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Practical science for uncertain futures

Using scenarios to improve resilience to earthquakes

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Abstract

Earthquake disaster risk resilience is an example of a complex problem that requires decision-making and action from different stakeholders. These multiple stakeholders each have different and sometimes competing agendas, as well as different understandings of the nature of the problem. We outline here the use of transdisciplinary research and futures studies as methods for tackling this type of complex problem. These offer practical steps to bring together stakeholders and actors from different disciplines and different lay perspectives to (1) agree a common understanding of the problem, (2) think systematically about how these problems may play out in the future, and (3) come up with actionable, strategic plans that bring the results to fruition on the ground. Drawing on the theoretical literature about futures studies and transdisciplinary approaches, as well as lessons from various practical applications, we find that scenarios are among the most widely used transdisciplinary futures approaches. There are several approaches to scenario building, depending on the aims of the exercise and the availability of resources. In particular, we explore the Geohazards International approach, which has been used with great success in resource-constrained contexts.

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About this paper

This paper is intended for researchers and practitioners interested in a scenario method, using a transdisciplinary approach, for earthquake disaster risk reduction. It provides an overview of transdisciplinary research, futures studies and scenarios in earthquake disaster risk reduction, drawing on current literature and examples from practice.

This paper was produced as part of the PAGER-O project in China, where a transdisciplinary scenario approach to earthquake disaster risk reduction is being tested. For readers interested in applying this approach, we recommend that you read our related article *Creating an Earthquake Scenario in China: A Case Study in Weinan City, Shaanxi Province* discussing its implementation in China, published in a special issue of the *International Journal for Disaster Risk Reduction* in August 2019.

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Acronyms

CEA	China Earthquake Administration
CDMG	California Division of Mines and Geology
DRR	disaster risk reduction
DEFRA	Department for Rural Affairs
EERI	Earthquake Engineering Research Institute
EWF	Earthquakes without Frontiers
FEMA	Federal Emergency Management Agency
GHI	GeoHazards International
KVERMP	Kathmandu Valley Earthquake Risk Management Project
MCA	China Ministry of Civil Affairs
NGO	non-governmental organisation
NSET	National Society for Earthquake Technology (NSET-Nepal)
PAGER-O	The Pan-participatory Assessment and Governance of Earthquake Risks in the Ordos Area
RAPID	Research and Policy in Development
ROMA	RAPID Outcome Mapping Approach
SAFRR	Science Application for Risk Reduction
SWOT	Strength, Weakness, Opportunity and Threat analysis
USGS	United States Geological Service

Executive summary

Introduction

The world is facing a number of complex, evolving challenges, and in this paper we focus on one such problem: that of intra-continental earthquakes. Managing earthquake risks presents a challenge for several reasons, not least of which is the involvement of diverse stakeholders from a range of academic disciplines and lay perspectives.

A method is required for these actors to integrate their various areas of expertise and design actionable strategies for earthquake risk management. This paper examines two theoretical models for achieving this: transdisciplinary research and futures studies. It then zeros in on a widely used tool in futures studies: scenario building. While concentrating on the background and theory of these approaches, the paper also looks at past practical applications and touches upon a current project underway in China, which is testing the scenario-building approach.

Transdisciplinary research

Transdisciplinary research is a way to bring together different stakeholders, with scientific as well as life-world knowledge, to create a new knowledge that transcends disciplinary boundaries. It is particularly well suited to researching and finding solutions for complex problems that are not well understood.

At its core, the transdisciplinary research process is about knowledge integration, and involves collaborative problem definition, the co-production of solution-oriented knowledge, and the integration of this knowledge into societal and scientific practice with demonstrable results.

A transdisciplinary research approach was used in an Earthquakes without Frontiers (EWF) project to improve resilience to intra-continental earthquakes in the Alpine-Himalaya belt. It was widely considered a success, due to the relationships that developed among participants and the lessons learned about disconnects between government policy and local preparedness, and between science and policy.

Futures studies

Futures studies is an approach to systematically studying and thinking about the future. The principles of futures studies are similar to those of transdisciplinary research in that they are *exploratory* (exploring alternative futures, or envisaging a desirable future and exploring different pathways to get there); *participatory*; and *action-oriented*.

The core stages of futures studies exercises are *diagnosis* (problem definition and background data); *prognosis* (exploring possible futures); and *prescription* (generating policy options and facilitating implementation). Practitioners have many methods and tools at their disposal at each of these stages.

Evidence on the impact of future studies exercises remains scarce, due to the methodological challenges of conducting such analyses. However, a meta study of several futures studies projects in Europe looked at the extent to which the exercise findings were implemented and utilised to inform policy, and found that they were broadly successful by this measure, although there were some exceptions.

Scenarios for earthquake disaster risk resilience

Scenario building is one of the most widely used methods in futures studies. Essentially, it is a process of collaboratively assembling knowledge, exploring assumptions about how a specific event might develop, and deciding what to do about it. The output of scenarios are plausible stories or narratives about future events, their causes and effects. These are then used to help decision-makers plan for or shape the future.

The United States Geological Survey (USGS) has used scenarios to explore a wide range of geological disasters, including earthquakes. The California 'shakeout' scenario is probably the most widely known earthquake scenario created to date, and utilised a methodology unique to USGS. It was highly influential in terms of shaping government plans and emergency response procedures, and has proven itself with long-lasting impacts on both official policy and public preparedness.

While the USGS approach has been very successful in the US, it is resource- and time-intensive. In response, GeoHazards International (GHI) developed an alternative approach based on the premise that, at a minimum, all that is required is for the estimated variables to be credible and technically sound. As such, its estimates of loss and damage are based on rapid assessment techniques and discussion among experts, rather than the sophisticated modelling techniques used by USGS, which admittedly produce more precise damage estimates.

The GHI methodology is regarded as highly successful. For instance, there is substantial evidence that a GHI-facilitated scenario exercise and subsequent action plan in the Kathmandu Valley substantially reduced the impact of the 2015 earthquake in that region.

Both the USGS and the GHI approaches to scenario building have demonstrated success in these respective high-profile examples, but the time- and cost-effectiveness of the GHI method makes it especially useful in developing countries.

Testing the approach in China

Based on the GHI model, a 12-step methodology was developed for testing the use of scenario building to support earthquake disaster risk resilience in China in the Pan-participatory Assessment and Governance of Earthquake Risks in the Ordos Area (PAGER-O) project. The present paper is a background companion paper to complement the exercise being carried out on the ground.

Substantial progress has been made on the practical side of the project, and the scenario itself has been written. The next stage for the project team is to prepare and implement an action plan. It is too early to draw any conclusions or recommendations from this project; interested readers should read the final report, published in a special issue of the *International Journal for Disaster Risk Reduction.*[1]

1 https://www.sciencedirect.com/science/article/pii/S2212420918314018

1 Introduction

The world and humanity are facing unprecedented challenges that are evolving rapidly and require decisions informed by the best possible science. And this needs to happen far more quickly than traditional processes for consensus-building in academia allow.

This paper describes an approach to the practical use of emerging science to improve uncertain futures. By emerging science we mean cutting-edge techniques for which there is not yet a strong consensus derived through peer-reviewed academic publications. By uncertain futures, we mean those problems we know are coming, but the impacts of which are not predictable, such as climate change or new pandemic diseases. These are often called 'wicked problems' because there is no single cause and no single solution. They affect multiple stakeholders in different ways, and apparent solutions in one area frequently cause trade-off problems elsewhere. There is no single governance mechanism to address them, and they often evolve very fast. We urgently need better ways to draw on science and other forms of knowledge to address them.

The specific problem we focus on in this paper is intra-continental earthquakes. These have killed over two million people in the last 100 years (ODI, 2015). Perversely, the geological factors that cause intra-continental earthquakes also create good conditions for human settlement, and the emergence of mega-cities on or close to active faults, and the migration of people into these areas, is rapidly increasing the number of people at risk. It is estimated that by 2050, more than two billion people in low- and middle-income countries will be exposed to serious disaster risks, including earthquake, floods, volcanoes and other risks (GCRF, 2019). However, mobilising action to reduce their impact before they occur presents a big challenge. Significant earthquake events are usually outside the living memory of policy-makers. Furthermore, it is difficult to estimate the timing or impact of their occurrence and they require a range of actors to come together from different disciplines.

A method is required for these different actors to integrate their various areas of expertise and design actionable strategies for earthquake risk management. This paper examines two emerging theoretical models for achieving this: transdisciplinary research and futures studies. It then zeros in on a widely used tool in futures studies: scenario building. While concentrating on the background and theory of these approaches, the paper also looks briefly at past practical applications and touches upon a current project underway in China.

Transdisciplinary research brings together different stakeholders to make decisions based on the best available evidence in the reality of policy-making and real lives.

Futures studies is a field of inquiry designed to study the future in order to determine how best to prepare for and increase human ability to influence and shape it, rather than just to react after the event. It is both a normative exercise that prompts thinking about what kinds of futures are desirable, as well as an instrumental exercise to think about possibilities, contingencies, discontinuities and possible surprises.

Scenario building brings together scientists, policy-makers, practitioners and lay people to think about and make plans to prepare for the future.

This paper has been prepared as part of the PAGER-O project in China, where a transdisciplinary, scenario-based approach to earthquake disaster risk reduction (DRR) is being tested. It is intended as a background paper and literature review to explore the theory behind the various tools being implemented in the project on the ground. It can therefore be seen as a companion paper to the final write-up of the project, published in a special issue of the *International Journal for Disaster Risk Reduction*.[2]

The next section of this paper provides an overview of transdisciplinary research: what it is, how it is done, whether it works, and how it has been applied in practice. The third section looks at the same questions in the field of futures studies and section four provides more detail on different approaches to scenario building. Section five focuses specifically on the use of scenarios for earthquake DRR, both in the US and developing countries. Towards the end of this paper you will find some information about how the tools discussed are being implemented in the PAGER-O project in China, although that project is still ongoing and as yet there are no conclusions or recommendations. Section six concludes with a summary of the background information and literature review presented by this paper.

2 https://www.sciencedirect.com/science/article/pii/S2212420918314018

2 Transdisciplinary research

2.1 Introduction

Transdisciplinary research brings together different stakeholders to make decisions based on the best available evidence, taking into account real lives and the reality of policy-making. In this section we start by defining transdisciplinary research, then discuss its key principles. We then outline the process and steps involved in conducting transdisciplinary research with a focus on knowledge integration, whether it works and how to evaluate its success. Finally, we describe how it was applied in the Earthquakes Without Frontiers (EWF) project.

2.2 What is transdisciplinary research?

Transdisciplinary research is an approach to solving socially relevant problems that are complex and transcend disciplinary boundaries. Problems are classed as 'socially relevant' where an issue is disputed in society, there is high societal interest in resolving the issue and the stakes are high for those involved in the research (Pohl and Hadorn, 2008a; Cronin, 2008). These complex problems are sometimes called 'wicked problems', as they are messy and characterised by circular change pathways (Wilkinson and Eidinow, 2008).

Transdisciplinarity starts from the premise that the nature of a problem of this type is not understood or predetermined and requires different scientific and societal actors to define it (Wiesmann et al., 2008). Defining the problem requires a blending of scientific, empirical evidence with professional and sometimes normative judgements. Moreover, addressing wicked, or complex, problems frequently involves stakeholders with divergent goals and distributed capacity (Young et al., 2014). Different stakeholders pull in different directions, sometimes proposing contradictory solutions, and there is a lack of clear decision-making structures. This leads to different actors influencing the decisions at different stages, instead of decisions being led by one actor (ibid: 16). As a result, the resources, skills and responsibilities required to make change happen are dispersed across different organisations and agencies (ibid). In sum, both wicked problems and socially relevant problems are characterised by the challenges and high stakes inherent both in defining the problem in the first place, and then in bringing different stakeholders together to resolve it.

Furthermore, socially relevant or wicked issues transcend disciplinary boundaries and therefore do not lend themselves to 'well-bounded, linear problem-solving approaches' or interventions that are purely based on historical and empirical evidence (Wilkinson and Eidinow, 2008: 1). By definition, socially relevant problems also transcend scientific boundaries as they cannot be resolved through purely scientific methods. Attempting their resolution requires both scientific and life-world knowledge.

Similar principles and practices have been utilised in climate change adaptation and are typically referred to as 'knowledge co-production' or 'joint knowledge production' (Hegger et al., 2012). In the field of risk reduction, knowledge co-production[3] brings together different stakeholders to produce the knowledge required for addressing complex ecosystem problems and their interactions with social components (Reyers et al., 2015).

This type of inquiry often also includes using bodies of knowledge accumulated through practical experience, for instance in problems that involve designing human interactions with the environment. In fostering resilience to natural hazards like earthquakes, for example, the professional knowledge found in the design professions (architecture, engineering, planning, industrial design) is an essential component for developing hazard maps and standards and codes for building safety (the focus of this paper). Engineers in this sector will rely heavily on the consensus of professionals on available research (both real-world and laboratory) and its applicability for design purposes. With the large number of uncertainties, earthquake engineers in particular find professional judgement to be essential when developing solutions. As will be discussed further in Section 4, these findings will often be combined with social, political and economic concerns and priorities, which further add to the complexity.

Transdisciplinary research focuses on finding practical solutions, by integrating scientific knowledge with life-world knowledge and values to identify implementable actions (Schaefer et al., 2010: 116). Because it centres on collaborative agreement of the problem definition and synthesises knowledge across disciplines, transdisciplinary research is well equipped to deal with complex problems where the body of knowledge about the problem is uncertain, the value and problem definition are disputed, and the stakes for those concerned with the problem are high (Pohl and Hadorn, 2008a; Hirsch-Hadorn et al., 2010).

In order to arrive at the solution to these wicked and socially relevant problems, transdisciplinary research seeks to generate and integrate three types of knowledge, through a participatory process among participants across different disciplines: (1) knowledge that describes the current status (systems knowledge), (2) knowledge that seeks to describe a (future) target status (target knowledge), and (3) knowledge that seeks to describe the transition from the current status to the target status (transformation knowledge) (Pohl and Hadorn, 2008a). These three types of knowledge have also been referred to as descriptive, informative and practice-oriented (ibid).

