Swedish Civil Contingencies Agency

RESEARCH/STUDY

Data and Methods for Disaster and Crisis Management

Empirical and predictive approaches focused on disaster risk management, critical infrastructure resilience & geographic information systems

Data and methods related to major accidents and crises - Empirical and predictive approaches focused on disaster risk management, critical infrastructure resilience & GIS

Year: 2020-2021
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Summary: Access to relevant data and applicable methods is of outmost importance to manage risks and impacts of crises and disasters. This report outlines, from a Swedish perspective, several important recommendations with respect to the needs of data and methods to support empirical and predictive assessments in the areas of disaster risk management, critical infrastructure resilience, and GIS.

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Content

Summary

For our ability to manage risks and impacts of crises and disasters, access to relevant data, statistical analysis, and applicable methods taking advantage of such data is of outmost importance. As example, one of four priorities for the global Sendai framework for disaster risk reduction is related to achieving a good understanding of disaster risks through the collection and usage of data. In addition, achieving the seven objectives outlined in the Sendai framework entails that all countries must collect data and report indicators for the consequences of disasters and the measures undertaken. Further, work is also underway in EU to develop collection and use of data of member states, with the ambition of national databases for disaster data. There is also an ambition that the national risk assessments, which all member states must conduct and report to the EU, should be based on crisis and disaster data. The collection and collating of such data is also essential for meeting requirements of EU Directives relating to critical infrastructure resilience and flood risk management. From a Swedish perspective, current existing databases do not cover the need of data for reporting and analyses for these purposes, where important information is either not collected at all or is not collected in a structured and purposeful way.

The overarching aim of this report is to, from a Swedish perspective, explore and give guidance towards future needs of data and methods as a basis for improved disaster risk and crisis management. This is done by exploring national and international academic literature, grey literature and policy work to pinpoint data and methods deemed as useful for empirical and predictive assessments and decisions with respect to societal safety. The focus is on data and methods in the context and intersection of the fields disaster risk management, critical infrastructure resilience, and geographic information systems (GIS). The study was guided by a framework towards identifying drivers in terms of demand and needs, available methods and data, existing gaps, and by summarizing the findings in terms of clear-cut recommendations. These in turn were divided into two overarching categories: empirical (e.g. disaster loss data) and predictive (e.g. risk, vulnerability and resilience assessments).

Through extensive explorations and analyses of relevant sources of information, the report outlines and summarizes, for example: required loss data for meeting SFDRR and EU minimum reporting requirements, useful datasets for disaster risk management, data needs and useful methods towards tackling critical infrastructure resilience challenges, and the importance and usefulness of GIS for addressing these issues. The report further outlines several important recommendations with respect to empirical, predictive and overarching challenges from a Swedish perspective. These are deemed as highly pertinent to take into consideration for an improved ability to manage societal crises and disasters i through the use of data.

1 Introduction

Data, statistics and applicable methods are vital for our ability to manage the risk of and impacts of crises and disasters. The overarching aim of this report is to explore national and international academic literature, grey literature and policy work to pinpoint data and methods that are useful for empirical and predictive assessments and decisions in support of societal safety. The focus is on data and methods for disaster risk management, critical infrastructure resilience management, and Geographic Information Systems (GIS) to support such work.

1.1 Background

The report is the result of one out of three parallel commissioned studies during the period 2019-2020 aimed at providing guidance to the Swedish Civil Contingencies Agency (MSB) with respect to current and future data and method needs related to, in a broad sense, disaster and crisis management.

MSB have two databases for information on major events towards this end: Major accidents and Natural disaster. The Major accident database include all types of Swedish incidents and events where at least four deaths occurred, at least ten people was injured, or where other types of extensive consequences has occurred. The information in the database, however, is brief and lacking in quality and quantity. The Natural disaster database only includes disasters caused by natural hazards and the focus has been on events with a "lessons to be learned"-perspective. The information in this database is more extensive than for Major accidents, but the information on consequences is lacking in completeness and consistency. Due to technical problems, the Natural disaster database has been closed down and the content is now only accessible in the form of an Excel file. In general, the databases are not deemed reliable by MSB to obtain quantitative data. Neither of the databases have been updated since 2015. Hence, there is a need to recapitalize and review the requirements of data and methods to be able to meet current and future needs for both MSB and the Swedish crisis management system as a whole.

There are also international activities related to data collection and use of data that to which MSB and Sweden need to relate. One of four priorities for the global Sendai framework for disaster risk reduction is related to achieving a good understanding of disaster risks (UNISDR, 2015). To collect and use data is described as one important factor in achieving this. In addition, to achieve the seven objectives outlined in the Sendai framework entails that all countries must collect data and report indicators for the consequences of disasters and the measures undertaken. Within EU, work is also underway to develop the member states' collection and use of data. The ambition is for the member states to have a national database for disaster data. Within the Disaster Risk Management Knowledge Centre (DRMKC), which is run by the Joint Research Centre (JRC), work is underway to consolidate knowledge and develop methods along with a

Risk Data Hub. Linked to the knowledge centre and DG-ECHO is a Disaster Loss and Damage working group, in which MSB has participated. There is also an ambition that the national risk assessments, which all member states must make and report to the EU, should be based on collected data.

The current existing Swedish databases do not cover the need for data for reporting according to the Sendai framework and provide far from a sufficient basis for risk assessments and risk modelling. Important information is either not collected at all or is not collected in a structured and purposeful way. The shortcomings in the existing Swedish data, in combination with increased demands and needs, mean that a review of the requirements on data collection and databases in Sweden is needed. A first step towards this is to map what data can be used for and what is required in the form of data and methodology for these areas of use.

1.2 Requested study

The study requested aims at producing a knowledge base for MSB's continued work with data collection and use of data on major accidents and crises by investigating and mapping (types or groups of) methods, models or approaches to make computerized assessments of risk, vulnerability, ability and other decision support for risk management. The data may be quantitative, semi-quantitative or qualitative and be used for both shorter- and longer-term forward-looking (predictive) and operational purposes.

The requested study consists of carrying out:

- A review of (types or groups of) databases, methods and models that exist and are used today mainly in Europe and USA. The review must contain information about the purpose of the method/model, which target group the method/model is intended for and an overview of the type of data used.
- A mapping of ongoing projects and development of possible future computerized methods, models or approaches.
- A discussion of the type of data that may be interesting to collect in the future but where there currently is no method or concrete development.

Methods, models and approaches covered by the assignment should use:

- data to analyse risk and/or factors of risk, such as hazards, exposure, vulnerability, resilience, ability, probability and possible consequences. This includes both holistic models as models for individual factors.
- data on the consequences of events that have occurred (loss data)
- data for investigations of the causes of events that have occurred

The mapping should further be based on scientific and other literature as well as information from relevant authorities and organizations about what has been done and what is developing in the field, nationally and internationally.

The study was carried out by Associate Professor Jonas Johansson and Postdoc Peter Månsson, both at the Division of Risk Management and Societal Safety at Lund University, during the fall of 2020 and spring of 2021.

1.3 Aim of study

Our interpreted aim of the commissioned study is to investigate the future need for data and methods as a basis for disaster and crisis management. For this, possible uses for data related to major accidents, crises, capabilities and vulnerabilities should be investigated. In addition, methods for using such data for disaster and crisis management and other decision support for crisis preparedness should be mapped. The aim is further to explore what is done in the field both nationally and internationally by reviewing scientific and other literature in the field.

1.4 Delimitations

Given the limited scope of the commissioned study in terms of available time and budget (150' SEK), several delimitations had to be set out.

First of all, the focus for the study is to give an overview of data relating to disaster risk management (DRM), critical infrastructure management and geographic information systems (GIS). Here with a specific focus on empirical loss accounting (to e.g. enable analyses of trends, comparisons of losses from various types of disasters and evaluate the effectiveness of risk reduction measures) and risk modelling (which seeks to establish the expected losses from prospective events and often visualize the effects of potential disasters with the help of diagrams and maps using GIS, cf. De Groeve et al., 2014, pp. 16-18). Regarding loss accounting, we have particularly focused on the data reporting requirements adhering to the Sendai Framework for Disaster Risk Reduction (SFDRR) and EU legislations. The scope of predictive risk modelling has been centred on methodologies related to critical infrastructure management (CIP) and GIS. Hence, we have consciously omitted related fields, such as loss compensation (insurances and compensation schemes that help to recover from disasters), and forensic analysis (involving analyses of loss drivers by measuring the relative contribution of exposure, vulnerability, coping capacity, mitigation and response to the disaster, cf. ibid). It is assumed that these related fields will be addressed by the two other parallel commissioned projects carried out by Karlstad University and Mid Sweden University.

Secondly, the aim has been to give an overarching account of data and methods in above mentioned fields. Hence, more in-depth scrutiny of specific data, databases, methods or ongoing research and policy work in the field had to be omitted to delimit the scope.

Thirdly, it should be noted that the area of data relating to risk and disaster management is truly extensive and intertwined with many research fields.[1] Hence, to limit time-consuming systematic review work we have used our previous knowledge and research experience as a baseline for explorations of the topic and put previous work by the authors in the larger context of this report.

Finally, the scope of this study has not allowed us to scrutinize to what extent the data and methods that we deem useful exist already (and, if so, who possesses them and how they can be obtained and for example structured in databases) or have to be developed.

1.5 Methodological approach

In order to address the research questions in a systematic manner, an overarching framework for the study was outlined. This framework was then used to guide collection and analysis of relevant material through review studies. In addition, two workshops have been performed that provided input to the current study. One of these targeted Swedish authorities at all administrative levels and focused on the use of geodata and GIS as basis for risk- and vulnerability assessments. The other workshop was conducted with our colleagues at the Division of Risk Management and Societal Safety at Lund University where the collected material and analysis results were discussed along with a deliberation on current and forthcoming risk assessment methodologies and adherent data needs (the workshops are further described in Section 1.5.2).

1.5.1 Framework for the study

To guide the work, a set of overarching research questions where set out. These were formulated with respect to the aim and the given delimitations of the study, and divided into three overarching themes: 1) Drivers in terms of demands and needs, 2) Available methods and data, 3) Gap analysis and recommendations. An overview of the framework for the study is given in Figure 1. Moreover, these themes have been structured between empirical and predictive data and methods. By empirical data and methods we refer to uses related to operational response and disasters loss data analysis which, for instance, serves trend analyses, lessons learned, and as input to predictive assessments (e.g. risk and vulnerability assessments). Predictive data and methods largely concerns such as to be used in proactive risk, vulnerability and resilience assessments, e.g. related to National risk and vulnerability assessments, Critical Infrastructure Directive, and Flood Directive.

Drivers in terms of demands and needs:

- What international demands are expressed with respect to the Sendai framework, EU policy work regarding disaster data, and related EU-

[1] A search using Scopus (the world's largest database for scientific publications) 2020-11-04 with the string "TITLE-ABS-KEY ("Data" AND "Disaster" AND "Risk") yielded over 10 000 publications (10,554).

directives, such as the Floods Directive (2007/60/EC), the Critical Infrastructure Protection Directive (2008/114/EC), and the National Risk Assessments (European Commission, 2010)?

- What national needs can be discerned relating to e.g., risk and vulnerability assessments that Swedish authorities are obliged to produce, Critical Infrastructure Resilience, and work towards Climate Change risks?

Available methods and data:

- What methods for analyses can be discerned and what data do they require?
- What type of data can be discerned as useful in the scientific and grey literature?

Gaps was identified through an analysis of the more descriptive findings above, guided by the questions:

- Given existing methods and required data, which demands and needs can be addressed?
- Given needs and demands, what data collection and method development are required?

Recommendations, based on above findings, was guided by the questions:

- How does existing data and methods match demands and needs?
- Which barriers exist (e.g. Data-availability, knowledge level, competence)?
- What future research and development need can be discerned with respect to data and methods?

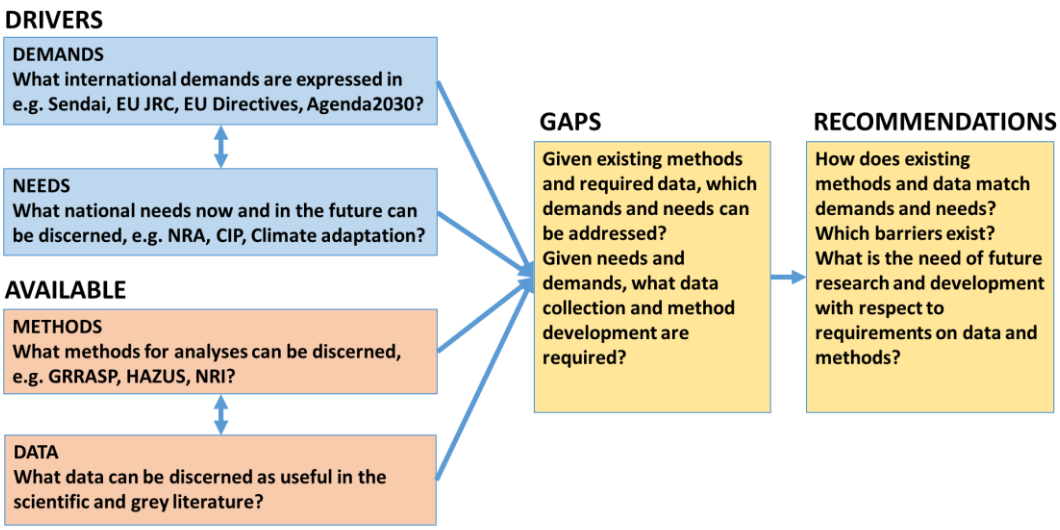

Figure 1. The framework and research questions guiding the study.

1.5.2 Methods applied and material

In order to seek answers to the questions set out in the previous section, two main approaches were utilized: literature review of relevant literature and material collection and scrutiny of our results through workshops.

Literature review

The search for relevant literature to include embraced scientific publications, grey literature and policy documents. The scientific publications mainly comprised of studies known by the authors to be of relevance through their research activities in the field and through previous commissioned work for MSB. Grey literature and policy documents consisted of documents containing relevant information from authorities and organizations regarding previous and future work in the field, both nationally and internationally. These latter types of documents were partly provided by MSB and partly identified through prior knowledge by the authors. During reading and analysing the initial identified documents, additional relevant documents was also identified and included in the study. In essence, those documents regarded especially relevant for the purpose of this report is given in the reference list and referenced throughout the report. Given the wide scope together with budget and time constraints of the commissioned work, a more systematic approach (e.g. performing a systematic review or scoping study[2]) for the identification of relevant literature of such an extensive topic was not deemed feasible. We instead focused on collecting and collating literature to strengthen and exemplify our overarching discussion on data and methods for improved crisis management in Sweden.

Workshops

Two workshops were arranged in relation to this report. The first workshop focused on gaps and opportunities related for using geodata and GIS in support of risk and vulnerability assessments. The second workshop focused more generally on data and methods for improved research and practical work related to management of disasters, risks and critical infrastructures.

The first workshop was organized by the authors in collaboration with the Department of Human Geography and the Department of Physical Geography and Ecosystem Sciences, through the GIS-centre at Lund University, the 12th of February 2021. It was a digital workshop with 32 representatives from Swedish authorities at different administrative levels (15 from national authorities, 11 from county administrative boards and 6 from municipalities) to survey their needs of geodata[3] as a basis for risk- and vulnerability assessments (RVA). 54% of the

[2] See for example: Arksey, H., & O'Malley, L. (2005). Scoping studies: towards a methodological framework. International journal of social research methodology, 8(1), 19-32.; Daudt, H. M., van Mossel, C., & Scott, S. J. (2013). Enhancing the scoping study methodology: a large, inter-professional team’s experience with Arksey and O’Malley’s framework. BMC medical research methodology, 13(1), 48.

[3] Geodata describes everything that has a geographical location (map data and register information). In a RVA context, it can be valuable assets and entities (e.g., population, critical infrastructure and vital societal functions, and the environment); hazards that threaten these values and aspects (e.g. distance, resources and measures) that are relevant to assess the vulnerability to these threats.

participants were desk officers in charge of RVA processes and 46% were GIS experts. The workshop enabled fruitful discussions on how GIS and geodata can be applied to facilitate the identification and analysis of risks to societal safety and resulted in the identification of a vast set of datatypes applicable for RVA-purposes. These datasets are included in Appendix B and denoted "EW 2021" (External workshop).

The second workshop was organized internally with colleagues at the Division of Risk Management and Societal Safety, Faculty of Engineering, Lund University on the 10th of March 2021. Here the aim was to present our results and get complementing perspectives. In total 10 persons (including the authors) attended the workshop, consisting of both faculty staff and doctoral students at the division. The format was a one-and-a-half-hour long online workshop where the authors first presented the findings of the study, which was then complemented with an hour long structured discussion regarding strengths and weakness of the results and missing/complementing perspectives. The questions below structure and questions was used to facilitate the discussion:

- **Part 1 – Empirical approaches**
    - Which methods or approaches of interest to this area have you come across within your line of research (both Sweden and internationally)?
    - Do you have any examples of "new" methods/trends that you believe will get increased attention in the future?
    - What data needs exist for application of current and future methods and what limitations exists?
- **Part 2 – Predictive approaches**
    - Which methods or approaches of interest to this area have you come across within your line of research (both Sweden and internationally)?
    - Do you have any examples of "new" methods/trends that you believe will get increased attention in the future
    - What data needs exist for application of current and future methods and what limitations exists?
- **Part 3 – Overarching**
    - Any ideas or suggestions towards better integration of empirical and predictive approaches?
    - What data do you see that MSB should be gathering/channelling to improve the Swedish crisis management capability?

1.6 Outline of the report

The structure of the report largely follows the logic of the framework as presented in Figure 1. In Chapter 2 an account of drivers for data and methods with respect to both empirical and predictive approaches are given. Here we focus of highlighting both demands (e.g. EU Directives) and needs (e.g. as highlighted by MSB or researchers in the field). In Chapter 3 an overview of empirical and predictive data requirements and available methods is given. The findings in Chapter 2 and 3 are then discussed through a gap analysis in Chapter 4, and then final recommendations are presented in Chapter 5.

2 Drivers

2.1 Empirical demands and needs

To explore demands related to empirical loss data collection we have primarily used documents stemming from the United Nations (UN), the European Union (EU) and Integrated Research on Disaster Risk (IRDR). The documents from the UN are mainly focused on reporting requirements in accordance with the Sendai Framework for Disaster Risk Reduction 2015-2030 (SFDRR) and the global goals as stipulated in the 2030 Agenda for Sustainable Development (UNISDR, 2015; United Nations, 2015)[4]. Here, we have focused on SFDRR targets A-D as targets E-G address other aspects than loss data (UNDRR, 2019, pp. 213-14). The EU documents stem exclusively from the Joint Research Centre (JRC). The JRC strives to align the ways that different EU member countries collect and report on disaster losses and have issued a number of guiding documents to this end. Whilst these documents seek to improve the comparability of data that EU member countries report in accordance with EU policies (including the INSPIRE Directive, the Flood Directive, the Seveso directive and the Union civil protection legislation), the JRC asserts that their proposed database frameworks conform with the indicators of the Sustainable Development Goals (SDG) and the Sendai Framework for Disaster Risk Reduction (De Groeve et al., 2015, pp. 4, 18; Ríos Díaz,, pp. 7, 22). Finally, the Integrated Research on Disaster Risk (IRDR), in collaboration with the International Social Science Council (ISSC) and the United Nations International Strategy for Disaster Reduction (UNISDR), also issued a guidance document to promote common ways of reporting on disaster losses (IRDR, 2015).

The three main sources of this review (UN, EU and IRDR) covers the minimum data reporting requirements bestowed upon Sweden in accordance with the SFDRR, Agenda 2030 and EU legislation. In addition, they contain recommendations on the collection of information beyond or related to these minimum requirements (e.g., prompts to specify losses by disaggregating estimates in e.g., hazard types, geography, gender, age or income). Whilst our report highlights the minimum data reporting requirements, it also contains reflections of needs upon which additional loss data that may be interesting and feasible to collect from a Swedish perspective. Here, we naturally consider the disaggregation units proposed by the UNISDR and the JRC, but also suggestions by the IRDR and strategy documents produced by MSB as well as inputs from colleagues at the internal workshop described above. The assembled needs of data for empirical assessments are provided in Appendix A, and further explicated by an Excel sheet ("Essential-data_SFDRR-JRC") separately communicated to MSB.

[4] The Inter-Agency and Expert Group on SDGs Indicators (IAEG-SDGs) proposed using the same indicators in measuring the disaster related Sustainable Development Goals (SDGs) 1, 11 and 13, which reinforces the importance of the Sendai Framework Targets and Indicators (UNISDR, 2019, p. 212; 2017, p. 7).

