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# Creating Stakeholder Value through Risk Mitigation Measures in the Context of Disaster Management

**Minna Räikkönen [1,*], Riitta Molarius [1], Kari Mäki [1], Kim Forssén [1], Peter Petiet [2] and Albert Nieuwenhuijs [2]**

1 VTT Technical Research Centre of Finland Ltd., 33720 Tampere, Finland; riitta.molarius@vtt.fi (R.M.); kari.maki@vtt.fi (K.M.); kim.forssen@vtt.fi (K.F.)

2 Netherlands Organisation for Applied Scientific Research (TNO), 2597 The Hague, The Netherlands; peter.petiet@tno.nl (P.P.); albert.nieuwenhuijs@tno.nl (A.N.)

* Correspondence: minna.raikkonen@vtt.fi

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**Abstract:** The resilience of critical infrastructure (CI) to extreme weather events (EWE) is one of the most demanding challenges for all stakeholders in modern society. Although partial risk reduction is feasible through the introduction and implementation of various risk mitigation measures (RMM), decision-makers at all decision-making levels are pressured to find ways to cope with the impending extreme weather and to have a thorough understanding of the EWE impacts on CI. This paper discusses how the value of RMMs can be created and assessed in a stakeholder network. Qualitative research methods, namely literature review and AHP (Analytic Hierarchy Process), were applied as research methods. The paper examines how disaster management and value creation both converge and differ from each other. It also presents a case study on the value of various RMM and the impacts of extreme winter conditions on electricity distribution in Finland. Based on the case study, the most important value criterion was the benefits of the RMM in economic, social, and environmental terms. At a fundamental level, the value of RMM should be expressed not only in terms of money but also in regard to safety, security, societal acceptability, CI dependability, and other typically intangible criteria. Moreover, the results reveal that the interrelationship of value creation and disaster management offers new insights to both approaches.

**Keywords:** critical infrastructure; extreme weather event; risk mitigation measure; value; value creation; assessment; disaster management; stakeholder

## 1. Introduction

The resilience of critical infrastructure (CI), such as electric power supply, transportation, ICT systems, urban water supply, and wastewater treatment to extreme weather events (EWE) is one of the most demanding challenges for all stakeholders in modern society [1,2]. The increased frequency and intensity of extreme weather events can cause events including flooding, drought, winter storms, and wild fires that present a range of complex challenges to CI [3,4]. Due to the interdependencies of CI, failures are less likely today to be isolated incidents, and thus they can often cause widespread disruption because of cascading effects. It is evident that in a system of interconnected critical infrastructure, the failure of one type of infrastructure can trigger a failure of another as they become overloaded or simply unable to operate [5,6]. For example, after a certain period of lost power delivery, communication and most ICT systems are typically paralyzed. This phenomenon can also prevent the operation of banking services. Damaged railroads might halt fuel deliveries to power plants. All of the service actions in such a situation are challenging. Moreover, electricity induced problems with fresh water, as well as sewage systems, may be faced. Especially in cold regions, cooling due to electricity blackouts can lead to the evacuation of people [7].

Infrastructure malfunctioning and (cascaded) outages can have far-reaching consequences and impacts, both on economy and society [8]. The cost of developing and maintaining CI is high if they are expected to have a realistic functional, economic, and social life (50+ years) [9–11]. This highlights economic and societal relevance of the dependability and resilience of CI. Partial risk reduction can be achieved, and the resilience of the CI increased by introducing and implementing different risk mitigation measures (RMM). In this paper RMM encompass engineering techniques and hazard-resistant construction, as well as improved policies and public awareness. RMM include, for example, investments in physical assets to reduce, offset, or eliminate EWE impacts, as well as plans and actions taken to avoid, reduce the severity of, or eliminate impacts of EWE on CI. Nevertheless, extreme weather continues to occur, and can cause severe damage to physical infrastructure, lives, and livelihoods [12–14]. Therefore, decision-makers, at all decision-making levels, are pressured to find ways to cope with the impending extreme weather and to gain a thorough understanding of the impacts and risks of these events and of the vulnerability and resilience of CI.

Infrastructure connects many parties. In most cases, the infrastructure users are not all within the same legal entity. This means that the terms of use of the infrastructure need to be negotiated between parties [15]. This can become very complicated. Furthermore, as CI is a very evolutionary system, its current state is typically a result of a long series of expansions in response to the actual needs of the users. Standards like the ISO 55000 and ISO 31000 series have been developed as a form of guidance on the management of assets and related risks [16–19]. The performance evaluation is part of ISO 55000; according to it, the organization shall develop processes to provide the systematic measurement, analysis, and evaluation of its assets on a regular basis [16]. However, the split between CI owners, operators, and users has major consequences with regards to balancing risks, costs, and performance of the asset base. The different assessment management needs of the (interdependent) CIs should be taken into consideration when assessing the value of various RMM.

Several scholars argue that although value creation is widely discussed in the current literature, it is still a complex concept and needs clarification (see, for example [20–24]). One such element that could be further discussed and researched is the differences and similarities between disaster management and value creation. In the context of EWE damaging CI, decision-makers usually find themselves confronted with the situation where they have to balance the uncertainties of potential EWE impacts, investment and operating costs of RMM, the level of information, and other possible priorities, for example [20–27]. In this respect, the value creation of RMM is crucial for decision-making and for the development of strategies to prevent or to reduce the EWE impacts. At a fundamental level, the RMM should be evaluated, selected, and prioritized, not only in terms of money, but also with regard to resilience, safety, security, quality, societal acceptability, and other typically intangible criteria [20,26,28]. However, the evaluation of these intangible and indirect impacts has rarely been included in the value assessment up to now. This is mainly because these value elements are typically difficult to measure in solely economic terms. In addition, the assessments are often under pressure to demonstrate the short-term effects rather than emphasizing the RMM's entire life cycle.

