Towards Systemic Governance of Critical Infrastructure Protection: *State and Relevance of a Swedish Case*

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Μὴ περισπάτω σε τὰ ἔξωθεν ἐμπίπτοντα
καὶ σχολὴν πάρεχε σεαυτῷ τοῦ προσμανθάνειν ἀγαθόν
τι καὶ παῦσαι ῥεμβόμενος.

Μάρκος Αυρήλιος
(Aurelius 2014:30)

Do the things external which fall upon thee distract thee?
Give thyself time to learn something new and good,
and cease to be whirled around.

Marcus Aurelius
(Aurelius 1889:98)

Zerren dich die von außen kommenden Ereignisse hin und her?
Nimm dir doch einmal die Zeit, etwas wirklich Gutes hinzuzulernen
und hör auf, im Kreise herumzuirren!

Mark Aurel
(Aurelius 1973:14)

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Sundsvall, April 2020.

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List of Abbrevitions

BBK	Federal Office of Civil Protection and Disaster Assistance [Bundesamt für Bevölkerungsschutz und Katastrophenhilfe]
CAB	County Adminitsrative Board
CIP	Critical Infrastructure Protection
DVG	German Association of the Transmission System Operators [Deutsche Verbundgesellschaft e.V.]
EA	Swedish Energy Agency [Statens energimyndighet]
ENTSOE	European Network of Transmission System Operators for Electricity
ICT	Information and Communication Technology
IT	Information Technology
KISA	Kaleidoscope for Integrative System Analysis
MLP	Multi-Level Planning
MSB	Swedish Civil Contingencies Agency [Mydighet för samhällsskydd och beredskap]
NERP	National Emergency Response Planning
PGO	Power Grid Operator
SCADA	Supervisory Control And Data Acquisition
SoS	System-of-Systems
STYREL	Steering electricity to prioritised power consumers [Styra el till prioriterade elanvändare]
SvK	Svenska Kraftnät

Keywords

Systemic Thinking, Infrastructure, Governance, Critical Infrastructure Protection, Complex Systems, Soft Operations Research, design-oriented Information Systems Research, Integrative System Analysis, KISA, *STYREL*, Multi-level Planning, Adaption, Emergence, Entropy, Systemic Governance.

Abstract

The protection of infrastructure that is critical to society's functionality, survival and progression has gained significance for both national security and research because of its large-scale and interdependent nature. Critical infrastructure can be viewed as a complex, socio-technical system-of-systems that imposes extensive requirements on governance efforts to foster critical infrastructure protection (CIP), regardless of whether it involves public organisations, private organisations or both.

This dissertation investigates how systemic thinking can develop understandings of CIP and its governance. For this purpose, the dissertation presents research that was conducted in the context of an unexplored Swedish governance approach for CIP against power shortages. The dissertation consists of a three-part thesis and six peer-reviewed publications.

PART A of this thesis presents the results of a substantial review of scientific literature on the concepts of systems, infrastructure and governance. Because of their recursive nature, the concepts encounter a common challenge in characterising their key elements, structures and processes. The multi-level character of CIP provokes governance to systemically address the behaviours of adaption, emergence and entropy which the complex system exhibits. Apart from contributing nuanced knowledge of systems, infrastructure and governance, PART A provides a novel frame of reference for research in the area in the form of a kaleidoscope for integrative system analysis – KISA.

PART B presents the key results of a case study on the Swedish *STYREL* approach. The investigation is based on an examination of documents that relate to the case, interviews with 66 responsible experts and a survey among all 21 County Administrative Boards and 10 power grid operators that are responsible for stabilising the power grid during disturbances. The contribution of PART B is threefold. First, it originates an extensive representation of an unexplored case of CIP governance. Second, it offers a new comprehension of practical challenges in CIP governance due to the complex nature of the system and the entangled processes. Third, it provides empirical evidence that indicates areas for development of CIP governance practices.

PART C presents the results of the synthesis of theoretical and practical findings. It coalesces perspectives of critical infrastructure and system protection to elaborate on the concept of systemic governance. Fundamentally, systemic governance of CIP integrates the nexus of governance, management and leadership to address challenges regarding key properties of complex systems: entropy, emergence and adaption. PART C defines the theoretical contribution of this dissertation, namely the concept of systemic governance of CIP.

Sammanfattning

Skyddet av infrastruktur och verksamheter som är avgörande för samhällets funktionalitet, överlevnad och framgång har fått betydelse, både inom ramen för nationell säkerhet och samhällsskydd och för forskning, på grund av dess storskaliga och inbördes beroende karaktär. Kritisk infrastruktur (i Sverige delvis kallad samhällsviktig verksamhet) kan ses som ett komplext, socio-tekniskt system-av-system som ställer omfattande krav på styrning för att främja skyddet av kritisk infrastruktur (CIP), oavsett om det involverar offentliga förvaltningar eller privata företag och organisationer, eller båda.

Dissertationens övergripande syfte är att belysa hur systemisk tänkande kan utveckla förståelsen om CIP och dess styrning. Forskningen för avhandlingen har genomförts i kontexten av en outforskad ansats i Sverige, som kallas *STYREL* och eftersträvar CIP vid ett nationellt elbristläge. Doktorsavhandlingen består av kappan och sex granskade publikationer.

Kappans kärna består av tre delar. PART A presenterar resultaten från en omfattande studie av vetenskaplig litteratur med avseende på begreppen system, infrastruktur och styrning. På grund av sin rekursiva struktur möts dessa koncept av en gemensam utmaning när det gäller att klargöra deras nyckelelement, strukturer och processer. Flernivåkaraktären av CIP sporrar styrning att hanterar egenskaperna som de komplexa system visar, såsom adaption, emergens och entropi, på ett systemiskt sätt. Förutom att tillföra nyanserad kunskap om system, infrastruktur och styrning utvecklar PART A en ny referensram för forskning inom området: ett kalejdoskop för integrativ systemanalys - KISA.

PART B presenterar de viktigaste resultaten från fallstudien. Undersökningen baseras på både granskning av dokument relaterade till fallet och intervjuer med 66 ansvariga experter samt en enkät bland alla 21 länsstyrelser och 10 elnätoperatörer som ansvarar för att stabilisera nätet under störningar. Bidraget från detta kapitel är tredelat. För det första skapas en omfattande representation av ett outforskat fall av CIP-styrning. För det andra bidras till en ny förståelse av utmaningarna vad gäller CIP-styrning i praktiken på grund av systemets komplexa karaktär och de invecklade processerna. För det tredje ges empiriska belägg som visar områden för utveckling av *STYREL*-ansatsen i praktiken.

PART C presenterar resultaten av syntesen av teoretiska och praktiska fynd. Perspektiven på kritisk infrastruktur och systemskydd sammanförs för att utarbeta begreppet systemisk styrning, som integrerar styrning, management och ledarskap i en nexus för att hantera utmaningar relaterade till elementära egenskaper hos komplexa system: entropi, emergens och adaption. Konceptet systemisk styrning av CIP befäster därmed avhandlingens teoretiska bidrag.

Kurzfassung

Der Schutz von Infrastrukturen, die einen essentiellen Beitrag zur gesellschaftlichen Stabilität und Entwicklung leisten, hat hohe Bedeutung erlangt, einerseits im Rahmen des Bevölkerungsschutzes und der nationalen Sicherheit und andererseits als Gegenstand der Forschung, insbesondere wegen des schieren Umfangs des Untersuchungsfelds und der vielfältigen, inhärenten Wechselbeziehungen. Die sogenannte Kritische Infrastruktur kann daher als komplexes, sozio-technisches System von Systemen aufgefasst werden, welches umfangreiche Anforderungen an Steuerungsbemühungen stellt, die den Schutz der Kritischen Infrastruktur voranzutreiben suchen, unabhängig davon inwieweit öffentliche oder private Akteure involviert sind.

Zweck der vorliegenden Abhandlung ist es darzulegen, wie Systemdenken dabei helfen kann, das Verständnis vom Schutze Kritischer Infrastruktur und dessen Steuerung (engl. governance) weiterzuentwickeln. Die folgenden Kapitel erörtern die Ergebnisse einer vierjährigen Studie eines unerforschten Ansatzes für den Schutz Kritischer Infrastruktur im Falle einer Strommangellage in Schweden. Die Dissertation besteht aus einer Thesis und sechs wissenschaftlichen Artikeln, die begutachtetet und veröffentlicht sind. Die nachstehenden Forschungsfragen strukturieren den Hauptteil der Thesis.

1. Wie wird der Schutz Kritischer Infrastruktur organisiert und gesteuert?
2. Was sind die Grundlagen für das Verständnis der Relevanz und des Standes des Schutzes Kritischer Infrastruktur und dessen Steuerung?

Der Hauptteil der Thesis besteht aus drei Teilen. Der erste Teil – PART A – widmet sich relevanter Literatur im Forschungsgebiet und bildet die theoretische Grundlage für die genannten Forschungsfragen. Der zweite Teil – PART B – fokussiert auf die Fallstudie des schwedischen Planungsansatzes *STYREL* im Kontext der Stromversorgung und untersucht dabei die erste Forschungsfrage. Der dritte Teil – PART C – verarbeitet die theoretischen und praktischen Erkenntnisse der Studie um mit der Adressierung der zweiten Forschungsfrage die Theoriebildung im Forschungsfeld voranzutreiben.

