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Reducing risks to electric power infrastructure due to extreme weather events by means of spatial planning: Case studies from Slovenia

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ABSTRACT

The paper concerns the potential for spatial planning to improve the reliability of electric power infrastructure. The aim is to reduce risks of electric power outages due to extreme weather events (EWE) by proper siting of installations. A method of evaluating risks due to EWE is applied in two case studies. The first considers ice storms and the damage they cause to power grids; the second considers the damage of heavy rainstorms to hydroelectric power plants (HPPs). The results are presented in the form of a risk assessment method that can be incorporated into spatial planning.

1. Introduction

In general, two approaches are available for avoiding and/or reducing major damage to the electric power infrastructure due to gradual climate change (CC) and extreme weather events (EWE). The first involves technical improvement of the mechanical components, making them more robust and resistant to physical stress, and the second involves consideration and implementation of the physical location of the infrastructure to where its vulnerability to CC and EWE is lower (Auld et al., 2006; Giordano, 2012; IAEA, 2013). Sudmeier-Rieux et al. (2015) emphasize the cost-effectiveness of risk-sensitive planning of land use relative to that of structural measures for risk reduction. The purpose of the research is to develop and test the feasibility of integration of risk assessment results into spatial planning in order to reduce damage to energy infrastructure caused by EWE.

Risks due to natural or anthropogenic extreme events have been the subject of research for several decades. Many of these studies were carried out with the support of international organizations, such as NATO (Briggs et al., 2002), the European Union,[1] the United Nations Office for Disaster Risk Reduction (UNISDR), and the International Atomic Energy Agency.[2] The body of scientific literature about risk assessment is extensive as well and considers risks due to different extreme events, for example erosion (Alder et al., 2015), floods (Camarasa-Belmonte and Soriano-García, 2012; Zhou et al., 2012; Canters et al., 2014; Prawiranegara, 2014; Foudi et al., 2015), forest fires (Thompson et al., 2015), ice storms (Bonelli et al., 2011; Dalle and Admirat, 2011; Grünevald et al., 2012; Lamraoui et al., 2013; Nygaard et al., 2014), and more. These studies place great emphasis on the development of methods for reducing or mitigating the consequences of different types of extreme events. Gall et al. (2015) studied interdisciplinary research on risks conducted over the prior fifteen years that connected different scientific fields, methods, and stakeholders, identifying a large gap between research and practice. Even

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[1] These include Accidental risk assessment methodology for industries or ARAMIS, 2002–2005; Sharing experience on risk management (health, safety and environment) to design future industrial systems known as SHAPE-RISK, 2004–2007; Applied multi risk mapping of natural hazards for impact assessment or ARMONIA, 2004–2007; Early recognition, monitoring and integrated management of emerging, new technology related risks known as iNTeg-Risk, 2008–2013; Technology opportunities and strategies towards climate-friendly transport known as TOSCA, 2010–2013; Coordination of European research on industrial safety towards smart and sustainable growth known as SAFERA, 2012–2015.

[2] CRP Techno–economic evaluation of options for adapting nuclear and other energy infrastructure to long-term climate change and extreme weather, 2012–2015.

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though most of these studies stress that risk assessment methods may be used for decision support and included in spatial planning (e.g., Camarasa-Belmonte and Soriano-García, 2012; Alder et al., 2015; Foudi et al., 2015; Thompson et al., 2015), this integration was not further explored. Most of the studies on integrating risk assessment into spatial planning (Schmidt-Thomé, 2006; ARMONIA, 2007; Sutanta et al., 2010; Storch and Downes, 2013; Prawiranegara, 2014) have concentrated on developing a decision-support system based on maps of integrated hazards or risks, and not specifically on the use of risk assessment results for locating new facilities. We focus on this particular issue with the aim of filling this gap. Berry and BenDor (2015) included projections of sea level rise and inundated areas due to storm surges into spatial suitability analysis but this mostly translates into siting activities away from coastal and lower lying areas; their study takes into account neither probability of occurrence of storms nor their consequences in an explicit way. Greiving et al. (2006) assert that risk assessments carried out by professionals from different fields are not used in spatial planning because information about risks must be transferred into the language of spatial planning in order for it to be useful. This problem was addressed by Kontić and Kontić (2008) in a case study of risks due to industrial accidents; the approach that is presented and applied here builds on and further develops their method by focusing on risks due to extreme natural events. The approach is illustrated by two case studies. In the first we consider risks to power grids due to ice storms with the ultimate goal of identifying a better corridor for transmission lines in the S–W Slovenia. In the second, we consider risks to hydroelectric power plants (HPPs) on the Sava River due to heavy rain storms with the aim of optimizing future HPPs location. An important component of the second case study is the evaluation of the HPP vulnerability to potential erosion in the Sava River watershed, which is then used for comparative assessment of different watershed areas for the ultimate purpose of informing future HPP siting.

