy transition dynamics [9,10]. It is difficult to visualize, let alone comprehensively analyze, such complex interdependencies. Scenario methods relying on a system analysis approach have proven useful in this context [11,12]. An increasingly popular approach to studying the energy transition scenario is cross-impact balance (CIB) analysis, which has gained prominence due to its application to Germany's *Energiewende* [13,14].

The CIB method depicts future scenarios as emerging from the interactions between combinations of driving factors or 'variables' (say, national trade policy), each with multiple possible 'end-states' (e.g., trade policy following a protectionist or a liberal paradigm) [15,16]. CIB considers interdependencies between both qualitative and quantitative driving factors through a systematic and transparent process, making it an effective method for assessing plausible outcomes of interconnected social, technological, economic, and environmental elements of energy transitions. Moreover, the CIB method can capture problems characterized by variables operating at multiple scales (e.g., global, regional), levels (e.g., community, national), and sectors (e.g., energy, agriculture, water).

Typically, CIB relies on expert elicitation [17]. While different

* Corresponding author.
E-mail address: jude.kurniawan@uwaterloo.ca (J.H. Kurniawan).

https://doi.org/10.1016/j.erss.2022.102815
Received 1 March 2022; Received in revised form 9 September 2022; Accepted 13 September 2022
Available online 28 September 2022

experts may provide input data for CIB analyses, these experts usually do not interact. This, presents a challenge to the CIB scenario method as conventionally applied, as well as against the backdrop of the rising prominence of transdisciplinary research on complex social challenges like the energy transition [18,19]. Transdisciplinary approaches highlight that research processes should center around the inclusion of practitioners and continued interaction with them, although discussions continue on definitions [10,18,20]. When it comes to generating knowledge and feasible suggestions regarding problems that are characterized by deep uncertainties, non-academic expertise is deemed equally important to scientific expertise. As part of transdisciplinary 'co-production of knowledge', practitioners are usually involved in all stages of the research which leads to the co-creation of knowledge and the use of the scientific outputs by both the scientific and the practitioner communities.

Studies have shown that participatory approaches in scenario development can improve outcomes. By drawing on different types of knowledge, they are better able to define the relevant factors of system changes from both techno-economic and socio-political perspectives, and therefore make scenarios more relevant and plausible. The participatory process also increases ownership for involved stakeholders as well as transparency, clarity, and the legitimacy of the findings. This can improve the usability of the results by the targeted audience and enable learning [21–26].

The growing importance of transdisciplinary research challenges established scenario techniques. It demands scenario analysis to be truly participatory, engaging experts and stakeholders across pertinent policy fields in an ongoing dialogue [27–29]. For researchers, increasing the participatory element in scenario development has the advantage of generating rich qualitative data through the discursive interaction among participants with different backgrounds [30,31]. However, the practical application of the participatory method also presents new methodological challenges. This Perspective reports and reflects on the experience gathered during a series of scenario workshops held in 2021, where the author team implemented a novel approach towards participatory CIB analysis for data collection for formal CIB analyses. We focus our analysis specifically on the learnings from the first workshop of this workshop series conducted online.

The aim of the present article is two-fold. First, it shows how formal scenario analysis can profit from participatory morphological analysis for collecting data for CIB analyses. The focus of the discussion here is on the methodological innovation regarding data collection and the combination of research techniques, and a critical reflection on the lessons learned. Second, the article highlights how scenario analyses used in energy transition research can be advanced by participatory approaches to data gathering. It argues that online-based stakeholder workshops using targeted visualization techniques for morphological analysis may offer a meaningful and feasible alternative to qualitative scenario building in physical settings. Overall, the article demonstrates that our novel approach will be useful for energy researchers working on developing energy transition scenarios that consider systemic interactions in a transdisciplinary manner.

2. A participatory approach to scenario building

2.1. Cross-impact balance analysis

Scenario analysis is an important component of energy transition research. It is used to understand alternative futures, also with a view to informing or influencing policy decisions [32–34]. Depictions of the future can be represented as quantitative projections and/or qualitative narratives. CIB has gained prominence as a scenario method that sits between quantitative and qualitative approaches, also in the field of energy research [12]. It produces qualitative scenarios by identifying pertinent elements of the studied system and analyzing interactions between driving factors (i.e. scenario variables), and how they unfold in the future (i.e. end-states) [15]. For example, a CIB study on the future of energy systems in Germany yielded three different scenarios: a small decentralized but sustainable system, a large centralized but fossil fuel-driven system, and a mix of the two systems [35]. Another study shows that the rapid exit from the nuclear and fossil fuel energy system is highly influenced by factors of transformational change that are more social than technical [36]. Further studies demonstrate that the multi-scale nature of energy transitions can be characterized through nested or multilevel CIB models [37–40].

CIB uses a matrix to document all pairwise interactions of end-states between two variables (Fig. 1), that is, how variable *X* directly influences variable *Y*. Only *direct* influences are explictly documented in a matrix; however, the matrix represetns all *indirect* influences as well. Influences are represented as numerical values, which are elicited by subject matter experts. These influence judgments result in a set of internally consistent scenarios, which comprise combinations of how different variables will unfold. Consistency is an important precondition for scenarios to be plausible [41].

2.2. Data collection for CIB analysis

Data collection is a two-step process in CIB analysis. First, driving factors (or variables) are identified, as well as how these variables could unfold in the future as distinct end-states in the system of interest [42,43]. Scenario variables and their associated end-states are central to construct a CIB matrix. Variables, end-states and how they interrelate can be generated from open-ended survey responses, interviews, or workshop transcripts [44,45] and by deconstructing scenarios in the relevant literature [46,47]. End-states are similarly determined using different types of information such as texts or transcripts of interest, the pertinent literature, and quantitative projections in relevant studies.

Second, CIB requires judgment on how different variables/ end-states interact, which is documented as influence judgments in the matrix cells. The focus of this article is on the latter step. Obtaining influence judgments typically is based on expert elicitation where specific experts are consulted anonymously, along the lines of the Delphi method. The type of actors involved in these exercises include experts who, in an interdisciplinary setting, can be from various related academic disciplines [48]. In a more transdisciplinary setting, a broader range of stakeholders is usually included as participants, including practitioners, members of the civil society or political decision makers [49,50]. Several CIB studies engaged in participatory modelling approaches, ranging from three-hour expert discussions [51] to workshops lasting several days to obtain influence judgments [50–54]. Participatory applications of CIB involve workshops or other interactive formats where participants are presented with a portion of a CIB matrix and influence judgments are elicited. Utilizing these formats arguably facilitates a richer and more inclusive data collection. Yet, it also presents trade-offs between the levels of participation and the mathematical formalization in an integrated modelling process [18]. This is, for example, because visualizing a portion of a matrix to elicit influence judgments may not be intuitive. Participants need some basic understanding of CIB to participate effectively but training them on the method's technical aspects may run into conflict with time limitations of a given workshop. Another challenge comes with translating participant knowledge into the appropriate format for CIB analyses. Here, a trade-off exists between ensuring a high level of stakeholder-based information and the degree to which this information can be formally processed. These challenges can be substantial when applying CIB in a transdisciplinary manner.