2.2 Predictive demands and needs

With respect to predictive analysis needs for disaster and crisis management in general, there exist several demands on a national level stemming from the EU. These demands leads to the requirement of national analysis capabilities, in turn creating needs for data supporting such analyses. Three main such demands are in focus here, namely the Critical Infrastructure Protection Directive (CIP), Flood Directive and National Risk Assessment (NRA). The appointed authority with respect to these demands in Sweden is MSB. An overarching approach focused on methods for addressing predictive analysis of societal consequences in a Swedish context has previously been presented in an MSB-report by one of the authors (Johansson et al., 2015b).

The CIP Directive relates here to the European programme for Critical Infrastructure and the Council Directive 2008/114/EC. This directive, later implemented by the European Programme for Critical Infrastructure Protection (EPCIP), highlights the cross-country scale of critical infrastructures by stating ”there are a certain number of critical infrastructures in the community, the disruption or destruction of which would have significant cross-border impacts. This may include transboundary cross-sector effects resulting from interdependencies between interconnected infrastructures” (European Council, 2008, p. 1). A first evaluation of EPCIP (European Commission, 2013) was conducted in 2013 and a second in 2019 (European Commission, 2019). In these, two main issues were identified: (1) how to address and manage CI interdependencies, and (2) how to enhance CI resilience. The latter one signals a clear shift, both in terms of policy and scientific interest, from the protection to the resilience of critical infrastructures during the last decade. During this period, it has also been acknowledged the limits of relying on sectorial approaches (silo-thinking) and moving towards more holistic cross-sector approaches (system-of-systems thinking), to address the issues of critical infrastructure interdependencies and cross-sector collaborations. To address the governance of critical infrastructure resilience (OECD, 2019), several needs relating to both empirical and predictive data in a Swedish context exist. As critical infrastructures, such as energy, transportation, telecommunications, and health care delivers essential services, they can be regarded as the backbone of the society. Since these systems are heavily interdependent, i.e. failures in an infrastructure does not stay isolated but can cascade to other infrastructures, there are several challenges related to understanding the full extent of societal impacts from failures in critical infrastructures when a hazard or threat impacts these systems. In order to effectively mitigate and respond to crises and disasters that involve critical infrastructures, knowledge about the cascading effects are essential. This can be addressed either by empirical approaches, through gathering systematic descriptions and extraction of key characteristics and conditions for cascading effects based on past events (McDaniels et al., 2007; Luiijf et al., 2010; Johansson et al., 2015a), or through predictive approaches, e.g. modelling and simulation approaches for exploring cascading impacts and risks related to interdependencies

(Ouyang, 2014; Johansson et al., 2015c; Johansson et al., 2015d; Rød & Johansson, 2020), or even better as a combination of the two. Data and methods related to these two main approaches, and how they are interconnected, is a focal area for the current study.

The Flood Directive (2007/60/EC) is a framework aiming for improved assessment and management of flood risks to reduce negative consequences of flooding. The Directive obligates EU Member States to perform a national assessment and develop a flood risk management plans. Every six years a report with respect to flood risks is to be developed. This six-year cycle is divided into three steps: 1) perform a preliminary flood risk assessment, 2) create a) flood hazard maps and b) flood risk maps, and 3) develop flood risk management plans (European Council, 2007). Data demands with respect to the Flood Directive can broadly be divided into two categories: 1) geography and hazard data (step 1-2a), and 2) societal and critical infrastructure data (step 2b-3). The first category concerns data related to river basin characteristics (such as water and elevation levels, physical measurements, and past floods) to assess the potential likelihood of future floods. For areas assessed to have significant flood risks, hazard maps of flood extent, water levels, and water velocity needs to be constructed through the use of relevant data. The second category relates to the construction of flood risk maps, as based on the hazard maps. In order to do so, data such as potentially affected inhabitants, service loss, economic activity, potential pollution sources, and other relevant societal and infrastructure data is necessary. The flood risk management plans then further necessitate data used for analysis of cost-benefit, flood extent, floodplains, water management, spatial planning, and land use. In Guldåker, Johansson, Arvidsson & Svegrup (2019), we discuss challenges for and present a method to address spatially oriented risks impacting critical infrastructures and vital societal functions. As one of the more pressing issues, i.e. were current analysis capabilities has been identified as lacking, concerns step 2b of the six-year cycle, the method aims on improved data collection and analysis of the impact of floods on critical infrastructures and vital societal functions aiming at assessing consequences at a societal level. Datasets supporting assessments according to the CIP Directive as well as Flood Directive are provided in appendix B.

National Risk Assessment is here referred to a need for participating states to periodically develop risk assessments and convey a summary of their National Risk Assessment (NRA) in accordance with Decision No 1313/2013/EU on a Union Civil Protection Mechanism. These are intended to be available to the European Commission (JRC) as a way to prevent disaster risk in Europe. In the report "Recommendations for National Risk Assessment for Disaster Risk Management in EU"5 from 2019, stemming from a collaborative effort between of the Disaster Risk Management Knowledge Centre and Joint Research Centre (JRC), several challenges and needs related to the process and the content of the assessments are

[5] JRC Science For Policy Report, (2019). Recommendations for National Risk Assessment for Disaster Risk Management in EU, JRC 114650, ISBN 978-92-79-98366-5, doi:10.2760/084707.

highlighted. The report focuses on tools and methods related to: drought, earthquakes, floods, terrorist attacks, biological disasters, critical infrastructures, chemical accidents, nuclear accidents and Natech accidents. In this report we focus on the aspects related to data and methods for supporting national risk assessments. Highlighted in the document is the major importance of disaster loss databases in order to, for example, identify and quantify socio-political-economic and physical drivers together with inherent vulnerabilities. The data needs related to the NRA are similar to the requirements of data that public authorities have when performing risk and vulnerability assessments in Sweden (not the least since the latter are a basis for the former). Hence, the datasets highlighted as important during the external workshop (and denoted "EW 2021" in Appendix B) are important for the NRA process as well.

3 Data and Methods

3.1 Empirical

As described in Section 2.1.1, the SFDRR, Agenda 2030 and EU legislation stipulate minimum data reporting demands with respect to disaster loss data. Appendix A presents an overview of the data that is necessary to collect to meet these demands. The table also contain additional data that we deem essential and feasible to collect to get a more comprehensive appreciation of the losses from disasters in Sweden.

The data is confined to what is proposed in the studied documents and whereas the table embrace all minimum data reporting requirements, a selection has been made regarding which of the so called "desirable" data to include. Our motivations and recommendations for such choices are provided in Section 6.1, whereas this section attempts to provide a condensed overview of the data requirements proposed by UNISDR (UNDRR)[6], JRC and IRDR. The presentation follows targets A-D in the SFDRR and includes an account of similarities and differences regarding how UNISDR, JRC and IRDR treat these data. To facilitate comprehension of how the different data sets relate, we have tried to visualize this by an Excel sheet ("Essential-data SFDRR-JRC"), which also contains comments with definitions that set boundaries for data collection and information that clarify how some of the data sets may be disaggregated.

3.1.1 UNISDR, JRC and IRDR

Hazard event identification

UNISDR is interested in aggregated losses from all events in a given time period. Hence, connecting loss data to specific events is not a minimum, but optional, requirement (albeit recommended, cf. UNISDR, 2017, p. 9). Accordingly, UNISDR does not present further ideas on how this should be done (e.g. on the type and structure of information to describe individual disasters). There is, for instance, no guidance as to the classifications of disaster types.

As opposed to UNISDR, **JRC** stresses the importance of connecting damage losses to specific events and is quite elaborate on the structure and type of information needed to do so. For instance, it promotes the use of e.g. "Event IDs" and inclusion of other information, such as type of disasters, where they occurred and when.

The JRC recommend that a "hazard event identification number" (Hazard ID) similar to the Global Disaster Identifier number (GLIDE) number

[6] The United Nations International Strategy for Disaster Reduction (UNISDR) changed its name to the United Nations Office for Disaster Risk Reduction (UNDRR) in May 2019. However, the main documents we refer to in this report were written before this and for the sake of consistency and to prevent confusion, we use the agency's old abbreviation consistently throughout the report.

(http://www.glidenumber.net/glide/public/about.jsp) should be adopted (De Groeve et al., 2015, p. 8). This allows for interoperability between different loss databases and unambiguous linking of loss records associated to the same disaster event. Accordingly, the JRC (Ríos Díaz et al., 2018, p. 31) proposes the following format: [Hazard] (code of 2 characters) + [Country] (ISO2 of country) + [Begin Date] (in YYYYMMDD format) + [Glide Number] (4 digit serial number). An example of how this might look like:

Hazard	*Country*	*Date*	*Glidenr*
Fl	*It*	*20170126*	*0015*

In addition to Hazard IDs, JRC (Ríos Díaz et al., p. 23) also proposes to:

- use "nicknames"/epithets, which may be easier to remember and use than "event-IDs" when searching for the disaster in databases.
- relate each disaster to a "disaster type" where the INSPIRE natural hazard categories is recommended as a standard. The JRC (De Groeve et al., p. 8) also claims that it is easy to integrate with IRDR's peril classification (IRDR, 2014).
- connect each disaster to geographical information (where it has happened and the extent of its consequences). Here one needs to separate between reporting on where specific losses have occurred (see column heading "Geographic location" in the Excel sheet) and reporting the geographical location/extent of events (see column heading "Geographic information where/scope" in the Excel sheet). The latter can be done in words by relating to the administrative areas in accordance with the NUTS division of administrative levels[7] or use specific geographical coordinates to indicate a more precise location of the event (e.g. industrial accidents, avalanches, earthquakes, meteorite impacts, volcanic eruptions, etc.). This is, for instance, done in the International disaster database EM-DAT (CRED, 2020) and also proposed by the JRC (Ríos Díaz et al., 2018, pp. 21, 24-25). For hydrological events, the JRC (De Groeve et al., pp. 8, 16) recommends to use the Units of Management as defined in article 3 of the EU Floods Directive (2007/60 / EC). The geographic location/extent of disasters should preferably also be visualized by GIS/maps (Ríos Díaz et al., 2018, p. 40).
- include temporal information (From - date and time) + (To-date and time)
- indicate severity level/intensity and offers guidance as to what parameters that may be relevant to include with regards to which type of hazard (Ríos Díaz et al., 2018, pp. 24-25).

[7] Nomenclature of Territorial Units for Statistics or NUTS (French: Nomenclature des unités territoriales statistiques) is a geocode standard for referencing the subdivisions of EU member countries for statistical purposes. For each country, a hierarchy of three NUTS levels is established by Eurostat in agreement with each member state. The subdivision of the country is then referred to with one number, whereas the second and third subdivision levels are referred to with another number each. Below the three NUTS levels are local administrative units, LAUs (Eurostat, 2020).

IRDR does not address the issue of connecting losses to specific events and is more concerned with describing the losses from the disasters than the events per se.

Target A (Mortality)

Datasets included in Target A: #Deaths; # Missing persons

UNISDR defines deaths as "The number of people who died during the disaster, or directly after, as a direct result of the hazardous event." and missing as “"The number of people whose whereabouts is unknown since the hazardous event. It includes people who are presumed dead, for whom there is no physical evidence such as a body, and for which an official/legal report has been filed with competent authorities." (UNISDR, 2017, p. 7).

On the national level, one shall report the number of dead (indicator A-2) and missing (indicator A-3) per 100.000 population and the sum of these two numbers correspond to the compound indicator A-1.

UNISDR stress that each death should be counted in the country where the death occurred, regardless of the nationality of the dead persons (UNISDR, 2017, 10). Beyond conveying the number of deceased and missing persons (minimum reporting requirement), UNISDR recommends (optional) to also disaggregate these data in sub-categories, denoted “desirable data requirements” (UNISDR, 2017, p. 9):

- Hazard
- Geography (Administrative unit)
- Sex
- Age
- Disability
- Income

UNISDR underscores the importance of distinguishing between deaths and persons that are missing/presumed dead, so that no-one should be double counted. The data is contingent upon the existence of legal reports or declarations. This means that missing persons should count as "dead" if those persons are legally declared dead (“declared death in absentia” or legal presumption of death) despite the absence of direct proof of the person’s death, such as the identification of physical remains (e.g. a corpse or skeleton) attributable to that person. Hence, the indicator should use only official country data, and not unofficial sources, such as mainstream media or reports from international sources (UNISDR, 2017, p. 7).

JRC uses very similar definitions as UNISDR, claiming that deaths “correspond to the number of people who died during the disaster, or some time after, as a direct result of the disaster” and missing “correspond to the number of persons whose whereabouts since the disaster are unknown. It includes people presumed dead without physical evidence." (Corbane et al., 2015, p. 281; De Groeve et al., 2015, pp. 11-12). In tandem with the UNISDR, the JRC also proposes (optional) to disaggregate "human losses" (deaths, missing and ill/injured) in different subclasses (Ríos Díaz et al., 2018, p. 36):

- Gender
- Age
- Income
- Disability

Similar to the UNISDR, the JRC stresses to differentiate between dead and missing people; disaggregates gender in males/female and uses the following age groups (UNISDR, 2017, p. 15; Ríos Díaz et al., 2018, pp. 12, 26): <18 yrs; 18≤65 yrs; >65 yrs. For the sake of aggregation, JRC underscores the importance of using the unit "persons" instead of households or families when recording losses for affected populations (Corbane et al., 2015, p. 281).

IRDR uses a distinctive definition of deaths and contends that it corresponds to the "Number of people who lost their life because the event happened." (2015, p. 9), whereas the definition of missing is more similar to the ones proposed by UNISDR and JRC: "The number of people whose whereabouts since the disaster are unknown, and presumed dead based on official figures." (2015, p. 12).

In addition, IRDR suggests that one should distinguish between *direct* and *indirect* deaths from disasters, but acknowledges the difficulties involved in defining what qualify as related to disasters (e.g. starvation due to food scarcity, diseases due to contaminations, social unrest due to lack of governmental ability to cope with the disaster) as well as establishing a time criteria for this, but does not provide any guidance in these regards. Yet, IRDR indicate the use of cut-off times for the collection of data regarding deceased persons (IRDR, 2015, pp. 9-11). Unlike the UNISDR, however, they do not propose any specific times with regards to different hazards but confine it to "immediate" deaths. In tandem with both UNISDR and JRC, the IRDR proposes to disaggregate data on deceased persons by location, age and gender (but does not propose the same disaggregation regarding missing and injured people).

Moreover, IRDR (2015, p. 9) promotes to include the *cause* of death, but does not propose a list of generic causes of death applicable for different types of disasters. Such a list could for example be: drowning; crush injuries; electrification/burns; radiation; diseases (including where the disease itself constitutes the disaster, but also epidemics that break out as a result of other events) starvation; heat stroke/dehydration; frostbite; poisoning; heart attacks and traffic accidents that are directly related to the event (e.g. in connection with evacuations), suicide etc. Access to this kind of information provides an idea of the main reasons to why people die in different types of disasters, which is a valuable input for the prioritization of measures to prevent deaths given, e.g. the risk profile of a country or region.

Target B (Affected people)

Datasets included in Target B: #Injured/ill people; # people with damaged dwellings; # people with destroyed dwellings; # people with disrupted or destroyed livelihoods

UNISDR uses the following definitions for the included indicators (UNISDR, 2017, p. 21):

Injured or ill: "People suffering from a new or exacerbated physical or psychological harm, trauma or an illness as a result of a disaster."

Damaged dwellings: "Houses (housing units) with minor damage, not structural or architectural, which may continue being lived in, although they may require some repair or cleaning."

Destroyed dwellings: "Houses (housing units) levelled, buried, collapsed, washed away or damaged to the extent that they are no longer habitable, or must be rebuilt."

Livelihood: "The capacities, productive assets (both living and material) and activities required for securing a means of living, on a sustainable basis, with dignity." UNISDR does not draw a line between the terms disrupted and destroyed (it only states that it is difficult to define the term disrupted, UNISDR, 2017, p. 29). Yet, the lack of indicators to separate these two concepts does not pose a problem with regards to reporting, since countries solely are supposed to convey the aggregated number of the two.

On the national level, countries shall report the number of people that are injured or ill (indicator B-2) per 100.000 population, whereas the number of persons with damaged dwellings (indicator B-3) and destroyed dwellings (indicator B-4) is based on the average number of occupants per household of the country. Disrupted or destroyed livelihoods (indicator B-5) is divided in three parts where average numbers are used of workers required per hectare of agricultural land, per livestock or per productive asset facility (e.g., industrial, commercial, services etc.). These numbers are then multiplied by the numbers of lost hectares of agricultural land, livestock or productive asset facilities destroyed (cf. UNISDR, 2017, pp. 22, 25). Those numbers are collected as part of target C, but used here as basis for the calculation of numbers of persons that lost their income. The sum of the numbers from the four indicators correspond to the compound indicator B-1, which represents the total amount of "affected people" and should be given per 100.000 population.

JRC differentiates between directly and indirectly affected persons, where the former embrace injured persons and people with affected livelihoods. It is more unclear what indirectly affected means, since there is neither a definition of what "affected" or "indirectly" entails, only that it may embrace people outside the directly disaster stricken area (De Groeve et al., 2015, p. 26). As opposed to UNISDR, the JRC does not include the number of persons with damaged or destroyed dwellings, only the number of destroyed and damaged buildings per se (indicators that UNISDR put under target C).

IRDR sticks out a bit regarding assessment of "affected people". Similar to UNISDR, it integrates injured and ill people and suggest disaggregating this indicator in age, gender and location (IRDR, 2015, pp. 7, 12). However, apart from that, IRDR does not have any indicator for the number of people who have lost their income or whether their houses have been damaged or destroyed. Instead, IRDR (2015, pp. 14-15) proposes assembling data about the number of:

- exposed: people who permanently or temporarily reside in the hazard area before or during the event
- homeless (people whose house is destroyed or heavily damaged and therefore need shelter after an event);
- evacuated (people who mobilise or are mobilised as a precautionary measure before, during and after the event)
- relocated (people who have been moved permanently from their homes to new sites).

Target C: (Direct economic losses)

Datasets included in Target C: Agriculture; Productive assets; Housing; Critical infrastructure; Cultural heritage

UNISDR: Following the open-ended intergovernmental expert working group on indicators and terminology relating to disaster risk reduction, UNISDR stipulates that only direct economic loss should be included. These are losses that usually happen during the event or within the first few hours after the event and often are assessed soon after the event to estimate recovery cost and claim insurance payments. Importantly, they are tangible and relatively easy to measure. Examples of physical assets that may be the basis for calculating direct economic loss include homes, schools, hospitals, commercial and governmental buildings, transport, energy, telecommunication and other infrastructure; business assets and industrial plants; production such as crops, livestock and production infrastructure. They may also encompass environmental assets and cultural heritage (United Nations General Assembly, 2016, p. 17)[8]

The United Nations General Assembly (2016, p. 6) stipulates that economic losses should be disaggregated in economic sectors, but aside from "agriculture" (indicator C-2)[9] and houses (indicator C-4), countries are left to decide which sectors to include and sort these under two main headings: "productive assets"

[8] *Indirect* economic loss, on the other hand, includes revenue declines owing to business interruption (e.g., due to missing assets, interruptions to transportation networks, supply chains or temporary unemployment) and macroeconomic impacts (e.g. price increases, increases in government debt, negative impact on stock market prices, and decline in GDP). Indirect losses can occur inside or outside of the hazard area and often with a time lag. As a result they may be intangible or difficult to measure (United Nations General Assembly, 2016, p. 18).

[9] Regarding "agriculture" UNISDR (2017, p. 41) contends that the direct losses should be disaggregated in five subclasses: crops; livestock; forestry; aquaculture and fisheries.

(indicator C-3) and "critical infrastructure" (indicator C-5). Moreover, the countries are urged to disaggregate the data by economic sectors, including services, according to "international standards" (without referring to which standards would be appropriate in this respect). It is also advised that countries should report on the basis of the economic sectors that are essential to their own economies (UNISDR, 2017, pp. 39, 48). Yet, UNISDR points out that indicator C-5 should embrace "protective" and "green" infrastructures[10] as well as the cost of damages related to indicators D-2 and D-3, i.e. educational and health facilities (UNISDR, 2017, p. 54).

UNISDR, calls for a value per asset that has been damaged, but also an estimated ratio of the damages, which together form basis for calculations of economic losses. The estimated value of assets is based on replacement values, or rehabilitation or reconstruction costs (UNISDR, 2017, p. 39). As it would be very tedious to identify the real replacement values of all assets of critical infrastructures, these are expressed as a ratio of the total value of the productive assets. The methodology for calculating losses in the agricultural sector is distinct from other sectors and described on pp. 41-91.

UNISDR proposes that all assets should be linked to hazard type, geography (administrative unit where damage occurred) and be assessed in terms of level of affectation (damaged or destroyed). The total economic loss should be reported in relation to the gross domestic product (C1 compound). In addition, losses expressed in national currency must be converted into USD, to enable global summation (UNISDR, 2017, p. 41).