From a network perspective, every decision on RMM is associated with some key stakeholders that are part of the decision process and have a major influence on the outcome [29–31]. This means that the scope of value needs to go beyond the main receivers of value from each of the RMM, and those who carry the investment and operating costs of RMM. These stakeholders, e.g., local, regional, and state authorities, European Union (EU) institutions, public organizations, private companies, and citizens, represent different levels of decision-making and constitutional power in society [20]. This implies the need for an improved understanding of stakeholder value of RMM that the enhanced situational awareness during extreme weather events, efficient and effective recovering after EWE, as well as improved resilience of CI and preparedness against future events can be achieved.

## 2. Objective, Materials and Methods

### *2.1. Objective*

This paper contributes to the value creation of risk mitigation measures. Firstly, we discuss various RMM and value creation in the disaster management context and consider how the value of the RMM can be created and assessed. Secondly, we briefly present the results of a case study dealing with the issue of EWE damaging CI. The underlying research questions of this paper are:

- How do the concepts of value creation and disaster management interrelate?
- How can the benefits of risk mitigation measures for various stakeholders be realized?

The paper is based on the research carried out in the INTACT project [1], co-funded by the European Union (EU) under the 7th Framework Programme. INTACT's primary focus was to bring together innovative and cutting edge knowledge and experience from across Europe in order to develop and demonstrate methods and tools that will enable CI operators and Critical Infrastructure Protection (CIP) policy makers to plan for infrastructure resilience, and the risks posed to CI, when taking future climate change into account. The INTACT project aimed to realize this through providing guidance on how to determine future risks due to climate change, and best practices on protective measures as well as crisis response and recovery capabilities. The INTACT Wiki [32] serves as the portal to this information.

### *2.2. Methodology*

The research questions are tackled by applying qualitative research methods: literature review and thematic group discussions in the expert session. The baseline case, that supported and guided our research, concerns the impacts of extreme winter conditions on electricity distribution in Pirkanmaa (also known as the Tampere Region) in South-West Finland. Weather extremes have become more common during recent years, and there are practical experiences of such events. The region is a rural area where electricity is still partly delivered by overhead lines located in forests. These areas are exposed to long electricity outages every winter [7]. Due to the criticality of power supply, strengthening the resilience of electricity networks to withstand, and to survive unwanted situations is extremely important.

A literature review is usually regarded as an essential step in understanding and structuring a research field [33]. Webster and Watson [34] defined an effective literature review as one that "creates a firm foundation for advancing knowledge. It facilitates theory development, closes areas where a plethora of research exists, and uncovers areas where research is needed". Thus, following the description, this study defines the literature review process: as sequential steps to collect, know, comprehend, apply, analyse, synthesize, and evaluate quality literature in order to provide a firm foundation to a topic [35]. The literature analysis was conducted to study the different aspects of value creation, to select the RMM to be applied in different phases of the disaster management, and to identify similarities and differences between value creation and disaster management that can be found in the academic publications. As we wanted the literature sample to include articles that consider value creation in the disaster management context, we defined the following keywords: value, value creation, assessment, disaster management cycle, stakeholder, critical infrastructure, extreme weather, model, tool, framework, and method. Keywords were combined into search strings that were applied to databases. A search engine that covers different databases (e.g., Scopus, Springer Nature, Emerald, IEEE, Taylor & Francis, Wiley, JSTOR) was used. The literature sample was collected in 2016 and no time limitations were set for the research. In order to find the relevant literature, the following criteria where applied [36]:

- Include only peer reviewed scientific journal articles
- Ensure relevance by selecting articles that contain at least one keyword in their title or abstract

- Exclude articles with very narrow aspects or context (e.g., suitable only for a single case)
- Read remaining abstracts and ensure their relevance to the subject
- Further, read remaining articles in their entirety to ensure relevance of content

The value assessment of RMM was carried out in the expert session. Expert sessions are widely used to overcome the lack of information by exploiting and combining the different types of expertise and knowledge on the part of the participants [37]. The participants must be carefully selected to cover all of the relevant views and fields of expertise in the system or issue examined, and there are a number of formal methods for eliciting expert judgment, which provide an aid to the formulation of appropriate questions (see e.g., ISO 31010). Public and private actors who contributed to the case study of this paper were the DSO (distribution system operator), regional rescue services, the City of Tampere, the health care district of Pirkanmaa, the Regional Centre for Economic Development, Transport and the Environment, the Finnish Red Cross, and the ICT Company that builds up the new Finnish emergency call system. The assessment was performed in the premises of VTT Technical Research Centre of Finland Ltd with 18 participants. During our research, thematic group discussions were arranged and facilitated by the researchers in order to define and assess the RMM and to test and validate the approach as well as to gather ideas for further development. The input data was mainly based on the subjective estimations of experts (expert judgement analysis). An Analytical Hierarchy Process (AHP) [38] was applied in order to make the assessment.

The AHP splits the decision process into partial problems in order to structure and simplify it. There is a hierarchy containing multiple target levels, such that the main target is broken down into sub-targets. At the lowest level of the hierarchy, the alternatives are included. Using the AHP, both qualitative and quantitative criteria can be considered. In each case, the relative importance (weightings) of the different criteria and the relative profitability of alternatives are determined with respect to each element at the higher level by using pair comparisons. Then, a total value is calculated for sub-targets to determine their relative importance in the whole hierarchy, and, ultimately, to assess the overall profitability of the alternatives [39]. Another possible and widely used method for this kind of problem is multi-attribute utility theory [40]. However, we chose AHP since it provides a flexible and easily understandable way of analysing complicated problems. AHP allows subjective as well as objective factors to be considered in the value creation process, and it can handle factors that may be conflicting [41] that cannot easily be monetarized. Additionally, AHP forms a systematic framework for group interaction and group decision-making.

## 3. Literature Review: Comparing Value Creation and Disaster Management Processes

Disaster management includes all activities, programmes, and measures that can be taken up before, during, and after EWE for the purpose of reducing its impact or recovering from its losses. In a disaster management cycle, there are several action phases as described in Figure 1.