2.3. Using morphological analysis for data collection for CIB analyses

A stakeholder-based approach speaks directly to participatory scenario planning [55,56] and morphological analysis [57]. Morphological analysis is a scenario method examining the interrelationships of non-

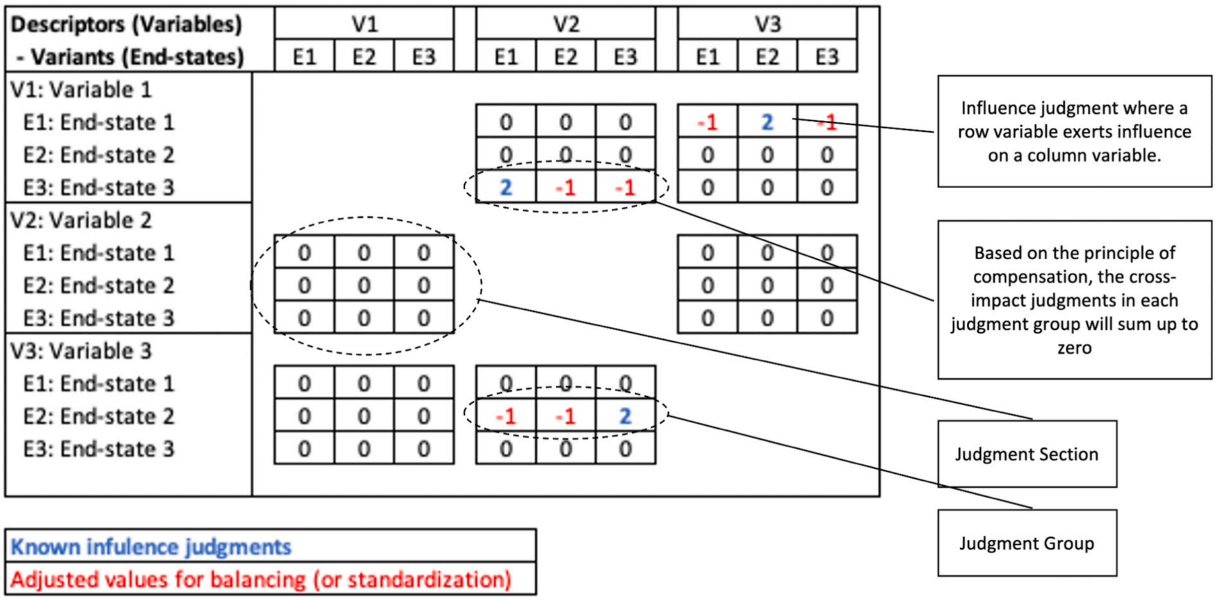

Fig. 1. Illustration of CIB matrix comprising three variables.

quantifiable, qualitative scenario variables. For each variable, end-states are assigned and arranged in a matrix form. The rows and columns comprise scenario variables and end-states respectively, thus producing a configuration space called a *morphological field* (a.k.a. "Zwicky box") [58]. For example, assuming there are three scenario variables with three end-states each, the resulting morphological field is one of 3×3. A scenario will then consist of a combination of end-states, one from each variable. Therefore, in the given morphological field, the total number of possible valid combinations will be 81 (Fig. 2). Each combination must simultaneously fulfill the two conditions of internal consistency (as opposed to being contradictory), and of plausibility (as opposed to wishful thinking).

As discussed, CIB analyses document influence judgments, that is, how one end-state of a given variable directly influences the end-state of another variable. Influence judgments can be presented in a morphological field. As shown in Fig. 2, end-state 3 of variable 1 directly influences end-state 1 of variable 2, represented by the blue arrow. Combined, several direct interactions may amount to indirect influences, too. For example, end-state 1 of variable 1 has an indirect influence on end-state 3 of variable 2, as represented by the dotted red arrow. The indirect relationship can be decomposed into two direct influences where end-state 1 of variable 1 influences end-state 2 of variable 3, and by extension, end-state 2 of variable 3 influences end-state 3 of variable 2. By capturing all direct influences, we also grasp indirect influences in the system.

Morphological analyses have been applied in a participatory manner [59]. For example, as part of the *Future of Urban Mobility* project in Singapore [60], diverse stakeholders were invited to a one-day workshop to develop scenarios. The participants were presented with a morphological field diagram to visualize and finally choose a combination of end-states that were consistent, meaning that these end-states could potentially occur together.

While this approach succeeded in engaging participants in a co-creation process, workshop participants would eventually only identify one or two consistent combinations from thousands of possibilities. This is, for most part, a function of the constrained human mental capacity to process the vast number of highly complex interrelationships between different end-states in a given morphological field, as well as of the limited time available in a participatory workshop. Furthermore, the use of intuitive judgments remains a subjective exercise even for expert stakeholders. This is where CIB offers a distinct analytical advantage, thanks to using a computational technique for identifying consistent

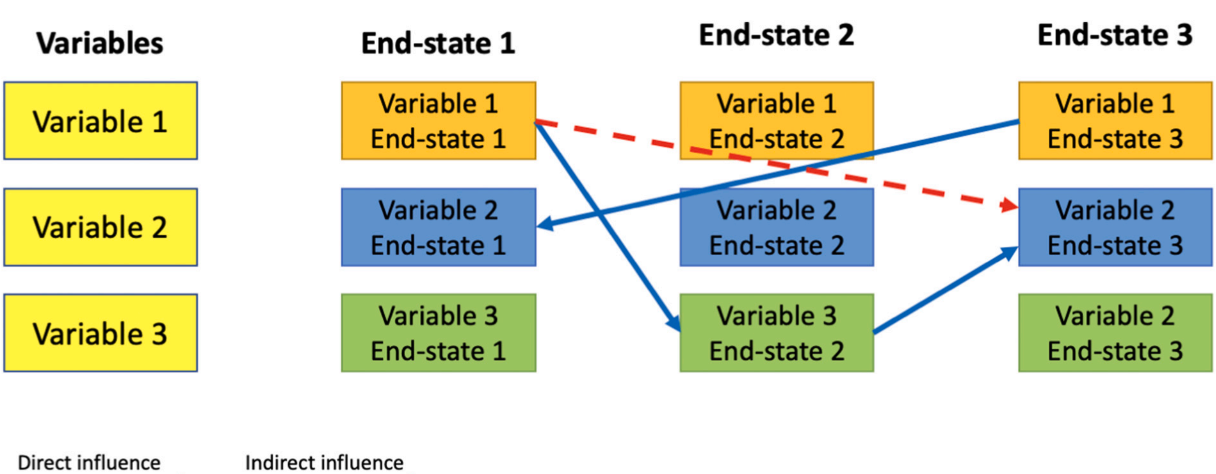

Fig. 2. Morphological field of stylized interactions of variables from CIB matrix.

scenarios. Though computer-based General Morphological Analysis (GMA) could, in principle, be also used, CIB is an easier and open-access way of doing it. Importantly, it is possible to translate a morphological field produced in a stakeholder-based scenario workshop into a CIB matrix by processing the interrelationships among different end-states identified by the workshop participants.