Concurrent with the UNISDR, **JRC** proposes to only report on direct economic losses (De Groeve et al., 2015, p. 14). It does not either stipulate sectors for which economic losses should be recorded, but refers to other sources for guidance in this regard, including the Damage And Loss Assessment methodology (The International Bank for Reconstruction and Development/The World Bank, 2010), the OECD Framework For Accounting National Risk Management Expenditures And Losses of Disasters (2014), the IRDR Guidelines on Measuring Losses from Disasters (2015). Notwithstanding, Table 9 (De Groeve et al., 2015, p. 17) includes some economic sectors that may be inspired from these documents.

As opposed to UNISDR, JRC recommends to include information about the owner of the damaged/destroyed assets (individuals, business, government, non-governmental organizations) as well as the extent to which the losses are covered by insurances (De Groeve et al., 2015, p. 14). This allows statistics on losses in the public sector, the industry sector, private citizens and so on and provides

[10] *Protective infrastructure* is defined as "The set of build elements designed to protect human life and societal assets from different hazards, including inter alia floods, flash floods, landslides, tsunamis, earthquakes, wind and storm surges." (UNISDR, 2017, p. 96). Examples of protective infrastructures include flood protection walls, dykes, dams and canals; drainage systems; ground reinforcement for landslide prevention, shelters and early warning systems infrastructure. *Green infrastructure* is a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services such as water purification, air quality, space for recreation and climate mitigation and adaptation, and management of wet weather impacts that provides many community benefits." (UNISDR, 2017, p. 96).

knowledge on the extent to which losses in different sectors are covered by insurances. In case not all losses are recorded (e.g. only insured losses), it is recommended to develop a method for estimating the total losses based on a coefficient factor on insured losses (ibid.).

For loss data recording, national currencies are recommended. For loss data sharing, however, the losses should be converted into euros (as opposed to USD in the case of SFDRR) at the Eurostat exchange rates of the month in which the recorded event has occurred (De Groeve et al., 2015, p. 14).

Contrasting to UNISDR and JRC, **IRDR** suggests recording and reporting on direct as well as indirect economic losses, but does not provide any method to assess the latter. Akin to JRC, IRDR also point out the possibility of disaggregating losses into insured and uninsured, which also is embraced by global loss databases such as the CRED's EM-DAT and Munich RE's NatCatService (IRDR, 2015, pp. 16, 21). As already mentioned, IRDR provides examples of pertinent economic sectors for which it is relevant to assess economic damages and also how these can be disaggregated in different sub-segments (2015, p. 17).

Target D (Damages & disruptions to critical infrastructures and basic services)

Datasets included in Target D: # Destroyed or damaged health facilities; # Destroyed or damaged educational facilities; # Other destroyed or damaged critical infrastructure units and facilities; # Disruptions to educational services; # Disruptions to health services; # Disruptions to other basic services

UNISDR proposes the collection and reporting of the number of infrastructure facilities that were damaged or destroyed by disasters and the number of times in which the provision of a basic services was disrupted. The target refers to two separate but interconnected situations. The first is situations in which critical infrastructure is damaged (without services necessarily being disrupted or compromised in terms of quality) or destroyed. The second is when basic services are disrupted, which could happen with or without damage (UNISDR, 2017, p. 93).

Beyond health and education facilities (which are particularly highlighted), countries can report on other "damaged infrastructure" or "basic services" as they wish (i.e. in accordance with the categorization of economic sectors they use themselves) as long as this is well described in the metadata (United Nations General Assembly, 2016, p. 7).

UNISDR (2017, p. 94) clarifies that "disruptions" include: "interruptions, either single or multiple, short or long, of the services, damage to the facilities or networks that provide the service, or a measurable/noticeable reduction in the quality of the service, or reduction in the population covered by the service, or a combination of all the above." On pages 93-94, UNISDR further clarifies how they perceive that countries should count the number of disruptions, treat the compound indicators D-1 and D-5 and the "units" of different critical infrastructures (indicator D-4).

JRC and **IRDR** are aligned with UNISDR in terms of target D (i.e. highlight reporting on the number of damaged/destroyed educational centres and health facilities and provide suggestions on - but do not stipulate – other sectors that may be important to assess in terms of affectation levels (De Groeve et al., 2015, pp. 12-13; IRDR, 2015, p. 17). JRC also stresses the need of assessing the ratio (percentage) of damages in relation to the asset values (Ríos Díaz et al., 2018, p. 28). Neither JRC nor IRDR address the need of collecting and reporting on the number of disruptions in basic services.

Temporal aspects of data collection

An important challenge associated with data collection is temporal aspects for attributing losses to specific disasters as well as deciding on what cut off times should be selected, if at all, for data collection. UNISDR, provides some reasoning and tentative ideas on suitable cut-off times for different types of disasters (2017, pp. 10, 12). As opposed to UNISDR, JRC does not suggest any cut-off times for collecting data. For slow onset disasters, e.g. droughts, where a start and an end date cannot be determined, the JRC suggests that the validFrom and the validTo must be the dates of occurrence of the first and the last damages or losses caused by the disaster (De Groeve et al., 2015, p. 8-9).

Metadata

Loss databases should be evidence-based and transparent. Providing metadata is central to this aim (i.e. information that clarify the basis of assessments, such as who made them, when and how). UNISDR stresses the importance of clarifying which economic sector and critical infrastructure categorization countries use when collecting data and estimating losses (2017, pp. 62-63) or the methods, formulas and input values for calculations (2017, p. 69). In addition, Annex 1 in the technical guidance on the monitoring and reporting of SFDRR progress (2017, pp. 69-74), specifies required and desired metadata with regards to different indicators. JRC points out that the format for metadata should be compliant with INSPIRE and contain information such as entry date, author, sources and methodologies used for assessing the damage (De Groeve et al., 2015, p. 11; Corbane et al., 2015, p. 281).

In addition, JRC as well as IRDR (2015, p. 7) recommend to include information about the level of uncertainty with which estimates are given (so called validation status). An approach to loss data quality assessment was proposed in De Groeve et al. (2014, pp. 56-57 and Annex 2 in the same report), which merges an update of the uncertainty classification framework of Skeels et al., (2010) and the Pedigree parameter of the numeral unit spread assessment pedigree (NUSAP) method (Boone et al., 2010). The following uncertainty types are considered: measurement, completeness, human error, disagreement and credibility. For each criteria, a quality score (ranging between one and five) is assigned. Following this approach, a score of Pedigree matrix can be established for each loss indicator and a global average (i.e., the average of all Pedigree matrices scores) can be used to assess the quality of the current system in the country (De Groeve et al., 2015, pp. 19-20).

3.2 Predictive

Proactively ensuring critical infrastructures, vital societal functions and critical flows is of utmost importance for a well-functioning society. In today's interconnected society, there is also a need for an increased focus on the repercussions of dependencies between systems, infrastructures and flows, which affects how and to what extent effects are spread across actors, sectors, and national boundaries. Disruptions in above infrastructures, functions and flows often have large and far-reaching consequences at both national and international levels, which ultimately also affects the local level and individuals. Further, there is numerous different hazards and threats that can lead to extensive disruptions and entail large societal impacts. Hence, systematically addressing these in proactive all-hazard approaches is hence also extremely challenging. The proactive management of risks and vulnerabilities related to societal safety and security issues can be summarized as extremely complex, as the responsibility is divided between a diversity of both private and public actors at different levels in society and a large set of hazard and threats need to be addressed. As such, there exist a very large variety of methods towards achieving this, all with their specific and varying data requirements. This section aims at giving a brief overview of relevant predictive methods and an overarching account of the data that they require. This account should not be considered exhaustive, but as a summarization and a highlighting of the most prominent methods and adherent data.needs. We have deliberately omitted some relevant methods and frameworks, such as HAZUS and flood risk methods, as they are covered by the parallel studies performed Karlstad University and Mid Sweden University.

The authors have been involved in several both scientific and commissioned projects and several commissioned projects relating to predictive approaches and data needs for addressing cross-sectoral risk and resilience management of critical infrastructures, critical flows, cascading effects, and societal consequences of disruptions. Based on these experiences, we here summarize and reflect on available data and methods and potential gaps relating to this.

As a baseline for the discussion of predictive methods and data, the following commissioned reports for MSB have been used:

- Guldåker, N., Johansson, J., Arvidsson, B., Svegrup, L., (2019). Utvecklad riskhantering för samhällsviktiga verksamheter avseende översvämningsrisker (Developed risk management for critical infrastructures and vital societal functions with respect to flood risk), MSB1352, ISBN 978-91-7383-919-8.
- Johansson, J., Arvidsson, B., & Tehler, H., (2017). Kunskapsöversikt säkra flöden, försörjningssäkerhet och kritiska beroenden (Systematic review: Secure flows, Security of supply and Critical dependencies), MSB1115, ISBN: 978-91-7383-759-0.

- Johansson, J., Hassel, H., Petersen, K., & Arvidsson, B., (2015). Metoder för konsekvensanalys på samhällsnivå (Methods for analysis of societal consequence), MSB906, ISBN 978-91-7383-595-4.
- Johansson, .J., Svegrup, L., & Hassel, H. (2015). Studie och översiktlig utvärdering kring applicerbara metoder för komplex beroendeanalys på såväl sektoriell som tvärsektoriell nivå (Analysis and overview of applicable methods for complex interdependency analysis at sectoral and cross-sectoral level), MSB904, ISBN 978-91-7383-593-0.
- Hassel, H., Johansson, J., Petersen, K., & Svegrup, L., (2014). Kunskapsöversikt – Skydd av samhällsviktig verksamhet (Systematic review – Critical infrastructure protection), LUCRAM report 3001, Lund University, Lund, Sweden.

The above findings are also complemented by more recent insights gained through various scientific reviews, research activities, and case studies. References to other activities and publications as also made throughout the text.

3.2.1 Critical Infrastructures

In Johansson, Svegrup and Hassel (2015), we presented a systematic inventory and evaluation regarding applicable methods for interdependency analyses of critical infrastructures at both sectoral as well as cross-sectoral levels aiming towards a more resilient society. The inventory and evaluation were based on in a total of 199 scientific journal articles that made the final inclusion process (resulting from a filtering process that initially comprised 2779 initial search articles, of which 324 deemed as relevant in a first inclusion process). Within this study, we also carried out an analysis of MSB's needs in this area through a workshop based on a number of evaluation criteria. The overall conclusion was that some methods might meet the needs of MSB, but in many cases extensive data collection together with further application and evaluations of the methods is required, and in some cases further method development and method adaptation was deemed necessary. Eight different overarching type of methods can be discerned in the scientific and grey literature, which are briefly described below. These categories are based on the report Johansson et al. (2015) but are well in line categorizations used in similar studies (see e.g. Ouyang, 2014).

1) Frameworks for describing and mapping interdependencies

In this category frameworks are included that aims to describe and map interdependencies between critical infrastructures and vital societal functions. These type of frameworks provide support for increased understanding of the phenomena by discussing important aspects of interdependencies that should be taken into account and how they can be described. Sometimes these frameworks also provide some guidance on how an analysis could be carried out, however usually with quite limited data and analytical support (e.g. visualization of interdependencies). A seminal, and well cited, framework in this field is the one proposed by Rinaldi, Peerenboom & Kelly (2001). Another example of a framework is the one developed by MSB (then KBM) around 2008-2009 as described in the report "Faller en, faller då alla?" (MSB, 2009). This framework supports how to identify and evaluate dependencies of a societal activity or function through expert assessments. A number of categories of dependencies are addressed (Values and regulations, Personnel, Infrastructure, business-related systems, Capital, Services, and Information). There is also number of suggestions on how aggregated data can be visualized and initial analyses of dependencies can be carried out, however there is very limited methodological support for data collection, aggregation and analysis.

2) Empirical methods

Empirical methods focus on analysing impacts of disasters and interdependencies of critical infrastructures based on past events (see e.g. Zorn et al., 2016, Johansson et al., 2015a; Van Eeten et al., 2011; Luiijf et al., 2009; Rahman et al., 2009; McDaniels et al., 2007; Zimmerman and Restrepo, 2006). This is done by collecting disturbance, consequence and interdependency data of past crisis and disaster in a database, regularly from secondary sources, e.g. news articles and internet, and more seldom from direct sources, e.g. infrastructure databases, accident reports, and interviews. Methods in this area are used to, for example, quantifying the strength of interdependencies between infrastructures and the impact on society of infrastructure disturbances. The result from such methods can then be used to complement expert judgements and inform predictive dependency models. As the approach is based on empirical evidence, of course, phenomena that have not yet occurred cannot be captured and it might be hard to extend the use of the data unless contextual information is also captured.

3) Agent-based methods

Agent-based methods use a so-called bottom-up perspective, which means that the system is built on the basis of interactions between, so-called, agents (see e.g. Basu et al, 1998; North, 2001; Ehlen et al., 2005; Dudenhoeffer et al., 2006; Kaegi et al., 2009). Critical infrastructures can be viewed as complex adaptive systems, which allegedly agent-based methods are fit to handle. The basic assumption for the approach is that all complex phenomena arise at a system level through the collective action of individual agents. A descriptive example of agent-based models is the modelling of the spreading of viruses through the interaction of humans and animals. Each agent interacts with other agents in their environment based on a set of rules, which for example can be based on how real individuals likely acts. Applications of agent-based models tends to have a very specific focus, such as for example pricing or market structures, as otherwise the models quickly become too extensive and unmanageable. Agent-based models are also often combined with other types of methods. One negative aspect of agent-based models is that they tend to be hard to validate. Regarding data, typically quite micro-level data (such as the behaviour of individual persons or components of a system) is needed regarding the agents and the interactions of agents, which might prove hard to collect.

4) System dynamics methods

In contrast to agent-based models, system dynamics methods take a top-down perspective (in contrast to agent-based methods), which means that it is system level that is in focus (see e.g. Sterman, 2000; Brown et al., 2004; Min et al. 2007;

Stapelberg, 2008). System dynamics methods can be said to be applied systems theory (e.g. Forrester, 1994). The fundamental concepts in systems theory consist of feedback loops (which indicate dependencies between variables in a system), stocks (the accumulation of resources) and flows (the rate of change of resources). Methods based on systems theory mean that the system is mapped through so-called casual-loop diagrams (describing causal relationships between different variables) and stock-and-flow charts (describing the flow of information and products through the system). System dynamics methods then utilize mathematical descriptions (differential equations) of relationships between different variables in the system to simulate how the system behaves in the event of disturbances and changes. The main use of system dynamic methods is decision-making at an aggregated system-wide level. Normally these types of models and methods requires the collection of quite extensive and specific data to and expert knowledge of setting up the model and carry out analyses.

5) Input-Output methods

The original input-output model was proposed in 1941 by Wassily Leontief (1941) and describes the economic equilibrium, for example, national or regional level across a variety of interacting sectors. In simple terms, a country's economy is divided into different industrial sectors and the accounts describes how many units each sector must trade from other sectors to produce one unit of output. This type of models can also be used in critical infrastructure context by analysing dependencies between sectors of society and the effect of disturbances on economic sectors (see e.g. Svegrup et al., 2019; Haimes et al, 2005; Leung et al., 2007; Barker et al., 2010; Setola, 2007, Rose et al., 1995, 2005). A variety of the more general versions of input-output models is the inoperability input-output model (IIM) and its dynamic extension (DIIM) (see e.g. Haimes et al., 2005). These models can be used to analyse how a disturbance in one or more economic sectors can cascade across the sectors and estimate the consequences that arise, as expressed in inoperability or in economic consequences. Hence, the interdependencies between sectors are hence here approximated with their economic dependencies (and hence thus limits the usefulness of the models). These methods are mainly valid for the long-term effects (month/year) rather than short-term (hours/days) of disturbances (see e.g. discussion in Svegrup et al., 2019). The major benefit if using these this type of methods is the, in many cases, readily available national economic data, as systematically collected for a large number of countries (see e.g. OECD database or the World Input Output Database[11]).

6) Infrastructure-based methods

In the scientific literature related to critical infrastructures, many approaches take a more technical infrastructure perspective by modelling components and interactions between components to attain a system level understanding of

[11] https://www.oecd.org/sti/ind/input-outputtables.htm and http://www.wiod.org/home, 2021-03-25

interdependent critical infrastructures. Here the infrastructures and the interdependencies are often modelled using either network theoretical based approaches (e.g. Zio et al., 2011; Hines et al., 2010;, Dueñas-Osorio et al. (2007), Apostolakis et al., 2005, Lee et al., 2007; Patterson et al., 2007; McCarter et al., 2018) or more engineering based approaches (e.g. Johansson et al., 2011; LaRocca et al., 2014; Landegren et al., 2016). For a comparison of the accuracy and validity of these two different types of approaches for guiding decisions, see e.g. Johansson et al. (2012) and LaRocca et al. (2014).

In network theoretical approaches, only the most salient properties of the infrastructures are modelled by using two component types: nodes (e.g. junctions, power substations, etc.) and edges (which connect and describes a relationship between the nodes, e.g. a road, a power line or a dependence to another infrastructure). In these cases, no or extremely simple models are used to describe how the network respond at system level when the network is disturbed in terms of removing nodes and/or links (either from a vulnerability perspective or linked to a threat/hazard model). Hence, these types of methods mainly focus on system behaviour from a topological perspective (e.g. how connected the system is after a disturbance by using various measures). Engineering based approaches takes also the physical and functional aspects (e.g. flow of traffic, electricity, or water) of the network into account. Hence, they describe how the network responds to disturbance in a more realistic way. Accordingly, these types of models are preferred in both scientific and practical engineering practices if studying the detailed behaviour of individual infrastructures, but cumbersome and computer intensive to use for interdependent infrastructure analysis. Network approaches tends to be far less computationally expensive and in need of far less data, as compared to engineering approaches. Hence, network analytical approaches have been popular in the scientific community when analysing interdependent critical infrastructures at a system-of-system level, however but their accuracy and usefulness is often questioned by infrastructure experts. Currently and moving forward, more engineering based approaches seems to gain ground also in the scientific community for addressing interdependent critical infrastructures.

To a large extent, infrastructure based approaches models a "one-to-one" representation of the real system. Hence, it is relatively straightforward to e.g. simulate impacts of hazards and threats on the infrastructure, identify critical components and to evaluate the effects of various improvement measures. However, data collection and modelling can be very extensive and analysis requiring expert domain knowledge, which often puts limits on the number of interdependent infrastructures that can be simultaneously addressed and the level of detail that can be attained.

7) Flow-based methods

Flow-based methods focus on addressing flows in society at a more abstract level compared to the more detailed infrastructure based approaches, as further explored and discussed in Section 3.2.2. Flows can be described as the movement of for example goods, services, people, energy, capital or information. Instead of describing interdependencies directly between different infrastructure nodes or actors, flow-based methods commonly instead describe interdependencies of different functions and flows at a more aggregated level. Then infrastructures and actors either depend upon or influence these flows. Flow-based methods can be used to identify critical flows from a holistic dependency perspective and connect to various types of risk and vulnerability, continuity and capability assessments. Furthermore, they also enable analyses of the effects of policy measures, for example by either by making flows more robust or by reducing dependence on flows (such as securing national supplies). However, as not modelling the detailed level it is harder to guide decisions towards e.g. specific infrastructure improvements and the effects of these. Input data is currently mainly based on expert assessments, as otherwise data collection will be extensive. Example of flow based methods is one developed by one of the authors and applied in a municipal context (Johansson et al., 2106: Svegrup et al., 2016) and one method for mapping (but not analysing) flows (Toubin et al., 2012).

8) Hybrid methods.

Naturally, there also exist many so-called hybrid methods where the different types of models and methods, as described earlier, are combined. The main reason for hybrid-methods is to try and utilize the advantages of each method and available data, and minimizing disadvantages, by modelling and analysing different parts of a system (or system-of-systems) with different methods to attain a more holistic system understanding (see e.g. Bush et al., 2005; MacKenzie et al., 2012; Johansson et al., 2013; Svegrup et al., 2019). The results from hybrid models can be used to investigate and illuminate longer chains of dependencies and wider assessments of impacts, e.g. to go from component level in an infrastructure (utilizing an infrastructure based approach) to consequences that arise at a societal level (by e.g. utilizing economic input-output models or utilizing societal vulnerability approaches, e.g. SOVI or BRIC as described later), see example in Svegrup et al. (2019). The main drawback of hybrid-methods is the need of expertise in several domains to apply the combination of methods and increased data needs to populate the models.