While there are other approaches that seek to combine knowledge from different disciplines, there are important differences between multidisciplinary, interdisciplinary and transdisciplinary approaches:

- Multidisciplinary research involves using knowledge and perspectives from different disciplines to enrich the given topic. It pays little attention to the initial synthesis of knowledge, and each discipline's participants are left to themselves to define the problem and methodology and to do their part autonomously from the others. 'Synthesising' the findings usually consists of a publication with different chapters from different contributors. Thus, it is about juxtaposing knowledge from different disciplines, where 'each discipline approaches the problem, interprets the results and reports them in a manner that is conventional for the discipline' (Bammer, 2013: 213). This can be challenging when the problem definitions offered by different participants do not fit together, and it is difficult to draw general lessons from the different contributions (ibid).
- Interdisciplinary research is about transferring methods from one discipline to another while remaining within the boundaries of disciplinary research. An example would be using the methods of nuclear physics within the discipline of medicine to treat cancer. It could also include the combination of methods to create new disciplines, such as biochemistry, astrophysics etc. (Choi and Pak, 2006).

3 The authors define 'knowledge co-production' as 'the collaborative process of bringing a plurality of knowledge sources and types together to address a defined problem and build an integrated or systems-oriented understanding of that problem' (Reyers et al., 2015).

- In transdisciplinary research, the problem is collectively and collaboratively defined at the beginning, and the methodological framework and plan for knowledge synthesis are also agreed from the start. Crucially, it engages decision-makers and practitioners in the development of the research framework as well as in the interpretation of results. Serving the common good is an important motivator in transdisciplinary research, and by explicitly asking whether a solution is serving the common good, diverse transdisciplinary researchers and participants are forced to reach consensus around the proposed solution (Pohl and Hadorn, 2007).

These differences are illustrated in Figure 1.

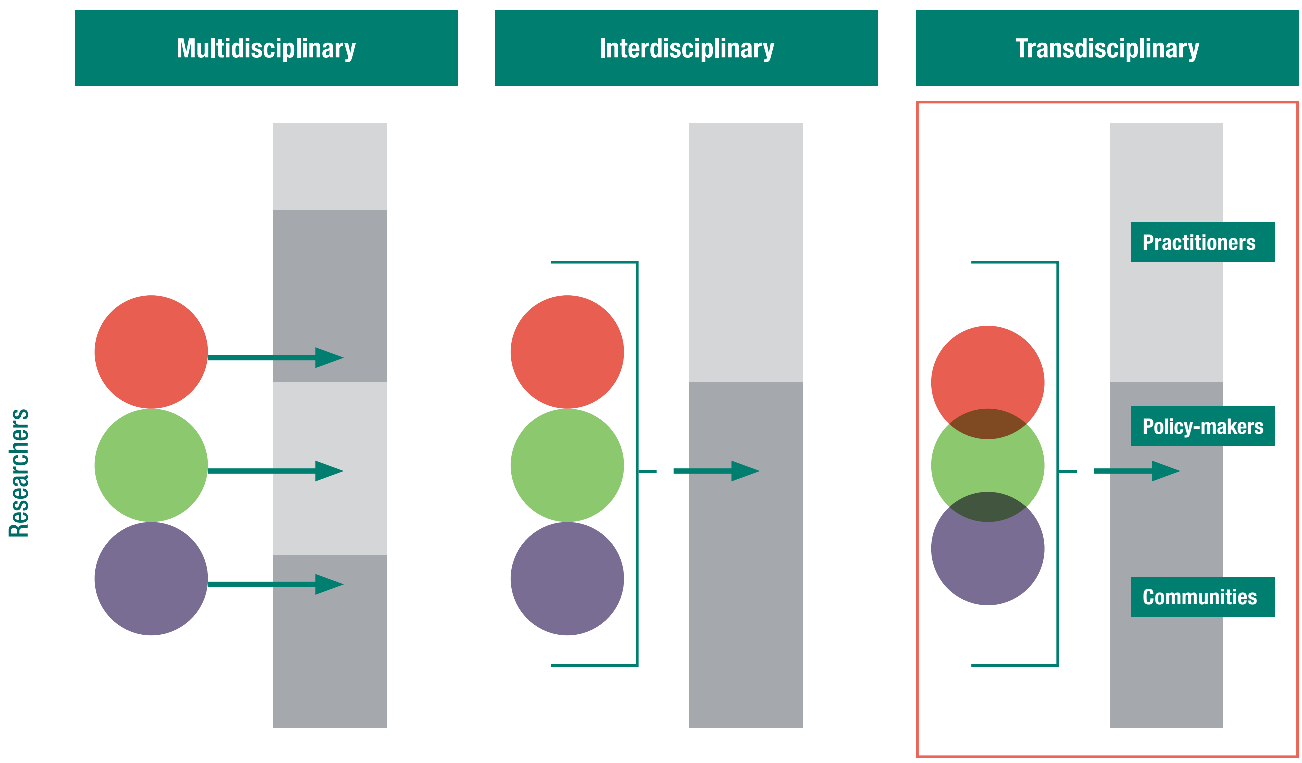
Transdisciplinary research is particularly useful for addressing complex problems and systems, and is widely used in issues around sustainability, health systems, environmental and innovation research (Schaefer et al., 2010). While transdisciplinary research is still a young field of enquiry, the principles and many of the methods have been used for a long time.

2.3 The principles and processes of transdisciplinary research

While still a young and expanding field, there are some well-established principles underpinning transdisciplinary research (Bunders et al., 2010; Lang et al, 2012; Pohl and Hadorn 2008a; Pohl and Hadorn, 2007). It is widely agreed that:

1. It is a joint process, initiated by non-academic actors from, for example, government or industry. It requires a joint problem definition, which seeks to ensure diversity of perspectives, to understand diverse scientific and societal views of the problem and engage in mutual learning (Pohl and Hadorn, 2008). At the same time it should seek to reduce complexity by clearly defining who needs the knowledge and for what purpose, and who should be involved. This definition should also indicate the type of knowledge that is ultimately sought, i.e. systems knowledge, target knowledge or transformation knowledge (Pohl and Hadorn, 2007).

Figure 1 Multidisciplinary, interdisciplinary and transdisciplinary research



Source: Halberg and Larsen (2002).

2. It uses a method-based analysis of systems complexity that employs methods such as actor analysis, causal analysis and system analysis.
3. It requires mutual learning among researchers, across different disciplines, and non-academic actors. Instead of central dissemination of knowledge, transdisciplinary research should use methods such as focus groups, roundtables, expert sessions and stakeholder dialogues. Central to this is the integration of different types of knowledge (disciplinary and life-world).
4. It focuses on societally relevant problems. Often this is associated with the principle of solving a problem to serve the common good.
5. It aims to create knowledge that is solution-oriented and socially robust and can be transferred to scientific and societal practice. Closely associated with this is the principle of designing real-world experiments in order to test underlying impact models and learn. This involves achieving effectiveness through contextual analysis, including identifying the needs, interests and preferences of stakeholders that are key to changing the real-life world.
6. It follows the principle of recursiveness, which cuts across all stages of the transdisciplinary research process. This means that the findings and lessons from one stage are used to inform the next stage of the research process in an iterative rather than linear manner. This also means revisiting decisions that were made at previous stages in the light of lessons learned.

In its broadest sense, the transdisciplinary research process consists of three stages (Pohl and Hadorn, 2007: 42–44; Lang et al., 2012): (1) problem definition: collaborative problem identification and structuring, (2) problem analysis: co-producing solution-oriented and transferable knowledge, and (3) application: bringing results to fruition and integrating this knowledge into societal and scientific practice (see Table 1).

Lang et al. (2012) outline in more detail what each of these stages entail. They summarise the process in a diagram, shown in Figure 2.

Table 1 Stages of transdisciplinary research

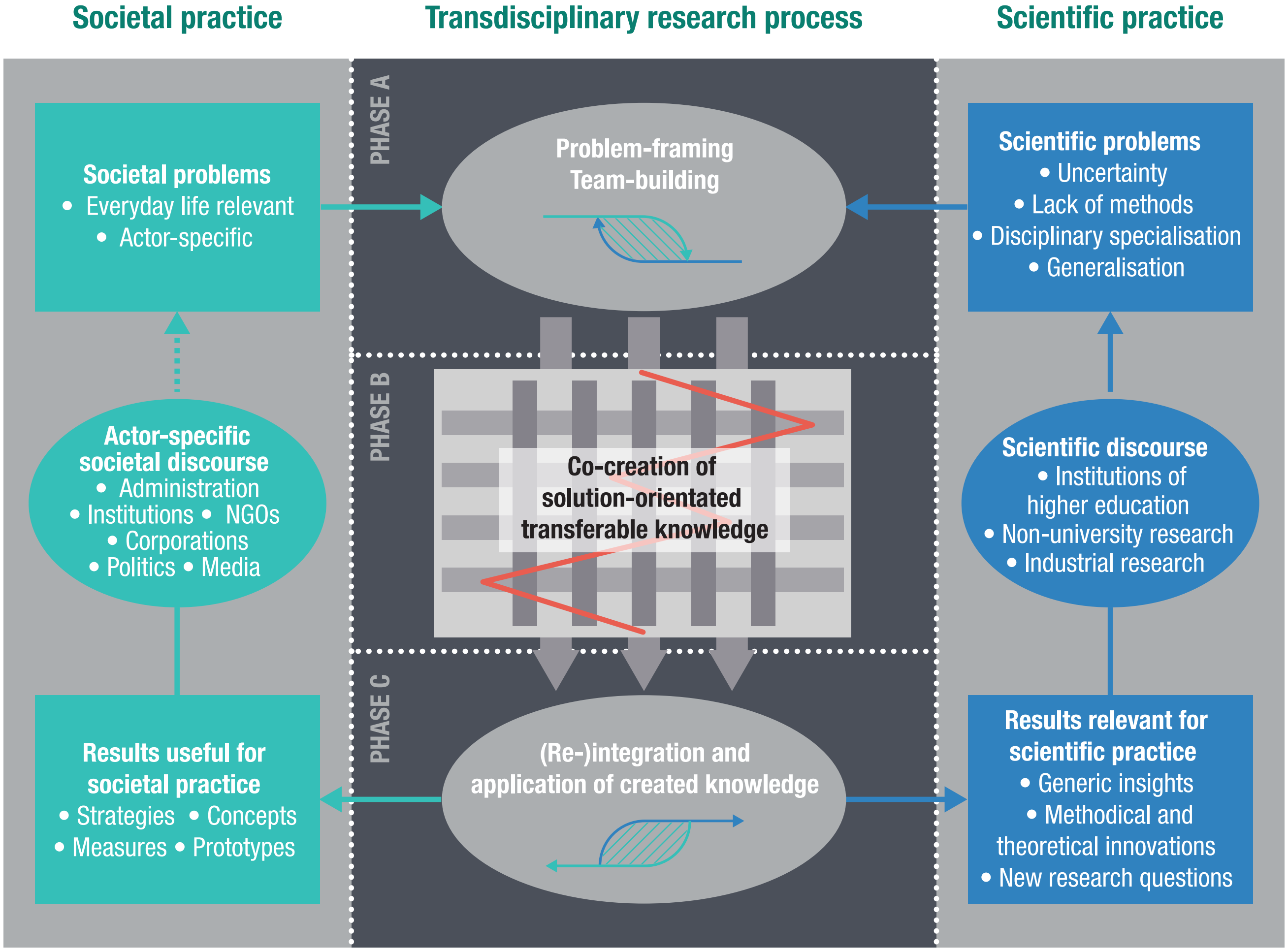
Phase	Activities
Phase A: Collaborative framing of the problem	First, begin by building the collaborative research team.
	Second, agree joint understanding and definition of the problem.
	Third, collaboratively define the boundary research object, research objectives and specific research questions, and success criteria.
	Fourth, design a methodological framework for collaborative knowledge production and integration.
Phase B: Co-producing solution-oriented and transferable knowledge	First, assign appropriate roles for practitioners and researchers.
	Second, apply and adjust integrative research methods for knowledge generation and integration.
Phase C: Integrating this knowledge into societal and scientific practice	First, ensure two-dimensional integration – feed the results of the work back into both the body of academic knowledge and into practical solutions on the ground.
	Second, communicate targeted outputs of knowledge to both scientific and societal actors.
	Third, monitor and evaluate the societal and scientific impact.

Integration of knowledge cuts across all phases of transdisciplinary research. The next section dives deeper into the theory and practical application of knowledge integration.

2.4 Knowledge integration

Knowledge integration is at the core of transdisciplinary research and is an important factor that differentiates transdisciplinary research from other multidisciplinary approaches. In transdisciplinary research, different types of knowledge, which are structured in fundamentally different ways (both academic and everyday life or life-world knowledge), have to be brought together – synthesised and combined – to create a new knowledge that transcends disciplinary boundaries and solves a complex problem (Godeman, 2008; Ayre and Nettle, 2015; Hirsch Hadorn et al., 2008; Klein, 2015).

Figure 2 The transdisciplinary research process



Source: Lang et al., 2012:4.

Systems thinking provides a conceptual basis for integrating these different types of knowledge. Pohl and Hadorn (2008) talk about two types of systems thinking. The first deals with hard systems, and is focused on integrating knowledge from different parameters to show how they correlate. For instance, an analysis of global hunger might incorporate economic data on hunger, knowledge on nutrients from biology and components on environmental change from ecologists. This would be enough for an interdisciplinary approach. A transdisciplinary approach will also involve soft systems thinking, which goes beyond the integration of different types of data and incorporates both disciplinary and non-disciplinary perspectives from life-world actors. For example, an understanding of the global HIV-AIDS problem must involve both medical knowledge and societal contextual analysis (ibid).