Part A trägt insbesondere zum differenzierten Verständnis der theoretischen Konzepte *System*, *Infrastruktur* und *Governance* bei. Gegenstand der umfassenden Literaturstudie sind in erster Linie neuere wissenschaftliche Artikel. Gleichwohl werden grundlegende Aspekte zu ihrem konzeptionellen Ursprung zurückverfolgt, weshalb auch ausschlaggebende, teilweise historische Literatur hinzugezogen wurde, um die angestrebte theoretische Mächtigkeit herauszuarbeiten. Die Literaturanalyse offenbart beispielsweise, dass die genannten Konzepte, besonders wegen ihrer rekursiven Eigenschaften,

ihren Anwender vor eine zentrale Herausforderung stellen, und zwar, die Charakterisierung ihrer Kernelemente, Strukturen und Prozesse vorzunehmen. Die aktuelle Literatur spiegelt dabei den uneindeutigen Gebrauch der Begriffe in Wissenschaft und Praxis wider. Die Literaturstudie eruiert den rekursiven Mehrebenencharakter des Schutzes Kritischer Infrastruktur im Detail und fundiert somit ein angepassteres, das heißt systemisches, Vorgehen im Rahmen von zugehörigen Steuerungsmaßnahmen, welches auf drei wesentliche, dynamische Eigenschaften eines komplexen Systems abzielt: Adaption, Emergenz und Entropie. Neben der Präsentation des aktuellen Standes der Wissenschaft im Forschungsgebiet der Kritischen Infrastruktur wird ein theoretischer Beitrag in Form eines konzeptuellen Kaleidoskops für integrative Systemanalyse geleistet. Mithilfe einer Methode für komplexe, interdisziplinäre Forschung, die PAPER I entwickelt, vereint das zu präsentierende Rahmenwerk (siehe Figure 5) die vier Perspektiven – System, Infrastruktur, Governance und Prozess – und deren rekursive Mehrebenenstruktur zu einem kognitiven Werkzeug für diese und zukünftige Analysen komplexer Problemstellungen, insbesondere wird die Anwendung in fachübergreifenden Forschungsvorhaben empfohlen.

PART B trägt wesentlich zum Erkenntnisgewinn über den praktizierten Schutz Kritischer Infrastruktur im Kontext der Stromversorgung bei. Die Ergebnisse basieren zum einen auf dem Studium verschiedenster Dokumente, die den schwedischen Ansatz zum Thema haben, und zum anderen auf der Durchführung und Auswertung semi-strukturierter Interviews mit 66 Entscheidungsträgern in Kommunen, Provinzialregierungen und Stromnetzbetreibern sowie einer Umfrage unter allen 21 Provinzialregierungen und den 10 Stromnetzbetreibern, die eine besondere Verantwortung für die Aufrechterhaltung der Stromversorgung im Falle einer Strommangellage tragen. PART B präsentiert zuerst einen Abriss über PAPER I – VI, welche sich ausgewählten Teilproblemen widmen. Danach setzt sich PART B mit dem schwedischen Fall unter dem Blick des genannten Kaleidoskops auseinander. Die Fallstudie demonstriert einige der Herausforderungen im schwedischen Kontext. Beispielsweise beleuchten die Ergebnisse wiederkehrende Schwierigkeiten, die sich auf das Design, die Durchführung und die Weiterentwicklung des schwedischen Planungsansatzes zum Schutz Kritischer Infrastruktur zurückführen lassen. Der Ansatz wurde im Zeitraum von 2004 bis 2011 entwickelt und nach der Pilotierung im Jahre 2009 bereits zweimal in vollem Umfang durchgeführt. Die Durchführung beinhaltet die Identifizierung und Priorisierung Kritischer Infrastruktur. Dieser Prozess ergibt eine Entscheidungshilfe für die Notfallplanung aller Stromnetzbetreiber. Besonders wichtig ist dieser Plan für die zurzeit 10 Stromnetzbetreiber, welche über die technischen und personellen Voraussetzungen verfügen, um während einer Strommangellage innerhalb eines Zeitfensters von 15 Minuten nach Order des nationalen Netzbetreibers den Stromverbrauch entsprechend reduzieren zu können. Darüber hinaus sind alle Stromnetzbetreiber gesetzlich angehalten, sich im Rahmen eines solchen Lastenabwurfs so weit wie möglich an die im *STYREL*-verfahren erstellte Entscheidungshilfe zu halten, damit Kritische Infrastruktur nicht oder nur in geringem Maße betroffen ist und somit die erwarteten negativen Konsequenzen für die Gesellschaft reduziert werden. Die Fallstudie zeigt unter anderem auf, dass trotz der Partizipation einer Großzahl öffentlicher und privater Organisationen und des Engagements der einzelnen Verantwortlichen keine zuverlässige Aussage über die Qualität und den Nutzen des erarbeiteten Planungsdokuments erstellt werden kann. Auch wenn Synergieeffekte für den lokalen Bevölkerungsschutz von vielen Interviewpersonen erkannt wurden, werden im Rahmen des Ansatzes keine Vorschläge für eine gelungene Integration vermittelt. Aus Sicht der Stromnetzbetreiber wurde das Planungsergebnis mit verhaltenen Reaktionen bewertet. Ein Grund dafür stellt die Beschränkung der formellen Nutzung der produzierten Entscheidungshilfe auf den sehr speziellen Anwendungsfall einer nationalen Strommangellage dar. Ein anderer Grund ist, dass durch die stufenweise Aggregation im Laufe des Prozesses nicht zweifelsfrei feststellbar ist, inwieweit die schlussendlich übermittelte Information aktuell ist, welche der eingangs als kritisch bewerteten Infrastruktur letztendlich enthalten ist und welche Stromabnehmer (unter Umständen fälschlicherweise) nicht berücksichtigt wurden sowie ob die Rangliste der Stromleitungen tatsächlich den Intensionen der lokalen, regionalen und nationalen Entscheidungsträger entspricht. Zusätzlich erschwert ein Mangel an hilfreicher Rückinformation zwischen den Teilnehmern die zielführende Weiterentwicklung des Vorgehens auf allen Ebenen. Ebenso mangelt es an angemessener Risikokommunikation, welche sich an die Bevölkerung und Unternehmen richtet, die schlussendlich von einem Lastenabwurf während einer Strommangellage betroffen wären. Mit der detaillierten Aufarbeitung der Ergebnisse liefert diese Fallstudie deshalb einen fundierten empirischen Beitrag zum Erkenntnisgewinn im Forschungsgebiet. Einerseits ermöglicht die ausführliche Repräsentation und Analyse des schwedischen Vorgehens ein tieferes Verständnis der umfangreichen Wechselbeziehungen zwischen Infrastruktur, gesellschaftlichem Wohlergehen, Schutzmaßnahmen und Steuerungsbemühungen. Zum anderen hat die Veröffentlichung der Ergebnisse in englischsprachigen Zeitschiften und Konferenzbänden sowie dieser Dissertation das Forschungsfeld nicht nur durch Erkenntnisse aus der

Praxis bereichert, sondern den Fall auch einem globalen Publikum aus Wissenschaft und Praxis zugänglich gemacht. Somit bildet die vorliegende Fallstudie die Grundlage für zukünftige Forschung, die sich beispielsweise mit dem Vergleich verschiedener nationaler Ansätze beschäftigen könnte. Darüber hinaus wurden im Rahmen der Fallstudie Bereiche mit Entwicklungspotential beleuchtet. Verbesserungsvorschläge betreffen insbesondere die praktische Integration des Ansatzes in das lokale, regionale und nationale Risiko- und Krisenmanagement sowie die avancierte Steuerung des sozio-technischen Mehrebenensystems, welches die Entwicklung, Entscheidungsfindung und Implementierung des Schutzes Kritischer Infrastruktur verfolgt.

PART C trägt schließlich maßgeblich zur Theorieentwicklung im Fachgebiet bei. Die Synthese führt die Grundsätze der Systemtheorie und die Evidenz des schwedischen Falls zusammen, um das Verständnis für die Relevanz und über den aktuellen Stand des Schutzes Kritischer Infrastruktur und dessen Steuerung zu fördern. Der Erkenntnisgewinn besteht in der Erörterung der Grundlagen, die das Konzept der Systemischen Governance substanziieren. Grundlegend muss die *Systemische Governance* die Steuerungsfunktion auf den verschiedenen Ebenen der Prozesse, Systeme und Kontrollmechanismen ausführen, welche zusammen den Schutz Kritischer Infrastruktur verfolgen. Diese besondere Form der Steuerung ist erforderlich um Adaption, Emergenz und Entropie eines komplexen Systems zu beeinflussen. Deshalb strebt das Konzept der Systemischen Governance eine Verschmelzung von Governance (die indirekte Steuerung durch Regelwerke), Management (die operative Implementierung der Regelwerke) und Führung (die direkte Steuerung) an. Um ein Verständnis über die Relevanz und den Status des Schutzes Kritischer Infrastrukturen und dessen Steuerung zu erlangen, sind die folgenden drei Grunddimensionen essentiell. Erstens, die rekursive Struktur von Systemen, Infrastruktur, Prozessen und Governance. Zweitens, das Ausmaß des Anliegens, das heißt lokale, regionale, nationale oder globale Bemühungen. Drittens, der Einfluss von Zeit auf die Kritikalität und den Schutz der Infrastruktur wie auch auf das Fortbestehen des komplexen Systems sowie dessen Prozesse und Steuerung.