3.2.2 Critical Flows

Critical Flows is a recent and complementing perspective to the Critical Infrastructure perspective. The difference between flows and infrastructure from a Swedish crisis management perspective can be thought of as in line with the difference between upholding vital societal functions (c.f. flows) compared to upholding vital societal activities/organizations (c.f. infrastructures). Hence, Critical Flows takes as slightly different and more aggregated perspective (see e.g. Lindström & Johansson, 2020, 2021), where e.g. infrastructures can be viewed as the enabler and upholder of critical flows. The perspective of Critical Flows has recently attracted an increased policy attention in Sweden in line with current discourse towards increased focus on Total Defence activities, as for example evidenced by a joint Nordic report relating to securing critical flows in the Nordic countries (Aula et al., 2019). There is also an ongoing research project, financed by MSB during the period 2019-2024, focusing on critical flows, in which one of the authors is active.[12]

In Johansson et al. (2017) a systematic knowledge review related to Critical Flows is presented. In total 394 articles were reviewed from 220 different journals (out of an initial scoping of 1173 articles). The main focus of the report was to shed light on research and identify research gaps regarding preparing, anticipating, responding to, securing and managing disruptions in the sectors: Transport, Food, Energy, Information and communication, and Health care. In total, 15 cross-sectorial and 25 sector specific knowledge gaps were identified, not outlined in detail here. Overall, it was clear that the majority of the research has a clear focus on security of supply, with a much lesser focus on dependencies and securing flows. Furthermore, the literature is dominated by the perspectives of securing, responding to and anticipating disturbance and only to a very small extent the perspectives of preparing for and managing disturbances where covered. The research is further mainly conducted from a national or international perspective, where only few articles addressed the local and regional level. One overall conclusion is that the field of critical flows is not a specific research field but rather a subset or a perspective in a large number of research disciplines with different conceptual, methodological and contextual points of departure, where a large diversity of, for example, models and methods are used to address specific research questions. Another overall conclusion is that the research area of Critical Flows has strong connections with the fields of Critical Infrastructure, Supply chain management and Security of Supply. Hence, this diversity and need for different methods and data hence strongly highlights the need of cross-disciplinary approaches and a breadth in the type of data that needs to be collected and utilized.

3.2.3 Cascading Effects and Societal Consequences

Cascading effects and societal consequences is also very closely related to the previous fields of critical infrastructures and Critical Flows. It can be viewed as a sub-part of these more overarching fields, but with a specific emphasis on understanding cascading effects that arises due to interdependencies and in more detail exploring the societal consequences that arise at a societal level. Cascading effects can be described as "[…] the dynamics present in disasters, in which the impact of a physical event or the development of an initial technological or human failure generates a sequence of events in human subsystems that result in physical, social or economic disruption." (Pescaroli and Alexander, 2015). From an incident/event perspective it can be described as "An incident can be said to

[12] "Kritiska flöden och försörjningskedjor under hot i förändring" (Eng. "Critical flows and supply chains under changing threats and hazards") is a cross-disciplinary research project 2019-2024 on the topic of critical flows in the society together with Umeå University (Dep. of Political Science), Lund University (Div. of Risk Management & Societal Safety and Engineering Logistics), and FOI.

feature cascading effects when a primary incident propagates resulting in overall consequences more severe than those of the primary incident." (Lönnermark et al., 2016).

One of the authors was involved in a larger EU-project (7th framework programme) termed CascEFF during 2014-2017 (see e.g. Johansson et al., 2015a; Lönnermark et al., 2016). This project was one out of five similar EU projects on the same call focusing on Cascading Effects[13]. All these project set out to improve disaster management of ongoing disasters with respect to increased understanding of and development of decisions support systems. However, on the jointly organized final seminar for these projects[14], it was clear that given the extremely rapid spread of cascading effects there is little to no opportunity to control or set in measures to minimize cascading effects during a crisis (see e.g. Johansson et al., 2015a). Hence, all the projects in the end largely focused on delivering predictive approaches and developing training exercise software for increased understanding of cascading effects. Within the project, we collected detailed data and empirically analysed over 40 major past events involving cascading effects (such as the European power blackout in 2006, UK floods in 2007, Eyjafjällagökull eruption in 2010, and Hurricane Sandy in 2012). To facilitate the data collection and analysis of cascading effects, we developed a framework for categorization of past event data and analysis perspectives (Johansson et al., 2015a). Experiences and lessons learned from this work has also been used as input to suggestion of what type of data to collect in order to enable predictive analyses, as summarized in Appendix B.

Johansson et al. (2015b) is a commissioned MSB report aiming at outlining a foundation and point out important aspects regarding improving consequence analysis at a societal level in Sweden. Consequence analysis at the societal level (or societal impact analysis) is defined as an impact assessment that takes into account the scope and how consequences, due to a disturbance, are spread between sectors of society, functions and activities at a local, regional or national level through dependencies and the resulting overall direct and indirect consequences that occurs in society (c.f. MSB, 2013, pp. 28). Hence, it is closely related to cascading effects – but here with added emphasis on improving consequence assessments. In the report we carried out: 1) a review of public actors' risk- and vulnerability analyses in Sweden to get an idea of current status with respect to interdependency analysis and consequence analysis from a societal perspective, 2) interviews with international bodies (DHS/NISAC, TNO, and JRC), focused towards modelling and analysis of cross-sectoral dependencies, and 3) a workshop with Swedish local, regional, and national public actors to gain additional insights and feedback on the conclusions from the report. In the report an initial framework, based on improving the collection and dissemination of data and information across both private and public actors within the crisis management system, was suggested, opportunities and challenges outlined, and important aspects and need of

[13] The five FP7 projects was CascEff, CIPRNet, FORTRESS, PREDICT, and SnowBall
[14] Cascading Effects Conference, Brussels, March 16-17, 2017.

development of methods and tools highlighted. Here we divided the need of method development and analysis support in accordance with three levels: 1) addressing individual dependencies (e.g. of an actor, organisation or sector - an example of a method for this is continuity management), 2) interdependency analysis (e.g. between actors, organisations or actors), and iii) impact assessment at a societal level (e.g. addressing cascading effects and incorporating societal vulnerability). We concluded that differentiated methodological and analysis support will likely be needed for different vertical and horizontal levels of society, based on e.g. available resources and competencies for carrying out the work.

One concrete method suggestion, that relates to above, is presented in the commissioned report Guldåker et al. (2019). Here we focused on improving the practical work of cascading effects and societal consequence analysis with respect to spatial hazards, and more specifically connected to the EU Flood Directive. Based on existing research as well as local, regional and international analyses and policy work, a methodology for mapping, analysing and visualizing direct and indirect consequences in the event of disruptions in critical infrastructures and vital societal functions was developed. This method was developed in close collaborations with, and on expressed needs, of several involved municipalities, county administrative boards and critical infrastructure operators. The method was mainly developed on the basis of a flood scenario related to the Flood Directive work process (more specifically step 2b in that process), but is considered applicable also to other types of scenarios and crisis management-oriented work processes. Among the challenges for developing a method was the difficulty of using and accessing classified information. The underlying conflict between working preventively and increasing society's ability to handle major societal events and the possibility of a more open collection, analysis and visualization of data must be bridged in some way. Other challenges are about being able to include complex technology within and between many societal sectors and functions as well as ensuring organizational competence and redundancy. Furthermore, it is also a challenge to ensure that visualization of the results on maps does not lead to misunderstandings, which places high demands on transparency in the method process, especially in map production and GIS analyses. Additional challenges concern how the method could be used to develop coordination and a common operational picture of the situation between different actors' dimensioning of crisis preparedness based on different scenarios. In the report we also drew some conclusions of relevance with respect to data and methods for crisis management at a more general level, the most important summarized here. Studies and analyses of indirect consequences in connection to and after events usually require extensive data collection. One problem is that crisis management organizations rarely focus on collecting appropriate data during the crisis. One proposal was hence to build up a methodology, support structure and/or organization with a focus on collecting this type of data at both local, regional and national levels.. This is to later have the opportunity to, for example, analyse the recovery of critical infrastructures and the societal consequences that arise. However, how such a structure or organization is to be built was however outside the scope of the report, but fits neatly in the needs highlighted in this report. Here we highlighted that data collection and analysis resources should suitably integrate a clear GIS-perspective. This as GIS is an important tool for continuous collection, structuring, analysis, maintenance and visualization of valuable data., which can further facilitate decisions about e.g. priorities and measures for improved resilience of critical infrastructures and vital societal functions. In order for collected data to be used for reliable decision support, these processes needs to be quality assured and transparent. We also concluded that most GIS applications focus on identifying vulnerabilities and socially important activities. There is, hence, a great potential in further integrating GIS with societal consequence analyses and to use the system to aggregate and visualize information in support of more efficient decision-making. Another important aspect, is the ability to weigh and rank different types of consequences as a priority basis for preventive measures. Currently, however, there is no universally accepted way of how to value and weight different types of consequences or rank different socially important activities in relation to each other, as this is to a large extent is contextually bounded, i.e. varies from study to study, between different applications and national values.

3.2.4 GRRASP (JRC)

The following is a brief description of GRRASP as a concrete and available tool for data collection and analysis of interdependent critical infrastructures. GRRASP stands for Geospatial Risk and Resilience Analysis Platform and is a platform developed and distributed by the European Commission/Joint Research Centre (JRC). The description is partly based on an extended scholarly visit by one of the authors to JRC Ispra. Italy, in 2017, and continued discussions with JRC since then.

In accordance with JRC, the aim of GRRASP[15] is to provide a platform with the ability to retrieve data from a variety of sources and enable analyses and visualisations with various supported methods and tools. The latter is an important feature, where similar initiatives in the field tends to stop at a platform for sharing GIS and Critical Infrastructure information without analytic support.

It is a web-based GIS-oriented platform. A strength of GRRASP is that it is open-source and is provided free of charge by JRC, and can be downloaded and installed locally on servers. This enables the platform to be used in a Member State to collect and structure, e.g. CIP-related data, where users can work on their own local GRRASP installations (and align with national data security concerns). However, it also means that potential privacy and sharing issues have to be resolved by those who choose to be responsible for the platform. The platform is being developed continuously at JRC and it is also marketed as a platform to e.g. H2020 projects as a way to collect case study data and opportunities to develop

[15] https://ec.europa.eu/jrc/en/grrasp, 2020-11-24

tools. If this succeeds, it can be a good platform with a library of input data and tools to use for analyses.

GRRASP supports loading and visualizing geospatial data in different layers from GIS databases. At present, the main source used, and for which there is direct built-in support, seems to be OpenStreetMaps (which is an open-source database with information entered by volunteers, wherefore the source is somewhat uncertain and potentially less valid for real-life applications). There are also opportunities in the tool to manually draw and add new layers and infrastructures, as well as to load standalone GIS shape files from databases. There are three main analysis tools that are integrated in the platform, briefly described below: 1) Network Analysis, 2) DMCI, and 3) CINOPSYS.

Network analyses (c.f. Ch. 3.2.1) are purely static analyses of the topology of an infrastructure. Classic network measurements, such as different centrality measurements, can be calculated using the tool. As static analyses, among other things, it is not possible to study how e.g. a disturbance in the form of a disconnected line or node has physical consequences for the network (e.g. loss of power supply or water supply) or the time aspects related to the recovery of the network. Furthermore, the focus has so far in the tool has been on analysis of individual networks without support for analyses of interdependent networks. Approaches for analysis of the interdependent behaviour of critical infrastructure and exploration of associated data needs have been addressed previously during the last decade by one of the authors of this report (see e.g. Johansson & Hassel, 2010; Whitman, Barker, Johansson & Darayi, 2017, McCarter, Barker, Johansson & Ramirez-Marquez, 2018).

DMCI stands for "Dynamic Functional Modelling of Vulnerability and Interoperability of Critical Infrastructures and Interdependencies" and has been developed in collaboration between JRC and the Polytechnic School of Milan. In short, it is a generic model (abstract) that can be applied to different infrastructures (mainly technical) with a focus on demand and supply (where details of the infrastructures are abstracted away, for better and worse) as well as dependencies between the infrastructures. As the name suggests, it is a dynamic model where time aspects of for example infrastructure recovery is also included. During the development, the Milan region in Italy was used as a case study. To apply the method, there are challenges towards collecting data, parameterizing the model and verify the accuracy of the model (i.e. through the use of domain experts who try to verify that reasonable results are attained, a disadvantage in itself). In the case study of Milan, Italy, three infrastructures (electricity, gas and transport) was in focus and it took about 3 years to complete the study (of course dependent on invested resources). The advantage of the model is that it is abstract and can be applied to several different types of infrastructures (unlike e.g. more traditional engineering models) and at different geographical levels (e.g. regional, national, international). This is also its major disadvantage as it is not possible to simply use available data on infrastructures (as opposed to infrastructure based approaches, c.f. Ch 3.2.1). Rather, the model must be constructed with expert assessments, adapt the model to the case, and then verify the model. Furthermore, the model focuses mainly on functional dependencies (to the authors knowledge), where geographical dependencies and logical dependencies are not as easily addressed. To fully understand the advantages and limitations of the model and data needs requires further analysis and testing.

CINOPSYS is a tool for analysing financial losses in the event of disruptions in national sectors. The model is based on economic Input-Output data (collected in most countries around the world, see e.g. http://www.wiod.org/home) and is based on a further development of the IIM model (Inoperability Input- Output Model) called DIIM (Dynamic Inoperability Input-Output Model) (cf. Ch. 3.2.1). Simplified, the model is based on economic data of how different sectors within a country trade with each other. Hence only economic dependencies are taken into account. With the model, it can be explored, for example, that the sector "Electricity, Gas and steam" is affected by a reduction (financially or percentage) and how other societal sectors are affected as a result (percentage or financially). As the model is dynamic, further collection of time-related data is also required, e.g. how long it takes for different sectors to economically recover from a disruption. This "dynamic" data is to a large extent lacking and is difficult to obtain or estimate and validate. There is some scientific literature focusing on trying to estimate the recovery time for different sectors, especially related to the electricity sector (e.g. MacKenzie & Barker, 2013).

It is not currently possible in GRRASP to directly link the results from e.g. the DMCI module (e.g. on how certain infrastructures are affected) to the CINPOSYS module to investigate the economic consequences of infrastructure disruptions. The integration of similar approaches, i.e. utilizing models of interdependent critical infrastructures and economic input-output models to be able to track the disruption of infrastructure components to overall economic impact on the society, have been developed by one of the authors of this report (see e.g. Svegrup, Johansson & Hassel, 2019).

In summary, there is potential in the fact that the JRC wants to provide a platform that member states can tailor to their specific needs. If this leads to some form of standardization of data across member states, it would in the longer run enable to more easily share data and experiences to be shared more easily between different member states. The type of data needed to support analysis would relate to critical infrastructure data (network structure, demand/supply patterns, etc.), and economic input-output data (which is available through e.g. SCB) and socio-economic and population data.

3.2.5 INSPIRE Directive

The EU INSPIRE (Infrastructure for Spatial Information in the European Community) Directive (2007/2/EC) entered into force in May 2007 and aims to facilitate the exchange and integration of geodata[16] across EU Member States. The directive was motivated by the apprehension that the hitherto disjointed geodata held by European countries undermined the development of EU policies on environmental issues of common concern. This include the management of hazards, which supersedes national borders, such as floods, forest fires and climate change. The directive pinpoints that EU Member States should collect and publish data related to 34 themes (presented in Annexes 1-3), including many datasets of relevance for disaster, crisis, and critical infrastructure management, which also have been included in the Excel sheet provided by this study (e.g., natural risk zones; population demography and distribution; land cover and use; transportation networks; buildings; energy resources; and orthoimagery)[17]. In addition, the data should be published on-line according to certain technical standards and metadata requirements to make it interoperable across Europe and easier for authorities, companies and the greater public to find and reuse (European Commission, 2021).

The INSPIRE enables a more comprehensive understanding of the consequences of disasters and thereby a better basis for loss accounting, risk modelling, loss compensation, and disaster forensics. INSPIRE allows, for instance, governments to better understand the attributes of different locations and thereby have a better basis for decisions on how to prevent and mitigate the impacts of various disasters. Moreover, by enhancing their understanding of risks at various locations, insurers can set premiums that better reflect actual risks and also reduce the number of fraudulent claims by understanding the areas impacted by events (Department for Environment, Food and Rural Affairs, n.d.).

INSPIRE constitutes a hierarchical structure of geoportals with a common portal at EU level and national portals in each of the EU member countries. In Sweden it is called "Geodataportalen", which is run by Lantmäteriet and available on https://www.geodata.se/geodataportalen. Lantmäteriet is tasked by the Swedish government to coordinate geodata nationally. The coordination responsibility means that Lantmäteriet develops and manages the national infrastructure for geodata. Authorities, regions, municipalities and organizations with public tasks can sign agreements for geodata collaboration and then gain access to geodata and services for public use. It is based on a broad collaboration that includes more organizations and more data and services than those covered by the EU directive Inspire. All authorities, municipalities and other organizations with government tasks can sign user agreements for geodata collaboration.

3.2.6 ORSA

ORSA (Area-based risk and vulnerability analysis) was a development project run by the County Administrative Board of Skåne together with a number of

16 Geodata is information that has a geographical connection. Geodata includes, for example, map data as well as register information about buildings, lakes, roads, vegetation and population (https://www.lantmateriet.se/en/about-lantmateriet/about-us/Vart-samordningsansvar/).

17 The data sets included in the directive have been further specified by technical guidelines (JRC, 2013), which also has informed the current study.

municipalities (Klippan, Åstorp, Perstorp and Hässleholm) as well as Lund University and Malmö University. The project was carried out between 2012-2015 and encompassed two phases. Phase one focused on how individual municipalities could increase the element of GIS in risk assessments and phase two concerned ways to collect and aggregate the results of different actors' GIS analyses at the county level. In addition, it explored how GIS could support operational crisis management work, i.e. when something had actually happened.

ORSA was intended to cover all forms of risks and integrate LSO (a law on the protection against everyday accidents such as house fires and traffic accidents) and LEH (another law on the management of the risk and consequences of major crises and disasters). The GIS analyses and visualization of risks would complement the conventional RVA work by starting from maps that provided an overview of various damaging events in the municipalities, which would then create a better basis for cross-departmental discussions and an understanding of the risks in the municipalities (easier to detect connections between where vulnerabilities and threats are). It was assumed that GIS could provide support in all phases of the risk management process; from inventory of protected objects and risk objects, threats and resources, via analyzes (of the risks, management ability, and the suitability of different risk reducing measures) to presentations of the results, where visualization with maps was seen as an effective means of communication for stressed decision-makers. Two handbooks related to each of the project phases were also produced, which contained examples of how different types of assessments could be performed and which types of data they would necessitate (Blom, Guldåker & Hallin, 2013; Nilsson, 2015). The recommended datasets have also informed the current study and are included in Appendix B.

3.2.7 National Risk Index (NRI)

The National Risk Index was launched by the Federal Emergency Management Agency (FEMA) in the USA during the fall of 2020 and aims to help public authorities, companies and the general public to understand their exposure and vulnerability to 18 different types of natural hazards[18]. As such, it also helps comparing and illustrating the communities most at risk, which e.g. supports the allocation of resources to reduce overall risk in a municipality, county or the country at large. The NRI incorporates hazards specific loss and frequency data with information on the built environment and socioeconomic factors that are decisive for people’s vulnerability and resilience to disasters (FEMA, 2020). These latter factors are rooted in research conducted by Susan Cutter and her colleagues, and stem notably from the Social Vulnerability Index (SOVI) and Baseline Resilience Indicators for Communities (BRIC) outlined in Cutter, Boruff & Shirley

[18] The natural hazards included are: Avalanche; Coastal Flooding; Cold Wave; Drought; Earthquake; Hail; Heat Wave; Hurricane; Ice Storm; Landslide; Lightning; Riverine Flooding; Strong Wind; Tornado; Tsunami; Volcanic Activity; Wildfire; Winter Weather.

(2003) and Cutter, Ash & Emrich (2014). More in-depth information on the NRI is provided in FEMA (2020).

Using national statistics, the NRI offers an alternative, top-down-based, approach to assessing risk that circumvents challenges of aggregating data from disparate authorities as observed with regards to the RVAs required of public authorities in Sweden (Månsson, 2018). The focus on households is also interesting as this has never been analytical foci in Sweden, where authorities typically assess their capabilities to uphold societal functions, but not the abilities that citizens have to fend for themselves. Hence, applying such indices could be a valuable supplement to the RVAs produced by Swedish authorities today, notably for directing public resources to areas where community resilience is deemed low. Yet, the SOVI and BRIC indices are developed in the USA and incorporate variables that do not fully agree with the socioeconomic realities in Sweden (such as race/ethnicity; health insurance coverage; ratio of mobile homes). However, one of the authors of the current study has supervised two master's theses (Wagner, 2018; Khairallah, 2020) that specifically scrutinized how the SOVI and BRIC indices can be adjusted to suit the Swedish context. The findings of these theses are incorporated into the suggestions of datasets listed in Appendix B, along with variables on household level resilience and vulnerability suggested by other researchers beyond the inventors of the SOVI and BRIC indices.