Bergman et al. (2012) identify three different types of knowledge integration: (1) communicative integration, which aims to develop mutual understanding of common terms, (2) social integration, which is about understanding different organisations' interests and roles, and (3) cognitive integration, which is about linking different knowledge bases, theoretical concepts and methods to create a common understanding. Exactly how to integrate different types of knowledge from disciplinary experts, practitioners, policy-makers and other stakeholders is a core methodological challenge of transdisciplinary research. This can be broken down into steps.

The first step of knowledge integration is the creation of a shared language. This will involve agreement on terminology and concepts, including both concept definition and concept analysis (Lang et al., 2012; Godeman, 2008). A common approach is to start by breaking up the research question or problem into its partial (disciplinary and non-disciplinary) areas and then bring the findings from these partial areas together (Godeman, 2008). Another method of achieving language integration, is to start with 'bridging' concepts, which are shared by different disciplines and covered by ordinary, everyday, language (Schaefer et al., 2014). The team can then progress to a collaborative discussion leading to consensus about other terminology and concepts.

Once a common language has been agreed it is possible to move on to the second step of integration: combining methods and theories into an appropriate methodology. The methodology needs to set out how the research findings will be assimilated, or integrated, into a final analysis of the problem and plans for real-world implementation. One way of doing this is by taking the output of one method as the input of another method, although this does require that they neatly fit together. For example, say an economic model has as its output levels of carbon-dioxide emissions (Hinkel, 2008). This data can then be used as input to a climate model (ibid). Scholz and Tietje (2002) also recommend the use of formative scenario analysis, multi-attribute utility theory,[4] system dynamics[5] and integrated risk management.[6] Others have used constellation analysis (see Box 1).

Box 1 Constellation analysis

Constellation analysis is a knowledge integration method and acts as a bridging concept to create mutual understanding between different disciplines and life-world actors. It translates the principles of contextualisation, reducing complexity, integration and recursiveness into a concrete method. It identifies interrelations between elements from the natural, technical, social and systemic worlds, and thus forces the different representatives from these worlds to take other's perspectives into account in their analysis of the given problem. These actors then describe the dynamics of the interactions using graphical visualisations while clarifying points of consensus and dissent. Actors from the life-world learn about the natural or technical elements to the given problem, while actors from the scientific or natural world learn about power relations and conflicting interests in the life-world, which in turn helps them design more effective strategies that cater to these realities.

Source: Schafer et al., 2010

The distance between the discrete disciplines in any particular research scenario (epistemological, methodological, analytical distance, and so on) will determine the amount of effort that needs to go into their integration. Some of the key elements required for successfully negotiating differences between disciplines are the regulation of one's emotions, good interpersonal relationships, good leadership and the prioritisation of interdisciplinary fieldwork (Datta, 2018).

Finally, Box 2 summarises some broad strategies and approaches to knowledge integration that could cut across any of the specific methods mentioned in this section[7].

4 A method whereby a decision-maker is presented with several alternatives. It involves listing factors that are important for the decision, assigning different weights (levels of importance) to different factors or attributes and calculating how well each alternative performs against each criterion.

5 This applies to 'any dynamic systems characterised by interdependence, mutual interaction, information feedback, and circular causality'. It involves defining problems dynamically and modelling and simulating interactions between factors, taking into account feedback loops, behaviour and structure. See Richardson, 2013 https://link.springer.com/referenceworkentry/10.1007%2F978-1-4419-1153-7_1030#howtocite for more information.

6 A decision-making approach that centres around risks. It involves aggregating different types of risk and their distribution to quantify unpredictability and uncertainty. It aims to move away from siloed risk considerations and instead analyse the relationships between different uncertainties.

7 Summarised in: https://i2insights.org/2017/05/09/transdisciplinary-integration-methods/.

Box 2 Methods for knowledge integration

The below is a synthesis of methods and instruments for knowledge integration, taken from 43 transdisciplinary research projects and distilled into seven discrete approaches (Bergmann, 2017):

- **Integration through conceptual clarification and theoretical framing:** whereby participants agree on concepts, the theoretical framework and terminology. The participants might start by creating a glossary of terminology, restructuring the conceptual terms to fit the purpose of the analysis or creating bridge concepts that merge disciplinary and/or life-world concepts (Pohl and Hadorn, 2008b).
- **Integration through research questions and hypothesis formulation:** formulating a problem-oriented rather than discipline-oriented hypothesis. The hypotheses formulated by each participating member can be merged into a group model.
- **Developing integrative scientific methods:** developing new, scientific, problem-oriented methods by unifying elements from different disciplines.
- **Integrative assessment procedures:** using an assessment framework that merges quality criteria from different disciplines and perspectives to create success criteria that transcend disciplinary boundaries.
- **Integration through models:** models act as intermediaries between theoretical and empirical descriptions of the world and can be used to combine information from different disciplines and societal fields of action. They integrate different types of knowledge by correlating various parameters from different disciplines and perspectives from different communities (Pohl and Hadorn, 2008). The means of integration might include conceptual models, system models, forecasting models and computer simulations. These can be either hard models (integrating parameters) or soft models, which depict perceptions among communities and facilitate mutual learning (ibid).
- **Integration through boundary objects/products:** boundary objects serve as interfaces between different fields of practice or discipline, and are a meeting ground for representatives of these fields. Products, artefacts, publications, questionnaires or a city development plan can all be utilised as boundary objects and thus as integrative tools.
- **Integration through integrative procedures and instruments of research organisations:** these instruments and procedures are utilised to aid cooperation, for example scientists and practitioners collaborating throughout a project, and forming interdisciplinary teams and institutions.

Source: Adapted from Bergmann, 2017 and Bergman at al., 2012

2.4.1 Findings in practice: bringing results to fruition throughout the process

Given the fact that transdisciplinary research sets out to transform society and serve a common good, putting research findings into practice is absolutely key. While this is sometimes seen as a discrete 'final stage' in transdisciplinary research (Pohl and Hadorn, 2007), the truth is that it cuts across the entire research process.

A linear model of converting scientific knowledge into practical use often assumes that scientific knowledge is first converted into technology and then into practice. According to this linear model, innovation is a result of basic and applied research combined with development, production and operation. This is called the 'technical rationality' model (Schön, 1983; Pohl and Hadorn, 2008). A more accurate model, perhaps, is the recursive model, whereby scientific research is converted into practical use but at the same the practical use informs the understanding of the theory (Pohl and Hadorn, 2008). In this model, theory and practice reinforce each other. This takes place through experimentation, where theory and methods are repeatedly applied in practice, testing and modifying underlying assumptions while learning from failures (ibid).

It is recommended that transdisciplinary research exercises utilise the recursive model and take an iterative approach to bringing results to fruition, using practical knowledge to inform theory along the journey, rather than concentrating on theory and applying it in practice only at the end.

2.5 Does transdisciplinary research work?

Transdisciplinary research focuses on societally relevant problem and aims to create knowledge that is solution-oriented and can be transferred to scientific as well as societal practice (Lang et al., 2012). It also aims to enable mutual learning among researchers, different disciplines and non-academic actors (ibid). An assessment of whether transdisciplinary research works therefore needs to include an assessment of the collaborative process and knowledge integration, as well as of its contribution to solving a real-world problem (Wiesmann et al., 2008).

A systematic review by Belcher et al. (2016) identified four broad criteria for assessing the success of a transdisciplinary research project: relevance, credibility, legitimacy and effectiveness:

- *Relevance* is about the usefulness of the knowledge produced for decision-making and problem-solving. This criterion refers to the extent to which transdisciplinary research is applicable and engages with the problem context within which it operates.
- *Credibility* asks whether the knowledge produced is scientifically trustworthy. This includes questions around adequacy of the data, whether methods are well presented and conclusions reached are logical; as well as questions around transparency and rigour. Also included in this is integration of epistemologies or methods and the competency of those involved in the process. It also includes engaging with the problem context while learning, and adapting research objectives to ensure research remains fit for purpose, while being transparent and explicit about these adaptations (what is called 'active reflexivity').
- *Legitimacy* looks at whether the research process is ethical, fair, acceptable and trustworthy in the eyes of those who will use the findings. It looks at whether the values, concerns and perspectives of different actors are incorporated through collaboration and mutual learning; whether researchers are transparent and disclose their partnerships, financing and collaborations; and whether inclusion and engagement is genuine and the roles are explicitly stated.
- *Effectiveness* assesses the degree to which transdisciplinary research solves real-world problems. It follows that transdisciplinary research should define at the outset (typically at the proposal stage) the potential of the research to solve a societal problem and describe the research process in relation to its usefulness to the problem context. As a result, transdisciplinary research should be evaluated according to whether it contributes to learning and change in behaviour, networks and relationships, or skills and attitudes.

While there are many studies confirming successes in the first three criteria, there is little empirical evidence on whether transdisciplinary research succeeds in having that societal impact. One study evaluating a transdisciplinary research project in the Swiss canton of Appenzell Ausserhoeden did identify clear societal impacts, however – as explained in Box 3.

Box 3 The regional development Appenzell Ausserrhoden project

The goal of the project was to identify cross-sectorial long-term development strategies to address problems of structural change and migration that were impeding different industry sectors (including timber, dairy farming, textile production) as well as regional development (including land use, mobility, landscape protection and tourism) in the Swiss canton of Appenzell Ausserhoeden. The project involved a number of officials and inhabitants from the canton as well as scientists and advanced students from different research institutes.

The project used a three-stage process called Transdisciplinary Integrated Planning and Synthesis consisting of problem identification, problem investigation and problem transformation (implementation). Each stage used different methods to integrate different types of knowledge, i.e. the system knowledge, the target knowledge and the transformation knowledge (Wiek et al. in Pohl and Hadorn, 2008).

In the first stage (problem identification), the scientists, in collaboration with the stakeholders, created a general theoretical model of the problem situation that would allow for the application of theories from different fields, and divided the case into facets on a conceptual level. In the second stage (problem investigation), the team used system analysis and scenario construction to conceptualise and analyse the problem using disciplinary scientific methods. Finally, in the third stage (problem transformation), results from the different facets set in the first stage were integrated, and stakeholders' preferences among the different scenarios in stage two were identified using a multi-criteria assessment procedure. Then the stakeholders mapped their preferences against a set of sustainability criteria that had been agreed upon beforehand in order to create a common vision. Finally, they defined strategies for implementing this vision, setting out roles and responsibilities and elucidating the decisions that needed to be made.

Several scientific follow-up projects resulted from this, in addition to important political decisions about the future of tourism in the area and implementation of some of the identified strategies.

An evaluation of this project's societal impact found that the transdisciplinary research process had a positive effect on stakeholders' decision-making capacity (ibid). Using a quantitative evaluation method involving interviews with 188 stakeholders who were involved in the transdisciplinary research project, the study found that the level of involvement of stakeholders facilitated the availability and use of transformation knowledge and the building of networks between participants, both of which in turn directly influence decision-making capacity.

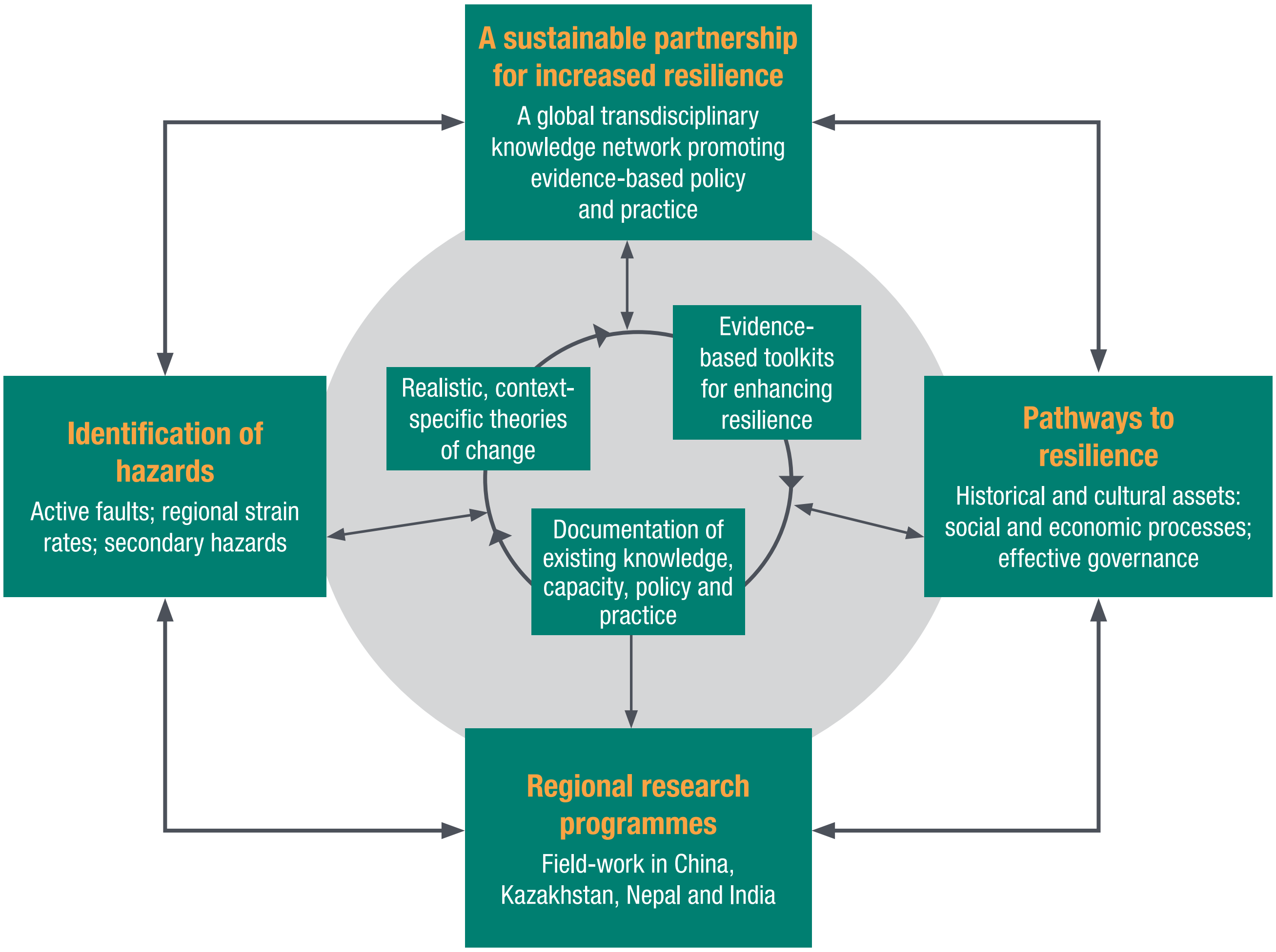
Source: Pohl and Hadorn, 2008b

2.6 A transdisciplinary research approach to earthquake resilience

The Earthquakes without Frontiers (EWF) project used transdisciplinary research to identify and then implement approaches to improve resilience to intra-continental earthquakes in several countries in the Alpine-Himalaya belt. The project took place in Nepal, Northern India, Kazakhstan and China. It brought together international and national social and natural scientists, with national policy-makers and government and non-government agencies, to explore how to improve earthquake resilience. The ultimate aim was to build a sustainable global and national partnership for increased resilience, using transdisciplinary research fieldwork. This included the identification of hazards and pathways to resilience, and the integration of multidisciplinary knowledge into evidence-based toolkits for enhancing resilience, as shown in Figure 3.

