Implementing societal values as drivers for performance indicators to improve resilience analysis of critical infrastructure

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The resilience of critical infrastructures is assessed with key performance indicators that are unavoidably based on the underlying societal values of the stakeholders. Though societal values are under constant change and critically determine the resilience management of critical infrastructures they are difficult to consider in decision-making approaches. This research presents a proof-of-concept approach to highlight the relevance of societal values for decision-making and resilience management. Previous research proposed to use abstract worldviews to solve the complex decision problem presented by the lake model, a human and nature coupled system model simulating the intricacy of societal decision problems and providing scenarios for research on decision-making under uncertainty. By replacing the abstract worldviews with a reduced set of societal values we establish a formalized relationship between the societal values and the lake model. We show that even slight changes in the societal values can lead to significantly different behavior of the lake model. Though the approach is extremely simplified it serves to highlight the sensitivity of decision problems to societal value changes.

Keywords: societal values, quantitative decision support, resilience analysis, resilience management, deep uncertainty, paradigm shifts, decision-making, worldviews.

1. Problem definition and approach

Considering the events of today, countries worldwide face pressing policy challenges relating to the resilience of critical infrastructures (CI), such as relating to the supply of energy, water, and food. The German Federal Office of Civil Protection and Disaster Assistance (BBK) describes critical infrastructure as a part of the broader system of society that bears significant importance to the functioning of a polity by providing indispensable goods and services, such as food and energy supply, public safety, among others (BBK). Shocks like natural disasters, accidents or man-made attacks are unavoidable and therefore the resilience of CI is vital to maintain the well-being of a society even under stressful conditions (BBK). Resilience can be understood as a system capacity that is commonly estimated by so called key performance indicators (KPI) (Carlson et al. (2012); Kanno et al. (2019); Rehak et al. (2019)). We argue that the KPI used in the resilience assessment of CI are unavoidably based on the stakeholders' societal values. Additionally, societal values are subject to change over time (Stehr (1998)), which can lead to profound paradigm shifts and a change of KPI within the resilience assessment of a CI with vital implications for its outcome. Therefore societal values should be taken into account in decision analysis. In the subsequent sections we highlight the relevance of societal values for decision-making by integrating a set of core societal values identified bySchwartz et al. (2012) into quantitative decision-making approaches as a proof-of-concept. The work of

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Lempert and Turner (2020) serves as a suitable starting point since they successfully illustrate the use of worldviews in decision analysis.

2. Introduction to the lake model

Lempert and Turner (2020) utilize the lake model for their study, a commonly used model for research on decision-making under uncertainty that represents the intricacy of societal decision problems (Lempert and Collins (2007); van Dorsser et al. (2018)). The related lake problem describes the interdependencies between a fictitious society living by a lake and the lake's ecosystem. An 'old' economy uses the lake for fishery and a 'new' economy uses the lake for cooling and process water as well as a pollution outlet. The phosphor eutrophication level of the lake determines its health and is increased by pollution and reduced by recovery mechanisms. Both economies' outputs are governed by their labor force. A so-called controller has two policy options available: (1) to regulate pollution streams into the lake and (2) to train workers to move from the old to the new economy. Additionally, the lake problem defines limits that can lead to the collapse of the lake's ecosystem or any of the two economies, and that can cause the available labor force to shrink. The study of Lempert and Turner (2020) assumes that the citizens have different worldviews and opinions about the KPI and how to solve the lake problem respectively. The worldviews are based on the works of Wildavsky (1987) and Schwartz and Thompson (1990) and describe patterns of shared values and beliefs about the environment, the hierarchist, egalitarian, individualist, and fatalist worldviews. According to Lempert and Turner (2020) those with a hierarchist view wish for a top-down and structured approach in which the controller decides on an appropriate strategy and governs the situation with the measures at his disposal. Citizens with an egalitarian view are more traditionalist and skeptical that neither the controller nor the citizens will make the right decisions and wish for everything to remain unchanged. Those with an individualist view share a liberal approach and desire to be able to make their own choices, believing that the market will regulate itself. However, the fatalist position can be ignored for decision analysis because it is indifferent to any available strategies (Linnerooth-Bayer et al. (2015)). Subsequently, several parameters of the lake model assume different values for each worldview. The relevant parameters are depicted in Table 1.