3.2.8 INFORM

INFORM is a global tool for assessing the risk of humanitarian crises and disasters. It aims to identify countries and regions at risk of humanitarian emergencies that could overwhelm national capacities and lead to a need for international assistance. Initiated in 2012 by the Inter-Agency Standing Committee and the European Commission, INFORM sought to address a situation where many different organisations were trying to find ways to understand the risk of disasters to help them prioritise their activities and allocate limited resources. These initiatives were trying to do the same thing, but they were agency-specific and not widely shared (and some were prohibitively expensive). To address these problems, it was decided to create a completely open-source tool that specifically would address disaster risk and that all actors could use. Thus, INFORM is not just a tool for humanitarian actors, but freely available to governments, development agencies, DRR actors and others (European Commission, n.d.).

INFORM creates a risk profile for every country by combining around 50 different indicators that measure three dimensions of risk:

A) Hazards (events that could occur) and exposure to them
B) Vulnerability (the susceptibility of communities to those hazards)
C) Capacity (resources available that can alleviate the impact).

INFORM was scrutinized as part of this study to discern whether it comprised indicators of value to disaster risk management in Sweden. However, whereas the indicators are relevant to distinguish the vulnerability of countries at large, they are not suited as a basis for comparing risk in different parts of one and the same country (and hence of less relevance to MSB and actors with a geographical area of responsibility, i.e. county administrative boards and municipalities). Moreover, the indicators are (and understandably so) focusing on issues that are more pertinent in developing parts of the world than in a stable well-fare state like Sweden[19]. For these reasons, we decided to refrain from incorporating INFORM indicators as part of the suggested datasets in this study.

[19] Examples of indicators include development aid (received) per capita; the amount of "uprooted people" (i.e. persons that have been forced to move); malaria mortality rate; prevalence of undernourishment; literacy rate; access to electricity; and the percent of internet users (Marin-Ferrer et al., 2017, p. 69).

4 Gaps and Discussion

There is always a need to strike a balance between collecting and collating data and the purpose for which the data is intended to be used for. The enabler of connecting data with a purpose is analysis capability, operationalized in terms of models and methods. Hence, there is a clear link between data, analysis methods and purpose, where decisions and constraints in one affects the other. This process is sometimes executed from left to right. This means that based on available data, one seeks models and methods that fit the data that in the end hopefully fulfils partial parts of the purpose. The reverse order also exists, i.e. the process is executed from right to left. This means that a purpose is clearly defined before models and methods are sought after, or developed, and finally data are gathered and collated to populate these models and methods. Both approaches have their benefits and drawbacks. Whilst the latter likely leads to more useful decisions support, the former entails less cost and time by utilizing already existing data.

Moreover, both data and models/methods comes with constraints. For data these can consist of availability, costs, security concerns, quality concerns, technical constraints (e.g. how to store and upkeep in databases), and resources available for collecting and collating data. For methods and models these can be related to complexity (e.g. what knowledge base is necessary to utilize the method), availability, maturity (e.g. to what extent has the method been validated), and applicability (i.e. does it fit the data and/or purpose). Given these constraints, it is natural to restrict data collection and method development to a specific purpose at a given time. However, as needs and demands shift over time (e.g. new EU Directives, changing societal challenges), new and changing purposes will arise. Hence, if the decision of what data is deemed relevant (and also how it e.g. is categorized) is too integrated and steered by a specific purpose and currently available models and methods, there is a significant risk that the collected data quickly becomes obsolete.

Consequently, we argue for an approach of more broadly collecting data, in the extent it is possible given constraints, that is deemed as potentially relevant from an overarching perspective of disaster, crisis, risk and resilience management. Having more relaxed constraints on the data being collected opens up for it to be applicable for a larger array of current and future purposes. It also becomes a richer source of data, that e.g. researchers can explore and develop specific methods that fit a varying set of purposes. Keeping this in mind, we here explore and discuss gaps relating to empirical and predictive approaches.

4.1 Empirical

Loss data versus operational data

When reviewing the indicators proposed by the UN and JRC, the impression is that their purpose is to contribute to a general understanding of disasters rather than serving as basis for decisions on how to respond to and recover from ongoing disasters. Hence, there is a clear emphasis on disaster loss data and less on operational aspects of disasters and aspects relating to cascading effects. Unquestionably, statistical overviews of disaster losses serve a number of important purposes, including *loss accounting* and *loss compensation*, *forensic analysis*, and *risk modelling* (see section 1.4). Collecting operational loss data, however, is also essential to safeguard lives and livelihoods amidst disasters. Some of this data are embraced by the SFDRR and JRC reporting requirements, others not. UNISDR also points out that information related to several of the indicators in the SFDRR (e.g., B3-B5) may be measured in situ (UNISDR, 2017, pp. 24-25).

Hazard event identification

Another identified gap relates to collection and recording of hazard event identification data. This type of data is important since it e.g., facilitates comparisons of losses from different types of disasters and from the same type of disasters over time (i.e. to monitor trends and calculate Annual Average Losses - AAL). Hence, we believe that MSB should adopt the proposal of JRC, but need to compliment the classifications used by INSPIRE (INSPIRE Thematic Working Group Natural Risk Zones, 2013.) and IRDR (2014) to cover more disaster type classifications than "natural hazards".

In addition to the data fields proposed by JRC, the field "type of cause" (of the disaster).) should also be collected. This is not a data requirement connected to either the SFDRR or JRC, but important input when seeking to prevent and mitigate disasters as well as a basis for compensation claims (i.e. especially relevant in case of man-made and technological disasters). This type of data is also useful for disaster forensics. The data field is included in the Spanish databases CDTE and CNIH and EU's own "e-mars" (for Seveso accidents) and typology of causes can potentially be fetched from these (see Ríos Díaz et al., 2018, pp. 16; 20)

Regarding temporal aspects of data collection, there is a need to decide upon hazard specific cut-off times for the collection of data, as this is a prerequisite for comparing losses from similar types of events over time (i.e. trend analyses). The initial ideas presented by UNISDR (2017, pp. 10-12) could be used as "food for thought".

Aside from stipulating the temporal extent of the disaster by recording start and end dates as prescribed by the INSPIRE directive (De Groeve et al., 2015, pp. 8-9), collecting data with respect to the time of the day for the onset of the event. is important. This may be crucial for the extent to which populations are exposed to and prepared to act in response to different hazards and thereby for the magnitude of consequences that disasters bring about (i.e. "commuter towns" are normally only populated at night, whereas people predominantly reside in industrial and commercial areas at daytime. It is also easier to be "quicker on ones feet" when being awake than being awoken by an alert of an imminent threat). Knowing the time of specific disasters is hence also important in relation to disaster forensics, i.e. to understand root causes of disasters, fundamental mechanisms and impact of contextual factors. This will likely provide important insights that are useful for preventing, preparing for and managing disasters.

Target A

Disaggregating data is helpful to be able to learn, for example, which consequences different types of disasters give rise to or how different segments of populations may be affected and tailor the capacities to respond accordingly. Yet, distinguishing between direct and indirect deaths is difficult and time consuming and unfit to do whilst responding to disasters. However, it could provide useful input to forensic analyses and predictive approaches. Hence, this is a topic for continued exploration and research efforts.

Given that MSB follows JRC's proposal on including the data fields related to hazard event identification, the connection between losses and specific hazards, events and locations (as also recommended by UNISDR) will be sorted for. It is also beneficial to use sex and age disaggregated data (SADD) and the provided Excel sheet abides with the age classifications utilized by UNISDR (2017, p. 15) and JRC (Ríos Díaz et al., 20182018a, p. 26) to enable more detailed analyses. Here it might also be useful to disaggregate age further so the youngest group (0-17) could be broken in at least two, enabling reporting of very young children (e.g. <5 yrs) as this group is physically more dependent on others and have less developed immune systems than older children (UN IGME, 2020; Simon, Hollander & McMichael, 2015). The mortality rate of children below 5 years of age is also an indicator used in the INFORM Global Risk Index (Poljanšek et al., 2019, pp. 14, 51). Regardless of which age categories that countries select, it is important that they stick to these for the entire time span of data collection, i.e. 2005-2030 (UNISDR, 2017, p. 12).

Regarding gender, the recommendation of UNISDR (2017, p. 15) and JRC (Ríos Díaz et al., 2018, p. 26) of only using male/female as gender classes seems reasonable (as also suggested in Appendix A). Yet, as there are people who do not perceive themselves belonging to either of these genders, one could reflect on whether to include additional categories for sex disaggregated reporting. However, using such a fine-grained disaggregation is only possible if the data is to be collected by in situ assessment teams or by surveys (both of which are time-consuming) and in case of living people (e.g. injured/ill or persons with destroyed dwellings). In Sweden it is the Police that registers missing people and the Tax Agency that registers deceased persons. Hence, these would be the prime sources of information on gender, however it also leads to a need of alignment with their gender categorization.

Whilst many researchers (Cutter et al., 2010; de Brito et al., 2018; Fekete, 2009; Flanagan et al., 2011; Garbutt et al., 2015; Ruiter et al., 2017; Tate, 2012; Yang et al., 2015) argue that disabilities complicate, and even might hinder, evacuation and the ability to reduce one's own vulnerability, the variable is difficult to use as the definitions of disability as used by the researchers are diverse. Neither do UNISDR or the JRC specify what they consider a disability. Just recording the number of disabled people does not generate an added value if the purpose of recording such data is to be able to better support people with a potential need of extra assistance. There is obviously a big difference in what kind of assistance one needs if being blind, deaf, paralyzed or mentally impaired. In addition, information about physical or mental disabilities is difficult to get hold of as data are not readily available from a national source (municipalities are the prime bodies responsible for disabilities in Sweden and there does not exist any national database regarding disabilities tied to geographical areas, see Wagner, 2018). The alternative is to task assessment teams to observe whether living people who have lost their homes etc. also are disabled and ask respondents whether missing/deceased persons were disabled, but this is a time-consuming and intrusive activity that most likely would not render reliable outcomes. Hence, as opposed to the UNISDR and the JRC, it might not be advisable to disaggregate persons according to disabilities[20].

UNISDR and JRC do not specify any categories regarding income. However, a screen shot of the Sendai Framework Monitor System (UNISDR, 2017, p. 15) testifies that UNISDR foresee the documentation of affected people with incomes below the global poverty line (i.e. living on less than USD 1.90 per day in 2020). However, in Sweden this measure is void since everyone has incomes exceeding the global poverty line and Statistics Sweden currently considers developing indicators to measure extreme poverty from a Swedish perspective (SCB, 2020). In any case, pure income levels say very little if a person is poor or not if one does not concurringly take the persons' debts and expenses into account. Statistics Sweden's website describes more applicable measures based on an EU and Swedish context (SCB, 2017) and some of these measures can possibly be used instead? (the figures within brackets represent the portion of Swedish citizens belonging to each of these categories):

- Severe material poverty (0.8%)
- Low income standard (6%)
- Low economic standard (14.8%)
- Risk of poverty or social exclusion (18.3%)

Numerous studies correlate lack of financial means with vulnerability, where people with less means are more prone to reside in hazardous areas and in less sturdy homes, are less insured, and generally have less possibility to influence

[20] Despite that we do not think it is viable to assemble information on disabilities in a national database, we acknowledge the importance of considering potential disabilities of missing people as search strategies may have to be adapted if missing persons are blind, deaf, or physically or mentally disabled.

decisions that may affect their safety (e.g., Cutter, 2003; Wisner et al., 2004; Cardona, 2005; Garbutt et al., 2015; Ruiter et al., 2017 and Hallegatte et al., 2020). If aggregated, one may compare vulnerability in certain municipalities or counties by using the proportion of households per different income classes (Ruiter et al., 2017). If feasible to collect, we believe information about the economic standard of individuals may be valuable for analysing the effects of disasters and for prioritizations of resources to enhance public safety.

IRDR's proposal to include the causes of death is worth looking further into, especially since this information is recorded by the National Board of Health and Welfare already ("dödsorsaksregistret"). From the perspective of decision-makers, however, one must question why IRDR only takes interest in documenting the causes of deaths, but not the type of injuries that living persons may have (which e.g. would feed into procurement of needed supplies for hospitals during a disaster). By and large, a lot of the data asked for is not "operational" or at least there are additional loss data that one would like to assemble to have a better appreciation of the needed resources as input to preparedness, response and recovery. This type of data would also be very useful as basis for predictive assessments.

MSB needs to ensure that acquiring information about deceased and missing people (e.g. their age, sex, and potentially economic status and causes of death) from the Tax Agency ("dödsbevis") and the National Board of Health and Welfare ("dödsorsaksregistret"), the Police and Statistics Sweden does not violate any legislations (e.g., the Secrecy Act, GDPR). If so, all this information will have to be collected by assessment teams, which does not seem viable, nor reliable. If not, MSB should also ask the Tax Agency to report where the persons died (the location) preferably in accordance with the NUTS.

Target B

It is also an open question regarding whether or not to distinguish between directly and indirectly affected people since we have not been able to identify a clear (operational) definition of the latter in the material studied. Further, JRC solely consider assembling data about directly affected a minimum requirement (De Groeve et al., 2015, p. 12). Concurring with UNISDR, we believe one needs not only knowledge about the number of damaged and destroyed houses, but also the number and type of people living in these.

UNISDR recommends that people with damaged or destroyed houses are disaggregated based on age, gender, income, disabilities. As pointed out by JRC, however, this level of disaggregation requires cadastral data with a high level of detail that also need to be continuously updated (Ríos Díaz et al., 2018, pp. 25-26). Yet, mindful of the difficulties of recording disabilities (as discussed above), such disaggregation may serve a purpose with regards to people with destroyed dwellings as these may be in need of temporary shelters (including camps). Information on age and sex are here useful as input to the planning of structures and basic necessities (e.g., provision of kindergarten/schools; gender separated latrines and hygiene facilities, sanitary products etc.). In addition, there is reason to have information on the economic status of these people as this is of great importance for the extent to which they are able to recover (rebuild their houses) by using own or public resources. However, there is a need to carefully consider if the value of this kind of disaggregation outweigh the costs of collecting it with regards to people with damaged dwellings who may continue living in their housing units. This type of disaggregation might be useful, but is not an obligatory requirement, and should only be undertaken if it serves a useful purpose and does not entail too much work. In the case of damaged dwellings, there seems to be less of a value of the disaggregation as basis for operational decisions (i.e. response), but potentially for recovery (dependent on the magnitude of damages), loss compensation and forensic analyses. Hence, it is suggested to further contemplate on the cost and benefits of disaggregating the data on persons with damaged buildings.

Moreover, we think IRDRs inclusion of exposed people is illogical in a disaster loss database, as even their definition of the term entails that one may assemble this data before an event has taken place. Assessment of exposure is part of risk assessments and, hence, a basis for predictive approaches rather than empirical analyses. Moreover, we believe their distinction between homeless, evacuated and relocated might be difficult to achieve amidst a disaster, since distinguishing and documenting people according to these different groups is likely administratively extremely cumbersome in a disaster situation with potentially thousands of people that have been forced to leave their homes. In terms of disaster relief, the most important thing is to know how many people that are homeless (and without any form of shelter) at different locations. How many that are homeless can be attained from UNISDR's indicator (destroyed dwellings). A quick (but rough) estimate can be obtained from high resolution satellite images, where the number of seemingly destroyed dwellings can be multiplied by the average sized household in the country. However, whether the houses are destroyed or damaged have to be verified by assessments teams in arrears. Experience shows that many people who have lost their homes in disasters receive shelter by friends and relatives (IFRC, 2012). Yet, one cannot expect relatives and friends to take care of homeless people for as long as it takes to rebuild their houses. For this reason, the rough estimate is a functional base (the overestimation rhymes with the precautionary principle) for planning the volumes of temporary shelters needed to be provided by public authorities. Although it is difficult to see the purpose of dividing people into above groups from an operational perspective, this type of information may nevertheless prove useful from a forensic and predictive analytical perspective.

Regarding disrupted or destroyed livelihoods, UNISDR base the calculations on the assumption that everything that were located in a disaster stricken area also gets destroyed, which is quite a simplification. Moreover, it is uncertain whether Sweden have the "averaged numbers of worker" as per the sectors proposed by UNISDR. If not, one must question whether it is worthwhile to produce. Sweden has a highly industrialized agriculture with very few workers per hectares of agricultural land or livestock. An alternative (and arguably more accurate) way to estimate the number of persons who may have lost their livelihoods is to use remote sensing (high resolution satellite images) in combination with verifications by field assessment teams to find out which workplaces have been put out of action due to the event and have the back office find out how many employees there were in each company (through the Tax Agency).

Target C

It is incredibly difficult to delimit, identify and quantify indirect economic losses of disasters and although both IRDR and the JRC are mentioning indirect and intangible losses (De Groeve, 2015, pp.13, 15; IRDR, 2015, p. 16), they do not provide any methods for assessing them and neither are we aware of any reliable methods to do so. Hence, to keep it "simple" at first and still abide with the requirements of the UNISDR and the EU, MSB is advised only to include direct economic losses until better estimates of indirect effects can be provided (potentially as proportional rates to direct losses). From a predictive perspective however, data regarding indirect economic losses is very valuable (e.g. connecting with input-output modelling in Ch. 3.2.1). Looking into this matter should thus be a question for further research. As IRDR mentions that both EM-DAT and CDD embrace indirect loses (IRDR, 2015, p. 21), these databases could be interesting to look into further.

Given that countries are free to choose which economic sectors to include, we here propose to align with the national strategies for the protection of critical infrastructures and vital societal functions. It could also be possible, and perhaps beneficial, to use the sector division as used in national economic input-output accounts as a baseline for improved integration with predictive approaches (cf. Ch. 3.2.1).[21] For a Swedish context we propose to use the 11 sectors that MSB identified as essential in this document, i.e., energy supply; financial services; food stuffs; health, medical and care services; information and communication; public-administration management; safety and security; social insurance; technical municipal services; trade and industry, and transport (first stipulated in MSB, 2011, p. 21 and further specified with sub elements in MSB, 2014, p. 13). To avoid overlaps between the economic sectors listed under indicator C-3 ("Productive assets") and the ones sorted under C-5 ("Critical infrastructure"), we propose that technical infrastructure can be sorted under indicator C-5 (i.e. energy supply; information and communication; technical municipal services, and transport), whereas the other sectors can be sorted under C-3 (i.e., financial services; food stuffs; medical and care services; public-administration management; safety and security; social insurances, and trade and industry). Beyond the 11 sectors that MSB has pointed out as important from a crisis management perspective, there are sectors that still are important to embrace in the calculations of economic losses from disasters. Based on a table presented by JRC (De Groeve et al., 2015, p. 17)

[21] The Swedish I-O data consist of 59 economic sectors. See: https://www.scb.se/hitta-statistik/statistik-efter-amne/nationalrakenskaper/nationalrakenskaper/nationalrakenskaper-tidigare-definitioner/pong/tabell-och-diagram/input-outputtabeller-2008-2016/, 2020-03-31

and, following the recommendations of UNISDR (2017, p. 54), we suggest "education" and "tourism" under indicator C-3 as well as "protective" and "green" infrastructure under indicator C-5. Further inputs as for which sectors to include, could be attained from the sources mentioned in Section 3.1 under "Target C" as well as the databases EM-DAT, NatCatService, EMADD and Desinventar.

Importantly, UNISDR (2017, p. 104) recommends that data connected to each of these sectors should be collected at a type-of-assets (element) level, rather than at the level of the major categories of infrastructure (e.g. transportation would be a critical infrastructure sector, but it contains several types of different transportation modes, e.g. road, railway, air and maritime). This is seconded by the JRC, which contends that the ideal database has a national scope (geographical coverage) but a local scale (high granularity) and that detailed loss accounts makes it easier to aggregate the information from the local, to the regional, national and global levels (De Groeve et al., 2015, pp. 7, 16; Corbane et al., 2015, p. 279). Following this, there is a need to clarify how the sectors under indicators C-3 and C-5 could be disaggregated. As mentioned, IRDR provides some examples of this (2015, p. 17) as do UNISDR (2017, p. 97), which also have been integrated as suggestions in Appendix A (and the supplemented Excel-file). The "Exposed Element Classification" in INSPIRE could be an additional useful basis in these endeavours. Note that UNISDR urges countries that wish to report more detailed losses by disaggregating (e.g. by size and type of asset) to declare this disaggregation by using the metadata specified in indicator C-5 (UNISDR, 2017, p. 99).