The approach to integrating knowledge was based on ODI's Research and Policy in Development (RAPID) Outcome Mapping Approach (ROMA)(Young et al., 2014). This is an iterative approach in which participants collaborate to identify the challenge and the scope for change; identify the evidence

Figure 3 The overall Earthquakes without Frontiers approach



Source: England P., Jackson J. et al. Earthquakes without Frontiers: A Partnership for Increasing Resilience to Seismic Hazard in the Continents. Proposal to the Natural Environment Research Council. Nov. 2011.

necessary to inform decisions; collect and then use the evidence to propose action to address the challenge; support implementation; and then monitor and evaluate progress. This approach is illustrated in Figure 4.

The focus, process and outcomes of the work were different in each context but were all remarkably successful. Box 4 describes the approach and results in China.

The EWF project used transdisciplinary research to address a problem that will occur in the future. It brought together researchers, policy-makers and practitioners to consider different forms of evidence and identify actions that could be taken to reduce the impact of a future earthquake. It is a form of future planning. In the next section, we introduce the field of futures studies and how it can be used to prepare for future events.

Figure 4 The RAPID Outcome Mapping Approach

Source: Young et al., 2014.

Box 4 Earthquakes without Frontiers in China

Earthquakes without Frontiers (EWF) in China built on several longstanding relationships and programmes of work with different, but unconnected, stakeholders working on earthquake resilience issues. These included: work on geology and seismology by the China Earthquake Administration (CEA); work on education and post-earthquake recovery with universities, social work organisations, and NGOs in Beijing, Chengdu and Xi'an; and work with development policy organisations in Beijing. A key early aim was to bring these different stakeholders together to identify a common problem, then work together to find solutions.

Early work to develop the programme involved joint field trips by natural scientists, social scientists and policy engagement specialists to get to know the key local stakeholders and find out what they were concerned about. Initially, these different stakeholders showed little interest in getting together with others. So, workshops were organised with each group individually: with NGO representatives in Xi'an; with CEA staff in Xi'an and in Beijing; and with academics and other stakeholders. The workshops always included presentations by international experts, and then discussion of experiences from other countries. These were always popular. They also usually included presentations of work being done by other stakeholders in China. For example, presentation to CEA staff of the disaster risk reduction (DRR) work being done by NGOs, and vice versa, about which they were frequently unaware. Gradually they became more interested, wanting to find out more, and looking for opportunities to collaborate. There was also a strong interest in making more of this knowledge more widely available.

The core transdisciplinary tool used in the early stages of the EWF project in China was an inter-agency multidisciplinary workshop to share information about different approaches and produce a bi-lingual publication (Young et al., 2015). Participants in the workshop also identified a pilot action research project at village level that would seek to integrate the NGO participatory approaches to DRR with scientific understanding of earthquake risk.

Relationships developed at the workshop, and further discussions at an international EWF workshop in Nepal in April 2015 led to the recognition by CEA staff that, in addition to the top-down bottom-up disconnect identified in the workshop, there is another disconnect: between science and policy. This resulted in the identification of further collaborative work in China, to try to use a scenario exercise to bring together scientists, policy-makers, government agencies and NGO staff to develop better earthquake DRR plans at city level: the Pan-participatory Earthquake Governance Project in the Ordos region of China (PAGER-O), described later in this paper.

3 Futures studies

3.1 Introduction

So far, the above description of transdisciplinary research has focused primarily on its use as an approach for finding solutions to current problems. Futures studies focuses on challenges that may occur in the future, and often draws on transdisciplinary research methods. In this section we outline what future studies is, the principles, and some of the methods and approaches. We then assess whether it works and provide some examples, then discuss the intersection between futures studies and transdisciplinary research.

3.2 What is futures studies?

Futures studies (also known as the futures field, futures research, futures planning, futuristics, prospective, prognostics or simply futures) is a field of inquiry designed for the purpose of systematically studying and thinking about the future (Puglisi, 2001). Recognising that uncertainties are an intrinsic part of the future, the field aims to explore multiple possible futures in order to draw conclusions on how to best prepare for them and increase human control over them (Bell, 1997). Thus, it enables organisations, governments, decision-makers and communities to identify possible opportunities and risks and begin to plan and adapt.

Consensus about what futures studies incorporates is somewhat unclear in the literature. Some refer to futures studies as the umbrella term referring to all exercises designed for systematically exploring the future including foresight, forecasting and modelling.[8] However, in this understanding of futures studies, the purpose is not necessarily to identify practical actions, and the exercises do not have to be participatory or exploratory (as they include forecasting, which is predictive rather than exploratory in nature). These are central principles to the understanding of futures studies utilised in this paper.

In this paper, we understand futures studies as related to the concept of 'foresight'. Futures studies meshes with foresight when it is connected to policy or practice and generates some form of practical action at the end of the process. It aims to gain an understanding of the forces that shape long-term futures and should inform policy (Government Office for Science, 2017).

Futures research methods have been used in various contexts and disciplines ranging from strategic planning in private sector companies such as the Shell corporation, to national security and defence, to sustainability research, disaster risk and resilience, health and many more. Some national governments have put in place departments that deal solely with the study of the future of different sections of society, such as the Finnish parliament's Committee of the Futures, Norway's 2030 project and New South Wales' Health Futures Planning project (the government long-term health and healthcare planning framework).

The methods used in futures studies and analysis are numerous and are often combined depending on the purpose and stage of the analysis. The level of participation varies from one method to the next, with some methods requiring only one analyst to define the problem, analyse the data and produce the output, while others involve a range of stakeholders from the problem definition to the co-production of output. Some of the most frequently used methods are outlined in the next section.

8 See: European Commision- European Foresight Platform http://www.foresight-platform.eu/community/forlearn/how-to-do-foresight/process/methodology/

3.3 Principles of futures studies and foresight

Futures studies methods are often used for foresight or strategic futures planning. It is important to be clear about the difference between foresight and forecasting or predicting. Forecasting, or prediction, aims to determine exactly what will happen in the future, so that people can take specific action. The classic example is weather forecasting. The problem is that while it is frequently impossible to be 100% accurate, people tend to behave as though it is possible, so if there is a forecast of rain, people will take an umbrella or wear a raincoat. There is of course no problem if it doesn't then rain – they just carry a raincoat and umbrella for no purpose. The other way around though can be more problematic.

Both futures studies and foresight are different from forecasting. Unlike forecasting, futures studies and foresight aim to explore and understand a possible range of futures, so that governments and organisations can make strategic decisions and plan to provide the best outcomes for a range of different eventualities. They do not aim to predict the future; epistemologically, there can be no knowledge about the future since it does not yet exist (Schumacher, 1973; Dator, 1995). Futures studies is an approach to thinking about the possible, probable and preferable futures (Government Office for Science, 2017). Foresight is a convergence of futures studies, policy analysis and strategic planning to 'develop strategic visions and anticipatory intelligence' (UNCTAD, 2017 citing Miles et al., 2008:11). Futurists follow the principles that the research must be participatory and action-orientated:[9]

- **Participatory:** Foresight encourages the participation of different individuals and groups.
- **Action-oriented:** The purpose of all foresight activity is to identify practical actions that can be taken to influence and shape the future.

Typically, foresight can be either exploratory, normative or both depending on the goal of the exercise. In the former approach, research participants start at the present moment situation and envisage multiple alternative futures. In the normative approach, they start by envisaging a desirable future and think about pathways to get there.

3.4 Futures studies methods and approaches

Futures studies and foresight include a large number of methods and approaches, but these can be grouped into three broad categories corresponding to different stages of inquiry: *diagnosis*, *prognosis* and *prescription*.

Diagnosis typically involves the identification of the problem as well as the collection of historical data and background information on the current situation. Diagnosis usually involves some preliminary scoping of the issue, and some data gathering using, for instance, environmental scanning or trend analysis along with structural analysis. In other words, this is the stage where researchers gather intelligence about the futures. Some specific diagnostic methods are:[10]

- **Scanning**: The term 'scanning' often refers to the wider practice of gathering information. With its origin in the military – where scanning techniques are used to identify emerging trends and developments in enemy territory – scanning may serve as an early warning system to identify potential threats along with opportunities (Bengston et al., 2012). 'Horizon scanning' is a method that looks at emerging trends, as distinct from 'environmental scanning', which is about understanding the current operating environment. Scanning techniques typically start with research of a wide range of information sources, including literature reviews, expert panels, websites and publications (ibid). Typically, the research

9 See: European Commission – European Foresight Platform http://www.foresight-platform.eu/community/forlearn/what-is-foresight/

10 See: http://www.foresight-platform.eu/community/forlearn/how-to-do-foresight/methods/analysis/

will look for drivers of change from the social, technological, economic, ecological/environmental and political fields, sometimes extending to legal, ethics and demographic or regulatory domains (UNDP, 2014).[11] The information gathered through scanning is a critical input for later stages of futures planning and foresight.

- **Environmental scanning:** This method is often used in the first stage of futures studies to gain an understanding of the current operating environment, to discern information and to define relevant issues as well as potential indicators and criteria. Techniques used are similar to those described for scanning in general, above, and might involve indicators and criteria from several fields. As with other types of scanning, the background information output is used to generate forecasts or scenarios.
- **Trend analysis:** Like environmental scanning, trend analysis is a method used for preliminary scoping of the issue under investigation and will involve some initial data gathering. However, trend analysis is primarily a forecasting method and uses this preliminary data to make predictions about likely futures. It operates on the premise that the future is a continuation of the present (Puglisi, 2001; Gidley et al., 2009), and that by describing trends and patterns in the present we can discern the future. To achieve this, trend analysis begins by collecting large amounts of quantitative data over a prolonged period of time to draw out recurring features and patterns.

Prognosis is the second stage – and core – of futures and foresight inquiry, as it explores possible futures and their likely implications. Several techniques are used for this, but the most commonly used are the Delphi method, cross-impact analysis, morphological analysis and scenario techniques. The first three are outlined below. Scenario techniques are described in more detail in Sections 4 and 5.

The Delphi method

The Delphi method originates in the myths surrounding the Greek oracle, and is a way to solicit and structure diverse expert opinions about a future event (Bengston et al., 2012). The Delphi method was developed by the RAND Corporation in the 1950s for the purpose of studying the likely effects of a nuclear war on the future (ibid).

- **How it works:** Several experts from different disciplines and backgrounds are asked to give their input on a given subject using semi-structured questionnaires. The responses are collected, collated and fed back to the experts so they can reflect on the responses of the other participants and re-evaluate their own responses. Afterwards, the participants receive a new questionnaire where they are asked to respond to the opinions of the other participants from the previous round. This process is repeated throughout for between two and five iterations until the questionnaire no longer elicits new debates (ibid).
- **Advantages:** The strength of this method lies in its ability to reap the benefits of group interaction while avoiding the common challenges associated with bringing experts together in a room to debate an issue – the difficulty of changing one's opinion in front of a large group of people or restricting one's imagination for fear of appearing ridiculous (Dator, 2009). The anonymity inherent in the Delphi method makes it particularly useful when the issue is strongly disputed and there is potential for conflict. Furthermore, it is used in contexts where there is little or weak data to draw on, such that one has to rely on expert opinion (Puglisi, 2009). Finally, it can be useful when the opinions of very many experts are required but there is no viable way of bringing them together in one room.

11 See: UNDP Centre for Public Service Excellence (2014). Foresight: The Manual https://www.undp.org/content/dam/undp/library/capacity-development/English/Singapore%20Centre/GCPSE_ForesightManual_online.pdf

Cross-impact analysis
The strength of this method lies in its consideration of how the occurrence of one event affects the likelihood of other events following. In the real world, events do not take place in a vacuum and are often connected to each other. Thus the probability of any one event occurring is directly or indirectly related to the probability of occurrence of another event. Unlike in the other methods, such as Delphi, participants are not only asked to rate the chance of occurrence, they are also asked to consider the effects of mutual interactions of events on their probabilities (Puglisi, 2001).[12]

- **How it works:** In practice, the method looks at chains of events, conditions or trends that may occur by using a matrix to determine the total effect on the probability of a given occurrence (Puglisi, 2001). It begins by defining a time span and looks at what events are likely to occur in that time span. These do not include the events that are under our control, events that are almost definitely going to occur, or events that are most definitely not going to occur (Blaming and Reinig, 1999; Helmer 1977). The next step is to gauge which of these are likely to affect the issue under investigation. The events are displayed in a matrix, with each occupying a row or column along with their probability of occurrence. The conditional occurrence of each event given the occurrence of any of the other events is calculated on this matrix (Bishop et al., 2007). The conditional probabilities of all events are then adjusted according to the contingent probabilities of the other events. The matrix is run many times to produce a distribution of probabilities for each event in the matrix.
- **Variations:** The selection of the events is very important because this will drive the analysis (Puglisi, 2001). Different methods can be combined to define the events, including the Delphi method at different stages, and statistical methods can be applied to come up with and evaluate the cross-impact matrix (ibid). It can also be used at the end of scenario building to see how the occurrence of each scenario might affect the occurrence of another scenario (see Section 4 for more on scenario building).

