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Critical infrastructure vulnerability: a research note on adaptation to climate change in the Nordic countries

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ABSTRACT
This research note reviews recent literature on the vulnerability of critical infrastructures caused by climate change with a focus on the Nordic countries. We integrate literature from three research areas: the role of critical infrastructures in the functioning of society, infrastructural vulnerabilities, and the long-term impacts of climate change. Focusing on climate change adaptation in the Nordic countries as a pivotal case, we discuss the mutually constitutive interrelationships between these three areas. The studies reviewed bring together social science and humanities research on infrastructure systems, their vulnerabilities, and climate change. By highlighting interdisciplinary perspectives on infrastructures, climate change, and societal security, this research note discusses a Nordic model of infrastructure provision and links the Nordic debate to a burgeoning European discussion on the role of the social sciences and humanities in addressing societal challenges related to climate change and the role of infrastructures in providing welfare.

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Vulnerability; adaptation; climate change; infrastructure; local communities

Introduction

In this research note, we review recent literature on the vulnerability of critical infrastructures caused by climate change. We integrate international literature from three research areas: the role of critical infrastructures in the functioning of society, infrastructural vulnerabilities, and the long-term impacts of climate change. Whilst research in these fields has generated important new understandings in their respective domains, we highlight the manifold interconnections and mutually constitutive relationships between them and show that there is a need for such research to integrate insights from these three areas. Our research note uses climate change adaptation in the Nordic countries as a pivotal case to examine these interrelationships and pursue new understandings of them.

Our text contributes to the development of geographical perspectives, such as territories, climate change adaptation, local knowledge, resilience, and the transformation of cities. In fact, Nordic geographical scholarship has actively highlighted these kinds of questions to make sense of the issues that Nordic countries face and has linked them to the long-term impacts of climate change (e.g., Cutter, 2019; Jacobsen et al., 2016; Juhola et al., 2012; Nielsen, 2015; Opach et al., 2020; Van der Leeuw, 2012; Winther, 2015). Recently an entire special issue of *Norsk Geografisk Tidsskrift–Norwegian Journal of Geography* was devoted to climate change and natural hazards and the geography of community resilience (Setten & Lujala, 2020). The relationships between socio-technical systems, infrastructures, and climate change adaptation constitute a large literature both within geography and beyond it. The research note produces a proclamation of a research programme that takes this scholarship into new directions in the following ways:

- *The Nordic model*. All Nordic countries – Denmark, Finland, Iceland, Norway, Sweden, the Faroe Islands, Greenland, and Åland – favour similar social democratic welfare regimes (Esping-Andersen, 1990). These are tax-funded regimes based on universalism and constitute the relationship between the state, the citizen, and the market in a particular way. Equal opportunities, equitable distribution of wealth, and public responsibility for citizens are known manifestations of the Nordic model. In our research programme, we propose that the Nordic model is also at play and enacted through critical infrastructures: in the Nordic countries, the responsibility for building and maintaining infrastructures has been understood first and foremost as a public and collective matter.

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- *Geographical and market policy differences*. While Nordic countries are connected in terms of critical infrastructures, the general similarities between the countries can be further elaborated on several dimensions. These include, first, geographical differences, both between and inside the countries, and the ensuing variation in tackling environmental and climate issues. Second, they include potential disparities between policies, especially in terms of marketization of critical infrastructure and European Union directives and regulations.
- *Inverting infrastructural vulnerabilities and climate change adaptation*. Our methodological approach to addressing these two issues comes from Science and Technology Studies (STS) and infrastructure studies scholarship. The research program proposed here is committed to examining those technologies and arrangements, maintenance, standards, and political and ethical consequences that are normally hidden from everyday life in terms of critical infrastructures. This premise extends to how we address vulnerabilities, adaptation, and related concepts such as resilience and risk. We aim for a conceptually informed, empirically rigorous examination of what makes infrastructures vulnerable and able to adapt to climate change in different enacted contexts.