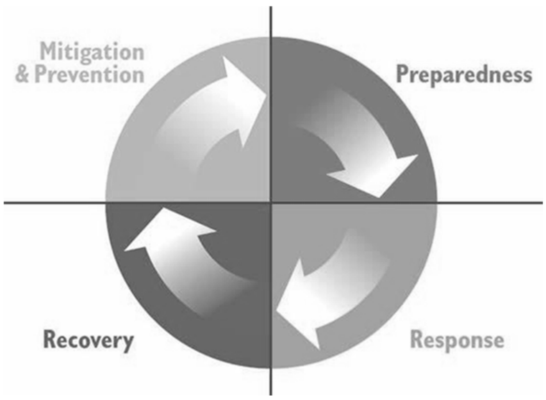


**Figure 1.** An example of the disaster management cycle [42].

In each of the phases, various measures can be taken to improve the resilience of the critical infrastructure [43–46]. In the context of natural disaster management, risk mitigation activities include structural and non-structural measures undertaken to limit the EWE impact on CI. Preparedness deals with the activities and measures taken in advance to ensure an effective response to the EWE impact, including the issuance of timely and effective early warnings and the temporary evacuation of people and property from threatened locations. Response refers to the provision of assistance or intervention during or immediately after EWEs to meet the life preservation and basic subsistence needs of people affected. Recovery involves decisions and actions taken after the EWE with a view to restoring or improving the pre-crisis living conditions of the stricken community, while encouraging and facilitating the necessary adjustments to reduce disaster risk [46].

The complex nature of value creation in the context of disaster management becomes clear when one asks where, when, how, and by whom this value is created [47]. Economic value is one of many possible ways to define and measure value. The term "profitability" is often used in this context and it indicates the achievement of positive (or high) economic returns on investments. Profitability on the basis of total cost can be defined in two ways [39]:

- Absolute profitability is achieved if the total cost of an investment (e.g., risk mitigation measure) is lower than the total cost of rejecting it.
- Relative profitability is achieved if investing (e.g., implementing a risk mitigation measure) results in a total cost that is lower than that of other options under consideration.

Porter and Kramer [48] argue that decision-makers continue to view value creation narrowly, concentrating on optimizing short-term financial returns and ignoring the most important stakeholder needs and the broader factors that are key to long-term success. Most decision-makers engage in activities that are related to societal and environmental responsibility, but very often, the societal issues are not at the core of the agenda. Lately, however, there has been increasing interest in societal value capture of investments. Social impacts and their value can be conceptualized as changes to one or more of the following aspects of society [49]:

- people's way of life
- culture
- community
- political systems
- the environment
- people's health and wellbeing
- personal and property rights
- people's fears and aspirations.

All of these aspects also play an important role when defining the value of RMM and assessing the EWE impacts on CI. Consequently, the total value of RMM should be created in such way that, in addition to economic value, they are also aimed at creating value for society by addressing its needs and challenges [48]. Moreover, it should be noted that typically the assumption considering most value studies is that the created value is positive, and thus they have focused only on the benefits and the positive value [22,23]. However, the value can be either increased or decreased. In Figure 2, the value concept adopted in this paper is presented. It considers RMM as investments and describes decision-making from the perspective of various stakeholders, and links together the diverging value provided to society, private companies, organizations, citizens, and other stakeholders.

A stakeholder network generates value through complex dynamic exchanges between companies, partners, society, citizens, and other stakeholders. Stakeholder value is created when different actors work together to co-produce value, not only from an economic perspective but with regard to sustainability, safety, security, and CI resilience, as well as social and environmental acceptability. The interdependency between societal and business results provides opportunities for improving resilience and societal impact. It is also evident that the diverse value systems of stakeholders can lead to different perceptions of benefits that may strengthen non-collaborative behaviours in the context of disaster management [50,51]. Thus, the creation and assessment of a stakeholder value is important in order to improve the resilience of CI to EWE and to support the decision-making on RMM for planning, designing, and protecting CI, and for preparing for response and recovery. In addition to the tangible value of infrastructure assets of electricity, water, services, etc., intangible stakeholder value needs to be taken into account.

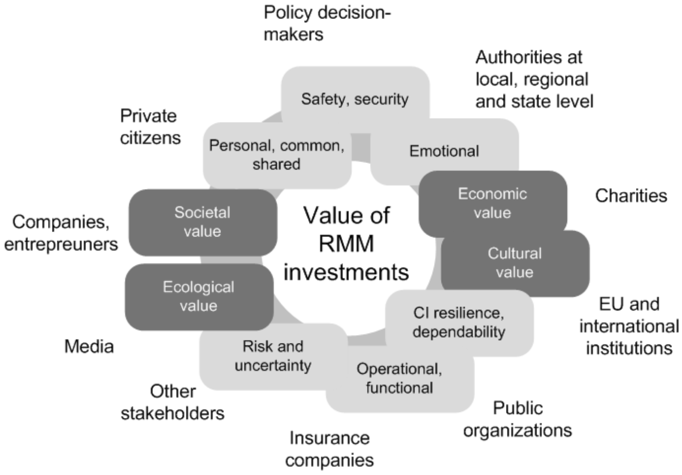


**Figure 2.** The value aspects of risk mitigation measures.

The stakeholder value of RMM during the entire life cycle of CI can be assessed in various ways. The primary purpose behind the assessment of the RMM is to determine the long-term implications of decisions. An important aspect of this is to assess the optimal level for the risk mitigation investment [20]. The assessment procedure for risk mitigation measure investments can be more or less analytical in depth, depending on the context and the actual infrastructure and the EWE. The level and type (qualitative, quantitative, or semi-quantitative) of detail in the assessment should be consistent with the level of the decision (e.g., local, national, or EU) [20]. To support cost-effective and transparent decision-making for the risk mitigation measures, different investment appraisal methods can be applied. A considerable amount of research has been done in this area and the general features of these methods are well known [39,52–54]. Additionally, a variety of methodological approaches on the economic assessment of alternative RMM exists. These are based, for example, on cost-benefit analysis (CBA), life cycle costing approaches (LCC), and MCDM (Multiple Criteria Decision Making) methods [20,38–40].