Morphological analysis
By sub-dividing complex broad topics into smaller sub-topics, this method organises information in new and useful ways to help understand complex issues. By doing so it stimulates new ways of thinking and thus helps to identify possible pathways of change.[13] The method can also be used in the diagnosis stage in order to understand the complexity of the issue under investigation.

- **How it works:** Morphological analysis starts by identifying a future need, objective or problem and then identifies what circumstances, technologies or actions are required to meet that need. This method focuses on using sources of uncertainty to identify alternative futures depending on how each of these uncertainties play out (Bishop et al., 2007). It utilises a multi-dimensional matrix where each column depicts a dimension of uncertainty with a number of alternatives to each uncertainty and then combines all parameters to identify possible futures. The feasibility of each of the outcomes can then be evaluated to create plausible scenarios (Ritchey, 1998).
- **Challenges:** While it is a useful method for organising information and unpicking complex issues, it can be complicated to apply in practice given that each dimension of uncertainty with several alternatives can generate a very large number of combinations. (Bishop et al., 2007).

12 European Commission – European Foresight Platform: Cross-Impact Analysis: http://www.foresight-platform.eu/community/forlearn/how-to-do-foresight/methods/analysis/cross-impact-analysis/

13 European Commission – European Foresight Platform: Morphological Analysis: http://www.foresight-platform.eu/community/forlearn/how-to-do-foresight/methods/analysis/morphological-analysis/

Prescription is the third stage of futures and foresight inquiry, and the one most associated with generating policy options and facilitating implementation. Two of the most commonly used methods for prescription are back-casting and multi-criteria analysis.

Back-casting
Back-casting is often used to connect long-term futures scenarios (50 years or more) to the present situation.

- **How it works:** Back-casting's main concern is not with which futures are likely to occur but with which futures are most desirable and how to achieve them (Robinson, 1990). A normative approach, back-casting starts by creating a vision of, or defining a criteria for, desirable futures. Participating stakeholders then set out alternative solutions (Neuvonnen, 2014). This is followed by an exploration of possible solutions and identification of bottlenecks, along with the implications of different alternative development paths (Robinson, 1990). The stakeholders select a solution option and come up with an action plan. This is accompanied by a definition of stakeholders' roles and cooperation agreements, along with a research agenda. The outputs of a back-casting exercise include sketches of futures visions and possible pathways to them, in addition to economic, cultural and technological analysis of the pathways.[14]
- **Advantages:** This method is useful when there is a normative objective and uncertain future events that might influence this objective. It involves strong participation by stakeholders and is particularly effective if the stakeholders agree on the desired futures but are not clear on how to get there.

Multi-criteria analysis
This method is used to compare different solutions according to criteria that are created by a participating group of stakeholders. It creates a hierarchy of solutions and is used in foresight exercises during the strategy development phase.[15]

- **How it works:** A group of experts prepares a list of weighted criteria for a group of decision-makers. In a more participatory variation, the group of experts prepares a set of criteria and then uses a questionnaire to grade each action according to the criteria. Criteria might include cost, expected benefits and so on. The participants then give a weight to each criterion and grade each solution option against each criterion. Finally, the participants compute the average score of each option. The end result is a hierarchy of the different options.
- **Advantages:** This method can also be used to find out which of the scenarios or futures best match decision-makers' expectations after completing a scenario-building exercise. The hierarchical output makes it especially suitable for explaining why a particular solution has been selected/prioritized over others.

This is only a small selection of the methods used in futures studies. There is necessarily a lot of creativity and imagination involved in each stage. Overall, there are an estimated 200 conceptual and methodological approaches to futures studies, and more work is needed to synthesise these (Kreibich, 2008).

3.5 Does futures studies work?

As with transdisciplinary research, research there is limited empirical evidence of the effectiveness of futures methods. Partly this is because they tend to be used very flexibly and in different combinations, so it is hard to determine exactly what worked and what didn't. In addition, much futures work is not in the public domain as it is often used for internal strategic planning and is therefore commercially sensitive (Bradfield et al., 2005). Nevertheless, futures methods have been very widely used, and considered successful, not least in military planning as described in Box 5.

14 See: European Commission – European Foresight Platform.

15 ibid.

Box 5 The use of futures methods in military intelligence: The RAND Corporation

Futures research has become an integral part of the US defence programme, through projects such as the Defense Advanced Research Projects Agency (Bengston et al., 2012).

The RAND corporation was the pioneering organisation in the US for using futures work to inform military strategy, technology and operations in the 1950s and 1960s. It is a research group, which at that time was mainly advising the US Airforce. It is considered to be the originator of the use of scenarios as a futures method for strategic planning and forecast.

After WWI, the US Department of Defense was faced with the challenge of deciding which weapons systems development projects to fund amidst uncertainties about the future political environment and about the weapons capabilities of other nations (Bradfield et al., 2005). They found that they needed a method with which to gather and synthesise the opinions of different experts on the topic, as well as a way to simulate or model the future environment for the purpose of exploring policy options (ibid).

Using data processing through computers and game theory to develop war game simulation models, the RAND Corporation under Hermann Kahn started developing scenarios for the Air Defense Missile Command, a large-scale early warning system (ibid). It was at this time that Kahn coined the scenario method as a way of 'thinking the unthinkable' and advocated for 'reasonable expectations' in military planning, as opposed to what had hitherto been 'wishful thinking' that could ultimately result in 'nuclear war by miscalculation' (Bradfield et al., 2005: 798).

The findings of Kahn and the RAND Corporation are considered to have been immensely influential in the Pentagon in the 1950s and 1960s (ibid), speaking to the success of using futures methods.

Despite positive examples such as this, evaluating whether futures studies or foresight works is challenging. Simply considering different possible futures is inherently valuable, but it is difficult to quantify this value. Furthermore, given the various goals that futures exercises pursue, it can be difficult to establish one measure of effectiveness to apply to every exercise across the board. Each individual futures or foresight exercise should therefore be evaluated on its own terms, according to the goal that it sought to achieve. Some might simply aim to challenge ways of thinking and suggest new ways of doing things, or agree on priorities, or create a shared understanding of a desirable future (Government Office for Science, 2017).

A further challenge to evaluating future studies or foresight exercises is that their goals often include preventing certain events from occurring. Evaluations therefore need to focus on intermediate impact and outcomes rather than the long term. An important measure of intermediate impact is the use of outputs from the foresight exercises in planning, policy and implementation. Havas et al. (2010) reviewed several foresight projects in Europe, measuring them specifically by their impact on policy. The authors describe three different impacts of foresight exercises on policy-making: policy informing, policy counselling (translating foresight information into new policies) and policy facilitating (stimulating development of a common vision for the future) (Havas et al., 2010). Some of the results are explained in Box 6.

In the public domain, these effects can be traced using publicly available policy documents. However in private industry, where strategy documents are seldom published, much of the available evidence of usefulness and effect relies on anecdotal reports from exercise participants (Havas et al., 2010).

The evidence on the impact of future studies and foresight exercises remains scarce, possibly due in part to the methodological challenges of conducting such impact analyses. One evaluation points to the difficulty of attributing the policy change to the foresight exercise as opposed to other policy documents and consultations (Cuhls and Georghiou, 2004), although the Hungarian project described in Box 6 is an example where the use of verbatim quotes from the research findings in the policy document evidences a direct attributive link. More research is needed into reliable methods to track policy influence, such as outcome mapping (ODI, 2014).

Finally, it should be noted that other intended and unintended outcomes can be measured by various means, for example network building among participants and decision-makers could be measured using social network analysis.

3.6 Futures methods and transdisciplinarity

There is a close relationship between transdisciplinarity and futures studies or foresight. Some claim that 'transdisciplinarity has always been about imagining futures' (Klein, 2015: 78). Moreover, the purposes of transdisciplinary research are closely connected with those of futures, including: developing solutions to societal problems while accounting for complexity, uncertainty and diversity; generating and implementing practical solutions; and considering risks and unintended consequences to those solutions (Pohl, 2014).

While the methods for exploring possible futures are numerous, most involve high levels of participation by different stakeholder groups. The Henley Centre's (2001) publication, *Understanding best practice in strategic futures work*, suggests that the best strategies for exploring and planning for futures use broad multi-dimensional approaches, as found in transdisciplinary research. Moreover, there is much evidence that relying on the expert knowledge of individuals for forecasts, without deliberation with and feedback from others, can be very unreliable, regardless of the seniority of the expert in question (Tetlock, 2005; Tetlock, 2016; Burgman, 2014).

Box 6 Examples of policy uses for foresight outputs

Using a number of recent foresight exercises, a 2010 study by Havas et al. looked at the extent to which the exercise findings were utilised by the intended audience, e.g. to inform policy or implementation.

In the case of a Hungarian foresight exercise, TEP, an evaluation found that in various policy domains (e.g. strategic documents by the prime minister's office, transport policy, the national health programme, environmental policy, IT policy), the statements and recommendations reflected those identified in TEP and sometimes featured verbatim passages from the TEP results documents.

In the UK, a foresight exercise project – looking at flood and coastal defences – was used by DEFRA to inform its long-term strategy on flooding and as a map on policy development and decision-making more generally. Foresight exercises in the UK have also shaped the research agendas of public as well as private bodies, including the UK Research Councils and UK government policy.

However, an evaluation of the Second Technology Foresight Programme in Sweden found that the primary users of the findings and recommendations were organisations, including consulting agencies and research organisations, and there was little evidence of direct influence on policy-making. Some research held that the lack of influence on policy was due to results coming in too late. However, others asserted that the lack of use of findings was a direct result of the nature of foresight exercises, whereby the identified solutions cannot subsequently be reconciled with departmentalised government structures. As a result, no particular government department can take ownership of the recommendations. To tackle this, it is recommended that the foresight process incorporates specific plans for the effective practical coordination of financial and intellectual resources, to ensure subsequent use of the findings.

Source: Havas et al. (2010)

Participatory processes are not just valuable for enhancing results but are also important in their own right, for the sake of democratic processes and ownership. The most reliable futures and foresight methods, therefore, are those that involve a number of diverse actors or perspectives (in disciplines, backgrounds, culture, gender etc.). As in transdisciplinary research, they also need to involve different processes for deliberation and feedback, ways of looking at the same issue from different backgrounds, and ways to mitigate the effects of 'group think' (ibid). Finally, by bringing together a range of experts from different disciplinary and life-world backgrounds, foresight processes create tacit knowledge among participants. This process helps to forge new networks between people who might traditionally not work together.

An example of an area where transdisciplinary research meshes inherently with futures studies is the field of sustainability research. By its nature, this field deals with both the scientific question of limited natural resources and normative questions of inter- and intragenerational justice (Havas et al., 2010). These questions cannot be resolved without including actors in the life-world, as normative decisions cannot be made through scientific knowledge alone; hence, most research conducted in this field is transdisciplinary. Futures studies is then brought into play because sustainability research calls for political action and strategies to cope with issues that might occur in the future, where causal relationships and the effects of interventions (intended or unintended consequences) are uncertain (ibid). Transdisciplinary research and futures studies intersect very effectively in this field, as transdisciplinary research is known for embracing uncertainty and complexity – and even vagueness – as assets (Clarke, 2017), all of which are features of futures studies and core challenges of sustainability research.

In conclusion, there is clearly much overlap between transdisciplinary research and futures studies, and this is especially the case in the futures studies tool known as 'scenario-building', which is described in detail in the next section.

4 Scenarios

4.1 Introduction

In considering the different types of futures methods as well as transdisciplinary research approaches, scenarios have been mentioned multiple times. Scenario building is one of the most widely used futures tools for helping decision-makers think about a range of plausible futures (Bengston et al., 2012). This section takes a closer look at scenarios and the way in which they are used to conceptualise future events and develop strategies to plan for and adapt to them.

4.2 What are scenarios?

There are wide-ranging definitions of scenarios depending on the purpose and the context within which scenarios are constructed (Puglisi, 2001). Scholz and Tietje (2002) describe scenarios as a scientific method to assemble a set of assumptions to gain insight into how a case might develop.

Van Notten (2006) summarises three uses of the term 'scenarios':

1. Sensitivity analysis: typically used in cash flow management, project management or risk assessment.
2. Contingency plan: frequently used in military or emergency contexts to decide who should do what when a certain situation occurs. It is also used in public and corporate policy.
3. Exploratory: a 'coherently structured speculation' where the scenario is not a strategy in itself but a way to speculate about the future in a structured manner. This approach to scenarios has been used widely in education.

Scenarios can be used to answer two types of question: (1) how might a hypothetical situation come about? and (2) what alternatives exist at each step to prevent, divert or facilitate the process of case development? (Scholz and Tietje, 2002: 79; Kahn and Wiener, 1967: 6).

The hypothetical future is constructed by introducing a set of variables that are likely to affect the current situation. These variables can be joined together in different ways to form a different set of plausible and coherent stories. In brief, scenarios are plausible stories that help investigators to understand cause-effect relationships and therefore our role in making future events come about or not come about.

4.3 Choosing a scenario approach

In order to decide on the best scenario approach to use, Van Notten (2006) sets out a number of considerations to be taken into account when designing a scenario planning exercise.

The first question to be answered is the purpose of the scenario. This could be to create an action plan or roadmap for strategic purposes. It could also be to create a common vision and buy-in from those involved. If, for instance, the purpose is to create a strategy or action plan, then the end product (i.e. the knowledge output) might be of key importance, but if it is about reaching a common vision then the process itself might be more or just as important.

Other questions to be answered include:

- What is the role of values in the scenario-building process? Is the scenario descriptive of what is likely to happen or is it more normative, looking at a shared desired goal?
- What is the subject area to be covered and what is the nature of the change to be explored?