The novel approach presented in this paper rests on combining formal CIB with a stakeholder-based morphological analysis to collect data (influence judgments). Morphological analysis can be used to make CIB studies more participatory engaging diverse stakeholders. At the same time, the computational strength of CIB can be used to comprehensively identify all consistent combinations of end-states, using a powerful software (i.e. ScenarioWizard) [61]. The next section reports on the insights gained from the first workshop conducted online, as part of a series of scenario workshops carried out on the energy transition in the Global South.

3. Applying the participatory CIB method to energy transition research

3.1. The context: the energy transition and the Global South

The participatory CIB approach was implemented in a series of scenario workshops conducted as part of the *Investigating the Systemic Impacts of the Global Energy Transition* (ISIGET) research project, funded as part of the French-German *Make Our Planet Great Again* research initiative. The aim of the project is to generate a set of comprehensive energy transition scenarios until 2050 and develop recommendations for equitable forms of energy transition governance in the Global South. Analytically, the research accounts for the complex interdependencies of driving forces at multiple scales (e.g. technology value chains, financial flows, geopolitics, and sustainable development).

A global workshop and four country-level workshops were conducted between February 2021 to December 2021 to map the landscape of energy transitions based on various challenges faced by developing countries and emerging economies. The learnings from the global workshop informed the participatory scenario planning exercises in four selected country case studies (Fig. 3). The scenarios produced for each country case study subsequently informed the policy recommendations in 'sensemaking workshops' with the participating country-level stakeholders. Below we report the learnings focusing on the global workshop that was conducted online.

The scenario workshops comprised two-day sessions either in a physical or in an online format. The online format was a function of necessity due to the Covid-19 restrictions in the various countries. The virtual setting, in turn, necessitated informed methodological choices for scenario development by adapting morphological analysis for participatory data collection in CIB. On the one hand, the online workshop clearly replicated the physical workshop. On the other hand, the format allowed us to critically revisit aspects of the physical workshop to optimize the participatory approach to gathering knowledge. We implemented a virtual collaboration tool using Miro and trained a support team as notetakers and modelers.

3.2. Global scenario workshop: extracting variables

The global workshop was held on February 10th and 11th, 2021. Participants comprised a select group of experts who were invited based on their knowledge of global as well as regional energy transition patterns and dynamics. Given the importance of an involved group discussion for the participatory scenarios (even more so in an online setting), the group was kept relatively small. The 22 international experts represented a gender-balanced cross-section of researchers and practitioners from the public and private sectors whose works related to one or more regions in the Global South such as Latin America and Southeast Asia. The workshop format started with a plenary session followed by four breakout group sessions. The goal of the plenary session was to identify the main challenges and barriers related to the energy transition, including geopolitical, financial, socio-economic, and socio-technical challenges. Recognizing that the energy transition could take shape differently across world regions [62], participants met in four breakout groups based on their specific regional expertise on Latin America, Sub-Saharan Africa, Middle East and North Africa, and Southeast Asia.

3.2.1. Plenary discussions: extracting scenario variables

Conventionally, scenario variables are extracted by the research team through horizon scanning, that is by identifying driving factors from a plethora of printed media (e.g., news articles, academic literature). However, such a process does not align with the transdisciplinary approach. In line with the latter, the workshop participants were instead asked to decide which variables should be considered in the scenario development process. The plenary was used for focus group discussions to extract scenario variables that may impact the energy transition. Two trained notetakers identified any factors that were mentioned by participants as impacting the trajectory of the global and regional energy transition. Using Miro, a visual mapping tool, the notetakers created a yellow sticky note for each distinct factor. The nature of the discussion meant that some factors identified were very specific (e.g., *levelized cost for solar and wind)* while others were more general (e.g., *cost of renewable energy*). The latter were used as 'containers' for the more specific factors.

These factors were grouped thematically by the notetakers to generate variables. The work of capturing and categorizing different factors to produce scenario variables was carried out in parallel to the plenary while the presentations and discussions were ongoing. The extracted scenario variables formed the basis of the second analytical step, that is their discussion in the regional respective breakout groups.

3.2.2. Regional breakout groups: selecting scenario variables, identifying, and interconnecting end-states

Four breakout group sessions on Latin America, Sub-Saharan Africa, Middle East and North Africa, and Southeast Asia then discussed the results from the plenary session and their applicability for a given region. The breakout group sessions were conducted in three stages, requiring participants to (1) select scenario variables, (2) identify plausible end-states for each variable, and (3) interconnect end-states that influence each other.

First, the participants of the regional breakout groups selected the

Fig. 3. Research strategy for producing energy transition scenarios.

most important and most uncertain variables in relation to energy transition processes in their respective regions, a process that was facilitated by a short open discussion followed by an online voting system. Second, participants were asked to identify at least two end-states that were mutually exclusive for each variable. A modeler assigned to each group worked in the background creating a morphological field (Fig. 4), depicting the variables and their respective end-states as envisioned by the group. This second step is identical to what is typically done in conventional scenario planning processes using morphological analysis.

Finally, the participants identified interrelationships between end-states, creating an influence diagram that would be used for the subsequent formal CIB analyses. Again, using Miro, arrows graphically indicated a directional influence (causation) between two variable end-states (Fig. 4).

Participants were only asked to describe direct influences promoting but not inhibiting transformative effects. They were encouraged to draw as many interconnecting arrows as they saw fit. Any influence inhibiting change was left to be calculated in the CIB. This is an analytical choice which leverages the CIB principle that the judgment group must be balanced: the promoting influence was recorded as a positive value, so the opposite end-states would record negative values, thus making the sum of the judgment group equate to zero or 'balanced'. Also, making participants focus on imagining promoting influences is more intuitive and can be done expediently within the available time. That said, this choice comes with limitations. Notably, it rests on additional assumptions on the logic of CIB models. Moreover, the magnitude of the influence is not captured. The approach as chosen therefore poses limitations for data collection for CIB, which could be an area for future improvement.

The influence diagram marks the end of data collection. We left the process of identifying consistent scenarios to CIB and the entailed computational techniques after the workshop (for more detail information on CIB analysis, please see Weimer-Jehle (2006) [15]).

3.3. Next steps: local expert interviews and case study scenario workshops

The results from the global scenario workshop informed the identification of local variables in four country case studies. After the completion of the global workshop, the transcripts from the global scenario workshops qualitatively coded to extract scenario variables and possible different end-states. Transcripts from the breakout groups further allowed analyses of which variables were relevant in specific regions. The workshops yielded three variables relevant to all regions and nine variables that were important for specific regions. For each region, one country was further selected as a case study for developing energy transition scenarios: Chile, Jordan, Kenya, and Malaysia.