Table 1. Model parameters of the lake model.

Parameters	**Effects**
X	Crit. threshold for irreversible lake pollution
Y	Pollution intensity inflection point
κ	Steepness of pollution intensity logistic curve
$\tau 1$	Effect of regulation on pollution
$\tau 2$	Effect of regulation on pollution intensity
ψ	Effectiveness of training

Source: Lempert and Turner (2020).

For example, the parameter for the lake's pollution threshold X is set to be low under the egalitarian but high under the individualist worldview. These worldviews can be understood as an aggregated and abstract representation of sets of societal values.

3. Societal values and value personas

In the present approach we replace the abstract worldview descriptions with the more refined value personas, comprised of sets of societal values. The societal values describe congruent ideas about something estimable and worth aspiring to (Deci and Ryan (2000); Scherr (2016)). Whereas people may share the same needs, only their values distinguish their unique individuality and guide their choices (Locke (1991)). Within a social group instead of uniformly valid values there are only value complexes that critically depend on the context (Scherr (2016)). Importantly, societal values are neither given and stable, nor equally and naturally acknowledged by all social groups (Stehr (1998)).

Based on extensive research spanning multiple countries, Schwartz (1992) and Schwartz et al. (2012) have developed a collection of 19 societal values that are: Benevolence: Dependability, Benevolence: Care, Self-Direction: Thought,

Self-Direction: Action, Hedonism, Stimulation, Power: Dominance, Power: Resources, Achievement, Face, Security: Personal, Security: Societal, Conformity: Interpersonal, Conformity: Rules, Tradition, Humility, Universalism: Societal Concern, Universalism: Nature, and Universalism: Tolerance. They appear basic yet complete enough to be useful in this research. Encompassing values with personal focus and social focus, they can be used to represent the personas of discernible stakeholders, that we shall call 'value personas'. A value persona combines an individually weighted set of the 19 societal values so that it represents a unique personality as suggested by Locke (1991). However, later on a selection of only four societal values are used in this study to define a value persona, which should be sufficient to provide a proof-of-concept.

4. Approach and methodology

This study is conducted in three steps. First we establish a relationship between the three worldviews and the societal values by representing each worldview in form of a value persona. Second, we create a simple linear model that describes how the weights of values of a value persona affect the model parameters of the lake model (Eq. (1)).

$$a_{p,v} * V_k + c_p = P_{p,k} \tag{1}$$

Here, $a_{p,v}$ represents a matrix of coefficients for each combination of model parameters p and societal values v. For each value persona k, each model parameter $P_{p,k}$ is obtained by multiplying the respective range of coefficients $a_{p,v}$ with the vector of weights of values of the value persona V_k, adjusted by a constant value per parameter c_p. Then, we develop four new value personas to parametrize this new model and obtain suitable coefficients ($a_{p,v}$) for future experiments. For this purpose, for each new value persona the weights of values (V_k) are selected and consistent model parameter values ($P_{p,k}$) are assigned to each value persona. Then, the values of the coefficients ($a_{p,v}$) and parameters (c_p) are determined in order to finalize the formal link between the value personas and the model parameters of the lake model (Eq. (1)). Applying Eq. (1), it is then possible in the third step to calculate model parameter values for any other value personas (with distinct sets of weights of values V_k) in a consistent way. Finally, the results are analyzed and discussed, highlighting the opportunities and shortcomings of this approach.