After answering these initial questions, the designers of the scenario planning exercise can begin to look at the scenario process, making decisions about how participatory it will be, the role of modelling and the balance between qualitative and quantitative methods (Iversen, 2006).

Finally, the project planners should consider the content of the scenarios: which issues should be covered, the time horizon of the scenario and the level of knowledge integration.

4.4 How to build scenarios

What all the definitions of scenarios have in common is that scenarios are not a way to predict the future. The future is unknown and full of uncertainties and one can only explore a range of plausible futures (Puglisi et al., 2001; Van Notten, 2006). Futurists also agree that scenarios are 'hypothetical, causally coherent, internally consistent, and/or descriptive' (Van Notten, 2006: 2). Scenarios depict alternative futures in order to help stakeholders explore possible opportunities, weaknesses and priorities, and thus to explore different courses of action.

Scenarios have been used for different purposes in a wide range of situations, and futurists have created a number of different typologies and approaches. These tend to relate to the purpose, the starting point, the underlying assumptions, the techniques used and the outputs. Some examples are provided in Box 7.

Box 7 Examples of approaches to scenario building

Bradfield et al. (2005) describe three different scenario types, which are largely based on the type of methods they use (qualitative or quantitative modelling):

- **Probabilistic modified trends** and the **La Prospective** method both rely on quantitative analysis of current trends and model what is likely to happen in the future based on the present situation.
- **Intuitive logics** draws on largely qualitative data and relies less on modelling. It was used by Shell and is therefore known as the Shell method.

Boerjeson et al. (2006) describe three different approaches to scenarios, based on the starting points (present or future) and the purpose of the exercise:

- **Predictive scenarios** examine the question of what is likely to happen given current trends.
- **Exploratory scenarios** do not aim to predict the future but to explore the question of 'what *can* happen'. This can mean what can happen in the outside environment (external scenarios) or what can happen if we act in certain ways (strategic scenarios). This is also referred to as the 'initial stage' scenario, as it starts from the present and then maps the possible futures course.
- Normative scenarios start from a desired future and examine how one can get to that future, i.e. how can a specific target be reached?

4.4.1 The generic scenario-building process

Scenario-building exercises differ in their length and resource requirements depending on the technical underpinnings as well as the background research that is required. While scenario building is used in many different fields, this paper focuses on the use of scenarios in projects related to natural hazards, particularly earthquakes.

The process will typically involve a scenario facilitation team to plan and facilitate the process, and a scenario group consisting of experts and stakeholders with diverse disciplinary and cultural backgrounds and different perspectives and responsibilities. The experts are there to provide lay participants with knowledge and insights that may be needed to understand an issue in more detail. The stakeholders, on the other hand, are those who will be affected by the scenarios and the ensuing decisions or strategies. These might include NGOs, business professionals, operational staff and others. The planners and policy-makers who will use the results, including the client who commissioned the scenario exercise, should also be included in the process (Rhydderch, 2009: 9; Iversen, 2006: 2).

The process of scenario building usually starts with the identification of stakeholders and the expertise required. In the example from China featured later in this paper, the government is a major stakeholder, as it owns the public buildings and infrastructure at risk from earthquakes, and is responsible for the policies and regulations that shape the built environment. After identifying the stakeholders, the process usually follows six stages.

Each of these stages will draw on different futures methods. It should be noted that this is unlikely to be a linear sequence and is more of an iterative process. For instance, having identified the key issues, trends and drivers, the scenario team might go back to redefining the stakeholders (Perry et al., 2011). Furthermore, at each of these stages there will be differences in terms of approaches and methodologies used. In the case of natural hazards scenarios, the final two steps will involve a lot of technical work to understand likely events and consequences. This will often involve the use of modelling, simulation and other methods.

Common approaches used for each step are shown in Table 2.

4.4.2 Scenario outputs

The main output of scenario exercises and analyses is usually a set of internally coherent and plausible stories describing different sequences of events, and their causes and effects between the present and the future (Bengston et al., 2012). They show what the world may look like if certain events occur or trends persist or diminish (Rhydderch, 2009). Typically, there will be between two and five scenarios, each of which will take into account key decisions, events and consequences (Bengston et al., 2012). In the field of natural hazards, however, it is more common to have one output scenario describing the event and its effects. In some cases, multiple stories and characters are used to present different aspects of the same event. The stories are intended to help decision-makers to build adaptive capacity and more resilient systems in order to prepare for a diverse set of alternative futures (ibid).

Table 2 Common approaches to scenario building

Step of scenario building	Examples of tools and methods
Step 1: Define the problem/ issue to be investigated along with the key factors and issues to be considered, and set the time horizon	Delphi, morphological analysis, relevance tree.
Step 2: Identify key issues, trends and drivers	Delphi, expert panels, environmental scanning, trend analysis, cross-impact analysis, causal layered analysis
Step 3: Prioritise the key trends, drivers and associated uncertainties	Modelling and simulation; force field analysis
Step 4: Manage complexity – explore possible interactions between different factors	Modelling, simulation, systems methods; ranking trends/ drivers, force field analysis, field anomaly relaxation
Step 5: Develop and flesh out the storylines, i.e. the different scenarios	Back-casting, modelling and simulation
Step 6: Identify and agree the implications of the different scenarios	SWOT analysis, force field analysis, AIIM, wind-tunnelling, back-casting

4.5 Do scenarios work?

The strength of scenarios lies in their ability to convince stakeholders and decision-makers of the reality of an issue and the need to act. By helping them envision the future through vivid stories, scenarios force actors to consider the consequences of their actions or lack of action. This creates a ‘future memory’, where stakeholders consider the circumstances before they unfold (Chermack and Van der Merwe, 2003; Chermack et al., 2001), and this improves response times when new circumstances come about (Chermack et al., 2001).

There are several examples of the successful use of scenario-building exercises. One is the project to establish Manchester as a Knowledge City.[16] The objective of the foresight exercise was for stakeholders to create a shared vision of the

16 European Commission – European Foresight Platform: From Knowledge Capital to Innovation System: http://www.foresight-platform.eu/tag/knowledge-society/

future use of the university-established science parks in Manchester.

During the foresight exercise different stakeholders were brought together including actors from universities, government and the private sector. The scenario exercise resulted in a shared vision, an action plan, and indicators to measure progress.

The exercise has been widely regarded as a success and been reported in national and regional journals. Strategies and recommendations identified in the exercise were adopted by the main body responsible for Manchester's knowledge society strategy, along with participating bodies.

Elsewhere, the Mont Fleur scenarios, used in South Africa to deliberate the future of the country after apartheid, is one of the most famous examples of scenario building. This is described in Box 8.

Scenarios have also been widely used in corporate strategic planning, most notably in Shell Global Business Network, as described in Box 9.

In the next section we zero in and look at a specific use for scenarios: to increase preparedness and resilience to earthquakes.

Box 8 The Mont Fleur scenarios in South Africa

In the years 1991–1992, 22 prominent South African academics, politicians, activists and businessmen, from different backgrounds and representing different ideologies, were brought together to deliberate the future of the country after apartheid. The output from this scenario-building exercise became known as the Mont Fleur scenarios.

The process was multi-faceted and ranged from off-the-record workshops to formal, public negotiations. The output was four different scenarios, which the participants considered plausible and relevant to South Africa at that time.

Each scenario had a descriptive name and contained within it a message about the possible results of alternative courses of action.

- Scenario one was named the Ostrich. It envisioned a future where no settlement was reached to the crisis in South Africa, and the country would continue to be ruled by a non-representative government.
- Scenario two was named the Lame Duck. It represented a future where there was a settlement, but one that was compromised by a slow and indecisive transition process.
- The third scenario, Icarus, depicted a future where the transition to a new government was rapid but the government's economic policies were both populist and unsustainable.
- The Flight of the Flamingos was the final and most desirable scenario, in which the future government's policies would turn out to be sustainable, leading to inclusive growth and democracy.

Each of these scenarios contained a message about the dangers of different courses of action. For instance, the Lame Duck narrative warned against a weak coalition that would lead to inaction, which at the time was particularly relevant in light of the negotiations on the rules governing the pre-election of the Government of National Unity.

These narratives were distributed using the national newspapers as well as cartoon videos depicting the different representatives/participants. The scenarios were also distributed to 50 groups, including political parties, companies, academics, trade unions and civic organisations.

In addition to finding a common ground in terms of what a desirable future looked like, the scenario process created a common language – even for those outside the actual exercise process – for talking about that future. The terms 'Lame Duck' and 'Flying Flamingos', for instance, were used on a rural radio phone-in and in a church sermon. A member of the National Party was quoted as saying, 'I am not an ostrich'. Furthermore, the scenario process succeeded in creating networks between participants and influential groups across the political spectrum.

Source: Ramalingam and Jones, 2007

Box 9 The use of scenarios at Shell Global Business Network

Shell Global Business Network's use of scenario building started with a study its managers commissioned in 1967, to envision what the business environment would look like in the year 2000.

The study revealed that the expansion of the oil industry would be unlikely to continue even until 1985. In reaction to the findings of the 1967 'Year 2000' studies, Shell companies started conducting horizon planning exercises to look ahead to the year 1985 and the driving forces (social, technical, economic and environmental) that would impact on Shell's business. The findings confirmed the Year 2000 study findings.

As a result Shell started to experiment with scenario-building techniques and presented the findings to management in the early 1970s. This proved to be very successful, because they accurately identified the impending scarcity of oil and the accompanying rise in prices (Bradfield et al., 2005).

When the oil embargo and the dramatic rise in oil prices came in the 1970s, Shell was much better prepared for it than other oil companies and thus became the second biggest oil company in the world (Ramalingan and Jones, 2007). Shell became the pioneer of using scenarios in corporate strategic planning and one of the techniques for scenario building, 'Intuitive Logics', is still known as the Shell method (Bradfield et al., 2005).

5 The use of scenarios in earthquake disaster risk reduction

5.1 Introduction

The following section introduces the use of scenarios in earthquake disaster risk reduction (DRR). While the focus here is on earthquakes, the concepts introduced also apply to other low-probability, high-consequence natural hazards including, for instance, tsunamis, floods, hurricanes[17] or similar events.

Earthquake DRR is particularly challenging. Major earthquakes can destroy or damage buildings and infrastructure over a wide area. Collapsing buildings can kill and injure large numbers of people, and damage to roads, railways, water and electricity supplies, telecommunications and other infrastructure can seriously disrupt rescue and recovery services. Longer-term disruption of agriculture, industry, services and other economic activity can have a catastrophic impact on the local and wider economy.

Fortunately for those at risk, major earthquakes are rare events in any one place. Most of the world's seismically active areas experience decades to centuries between damaging earthquakes in the same location. Unfortunately, these long periods of quiescence make it easier for society and policy-makers to ignore earthquake risk. Therefore, there is often little political will to put measures in place or organise collective action to reduce the risk of damage (Caddick et al., 2016).

Responsibility for managing earthquake risks is diffused across government, industry and the community. All organisations, institutions and individuals within a community are responsible for managing risks. The high number of stakeholders, the diffusion of responsibilities and roles, and the lack of a clear decision-making structure makes earthquake resilience a highly complex problem. Coupled with the uncertainty of when an earthquake may occur, its magnitude and the possible impact on buildings, infrastructure, lifelines, society and economy, earthquake resilience and risk mitigation pose great challenges for action and problem-solving.

At its core, the challenge for achieving earthquake resilience lies in bringing the right stakeholders together, ensuring buy-in from them in regard to the necessity of taking action now and finally, convincing them to invest resources in DRR. This is difficult because of other competing priorities and because often the last incidence of an earthquake was not within the stakeholders' living memory (ibid).

Furthermore, short-term political cycles mean governments think in different timelines and tend to concentrate on more immediate and visible issues (Caddick et al., 2016; Birkland, 1998, 2016).

17 See: https://wtop.com/national/2018/09/in-simulation-category-4-hurricane-devastated-east-coast/

A combination of transdisciplinary research and scenario exercises provides an excellent mechanism with which to address this challenge. In summary, it has the potential to:[18]

1. Bring people together who otherwise might not interact before disaster strikes;
2. Build relationships that will be crucial should a real disaster occur – 'a benefit that can't be overestimated!'(USGS, n.d.);
3. Facilitate collective problem-solving on an issue involving multiple actors;
4. Provide a common foundation for decision-making and action by achieving consensus on the problem definition;
5. Serve as an advocacy tool, building commitment and raising awareness among members of a community;
6. Provide a model for testing, training and improving the community's capacity to respond to and recover from an earthquake;
7. Ensure buy-in from stakeholders along with ownership and responsibility, by painting a clear and plausible picture where each member can visualise their role in the case of an earthquake.

The application of scenario studies to earthquake research began in Japan in the early 1960s. A detailed 15-year study, released in 1978, looked at the effects that a repeat of the 1923 Kanto earthquake (magnitude 7.9) would have on contemporary Tokyo (Katayama, 1992). Since then various organisations have developed this field further, with the United States Geological Survey (USGS) and the California Division of Mines and Geology (CDMG) at the forefront of these developments. In the early to mid-1970s, the USGS and the US National Oceanic and Atmospheric Administration the first US earthquake scenarios for emergency planning purposes (Algermissen et al., 1972, 1973; Hopper et al., 1975; Rogers et al., 1976). The CDMG has been publishing earthquake scenarios for planning purposes since the 1980s.[19]

Many other organisations have also developed approaches to increasing earthquake disaster risk resilience using scenarios. These include the Earthquake Engineering Research Institute (EERI), US state-level geological survey organisations, (e.g. Oregon's Department of Geology and Mineral Industries), and GeoHazards International (GHI). EERI, a national US non-profit society, mobilises volunteer professionals in the local community including engineers, architects, public officials, social scientists and others to investigate earthquake risks and disseminate risk reduction information. EERI has also published guidelines[20] on developing earthquake scenarios.

The following sections will look in depth at two different approaches to scenario building in the field of earthquake resilience, and assess the effectiveness of each.