We draw from and complement the international academic debate on infrastructures, vulnerabilities, and climate change to rise to these research challenges. This research note is structured as follows. We begin by outlining the three bodies of literature noted above and outline their core messages. We then expand and elaborate on that research, using the Nordic countries as an exemplar. We draw on the notion of infrastructural scale and how scaling work appears in the scholarly literature on infrastructure, vulnerabilities, and climate change; this section argues that one specific scale – that of localities and municipalities – demands further attention in infrastructure scholarship. Our note relates these considerations to specific examples in the literature involving Nordic countries. The research note concludes with a way forward that links our initial findings from the literature to a putative Nordic model of critical infrastructure provision and to issues around the distribution of risk and inequalities that arise in this model.

Critical infrastructure, vulnerabilities, and climate change

Critical infrastructure

The first body of literature on which we draw emphasizes infrastructures as vital systems that enable the functioning of cities, regions, countries, and entire continents. Infrastructure ensures political decision making on many scales and in different contexts, such as products and services, security, health, and the movement of people (Collier & Lakoff, 2015; Edwards, 2003; Silvast, 2017; Star, 1999).[1] Infrastructures are not merely closed supply chains or systems that support collective life. Rather, they are at the centre of collective life and sociality (Anand et al., 2018; Graham & Marvin, 2001) and produced as public goods for the public interest (Collier et al., 2016a). Thus, they can be characterized as "dense social, material, aesthetic, and political formations" (Anand et al., 2018, p. 3) and as inseparable from sociality, everyday life, and future expectations. Infrastructures have been defined as "critical locations through which sociality, governance and politics, accumulation and dispossession, and institutions and aspirations are formed, reformed, and performed" (Anand et al., 2018, p. 3).

Infrastructure studies constitute an interdisciplinary field that examines all "big, durable, well-functioning systems and services" (Edwards et al., 2009, p. 365). Especially in the EU – and there are key differences from Nordic designations, as we show below (Pursiainen, 2018) – these infrastructures become "critical" once they are "essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people, and the disruption or destruction of which would have a significant impact in a Member State as a result of the failure to maintain those functions" (European Council, 2008, Article 2(a)). Internationally, the catalogues of critical infrastructures are typically heterogeneous: electricity and energy provision, heating systems, water supply, drainage and sewerage systems, transportation and logistics, telecommunications and information technologies and systems, banking and finance, national and municipal governments, emergency and rescue services, health services, and so on (Brunner & Suter, 2008, pp. 530–531).

While these catalogues bring together networked systems and industrial sectors, an important contribution from infrastructure studies is that all such large systems are both social and technical; hence, the common term *socio-technical systems* (Silvast et al., 2013). This argument runs against efforts to pull apart the social and technical kinds of components or whole systems (cf., Glaas et al., 2010). For instance, Van der Leeuw (2012) argues in the *Geografisk Tidsskrift–Danish Journal of Geography* that technical, environmental, and social systems develop in inherently different manners and should thus be studied using different approaches:

> Technical systems do not follow the logic of the societal systems in which they are embedded, nor do they follow the logic of the environmental systems with which they interact. In fact, they have their own logic that needs to be investigated by appropriate means. (p. 126)

However, from the perspective of infrastructure studies, purely technical systems and the societal systems that embed them are rarely easy to separate. STS scholar and historian Thomas P. Hughes (1986) contributed to this issue when he described large systems such as electricity networks as "seamless webs," systems whose engineers and managers themselves routinely cross the boundaries between the technical and the social components of these systems. Thus, all infrastructures are already enmeshed with sociality. This interdependency becomes even more pronounced when we examine below the vulnerabilities of critical infrastructures.