In essence, spatial planning can be used to increase the reliability of energy supply under variable climatic circumstances by preventing or reducing structural damage to energy infrastructures caused by EWE in the future. A spatial planning approach to EWE risks will thus benefit the energy sector, energy consumers, the economy, and society as a whole.

2. Material and methods

Risk analysis is comprised of four steps:

1. Determination of the geographic scope and intensity level of an extreme weather event based on data from past occurrences.
2. Analysis of the vulnerability of a system (the electric energy infrastructure and the environment in which the infrastructure is situated) to a specific EWE.
3. Assessment of the probability and frequency of occurrence of an extreme weather event at a particular site or region where specific energy infrastructure is, or is going to be, located.
4. Integration of the above three steps with the aim of determining physical and other (e.g., economic, communication, health) consequences that will lead to the specification of a risk index pertaining to the particular area and infrastructure. In this step, the risk index is determined based on the integration of the first three steps.

Further explanation of the steps:

Step 1: The scope and intensity level of an EWE provide an indication of the magnitude and spatial distribution of its consequences. The intensity level of each EWE (e.g. mass, force, temperature, burden due to glaze ice, strong wind, heavy snow, heavy rainstorm, etc.) can be represented on GIS-based maps on which each cell is evaluated on a scale from 1 (low) to 4 (high) physical burden expected on the electric energy infrastructure. The size of the cell depends on the size of the analysed area and the detail of the analysis. For our analysis of the entire Slovenian territory, the 100 m × 100 m cell has been applied. The data were obtained from the archives about past EWE (Slovenian Environment Agency, 2014a,c).

Step 2: A particular EWE can cause direct (primary) damage to energy infrastructure as well as secondary structural damage due to environmental damage (for example falling trees or erosion). Thus, the total vulnerability of an energy infrastructure should be evaluated. Vulnerability of infrastructures in terms of primary damage can be specified and evaluated by using construction and other engineering and service quality standards, while vulnerability due to secondary damage is more complex and affected by various factors. In our first case study, damage to forests was used as a determinant of total environmental vulnerability, while in the second case susceptibility to erosion in watersheds was used for this purpose. The reasoning for the first case was that falling trees may directly damage transmission lines and related infrastructure; in the second case potential for secondary damage to HPPs was assigned to suspended material and floating trees and debris. Total vulnerability is then expressed as the ratio of the expected level of damage or loss of the infrastructure to the maximum possible damage or loss, i.e. between 0 and 100%, and expressed on a scale 1 to 4. The results are represented on GIS based maps for different EWEs at specific locations. We note that in practical applications of the approach, vulnerability can be addressed in different ways depending on the type of EWE, analysed infrastructure, and availability of data (see the discussion section).

Step 3: The probability or frequency of occurrence of an extreme weather event is calculated on the basis of historical data and/or application of meteorological and other models. The results are presented on GIS maps in combination with the vulnerability of infrastructure and possible damage of an EWE, thus providing a joint information on how often a certain damage may occur in a specific geographical area (see Step 4). Regarding expected increased frequency of events due to climate change in the future a regular update of historical data is needed. Also, a combination of historical data with an updated assessment of probabilities of occurence of EWE based on models can be used as to adequately capture future climate change.

Step 4: The risk index combines the intensity level of an EWE and the vulnerability of a particular electric energy infrastructure/system, taking into account the frequency or probability of occurrence of an EWE on the one hand, and the resulting consequences, impacts, and damage on the other. Basically, the index expresses the degree of damage to an electric energy infrastructure resulting from an EWE. Damage can be further specified in terms of the impacts for society, for example, the cost of outages of electricity supply to economy in general or to specific important sector, or disturbance of different services, such as hospitals. Risk indices are similar to ordinary risk matrices (Calow, 1998; Debray and Salvi, 2005; Salvi, 2005), which combine the frequency or probability of an incident (event), and the severity of its consequences.

The steps are presented schematically in Fig. 1.

3. Case study 1: application of risk assessment results due to ice storms in the planning process of transmission lines in Slovenia

Assessment of risk to electric power lines due to ice storms has been carried out using data on the occurrence of ice stroms between 1961 and 2014 collected by the Slovenian Environment Agency (ARSO) and reports about physical damage in forests and on the electric infrastructure caused by glaze ice (Šifrer, 1977; Radinja,