5.2 The USGS approach

The United States Geological Survey (USGS) is a science agency for the Department of Interior, tasked with providing scientific information on earth sciences, biological sciences, water, energy and issues relating to natural disasters to resource managers, planners and other actors.[21]

The USGS initiated the Science Application for Risk Reduction (SAFRR) programme in order to estimate the consequences of natural hazard disasters and engage decision-makers to increase community resilience to these disasters.[22] The SAFRR project team conducted scenarios

18 For more about the use of scenarios specifically, see Earthquake Engineering Research Institute: http://www.nehrpscenario.org/what/why-conduct-a-scenario/

19 See: https://www.conservation.ca.gov/cgs/about/history; scenario publications include Davis et al. (1982a,b).

20 Earthquake Engineering Research Institute (2006). Guidelines for Developing an Earthquake Scenario https://mitigation.eeri.org/files/Developing.a.Scenario.pdf

21 See: https://www.usgs.gov/about/about-us/who-we-are)

22 See: https://geography.wr.usgs.gov/science/mhdp/index.html

on a wide range of natural hazards including tsunamis, earthquakes and mega-storms. Their general approach to constructing these scenarios is summarised here, with a focus on the earthquake scenarios.

5.2.1 The USGS earthquake scenario approach

The USGS scenario approach has four broad steps: (1) using earth science to describe the hazard events, which are then (2) translated into physical and environmental damages incurred, (3) the social and economic consequences are assessed, and (4) policy implications are identified.

All SAFRR scenarios begin with a description of the expected event, in this case the earthquake and how it unfolds. Then they expand to cover secondary hazards including, in the case of earthquakes, landslides, afterslip (the continued aseismic fault movement following an earthquake), liquefaction, aftershocks and then finally a description of the physical damage to structures, facilities and environmental health as well as social and economic consequences. This information is written up into a final report and technical and policy briefs are also produced, designed specifically for easy use by policy-makers and managers responsible for DRR (Detweiler and Wein, 2017).

Reports typically begin with a description by the physical scientists to help lay stakeholders understand the technical aspects of an earthquake event. This is followed by an analysis by engineers to promote understanding of the likely damage, with suggestions on ways to improve the resilience of facilities and infrastructure. Then, biogeochemical analysis describes the effects on human health as a result of exposure to hazardous building materials (including friable asbestos or contamination of groundwater) during the earthquake. After this, social scientists prepare analyses of the social and economic consequences.

USGS prepares scenarios in partnership with state and local agencies and organisations that can undertake mitigation exercises and implement changes in response to scenario findings. Other federal agencies and private sector stakeholders may participate. The whole process can take several years. For example, the USGS tsunami scenario began in January 2011 and was published in September 2013.

The USGS classic scenario approach is illustrated in more detail in Box 10, using the 'shakeout' scenario as an example.

5.2.2 Does the approach work?

Considering the shakeout scenario as a prime example of the USGS approach to scenario building, the success of this method is plain to see. The scenario has been used widely in disaster preparedness events for several years, and inspired the 'California ShakeOut',[23] an annual earthquake preparedness exercise focusing on actions that can be taken by individuals to protect themselves during an earthquake. The ShakeOut scenario exercise is the largest event of its kind in the world.

The scenario was also used in the preparation of the 2010 FEMA Catastrophic Plan for Southern California and the 2012 Golden Guardian state-wide emergency simulation exercise. The exercise is now an annual event and is part of the country's biggest emergency preparedness event (Ross et al., 2013: 10).[24] At these events, emergency and contingency planners along with health professionals conduct exercises mimicking real emergencies based on the scenarios. After each exercise, they review what went wrong and debate areas for improvement.

Clearly the shakeout scenario has been highly influential in terms of informing and influencing individuals as well as shaping government plans and emergency response procedures. Perry et al. (2011) identify three main factors as having been key to the approach's success:

- The *incorporation of social science research* generated information that was vital for decision-makers and for convincing actors how the earthquake would affect them and how they should prepare for it (Perry et al., 2011: 265).

23 See: https://www.shakeout.org/

24 See: https://pubs.usgs.gov/of/2013/1170/a/pdf/of2013-1170a.pdf

Box 10 The shakeout scenario

The shakeout scenario is probably the most widely used and known earthquake scenario created to date (Perry et al., 2011). It was developed with over 300 contributors from a range of backgrounds and expertise from government, private sector, academia and (southern Californian) community. It forms the basis of one of the largest disaster risk preparedness exercises, involving 7.9 million members of the California public in 2010.

In the scenario, an earthquake of magnitude 7.8 on the southern San Andreas Fault was modelled to analyse its economic and social impact. The process began by estimating ground motions (shaking) from this earthquake using physics-based computer simulations. To triangulate findings, four different teams created the model independently of each other and then compared the output. The shaking and damage estimation models were complemented with data from real earthquakes, along with expert opinions generated through expert panels and special studies.

Each step of the exercise involved different actors (adapted from Wein, 2010):

1. Geologists detailed the hypothetical earthquake by describing a fault in the region with a high likelihood of rupture.
2. Using this knowledge, seismologists and computer scientists modelled the ground shaking that would occur in this earthquake.
3. Drawing on the seismologists' and computer scientists' model, engineers produced a realistic picture of damage to buildings, roads, lifelines and other infrastructure.
4. Geologists used the findings from the ground-shaking modelling to further model liquefaction and landslides.
5. From this picture of physical damages, social scientists projected casualties, emergency responses, and the impact on the region's economy and society.

The earthquake, its projected damages and resulting losses are intended to represent one possible, realistic outcome worth preparing for and mitigating against, and is deliberately not a worst-case scenario.

Within the shakeout scenario process, supplemental studies were used to describe the physical consequences in more depth. These supplemental studies relied on expert judgement and involved a four-hour discussion among engineers and local utilities operators, who were briefed on the ground motion findings and asked to judge the likely damage that would result. They were also asked to suggest mitigants that could significantly reduce the damage caused. Panel members and the authors of non-panel studies were then invited to discuss the findings in a symposium. These panels and studies were conducted in areas where particularly specialised and detailed expertise/information was required, for example on dams, highways, waste water, goods movement, and more. In addition to providing specialised information on their areas of expertise, participants in the panels also responded to the shakeout scenario by suggesting ways to increase resilience, and identified further research to help inform decision-making.

Thus, the shakeout scenario developed through a process of transferring information from one set of experts to another. The way in which the information was transferred/communicated from one discipline to the other was through presentations and reports. In other words, the geologists presented their findings to the seismologists, who then presented their model to the engineers, who in turn described their findings to social scientists. The presentation at each stage included a mixture of face-to-face meetings and reports. Following this process, the project's research team brought together the findings to form the scenario.

- The *involvement of end users from the beginning* had several benefits, including: revealing datasets and perspectives that were unknown to the scenario team; greater acceptance of conclusions and agreements reached on 'hot button' topics; greater ownership of the results; the establishment of partnerships between key stakeholders; and identifying the most effective wording for communication and information dissemination.
- The use of *innovative products and partnerships for the communication of the results*. This included specialised documents and other media for communication to different audiences, such as civil servants, government officials, community organisations and the public.

The USGS scenario approach has been referred to as multidisciplinary rather than transdisciplinary (Wein, 2010). However, it does contain elements of Common approaches to scenario building by going beyond academic disciplines to incorporate actors from society and policy-making, and in some exercises, such as the Haywired scenario exercise,[25] an action plan was produced as part of the scenario, before the final report.

5.3 The GeoHazards International approach

5.3.1 GeoHazards International

While the USGS approach has been successful in mobilising people and resources to improve risk mitigation and raise awareness in the US, it is extremely resource- and time-intensive. Others have found ways to conduct more cost-effective mobilisation. One such approach is that of GeoHazards International (GHI), a US-based NGO that specialises in work to reduce the vulnerability of communities in low-income countries to natural hazards including earthquakes and landslides.

Drawing and building on the scenario model used by the California Department of Geology and Mines (CDMG), GHI developed an economical, mitigation-focused approach to scenario development and applied it in India, Nepal, Ecuador and China. In the early 1990s, GHI developed this model further to include estimates of human casualties and building damage, whereas the original CDMG model had only focused on effects on lifelines. In this section, we describe the GHI approach, and provide a detailed example of how it was used in Kathmandu, Nepal.

5.3.2 The GHI approach to scenarios

Improving resilience to earthquakes in developing countries is particularly challenging. There is frequently little reliable geological and seismological data, as well as numerous vulnerable buildings, few trained seismologists and, in some cases, limited experience in earthquake preparedness. While some areas are more prepared than others – for instance, Nepal has conducted more preparedness activities than Haiti – one of the biggest challenges still remains the existing stock of vulnerable buildings. At the same time, the government's human and financial resources are often very limited, and there are many competing demands to deal with, including more frequent natural hazards (such as floods) and basic development efforts (Villacis et al., 2000).

As a result, governments and decision-makers in developing countries cannot invest a lot of money and resources in precise damage estimation and prefer to invest their resources in on-the-ground actions rather than studies (ibid). Over its 25 years developing earthquake scenarios, GHI has concluded that the higher cost of very precise damage estimates (e.g. using microzoning) cannot be justified on the basis of greater benefits. At a minimum, the damage estimates need only be credible and technically sound – performed by earthquake specialists – to ensure that the public and government realise their community's vulnerability. This forms the basic premise behind the GHI approach to scenario building (ibid).

25 See: https://wim.usgs.gov/geonarrative/safrr/haywired_vol1/

The GHI approach has seven stages:[26]

- **Step 1: Identifying the main participants.** The first step is to identify the people who need to be involved in the scenario-building process. These will typically include government officials, managers of facilities whose vulnerability will be assessed, and technical experts. Meetings are then held with the selected participants to explain the purpose of the exercise, the process itself, what will be required from each stakeholder and how they will benefit from the exercise. This may be a larger meeting of all key stakeholders including government officials and local technical agencies, or a number of meetings of smaller groups. These initial meetings ensure buy-in from the beginning and provide an opportunity to identify champions who can lead the implementation of the action plan.
- **Step 2: Identifying the risk problems.** The next step is gathering information about local earthquake and secondary hazards, vulnerabilities in the built environment, local capabilities, the regulatory environment and social context. Typically, a small core team from several key disciplines conducts a site visit to the scenario location for field reconnaissance and stakeholder consultations, to supplement a desk review of available information. An essential part of this stage is what GHI calls 'characterising the community' – learning how the communities work (e.g. whom do people respect, what are the power structures in the social system, how does information spread and what are the prevalent values). The goal of this stage is identifying and developing a qualitative understanding of the main risk problems. With this understanding, GHI assembles the full team, including local, national and international members with practical experience in addressing earthquake risk problems.
- **Step 3: Selecting the scenario earthquake.** The team selects an earthquake that could plausibly occur within the next few years or decades, and develops a map showing the likely intensity of shaking across the earthquake zone. A historical earthquake that could plausibly recur is frequently a good candidate. The advantages of this approach are that it is often possible to make a more accurate estimate of shaking because there may be some historical data about damage and intensities to draw on, and it is easier for community members to identify with something that has already affected their city. A 'worst case' with effects so devastating that it causes despair and de-motivation will be a poor choice for a scenario intended to motivate public action. This step can also be done alongside or after the next step.
- **Step 4: Assessing the built environment, infrastructure, lifelines and community.** A multidisciplinary scenario team, including GHI and national earth scientists and engineers, then compiles or estimates an inventory of the buildings and other elements of infrastructure, water, power, healthcare facilities and other lifelines in the areas and assesses their vulnerability to earthquake damage. The team meets with, interviews and involves local stakeholders. The team examines the social context and vulnerabilities, and local capacity to respond to and address earthquake risk problems.
- **Step 5: Assessing the likely damage and consequences.** During this step, initial observations are discussed with local experts and decision-makers. The goal is to prepare a detailed estimate of the likely impact on buildings and other infrastructure, people, and lifelines, and to assess the ability of the local authorities, the public and relevant agencies to respond. The physical information about the likely earthquake, the damage it would cause, and the impact on people and services, is compiled into a 'scenario report'. This often includes a personal story about how the event might affect a particular individual and describes how events are likely to unfold in the immediate aftermath of the earthquake and over the ensuing days, weeks and months.
- **Step 6: Developing technical recommendations.** The project technical team presents findings,

26 Adapted from Villacis et al., 2000.

to representatives of key stakeholders in the city and often to national agencies as well. The aim is to validate the scenario and to brainstorm possible solutions. With this input, the team develops a set of technically sound recommendations to address the major risk problems that the scenario exercise identified. The team provides detailed recommendations that are broken into small enough steps to facilitate planning and encourage implementation. Recommendations cover the range of relevant topic areas (e.g. building safety, water supply, transport, land use) that are typically the responsibility of different agencies. These recommendations form a sound technical basis for action planning.

- **Step 7: Action planning.** The final step is to prioritise ways to reduce earthquake risks and develop an action plan. This is a facilitated process with the relevant stakeholders, which combines the responsible agencies' economic, social and political priorities and existing plans with the technical recommendations. Ideally, the action plan is eventually presented to the public by a government official, in order to aid ownership and demonstrate endorsement of the recommendations to the community. Following this presentation, the local champions continue to support on the planning and implementation phases.

Box 11 describes how GHI implemented this process in the Kathmandu Valley Earthquake Risk Management Project between 1997 and 1999. GHI has used similar methods in Aizawl (India),[27, 28] and Bajhang, Dadeldhura and Rukum districts (Nepal),[29] to address risks posed by earthquakes and landslides.

5.3.3 Does the approach work?

There is substantial evidence that the Nepal project made meaningful progress against all four objectives (see Box 11). The scenario report and action plan are widely regarded as a valuable addition to local understanding of risk and mitigation plans. The National Society for Earthquake Technology (NSET-Nepal) now employs almost 100 employees, and promotes building standards and retrofitting of schools (NSET, 2014).