5. Establishing the relationships of worldviews and societal values

Starting from the definitions of the worldviews, we establish the relationship to each individual societal values. We assign three types of alignment to the relationships as depicted in Table 2, which may be used synonymously with weights of values in the following sections:

- positive (+1)
- neutral (0)
- negative (-1)

The neutral qualification is helpful to account for the overlaps in meaning between different values and can describe relationships as either not having a trivial connection, having an ambivalent connection that could be either positive or negative depending on the circumstances, or having a rather indifferent connection. The mapping process specifically highlights that the worldviews represent abstract concepts that are not intuitively convertible to the more detailed collection of societal values. Both concepts can help to explain how people experience, interpret, and act in specific situations. However, the two concepts do not perfectly align and also Schwartz et al. (2012) show that the meaning of adjacent values can overlap to some extent. For this study we focus on presenting only an approximate mapping of worldviews and societal values, which is sufficient for this research goal. In consequence only ten out of 19 societal values are applicable in this study. Values such as benevolence, face, hedonism, power-dominance, personal security, and tolerance have no relation to the lake model and are disregarded. Additionally, two value pairs are each combined into one value for this study because their distinction with regard to the lake problem is negligible. Therefore the value self-direction: thought is integrated into self-direction: action and the value conformity:

rules also comprises conformity: interpersonal. Table 2 shows how weights V_k are assigned to the ten relevant societal values for each of the three worldviews, following the logic below.

Table 2. Mapping of worldviews and societal values.

Societal Values	**Abbr.**	**Hie.**	**Ega.**	**Ind.**
Self-Direction: Action	(SDA)	0	-1	+1
Stimulation	(STI)	0	-1	+1
Achievement	(ACH)	0	-1	+1
Power: Resources	(POR)	0	-1	1
Security: Societal	(SES)	+1	0	0
Tradition	(TRA)	0	+1	-1
Conformity: Rules	(COR)	+1	+1	-1
Humility	(HUM)	0	+1	-1
Universalism: Nature	(UNN)	0	+1	-1
Universalism: Societal Concern	(UNS)	+1	0	-1

The hierarchist worldview (Hie.) is mainly concerned with a strong and stable government, whereas the egalitarian worldview (Ega.) takes a conservative stance that favors a strong government and appeals to self-discipline and conformity aspects, and the individualist worldview (Ind.) represents a liberal position, mainly concerned with maximizing opportunity. The mapping shows that it appears worthwhile to distinguish between the values "Universalism: Nature" and "Universalism: Societal Concern". While both values address different aspects of the lake problem, they also show different characteristics per worldview.

6. Development of four new value personas

The value personas are generalized versions of distinct character groups that we find in many societies. Without the claim of offering the perfect character definition, each character's unique features are made explicit to establish a common understanding for this research. We focus specifically on those features that could be relevant to the lake problem. The formalized value personas are presented in Table 3. The first value persona represents the owner of a small to medium sized business (SME), incorporating independent, economic, protective and traditional values. The second value persona represents an artist (Art.), like a painter or sculptor, with independent, critical and social character. The third value persona represents a self-supporting recluse (Rec.), with a focus on humility and nature. The fourth value persona describes an entrepreneur (Ent.), portraying a progressive spirit with societal concern.

Table 3. Weights V_k of four new value personas.

Societal Values	**SME**	**Art.**	**Rec.**	**Ent.**
SDA	+1	+1	+1	+1
STI	0	+1	-1	+1
ACH	+1	+1	-1	+1
POR	+1	-1	-1	0
SES	+1	+1	0	0
TRA	+1	-1	0	-1
COR	+1	-1	0	-1
HUM	0	0	+1	-1
UNN	0	0	+1	0
UNS	+1	+1	-1	+1