Vulnerability of interdependent critical infrastructures

As defined above, infrastructures are large-scale systems that are inseparable from the functioning of society. At the same time, all infrastructures are potentially vulnerable systems. The concept of "vulnerability" spans several academic fields, including economics, climate change research, disaster studies, development studies, and anthropology (Bijker et al., 2014, p. 5). For example, from the viewpoint of critical infrastructure protection, vulnerability means that some characteristics of critical infrastructures – whether in their operation, design, or implementation – make them prone to incapacitation (Dunn, 2006; Silvast, 2019). Any piece of infrastructure is generally vulnerable when it does not have adequate capacities to plan for, prevent, respond to, and recover from threats. A vulnerability assessment means comparing potential future threats to existing capacities and desired protection levels (Pursiainen, 2018). Furthermore, the bigger an infrastructural system is and the more interconnected is to other infrastructures (such as global information and communication technologies), the more difficult it may be to recognize its vulnerabilities. The Princeton sociologist Miguel A. Centeno and colleagues sum up this problematic in their research programme for global systemic risk: "tightly coupled and interdependent infrastructure networks may be vulnerable in a way that cannot be predicted on the basis of the properties of the constituent networks themselves" (Centeno et al., 2015, p. 75).

However, these viewpoints centred on network properties may not be recognized by all social science scholars. STS scholars Bijker et al. (2014, p. 21) have developed a constructivist perspective on vulnerabilities in technological systems. They emphasize that vulnerabilities are not intrinsic to systems but emerge in particular ways in localized contexts: geographical, historical, political, and so on (e.g., Setten & Lujala, 2020).

The interdependencies between critical infrastructures, vulnerabilities, and the functioning of society have been demonstrated during disasters and social crises, recently during the COVID-19 pandemic. To draw from infrastructure studies concepts (Bowker & Star, 1999), infrastructure is "inverted" during exceptional crises: these events expose those infrastructure technologies and arrangements, maintenance practices, physical networks, standards, and political and ethical consequences that are normally hidden from everyday life (Silvast & Virtanen, 2019; cf. Larkin, 2013). With COVID-19, while the population at large has been asked to engage in social distancing, professionals working in infrastructures vital for society, such as power supply, financial services, and health care, have remained at work in order to maintain these crucial functions and sustain the welfare of the population. Early reports on the impacts of COVID-19 in the energy sector have pointed to falling energy demand and prices (particularly for oil and partly electricity) and a clear step up in the role of national governments especially in public health but with potential implications for energy policy (Kuzemko et al., 2020). Meanwhile, the crisis seems to have disrupted sustainable energy provision, especially by interrupting international supply chains that the clean energy sector needs in order to function (Sovacool et al., 2020). These kinds of manifold supply chains, normally backgrounded systems, and political arrangements have been now made more visible also in the everyday life.

The interdependencies and dependencies between various critical infrastructures require more scrutiny. The empirical findings by Luiijf et al. (2008) showed that an overwhelming amount of infrastructural dependence exists on ubiquitous energy and the telecommunications infrastructures, hence suggesting one-way dependence between critical infrastructures, not interdependence per se. Also, Rinaldi et al. (2001) highlighted nearly two decades ago that interdependencies between critical infrastructures are diverse in themselves. The main kinds of interdependency that they conceptualized included physical interdependency (the output of one infrastructure depends on another infrastructure, e.g., railroads depend on constantly available electricity distribution); cyber interdependency (infrastructures using computerized control systems, such as SCADA); geographical interdependency (when infrastructures are proximate geographically, the effects of risks such as flooding could spread among them); and logical interdependency (a more conceptual connection, such as current electric power infrastructures depending on the financial infrastructures of energy markets). These classifications provide an interesting window into the diverse socio-material interdependencies of infrastructures and the vulnerabilities that are enacted, thus contributing to the research interest of this note.