By the time of the 2015 Gorkha earthquake in Nepal, 160 schools had been retrofitted or replaced with seismically resistant buildings, and almost 700 masons had been trained to retrofit schools in Kathmandu and other areas (Paci-Green et al., 2015, 2016). NSET-Nepal provided support in all cases (ibid). In the areas affected by the 2015 earthquake, all the school building that had been retrofitted remained structurally intact, with some suffering only minor or moderate damage (Anwar et al., 2016; Acharya, 2017).[30] Many of these were used as emergency shelter by the community and some to house medical staff and facilities (Lizundia et al., 2016).

Public awareness has been increased through the prime minister's public endorsement of and support for the action plan (a product of the GHI scenario), which was timed to coincide with the first Earthquake Safety Day. Earthquake risk management has been institutionalised through the strengthening of NSET and the incorporation of disaster management activities into local government (Dixit et al., 2000).

In summary of this section, both the USGS and the GHI approaches to earthquake scenario building have demonstrated success in respective high-profile examples. Of the two, the USGS approach produces more precise damage estimates, but the GHI method is more time- and cost-effective in situations where a credible and technically sound estimation is all that is required. The latter makes the GHI approach especially useful in developing countries.

27 See: https://www.geohaz.org/aizawl-landslide-action-plan

28 See: https://www.preventionweb.net/files/38839_38839aizawlearthquakescenario1.pdf

29 See: https://www.geohaz.org/earthquake-scenarios-nepal

30 Three hundred school buildings were retrofitted and survived according to Dixit et al. (2015).

Box 11 The Kathmandu Valley earthquake scenario

Kathmandu Valley has a long history of destructive earthquakes, the most recent being in 2015. Despite this risk, at the time the scenario was prepared in the late 1990s, there was no institution within the valley with the responsibility to assess and mitigate the risk. Several government agencies had some information, but it was neither synthesised nor adapted to Kathmandu Valley's then-current conditions. The Kathmandu Valley Earthquake Risk Management Project (KVERMP) commenced in 1997 and was implemented by the National Society for Earthquake Technology (NSET-Nepal) and GHI. The objectives of the project were to:

- Evaluate the risk to the valley and prescribe a risk management plan;
- Reduce vulnerability in schools;
- Raise awareness among the public, government officials and international organisations about the risks in the valley; and
- Build local institutions to continue this work in the long term.

GHI conducted an earthquake scenario to establish the impact of a potential earthquake similar to one in Kathmandu in 1934, which killed 4,500 people and destroyed more than 20% of the valley's building stock. The project convened more than 80 government and non-government institutions to develop an action plan, which was released and endorsed by the prime minister of Nepal on Earthquake Safety Day in January 1999.

The potential damage in the scenario was estimated by interviewing operators of critical facilities, synthesising existing studies and conducting a workshop to examine interrelations between the lifelines in Kathmandu Valley. It was apparent that the area had been subject to rapid development and population growth, which was not accompanied by any implementation of seismic building codes. Therefore, earth scientists and engineers concluded that if an earthquake with a similar magnitude to that of the 1934 earthquake were to occur in this area in 1999, it would result in significantly worse consequences – and 40,000 deaths.

The resulting scenario was used as the basis for creating an action plan with recommendations for mitigation activities. The action plan set out eight long-term objectives and recommended ten manageable initiatives to be implemented by NSET, in its role as the local champion.

The long-term outcomes of this scenario exercise included:

- Institution building: NSET was strengthened and is now an effective regional leader of earthquake risk assessment and management.
- Risk management: a Disaster Risk Management Unit was created as part of the city government in Kathmandu Metropolis, and other municipalities created equivalent units. NSET's achievements have included educating local officials, leading to the creation of Disaster Management Committees comprising residents and community organisations.
- Action plan: ten initiatives were defined to improve national disaster management, raise awareness, implement and enforce building codes, and strengthen schools.
- School safety and retrofits: vulnerability assessments were conducted in public schools, assessing and quantifying the risks faced and suggesting how to plan earthquake risk mitigation. Several schools have been retrofitted to address these risks.
- Knowledge transfer: masons trained in Nepal for the school retrofit project retrained other masons in Gujarat, India.

Source: Dixit et al., 2000

Testing the scenario approach in China

A transdisciplinary scenario approach was tested in China, with the aim of addressing gaps between government earthquake policies and local-level earthquake preparedness in two administrative districts of the Weinan municipal area, in Shaanxi Province. The transdisciplinary research team co-developed scenarios through a combination of planning workshops, online communication, site visits and collaborative writing sessions.

The scenario used historical data about the 1568 Weinan earthquake in northeast Xi'an, to model ground motion and loss estimates, alongside fieldwork and local consultation to understand the main earthquake risks in the area. Two science-based narratives were produced in English and Chinese: (1) a graphic novel with earthquake mitigation and preparedness tips for the general public, and (2) a narrative story with recommendations for relevant local agencies (GeoHazards International, 2019).

Context: Earthquakes in China

The geographic location of China between the tectonic plates of the Eurasian, Pacific and Indian Ocean makes China one of the most earthquake-prone countries in the world. In the 20th century alone, 35% of the world's continental earthquakes with a magnitude higher than seven have taken place in China.

China's response to these risks has significantly changed over the years. After initially centring on earthquake prediction, government focus moved towards risk mitigation, following scientists' failure to predict the 1976 Tangshan earthquake, which significantly diminished confidence in prediction methods. Policy and planning moved its focus from recovery and response to disaster risk reduction (DRR) and prevention (Cui, 2018). The government has also emphasised community-based DRR in disaster-prone areas, promoting preparedness and self-help (ibid).

The China Earthquake Administration (CEA) coordinates and administers national seismological work. There is a very strong focus on ensuring the seismic safety of schools, hospitals and other vital buildings, and there has been a substantial investment in this since the 2008 Wenchuan earthquake. The CEA also has projects at village level aiming to improve earthquake disaster preparedness and response, though those tend to focus on the more common types of disasters, such as drought and fires, hail and rain, and floods.

The PAGER-O project

While institutional and policy arrangements to incentivise earthquake DRR in China are well established, there remain challenges in the coordination of efforts in practice, especially between central and local governments, between rural and urban areas and between government and non-government actors (Shi et al., 2014). In light of these challenges, a method that brings these different actors and stakeholders together is crucial for effective earthquake DRR.

The Pan-participatory Assessment and Governance of Earthquake Risks in the Ordos Area (PAGER-O) project emerged from a longstanding partnership between the Earth Science Departments of Oxford and Cambridge Universities and the CEA. Early collaborations focused mainly on natural science – seismology and geology – but the Earthquakes without Frontiers (EWG) project (see Box 4) brought together social scientists as well as natural scientists, policy-makers and practitioners in a transdisciplinary project aiming to improve earthquake resilience. The idea of using scenarios emerged during that workshop.

PAGER-O aims to improve earthquake resilience in China through collaborative multidisciplinary research. It seeks to integrate local (bottom-up) and national (top-down) approaches to earthquake DRR, and to close the science–policy gap.

Specific objectives of the project include:

- Updating the historical record of earthquakes in mainland China;
- County-level mapping of hazard, risk and vulnerability;
- Regional and sub-regional analysis of factors that affect resilience;
- Using a scenario to develop an integrated approach;
- Testing the scenario approach in pilot projects in different contexts;
- Testing different channels for communication; and
- Feeding findings into provincial and national long-term DRR plans, laws and regulations.

The scenarios

PAGER-O was formally launched in China in April 2016. Based on GHI's experience in other countries and other partners' experiences in China, GHI suggested a generic six-step approach:

1. Estimate earthquake damage and understand causes;
2. Interview and involve 'risk owners';
3. Discuss risks and anticipated damage to determine impacts and mitigants;
4. Write the earthquake scenario and recommendations;
5. Develop an action plan; and
6. Ensure that a local NGO or government adopts and implements the plan.

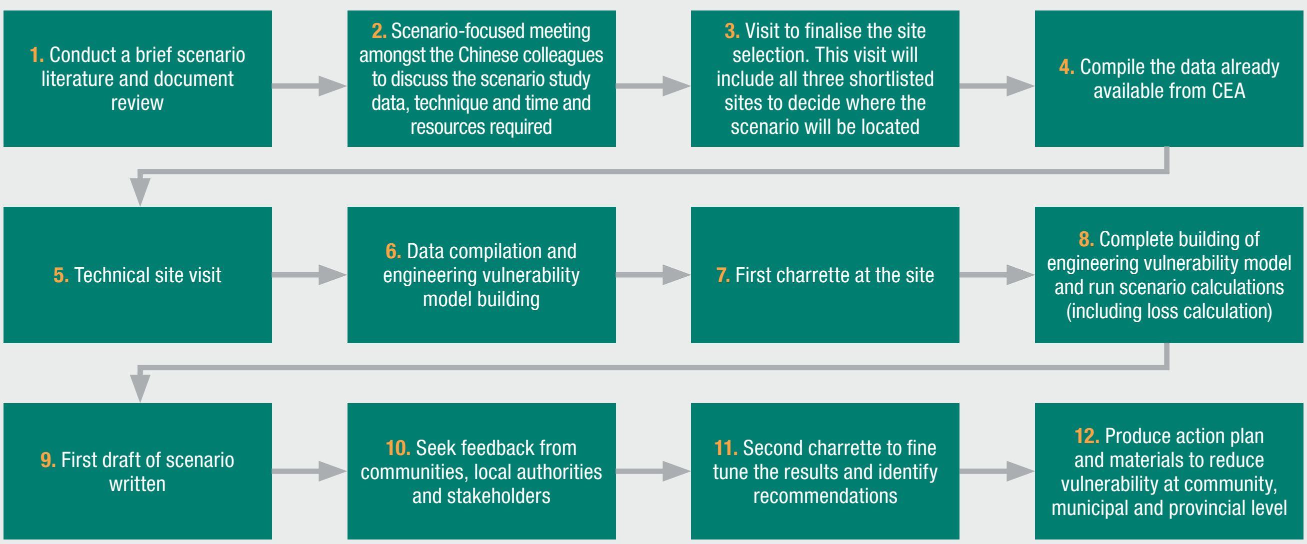
The primary approach used for each of these stages is known as a 'charrette' – an iterative, collaborative dialogue involving all stakeholders.[31] The methodology was ultimately developed from the six-step outline to a tailored 12-stage process (Figure 5).

Since then much has been done. The Chinese team collected some initial data and held a series of meetings to identify possible scenario sites. These were discussed with the international team, after which the Chinese team visited all three sites (stage 3). Following further discussion with the international team, Weinan municipality in Shanxsi Province was selected.

Core members of the Chinese and international teams visited the city in December 2016 to observe sources of vulnerability and hold discussions with local officials (stage 5). The Chinese team then collected primary data on the built environment, infrastructure and lifelines (stage 6) in preparation for the first charrette in June 2017 (stage 7).

It then took another year of collaborative work by the Chinese and international teams to identify the most appropriate historical event (the 1568 Weinan earthquake) to form the basis for the scenario, to develop a valid 'shake map', analyse the likely impact on the built environment (stage 8), and draft the scenario (stage 9). The results were discussed with local authorities (stage 10) during the second charrette in May 2018 (stage 11).

Figure 5 The PAGER-O scenario process



Adapted from UK–China Collaboration Launch Meeting Summary Report 2016.

31 The word *charrette* is French for 'cart'. Its use in design arose in the 19th century among teams of student architects working together to produce prototypes right up to the deadline, when their models would be collected in a cart.

6 Conclusion

The world and humanity are facing unprecedented challenges that are evolving rapidly and require decisions informed by the best possible science. In fact, these decisions need to be taken far more quickly than the process for consensus-building in academia traditionally allows. This paper has explored how new, interlinking methods are emerging in response to this need, and has shown how they can be applied to the important work of earthquake disaster risk reduction (DRR).

Transdisciplinary research is designed to address complex problems. It brings together scientists, policy-makers, operational agencies and communities to work together to address a shared challenge. It combines scientific research with existing knowledge and collaborative decision-making. The key element is knowledge integration. The approach is increasingly well understood, and has been applied to a wide range of challenges in different contexts. There are many well-documented approaches and tools that can be utilised for specific elements, for example constellation analysis for knowledge integration, or the RAPID Outcome Mapping Approach (ROMA). There is some evidence that it works, although since by its nature it is applied in unique ways to unique challenges, there is little empirical data confirming its success across the board.

Futures studies is an approach to planning for future challenges. Fundamental principles, held in common with transdisciplinary research, are to bring together different stakeholders and to draw on a very wide range of knowledge. Emerging from the defence and national security fields and widely used by the private sector, futures studies has been applied to health, DRR and resilience contexts. As with transdisciplinary research there are many tools available to futures studies practitioners, including the Delphi method, cross-impact analysis and scenarios. As with transdisciplinary research, futures studies has been used in a wide range of situations, and is widely regarded as helpful. It has certainly led to changes in policy and investments in certain cases, but its effectiveness has not yet been rigorously interrogated.

One of the most widely used methods in futures studies is scenarios. These incorporate the principles of transdisciplinary research, bringing together scientists, policy-makers and other stakeholders, to make decisions based on the best possible evidence for events that may happen in the future. There are broadly two types of scenario. One considers a range of plausible futures and develops plans to facilitate progress towards a preferred scenario. The most commonly cited example of this is the Mont Fleur scenarios in South Africa, widely credited with contributing to South Africa's transition towards inclusive growth and democracy following the end of apartheid.The other focuses on a single, often catastrophic event, and develops plans to minimise its impact. The US Geological Survey (USGS) has been using this type of scenario for many years to develop plans for geological hazards including earthquakes and tsunamis.

GeoHazards International (GHI) has pioneered a simplified version of this type of scenario, which is more time- and cost-effective. An example of this is being tested by the PAGER-O project in China. That process is now well underway, but it is too early to draw any conclusions about the process or its effectiveness. For more information about the outcomes of this project in the future, read the *Creating an earthquake scenario in China: A case study in Weinan City, Shaanxi province* paper published in a special issue of the *International Journal for Disaster Risk Reduction.*

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