In agreement with IRDR and JRC, it is necessary to distinguish between insured and uninsured losses, as this knowledge is instrumental for acquiring an overview of the degree to which stakeholders in different economic sectors are using insurances as protection from financial losses, which also affect the speed with which they – and, in extension, the society at large - are able to recover. In effect, such knowledge may also serve as basis for discussions and demands on liability, i.e. the extent to which the state should assist private property owners through public disaster compensation funds. For this to function, there is a need to find out whether (and potentially ensure that) insurance companies attribute losses to specific disaster events and that this data can be made available as a basis for reporting against the SFDRR.

Target D

UNISDR defines critical infrastructure as "The physical structures, facilities, networks and other assets which provide services that are essential to the social and economic functioning of a community or society" (2017, p. 96). Indicator D-4 focuses on the number of critical infrastructure units and facilities that have been damaged or destroyed, whereas indicator D-8 focuses on the number of disruptions that have occurred within each type of "basic service" defined as "Services that are needed for all of society to function effectively or appropriately." (UNISDR, 2017, p. 97). For this reason, indicator D-4 as well as

D-8 embrace all 11 sectors that MSB highlighted as pertinent from a crisis management perspective, where D-4 also includes the "protective" and "green infrastructure" that UNISDR urges countries to include.

UNISDR suggest reporting on the number of times that health facilities, schools and basic services have been disrupted. Surprisingly however there is no requirement of reporting on the extent of disrupted services. This could for instance include the number of hospital beds and other medical capacities that were lost due to the damages of hospitals/care centers or the number of pupils that normally were served by the damaged/destroyed schools or how many customers that lost access to the basic services and for how long. Such information is not only crucial as basis for response, but also for preparedness planning for potential forthcoming disasters and for predictive approaches. Admittedly, UNISDR discusses such aspects, but omit them from reporting requirements as they are deemed too difficult for many countries to collect and overly complex to aggregate on a global level (UNISDR, 2017, p. 93). Notwithstanding, it is strongly suggested to include extent of disrupted services in an national disaster loss database.

Metadata

We concur with UNISDR and JRC about the value of metadata and suggest that it should be coupled with each information entered in a national disaster loss database. To simplify for persons administrating the database, some of the metadata fields (e.g., the date and time as well as the author) could be automatically assigned given that there is a connection between the metadata fields and the usernames of persons administering the database.

Regarding quality assurances, this is not addressed by the UNISDR, but in tandem with IRDR and JRC we believe it is good practice to reflect upon and convey the uncertainty with which estimates are given. This enables users of the information to weigh/value the information in relation to other inputs and also decide whether or not to collect more precise data before being used for decision support. One such approach for this is to use the pedigree uncertainty levels as proposed by De Groeve et al. (2015, pp. 19-20). These authors propose to assess the certainty of each estimate, but given the multitude of information requirements, this is a quite tedious exercise. For this reason, one could perhaps delimit these assessments to the most pertinent reporting obligations, e.g. the minimum requirements of the SFDRR.

Other observations

A noteworthy gap, is that none of UNISDR, JRC or IRDR put forth recording damages to the environment as a minimum requirement (other than treating the environment as a means for something else, e.g., destroyed hectares of agricultural land or green protective infrastructure). Thus, damages to the environment (e.g., water systems, ecosystems and habitats) does not seem as pertinent as, for instance, economic losses or damages to cultural heritage.

Inspired by the "eMars" database (Ríos Díaz et al., 2018, s. 20) and with the view of using a loss database as input for continuous improvements of the Swedish DRM system, it might for a lessons learned perspective be a good strategy to include a possibility to add observations and contextual factors concerning constraints during response/recovery and how they were solved/managed. Such observations could be done in free-text fields or more organized according to themes, e.g., inter-agency collaboration, communication systems, resources etc.

4.2 Predictive

Integrating RSA and GIS

A major current challenge to the possibility of attaining holistic pictures of societal risks is the quest of aggregating (assembling and synthesizing) risk information from numerous and heterogeneous actors (e.g. authorities at different administrative levels and with shifting mandates, private business and the public at large). Contemporary welfare societies are based on specialization and trade. Whilst the division of labor has been beneficial by increasing the quantity and quality of the goods and services we need, it has also resulted in a fragmentation of knowledge about the processes and resources needed to ensure the functionality of critical infrastructures and vital societal functions. Synchronously, it has generated a need to aggregate that information in order to understand risks to societal safety. In Sweden, this is for example done through public authorities' risk- and vulnerability assessments (RVA).

According to Swedish legislation, all municipalities, county administrative boards, county councils, and a number of national authorities and critical infrastructures are obliged to carry out RVAs to identify and reduce risks within their respective areas of responsibilities. The system is based on a bottom-up approach, where assessments from a local level are input to analyses at the regional level, which in turn are used as the basis of assessments at the national level. Studies show that discrepancies with respect to how these actors describe risks undermine their possibilities of using each other's assessments and, thus, the prospect of attaining comprehensive pictures of risk at various levels of the society (Cedergren & Tehler, 2014; Månsson et al., 2015). Moreover, the time and cognitive strains involved in collecting, synthesizing, and disseminating risk information are key challenges reported by risk managers at all levels (Månsson, 2018; Lin & Abrahamsson, 2015).

Research has shown that visual compilations (e.g. colors, tables, matrices, maps, and diagrams) can reduce these problems by compressing, sorting, and creating overviews of different forms of risk-related information (Eppler & Aeschimann, 2009; Lipkus & Hollands, 1999). These facts create strong motives for exploring whether GIS can facilitate the production and aggregation of the information that is requested of Swedish authorities in connection to their RVA work. Aside from reducing time and cognitive efforts in processing information, the ability of GIS to combine different datasets (e.g. hazardous areas, critical infrastructures, resources) can support overviews of risks and vulnerabilities for individual actors (e.g. a municipality) and aggregation of risk information from different actors, e.g. to create a regional overview based on data from several municipalities and local critical infrastructures.

Although risk information is predominantly spatial and research provides numerous examples of how GIS can benefit DRM (see e.g. Altan et al., 2013 and Tomaszewski, 2021), the use of GIS for RVA purposes is still limited in Sweden. A content analysis of 120 RVA reports, showed that only 30% of these contained maps and most of these were restricted to display boundaries of administrative areas (Månsson et al., 2015). A plausible explanation for this is that risk managers at public authorities generally have poor knowledge of how GIS can enhance their work (Månsson, 2018). The lack of GIS-skills amongst risk managers at Swedish authorities - but also their interest in acquiring it - was confirmed by an electronic survey answered by 83 risk managers across the Swedish DRM system in the spring of 2020 (not yet published). There is untapped potential here, then, to utilize GIS for the production and aggregation of RVAs, but there are currently no trainings in Sweden to meet this demand. Yet, with outstanding research and educational programs in both risk management and GIS, Lund University is well positioned to fill this gap. The division of Risk Management and Societal Safety, the GIS Centre, and the Department of Human Geography are currently contemplating a joint venture to make such courses a reality.

Integration of Critical Infrastructure and Disaster Risk Management

There are several gaps when it comes to integrating critical infrastructure and disaster risk management research and activities. In Hassel, Johansson, Petersen and Svegrup (2014) we present a knowledge overview relating to the field of Critical Infrastructure Protection (Swe: Samhällsviktig verksamhet/funktion). In total a systematic overview of 523 journal articles (from an initial scoping of 2813 articles) is presented. Although the report is a bit dated as of date, much of the identified research and practical gaps are still highly relevant (e.g. as seen also in more recent review studies and the authors being an active part of the research community, see e.g. Rød & Johansson, 2021; Rydén Sonesson, Johansson, J. & Cedergren A., 2021; Arvidsson, Johansson & Guldåker, 2020). One such clear gap of relevance here is that, although existing models and methods for interdependency analyses exist in the scientific literature (as depicted earlier), they are seldom applied in a real-life context and often mainly focus on direct impact for the critical infrastructures (Rød & Johansson, 2021). Hence, methods and approaches for societal impact and consequence analyses of critical infrastructure disruptions is to a large degree lacking. A practical gap is that the suggested methods and approaches tend to be developed for a research community, hence substantial effort is needed to bridge them to a more practical context. There is further a lack of methods and approaches for analysis and governance at a cross-sectoral level – where the majority of approaches focus on supporting decisions within a sector, sub-sector or individual business (Rydén Sonesson, Johansson, J.

& Cedergren A., 2021). Hence, for example, approaches that support prioritization and resource allocation across sectors is to a large extent lacking (ibid.). This leads to a need of research and practical development towards methods for risk, vulnerability, continuity and resilience analysis that integrates and explicitly address interdependencies across critical infrastructures and vital societal functions. This is important as the Swedish disaster and crisis management work has a clear ambition of ensuring holistic approaches that integrates multi-hazard and multi-stakeholder perspectives (Lindberg & Sundelius, 2013) across sectors of society, societal functions and societal important activities. Here it is also of importance that consequence analyses move beyond direct impact on critical infrastructures, business and public activities and also incorporates impact on the societal level (e.g. addressing societal vulnerabilities at a citizen level). From our research experiences, there is also a need for increased attention towards using empirical data and learning from previous disasters, relating to both data and methods. In scientific articles, mainly only media reports are used as a source of information for finding empirical evidence. Hence, there is a need to evaluate and investigate how other sources of information, e.g. geodata, can be used to compile and analyse data from past events by various methods (as discussed in the previous sections). For example, such empirical data to be collected within the UNISDR, JRC, and IRDR frameworks. Lastly, there is also a limited focus on specific threats and hazards[22], where a large part of the research is devoted towards earthquakes, hurricanes and flooding. Much less focus is devoted to other hazards that are relevant from a Swedish perspective, such as climate change, solar storms and heat waves. Further, a general conclusion is that there is also a need for more concrete development of methods, strategies, and analysis of lessons learned related to threats such as terrorism and cyberterrorism in terms of more clearly connecting these type of threats to a critical infrastructure , societal consequence, and disaster risk managment context.[23]

4.3 Integrating empirical and predictive

This study has generated suggestions on a good number of datasets that are deemed useful for empirical as well as predictive assessments. Although the empirical frameworks include information that are useful for response, their main purpose is to be used as basis for predictive disaster risk reduction in line with the goals of the Sendai framework, the guidelines from the EU/JRC and the IRDR upon which the proposed datasets are based. As stated earlier, however, Sweden lacks an agreed upon approach to assess damages in the wake of disasters or major societal perturbations. For this reason, we recommend that MSB initiate studies that complement the current one by uncovering the needs of "operational" data with the view to establish a common template for needs assessment during disasters. In this endeavour, it is prudent to look at which of the loss data in the

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[22] Still valid conclusion as also more recently highlighted in: Arvidsson, B., Johansson J., Guldåker, N. (2020) and Rød, B. & Johansson, J. (2021).

[23] One such recent development in Sweden relates to the project Elvira at Skövde Högskola, https://www.his.se/forskning/informationsteknologi/distribuerade-realtidssystem/elvira/, 2021-03-24.

current report that could be assembled by assessment teams in the field vis-à-vis ought to be collected through remote sensing and by MSB HQ in collaboration with other national authorities (i.e. establish a division of labour and interagency agreements on the collection and communication of data). This is also to ensure that needs assessments during specific disasters do not become stand-alone outputs, but serve the overall reporting requirements as stipulated by EU legislation and international agreements such as the SFDRR and Agenda 2030. To this end, we recommend reviewing and adapting (or adopting) already established needs assessment methodologies and templates, such as those used by the United Nations Disaster Assessment and Coordination teams (UNOCHA, 2018), the Field Assessment and Coordination teams (FACT) of the International Federation of the Red Cross and Red Crescent Societies (ICRC & IFRC, 2008) and assessment teams of the Union Civil Protection Mechanism (DG ECHO, 2010).Further, MSB is advised to consider developing processes and templates that would both support decision-making during response and simultaneously feed in to the reporting requirements outlined in the empirical part of this study and, thus, facilitate comparisons and lessons learned from various events over time. This also extends towards the integration of collected empirical data to improve and support predictive analysis capabilities.

Regarding predictive assessments, the data in Appendix B provides a sound basis for various types of analyses and methodologies. Yet, the table is confined to information acquired through the literature studied and the workshops conducted as part of this study. Hence, there is surely other data needs beyond the ones listed here, however we believe that our lists and discussions are relatively comprehensive. To further validate our findings it is recommended that MSB organises a number of smaller hazard and threat specific workshops (e.g. one workshop per the 5-10 most common hazards and threats in Sweden) where experts on these types of hazards and threats, critical infrastructure experts, as well as disaster managers and responders from various public authorities discuss whether the datasets in Appendix A and B are sufficient or need to be supplemented to assess the risk and consequences of events as well which granularity the data needs to have. The results of these workshops should then be used to enact a similar list as the one in appendix 2 (that comprise the type of dataset needed, the rationale for it and exchange the source column for the recommended granularity) and communicated to all county administrative boards in Sweden so that they can assess whether these data are relevant and/or needs adjustments from their perspective and then collect these data for the county on behalf of all the municipalities and citizens at large.

In this study we have identified a vast amount of data that we deem are useful for disaster and crisis management purposes. In this endeavour, we have let existing requirements and needs related to current and prospective frameworks and methodologies guide us rather than being confined to the availability of data per se. Nevertheless, considerations are needed regarding the availability, feasibility and costs involved in acquiring the data. A logical, and necessary, next step is thus to map whether the desired data exist already or need to be produced, which actor that potentially owns/manage these data, where they are located (websites/platforms), what may be required (in terms of fees/agreements), and any other barriers (e.g. secrecy) that may affect their accessibility. Such a mapping is not only useful for disaster and crisis management in Sweden; it is also a basis for determining the extent to which Sweden complies with the INSPIRE Directive and its calls on governments to ensure access to 34 datasets, whereof many have been highlighted in this study.

4.4 Overarching

The discussions here are based on previously presented findings together with deliberations and input from the workshops, structured according to empirical, predictive and general insights and conclusions drawn.

Empirical

When it comes to collecting and collating empirical data as deemed useful for informing crisis management, in a broad sense, there exist many examples of efforts towards this (e.g. the two previous MSB-databases). However, as also highlighted during the workshops, there still exist a somewhat surprising sense of lack of both data and methods of how to analyse this type of data in this context. Here, there might be lessons to be learned from other fields, e.g. traditional public health research and the methods they use in that field to analyse empirical data (e.g. logistic and Poisson regression methods). However, there are also both good and bad examples of the usefulness of collected data. If collected in a stringent manner, data on past events can prove to be very useful in a risk management context. Examples of this is for example reliability data collected for the Swedish electricity sector in Sweden by the Energy market inspectorate and Offshore databases in the oil- and gas industry relating to failure frequencies and accidents (e.g. North Sea database). To make such approaches successful, we believe that there likely needs to be regulations in place, resources allocated, and ensuring confidence among practitioners regarding the validity of the data. Here it is also important, as also brought up in one of the workshops, that the intended users of the data have knowledge regarding how to access and use the data. An example of where this has failed is the maritime MARS database where users find the database very cumbersome to use. Here one successful venue could be to enable training courses or certifications of users on both reporting and accessing data (c.f. the Strada traffic accident database by the Swedish Transport Agency).

Relating to the granularity of the data collected during crises and disasters, one aspect that has been brought up, both previously in the report and in the workshops, is the need to ensure relatively detailed data on consequences. Not only collecting data relating to dead, injured, economic impact, etc. but also disaggregated by gender, class, age, etc. and contextual factors to improve our understanding on how disasters can strike different groups in society and under which conditions.

When it comes to type of data to collect regarding accidents and crises, it is important to not only collect data directly connected to the consequences that arise but also take contextual and exposure measures into account. This type of contextual data can e.g. relate to geographical extents, weather conditions, enabling or hampering conditions, level of functionality of the system before the event and 'close calls' in terms of contextual factors or exposure levels that given slightly different would have rendered significant different outcomes. These contextual factors are also important when assessing the validity of the data and for filtering the data for analytical purposes. Connected to this is also the need to collect data about the system under normal conditions, as to have a baseline to contrast more extreme event situations. Here for example it could be useful to have some measure of the current capability of the system, in a broad sense, regarding the type of disaster or crises. This could for example relate to what different actors can and cannot do and limits of both the technical and organizational systems. Such information could, for example, be attained from RVAs and incident reports.

It is also possible to use different sources of data that could be useful to collect and collate during a disaster or crisis. One such source could stem from common operational/situational pictures (Swe: lägesbilder) that are enacted and used during various crisis response activities. These can potentially be collected and analysed after an event and relevant data collected during the recovery phase of an event. These normally give a picture of perceptions, needs, abilities, etc. that existed during a crisis, which can be used as useful contextual factors in addition to only consequence descriptions. This, however, would likely require post-processing and validation of the information. Another potential good source of information, frequently used in the research community, is compiled information from social media sources. However, how can this can be used to improve understanding of the dynamics of a crisis (e.g. what happened, who was affected at what time, etc.) needs further exploration.

Predictive

As described earlier, there generally exists many methods towards improved risk, vulnerability and resilience analysis of critical infrastructures, however real-life applications of these type of methods are still rather limited – especially toward interdependency analyses and resilience analyses.[24] When it comes to sector-specific risk management methods tailored towards specific purposes there is generally also a large amount of practically applied methods. Examples include fire and rescue services utilization of GIS-approaches to analyse response time and reliability and contingency analyses within the electricity sector. However, when it comes to methods for horizontally, e.g. cross-sectoral, and vertically (e.g. local, regional to national) some apparent gaps exist. One such example is the need of methods and method support to that clearly describe how actors within the crisis

[24] See e.g. Rød, B., Johansson, J., (2020). Critical infrastructures – How resilient are they? In review for an international journal.

management system can adapt general data at a national level to a specific context at a regional and municipal level, and vice versa (i.e. aggregation of data). Here it is also worth reflecting on who should produces the data necessary for various methods? In a municipality, for example, is it the municipality that is to produce information about a certain sector (e.g. electricity or health care) or is it the sector authority that is to produce the information of relevance to the municipality?

Here, as also highlighted earlier in the report, there is also a clear need of methods towards analysing recovery aspects of large scale disturbances that goes beyond using experiences of previous crises. This also extends to a more fundamental understanding of system vulnerabilities, as not only to build back to previous system, but to build back better. An example of this is the major shift from overhead power lines to underground cables in the electricity distribution system after the storm Gudrun in 2005.

General

Based on our findings and the discussions during the workshops, there seems to be a clear need of integrating and increasing the compatibility between the predictive and the empirical approaches and the use of databases. Aiming at more readily connecting different data sources, methods, etc.

MSB should create conditions for collecting and channelling relevant data from all societal sectors to be used in the crisis management system. In essence acting as a hub for data of importance to the crisis management system. This extends to cross-sector data (horizontally) as well as data for vertical integration (from national, regional to local) – both top-down and bottom-up. In many instances, this does not necessitate collection of new data, but rather as acting as a broker across these levels and ensuring that the data is up to date and continuously working on searching for new relevant data from other authorities and actors. Here, MSB could collect data, and ensure compatibility, from other sectors that actors at for example regional and local levels in the crisis management system would have more difficulties getting access to.

Further, there is an identified need for MSB to collect and encourage the use of data. For example, that MSB collects base-line data and then clearly depicts how it can be used at regional and local levels. Here, there is also room to make efficiency gains in the system – so that not the "same type" of data collocations and analyses are carried out across a variety of different actors when MSB could more efficiently gather required data and carry out the fundamental analyses of relevance to most actors in the crisis management system. An example of where this is already in existence is the work related to the EU Flood Directive in Sweden.

5 Recommendations

Based on the requirements and needs with respect to collecting and collating empirical data about crises and disasters and the data needs for predictive analyses, we here present a summary of what we have deemed the most important recommendations of relevance from a Swedish perspective as highlighted in Chapter 3 and as discussed in Chapter 4. Below lists should hence not be viewed as exhaustive with respect to the findings presented in the report.

Empirical

- **Stipulate hazard specific cut-off times for the collection of data** to enable comparisons of losses from similar types of events over time (i.e. trend analyses)
- **Stimulate further research to the quest of delineating indirect consequences from different types of disasters** (e.g. deaths as well as financial losses and disruptions to critical infrastructures and vital societal functions)
- **Establish a suitable metric to measure the financial means of households** as this is currently lacking but vital for discerning socio-economic vulnerability
- **Develop an approach (templates and procedures) for performing post-event damage and needs assessments** that both feed into the SFDRR and EU reporting requirements (Appendix A) and provide useful input to predictive assessments (e.g. contextual information and lessons learned on challenges and how they were resolved)
- **Ensure good practices with regards to the provision of metadata and probe the feasibility of attributing uncertainty assessments to loss estimates** (such as the pedigree score), which is ways to ascertain the quality of data.
- **Sources for empirical data.** There is a need to evaluate and investigate how different sources of information can be used to compile and analyse data from past events by various methods, e.g. information contained in common operational pictures, field assessments data, news and social media, interview data.