Climate change

The critical role of infrastructures and their vulnerability has been highlighted in research on different kinds of disaster and crisis situations, including the impacts of Hurricane Katrina in 2005 (Lakoff, 2006) and Hurricane Sandy in 2012 (Collier et al., 2016b). Most infrastructures, due to long life cycles that extend decades into the future, will be more and more likely to experience vulnerabilities due to climate change, which is expected to increase the magnitude and frequency of extreme events such as heatwaves, forest fires, floods, violent storms, and strong winds. Risk management for uncertain events caused by climate change and strengthening the resilience of infrastructure systems are high priorities for technical experts and scholars (Balston et al., 2017; Räikkönen et al., 2017) and of interest to governments and the EU (e.g., US Department of Homeland Security, 2012; Karagiannis et al., 2019) and the Intergovernmental Panel on Climate Change (IPCC, 2018). The IPCC (2018) has anticipated the infrastructural impacts of extreme weather events to be manifold. Indeed, most relevant infrastructures will be affected by climate change. Hot and cold weather affect transportation infrastructure, including roads and railroads. Floods have demonstrated impacts on water and power provision, communications, transportation, and health care systems. Higher temperatures, including heatwaves, also have several adverse impacts on health care, including overheating buildings, imperilling safe drug storage, and disrupting transportation.

The banking and finance sectors are exposed to multiple risks of harm from weather-related catastrophes.[2] At the same time, however, these industries have boasted strong actors who have prepared for the effects of climate change through advanced modelling, reinsurance, new financial instruments such as index bonds, and other initiatives. As a result, climate change is not only a risk but also an opportunity for banking and finance. Being able to calculate and commodify uncertainties implies that risks are, at least to some extent, manageable – the view that reinsurance companies in particular sell to the customers. Consequently, the climate change threat also presents a business opportunity for those actors who provide the services that ensure the future economic value of other infrastructure elements (Christophers et al., 2020; Collier et al., 2021; Jarzabkowski et al., 2015; Johnson, 2013, 2014; Lehtonen, 2017).

A note on infrastructural scale

The protection of critical infrastructures has most prominently operated at one scale: the nation-state (Silvast, 2019; Sims, 2011). This implicitly national-level focus tends to overlook other scales where activities to mitigating and adapting to climate change are increasing rapidly. Municipalities and local authorities are one such particularly important site (Tøsse, 2012). Municipal organizations lie at the crossroads, connecting global and national issues, policies, and local activities and particularities. Their relevance for infrastructure research can be highlighted both methodologically – as research sites that can reveal valuable interconnections – and ontologically, because they are important actors in a wide variety of sectors, and many kinds of infrastructures are actually rooted in municipalities, both concretely and in terms of administration and liability. The kinds of problem solving, risk and vulnerability analyses, planning practices, policies, and general approaches to doing things in municipalities could be shifted to respond to the long-term impacts of climate change (Glaas et al., 2010; Gundersen et al., 2016; Räsänen et al., 2020), and concrete climate change measures in municipalities can demonstrate how to create much needed synergies and complementarities between climate change adaptation and mitigation (Kongsager, 2015, 2018).

Municipalities, especially in remote areas, are also particularly important and often overlooked settings for critical infrastructures. Whereas the means with which modern cities and affluent regions are sustained has commanded attention in social science literature (Graham, 2009; Graham & Marvin, 2001) – as in recent examinations of infrastructure arrangements in "smart cities" (Hommels, 2020; Miller, 2019; Parks, 2019) – some of the most critical infrastructures are situated in remote areas. Examples in the Nordic countries are electric power production, international roads, drainage systems, railroads, and digital communications. Critical infrastructures also have universal coverage across remote areas and, as many infrastructures are located in these areas, disruptions to them ranging from wildfires to floods and landslides can affect infrastructures throughout the Nordic countries, whether in urban or remote areas.

Infrastructures and vulnerabilities caused by climate change in the Nordic countries

To date, critical infrastructures and their protection have been most systematically addressed by national security experts, government officials, risk managers, engineering scholars, and to some extent economists, especially when it comes to infrastructure investment, maintenance, and development (Gramlich, 1994). The novelty of this research note is in bringing together social science and humanities research on infrastructure systems and their vulnerabilities in the Nordic countries, which are an especially suitable case for this development because of the underpinning of their critical infrastructure concept. As Pursiainen argues, the Nordic countries have a more holistic conception of critical infrastructure than the EU; it emerged from the Cold War civil defence systems and focused "on vital societal functions rather than mere sector-based infrastructures" (Pursiainen, 2018, p. 640). These vital functions are those that cover society's basic needs and include not only socio-technical infrastructures, but also other abstract collective aims such as a functioning economy, national sovereignty, and income security for the population (Silvast, 2017). This comprehensive focus makes the ability of disciplines in the social science and humanities to contribute readily apparent.