7. Operationalizing the value personas

Establishing a quantitative link between each societal value and the parameters of the lake model is the core challenge of this research. The model proposed here (Eq. (1)) contains only coefficients $a_{p,v}$ and parameters c_p which are not specific for any value persona. Once suitable values for the coefficients $a_{p,v}$ and constants c_p have been identified, it is possible to insert weights of values V_k for any possible value persona k in order to obtain consistent model parameters $P_{p,k}$ for this value persona. Therefore, one of the main goals of this research was to identify a suitable set of values for the coefficients $a_{p,v}$ and parameters c_p for all relevant model parameters $P_{p,k}$. The six model parameters of interest and their meaning are depicted in Table 1. Each of the model parameters $P_{p,k}$ can take a value within the interval $[0.0, 1.0]$, while the weights of values V_k are restricted to the set of values $\{-1, 0, 1\}$. These boundary conditions can be used to derive a valid range of values for the coefficients $a_{p,v}$, which can be viewed as partial derivatives of the model parameters with respect to the weights of values $V_k : a_{p,v} = (dP_{p,k})/(dV_k)$. Therefore, the values of the coefficients $a_{p,v}$ must lie within the interval $[-0.5, 0.5]$. The constants c_p represent the value

of the respective model parameter $P_{p,k}$ when all weights of values V_k are equal to zero. Therefore, the parameters c_p have to take a value within the interval $[0.0, 1.0]$. Furthermore, it can be derived from the above-mentioned boundary conditions that for each model parameter $P_{p,k}$ the values of the coefficients $a_{p,v}$ need to fulfill the following Eq. (2):

$$\sum\nolimits_v |a_{p,v}| \leq min\left((1 - c_p), c_p)\right) \qquad (2)$$

In mathematical terms, the identification of consistent values of coefficients $a_{p,v}$ and parameters c_p based on Eq. (1) is a well-determined task, if the number of societal values V_k and the number of value personas, which are available for parametrization, is equal. For the purpose of a proof-of-concept, it is legitimate to limit complexity. Therefore, the number of societal values was reduced to four, in order to use the four new value personas for parametrization. Four societal values that seem highly relevant with respect to the lake problem are selected (Table 4) from the ten societal values shown in Table 3.

Table 4. The final selection of four societal values that describe the four value personas.

Societal Values	**SME**	**Art.**	**Rec.**	**Ent.**
STI	0	+1	-1	+1
POR	+1	-1	-1	0
COR	+1	-1	0	-1
UNN	0	0	+1	0

With all these important conditions in mind it is possible to determine a valid set of values for coefficients $a_{p,v}$ and parameters c_p based on the weights of values of the four new value personas (Table 4) and their respective model parameter values (Table 5).

These model parameter values of the value personas (Table 5) and the values for coefficients $a_{p,v}$ (Table 6) and parameters c_p (Table 7) were determined iteratively based on some initial guesses using Eq. (1). These findings are applied to the experiments in the next section.

Table 5. Model parameters $P_{p,k}$.

Parameters	**SME**	**Art.**	**Rec.**	**Ent.**
X	0.7	0.5	0.2	0.6
Y	0.3	0.61	0.89	0.46
κ	0.35	0.55	1.0	0.35
$\tau 1$	0.55	0.35	0.55	0.25
$\tau 2$	0.65	0.45	0.65	0.35
ψ	0.75	0.3	0.25	0.35

Table 6. Coefficients $a_{p,v}$.

Parameters	**STI**	**POR**	**COR**	**UNN**
X	0.0	0.1	0.0	-0.3
Y	0.01	-0.15	0.0	0.3
κ	-0.2	-0.2	0.0	0.05
$\tau 1$	0.0	-0.1	0.2	0.0
$\tau 2$	0.0	-0.1	0.2	0.0
ψ	0.15	0.05	0.25	0.0

Table 7. Constants c_p.

Parameters:	X	Y	κ	$\tau 1$	$\tau 2$	ψ
Constants:	0.6	0.45	0.55	0.45	0.55	0.45

8. Experiments

In order to conduct the experiments, we apply the previously defined coefficients $a_{p,v}$ and constants c_p in Eq. (1). For the experiments we plug in a designated value persona V_k and feed the resulting model parameter values $P_{p,k}$ into the simulation model. The first experiment focuses on the original three worldviews, followed by further experiments that focus on the four defined value personas. A third exercise investigates the sensitivity of the model behavior of only slight changes to a given value persona. The graphs in this section illustrate the lake model behavior per worldview, each showing the curves of pollution, economic output and unemployment.