The next step after the global workshop was to determine the relevance of 'regional' variables for specific country cases. To this end, for each country case study we conducted around ten semi-structured interviews with the local experts and stakeholders. These interviews took place in the summer and early fall of 2021. During these interviews, we asked participants to rate the importance of the nine scenario variables for their respective countries and suggest potential missed variables. Reflecting specific local contexts, certain variables were selected as being a determining factor for a given country whereas others were not. Given the nature of the participatory scenario planning exercise, we impose a limit of selecting up to nine scenario variables for the scenario development process. The nine variables could be adequately discussed in the two-day workshops that followed for each country case study. The participatory scenario workshops for the four country case studies were conducted in the fall of 2021. They were conducted in different formats: fully online (Chile), physical setting (Jordan and Kenya), and hybrid (Malaysia). During these workshops, participants were presented with a morphological field diagram comprising of scenario variables and end-states for each country, and then produced corresponding influence diagrams as data inputs to computational scenario modelling using CIB analysis.

4. Methodological add-on and limitations of participatory scenario development using CIB

Overall, the workshops conducted with the novel approach demonstrated that an expert-based scenario analysis technique such as CIB can be reconciled with the imperative of stakeholder-based research by adapting morphological analysis as an intuitive data collection tool. Here, we offer reflections on the methodological add-ons, describe lessons learned during the process, and discuss the limitations of using intuitive participatory CIB.

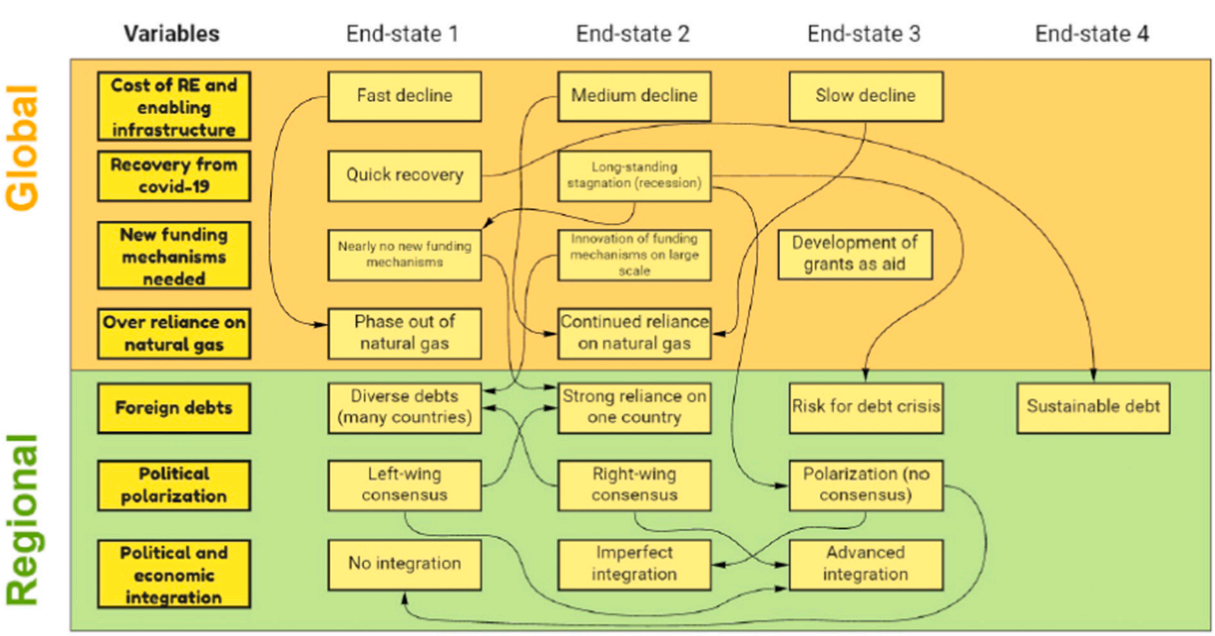

Fig. 4. Influence diagram for Latin America breakout group.

4.1. Reconciling inherent epistemological tensions

As a matter of principle, the specific benefit of scenarios differs depending on whether the focus of a given scenario exercise is on the 'process' or the 'product' [63]. 'Scenario-as-a-process' aligns with participatory scenario development including, in our case, morphological analysis. It engages participants to imagine radical but plausible futures [64]. Because participants are encouraged to think out of the box, they are able to internalize different options for future developments and, therefore, learn during the exercise [55,62]. However, participatory scenarios are based on the participants' subjective interpretations. This inevitably raises issues on the subjectivity of the scenarios [65]. In other words, scenario-as-process may not align with the core criterion of a scenario being objective. In contrast, the 'scenario-as-product' approach is often viewed as a scientific assessment that can chart the evolution of driving forces [66]. Evolutionary pathways can inform policy decisions as they allow tailoring the scenario process to support desirable pathways or resist undesirable ones.

This tension can in part be reconciled by separating data collection from formal scenario development. For CIB studies, participants may find it hard to envision the cross-impact relationships among variables presented in a matrix. Fortunately, morphological analysis can be applied in a participatory manner, allowing data collection for the purpose of CIB analysis. Moreover, the morphological field presented visually facilitates qualitative data collection more expediently in a participatory scenario workshop. Morphological analysis can help identify, structure, and investigate possible relationships involved in the complexity of energy transitions [67]. For *participatory* CIB, as proposed in this article, we combined morphological analysis and CIB analysis into a coherent scenario development process. Stakeholder-based morphological analysis allows focusing on the participatory component of this process, whereas testing what-if assumptions, as well as traceability, is fundamental to CIB analysis [68]. Thus, participatory CIB is both scenario-as-a-process and scenario-as-a-product, resulting in (1) the ability to test what-if assumptions and (2) an internalization of knowledge, problems, and solutions as participants interact to find a common ground and shared visions.

4.2. Procedural innovation

Research suggests that graphical products such as diagrams, sketches or drawings help with human visual cognition [69]. Visual representation of knowledge in a form of concept mapping like the morphological field produced in these workshops can aid the participants' comprehension in assimilating abstract ideas [70]. Several procedural tweaks helped enhance data to be collected more expediently and improve interaction among participants. Notably, virtual whiteboard tools such as Miro allowed for a tangible display of the constructed morphological field from which an influence diagram was then produced.

For the global online scenario workshops, placing a modeler in each breakout group to assist group moderators proved crucial for the session chair to focus on moderating the discussion and the interactions among participants, while the modeler secured data and captured the complex interrelations between end-states. Having a modeler to graphically present integrated knowledge shared by the participants freed participants up from time-consuming tasks such as updating the virtual whiteboard. Without such a burden, participants were able to concentrate on speaking about and sharing their insights on the topics being discussed. Together with the 'live' visualizations, this helped keep the discussion focused. The interactive exchange among participants also fostered co-learning, which is typical in any participatory scenario workshop.

Moreover, the modelers assumed an important role in data extraction. There were continuous feedback loops between the modeler and participants about whether their ideas were correctly represented and visualized on the virtual whiteboard. Hence, the presence of a modeler to facilitate better collaboration in an online workshop—meant as a precautionary step—helped participants focus and added clarity. That said, the approach comes with additional resource requirements. All modelers were scenario researchers with CIB knowledge and a background in systems thinking. Hence, for online workshops, it is imperative to ensure sufficient support to facilitate smooth data collection in a virtual setting. For the workshops done in physical settings, we specifically trained the facilitators to draw interconnections while they were moderating the discussions, which also meant additional resource requirements.