In some ways, infrastructure challenges in the Nordic countries are obvious, given their long distances, challenging climate, and dispersed populations. All Nordic countries are affluent in a global context, and their capacity for adapting to climate change is generally seen as high (Juhola et al., 2012). Yet, there are also key differences both between the Nordic countries and within each of them. The differences among municipalities and regions within individual Nordic countries are particularly visible and at times more significant than those between the countries (Juhola et al., 2012; Opach et al., 2020). Vulnerability can have no single designation that applies across all Nordic countries, as two Nordic geographers have noted: "the existence of community networks and relationships, good governance and leadership, local knowledge, communication, material resources, and economic investment, [and] preparedness" (Setten & Lujala, 2020, p. 133) are among the contextually specific traits that contribute to the resilience of Nordic communities and reduce their vulnerabilities to "natural" hazards.[3] This situation reinforces our interest in infrastructure scales and the importance of localities and municipalities as the unit of analysis.

To our knowledge, information on critical infrastructure vulnerabilities caused by climate change has never been aggregated in the Nordic region, although several recent examples have been documented in individual countries. In Norway and Sweden, nationally critical hydroelectric power stations and international transportation infrastructures are situated in small municipalities in remote, mountainous regions. These kinds of regions are especially vulnerable to the impacts of extreme weather like landslides and flooding (Gundersen et al., 2016). Climate change is expected to raise flood risks on railways; in one study, Norway was recognized as among the highest-risk European countries because of the length of its rail networks (Bubeck et al., 2019). Geographical scholarship exploring remote communities in Norway has also characterized the road system, when it is cut off by weather conditions, as a lifeline infrastructure made up of "networks upon which health, safety, comfort, and social and economic activities depend" (Jacobsen et al., 2016, p. 292).

In Denmark, water-related agriculture sectors, freshwater ecology, water infrastructures in rural areas, and urban water infrastructure manifest key uncertainties in terms of climate change adaptation (Refsgaard et al., 2013). Denmark's remote islands, which are affected by flooding and storm surges, also host many commuters and tourists. Similar issues have been documented on the Swedish island of Gotland, where sea level rise has significant consequences for touristic and natural value, such as camping areas, shore meadows, sea stack areas, and endangered species' habitats (Ebert et al., 2016). Similarly, high precipitation and melting snow in Iceland trigger frequent floods, which have been measured as a high risk to the transport, agricultural, and housing infrastructures in a national risk assessment published by Iceland's Department of Civil Protection and Emergency Management (Johannesdottir, 2011).

The 2018 heatwave in the Nordic countries affected hydroelectric production through changing water levels in Norway, damaged agricultural infrastructures in Finland and Sweden, and triggered wildfires in Sweden that affected the functioning of several infrastructures simultaneously (Cutter, 2019). The wildfires affected areas with low population density, yet forest fires tend to have significant effects on telecommunication and electricity distribution networks, transportation routes, and water networks. Forest fires can also have a knock-on effect on the insurance system that other critical infrastructures require in order to function. It is expected that with ongoing climate change and as extreme weather events become more usual, the frequency of wildfires will also increase and raise the costs of commercial forestry (Sveriges Radio, 2019).

In all Nordic countries, remote areas have historically suffered from a high frequency of lengthy electrical power failures because of the vulnerability of overhead power lines to weather events, especially windstorms, which has created an active political debate over protecting these infrastructures (Heidenstrøm & Throne-Holst, 2020; Räikkönen et al., 2017; Rinkinen, 2013; Silvast, 2017). Examining extreme winter events and electricity distribution in Finland, one study concluded that relevant risk mitigation should not only be valued in monetary terms and investment analyses (cf. Karagiannis et al., 2019), but also in more qualitative valuations concerning the importance of safety, security, and the recognition of infrastructure interdependencies (Räikkönen et al., 2017).