Eine Diskussion des Erkenntnisgewinns aus der theoretischen und empirischen Analyse und Synthese aus Sicht der Forschungsfragen beschließt die Thesis. Überdies werden die Limitationen der Studie aufgezeigt und Potentiale für zukünftige Forschung bewertet. Das Fazit betont den Beitrag dieser Dissertation und beantwortet die Forschungsfragen. Die im Anhang enthaltenen wissenschaftlichen Publikationen bieten zudem weitere Details über die Methodik, den untersuchten Fall und Perspektiven künftiger Forschung.

List of Papers

PAPER I: Große, Christine (2017). Research in Complex Planning Situations: Dimensions and Challenges from Swedish Response Planning. In: Anthony Buckley (Ed.) *Proceedings of the 16th European Conference on Research Methods in Business and Management (ECRM)*. ACPIL, pp. 432–440.

PAPER II: Große, Christine (2017). Applying Systems Thinking onto Emergency Response Planning. Using Soft Systems Methodology to Structure a National Act in Sweden. In: *Proceedings of the 6th International Conference on Operations Research and Enterprise Systems (ICORES)*. SCITEPRESS, pp. 288–297. DOI: 10.5220/0006646302870296.

PAPER III: Große, Christine & Olausson, Pär M. (2018). Swedish Multi-level Planning System for Critical Infrastructure Protection: The Regional Core. In Stein Haugen, Anne Barros, Coen van Gulijk, Trond Kongsvik, Jan Erik Vinnem (Eds.) *Safety and Reliabilty - Safe Societies in a Changing World. Proceedings of the 28th European Conference on Safety and Reliability (ESREL)*. CRC Press, pp. 1893-1901.

PAPER IV: Große, Christine & Olausson, Pär M. (2019). Blind Spots in Interaction between Actors in Swedish Planning for Critical Infrastructure Protection. *Safety Science*, vol. 118, pp. 424-434. DOI: 10.1016/j.ssci.2019.05.049.

PAPER V: Große, Christine (2018): The Systemic Implications of Emergent Strategic Objectives in Complex Planning Situations. In: *Proceedings of the 7th International Conference on Operations Research and Enterprise Systems (ICORES)*. SCITEPRESS, pp. 287–296. DOI: 10.5220/0006646302870296.

PAPER VI: Große, Christine (2019). Sources of Uncertainty in Swedish Emergency Response Planning. *Journal of Risk Research*, vol. 22 (6), pp. 758–772. DOI: 10.1080/13669877.2018.1459796.

1

Introduction

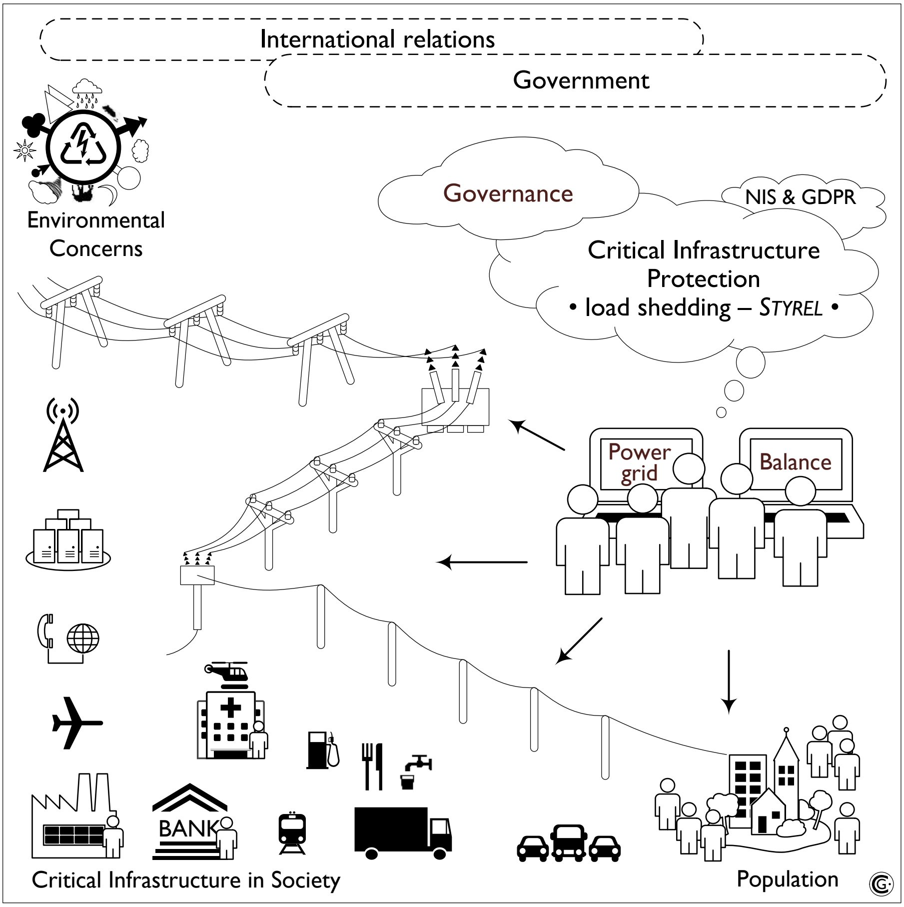

Figure 1: Critical Infrastructure Protection in the Swedish Power-Supply Context

1.1 Purpose, Research Questions and Contribution

The purpose of this study is to investigate how systemic thinking can develop understandings of critical infrastructure protection and its governance. For this purpose, the study scrutinises current scientific literature in the field, thoroughly analyses an unexplored Swedish case and synthesises the gained insights and knowledge of governance in the context of such a complex system-of-systems (SoS). This doctoral dissertation is comprised of a thesis and six scientific papers, which have been peer-reviewed and published.

The thesis addresses the following research questions:

RQ 1) How does Sweden organise and govern critical infrastructure protection?

RQ 2) What are the fundamentals for understanding the state and the relevance of critical infrastructure protection governance?

The research for this dissertation employs several methods (see Section 2 for more details). First, PART A conducts a literature review of current scientific articles and papers on critical infrastructure protection (CIP). The review focuses on how recent literature communicates and applies the concepts of systems, infrastructures and governance. In addition, PART A analyses contrary understandings, the common usage of concepts or problems of particular interest in the context of the thesis. Finally, a framework of reference synthesises the considerations in PART A.

Second, PART B utilises the methodical approach of a case study on a Swedish governance approach for CIP against power shortages in Sweden, called *STYREL*. Besides presenting the included six papers and their specific contributions, PART B of this thesis conducts a meta-analysis of the Swedish case by applying the framework that is developed in Part A. With regard to the first research question, PART B analyses the SoS of CIP in the studied context as well as the implications of the approach for CIP in Sweden and the appearance of governance in the particular case. On the basis of these findings, PART B imparts further insights for future developments.

Third, PART C uses the method of synthesis as a complimentary course of action to the preceding analyses in order to approach the second research question. Therefore, it departs from the findings of the literature review and the case study and concentrates on an elaboration of the concept of *systemic governance*, which addresses the nexus of governance, management and leadership in the context of CIP from a system perspective.

The discussion section reflects on the conducted study and its implications for research and practice. This dissertation concludes with a short summary, key answers to the research questions and some prospects for future research.

This dissertation contributes novel tools and comprehensive knowledge for understanding the multi-faceted and complex system of CIP governance.

First, besides the state of the art in the current scientific literature, PART A provides a detailed conceptualisation of the terms *system*, *infrastructure* and *governance* in the realm of CIP. As an essential aspect of the theoretical contribution of this dissertation, PART A originates a multi-perspective frame of reference called a kaleidoscope for integrative system analysis (KISA) by way of the method for complex and interdisciplinary research that is developed in PAPER I.

Second, PART B contributes both an extensive representation of the Swedish case of *STYREL* and a detailed analysis that applies the originated kaleidoscope. While PAPERS I–VI target different facets of the research problem, the thesis primarily consolidates the study. Thus, the papers properly embody a representation of the Swedish case and report notable findings regarding the *STYREL* approach. The meta-analysis in this thesis extends insight into systems, infrastructures and expressions of governance in the context of this particular case. Consequently, PART B emphasises areas for further development of this governance approach for CIP against power shortages in Sweden.

Third, PART C synthesises the theoretical concepts from the literature review and the empirical findings from the case study to support the notion of *systemic governance*. This novel concept development contributes the fundamentals for understanding the state and the relevance of CIP governance. The new approach highlights the multi-level nature of critical infrastructure and its protection and governance. The findings concerning systems, processes and control in the context of CIP and the interrelated consequences of adaption, emergence and entropy inform a novel approach to address the nexus of governance, management and leadership.

The remainder of this chapter frames the inquiry and disposition of this dissertation. The following section briefly defines the key terms of this study to clarify their meanings in the context of this thesis. The subsequent section provides more background information to motivate the relevance of the investigation. The first subsection substantiates the theoretical point of departure by focusing on society's increasing dependency on infrastructures and services as well as highlighting the inherent complexity of these systems. The second subsection elaborates on interdependent infrastructures in society through the example of the power supply, including its shaping factors and measurements for handling disturbances. The third subsection outlines the context of the Swedish case of *STYREL* and accentuates its relevance to the problem area of CIP. Finally, after clarifying the subject and theoretical lens for the investigation, this introductory chapter summarises the disposition of this doctoral dissertation.

1.2 Key Terminology

A **system** is an assemblage of *components* with properties that, through certain *interaction* within an *environment*, fulfil a common (i.e. critical) *process.* In this form, a system has properties, can exhibit behaviour and may interact with its environment (e.g. Bertalanffy 1950, 1968).

A **process** is a content-related and self-contained sequence of timely and logically consistent events and activities that processes a central, process-characterising object (e.g. Becker, Schütte 2004; Davenport 2017; Davenport, Short 1990; Scheer 1991). A process strongly depends on proper functionality of the majority of system components.