On the previous pages, the processes of value creation and disaster management were discussed. Now, we go one step further and aim to identify the similarities and differences between these processes. The key features of both of the processes we discovered are presented in Table 1.

As described in Table 1, firstly there is a difference in the aims of value creation and disaster management. Whereas, disaster management aims to prevent and avoid losses, value creation focuses on providing novel and appropriate benefits for stakeholder groups. In other words, in disaster management impacts are typically seen as negative, but value creation highlights the positive benefits. Secondly, value creation and disaster management have roots in different research disciplines. The roots of disaster management are in risk management and reliability engineering, although there is clear link to, e.g., cost-benefit analysis. On the contrary, value creation has mainly been discussed and developed in the fields of management science, service development, marketing, and management accounting. Thirdly, disaster management is typically divided into four phases, namely mitigation, preparedness, response, and recovery; as an approach disaster management applies quite specific methods and models like hazard models, vulnerability models, and loss models, methods for capacity, capability, and resource management. In contrast, specific process phases are only rarely mentioned in the context of value creation, and the methods are typically those of investment appraisal and cost accounting, and more emphasis is put on developing framework value elements, for example. As a result, practical solutions based on the theories of value creation hardly exist. However, even though the differences between value creation and disaster management are salient and obvious, there exists some similarities as well. Both approaches emphasize the viewpoint, role and co-operation of various stakeholders. Both approaches also remind decision-makers to consider not only the direct and tangible impacts, but also the indirect and intangible impacts.

**Table 1.** Features of value creation and disaster management.

| Characteristics | Disaster Management | Value Creation |
| --- | --- | --- |
| *Description* | The range of activities designed to maintain control over disaster and emergency situations and to provide a framework for helping those who are at risk to avoid or recover from the impact of the disaster [55,56]. | A process that provides more novel and appropriate benefits than target users currently possess, and that they are willing to pay for [23]. |
| *Aim* | Reducing (avoiding, if possible) the potential EWE impacts on CI, assure prompt and accurate assistance during the EWE, achieving rapid and durable recovery, business continuity, facilitating decision-making, increasing stakeholder wealth. | Focus on economic profitability, but lately also on societal and environmental value, investment decision-making (risk mitigation measures), financial situation and standing, company success. |
| *Research disciplines* | Risk management, reliability engineering, insurance, management, psychology. | Management accounting, finance, service research, marketing. |
| *Elements* | Hazards, losses, tangible and intangible impacts, resilience, vulnerability, dependability, uncertainty, probability, consequences, risk. | Cost, profit, value, benefit, sacrifices. |
| *Methods and models* | Hazard models, vulnerability models, loss models, methods for capacity, capability and resource management. | Investment appraisal, impact assessment, value propositions, service concept models. |
| *Stakeholders* | All stakeholder groups of the society. Decision-makers at all decision-making levels: local, regional and state authorities, EU institutions, public organisations, private companies and citizens. | All but focus typically on private companies ability to create value and on creating economic value to shareholders. |
| *Critique* | Focusing on negative impacts. | Challenges and ethical implications related to the valuation of intangible impacts, e.g., economic valuation of life. |

## 4. Creating Stakeholder Value through Risk Mitigation Measures

The case study considered the value of RMM and the impacts of extreme winter conditions on electricity distribution in Finland, especially in the Tampere Region. For example, winter storms in 2001, and in particular in 2010 and 2011, led to substantial damage to the electricity distribution network. The most recent example of snow-induced mass power outages in the Tampere Region happened in November 2015, when an unexpected amount of unusually wet snow fell on parts of the region, disconnecting the electricity supply from tens of thousands of inhabitants [7]. In the late evening of Thursday 19 of November 2015, a low-pressure area, and snowfall with it, moving over the Gulf of Finland reached the mainland of Finland, and on Friday night spread into the southern and central parts of the country. There, it remained almost still from Friday till Sunday. In the worst areas, the snow load of 40 cm, to a maximum 44 cm, was recorded. The fallen snow was wet, but it began to freeze on trees and electricity lines, as the air temperature was in minus degrees. Snow fell on unfrozen ground, and it loaded on trees that could not bear the load but they sank or fell down to the ground and the same happened on electricity networks. The distribution system operator (DSO) started repairs immediately. On Sunday morning, the DSO and the municipalities arranged the local crisis management meetings to analyse the situation and find out where the most serious blackouts were located. The aim was to ensure the electricity supply for critical operations. Rescue services worked full time in cooperation with the DSO. In the DSO's distribution area, snow load caused about 900 power blackout areas. Over 5000 faults were detected and located by helicopters. During the emergency situation, there were more than 60,000 customers without electricity in the whole DSO's distribution area. Generally, blackouts lasted 0.5–1.5 days, at worst, even three days. More than 750 professionals took part in the emergency work, 650 of which were forest workers and electricity technicians in the terrain. Six helicopters surveyed the destroyed area and four helicopters sawed trees and knocked the snow. 10 multi-purpose forest machines cleared the trees. More than a hundred of the electric company's own employees took part in the work during that weekend [14,32].