8.1. *Experiment 1: worldviews*

The estimated model parameters of the three worldviews (Table 8) show an especially low value of X (critical threshold of pollution) for the Egalitarian worldview. Thus, it appears that the threshold is hit immediately at the start of the simulation, resulting in a further boost in pollution. In contrast, the threshold for the Individualist worldview is at full capacity, meaning that the

lake's health can never turn bad.

Table 8. Model parameter values $P_{p,k}$.

Parameters	**Hie.**	**Ega.**	**Ind.**
X	0.6	0.2	1.0
Y	0.45	0.89	0.01
κ	0.55	1.0	0.1
$\tau 1$	0.65	0.75	0.15
$\tau 2$	0.75	0.85	0.25
ψ	0.7	0.5	0.4

In comparison to the original parameter values (cf. Lempert and Turner (2020)), the model shows slight discrepancies under the estimated parameters for the three worldviews (Figure 1). Especially the Egalitarian worldview shows greater deviations. For example the lake pollution level has a different starting point for the Egalitarian worldview with immediate effects on the unemployment level and economic performance (Figure 1) as opposed to the original behavior in Lempert and Turner (2020).

8.1.1. *Experiment 2: four value personas*

Figure 2 depicts the model behavior under the four value personas. With exception of the persona Recluse, the majority of the personas have the same starting point and similar trajectories for more than a quarter of the simulated time.

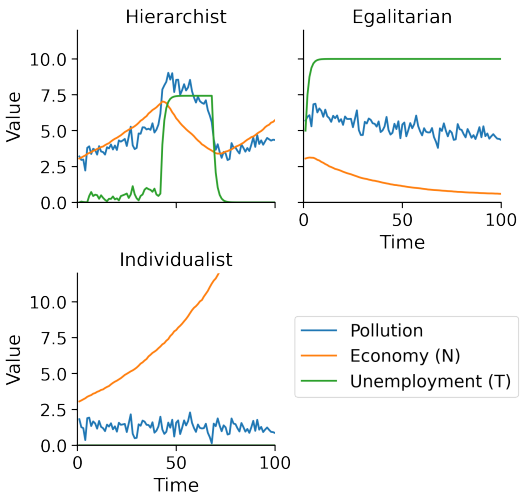

Fig. 1. Estimated lake model behavior under the three worldviews.

Eventually the lake eutrophies under each of the value personas.

Similar to the Egalitarian estimate (Figure 1), the Recluse persona also suggests immediate eutrophication (Figure 2) due to the low parameter value of X (Table 5). Interestingly, the behavior of the Hierarchist worldview (Figure 1) and the entrepreneur (Figure 2) show almost the same performance curve for pollution and economy, only the unemployment curves differ slightly in height.

8.1.2. *Experiment 3: value changes within a value persona*

For the final experiment we take the Artist value persona to simulate a slight change in societal values. For each of the four values the value is changed by 1 whilst keeping the other values equal as shown in Table 9. The societal value of Universalism: Nature can change both, positively and negatively.

The graphs of the variations of the Artist value persona are illustrated in Figure 3.

The personas New1 through New5 are based on the Artist value persona and the graphs of the new personas depict the variations of behavior

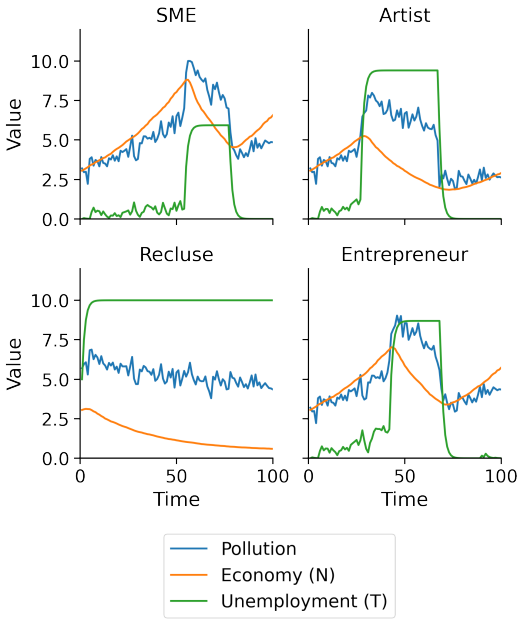

Fig. 2. Lake model behavior under the four value personas that were also used to parametrize the model.