System control: To maintain a (critical) process, a system must master *entropy*, which necessitates a *control* mechanism, such as mechanic control, artificial reasoning or human decision-making (Clausius 1865; Maxwell 1871).

A **complex adaptive system** consists of interconnected and autonomous agents that can act in parallel and adapt to interactions and environmental conditions. Such adaption and the extent of the system can lead to non-linear consequences that can even be recognised as emergent behaviour and unpredictable outcomes (Hokstad et al. 2012; Holland 2006; van der Lei et al. 2010).

A **system-of-systems** evolves if constituting, independent (and complex adaptive) systems interact to achieve a common purpose, and each system gains some benefit from its participation (Ackoff 1971; Maier 1996, 1998).

Infrastructure is perceived as always existing, long-lasting and *fixed common good* that, however, unites material, building processes and an expression of will (c.f. Buhr 2009). At the same time, it is viewed as an *operative process* of an SoS that, through control of the former, provides essential goods and services for public well-being, such as water, food, healthcare, power supply and information and communication services (e.g. Katina et al. 2017).

Infrastructure becomes **critical** if the survival, well-being and progress of a society depend on its maintained functionality (Cohen 2010).

Governance concerns how society or a system is organised and governed and who is involved in the dialogue, participation and networking, wherein networks are an important phenomenon (e.g. Henry 2011; McGinnis 2011; Petridou 2014).

Systemic governance enhances governance as a multi-layered, multi-faceted and recursive concept that is similar to those of systems and infrastructure. In governing an SoS, such as CIP, the governance system (or network) can be considered a similarly complex system (Ashby 1956; McIntyre-Mills 2006). This complexity, which is due to variety in participation, knowledge and proceedings, encourages an approach to address the governance of CIP in its entirety.

1.3 Systems and Processes

1.3.1 Critical Infrastructure Protection and Governance

The growing interconnectedness of modern societies has increased their dependency on vital societal functions, such as electricity, heating, water supply, healthcare, and information and communication technology (ICT) (Johansson et al. 2014; Roukny et al. 2016). Public and private organisations as well as governments have recently recognised the vulnerability that is associated with this dependency given that exploiting this vulnerability could result in catastrophic consequences (Boin, McConnell 2007; Buldyrev et al. 2010; European Commission 2004a; Rinaldi et al. 2001). Therefore, the protection of infrastructure that is critical to society's functionality, survival and progression (Cohen 2010) has gained significance for national security in many countries and for research in this area (Birkmann et al. 2016; BMI 2009; Canada 2009; European Commission 2004b; MSB 2011a). In addition, critical infrastructure has been characterised as a complex 'socio-technical system-of-systems' (Gheorghe et al. 2006).

The concept of complexity is closely related to systems in a societal context. Common criteria for classifying a system as 'complex' include interconnectedness and interdependency of system components, autonomous and adaptive behaviour of components, non-linearity of consequences and the extent of the system (Hokstad et al. 2012; Holland 2006). Moreover, this non-linearity of cause and effect due to interconnected subsystems can evoke an emergent system behaviour, which the properties of the subsystems cannot completely explain (Bar-Yam 2009). Complexity challenges the analysis, modelling and governance of such systems since a multitude of factors can contribute to the problem. The reduction of complexity to facilitate analysis, model-building and governance of complex systems (Rosenhead, Mingers 2008) has therefore been a subject of discussion in the field. Approaches span from dividing such systems into parts to examine them separately or reducing the extent of the system to the simplest working model for a particular phenomenon without separating the elements to systems thinking that encourages a holistic view of a system or problem (Ackoff 1999; Avison, Taylor 1997; Checkland 1989; Stachowiak 1973; Sterman 2006). In the context of CIP, a holistic perspective of the complex SoS seems preferable for understanding how governance can foster the alignment of goals and means for CIP. Accordingly, research on complex systems also concerns governing dynamics and multidimensional problems, which invoke complex system governance to produce system viability through control, communication, co-ordination and integration (Katina et al. 2017; Keating et al. 2014; Keating 2014; Keating et al. 2015;

Keating, Bradley 2015). However, in its focus on technical systems, this approach struggles with the complexity of the multi-level construct of the governed and governing system, its processes and the underlying infrastructure as well as strategic objectives that connect the different systems.

The term *infrastructure* stems from the Latin words *infra* (underlying) and *structura* (assemblage). Thus, infrastructure is defined as an underlying base or framework. Buhr has argued that a country's infrastructure system consists of a combination of material, institutional and personnel infrastructure (Buhr 2009:40). Although this perspective acknowledges both processes and expressions of will in the infrastructure context, it entangles building, maintenance, operation and governance processes in a questionable manner. Nevertheless, infrastructure is mainly perceived as an always-existing common good (i.e. a provision of service upon physical structures), whereas the interconnected processes and governance are underrepresented. Definitions of *critical infrastructure* from official institutions illustrate this phenomenon.

- The European Commission has defined critical infrastructure as structures that '*consist of those physical and information technology facilities, networks, services and assets which, if disrupted or destroyed, would have a serious impact on the health, safety, security or economic well-being of citizens or the effective functioning of governments in the Member States. Critical infrastructures extend across many sectors of the economy, including banking and finance, transport and distribution, energy, utilities, health, food supply and communications, as well as key government services. Some critical elements in these sectors are not strictly speaking 'infrastructure', but are in fact, networks or supply chains that support the delivery of an essential product or service. For example the supply of food [...] is dependent on some key facilities, but also a complex network of producers, processors, manufacturers, distributors and retailers*' (European Commission 2004b:3-4).
- The Swedish Civil Contingencies Agency (MSB) has defined critical infrastructure as a '*physical structure whose functionality contributes to ensure the maintenance of important functions of the society*' (MSB 2011a:6).

However, reliable functionality of important societal functions depends on not only fixed or physical assets but also multi-level systems that perform interrelated processes, such as operation, maintenance and development (i.e. management), and decision-making (i.e. governance) regarding operational, managerial and strategic objectives. Therefore, a holistic view of the SoS of critical infrastructure is suggested to harmonise the perceptions of decision-makers who are entrusted with planning and policy-making in the context of CIP (Pescaroli, Alexander 2016) both within a national system and across country borders (Masera et al. 2006a).

Critical infrastructure protection can be viewed as a common, societal concern that is located in the field of governance between governmental control and competitive market dynamics as well as the private sphere of citizens (Offe 2008). According to Lovan et al., governance involves 'processes of making decisions' and particularly the 'distribution of public responsibilities across multiple stakeholders' which interact 'both as individuals and as participants with mutual interests' (2016:xv-xvi). Pierre and Peters (2000) have framed the management of society as a continuum that extends from traditional top-down control to self-organisation and networks, while the concept of governance is the common element of the entire continuum. In this study, governance is perceived as a steering instrument which activates a network in policy-making. Individual organisations often use networks to achieve their strategic and operative objectives, maximise their influence over outcomes or avoid dependence on other actors in the system. From this perspective, governance involves managing networks (Rhodes 1996). However, practicing decentralised governance as the opposite approach to centralised government has revealed deficit symptoms, such as dysfunctionality and loss of institutional memory about 'how things have come about, and, more importantly perhaps, why they did' (Tingle 2015).

Consequently, Australian scholars have (re-)discovered the relevance of more systemic perspectives to governance by recalling cybernetics to contend with complexity in society (Ison et al. 2018; McIntyre-Mills 2006). Ison et al. (2018) have applied the term 'cybernetics' by Wiener (1948) and a sailor metaphor to establish the term 'cyber-systemic governance'. They have claimed that 'there are cyber-systemic antidotes to the malaise of modern governance' and emphasised a significant structural reform from two-dimensional to three-dimensional governance, which includes the social purpose, the biosphere and the technosphere (Ison et al. 2018). Moreover, McIntyre-Mills (2006) has illustrated a shift in thinking with the metaphor of tadpoles transforming into frogs to signify adaption, emergence and extension of boundaries. McIntyre-Mills (2006) has further claimed that 'systemic governance starts at the local, but it spans multiple areas' to address Ashby's rule of social cybernetics, which dictates that 'complex decisions need to be based on or reflect the complex base of people that the decision will affect'. According to Ashby, the governing system is similarly complex as the governed system (Ashby 1956), which implies that the governance of CIP could be considered a similarly complex system as that of the whole society. However, both approaches have difficulties with applying truly systemic thinking that stresses pluralism and integration instead of the 'either/or' mode of thought. In addition, the simplicity of the metaphors neglects the complexity of the governing system, which motivates an elaboration of the concept of systemic governance.

1.3.2 Power Supply Infrastructure – Grid, Transmission and Demands

Electricity is crucial to society and the critical infrastructure network (Yusta et al. 2011). Since other infrastructure largely relies on the availability of electricity, the power supply has a key position among the interdependent sectors of critical infrastructure (Rinaldi et al. 2001). However, the demand for a power supply at any time confronts physical challenges. Electricity has thus far been difficult to store, but it possesses good transfer properties. Therefore, engineers commenced the development of power grids 130 years ago (Schufft 2007b) to transfer electricity from power production sites to power demand sites. At the turn of the previous century, power grids served local and regional purposes within and across political borders in the European context. Increasing demands, technical developments and changing political ambitions were drivers behind the formation of the current power grid structure (van der Vleuten, Lagendijk 2010a, 2010b). The power grid in Sweden is part of *Nordel*, the Nordic power grid, which involves a part of Denmark in addition to Norway, Finland and Sweden (ENTSOE 2006). The establishment of *Nordel* in the 1960s also exemplifies how organisational considerations and political will have affected infrastructure developments in northern Europe apart from technical necessities (van der Vleuten, Lagendijk 2010b).