The stakeholder value of RMM in this case study was assessed by applying AHP and carried out in an expert session organized by the INTACT project. Altogether, 18 experts brought their domain competence to the analysis. They participated in creating the value criteria for comparing the RMM to enhance the transparency in decision-making as well as in the assessment of the RMM. The three criteria that were selected by the expert panel were:

1. Benefits of the risk mitigation measures in economic, environmental, and social terms
   The environmental dimension, the natural environment: "a cleaner environment", "environmental stewardship", "environmental concerns in business operations".
   The social dimension, the relationship between business and society: "contribute to a better society", "integrate social concerns in their business operations", "consider the full scope of their impact on communities".
   The economic dimension, socio-economic or financial aspects: "contribute to economic development", "preserving the profitability", "business operations" [57].
2. Impact of the risk mitigation measures on reliability, availability, and maintainability of electricity distribution network
   Reliability is the ability of a system to perform a required function under given conditions for a given time interval. Availability is the ability of an item to be in a state to perform a required function under given conditions at a given instant of time, or in average over a given time interval, assuming that the required external resources are provided. Maintainability is that aspect of maintenance that takes downtime of the systems into account [58].
3. Life-cycle cost (investment and operating costs) of the risk mitigation measures
   Life-cycle cost is the total cost incurred during the life-cycle of an RMM including both investment and operating cost [59].

Each expert was requested to compare the mutual importance of the above-mentioned value criteria using Saaty's [38] scale. According to the experts' opinions the most important value criterion was the benefits of the RMM in economic, social and environmental terms (weighted value 1.25; relative weight 42%). The dependability of the electricity network was ranked second (weighted value 1.1; relative weight 37%). The lowest criterion value was given to the life-cycle costs of the RMM (weighted value 0.64; relative weight 21%). After defining the criteria values, the stakeholders were divided into three groups and started to define alternative RMMs. The identified RMM were categorized according to the phases of the disaster management cycle. In this case study, the identified RMM were both investments in the electricity distribution network to reduce, offset, and eliminate adverse impacts of extreme winter weather, as well as plans and actions taken to avoid, reduce the severity of, or to eliminate an adverse impact on the electricity distribution network. RMM that were identified by the experts in the case study include heavy underground cabling of power lines, increased network automation, remote controls, and movable reserve power units. Much attention has been drawn to co-operation between utilities and authorities, and making an up-to-date situation report open for all parties [14,60]. Thus, there were both "hard" measures, such as infrastructure investments and non-structural measures, such as small-scale mitigation actions, monitoring and warning systems, and emergency response capacities (see Table 2).

**Table 2.** Examples of risk mitigation measures identified in the case study to improve the resilience of electricity distribution networks against extreme weather events (EWE) [14,20,60].

| Mitigation | Preparedness | Response | Recovery |
|---|---|---|---|
| Overhead line placement | Adjacent forest management | Situational awareness | Distributed generation |
| Underground cabling | Inspection of the network condition | Cooperation and lending arrangements | Micro grids |
| Coating of conductors | Contingency plans | | |
| Regular aerial inspections | Emergency power systems | | |
| Network structure modifications | Smart grids | | |
| | Preparedness of households | | |
| | Mutual planning and training | | |

The measure specific valuation was determined based on a fixed value system with the aim of increasing the objectivity. The scales, i.e., the values for different RMM, were modelled on a "very high (5)", "high (4)", "medium (3)", "low (2)", and "very low (1)" scale. By multiplying the criterion values and the RMM values, the profiles for RMM options were illustrated and the stakeholder value of RMM determined. Table 3 presents the results of the value assessment and the ranking "Top 8" of RMM where the RMM with the highest stakeholder value is listed in the first column. Based on the assessment, the most important RMM were mutual planning and training, underground cabling, ICT systems, and forming and disseminating situational awareness. The main parties that are involved in EWE related disaster management in Finland are authorities at distinct levels, emergency organizations, private parties, as well as non-governmental voluntary organizations [14]. To maximize the effectiveness of the disaster management, all of these stakeholders already work together before an EWE in order to develop plans for managing and employing resources in a variety of possible emergency circumstances. Even though extreme winter weather is recurrent in Finland and there are many commonly agreed courses of action, it seems that there is still a need to improve co-operation between distribution system operators, municipalities, and rescue services [60]. For example, training exercises, in which each partners in the network are involved were considered as one of the important RMM. The other highly valued RMM were technical ones, underground cabling, and ICT systems. As long as the electricity distribution network includes overhead lines, it is vulnerable to natural phenomena and extreme weather. The most effective technological solution to improve the resilience of the electricity distribution networks is underground cabling, as it replaces the most vulnerable and disruption-prone part of the networks, overhead lines. Underground cables are not affected by storms, snow loads, and lightning or other extreme weather conditions [61]. However, underground cabling as well as novel ICT system investments are typically very expensive RMM.

Situational awareness was also considered as one of the important RMM. In short, the idea of situational awareness is to understand what led to the event, what is happening at the moment and what is likely to happen next. It is a tool for quick decision-making and actions based on a good understanding of an event and reliable predictions on its evolution. Real time situational awareness allows the management to efficiently lead the situation during a disruptive event, to estimate the duration of the event, to prioritize repair works, to optimize the use of available resources, to assess the work load, to place materials orders, to estimate the fault-clearing durations by geographically different areas, and to deliver information quickly to all of the parties involved in the event. The broader the disruptive event is, the more essential a high-quality and reliable situational awareness is.

**Table 3.** Results of the assessment of the risk mitigation measures identified in the expert session.

| | **Preparedness: Mutual Planning and Training** | **Underground Cabling (Weather-Proof Network)** | **ICT Solutions (Technology, Systems)** | **Forming and Disseminating Situational Awareness (Method)** | **Up-to-Date Contingency Plans (i.e., Critical Points of Consumption Listed, Increasing of Preparedness Level etc.)** | **Adjacent Forest Management, Sufficient Vegetation Clearance Resources (Weather-Proof Network)** | **Backup Power** |
|---|---|---|---|---|---|---|---|
| Economic, environmental and social benefits of RMMs (scale 1–5) | 5 | 5 | 5 | 4 | 4 | 3 | 3 |
| Impact of the RMMs on RAMS* of electricity distribution network (scale 1–5) | 5 | 5 | 5 | 5 | 4 | 4 | 2 |
| LCC (investment and operating costs) of the RMMs (scale 1–5) | 5 | 4 | 2 | 3 | 2 | 4 | 2 |
| Total (weighted) (Benefits: 42%, RAMS: 37%, Life-cycle costs: 21%) | 15.0 | 14.4 | 13.1 | 12.5 | 11.4 | 10.7 | 10.7 |

* reliability, availability, maintainability, safety.