4.3. Procedural challenges and support structure

Building on the above, time was a key challenge to facilitate smooth and meaningful scenario building in a participatory online setting. The resources needed can be significant, as they imply both a larger team of researchers as well as targeted training for modelers, workshop facilitators or involved support staff. That said, a clear benefit of separating participatory data collection from computational scenario modelling is avoiding long online sessions that tend to cause 'zoom' fatigue. Moreover, online workshops were instrumental in overcoming limitations to field research brought about by the pandemic. Virtual settings allowed interactions across time zones and with support staff located in geographically distant regions. For example, the global scenario workshop involved facilitators based in Potsdam, Germany, modelers based in Waterloo, Canada, and expert participants based in different countries and world regions.

During Covid-19, many workshops were moved into the virtual space. This has stimulated debates about the advantages and disadvantages of online workshops and their future use [71–73]. Advantages include reduced costs, less time required for planning, more access to geographically dispersed participants and reduced environmental impacts. This often enables projects that would not have been possible otherwise. However, there are certain limitations that need to be considered, like the fact that limited online literacy of participants or a lack of sufficiently fast and reliable internet access might create new patterns of exclusion and reinforce existing ones. In addition, online workshops typically come with less in-depth participant interaction than in physical settings, which may also reduce their level of engagement. These disadvantages can be remedied by adapting the structure of the workshop (smaller and shorter workshops are recommended) and facilitation technique training. Although we acknowledge calls for online events to be used as a stand-alone option that is in itself more suited for specific aims [72], this requires a proactive use of the possibilities of the online setting and compensating for disadvantages as much as possible [74].

Another aspect worth discussing is the process of selecting workshop participants. As in any research aimed at co-production of knowledge, the composition of the group of participants can influence which scenarios are produced. According to Musch and von Streit (2020) [75], participatory elements often fall short of ensuring diversity and research teams tend to gravitate to inviting participants with similar backgrounds. While we were careful to consider a balanced selection in terms of gender and region, there were other potential group biases that need mentioning [76]. Notably, the global workshop was conducted in English and ended up featuring English-speaking experts working for prominent international agencies active in the fields of the energy transition, finance, and development. Ensuring an even more diverse group of participants would bring additional insights as well as competing ideas [77,78]. It is important to qualify that a diverse group of participants adds benefit only if the participants' level of engagement is high. This is especially true when workshops are conducted in a foreign language. Ensuring high-level interaction and diversity therefore necessitates additional support in the shape of simultaneous translation, a challenge that is often difficult to solve for online workshops. For the country case studies, we address this by providing translated introductory materials and conducting workshops in the native language (Spanish in Chile) or providing native-language breakout groups (Arabic in Jordan).

Finally, separating participatory data collection from computational scenario modelling comes with the procedural challenge of leaving participants without final results at the close of data collection workshops. Participants clearly co-produce the underlying logic of energy transition scenarios, but the full set of scenarios was produced only after the workshop had ended. In light of this, one participant suggested that demystifying scenario modelling done in the 'backstage' would assure participants that their contributions to the exercise were not merely an 'early prototype', but instead leading towards the production of more robust scenarios using computational models such as CIB. The way we dealt with this challenge is by trying to manage participants' expectations by briefly introducing the entire scenario process, unravelling that the scenario exercises are more than a 'black box'. We also set up a series of subsequent sensemaking workshops where we discussed the results with the involved stakeholders aimed at co-producing policy recommendations to achieve desirable scenarios for the energy transition of the different country case studies.

4.4. Resolving differences in opinions

A final element pertains to dealing with differing opinions. It is important to stress that, besides identifying the influence judgments that would go into the CIB model, we were also interested in capturing areas of participants' agreements and disagreements. In this, our approach differed from participatory scenario approaches where participants must come to a consensus and differences in viewpoints are typically discouraged. In our case, when participants failed to reach a consensus, different inputs were considered in the scenario development. In fact, the CIB method is attuned to resolving different views. For instance, two or more CIB matrices can be constructed each with different influence judgments [45]. These matrices can be 'solved' individually by producing different sets of solutions that can be harmonized afterwards. Alternatively, the CIB software has an *ensemble* feature that combines different matrices together to form a single matrix to be subjected to CIB analysis. The take-away from the workshops as implemented, however, is that it is important to reflect on the value of differing opinions prior to conducting the analysis.

5. Conclusion

This Perspective reported how on a novel participatory approach for creating scenarios of the energy transition in the Global South. We demonstrated how a formal scenario technique such as CIB can be reconciled with the imperative of stakeholder-based research, by way of leveraging morphological analysis as an intuitive data collection tool and by combining both into a coherent scenario development process. Even under conditions of severe pandemic-induced limitations, online-based stakeholder workshops were found to offer a meaningful and feasible alternative to qualitative scenario building in physical settings. In fact, what started as a necessity became an innovative way of thinking about scenario research. More specifically, online participatory scenario workshops can be facilitated by adopting a morphological analysis approach to help structure the scenario process more clearly and collect data more expediently. Even as the pandemic situation may ease, the way forward will be to build on the reported approach and to innovate further in making participatory research methods more resilient, including through virtual platforms.

More fundamentally, we showed that the use of morphological analysis in the scenario planning workshop indeed makes CIB more participatory. Co-learning was also observed as a benefit of participatory scenario planning techniques. As a quasi-quantitative technique, CIB offers the benefit of the computational prowess to perform a complete search for internally consistent scenarios given complex interactions among scenario variables. Scientific communities working on developing scenarios for other sectoral analyses that consider systemic interactions of various driving forces may find our novel approach useful. Building on stakeholder knowledge, collaborative effort in co-producing energy transition scenarios will clearly help better reflect local cultural, social, political and economic conditions.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acknowledgements

Research for this paper is funded by the Investigating the Systemic Impacts of the Global Energy Transition (ISIGET) project financed by the Federal Ministry of Education and Research (BMBF) under the "Make our Planet Great Again - German Research Initiative", grant number 57429628, implemented by the German Academic Exchange Service (DAAD). The work of A. Lazurko is funded by the Pierre Elliott Trudeau Foundation (PETF) and the Social Sciences and Humanities Research Council of Canada (SSHRC). E. Nordermann and A. Sharma are funded by the Natural Sciences and Engineering Research Council of Canada (NSERC). N. Siddhantakar is funded by the Faculty of Environment's Dean's Doctoral Initiative, University of Waterloo. We also thank the workshop participants for their insightful contributions.

References

[1] J. Wiseman, The great energy transition of the 21st century: the 2050 Zero-Carbon World Oration, Energy Res.Soc. Sci. 35 (2018) 227–232, https://doi.org/10.1016/j.erss.2017.10.011.

[2] B.K. Sovacool, R.J. Heffron, D. McCauley, A. Goldthau, Energy decisions reframed as justice and ethical concerns, Nat. Energy 1 (2016) 1–6, https://doi.org/10.1038/nenergy.2016.24.