Predictive

- **Aggregating risk information from numerous and heterogeneous actors.** There is a need for development of methods and approaches regarding how to assemble and synthesize results from predictive approaches from heterogeneous public and private actors in order to understand risks and vulnerabilities holistically in a highly specialised and interconnected society.

- **Secrecy and classified data.** The underlying conflict between working preventively and increasing society's ability to handle disasters and crises and the constraints relating to secrecy and classified data must be bridged to enable a more open collection, analysis and visualization of data.

- **Investigate needs of analytical support.** Differentiated methodological and analysis support is needed for various types of actors at different vertical and horizontal levels of the crisis management system, as constrained by e.g. available resources and competencies for carrying out the work. Such an "inventory of needs" is suggested to be addressed in future studies.

- **Improved understanding and methods for addressing interdependencies and cascading effects.** Current risk oriented analyses often mainly focus on direct impact of hazards and threats and disruptions in critical infrastructures and vital societal functions. Hence there is a need, as exemplified throughout the report, to improve current practices and methods to enable inclusion of such aspects.

- **Application of predictive approaches in real-life contexts.** Models and methods for interdependency analyses in the scientific literature are seldom applied in a real-life context. Hence their validity and usefulness can be hard to discern, and further there is hence limited scientific support for guiding policy actions.

- **Inclusion of a broader spectrum of hazard and threats.** Much research is devoted towards earthquakes, hurricanes and flooding towards other hazards that are relevant from a Swedish perspective, such as storms, solar flares and heat waves. There is also a need for more concrete development of methods, strategies, and analysis of lessons learned related to antagonistic threats, such as terrorism and cyberterrorism, in terms of more clearly connecting these type of threats to a critical infrastructure, societal consequence, and disaster risk management context.

Overarching

- **Need of a hub for crisis management data.** Based on our findings and research experiences, there is a need of a centralized hub for data to support the Swedish crisis management system at all levels, including both public and private actors. Data would not here only be limited to collecting specific disaster and crises data, but even more importantly aid in collecting and collating data from all societal sectors and authorities of relevance for crisis management. It our recommendations that MSB explores the potential of taking such a role.

- **Improved support for collection of data.** Critical infrastructures and crisis management organizations rarely focus, due to time and resource constrains, on collecting appropriate data to be used for more detailed empirical analyses and predictive approaches during a crisis. Hence, one recommendation is to further study how support structures and/or organizations with a focus on collecting this type of data at both local, regional and national levels can be achieved.
- **Expanded and improved utilization of GIS.** GIS is an important tool for collection, structuring, analysis, maintenance and visualization of valuable data for decision support. There is a great, largely untapped, potential of expanded and improved utilization of GIS connected to empirical analyses, risk and vulnerability assessments, critical infrastructure interdependencies and consequence analyses at a societal level (societal impact analysis). Hence it is recommended support and aid research and practical work towards such a direction.
- **Validate and refine the findings of this study** (notably the comprehensiveness and granularity of datasets provided in Appendices A and B) through workshops with a varied groups of experts and share the updated recommended list of useful datasets for DRM purposes with relevant actors in the Swedish crisis management system.
- **Assess the availability and accessibility of proposed datasets** of the study by conducting further studies to delineate whether proposed datasets exist already or need be developed, who possesses the datasets and how they can be made available to other stakeholders in the Swedish crisis management system (including assessing potential barriers and remedial actions to this end)
- **Integration of empirical and predictive approaches**. There is a need of approaches and structures that supports and integrates a) the empirical reporting requirements as outlined in the empirical parts of the report, b) decision-making during response, and c) predictive analysis capabilities as outlined in predictive parts of the report. It is hence recommended that further research and practical work is taken in this direction.

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Appendix A

Table A.1. Required loss data for meeting SFDRR and EU minimum reporting requirements and beyond. This table is further explicated by an Excel sheet ("Essential-data_SFDRR-JRC") which has been separately communicated to MSB.

Aspect/data type	Minimum data requirement	Desirable data	Additional background data needed
Hazard Event Identification	• Geographical information (local, regional and national units of administration) • Hazard event classification number • Hazard type classification • Temporal information	• Hazard name ("denomination/epithet") • Geographical coordinates to indicate a more precise location of events when applicable • Cause of disaster • Severity level/intensity	• Base maps with administrative units (according to NUTS) & Units of Management demarcated • Maps to visualize the location and geographical extent of disasters
Target A (Mortality)	• # Deaths • # Missing people	• Hazard (event) • Geography (administrative unit) • Age(group) • Sex • Economic status (?) • Cause of death (?)	• Base maps with administrative units (according to NUTS) • Census data (population per administrative area according to NUTS) • Proof of death (dödsbevis) • Cause of death certificate register (dödsorsaksregistret)
Target B (Affected people)	• # Injured or ill persons • # persons with damaged dwelling • # persons with destroyed dwellings • # persons with disrupted or destroyed livelihoods	• Hazard (event) • Geography (administrative unit) • Age(group) • Sex • Economic status (?)	• Base maps with administrative units (according to NUTS) • Census data (population per administrative area according to NUTS) • National registers (folkbokföring) • Average number of persons per household in Sweden • High resolution satellite imagery • Number of workers per disrupted/destroyed workplace (e.g., farms, companies, organizations) within disaster stricken area
Target C (Direct economic losses)	Direct economic losses in: • Agriculture (subdivided in crops; livestock; forestry; aquaculture and fisheries) Losses are calculated as the sum of the:	• For all types of assets: - Hazard (event) - Geography (administrative unit) - Level of affectation (damaged or destroyed) - Owner (disaggregated in the subgroups: Individuals; Business,	• Number of damaged buildings (per economic sector), preferably disaggregated in size • Affected ratio (i.e. estimated damages per productive asset expressed as percentage of

Aspect/data type	Minimum data requirement	Desirable data	Additional background data needed
	1. replacement value of stocks subdivided in input (e.g. seeds and fertilizers) and finished products (e.g. crops and fish) 2. difference between expected and actual value of production the disaster year 3. replacement cost of machinery, equipment and tools (see UNISDR, 2017, p. 61 for required metadata with regards to productive assets within the agricultural sector) • Other economic sectors (countries report according to sectors relevant to their economies). Minimum requirements are number of productive assets of each type, either damaged or destroyed. Losses are calculated as the replacement value of productive assets (buildings, equipment and connections to utilities infrastructure). See UNISDR, 2017, p. 69 for required metadata with regards to productive assets. • Housing Numbers of houses destroyed and damaged (disaggregated) + replacement cost of buildings, furniture and home equipment as well as connections to utilities infrastructure) • Critical infrastructure Type and number of assets damaged or destroyed as well as their replacement/rehabilitation value • Cultural heritage Number and economic values of damaged as well as destroyed non-movable (e.g. buildings, infrastructure, monuments) and movable objects (e.g. art, historical artefacts)	Government; Non-governmental organizations) - Extent to which losses are covered by insurances • Agricultural assets could further be disaggregated in types of cultivated crops; livestock; forests; aquaculture and fishing activities • For other economic sectors: size of facilities (small/medium/large). • Housing can be further disaggregated into: - size of house (small/medium/large) - rural/urban - material (wood, cardboard, masonry, etc.) • Critical infrastructure can also be disaggregated by size of facility (small/medium/large or criteria such as unpaved, single paved, highway for roads)	the total value of the assets) • Average size of houses as well as of productive assets (industries, commercial facilities, public premises) • Average value of stored furniture and home equipment • Average values of construction cost per square meter • Equipment ratio (i.e. the estimated value of stored equipment and products (including raw materials and finished products) expressed as percentage of asset value • Infrastructure ratio (i.e. the estimated value of the associated connections to utilities infrastructure) expressed as a percentage of asset value • market or real estate values (alternatively restoration costs) related to cultural heritage (e.g. monuments, buildings, infrastructure, art and historical artefacts) • Gross Domestic Product (GDP) the year the disaster happened

Aspect/data type	Minimum data requirement	Desirable data	Additional background data needed
Target D (Damages & disruptions to critical infrastructures and basic services)	• # Destroyed or damaged health facilities • # Destroyed or damaged educational facilities • # Destroyed or damaged critical infrastructure units and facilities • # Disruptions to educational services • # Disruptions to health services • # Disruptions to other basic services • <u>Indicator D4</u> For each of the infrastructure types, it is required to declare: - Type of asset (code according to metadata for indicator C-5) - Number of units or facilities of these infrastructure assets damaged/destroyed - Measurement of the damage for network units (in measurement units such as meters or km)	• <u>For Indicators D2-D4:</u> - Hazard - Geography (Administrative unit) - Level of affectation (damaged/destroyed and expressed as a percentage of the total value of the assets) - The size of facilities (small/medium/large) or criteria such as unpaved, single paved, highway for roads • <u>For indicators D6-D8</u> - Hazard - Geography (Administrative unit) - The length of time of the disruption - The numbers of users that suffered the disruption • Denote whether the disruption means one or a combination of the following: - Provision of the service was partially or totally interrupted one or more times - Level of quality of the service was degraded - Coverage of the service was reduced - Service Infrastructure was damaged/destroyed	• Census data (population per administrative area according to NUTS)

Appendix B

The table in below shows the datasets that we have identified as useful for disaster and crisis management purposes, sources that highlight them as valuable for these purposes as well as ideas on how they can be applied for disaster risk management at large. The datasets have been identified from the literature we have studied and two workshops that we organized within the timeframe of this assignment. The table is not complete in the sense that all fields are filled out, but reproduces the information conveyed via the sources we have used. To create an overview, the datasets have been categorized by the authors of this report. In many cases, this division has not been self-evident. Although some data types could be ranked under more than one category, for the sake of simplicity, they have only been ranked under the category to which the authors considered them correlate the best.

Table B.1. Useful datasets for disaster risk management, sources that pinpoint the datasets as useful and examples of application areas

Reference data/maps		
Datasets	**Sources**	**Rationale for including datasets & examples of application areas**
Political maps that show the geographic boundaries between governmental units, such as countries, counties and municipalities.	Blom, Guldåker & Hallin (2013); EW (2021); Inspire directive (2013)	Serve the purpose of orientation and provides context to which other types of datasets (e.g. population, buildings etc.) can be related. Aside from administrative boundaries, political maps normally show other types of features that are pinpointed as important in this table (e.g. roads, cities, rivers and lakes). Administrative boundaries are also of importance to determine who “owns” a certain event (which, amongst other things, are essential for compensation issues)
Municipal overview plans/detailed plans	Blom, Guldåker & Hallin (2013); EW (2021)	Planning evacuation routes, the distribution of emergency water and location of shelters. Knowledge on the concentration of green areas and impermeable ground surfaces is also useful for assessing urban flood risk and the selection of areas for e.g. tent camps, and field hospitals.

Land use/cover registry (residential, industrial, commercial, recreational, agricultural, forestry, and other types of vegetation)	EW (2021); Inspire directive (2013)	To assess potential damages for humans, property and the environment from hazards in various geographical areas; vegetation data is also useful for fire risk forecasts/models.
Cadastre/Land registers (sve: fastighetsregister)	Armenakis & Nirupuma (2013); Dimova (2010); Ríos Díaz (2018); Blom, Guldåker & Hallin (2013); Inspire directive (2013); Tomaszewski et al. (2020)	To e.g. identify the location and owners of hazardous objects, industries and areas as well as vital societal functions (such as critical infrastructure and farms) that need to be protected from harm, equipped with reserve power etc. The Cadastre is also crucial for knowing where people reside (the number and characteristics of people at different places) and, hence, for estimating the damages on the population from different types of hazards.
Topographic maps (digital elevation/terrain models)	Arar & Chenchouni (2012); Başaran-Uysal et al. (2014); Blom, Guldåker & Hallin (2013); Inspire directive (2013); Tomaszewski et al. (2020);	Flood and fire risk forecasts/models; selecting locations for evacuation zones/shelters
Hydrographic data (e.g., marine areas and main water bodies, including large inland waters and river basins).	Inspire directive (2013)	A basis for assessing flood risk potential
Geology (composition and structure, including bedrock, aquifers and geomorphology).	Inspire directive (2013);	Landslide risk forecasts/modeling
Soil (texture, structure and content of particles and organic material, stoniness, erosion, where appropriate mean slope and anticipated water storage capacity)	Arar & Chenchouni (2012); Başaran-Uysal et al. (2014); Blom, Guldåker & Hallin (2013); Inspire directive (2013); Tomaszewski et al. (2020);	Landslide risk forecasts/modeling

Traffic flow (historical and dynamic/real time data)	EW (2021); Tomaszewski et al. (2020)	Input to evacuation route planning; to detect abnormalities indicating and input to GPS algorithms to select the most suitable routes (for evacuation from an area as well as access to that area for response units)
Geo-referenced image data of the Earth's surface, from either satellite or airborne sensors (e.g., oblique aerial imagery and ortophotos)	Dimova (2010); EW (2021)´; Inspire directive (2013)	Assessments of how the development of different areas may have affected the level of risk at different areas over time; assessments of damages from occurred events by comparing pre- and post images (using e.g. "swipe-tool" in ArcGIS)

Valuable assets to protect (sve: Skyddsvärden)		
Datasets	**Sources**	**Rationale for including datasets & examples of application areas**
Population density, incl. demographic statistics areas (Sve: Demografiska statistikområden – DeSO*) * Demographic statistics areas (DeSO) are a regional division below the level of Sweden's municipalities. The division has been developed by Statistics Sweden (SCB) and was introduced on 1 January 2018. Sweden has been divided in approximately 6,000 areas with between 700 and 2700 inhabitants each. The purpose is to be able to produce statistical data for smaller areas over time. Could be used for e.g. assessing and comparing household level vulnerability in different geographical areas.	Adger et al. (2005); Armenakis & Nirupuma (2013); Başaran-Uysal et al (2014); Blom, Guldåker & Hallin (2013); Cardona (2005); Dimova (2010); EW (2021); Fekete (2009); Holand & Lujala (2013); Inspire directive (2013); Ruiter et al. (2017); Tate (2012); Tomaszewski et al. (2020)	To assess the exposure of humans (and their assets) to various hazards/events in different geographical areas (e.g. how many people that live in close vicinity to risk objects; in areas with contaminated water, power outages etc). It is also crucial for preparedness efforts (e.g. the amounts and positioning of shelters; suitable evacuation routes; the location and volume of emergency water tanks etc) Statistics on demography are also fundamental for assessing and comparing household level vulnerability in different geographical areas (e.g. where isolated and marginalized people reside).

Residential homes (incl. number of inhabitants per house/tenement house and number of floors)	EW (2021)	To know the number of people residing at different places is essential for estimating the damages on the population from different types of hazards. Moreover, knowing the number of people residing in each house/tenement house is crucial for planning purposes (e.g. numbers of people needed to be evacuated from risk areas and later sheltered). In addition, cramped housing conditions increase risk of devastating residential fires. The rescue services are also benefitted from knowing the number of floors of tenement houses.
Roads (incl. road type – single/multilane; speed limits; width; direction – one-way/multidirectional)	Armenakis & Nirupuma (2013); Blom, Guldåker & Hallin (2013); Dimova (2010); EW (2021); Inspire directive (2013); Tomaszewski et al. (2020);	To enable assessments of which roads and transports that may be/are affected by floods, storms, landslides etc.; developing evacuation plans; ensure efficient logistics and redirect traffic during disasters.
Railroads (incl. switch yards)	Armenakis & Nirupuma (2013); Blom, Guldåker & Hallin (2013); Dimova (2010); EW (2021); Inspire directive (2013); Tomaszewski et al. (2020);	To enable assessments of which railroads and transports that may be/are affected by floods, storms, landslides etc.; developing evacuation plans and ensure efficient logistics during disasters.
Harbors (incl. water depth and offloading capacity)	Blom, Guldåker & Hallin (2013); EW (2021); Inspire directive (2013)	Provision of necessities from other countries; Planning for incoming resources/outside help (logistics)
Airports and helicopter pads (incl. runway length and width + size of pads and offloading capacities/warehouses)	Blom, Guldåker & Hallin (2013); EW (2021); Inspire directive (2013)	Provision of necessities from other countries; Planning for incoming resources/outside help (logistics)
Fuel stations/depots (incl. type of fuel)	Blom, Guldåker & Hallin (2013); EW (2021); Inspire directive (2013)	To ensure that transportation needs are met

Infrastructure for electricity production (e.g. hydropower, nuclear power plants, wind power plants, solar power plants, district heating plants, power lines, distribution and transformation stations, gas lines).	Armenakis & Nirupuma (2013); Başaran-Uysal et al. (2014); Blom, Guldåker & Hallin (2013); Dimova (2010); EW (2021); Inspire directive (2013)	To prevent and remedy problems with energy supply
Infrastructure for telecom systems (incl. masts)	Başaran-Uysal et al. (2014); Blom, Guldåker & Hallin (2013)	To prevent and remedy problems with telecommunication
Water sources, groundwater reservoirs and water protection areas	Başaran-Uysal et al. (2014); Blom, Guldåker & Hallin (2013); Dimova (2010); EW (2021) Inspire directive (2013)	Important to prevent and remedy problems with drinking water
Infrastructure for water and sewage (treatment plants and pipelines)	Başaran-Uysal et al. (2014); Blom, Guldåker & Hallin (2013); Dimova (2010); EW (2021); Inspire directive (2013)	-II-
Wells/Overview of individual households' access to own water	EW (2021)	To assess household vulnerability/resilience
Waste facilities	Başaran-Uysal et al. (2014); Inspire directive (2013)	To prevent and relieve problems with disaster waste/rubble
Arable land and farms (incl. animal herds and pasture lands)	EW (2021)	To ensure food security and estimate potential damages that may disrupt the availability/provision of food during disasters Note: this data is provided by the Land use and Cadaster registers mentioned under reference data above
Small and large companies that produce food (bakeries and industries)	EW (2021)	To ensure food security and estimate potential damages that may disrupt the availability/provision of food during disasters

Food warehouses	EW (2021)	-II-
Grocery stores	EW (2021)	-II- Grocery stores must be open (even during pandemics) and mobile safety centers (barracks) can be set up next to these (with the possibility to get information, warm up and charge mobile phones) as market forces have made grocery stores located at suitable places and in appropriate numbers based on population density (catchment areas) already
Facilities for elderly care (incl. number of caretakers)	EW (2021)	Difficult to evacuate
Schools and day care centers (incl. number of pupils/caretakers)	Armenakis & Nirupuma (2013); Blom, Guldåker & Hallin (2013); EW (2021); Inspire directive (2013); Tomaszewski et al. (2020)	If younger children cannot be taken care of by public activities, parents who could otherwise be involved in response or upholding other types of societal functions must stay at home. Information on the number of students is also vital in case of need for evacuation. As schools have infrastructure for hygiene and sanitation, they can potentially also function as evacuation centers (yet, one should be mindful that this option creates problems from an educational point of view)
Protected property/areas (Sve: “Skyddsobjekt”)	EW (2021)	To protect facilities and areas (as well as information about them) of importance to the national defense.
Protected nature areas/reserves ("Natura 2000 sites”)* * Natura 2000 is a network of protected areas throughout the EU and has been created to protect certain habitats and species as well as their habitats.	Blom, Guldåker & Hallin (2013); EW (2021); Inspire directive (2013)	To protect environmental values. If natural reserves (e.g. forests) are close to urban areas there is also a risk of forest fires spreading to urban environments.
Species worthy of protection	EW (2021)	To protect environmental values and sensitive habitats

Cultural heritage and buildings of national interests (Sve: “fornminnen” och “riksintressen”)	Blom, Guldåker & Hallin (2013); EW (2021)	To protect cultural values connected to the national identity of the population
Registry for private companies (small and large businesses, incl. tourist attractions), incl. revenues and number of employees	Tomaszewski et al. (2020)	To be able to estimate financial/socioeconomic losses in the event of potential disasters that result in businesses being disrupted/closed

Risk sources and hazardous areas		
Datasets	**Sources**	**Rationale for including datasets & examples of application areas**
Weather data (historical and real time)	Arar & Chenchouni (2012); EW (2021); Inspire directive (2013); Tomaszewski et al. (2020)	Assessments and modeling of the probability and magnitude of weather related events (storms, floods, landslides, forest fires) at different geographical areas periods in time (cf. effects of climate change)
Rainfall (cloudburst) mapping	EW (2021)	To monitor, model and communicate flood risk
Flood risk maps	Blom, Guldåker & Hallin (2013); EW (2021); Inspire directive (2013)	Model, assess and communicate flood risk; to know which valuable assets that are at risk of floods; support prepositioning of emergency equipment
Risk areas for landslides and avalanches; Stability mapping.(Sve: stabilitetskarteringar)	Blom, Guldåker & Hallin (2013); EW (2021); Inspire directive (2013)	Model, assess and communicate landslide and avalanche risk; to know which valuable assets that are at risk of landslides and avalanches; support prepositioning of emergency equipment Note: mapping need input from e.g. soil type and slope (topography) as mentioned in reference data above
Risk areas for erosion of sea shores and coasts	EW (2021); Inspire directive (2013)	Model, assess and communicate the risk of erosion and storm surges; to know which valuable assets that are at risk of landslides and avalanches; support prepositioning of emergency equipment