Table 9. Variations in value weights V_k.

Societal Values	**Artist**	**New1**	**New2**	**New3**	**New4**	**New5**
STI	+1	+1	+1	0	+1	+1
POR	-1	0	-1	-1	-1	-1
COR	-1	-1	0	-1	-1	-1
UNN	0	0	0	0	-1	+1

invoked by the slight changes of the Artist value persona (Table 9). Where the variations of the personas New2 and New3 show almost no difference in model behavior, the behavior changes significantly for personas New1, New4, and New5 (Figure 3). The latter represent value changes in the societal values of Power: Resources and Universalism: Nature. The change to the societal value of Power: Resources mainly results in a boost to the economic output because the lake appears to have a higher threshold of eutrophication for this value persona. A value change regarding the concern of nature can have either a liberating effect on the economy (New4) while the pollution threshold seems to be ineffective or a restricting effect on the economy (New5) due to a strongly lowered threshold, similar to the Recluse persona.

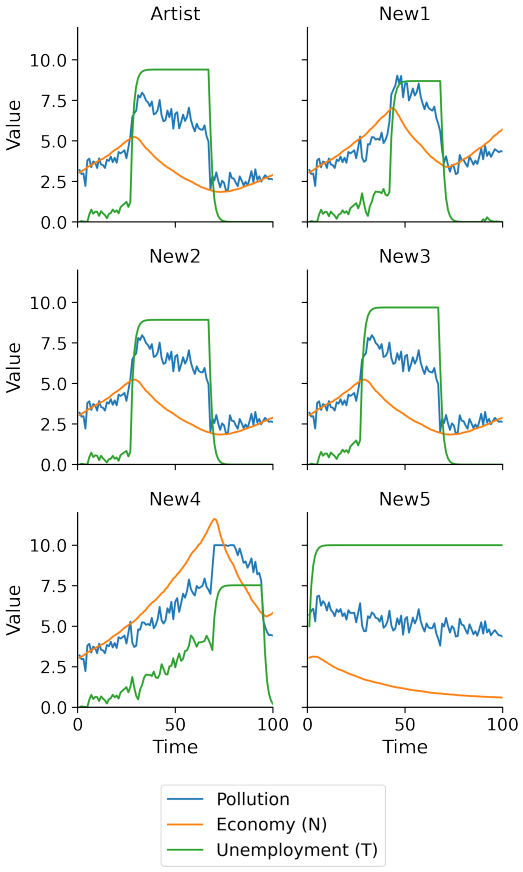

Fig. 3. Comparing the lake model behavior of the the original Artist value persona to the behavior of its variants.

In conclusion, the results show how modest changes in societal values can have drastic implications for the expectations regarding the system's behavior, which in turn might affect a stakeholder's assessment of the state of resilience of the system. Under some value personas, the model behavior portrays immediate collapse of the lake with severe implications for the society and its economy. Other value personas illustrate that the lake's health can be maintained for the prosperity of the society.

9. Discussion

The last experiment portrays that distinguishing between value personas as opposed to worldviews has several advantages. We show that it is possible to assess different value personas and changes in value personas with this approach. It should also be noted that several parts of the approach were simplified for demonstration purposes. Reducing the approach to only four value personas consisting of only four societal values has the advantage of simplicity. The reduced accuracy is an acceptable sacrifice for the purpose of this study.

Nonetheless, the use of value personas, even with the aforementioned simplifications, already enables a significantly more complex and versatile assessment of the lake problem than the use of worldviews. In our approach a societal value can assume one of three states $\{-1, 0, +1\}$. Mapped over the four values of a value persona we are able to distinguish between 3^4 different value personas. However, in a real world application the values could realistically assume any weight-value between $[-1, +1]$ in order to represent nuanced differences of value personas as proposed by Heblich (2016). A more refined approach that is optimized to handle all 19 societal values identified by Schwartz et al. (2012) (Section 3) could there-

fore enable the use of fine-tuned value personas and present important insights for the resilience management of CI.