When assessing the RMM, it should be taken into account that the total value of each of the RMM is different for different parties involved. In order to optimize the value creation in the stakeholder network, RMM and their value should be defined and assessed from different perspectives. The positive added value to one stakeholder may result in a negative value for the other.

## 5. Conclusions

This paper sought to understand how the value of RMM for various stakeholders can be created and assessed, and how the concepts of value creation and disaster management interrelate. Our findings bring valuable insights into disaster management and value assessment, as well as into decision-making on RMM to reduce and to mitigate the risk. In this paper, we emphasized the economic and societal relevance of the dependability and resilience of CI in the light of the increased frequency and intensity of extreme weather events. Due to the interdependencies of CI, failures can often cause widespread disruption because of cascading effects and thus have far-reaching consequences on both economy and society. This indicates that in each of the phases of the disaster management cycle, stakeholders should jointly consider RMM.

This paper considered disaster management in the value context. The approaches to disaster management and value creation have typically researched separately and the link between these two approaches may be missing because disaster management focuses on losses and negative impacts, but value creation highlights the positive benefits. However, the interrelationship of value creation and disaster management offers new insights to both approaches. Thus, our study may help researchers to see disaster management in a broader context. We adopted the wider value concept and value creation perspective in the context of the assessment of RMM. We considered the RMM as investments and described decision-making from the perspective of various stakeholders, and linked together the diverging value provided to society, private companies, organizations, citizens, and other stakeholders. We also studied how the value of various RMM could be expressed, not only in terms of money, but also with regards to resilience, societal acceptability, and other typically intangible criteria.

The case study presented briefly in this paper focused on the impact of extreme winter weather on electricity distribution networks. There are several RMM available, which can improve the resilience of electricity distribution networks against extreme weather. The value assessment of RMM was performed in co-operation with stakeholders who were interested in improving the resilience of CI against extreme weather. The assessment followed mainly the AHP and comprised structuring hierarchies for RMM, pairwise comparison, and determination of the criteria value and synthesis to reach an overall value for each of the RMM. During the value assessment, we focused on determining more carefully which of the RMM creates what kind of value for whom, what kinds of resources are needed and used, and from which perspective this assessment was made. In that way, we improved stakeholder value creation during the assessment. According to the stakeholders, the most important value criterion was the benefits of the RMM in economic, social, and environmental terms. The dependability of the electricity network was ranked second. The lowest value weight was given to the life-cycle costs of the RMM. AHP also proved to be a useful tool in analysing the value of various RMM as it treats all of the parties equally and focuses on the proper interaction of various actors.

As a conclusion, there are many alternatives for improving the resilience of CI against EWE, which all generate value for different stakeholders in different ways. The stakeholder value creation and wider value perspective in the assessment of risk mitigation measures provide interesting insights for disaster management dealing with critical infrastructure and their management in the case of extreme weather events.

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**Author Contributions:** M.R. is the main contributor to this article. She studied stakeholder value in the INTACT project and arranged the AHP assessment in the Finnish case study. R.M. contributed to the INTACT research by facilitating the Finnish case study (risk assessment workshop). To this paper she contributed by describing the extreme weather event and the Finnish case study. K.M. worked as a project manager of INTACT from VTT's side and he enabled the Finnish case study. He contributed to the paper with literature review. K.F. studied the impacts of EWEs on electricity network in INTACT. For this paper he contributed to literature review. P.P. worked as a coordinator of the INTACT project, and in this position he enabled the study. He worked also as the first commentator of this paper. A.N. was responsible of the INTACT-wiki, and he was the other commentator of the paper.