		Note: mapping need input from e.g. soil type and slope (topography) as mentioned in reference data above
Sea levels	EW (2021)	To monitor and model sea level rise of importance for coastal erosion and the consequences of storm surges
Heat waves/urban heat islands	EW (2021)	To monitor, model, assess and communicate the risk of hot temperatures
Risk areas for drought (incl. reduced risk of groundwater formation)	EW (2021); Inspire directive (2013)	
Risk areas for forest-/wildfires. Fuel maps (Sve: bränslekarta), incl. area/distribution, type, age.	EW (2021); Inspire directive (2013)	To monitor, model, assess and communicate the risk of forest-/wildfires to know which valuable assets that are at risk of forest-/wildfires; support prepositioning of emergency equipment
Geographical distribution of air pollution, chemicals, depletion of the ozone layer, radioactivity etc.	EW (2021); Inspire directive (2013)	To monitor, model, assess and communicate the risk of pollution
Geographical distribution of pathologies (allergies, cancers, respiratory diseases, etc.)	Inspire directive (2013)	
Contaminated land areas (incl. area/distribution, type of contamination)	Blom, Guldåker & Hallin (2013); EW (2021); Inspire directive (2013)	Basis for decisions on decontamination or regulations to prevent exposure; assess risk of further spread of hazardous substances due to e.g. floods
Sites with processes involving dangerous substances (Sve: farliga verksamheter enligt 2 kap 4 § LSO), including industries that falls under the Seveso Act; dams; nuclear facilities, certain airports and mines) + type and volumes of dangerous substances.	Armenakis & Nirupuma (2013); Blom, Guldåker & Hallin (2013); EW (2021)	To model, assess and communicate the risk of accidents with dangerous substances; planning of riskzones and evacuation routes

Transport routes for dangerous substances by road and railroads (Sve: farligt godsleder), incl. type and volumes of dangerous substances.	Blom, Guldåker & Hallin (2013); EW (2021)	To model, assess and communicate the risk of accidents with dangerous substances; see what is located within certain safety distances or to prevent new buildings from being placed within risk zones, or as a basis for the design of new dangerous goods routes.
Public arenas	EW (2021)	Arenas assemble large groups of people, which increases the risk of fires and hooliganism/large-scale violence. Reversely, public arenas may also play an important role as evacuation centers and mass mortuaries (ice-skating rinks in the latter case)
Household level resilience/vulnerability		
Datasets	**Sources**	**Rationale for including datasets & examples of application areas**
Population stability (yearly population change %)	Cardona (2005); Cutter (2003); Fekete (2009); King & MacGregor (2000); Holand and Lujala (2013); Opach et al. (2020); Vincent (2004)	Many researchers claim that large influxes of people into societies where "everyone previously knew everyone", change the dynamics and can make people no longer identify themselves as part of a cohesive group, which can make them withdraw and increase isolation and thus vulnerability. In addition, new migrants that cannot speak the language and are not familiar with where to turn for help, increases overall vulnerability. Municipalities that are experiencing rapid growth may also lack high-quality housing for newcomers. On the other hand, people that move into a community may also contribute to taxes, which can be used to fund measures that increase resilience and vice versa.
Proximity of population to risk areas/objects	Adger et al. (2005); Armenakis & Nirupuma (2013); Başaran-Uysal et al (2014); Blom, Guldåker & Hallin (2013); Cardona (2005); Dimova (2010); Fekete (2009); Holand & Lujala (2013); Ruiter et al. (2017); Tate (2012); Tomaszewski et al. (2020)	Exposure to danger is crucial for the degree of risk and thus for the ability (in terms of awareness and preparatory measures) one ought to have. Note: this information can be derived from demography statistics and the location of the mentioned risk areas/objects (datasets included under the category “Risk sources and hazardous areas”)

Proximity of population to "blue light authorities"/rescuers and other assets that may reduce consequences of events (e.g. shelters, hospitals/care centers)	Cutter et al. (2010); de Brito et al. (2018); Fekete (2009); Garbutt et al. (2015); Holand & Lujala (2013); Marzi, et al. (2019); Scherzer et al. (2019)	Proximity to risk reducing resources naturally reduces vulnerability. The LSO act (Sve: Lagen om skydd mot olyckor) states that there should be a satisfactory and equal protection against accidents and the travel time for emergency services are an important factor of fulfilling that paragraph in the law. Note: this information can be derived from demography statistics and the location of the mentioned assets (datasets included under the category "Response capability of the enabling environment")
Property register about building materials, condition and age	Cutter et al. (2003, 2010); Fekete (2009); Holand & Lujala (2013); Tomaszewski et al. (2020); Van Zandt et al. (2012)	The structure, condition and materials of buildings are important for their vulnerability to stress and whether or not people can use them as shelters in the event of impending dangers (e.g. floods and storms). Many authors rate the vulnerability of buildings according to the years in which they were built (based on the prevailing building standards/legislation at the time).
Age (% of population disaggregated in different age groups)	Adger et al (2005); Armenakis & Nirupuma (2013); Blom, Guldåker & Hallin (2013); Cardona & Carreño (2011); Cutter et al. (2003, 2010); EW (2021); Fekete (2009); Holand & Hulaja (2013); King & MacGregor (2000); Tate (2012); Tomaszewski et al. (2020); Vincent (2004)	The relationship between age and vulnerability is well-documented. Usually one divides the population in different age-groups where the youngest and eldest part of the population are considered the most vulnerable as they often are physically weak and less capable to fend for themselves in cases where physical strength is needed (e.g. when needing to run, climb or swim). In alignment with requirements of the empirical data (and thus aligned with the Sendai framework and JRC requirements), it is suggested to have at least three and perhaps four categories, i.e. 0-17; 18-64; >65 (and perhaps divide the first category in two by including a forth category: <5). See further notes about this in Section 4.1 under "target A".
Mental and physical disabilities (% of population dependent on special care)	Cutter (2010); Armenakis & Nirupuma (2013); de Brito et al. (2018); EW (2021); Fekete, (2009); Flanagan et al. (2011); Garbutt et al. (2015); Ríos Díaz	Although highlighted by many researchers and intuitively understood as factors that may increase vulnerability, there is no consensus on what types of disabilities that increases vulnerability and how (in what ways and how much). Moreover, data about disabilities are not readily available at national level in Sweden, but ought to be assembled by municipalities. This

	(2018); Ruiter et al. (2017); Scherzer et al. (2019); Tate (2012); Tomaszewski et al. (2020); Yang et al. (2015)	is unconfirmed, however, as is the possibility to attain this data due to the integrity of the individuals concerned. Further studies are needed to establish the feasibility of attaining aggregated (de-personalized) information on this variable and its usefulness for planning purposes. Hence, we are currently ambiguous to the feasibility of using disabilities as an indicator for establishing vulnerability/resilience on a household or community level (see further discussion about this in Section 4.1 under “Target A”). Potentially one could use percent of population that are dependent on special assistance (elderly care, personal assistance).
Education (% of population with fewer than 9 years of education)	Arbetsförmedlingen (2018); Armenakis & Nirupuma (2013); Copeland, et al. (2020); Cutter (2003); Fekete (2009); Garbutt et al (2015); Tate (2012); Ruiter et al (2017); Tomaszewski et al. (2020)	Many researchers believe that there is a connection between level of education and vulnerability, where the higher the education, the lower the vulnerability. This is partly ascribed to the positive correlation between education and income, but this relationship is not absolute. Notwithstanding, education is important for the ability to find and understand warning messages as well as crisis information (e.g. advice on self-help) in general. Education levels are also relevant for the Swedish context as unemployment rates are rising among those without a high school diploma, and many of the employments that these people hold are time-limited, hourly payed and/or part-time.
Financial means	Armenakis & Nirupuma (2013); Blom, Guldåker & Hallin (2013); Cardona (2005); Cutter (2003); de Brito et al. (2018); EW (2021); Fekete (2009); Garbutt et al. (2015); Liu & Li (2016); Marzi, et al. (2019); Ruiter et al (2017); Scherzer et al. (2019); Tate	The financial assets of households/individuals are decisive for their ability to prepare for and recover from disasters (e.g. to invest in emergency supplies and insurances). However, income is not the only aspect of importance as household size and adhering expenses (rent, loans, food, clothes etc.) also need to be considered. Section 4.1 (under “Target A”) renders an account of possible measures to use.

	(2012); Tomaszewski et al. (2020); Yang et al (2015)	
Social Security recipients (% of population)	Adger et al. (2005); Fekete (2009); Garbutt et al. (2015); Holand & Lujal (2013); Ruiter et al. (2017); Tate (2012)	Receiving social security contributions is, naturally, an indicator of low wealth and high vulnerability. However, one can also imagine that the social contribution itself helps to reduce vulnerability since it guarantees a minimum level of assets that enables a decent life. How this indicator is to be treated is, thus, an issue for future concern.
Unequal distribution of wealth (GINI coefficient for the administrative area)	Adger et al. (2005); Becker (1968); Cobham et al. (2015); Cardona (2005); Cutter et al. (2010); Lindgren (2019); LO (2019); Ruiter et al. (2017)	Unequal distributions of wealth has the potential to create social unrest and violent crime, which in turn may undermine public trust in authorities and their recommendations in relation to disaster risk management. The Gini index or Gini coefficient is an internationally well-established method of measuring the dispersion of income or wealth among the residents of a nation. If everyone in a nation would have an equal income or wealth, the Gini coefficient would be 0, while a value of 1 would mean a single person possesses all the income or wealth. The Gini coefficient is scalable and could also be adopted to measure the degree of income equality at regional, municipal or sub-municipal levels. However, In 2013, an alternative to the Gini coefficient was proposed: the Palma ratio, which purportedly better reflects changes amongst the richest and poorest in a population. The OECD and UN have now included it in their databases alongside the Gini, so MSB must decide which of these indices that ought to be used (if at all).
Crime rates	Garbutt et al. (2015); Ruiter et al. (2017)	The level of crime in an area affects the population's sense of safety. This, in turn, may undermine public trust in authorities and their recommendations in relation to disaster risk management, not the least to abide by calls to evacuate (due to the fear of burglary).
Number of companies with fewer than five employees/total	Cutter et al. (2010); Kienberger et al. (2009)	Small business owners tend to be more vulnerable and at higher risk of bankruptcy during disasters than larger companies as they often lack

population		financial buffers and do not have a geographical spread that allows income to come from other non-affected regions.
Sector dependence/diversification of income sources (% of population working for a particular industry/sector)	Adger et al. (2005); Cardona (2005); Cutter et al. (2010); Ruiter et al. (2017); Tate (2012), Yang et al. (2015)	Some industries have been shown to be more vulnerable to hazards (such as storms, floods, forest fires, droughts, invasive species) than others, including agriculture, forestry, fishing and the extraction of raw materials. Being dependent on a sector/industry is a vulnerability in itself. In the event of major disasters, people will also hold on to their resources so the demand for household services, such as babysitters, gardening, cleaners and general maintenance will also decrease.
Ratio of public tax-financed employments per capita	Scherzer et al. (2019)	The number of people employed within the public authorities facilitates the response and resupply during and after occurred events. Moreover, public tax-financed employments are safer because they are not dependent on profit margins and are therefore less dependent on economic turmoil in the wake of disasters.
Unemployment (% of population)	Cardona (2005); Cutter et al. (2003, 2010); Fekete (2009); Garbutt et al. (2015); Holand & Lujala (2013); Ruiter et al., (2017); Scherzer et al. (2019); Tate (2012); Yang et al. (2015)	Employment rate is a proxy variable to measure the economic vitality of a community (incl. tax base necessary to undertake risk reducing measures). On an individual level, unemployment is also linked to income level, which in turn have a strong impact on the vulnerability of individuals/households. It is also linked to social inclusion and the possibility of assimilation into societies (from an immigrant perspective), which in turn affects one's ability to seek and attain information about relevant measures to protect oneself.
Swedish language competence and cognizance of Swedish sociopolitical structures and norms (measured by % population with other citizenship than Swedish, incl. type of citizenship)	Armenakis & Nirupuma (2013); Cutter (2010); Fekete (2009); Flanagan et al. (2011); Garbutt et al (2015); Holand & Lujala (2013); Tate (2012); Tomaszewski et al. (2020)	This indicator is indicative of the possibility of digesting/communicating information in Swedish. This is important for the ability to find out and absorb crisis information from authorities and neighbors, as well as to communicate one’s own needs for help in the immediate aftermaths of disasters. Crisis information will always be communicated in the main language of a society before the messages are translated and communicated in other languages. This means that those who speak the

		country's main language have a temporal advantage over those who do not. Furthermore, knowledge about the Swedish crisis management principles and the mandate of different actors is also an asset when seeking information or requesting for assistance during response and recovery from disasters. From the perspective of public authorities, knowledge about the languages spoken in different areas is vital when deciding how to communicate risk/crisis information. Moreover, awareness of the cultural heritage (religions and norms) of the population is also useful during response, for e.g. the provision of psychosocial support and hygiene/sanitation and food in temporary shelters. To become a Swedish citizen, one must have been living in Sweden on a long-term basis for a certain period of time (most often for a continuous period of five years), under which time it is expected that the persons have learnt how to communicate in Swedish and assimilated norms of and knowledge about the Swedish society.
Municipal election participation (%)	Cutter (2010); Holand & Lujala (2013); Marzi et al. (2019); Opach et al. (2020)	Voting participation reflects on how strong a democracy is, which in turn indicates trust for governmental institutions. Participation in elections are also assumed to indicate that people are interested in and involved in the development and safety of their communities, are generally responsible/dutiful and able to be motivated to assist in the protection of their communities.
Ratio of population born in a municipality that still resides in that municipality	Cutter et al. (2010)	Indicator of place attachment/social cohesion, i.e. the feeling of belonging/affection to a place, which affects the desire to help protect and rebuild the society instead of moving away in the aftermaths of disasters.

Ratio of population that are members of civil society organizations (e.g. sport associations, religious organizations, choirs, cultural clubs)	Cutter et al. (2010); Marzi et al. (2019); Scherzer et al. (2019)	Indicator of place attachment/social cohesion. Social networks can provide informal safety and support in crisis and could also contribute to a faster recovery.
Ratio of population that are engaged in either one of the 18 voluntary defence organizations in Sweden	Liu & Li (2016); Tomaszewski et al. (2020);	High levels of organized and trained "disaster volunteers" increase the likelihood of the population understanding how to act in the event of different types of disasters and actually take measures to prevent, prepare for and manage disasters.
Number of public advisories and number of times the municipality has applied for state compensation according 7 Chapter 3§ LSO (2003:778) and/or 5 Chapter 1§ LEH (2006:544)	Cutter (2010); Coulston & Deeny (2010); Liu & Li (2016); Ruiter et al. (2017); Tomaszewski et al. (2020)	Previous experience from disasters and societal perturbations is expected to enhance resilience as decision-makers and the general public are expected to have an increased mental preparedness and perception of what measures that are relevant.
Ratio of households that has prepared emergency supplies that cover their needs of warmth, water, food and information (for X number of days) without access to public services/utilities (e.g. water/sewage, power)	EW (2021); Bergström (2016); Lindberg & Sundelius (2013)	Given the ambition of the Swedish government and MSB to make Swedish citizens more aware of their responsibility and necessity of preparing themselves for disasters, this might be a good indicator assembled through electronic surveys and sample techniques. The survey per se could likewise be a "gentle reminder" of the importance of becoming or remaining prepared.
Ratio of population with home- and health insurances	Adger et al. (2005); Cutter et al. (2010); Fekete (2009); Tomaszewski et al. (2020)	To be able to estimate the economic vulnerability to potential disasters in different areas. Those with insurances have a lower vulnerability and better recovery ability than people who do not have insurance cover.
VGI (Volunteer geographic information)	EW (2021)	Collection of information from the public ("grassroots data") via social media, surveys, photos and applications for so-called "Collaborative mapping" that may feed decision makers with information as basis for measures that enhance societal safety (e.g. "safe city" and fixamingata.se)

Movement patterns of the population (traffic flows and individual mobility – incl. real time/live updates)	EW (2021)	Understanding the whereabouts of the population at different times of the day is important to assess potential damages from events at different locations; input to the planning of evacuation routes; real time data could be indicative of that something has occurred that need attention from authorities

Response capability in overall society (public authorities, private companies, NGOs)		
Datasets	**Sources**	**Rationale for including datasets & examples of application areas**
Government buildings	Armenakis & Nirupuma (2013); Inspire directive (2013)	To ensure that crucial emergency operation centres are not located within risk areas or affected in terms functionality or access
Infrastructure for early warning systems (sensors and equipment for dissemination)	Tomaszewski et al. (2020)	To facilitate maintenance/reparations and monitoring of the suitability of the positioning of system components in relation to land use changes and population coverage over the long term
Environmental monitoring facilities (including facilities for observation and measurement of emissions; biodiversity, conditions of vegetation)	Inspire directive (2013)	
Hospitals and health centers (incl. capacities in terms of e.g. numbers of hospital beds and types of care available)	Armenakis & Nirupuma (2013); Blom, Guldåker & Hallin (2013); Cutter (2003); EW (2021); Inspire directive (2013); Marzi et al. (2019); Scherzer et al. (2019); Tomaszewski et al. (2020)	To calculate the distance (i.e. coverage in different time spans) between ”blue light resources” and assets to protect (incl. population and risk objects/areas); to estimate the need of outside help (resources from other jurisdictions) to deal with different risk scenarios and real events.
Fire stations (incl. capacities in terms of e.g. numbers of staff, numbers and types of fire trucks, specialized equipment/ abilities, such	Armenakis & Nirupuma (2013); Blom, Guldåker & Hallin (2013); EW (2021); Inspire directive (2013); Marzi et al. (2019);	-II-

as ladders for high rise buildings, diving, hazmat)	Scherzer et al. (2019); Tomaszewski et al. (2020)	
Police stations (incl. capacities in terms of e.g. number of staff, number and types of vehicles and protective gears)	Armenakis & Nirupuma (2013); Blom, Guldåker & Hallin (2013); EW (2021); Inspire directive (2013); Marzi et al. (2019); Scherzer et al. (2019); Tomaszewski et al. (2020)	-II-
Number of volunteers, set of capabilities and material resources of the 18 voluntary defence organisations in Sweden	EW (2021)	To raise awareness about the types of support that these organizations can provide and thereby increase the likelihood that they will be utilized in support of public safety
Private companies that can assist with the provision of various necessities during disasters	EW (2021)	To speed up request for assistance and provision of necessities in line with a whole of society approach to disaster management
Regiments/military units (incl. their capabilities that could be used for responding to disasters in peace time)	EW (2021)	-II-
Shelters	Blom, Guldåker & Hallin (2013); EW (2021)	To know where to go in case of need of protection
Safety centers (Sve: ”trygghetspunkter”)	Blom, Guldåker & Hallin (2013); EW (2021)	To know where to go in case of need of warmth, food, water and information
Anläggningar med större tillagningskök och sanitetsmöjligheter (ex. skolor, hotell, restauranger)	Blom, Guldåker & Hallin (2013); Cutter (2010); EW (2021)	Could potentially be used as temporary housing/shelters or providers of food and water to displaced persons or responding personnel
Hotels/motels (incl. the number of beds)	EW (2021); Félix et al. (2013); Johnson (2007)	Could potentially be used as temporary housing/shelters

Ratio of hospital beds/population	Cutter (2010); Cardona (2005); Garbutt et al. (2015); Yang et al. (2015)	
Ratio medical staff (doctors and nurses)/population	Cutter (2010); Fekete (2009); Tate, (2012); Yang et al. (2015)	
Sites for the provisions of emergency water	Blom, Guldåker & Hallin (2013)	
Pharmacies	EW (2021)	Provides the population with supplies to take care of their own health
Portion of budget allocated for public safety and security	Adger et al. (2005); Cutter (2010); Ruiter et al. (2017); Vincent (2004)	Note: the services included the notion of "safety and security" need to be further defined in order to enable comparisons across different governmental units
Portion of budget allocated for critical infrastructure	Cardona, (2005); Holand & Lujala (2013); Kienberger et al. (2009)	Technical infrastructure needs to be maintained and possibly expanded so that it can provide the population with what they need (e.g. electricity, heat, water and communication). Investments in road networks are important to ensure the accessibility of blue light authorities to reach affected populations as well as evacuations from affected areas. Note: what kind of critical infrastructure to include need to be further defined in order to enable comparisons across different governmental units

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