[3] C.-F. Schleussner, J. Rogelj, M. Schaeffer, T. Lissner, R. Licker, E.M. Fischer, R. Knutti, A. Levermann, K. Frieler, W. Hare, Science and policy characteristics of the Paris Agreement temperature goal, Nat. Clim. Chang. 6 (2016) 827–835, https://doi.org/10.1038/nclimate3096.

[4] A. Dall-Orsoletta, J. Cunha, M. Araújo, P. Ferreira, A systematic review of social innovation and community energy transitions, Energy Res. Soc. Sci. 88 (2022), 102625, https://doi.org/10.1016/j.erss.2022.102625.

[5] A. Gatto, The energy futures we want: a research and policy agenda for energy transitions, Energy Res. Soc. Sci. 89 (2022), 102639, https://doi.org/10.1016/j.erss.2022.102639.

[6] K. Rabiej-Sienicka, T.J. Rudek, A. Wagner, Let it flow, our energy or bright future: sociotechnical imaginaries of energy transition in Poland, Energy Res. Soc. Sci. 89 (2022), 102568, https://doi.org/10.1016/j.erss.2022.102568.

[7] J.M. Wittmayer, S. Hielscher, M. Fraaije, F. Avelino, K. Rogge, A typology for unpacking the diversity of social innovation in energy transitions, Energy Res. Soc. Sci. 88 (2022), 102513, https://doi.org/10.1016/j.erss.2022.102513.

[8] B.K. Sovacool, D.J. Hess, R. Cantoni, Energy transitions from the cradle to the grave: a meta-theoretical framework integrating responsible innovation, social practices, and energy justice, Energy Res. Soc. Sci. 75 (2021), 102027, https://doi.org/10.1016/j.erss.2021.102027.

[9] A. Goldthau, L. Eicke, S. Weko, The global energy transition and the global south, in: M. Hafner, S. Tagliapietra (Eds.), Geopolit. Glob. Energy Transit, Springer International Publishing, Cham, 2020, pp. 319–339, https://doi.org/10.1007/978-3-030-39066-2_14.

[10] B.K. Sovacool, D.J. Hess, S. Amir, F.W. Geels, R. Hirsh, L. Rodriguez Medina, C. Miller, C. Alvial Palavicino, R. Phadke, M. Ryghaug, J. Schot, A. Silvast, J. Stephens, A. Stirling, B. Turnheim, E. van der Vleuten, H. van Lente, S. Yearley, Sociotechnical agendas: reviewing future directions for energy and climate research, Energy Res.Soc. Sci. 70 (2020), 101617, https://doi.org/10.1016/j.erss.2020.101617.

[11] S. Elsawah, S.H. Hamilton, A.J. Jakeman, D. Rothman, V. Schweizer, E. Trutnevyte, H. Carlsen, C. Drakes, B. Frame, B. Fu, C. Guivarch, M. Haasnoot, E. Kemp-Benedict, K. Kok, H. Kosow, M. Ryan, H. van Delden, Scenario processes for socio-environmental systems analysis of futures: a review of recent efforts and a salient research agenda for supporting decision making, Sci. Total Environ. 729 (2020), 138393, https://doi.org/10.1016/j.scitotenv.2020.138393.