These values and valuations are readily recognizable in the Nordic welfare model. The region's infrastructure systems were built upon the principles of the welfare state, including expansion by social and political rationale, equal opportunity, redistribution of wealth, and sometimes direct state support or ownership (e.g., Kaijser, 1994; Myllyntaus, 1991; Thue, 2013) partly to establish the provision of infrastructure even to remote areas. As a result, each citizen in these countries, no matter where they live, has the right to access to critical infrastructure, and this remains true even during the extreme events expected to result from climate change.

However, universal infrastructures have also been in transformation for decades (Graham & Marvin, 2001). Norway, Sweden, and Finland have pioneered opening infrastructure like electricity to competition (Silvast, 2017). This change is reinforced by EU policies, as with the creation of a single market for electricity and gas (European Commission, 2019a; European Parliament and European Council, 2019), that seek to make the provision of critical infrastructures more market-based, customer-oriented, and efficient. This creates a key potential tension in which future research will be vital. Specifically, a holistic understanding of how the Nordic welfare model can be practically aligned with dominant market models and international competition in infrastructure provision remains lacking.

The road ahead

When it comes to improving resilience in remote areas, future scholarship can obtain significant insights by making comparisons across regions and the different hazard types related to climate change. Whether the threat comes from the increased risk of flood, wildfire, or storms – or a combination thereof – the effects of climate change will have an increased impact on critical infrastructures. Furthermore, climate change creates conflicts between different interests, such as national and municipal policies or the interest of residents and businesses. Here, we expect lessons to be learned from across all the Nordic countries. Room needs to be made for cooperation and comparisons across academic fields and borders; this would add value to the Nordic countries for both the research community and stakeholders working practically on securing critical infrastructure in remote areas in the fact of the climate changes now anticipated. To communicate the main trends found out, we have summarized the literature findings in Tables 1 and 2. Table 1 contains the conceptual contributions in the three international literatures outlined: infrastructures, vulnerabilities, and climate change. Table 2 is an indicative list of the types of hazards Nordic countries have faced and the main critical

Table 1. Key themes in critical infrastructure, vulnerability, and climate change research.

Themes	Disciplines and fields	Key contributions	References
Infrastructure and critical infrastructure	Anthropology, infrastructure studies, Science and Technology Studies (STS), security research, urban geography	*Collective life*: infrastructures are inseparable from collective life and its maintenance. *Socio-technical systems*: "social" and "technical" systems or their components are rarely easy to separate.	Anand et al. (2018); Collier & Lakoff (2015); Edwards et al. (2009); Graham & Marvin (2001)Silvast (2017); Star (1999)
Critical infrastructure vulnerability	Anthropology, economics, climate change research, disaster studies, development studies, STS	*Constructivism*: vulnerabilities are not intrinsic to technological systems, but emerge in geographical, historical, and political contexts.	Bijker et al. (2014); Centeno et al. (2015); Dunn, (2006); Pursiainen (2018); Silvast (2019)
Vulnerability caused by climate change	Anthropology, climate change research, economic geography, human geography, security policy, systems engineering	*Long-life cycles*: most infrastructures will exist decades into the future and are more and more likely to experience vulnerabilities caused by climate change. *Risk/opportunity*: climate change provides both a risk and an opportunity for the insurance of infrastructures.	S. Collier et al. (2021); IPCC (2018); Johnson (2014); Karagiannis et al. (2019); Lakoff (2006)

infrastructures impacted in each case, according to the Nordic literature reviewed. Both tables contain references to key publications which represent these themes and provide resources for further research.

Given the lack of scholarly engagement with the different challenges located across the Nordic countries, we want to highlight not only the differences between the challenges that regions face but also their commonalities. The outcome of this exercise will give stakeholders in remote communities' insights into where they can learn from and how they can draw on each other's solutions. Our research note thus contributes with knowledge and tools directly targeting people working towards climate change adaptation and ensuring the resilience of critical infrastructure in remote areas in the Nordic countries.