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## References


1. The INTACT Project—Impact of Extreme Weather on Critical Infrastructure. Available online: http://www.intact-project.eu (accessed on 4 May 2017).
2. Heikkilä, A.-M.; Molarius, R.; Rosqvist, T.; Perrels, A. Mitigating the impacts of extreme weather originated disasters by simulating the effects of different preparation and action decisions of crisis management. In Proceedings of the Programme and Abstracts of the Second Nordic International Conference on Climate Change, Adaptation Research Meets Adaptation Decision-Making, Helsinki, Finland, 29–31 August 2012; Carter, T., Perrels, A., Hildén, M., Eds.; Finnish Environment Institute: Helsinki, Finland, 2012.
3. Birkmann, J.; Cutter, S.; Rothman, D.; Welle, T.; Garschagen, M.; van Ruijven, B.; O'Neill, B.; Prestion, B.L.; Kienberger, S. Scenarios for vulnerability: Opportunities and constraints in the context of climate change and disaster risk. *Clim. Chang.* **2015**, *133*, 53–68. [CrossRef]
4. Stephenson, D.B. Definition, diagnosis, and origin of extreme weather and climate events. In *Climate Extremes and Society*; Murnane, R., Diaz, H., Eds.; Cambridge University Press: Cambridge, UK, 2008; pp. 11–23.
5. Cutter, S.; Barnes, L.; Berry, M.; Burton, C.; Evans, E.; Tate, E. A place-based model for understanding community resilience to natural disasters. *Glob. Environ. Chang.* **2008**, *18*, 598–606. [CrossRef]
6. Gheorghe, A.V.; Masera, M.; Weijnen, M.; de Vries, L. *Critical Infrastructures at Risk*; Springer: Dordrecht, The Netherlands, 2006.
7. Räikkönen, M.; Mäki, K.; Murtonen, M.; Forssén, K.; Tagg, A.; Petiet, P.J.; Nieuwenhuijs, A.H.; McCord, M. A Holistic Approach for Assessing Impact of Extreme Weather on Critical Infrastructure. *Int. J. Saf. Secur. Eng.* **2016**, *6*, 171–180. [CrossRef]
8. Linnenluecke, M.K.; Griffiths, A.; Winn, M.I. Organizational adaptation and resilience to extreme weather events. In Proceedings of the Annual Meeting of Academy of Management, Anaheim, CA, USA, 8–13 August 2008.
9. Lindström, M.; Olsson, S. The European programme for critical infrastructure protection. In *Crisis Management in the European Union*; Springer: Berlin/Heidelberg, Germany, 2009; pp. 37–59.
10. Simonovic, S.P. From risk management to quantitative Disaster resilience—A paradigm shift. *Int. J. Saf. Secur. Eng.* **2016**, *6*, 85–95. [CrossRef]
11. Kröger, W.; Zio, E. *Vulnerable Systems*; Springer: London, UK, 2011.
12. Mäki, K.; Forssén, K.; Vidar Vangelsten, B. Factors Contributing to CI Vulnerability and Resilience, INTACT Deliverable D3.2. Project Co-Funded by the European Commission under the 7th Framework Programme; Project Report. 2015. Available online: http://www.intact-project.eu/intact/assets/File/D3_2%20-%20Factors%20Contributing%20to%20CI%20Vulnerability%20and%20Resilience.pdf (accessed on 18 October 2017).
13. Pursiainen, C.; Rød, B.C.; Baker, C.; Honfi, D.; Lange, D. Critical Infrastructure Resilience Index. In Proceedings of the European Safety and Reliability (ESREL) Conference on 2016 European Safety and Reliability, Glasgow, UK, 25–29 September 2016.
14. Molarius, R.; Räikkönen, M.; Forssén, K.; Mäki, K. Achieving enhanced resilience of electricity networks by multi-stakeholder assessment of co-operation and communication risk: A case study of adverse winter weather in Finland. *J. Extreme Events* **2016**, *3*. [CrossRef]

15. Wijnia, Y. The asset management process reference model for infrastructure. In Proceedings of the 10th World Congress on Engineering Asset Management, Tampere, Finland, 28–30 September 2015.
16. ISO 55000. *Asset Management-Overview, Principles and Terminology*; International Organization for Standardization: Geneva, Switzerland, 2014.
17. ISO 55001. *Asset Management-Management Systems-Requirements*; International Organization for Standardization: Geneva, Switzerland, 2014.
18. ISO 31000. *Risk Management-Principles and Guideline*; International Organization for Standardization: Geneva, Switzerland, 2009.
19. ISO 31010. *Risk Management: Risk Assessment Techniques*; International Organization for Standardization: Geneva, Switzerland, 2009.
20. Bowman, C.; Ambrosini, V. Firm value creation and levels of strategy. *Manag. Decis.* **2007**, *45*, 360–371. [CrossRef]
21. Saarijärvi, H.; Kannan, P.K.; Kuusela, H. Customer participation and value creation: A systematic review and research implications. *Eur. Bus. Rev.* **2013**, *25*, 6–19. [CrossRef]
22. Lanne, M.; Jähi, M.; Murtonen, M. Risk-conscious value creation. In Proceedings of the XXIV Annual RESER Conference 2014, Helsinki, Finland, 11–13 September 2014; pp. 843–852.
23. Lepak, D.P.; Smith, K.G.; Taylor, S.M. Value creation and value capture: A multilevel perspective. *Acad. Manag. Rev.* **2007**, *32*, 180–194. [CrossRef]
24. Khalifa, A.S. Customer value: A review of recent literature and an integrative configuration. *Manag. Decis.* **2004**, *42*, 645–666. [CrossRef]
25. Räikkönen, M.; Pilli-Sihvola, K.; Kunttu, S.; Yliaho, J.; Jähi, M.; Zuccaro, G.; del Cogliano, D. Assessing economic impacts of crises—A decision-support approach to long-term strategic planning. In Proceedings of the IX International Conference on Risk Analysis and Hazard Mitigation (Risk Analysis 2014), The New Forest, UK, 4–6 June 2014; pp. 229–241.
26. Guha-Sapir, D.; Santos, I. *The Economic Impacts of Natural Disasters*; OUP: Oxford, MS, USA, 2013.
27. McKenzie, E.; Prasad, B.; Kaloumaira, A. *Guidelines for Estimating the Economic Impact of Natural Disasters in the Pacific, the Australia Agency for International Development*; The Australia Agency for International Development: Canberra, Australia, 2005.
28. Middelmann, M.H. *Natural Hazards in Australia. Identifying Risk Analysis Requirements*; Geoscience Australia: Canberra, Australia, 2007. Available online: https://d28rz98at9flks.cloudfront.net/65444/65444.pdf (accessed on 17 October 2017).
29. Freeman, R.E. Managing for stakeholders: Trade-offs or value creation. *J. Bus. Eth.* **2010**, *96*, 7–9. [CrossRef]
30. Parmar, B.L.; Freeman, R.E.; Harrison, J.S.; Wicks, A.C.; Purnell, L.; de Colle, S. Stakeholder theory: The state of the art. *Acad. Manag. Ann.* **2010**, *4*, 403–445. [CrossRef]
31. Tantalo, C.; Priem, R.L. Value creation through stakeholder synergy. *Strateg. Manag. J.* **2016**, *37*, 314–329. [CrossRef]
32. The INTACT Wiki. Available online: http:www.intact-wiki.eu (accessed on 4 May 2017).
33. Easterby-Smith, L.; Thorpe, R.; Lowe, A. *Management Research. An Introduction*, 2nd ed.; SADE Publications: London, UK, 2002.
34. Webster, J.; Watson, R.T. Analyzing the past to prepare for the future: Writing a literature review. *MIS Q.* **2002**, *26*, 13–23.
35. Yair, L.; Ellis, T.J. A Systems Approach to Conduct an Effective Literature Review in Support of Information Systems Research. *Inf. Sci. J.* **2006**, *9*, 181–212.
36. Newbert, S.L. Empirical research on the resource-based view of the firm: An assessment and suggestions for future research. *Strateg. Manag. J.* **2007**, *28*, 121–146. [CrossRef]
37. ISO 31010:2009. Risk Management-Risk Assessment Techniques. Available online: http://www.iso.org/iso/catalogue_detail?csnumber=51073 (accessed on 4 May 2017).
38. Saaty, T.L. *The Analytic Hierarchy Process*; McGraw-Hill: New York, NY, USA, 1980.
39. Götze, U.; Northcott, D.; Schuster, P. *Investment Appraisal: Methods and Models*; Springer: Berlin/Heidelberg, Germany, 2008.
40. Keeney, L.; Raiffa, H. *Decisions with Multiple Objectives: Preferences and Value Trade-offs*; Cambridge University Press: Cambridge, UK, 1993.