[12] W. Weimer-Jehle, S. Vögele, W. Hauser, H. Kosow, W.-R. Poganietz, S. Prehofer, Socio-technical energy scenarios: state-of-the-art and CIB-based approaches, Clim. Chang. (2020), https://doi.org/10.1007/s10584-020-02680-y.
[13] T. Pregger, T. Naegler, W. Weimer-Jehle, S. Prehofer, W. Hauser, Moving towards socio-technical scenarios of the German energy transition—lessons learned from integrated energy scenario building, Clim. Chang. (2019), https://doi.org/10.1007/s10584-019-02598-0.
[14] W.-R. Poganietz, W. Weimer-Jehle, Introduction to the special issue 'Integrated scenario building in energy transition research', Clim. Chang. (2020) https://doi.org/10.1007/s10584-020-02871-7.
[15] W. Weimer-Jehle, Cross-impact balances: a system-theoretical approach to cross-impact analysis, Technol. Forecast. Soc. Chang. 73 (2006) 334–361, https://doi.org/10.1016/j.techfore.2005.06.005.
[16] W. Weimer-Jehle, Properties of cross-impact balance analysis, ArXiv09125352 Phys. http://arxiv.org/abs/0912.5352, 2009. (Accessed 12 May 2016).
[17] V.J. Schweizer, Reflections on cross-impact balances, a systematic method constructing global socio-technical scenarios for climate change research, Clim. Chang. (2020), https://doi.org/10.1007/s10584-019-02615-2.
[18] E.A. Moallemi, F.J. de Haan, M. Hadjikakou, S. Khatami, S. Malekpour, A. Smajgl, M.S. Smith, A. Voinov, R. Bandari, P. Lamichhane, K.K. Miller, E. Nicholson, W. Novalia, E.G. Ritchie, A.M. Rojas, M.A. Shaikh, K. Szetey, B.A. Bryan, Evaluating participatory modeling methods for co-creating pathways to sustainability, EarthsFuture 9 (2021), e2020EF001843, https://doi.org/10.1029/2020EF001843.
[19] M.G. Lawrence, S. Williams, P. Nanz, O. Renn, Characteristics, potentials, and challenges of transdisciplinary research, One Earth 5 (2022) 44–61, https://doi.org/10.1016/j.oneear.2021.12.010.
[20] L. Pereira, T. Karpouzoglou, S. Doshi, N. Frantzeskaki, Organising a safe space for navigating social-ecological transformations to sustainability, Int. J. Environ. Res. Public Health 12 (2015) 6027–6044, https://doi.org/10.3390/ijerph120606027.
[21] A. Ernst, K.H. Biß, H. Shamon, D. Schumann, H.U. Heinrichs, Benefits and challenges of participatory methods in qualitative energy scenario development, Technol. Forecast. Soc. Chang. 127 (2018) 245–257, https://doi.org/10.1016/j.techfore.2017.09.026.
[22] D.J. Lang, A. Wiek, M. Bergmann, M. Stauffacher, P. Martens, P. Moll, M. Swilling, C.J. Thomas, Transdisciplinary research in sustainability science: practice, principles, and challenges, Sustain. Sci. 7 (SUPPL. 1) (2012) 25–43, https://doi.org/10.1007/s11625-011-0149-x.
[23] M. Patel, K. Kok, D.S. Rothman, Participatory scenario construction in land use analysis: an insight into the experiences created by stakeholder involvement in the Northern Mediterranean, Land Use Policy 24 (3) (2007) 546–561, https://doi.org/10.1016/j.landusepol.2006.02.005.
[24] J. Rotmans, M. van Asselt, C. Anastasi, S. Greeuw, J. Mellors, S. Peters, D. Rothman, D. Rijkens, Visions for a sustainable Europe, in: Futures Vol. 32, 2000 www.elsevier.com/locate/futures.
[25] E. Schmid, B. Knopf, Ambitious mitigation scenarios for Germany: a participatory approach, Energy Policy 51 (2012) 662–672, https://doi.org/10.1016/j.enpol.2012.09.007.
[26] J. Wachsmuth, Cross-sectoral integration in regional adaptation to climate change via participatory scenario development, Clim. Chang. 132 (3) (2015) 387–400, https://doi.org/10.1007/s10584-014-1231-z.
[27] S. Hansson, M. Polk, Assessing the impact of transdisciplinary research: the usefulness of relevance, credibility, and legitimacy for understanding the link between process and impact, Res. Eval. 27 (2018) 132–144, https://doi.org/10.1093/reseval/rvy004.
[28] M.H. Guimarães, C. Pohl, O. Bina, M. Varanda, Who is doing inter- and transdisciplinary research, and why?An empirical study of motivations, attitudes, skills, and behaviours, Futures 112 (2019), 102441, https://doi.org/10.1016/j.futures.2019.102441.
[29] L.J. Bracken, H.A. Bulkeley, G. Whitman, Transdisciplinary research: understanding the stakeholder perspective, J. Environ. Plan. Manag. 58 (2015) 1291–1308, https://doi.org/10.1080/09640568.2014.921596.
[30] M.D.A. Rounsevell, M.J. Metzger, Developing qualitative scenario storylines for environmental change assessment, Wiley Interdiscip. Rev.Clim. Chang. 1 (2010) 606–619, https://doi.org/10.1002/wcc.63.
[31] P. Baard, Knowledge, participation, and the future: epistemic quality in energy scenario construction, Energy Res. Soc. Sci. 75 (2021), 102019, https://doi.org/10.1016/j.erss.2021.102019.
[32] N. Nakicenovic, J. Alcamo, G. Davis, B. de Vries, J. Fenhann, S. Gaffin, K. Gregory, A. Grubler, Y.J. Tae, T. Kram, E.L. La Rovere, L. Michaelis, S. Mori, T. Morita, W. Pepper, H. Pitcher, L. Price, K. Riahi, A. Roehrl, H.-H. Rogner, A. Sankovski, M. Schelsinger, P. Shukla, S. Smith, R. Swart, S. van Rooijen, N. Victor, D. Zhou, Emissions Scenarios: A Special Report of IPCC Working Group III, Cambridge University Press, Geneva, 2000.
[33] WEC, World energy scenarios 2016, World Energy Council, 2017. https://www.worldenergy.org/wp-content/uploads/2016/10/World-Energy-Scenarios-2016_Full-Report.pdf. (Accessed 31 August 2017).
[34] S. Teske, Energy Revolution - A Sustainable World Energy Outlook, GreenpeaceInternational, 2012.
[35] E. Schmid, A. Pechan, M. Mehnert, K. Eisenack, Imagine all these futures: on heterogeneous preferences and mental models in the German energy transition, Energy Res.Soc. Sci. 27 (2017) 45–56, https://doi.org/10.1016/j.erss.2017.02.012.
[36] A. Grunwald, O. Renn, J. Schippl, Die Energiewende verstehen – orientieren – gestalten: der Ansatz der Helmholtz-Allianz ENERGY-TRANS, in: L. Holstenkamp, J. Radtke (Eds.), Handb. Energiewende Partizipation, Springer Fachmedien, Wiesbaden, 2018, pp. 829–846, https://doi.org/10.1007/978-3-658-09416-4_49.
[37] E. Kemp-Benedict, H. Carlsen, S. Kartha, Large-scale scenarios as 'boundary conditions': a cross-impact balance simulated annealing (CIBSA) approach, Technol. Forecast. Soc. Chang. 143 (2019) 55–63, https://doi.org/10.1016/j.techfore.2019.03.006.
[38] V.J. Schweizer, J.H. Kurniawan, Systematically linking qualitative elements of scenarios across levels, scales, and sectors, Environ. Model. Softw. 79 (2016) 322–333, https://doi.org/10.1016/j.envsoft.2015.12.014.
[39] P. Hansen, C. Pannaye, S. Vögele, The Future(s) of the Energy Consumption of Private Households in Germany - A Multilevel Cross-impact Analysis, IEK-STE, Jülich, Germany, 2013.
[40] S. Vögele, P. Hansen, W.-R. Poganietz, S. Prehofer, W. Weimer-Jehle, Building scenarios for energy consumption of private households in Germany using a multi-level cross-impact balance approach, Energy 120 (2017) 937–946, https://doi.org/10.1016/j.energy.2016.12.001.
[41] R. Schmidt-Scheele, The Plausibility of Future Scenarios: Conceptualising an Unexplored Criterion in Scenario Planning, transcript-Verlag, 2020, https://doi.org/10.14361/9783839453193.
[42] V.J. Schweizer, E. Kriegler, Improving environmental change research with systematic techniques for qualitative scenarios, Environ. Res. Lett. 7 (2012), 044011, https://doi.org/10.1088/1748-9326/7/4/044011.
[43] N. Kearney, Guided cultural evolution and sustainable development: proof of concept and exploratory results, University of Waterloo, 2021. https://uwspace.uwaterloo.ca/handle/10012/16829. (Accessed 24 August 2021).
[44] E. Kemp-Benedict, W. de Jong, P. Pacheco, Forest futures: linking global paths to local conditions, in: P. Katila, G. Galloway, W. de Jong, P. Pacheco, G. Mery (Eds.), For. Press. Local Responses Glob. Issues, 2014 http://www.cifor.org/library/5028/forest-futures-linking-global-paths-to-local-conditions/ (accessed May 12, 2016).
[45] V.J. Schweizer, B.C. O'Neill, Systematic construction of global socioeconomic pathways using internally consistent element combinations, Clim. Chang. 122 (2014) 431–445, https://doi.org/10.1007/s10584-013-0908-z.
[46] J.H. Kurniawan, V.J. Schweizer, Using network analysis to identify key scenario elements across multiple energy scenario studies, Soc. Nat. Resour. (2020) 1–19, https://doi.org/10.1080/08941920.2020.1781988.
[47] R. Scheele, N.M. Kearney, J.H. Kurniawan, V.J. Schweizer, What scenarios are you missing? Poststructuralism for deconstructing and reconstructing organizational futures, in: Organ. Manage Future, Palgrave Macmillan, Cham, 2018, pp. 153–172, https://doi.org/10.1007/978-3-319-74506-0_8.
[48] W. Weimer-Jehle, J. Deuschle, R. Rehaag, Familial and societal causes of juvenile obesity—a qualitative model on obesity development and prevention in socially disadvantaged children and adolescents, J. Public Health 20 (2) (2012) 111–124.
[49] M. Schütze, J. Seidel, A. Chamorro, C. León, Integrated modelling of a megacity water system–the application of a transdisciplinary approach to the Lima metropolitan area, J. Hydrol. 573 (2019) 983–993, https://doi.org/10.1016/j.jhydrol.2018.03.045.
[50] H. Kosow, C.D. León, in: Die Szenariotechnik als Methode der Experten-und Stakeholdereinbindung. In Methoden der Experten-und Stakeholdereinbindung in der sozialwissenschaftlichen Forschung, Springer VS, Wiesbaden, 2015, pp. 217–242.
[51] A.K. Musch, A. von Streit, Szenarien, Zukunftswünsche, Visionen. Ergebnisse der partizipativen Szenarienkonstruktion in der Modellregion Oberland. Projekt INOLA. München (INOLA-Arbeitsbericht, 7), Online verfügbar unter, 2017 (Zugriff vom 03.03. 2020).
[52] J. Venjakob, D. Schüwer, C. Schneider, M.C. Gröne, Cross-Impact-Analysen zur Transformation städtischer Energieinfrastrukturen am Beispiel KWK und Wasserstoff: Ergebnisse des Teilprojekts" Transformation und Vernetzung städtischer Energieinfrastrukturen" im Gesamtprojekt" Energiewende Ruhr", 2018, https://doi.org/10.1016/j.jhydrol.2018.03.045.
[53] C. Drakes, A. Cashman, E. Kemp-Benedict, T. Laing, Global to small island; a cross-scale foresight scenario exercise, Foresight (2020), https://doi.org/10.1108/FS-02-2020-0012 ahead-of-print.
[54] I. Stankov, A.F. Useche, J.D. Meisel, F. Montes, L.M.O. Morais, A.A.L. Friche, B. A. Langellier, P. Hovmand, O.L. Sarmiento, R.A. Hammond, A.V. Diez Roux, From causal loop diagrams to future scenarios: using the cross-impact balance method to augment understanding of urban health in Latin America, Soc. Sci. Med. 282 (2021), 114157, https://doi.org/10.1016/j.socscimed.2021.114157.
[55] A. Wilkinson, R. Kupers, The Essence of Scenarios: Learning From the Shell Experience, Amsterdam University Press, Amsterdam, 2014.
[56] T.J. Gordon, Energy forecasts using a "Roundless" approach to running a Delphi study, Foresight 9 (2007) 27–35.
[57] T. Ritchey, General morphological analysis as a basic scientific modelling method, Technol. Forecast. Soc. Chang. 126 (2018) 81–91, https://doi.org/10.1016/j.techfore.2017.05.027.
[58] J.C. Glenn, T.J. Gordon (Eds.), Futures Research Methodology Version 3.0, The Millennium Project, Washington DC, 2009.
[59] I. Johansen, Scenario modelling with morphological analysis, Technol. Forecast. Soc. Chang. 126 (2018) 116–125, https://doi.org/10.1016/j.techfore.2017.05.016.
[60] S.M. Zahraei, J.H. Kurniawan, L. Cheah, A foresight study on urban mobility: Singapore in 2040, Foresight 22 (2019) 37–52, https://doi.org/10.1108/FS-05-2019-0044.
[61] W. Weimer-Jehle, <book-title>Scenario Wizard 4.3: Constructing Consistent Scenarios Using Cross-impact Balance Analysis</book-title>, Zirius, University of Stuttgart, Stuttgart, 2018 http://www.cross-impact.de/Ressourcen/ScenarioWizardManual_en.pdf.