For example, the majority of power production in Sweden occurs in the north, while most of the demand is concentrated in the southern region of the country. To bridge this long distance with a low electricity load loss, high-voltage overhead power lines constitute the main, national power grid, which supplies electricity to lower-voltage grids. This dissertation refers to the latter type as regional and local power grids. Similarly to other power networks, the Swedish grid must manage the frequency within the network to prevent blackouts (Bömer et al. 2011). The members of the continental power grid collaborate with those of the Nordic grid to balance the grid in the event of instabilities, which also stresses the significance of a European dimension of planning for CIP (Masera et al. 2006a).

Grid frequency maintenance involves continuously balancing production and consumption to ensure the stability of network conditions. However, in all subsystems alongside the power supply—namely those for the production, distribution and consumption of electricity—disturbances can emerge. Apart from natural or weather-induced events, such as storms or falling trees, such disturbances can be caused by the aging of components (Schufft 2007a). Human error, which resulted in a two-hour blackout in central Europe in 2006 (UCTE 2006), or cyber-attacks, such as those recently reported in Ukraine (ICS-CERT 2016) and Russia (Sanger, Perlroth 2019), are additional origins of disturbances. Electrical installations contain various protection systems to prevent humans and devices from experiencing damage. Such local protection systems respond quickly to the cause of failure; however, even a local protection can have significant repercussions for power grid balance depending on the amount of electricity that is severed (Masera et al. 2006b). Therefore, disruptions that are associated with consumption require an electricity-feed reduction, whereas disruptions in production demand a reduction of consumption. Disturbances of the power grid can thus require various adaptations to adequately meet the emerging conditions and immediately restore the grid balance at the local, regional, national and international levels (ENTSOE 2010). Europe closely maintains the power grid at a 50-Hz frequency. Frequencies over 50.1 Hz indicate an overload and require a disconnection of surplus production, while frequencies under 49.9 signify the opposite case. The following paragraphs describe a few balancing measurements without focusing on technical details. This presentation of measurements demonstrates significant challenges that require adequate consideration in the governance of CIP.

A few decades ago, power production was achieved mainly by large plants, such as coal-fired, nuclear or hydroelectric power plants. These types of generation unit have a plannable capacity regardless of weather conditions. A stronger focus on renewable energies as part of electricity production has recently yielded wind parks and solar panels with a varied spectrum of capacities as well as an increased number of power producers. In particular, the output of these generation units depends on actual weather conditions. To maintain the balance of the power grid, automatic disconnection was required when the frequency exceeded 50.2 Hz. Studies have evidenced that, depending on the effect that is currently installed, this general requirement runs the risk of resulting in an over-adjustment (Bömer et al. 2011). Such an incorrect adjustment can prompt further instability in the grid and cascading consequences (Vaiman et al. 2013). Therefore, regulations now discourage an automatic disconnection of production units between 47.5 and 51.5 Hz (ENTSOE 2014; BMJV 2012). If the frequency falls below 47.5 Hz, production plants are disconnected to protect them from demolition (DVG 2000), which in turn requires a reduction of consumption to balance the frequency.

The reduction of electricity consumption, which is known as load shedding, constitutes a measure for stabilising the frequency of the power grid. It is applied when the frequency is low, and no reserve can be activated or imported. The European Network of Transmission System Operators for Electricity (ENTSOE) has recommended a load shedding stepwise up to 50% of consumption between 49.0 and 48.0 Hz and an automatic shedding of heating pumps between 49.8 and 49.2 Hz for continental Europe (ENTSOE 2010).

A major electrical blackout in southern Sweden in 2003 was a catalyst for the development of the Swedish case under investigation. The 2003 blackout was due to the tripping of a unit at a nuclear power station that was shortly followed by a major fault in a sub-station. After 90 seconds, these events caused a blackout in southern Sweden with further consequences for eastern Denmark. The power grid operators (PGOs) restored the current stepwise and completed the restoration after 10 hours. Although both national PGOs considered the co-operation to be reliable, the Danish report identified technical, managerial and policy-related issues, such as a need to revise the principles for restoration 'with a view to ensuring the right order of priority for disconnection and reconnection of consumers' (Elkraft System 2003:6; Larsson, Danell 2006; Larsson, Ek 2004; Svenska Kraftnät (SvK) 2003).

The continued relevance of planning for CIP is also apparent in a recent major blackout in Turkey in 2015. During this event, the majority of Turkey experienced an electrical blackout 12 seconds after the initial event that was due to several cascading effects. Fortunately, this outage did not affect neighbouring countries, and the official report stated only minor effects on critical infrastructure since it mostly possessed its own emergency power during the outage. The system was restored after 10 hours (ENTSOE 2015).

In view of such power supply disturbances, studies have investigated the reliability of power transmission (Alvehag, Söder 2011; Münzberg et al. 2014) and how to address cascading failures in power systems (Vaiman et al. 2013). Other research has illustrated how to facilitate power system restoration (Barsali et al. 2008; Soman et al. 2015; Tortos, Terzija 2012) but has adopted a purely technical perspective which ignores any after-effects on the national society. Such further impacts are likely to emerge since the power sector is central to other belonging sectors of critical infrastructure (Rinaldi et al. 2001), where cascading failures due to interdependencies in urban settings can have serious consequences (Hines et al. 2009). Therefore, some studies have been further concerned with the potential impact of climate change on power supplies and predicted moderate to severe consequences (Bardt et al. 2013; Bartos, Chester 2015; Birkmann et al. 2016). Boin and McConell (2007) have acknowledged the limits of national planning for CIP and identified a societal need to enhance resilience. In addition, national regulations and policies have been considered to provide implications for the power supply and for potential consequences of an outage (Goldman et al. 2002; Johnson 2006), while the electrical system as transnational infrastructure poses challenges for the governance of such a complex system owing to various strategic interests (van der Vleuten, Lagendijk 2010b).

1.3.3 The Swedish Case of *STYREL*

The *STYREL* approach represents a novel and unexplored type of policy-making for CIP, as the scientific literature does not discuss similar processes. In 1995, governmental investigations had already identified the power supply as a critical area for national security and development in Sweden and noted a change in threats as well as an increased vulnerability of critical infrastructure (SOU 1995:19). However, the compilation of a ranking of power consumers to prioritise during such events was not encouraged until after the 2003 blackout in Sweden and Denmark (Elkraft System 2003). Since 2004, the Swedish Energy Agency (EA) has been responsible for the development of *STYREL*, which is an acronym for 'steering electricity to prioritised power consumers' (EA 2014c). This dissertation examines the perspectives, interactions and boundaries that are interconnected within the Swedish case of *STYREL*, which it considers as a governance approach to CIP against power shortages in Sweden. *STYREL* stipulates a planning process that involves a large number of actors in the creation of a policy, which is intended to support planning for and decision-making during a national power shortage situation.

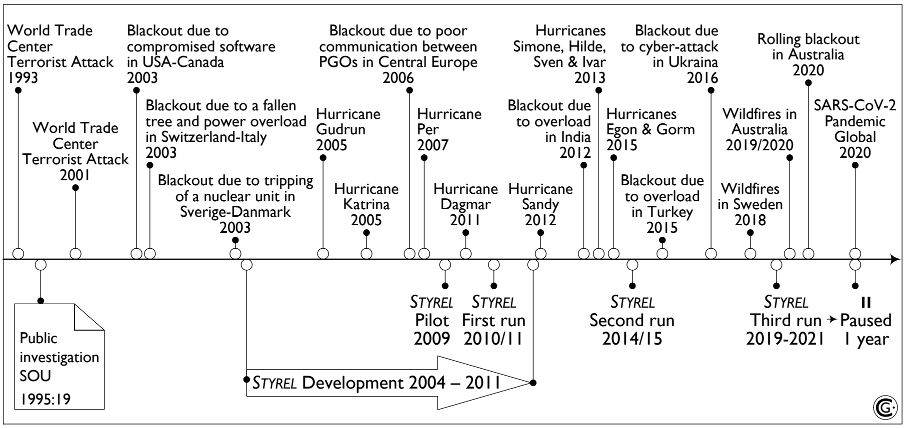

Figure 2: The Development of *STYREL* along Selected Disaster Events

As Figure 2 depicts, this approach was developed between 2004 and 2011 and was executed on two occasions: in 2010/2011 and 2014/15 (EA 2014c). A third iteration was scheduled to run between 2019 and 2021; however, due to the SARS-CoV-2 pandemic, the process has been postponed by one year (EA 2020). The process applies a four-year interval and plans for an emergency response to power shortage situations in Sweden. *STYREL* involves many actors from the local, regional and national levels (see Table 10). This planning is part of the Swedish Crisis Management System and aims to proactively enhance preparedness (MSB 2011a). The policy-making process relies on collaboration among actors from public and private organisations as well as on highly limited technical support for decision-making, information processing and communication. Many actors represent the executing body, including various national agencies, county administrative boards (CABs) as regional co-ordinators, municipalities as holders of local knowledge, and individuals as decision-makers, upon a ranked list of prioritised power consumers.

Furthermore, all PGOs participate in the planning process of *STYREL*, which seeks to identify and prioritise power consumers that provide society with critical services. The communicated rationale for the approach is to reduce the negative consequences of power shortages for society, as Figure 1 illustrates. Therefore, the Swedish case is also an interesting example of potential competing interests in such a governance system for CIP.