The research note's findings from the Nordic countries are aligned with a new and an increasingly prominent European discussion on strengthening the role of the social sciences and humanities in addressing societal challenges and industrial leadership priorities (European Commission, 2019b), including interdisciplinary fields such as energy infrastructure research (Foulds & Robison, 2018) and security research (Kreissl, 2018). Social sciences and humanities will be an increasingly integral part of Horizon Europe, the European Commission's next funding programme. A focus on climate, energy, and mobility cuts across European research priorities, including climate resilience and climate proofing in infrastructures (European Commission, 2019c). This focus on the humanities and the social sciences, especially in the areas of infrastructures, societal security, and climate change adaptation, means that our proposed vision will help Nordic researchers produce competitive bids in forthcoming European and Nordic funding competitions. We envision developing strong perspectives based on combining the social, political, and technical aspects of infrastructures in climate change and offering a concrete viewpoint on everyday life and lived experiences in these settings.

This research vision aligns with several of the main thematic areas in the social sciences, human geography, and human-environment interactions – and consequently strengthens them. First, while the Nordic model has been exhaustively discussed in the social sciences in general, the infrastructure perspective has remained underdeveloped (see Pursiainen, 2018 for a notable exception). We take up the challenge and encourage other scholars to develop conceptualizations and produce empirical findings on how the Nordic model is, in practice, also a dynamic model for building and sustaining vital security through the development of infrastructure. Our respective research projects have developed perspectives where infrastructures – broadly

Table 2. Documented examples of critical infrastructure vulnerability caused by extreme weather events in the Nordic countries.

Hazard	Infrastructures impacted	Countries impacted	References
Wind storms	Electricity distribution, ICT infrastructure	All Nordic countries	Heidenstrøm & Throne-Holst (2020); Rinkinen, (2013); Silvast (2017)
Flooding and storms	Water infrastructure	Denmark	Refsgaard et al. (2013)
Flooding	Roads, housing infrastructure	Finland	Räsänen et al. (2020)
High precipitation, melting snow, flooding	Transport, agricultural, housing infrastructure	Iceland	Johannesdottir (2011)
Flooding	Railroads	Norway	Bubeck et al. (2019)
Snowfall	Road systems	Norway	Jacobsen et al. (2016)
Flooding and landslides	Paved roads, forest roads, bridges, dams, and culverts	Norway	Gundersen et al. (2016)
Wildfires	Hydroelectric production, agricultural infrastructure	Norway, Finland, Sweden	Cutter (2019)
Water level rise	Tourism infrastructure	Sweden	Ebert et al. (2016)
Water level rise	Water, sanitation, power-generation infrastructures	Sweden	Glaas et al. (2010)

defined to include material systems like the supply of energy and more abstract infrastructures such as insurance – are conceptualized as technologies that serve as vital underpinnings of the provision of welfare. In these projects and with this note, we have asked whether there is a particular Nordic model of infrastructure, including specific institutional and market dynamics such as universal provision, redistribution of risks, and the maximization of societal security. The considerable body of literature on similar topics from other countries all over the world (e.g., Bijker et al., 2014; De Bruijne & Van Eeten, 2007; Collier & Lakoff, 2015; Graham, 2009; Graham & Marvin, 2001; Hommels, 2020; Perrow, 1999; Roe & Schulman, 2008, 2018) offers an opportunity to compare Nordic arrangements to the different governance models that have evolved in other settings.

Second, this research interest highlights social justice and open new pathways for the development of geographical and social scientific research on inequalities in contemporary societies. Amid globalization and market policies for public infrastructure, we argue that current market-based arrangements are creating novel kinds of relationships to using infrastructures in everyday life. Capacities, fairness, and universal provision are increasingly aligned with market models of rational consumers. Energy social scientists have been building research programmes around highly similar themes, including a socially just low-carbon society and energy justice research (Jenkins et al., 2020). The prominence of these themes shows that social science theories and methods are key to this area and need more consideration.