[62] R. Swart, P. Raskin, J. Robinson, The problem of the future: sustainability science and scenario analysis, Glob. Environ. Chang. 14 (2004) 137–146, https://doi.org/10.1016/j.gloenvcha.2003.10.002.

[63] J.H. Kurniawan, Assessing Consistency of Scenarios Across Scales: developing globally linked internally consistent scenarios under the Shared Socioeconomic Pathways framework, University of Waterloo. https://uwspace.uwaterloo.ca/handle/10012/16019, 2020. (Accessed 31 January 2021).

[64] B. Anderson, Preemption, precaution, preparedness: anticipatory action and future geographies, Prog. Hum. Geogr. 34 (2010) 777–798, https://doi.org/10.1177/0309132510362600.

[65] E.A. Lloyd, V.J. Schweizer, Objectivity and a comparison of methodological scenario approaches for climate change research, Synthese 191 (2014) 2049–2088, https://doi.org/10.1007/s11229-013-0353-6.

[66] J. Alcamo, Environmental Futures: The Practice of Environmental Scenario Analysis, Elsevier, Amsterdam, 2008.

[67] M. Nayebi, G. Ruhe, Chapter 19 - analytical product release planning, in: C. Bird, T. Menzies, T. Zimmermann (Eds.), Art Sci. Anal. Softw. Data, Morgan Kaufmann, Boston, 2015, pp. 555–589, https://doi.org/10.1016/B978-0-12-411519-4.00019-7.

[68] H. Kosow, New outlooks in traceability and consistency of integrated scenarios, Eur.J.Futures Res. 3 (1) (2015) 1–12, https://doi.org/10.1007/s40309-015-0077-6.

[69] S. Pinker, Visual cognition: an introduction, Cognition 18 (1984) 1–63, https://doi.org/10.1016/0010-0277(84)90021-0.

[70] W.M.K. Trochim, An introduction to concept mapping for planning and evaluation, Eval. Program Plann. 12 (1989) 1–16, https://doi.org/10.1016/0149-7189(89)90016-5.

[71] B. Wilkerson, A. Aguiar, C. Gkini, I.Czermainski de Oliveira, L.K.Lunde Trellevik, B. Kopainsky, Reflections on adapting group model building scripts into online workshops, Syst. Dyn. Rev. 36 (3) (2020) 358–372, https://doi.org/10.1002/sdr.1662.

[72] R. Willis, A. Yuille, P. Bryant, D. McLaren, N. Markusson, Taking deliberative research online: lessons from four case studies, Qual. Res. (2021), https://doi.org/10.1177/14687941211063483.

[73] N. Zimmermann, I. Pluchinotta, G. Salvia, M. Touchie, H. Stopps, I. Hamilton, T. Kesik, K. Dianati, T. Chen, Moving online: reflections from conducting system dynamics workshops in virtual settings, Syst. Dyn. Rev. 37 (1) (2021) 59–71, https://doi.org/10.1002/sdr.1667.

[74] A. Davies, A. Seaton, C. Tonooka, J. White, COVID-19, online workshops, and the future of intellectual exchange, Rethink. Hist. 25 (2) (2021) 224–241, https://doi.org/10.1080/13642529.2021.1934290.

[75] A.K. Musch, A. von Streit, (Un)intended effects of participation in sustainability science: a criteria-guided comparative case study, Environ. Sci. Policy 104 (2020) 55–66, https://doi.org/10.1016/j.envsci.2019.10.004.

[76] B.K. Sovacool, M.-C. Brisbois, Elite power in low-carbon transitions: a critical and interdisciplinary review, Energy Res. Soc. Sci. 57 (2019), 101242, https://doi.org/10.1016/j.erss.2019.101242.

[77] J.H. Kurniawan, A. Kundurpi, Integrating human geography into futures studies: reconstructing and reimagining the future of space, Geogr. Compass 13 (2019), https://doi.org/10.1111/gec3.12443.

[78] E. Trutnevyte, J. Barton, Á. O'Grady, D. Ogunkunle, D. Pudjianto, E. Robertson, Linking a storyline with multiple models: a cross-scale study of the UK power system transition, Technol. Forecast. Soc. Chang. 89 (2014) 26–42, https://doi.org/10.1016/j.techfore.2014.08.018.