Since private actors operate the majority of electricity production and supply in Sweden and elsewhere, planning and co-ordination of measures are essential for CIP (Cedergren et al. 2015; Shore 2015). *STYREL* has been developed to facilitate the maintenance of vital societal functions during an under-frequency situation in Sweden. Therefore, alignment of the various demands (i.e. strategic objectives) of the concerned socio-technical SoS requires careful consideration and governance. For instance, because of the central role of the power production and distribution system in a complex system of critical infrastructure, the case of a critical power shortage is likely to yield cascading effects that pose severe consequences for society (Hines et al. 2009; Vaiman et al. 2013). Hence, a plan for mitigating the impacts of future power shortages must take into account the interests of concerned stakeholders, such as national governments, public and private organisations, civic society and individuals (Aven, Renn 2009; Fekete 2018).

Apart from the research for this dissertation, only a few studies have examined *STYREL.* These studies have indicated a lack of real participation and networking (Danielsson et al. 2020, Olausson 2019) and that outage compensation, which is an incentive for PGOs to enhance power-supply reliability, poorly correlates with top-priority power consumers (Landegren et al. 2014), which calls into question the integration of CIP in present power outage regulation. Moreover, electricity-dependent critical infrastructure that has a substantial impact on life and health or vital societal functions (see Table 11) seems to lack due attention in the present regulations (Landegren et al. 2019). Thus, a holistic system view may facilitate governance efforts to align strategic objectives within the complex system of CIP. However, the perspectives, interactions and boundaries that are involved in the large-scale, socio-technical, adaptive systems that deal with national CIP challenge further governance of such complex systems and their environment (Adelt et al. 2014; Hassel, Cedergren 2017; McGee, Edson 2014; Nagel, Wimmer 2003).

The *STYREL* approach is a suitable case of a complex system that concerns policy-making for CIP and is accordingly relevant well beyond the Swedish context. Critical infrastructure protection involves sensitive information about certain vulnerabilities, which may explain why discussions in literature are limited to only a few cases, such as Canada's approach to CIP (Quigley 2013). Germany has recently acknowledged the importance of such planning and initiated the enhancement of civic defence by elaborating on a concept regarding emergency power, among other measures (BMI 2016). Based on previous research on criticality assessment and risk management (Fekete 2011; Fekete et al. 2012), the Federal Office of Civil Protection and Disaster Assistance (BBK) has consequently provided a seven-step guideline to identify critical infrastructure in society (BBK 2019). In contrast to the Swedish case, which legally stipulates a co-ordinated policy-creation process among certain public and private actors, the German approach conveys recommendations for individual public authorities to analyse infrastructure and processes in their respective areas of jurisdiction. In addition, it explicitly encourages an integration of the knowledge that authorities obtain through the approach to public risk and crisis management. The Swedish case of *STYREL* implicitly expects such integration but struggles with proper inclusion in the approach as well as in emergency response planning and crisis management as the following research will elaborate on in more detail.

However, there is a notable absence of concrete descriptions of such systems and their parts and interrelations as well as of the proceedings during policy-making. To address this gap, the research in this dissertation examines the Swedish case of *STYREL*. Due to the advanced stage of this complex SoS, a representation of the Swedish case is of major interest to research on complex systems, public and private policy makers and practitioners in the field of CIP and similar contexts, including and beyond the Swedish case.

Moreover, one concern behind *STYREL* is the challenge of balancing the electricity production and the increasing demands of the depending society and its critical infrastructure over the long transmission distances in Sweden. Especially, a cold winter day provides particular difficult conditions, for example, a low capacity of transmission cables on the one side and a high demand due to heating on the other. Climate change seems to further amplify such problematic situations and create new ones, such as those that emerged during the wild fires 2018 in Sweden. In the summer of 2018, the national PGO had to disconnect a few high-voltage transmission lines for several days, two 400 kV power lines and one 220 kV power line (SvK 2018a, 2018b, 2018c).

The above considerations position the Swedish case of *STYREL* as a case of particular interest in the evolving and multidisciplinary field of CIP.

1.4 Disposition of the Dissertation

The previous sections have indicated how the selection of the Swedish case narrowed the research field of complex systems to the problem area of CIP and its backbone, namely the (emergency) power supply. Since this national case is complex and can be approached from multiple angles, this thesis focuses particularly on the involved governance efforts. This planning for cases of power shortages represents a novel and unexplored type of policy-making for CIP, which limited the selection of method alternatives. Despite such constraints, the unique insights from this case of CIP governance can also be of interest beyond the Swedish context for similarly complex planning situations. Although a single case study may be unable to provide all-encompassing answers to any type of question, it can reveal valuable knowledge of real-world phenomena. In view of the extent and complexity of the investigated case, a timely effort for a thorough investigation could not be underestimated. These conditions motivated an adequate limitation of the study's focus. Hence, out of the many variables of interest, this study specifically concerns perspectives, interactions and boundaries with regard to systems, critical infrastructure and governance in the context of CIP.

This doctoral dissertation consists of a three-part thesis and six papers. Figure 3 demonstrates the disposition of this dissertation at a glance.

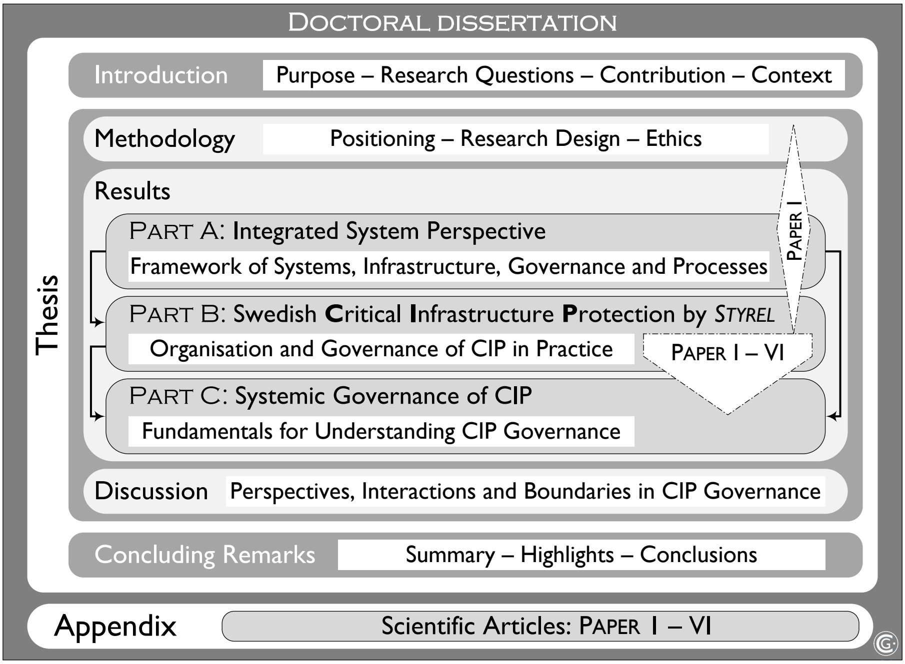

Figure 3: Disposition of the Dissertation

2
METHODOLOGY

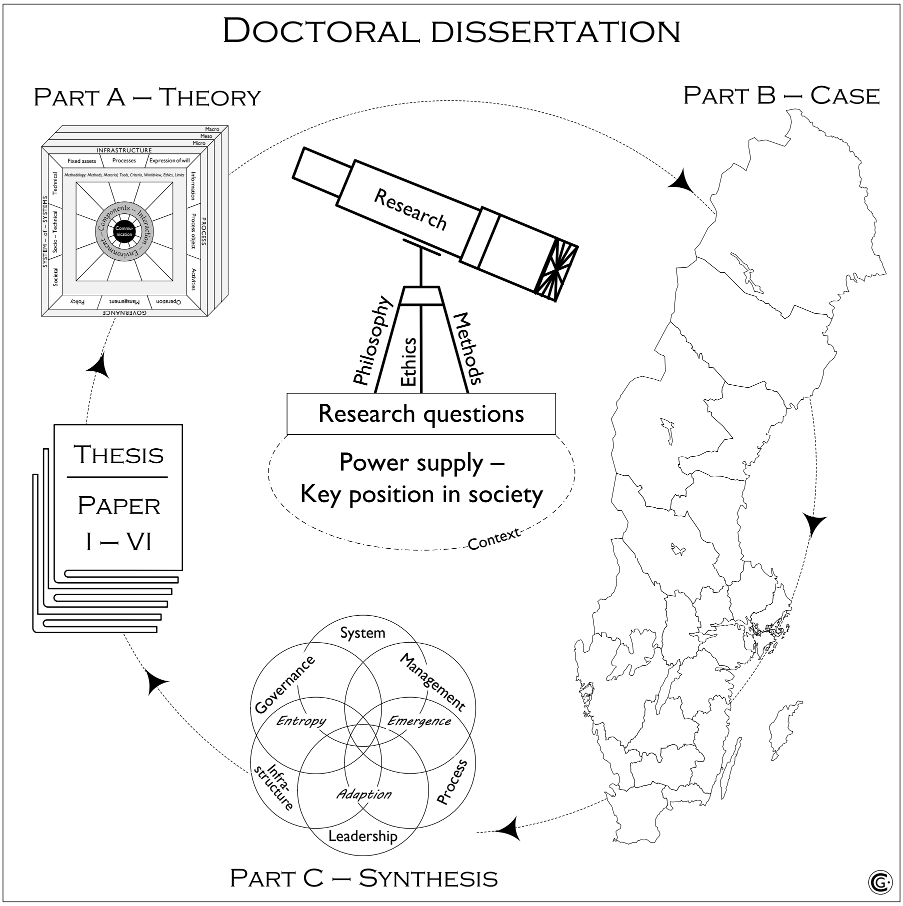

Figure 4: The Research Cycleof Theoretical and Empirical Inquiry, Analysis and Synthesis

2.1 Introduction

This chapter provides the epistemological, methodical and ethical foundations that supported the research for this dissertation. It situates the thesis and its parts within the complex system of scientific paradigms, methods and *ethos* of the community. The sub-sections describe methodological components for data collection and analysis and the treatment of limitations. In addition, PAPER I delivers further theoretical background about epistemological and methodical approaches in information systems research.