41. Millet, I.; Wedley, W.C. Modelling Risk and Uncertainty with the Analytic Hierarchy Process. *J. Multi Criteria Decis. Anal.* **2002**, *11*, 97–107. [CrossRef]
42. Crisis Management Cycle. The Vitruv Consortium. Available online: http://securipedia.eu/mediawiki/index.php/Crisis_management_cycle (accessed on 3 October 2016).
43. Disaster Management Cycle. Available online: https://sites.google.com/site/dimersarred/disaster-management-cycle (accessed on 25 April 2017).
44. Lin Moe, T.; Pathranarakul, P. An integrated approach to natural disaster management: Public project management and its critical success factors. *Disaster Prev. Manag. Int. J.* **2006**, *15*, 396–413. [CrossRef]
45. Coetzee, C.; van Niekerk, D. Tracking the evolution of the disaster management cycle: A general system theory approach. *J. Disaster Risk Stud.* **2012**, *4*, 9. [CrossRef]
46. Lin Moe, T.; Gehbauer, F.; Senitz, S.; Mueller, M. Balanced Scorecard for Natural Disasters on Development in the Pacific. *Disaster Prev. Manag.* **2007**, *16*, 785–806. [CrossRef]
47. Voima, P.; Heinonen, K.; Strandvik, T. Exploring Customer Value Formation—A Customer Dominant Logic Perspective. In *Working Paper, 552, Workbooks of Hanken School of Economics*; Laurea publications: Helsinki, Finland, 2010.
48. Porter, M.E.; Kramer, M.R. Creating shared value. *Harv. Bus. Rev.* **2011**, *89*, 62–77.
49. Vanclay, F. International principles for social impact assessment. *Impact Assess. Proj. Apprais.* **2003**, *21*, 5–12. [CrossRef]
50. Abreu, A.; Camarinha-Matos, L.M. On the role of value systems to promote the sustainability of collaborative networks. *Int. J. Prod. Res.* **2008**, *46*, 1207–1229. [CrossRef]
51. Räikkönen, M.; Kunttu, S.; Uusitalo, T.; Takala, J.; Shakeel, S.R.; Tilabi, S.; Forss, T.; Koivunen, J. A framework for assessing the social and economic impact of sustainable investments. *Manag. Prod. Eng. Rev.* **2016**, *7*, 79–86. [CrossRef]
52. Meyer, V.; Becker, N.; Markantonis, N.; Schwarze, R.; van den Bergh, J.C.; Bouwer, L.M.; Bubeck, P.; Ciavola, P.; Genovese, E.; Green, C.; et al. Review article: Assessing the costs of natural hazards-state of the art and knowledge gaps. *Nat. Hazards Earth Syst. Sci.* **2013**, *13*, 1351–1373. [CrossRef]
53. Pike, R.; Neale, B. *Corporate Finance and Investment: Decisions and Strategies*, 4th ed.; Prentice Hall: Harlow, UK, 2003.
54. Boardman, A.E.; Greenberg, D.H.; Vining, A.R.; Weimer, D.L. *Cost–Benefit Analysis: Concepts and Practice*, 3rd ed.; Prentice Hall: Upper Saddle River, NJ, USA, 2006.
55. Rose, A. Defining and measuring economic resilience to disasters. *Disaster Prev. Manag.* **2004**, *13*, 307–314. [CrossRef]
56. United Nations Office for Disaster Risk Reduction (UNIDSR). *2009 UNIDRS Terminology on Disaster Risk Reduction*; United Nations Office for Disaster Risk Reduction: Geneva, Switzerland, 2009.
57. Dahlsrud, A. How Corporate Social Responsibility is Defined: An Analysis of 37 Definitions. *Corp. Soc. Responsib. Environ. Manag.* **2008**, *15*, 1–13. [CrossRef]
58. Tiusanen, R.; Jännes, J.; Liyanage, J.P. Evaluation of RAMS + I factors affecting different offshore wind turbine concepts. *Int. J. Offshore Polar Eng.* **2013**, *23*, 137–142.
59. IEC60300-3-3. *Dependability Management—Part 3–3: Application Guide—Life Cycle Costing*, 3rd ed.; IEC Commission Electrotechnique Internationale: Geneva, Switzerland, 2017.
60. Molarius, R.; Tuomaala, P.; Piira, K.; Räikkönen, M.; Aubrecht, C.; Polese, M.; Zuccaro, G.; Pilli-Sihvola, K.; Rannat, K. A Framework for Comprehensive Impact Assessment in the Case of an Extreme Winter Scenario, Considering Integrative Aspects of Systemic Vulnerability and Resilience. *Comput. Model. Eng. Sci.* **2015**, *109*, 131–158.
61. Forssén, K. Resilience of Finnish Electricity Distribution Networks against Extreme Weather Conditions. Master's Thesis, Aalto University, Espoo, Finland, 2016.