Third, and building on the last point, we argue that more attention needs to be paid to the impacts of finance and the redistribution of wealth that relates to infrastructures and to how that may trigger new, unforeseen forms of inequality (Gramlich, 1994). The funding of critical infrastructures differs in the Nordic countries – and across infrastructure types – which affects their functioning and vulnerabilities. Hydropower is a typical example. If hydro plants and their owners' main offices are located in different municipalities, the revenues and taxes from said plants may not end up supporting the infrastructure needs of the plants' location but instead the large cities where the offices are located, as already happens in parts of Sweden (Össbo, 2018). Where municipalities and local authorities have made large investments in hydropower, the situation when it comes to responsibilities and wealth distribution is different, as is largely the case in Norway.

In using this example, we do not wish to underestimate the complexity of these issues concerning infrastructure finance; rather, we claim that this is precisely why it opens an important avenue for future scholarship. Much infrastructure is not owned solely by the public sector but by a mix of institutional actors and companies, including pension funds and insurance companies. Any earnings are distributed among these actors and affect end-user prices sometimes only through political negotiations. Infrastructures are also regulated services, which means that their profits and quality are controlled and monitored by public authorities. The model in which all earnings are directly distributed to residents is primarily appropriate for infrastructures organized by citizens themselves, which is a recognized legal category within the EU energy market rules (European Parliament and European Council, 2019, Article 2(11)) but does not address all infrastructures. Speaking about resilience and vulnerabilities, what also emerges is a dynamic loop between infrastructure and insurance practices: infrastructure companies take out insurance to mitigate their losses from threats, and insurance companies amass financial capital that is then used to finance future infrastructure projects.

This kind of knowledge of the distribution of responsibilities and wealth has not been aggregated in the Nordic region, though a wealth of information on these matters certainly exists in individual Nordic countries. Collectively, the Nordic countries provide a highly relevant unit of analysis and enable new research that can offer a better understanding of the production of welfare and disaster preparedness as part of critical infrastructure provision.

Notes

1. We use "scale" not to refer primarily to space, although the work of scaling and the related political processes and contestation have also been of considerable interest to infrastructure researchers and geographers (see Bridge et al., 2018 for a review). Our use of the term is closer to its meaning in Science and Technology Studies, where "scales" designate multiple enacted contexts for situations of infrastructure management and use (Hyysalo et al., 2019); in this case, these are contexts of politics and decision making. We therefore also prefer not to refer to "levels" of infrastructure, since that term suggests distinct and separate categories of infrastructure administration: local, regional, national, and international. We believe that there are rarely easy ways to draw such distinctions with infrastructure technologies, whose very point is transgressing boundaries of space and time (Star, 1999), and that exist simultaneously in, for example, households, regulatory organizations, companies, and international markets (Edwards, 2003).
2. The terminology we use relies mainly on technical definitions from the insurance industry, within which it is said that climate change is behind the massive growth of weather-related harmful events. Similarly, in their communications, people in the industry talk about "catastrophes" in the cases where massive

amounts of assets are destroyed, even if much of it is financially secured through (re)insurance. We acknowledge that the scholarly discussion in disaster research distinguishes between incidents, disasters, and catastrophes in a different manner than we do here (Coppola, 2015, p. 283).

3. Further conceptual discussion on resilience and vulnerability is not in the agenda of this paper. We acknowledge that our formulation almost literally understands resilience to be the opposite of vulnerability. This concerns an ongoing debate and some, such as Gu et al. (2020), have viewed resilience to be more holistic than vulnerability. Resilience includes considerations on recovery, absorption, and adaptation, while vulnerability can be more intrinsically connected to the concept of risk. Resilience is also commonly associated with different domains of applications with their specific histories and disciplinary orientations, such as technological, organizational, societal, community, ecological, and economic resilience, and so on. While we adopt some of these qualifiers from our primary sources, this note does not use the distinction between different resilience "domains" for analytical purposes. For further details on the resilience discourse with a specific focus on critical infrastructures, see Rød et al. (2020).

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