This chapter unfolds the *Weltanschauung* that saturates the research for this study. Unfolding the underlying structure of *Bildung*, scientific education and reflexion offer insights into the formation of the research design, including the selection and application of several methods with consideration of propensity, capability and capacity limitations.

Section 2.2 describes the three main approaches for extending the body of knowledge: deductive, inductive and abductive. In addition, it discusses the implications of these approaches for scientific research in general and for this study in particular. This sections bridges the gap between certain paradigms and suggests a more systemic perception of knowledge development.

The multi-disciplinary research project *From authorities to citizens and back*, which was conducted between 2015 and 2018 at the Mid Sweden University, inspired the research design of this doctoral thesis, as outlined in Section 2.3. The sub-sections describe the methodical proceedings of the study and its three parts. First, an overview provides an initial understanding of how the materials and methods connect with PAPERS I-VI and PARTS A-C of this thesis. Second, a description of the methodical proceedings conveys additional details about the extent, content and quality of the obtained material as well as the methods that were applied to collect and analyse it. Finally, aspects that limited the study complete the methodological contour of the research. This outline of performed actions and employed methods can enable the reader to comprehend the presented results and associated conclusions.

Ethos – ἔθος – is central to the reflections that finalise the explication of the underlying point of view. Apart from general contemplations of research ethics, this section presents perceptions of the scientific community regarding ethical aspects that warrant consideration in research and their observance throughout the research process for this dissertation.

The concluding section summarises the main points of the proceedings in relation to the three parts of this thesis: the literature review, the case study and the synthesis of theoretical and empirical insights. In addition, it discloses certain limitations and indicates prospects for further research.

2.2 Scientific Positioning

Since the time of Aristotle, three main types of approach have existed to extend the world of knowledge: deductive, inductive and abductive. The deductive option progresses from general to specific cases and consults existing theories and premises to establish logical conclusions. According to Aristotle, deduction constructs an epistemological foundation for concluding rational and true insights (Kirchner, Michaëlis 1911:96). In contrast, the second approach is based on empirical findings and observations. By way of induction, specific findings can be generalised and theorised to build upon the available body of knowledge (Welch et al. 2011). The third approach, namely abduction, can be useful for explaining observed divergences in facts. Thereby, a study can formulate new hypotheses that facilitate the comprehension of sensations. Abduction is applicable either to draw a conclusion from a major premise that is known to be true (Kirchner, Michaëlis 1911:76) or to argue new hypothetical premises that remove the surprising character of the empirical perception (Hartshorne, Weiss 1934; Reichertz 2013). Peirce has summarised the approaches as follows (Hartshorne, Weiss 1934):

> *'Deduction proves that something* ***must be****; Induction shows that something actually* ***is operative****; Abduction merely suggests that something* ***may be'****.*

The attending problem concerning the validity of research findings is still subject to discussion among the research community. One tendency assumes the view of rationalism in science, which follows the basic attitude that cognition of reality occurs through rationality and reasoning (Descartes, Hammacher 1996). The deductive approach is therefore used mainly as the appropriate means. In addition, rationalists are sceptical of empirical research and accordingly communicate doubts regarding the truth and relevance of empirical findings (Leibniz 1714). Another tendency is the approach of empirical knowledge. This approach employs gained experience as a strategy for conducting cognition (Locke 1824) since acquiring knowledge *a priori* is considered impossible. Research that adheres to this credo reflects general scepticism of the validity of scientific knowledge since it assumes that experience is empirical, and, therefore, only empirical experience can result in cognition (Hume 1998). In an attempt to combine these rather categorical approaches, Kant has suggested that knowledge is based on empirical impressions, though cognition accrues through use of the mind and reasoning about empirical impressions to structure perceptions (Kant 1956).

In summary, a key question concerns the extent to which knowledge can be considered universal and true. According to Popper, definitive knowledge is impossible (Popper 1935). He has opined that the only way to perform research is to falsify statements against theory, which implies that one can demonstrate that an idea is not true but never that it is. Even Gettier has queried the quality of reasoning by arguing that a justified true belief can be true, per accident, even though someone's reason for the belief is false (Gettier 1963). However, estimating the reason's quality—which underlies an individual belief that a claim is true—requires general valid criteria, which are still absent. Therefore, the term 'knowledge' is supposedly indefinite (Welding 2016) similarly to the concept of 'theory' on which to base that scientific knowledge (Bichler et al. 2016b).

Hence, this dissertation applies the term 'knowledge' with an understanding of its limitations. The primary intention of this study is to extend the base of knowledge rather than to provide a generic answer to the topic (Welch et al. 2011). Nevertheless, it aims to yield proper results and arguments for the reasoning to conduct a well-informed debate about the Swedish case of CIP with respect to system theories and the context of power supply in practice. In consequence, during the inquiry of the Swedish case, the investigation adopts a rather systemic attitude to move beyond the distinction between constructivism and (neo-)positivism (Mingers et al. 2013).

This dissertation thus considers that 'science is not a specialist business; it is completely universal' (Feynman 1998), which emphasises the preference for a systemic perspective of science. The following research seeks to adopt this perspective through a cycle of deduction, induction and abduction that revolves around the concepts of system, infrastructure and governance in the context of CIP in Sweden and beyond. However, the interdisciplinary character and complexity of the investigation in combination with the timely limitations of this study have led this dissertation to deliberately omit details and incorporate uncertainty. In turn, these limitations highlight promising prospects for future research, according to Feynman (1998), who has acknowledged the value of uncertainty and doubt in science as a catalyst for pursuing open questions and refining previous statements through new methods, knowledge and conclusions as well as innovative technologies.

The extent of the interdisciplinary research field, the complexity of the Swedish case, the heterogeneity of the related information systems and the variety of actors in this SoS limited the selection of methods. Moreover, the particular perceptions of the interviewees cannot completely explain the behaviour of the whole system. Nevertheless, the theoretical and empirical inquiries can reveal important insights to represent and analyse the existing complex system of CIP and its governance and, furthermore, to inform the suggestion and design of new types of systems, processes, technology methods or governance concepts, such as the concept of systemic governance.

2.3 Research Design

2.3.1 Methodological Proceedings

The research design of this study unites the approaches to incrementally extend the world of knowledge in a cycle of data and information gathering, analysis and synthesis. The main body of this thesis is comprised of three parts.

First, PART A reviews current literature in the field of CIP with a concentration on systems, infrastructure and governance. In addition, it synthesises the results of this analysis of theories and concepts and contributes a new theoretical frame of reference. Then, PART B applies the methodical approach of a case study, which allows this study to investigate a real-world phenomenon of significant complexity while maintaining a holistic perspective (Flyvbjerg 2011; Remenyi 2012; Welch et al. 2011; Yin 2014). The multi-disciplinary research project *From authorities to citizens and back* was conducted between 2015 and 2018 at the Mid Sweden University. This project selected three counties for conducting interviews with a total of 66 persons. Prior to this study, which started in 2016, four persons had been interviewed by three researchers. Over the course of this case study, I personally conducted interviews with 41 individuals. This number of personal contacts and individual views facilitated not only the maintenance of a holistic perspective during this study but also the involvement of the results of my partial studies and follow-up questions to yield a deep understanding of the case. The remaining 21 persons were interviewed by four other researchers in the project group. Since the use of multiple sources of evidence arguably benefits the overall quality of case study research (Flyvbjerg 2011; Yin 2014:119), this study further incorporated documentation and a survey as well as the researchers' individual notes and reflections to enrich the evidence. Archival records could not be included due to information security concerns. The collected material was then subject to several studies, some of which are not part of this dissertation. PART B briefly presents both the included papers and the analysis of the case in accordance with the theoretical framework of PART A. Besides valuable knowledge of the unique *STYREL* process, this part contributes a concise synthesis of practical implications for Swedish CIP. Finally, PART C primarily develops the concept of systemic governance, which represents the nexus of governance, management and leadership in the context of CIP. This synthesis provides the results of a multi-step process and proposes the outcome of the synthesis as a novel contribution to theory development.

This overview offers a brief understanding of the main body of this thesis. The entire doctoral dissertation is a compilation of this thesis and six articles.

The thesis contains both original research and the representation and synthesis of already-published journal articles and conference papers. Table 1 summarises the materials, approaches and methods for each component of the compilation.