With regard to resilience management under societal values, the third experiment illustrates the sensitivity of the approach to only slight changes of values within a value persona. The example of the Artist-persona and its five variations (Table 9) highlight the potential impact of value changes on a decision problem or a resilience assessment by resulting in different outcomes regarding the economic, environmental and societal aspects of the lake model (Figure 3).

As we applied a linear model in Eq. (1), it can also be useful to investigate a non-linear approach in future research.

10. Conclusion

This proof-of-concept shows the relevance of integrating societal values in resilience management and related decision-making problems. Though the approach is still limited and calls for refinement in future research.

References

Carlson, L., G. Bassett, W. Buehring, M. Collins, S. Folga, B. Haffenden, F. Petit, J. Phillips, D. Verner, and R. Whitfield (2012). Resilience: Theory and Applications. Technical report, Argonne National Laboratory, Argonne.

Deci, E. L. and R. M. Ryan (2000). The "What" and "Why" of Goal Pursuits: Human Needs and the Self-Determination of Behavior. *Psychological Inquiry 11*(4).

Heblich, B. (2016). *Autonomous and intrinsically aspirated Self-Leadership (German Version)*. Ph. D. thesis, Karlsruher Institut für Technologie (KIT).

Kanno, T., S. Koike, T. Suzuki, and K. Furuta (2019). Human-centered modeling framework of multiple interdependency in urban systems for simulation of post-disaster recovery processes. *Cognition, Technology & Work 21*(2), 301–316.

Lempert, R. J. and M. T. Collins (2007). Managing the Risk of Uncertain Threshold Responses: Comparison of Robust, Optimum, and Precautionary Approaches. *Risk Analysis 27*(4), 1009–1026.

Lempert, R. J. and S. Turner (2020). Engaging Multiple Worldviews With Quantitative Decision Support: A Robust Decision-Making Demonstration Using the Lake Model. *Risk Analysis 41*(6), 845–865.

Linnerooth-Bayer, J., A. Scolobig, S. Ferlisi, L. Cascini, and M. Thompson (2015). Expert engagement in participatory processes: translating stakeholder discourses into policy options. *Natural Hazards*.

Locke, E. A. (1991). The Motivation Sequence, the Motivation Hub, and the Motivation Core. *Organizational behavior and human decision processes 50*, 288–299.

Rehak, D., P. Senovsky, M. Hromada, and T. Lovecek (2019). Complex approach to assessing resilience of critical infrastructure elements. *International Journal of Critical Infrastructure Protection 25*, 125–138.

Scherr, A. (2016). *Soziologische Basics* (3 ed.). Wiesbaden: Springer VS.

Schwartz, S. H. (1992). Universals in the content and structure of values: Theoretical advances and empirical tests in 20 countries. *Advances in experimental social psychology 25*.

Schwartz, S. H., J. Cieciuch, M. Vecchione, R. Fischer, A. Ramos, and M. Konty (2012). Refining the Theory of Basic Individual Values. *Journal of Personality and Social Psychology 103*(4), 663–688.

Schwartz, S. H. and M. Thompson (1990). *Devided we stand: Redefining Politics, Technology and Social Choice*. Philadelphia: University of Pennsylvania Press.

Stehr, J. (1998). *Sagenhafter Alltag. Über die private Aneignung der herrschenden Moral.* Frankfurt am Main/New York: Springer VS.

van Dorsser, C., W. E. Walker, P. Taneja, and V. A. W. J. Marchau (2018). Improving the link between the futures field and policymaking. *Futures 104*, 75–84.

Wildavsky, A. (1987). Choosing preferences by constructing institutions: A cultural theory of preference formation. *American Political Science Review 81*(1), 1–21.