Table 1: Research Approaches, Material and Methods

Part of the Compilation	*Main Approach*	*Key Material*	*Methods*
PART A	Literature review	▪ 30 scientific publications ▪ Complementing literature	▪ Meta-analysis ▪ Concept analysis ▪ Synthesis
PART B	Case Study	▪ Six articles included ▪ Some unpublished material	▪ Case description ▪ Content analysis ▪ Synthesis
PAPER I	Methodical	▪ Theory associated with the research field and research paradigms	▪ Literature review ▪ Modelling ▪ Model evaluation
PAPER II	Design-oriented	▪ Publicly available documents regarding the case ▪ Interviews with eight officials from municipalities	▪ Content analysis ▪ Modelling ▪ Model evaluation
PAPER III	Empirical	▪ Publicly available documents regarding the case ▪ Interviews with four officials from three CABs ▪ Survey with all 21 CABs	▪ Policy analysis ▪ Content analysis ▪ Descriptive statistics
PAPER IV	Empirical	▪ Publicly available documents regarding the case ▪ Interviews with 66 officials from 47 municipalities, 3 CABs and 8 PGOs ▪ Survey with all 21 CABs and 10 PGOs (responsible for load shedding)	▪ Policy analysis ▪ Modelling ▪ Content analysis ▪ Descriptive statistics ▪ Synthesis
PAPER V	Theoretical	▪ Publicly available documents regarding the case ▪ Interviews with 57 officials from municipalities, CABs and PGOs	▪ Content analysis ▪ Modelling ▪ Concept development
PAPER VI	Theoretical & Empirical	▪ Publicly available documents regarding the case ▪ Interviews with 18 officials from 15 municipalities and two CABs	▪ Concept development ▪ Content analysis ▪ Synthesis
PART C	Synthesis	▪ PART A and B	▪ Concept/Theory development

Each paper contains a separate method description which details each applied approach. The following section details the methodological instruments for this study.

2.3.2 Material and Methods for Data Collection, Analysis and Synthesis

This section details the material and methods for data collection, analysis and synthesis according to PARTS A, B and C of this thesis.

PART A – Literature Review. The review of literature accompanied the entire research process, although intensified efforts occurred at specific points in the process, such as the initial stage, the translation of partial studies into scientific papers and the writing of this thesis. Apart from this reading and utilisation of related work and theoretical concepts, PART A of this thesis conducted a systematic literature review (Paré et al. 2015). This literature review consisted of a search for relevant scientific articles (vom Brocke et al. 2009) and a content analysis of a selection of articles.

During the initial phase, the structured process of the literature search and selection applied broad and general search terms in various databases to identify the most comprehensive option. The initial search returned a vast range of hits in various databases, including 1,370 in ProQuest Social Sciences, 5,646 in Ebsco, 9,114 in Scopus and 3,662 in World of Science. On the basis of this initial assessment, Scopus was selected for the subsequent literature search. The initial search term was varied with regard to wording and search location to reduce the number of results and, thereby, to obtain a selection that suitably represents current research in the field of complex systems, CIP and governance. Table 2 displays key words, search terms and results.

Table 2: Key Words, Modified Search Terms and Hits in Scopus (April 2019)

N	*Search Term*	*Hits*
0	(T-A-K[+] ("system* governance*")) ∨[++] (T-A-K ("critical infrastructure*"))	9 114
1	T-A-K ("complex system*")	62 997
2	T-A-K ("critical infrastructure")	8 711
3	(T-A-K ("critical infrastructure")) ∧[+++] (protection)	3 936
4	(T-A-K ("critical infrastructure")) ∧ (protection) ∨ (governance)	4 141
5	(((T-A-K ("critical infrastructure*")) ∧ (protection) ∨ (governance)) ∧ (system*))	3 796
6	(((T-A-K ("critical infrastructure*")) ∧ (protection) ∨ (governance)) ∧ (system*)) ∧ (complex*)	1 441
7	(((T-A-K ("critical infrastructure*")) ∧ (protection)) ∧ (system*)) ∧ (governance)	288
8	(((T-A-K ("critical infrastructure*")) ∧ (protection)) ∧ (system*)) ∧ (governance) ∧ (complex*)	155
9	(((T-A-K ("critical infrastructure*")) ∧ (protection)) ∧ ("complex system*")) ∧ (governance)	35

[+](TITLE-ABS-KEY), [++] OR, [+++] AND

The abstracts of the literature that the last two search terms identified were subject to closer investigation. The final selection included 30 scientific articles and book chapters that were identified by the final search term; five matches that targeted entire books were excluded.

In pursuit of a solid point of departure for the academic community that is interested in systems and CIP (Paré et al. 2015; Pfeffer, Sutton 2006), the literature analysis started during the selection process by assessing the type of literature, the year and place of publication, the number of authors and other available meta-information. As Table 3 indicates, the final selection consisted of 18 journal articles, of which two provided literature reviews, and two chapters of a serial publication. Furthermore, the selection included 10 conference articles, of which the majority had been published in or after 2016.

Table 3: Sources of Journal Articles and Serial Publications Included in the Literature Review

Source of publication	*n*
International Journal of Critical Infrastructures	6
Energy Policy	2
Journal of Contingencies and Crisis Management	2
Nato Science For Pease And Security (Series C: Environmental Security)	2
Reliability Engineering And System Safety	2
ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part B: Mechanical Engineering	1
Cognition, Technology & Work	1
IFIP Advances in Information and Communication Technology	1
International Journal of Disaster Resilience in the Built Environment	1
International Journal of Disaster Risk Science	1
Safety Science	1

The analysis then followed the key words from the literature search and examined the selected articles in more detail. The main categories—system, infrastructure and governance—directed the reading and a close textual analysis. Definitions, examples and certain aspects that the authors have emphasised were extracted from each article. The analysis was also attentive to issues that emerged from the texts, such as contrary understandings, common usage of concepts and problems of particular interest for this thesis. One observation is that about three-quarters of the articles contain no description of the actual research process or epistemological position, which can reflect the immaturity of the relatively new research field of CIP (see e.g. Katina, Keating 2015; Seager et al. 2017), its strong anchorage in engineering and its preference for multi-disciplinary approaches in the interplay between solution-orientation and theory development. However, excerpts from the articles substantiate the discussion of concepts in Section 3.

Some of the concepts either appeared in the articles as common knowledge or were completely absent. The literature review has filled these gaps with the aid of complementing literature. It has also described and contextualised the missing aspects and concepts.

The theoretical frame of reference that concludes PART A synthesises the results of the literature analysis via the method for complex and interdisciplinary research that PAPER I develops. Following this approach, a multi-perspective kaleidoscope for integrative system analysis has been defined. Key dimensions and reoccurring aspects that emerged from the analysis formed the categories of the framework. The results of the previous analysis further facilitated arrangement of the adjacent areas and, ultimately, the assembly of the kaleidoscope as depicted in Figure 5. By way of deviation from the method in PAPER I, the framework does not include methodologies because they were not part of this literature review.

PART B – Case Study. This part of the thesis studies the Swedish *STYREL* case in detail. The examination employed several methods for data collection and analysis and the design of conceptual models. Apart from regularly conducting the literature review, this study mainly examines documents that relate to the case, interviews and a survey with involved experts, which allowed for data triangulation (Denzin 2012; Gerring 2007). Confidential meeting protocols, field notes, individual experiences and reflections of the involved researcher enriched the material basis (Bryman, Bell 2015). The case study additionally entailed the development of models, which are rooted in the results of the content analyses of the collected material and their evaluation (e.g. during interviews with experts who are involved in the Swedish case).

First, this research investigated publicly available textual material regarding *STYREL*. The collection mainly consisted of official policies and user instructions, legal regulations, public investigations and reports as well as evaluations of the pilot in 2009 and the first run of *STYREL* in 2011. Such material included the following sources:

- *Preparatory documents* (Eusgeld, Kröger 2008; Fell 2008; Johnsen, Veen 2013; Ouyang 2014; Sajeva, Masera 2006)
- *User instructions and guidelines* (Municipality of Uppsala 5/18/2015; EA 2010, 2011, 2012b, 2014a, 2014b, 2014c)
- *Laws and regulations* (SFS 2013:282; MSB 2010; Riksdagsförvaltningen 2014a, 2014b, 2019; EA 2010, 12/2/2013; SvK 1996, 2012, 2017b, 2017c)
- *Evaluations at local, regional and national levels* (CAB Blekinge 2009; CAB Dalarna 2009; CAB Stockholm 2012; E.ON 2016; MSB 2011b; Municipalities of Falkenberg, Halmstad, Hylte, Kungsbacka, Laholm & Varberg 2011; EA 2012a; Veibäck et al. 2013; Veibäck, Stenérus Dover 2011)
- *Public crisis management exercises that used the results of STYREL* (CAB Västernorrland 2013; CAB Västmanland 2012)
- *Future adoption of the concept* (EA 2016, 2019; Swedish Food Ageny 2017)

During several iterations, the analysis used the theoretical framework that PART A originated to identify relevant information in the documents and understand particular aspects of the problem situation.

Second, this study selected three counties for conducting interviews with a total of 66 responsible individuals from CABs, municipalities and PGOs. Table 4 contains further information about the counties and the participation in the study. The size and structure variation in the regions allowed for a broad spectrum of local experiences, requirements and constraints, which imparted appropriate information power in the sample (Guest et al. 2006; Malterud et al. 2016) and supported a thick description of the *STYREL* process and the executing system.

Table 4: Participation in the Case Study (Source: Große et al. 2019)

Region	*Interview Study Participants acting on behalf of a*			*Survey Respondents*
	CAB	*Municipality*	*PGO*	
All counties (n=21)				15
North: rural countryside	1	8		
Middle: includes heavy industry close to the capitol	2	7		
South: includes one of the three major cities	1	32	3	
Further national, cross-regional and local PGOs			12	
All certainly responsible PGOs (n=10)				10

Material was collected from semi-structured face-to-face interviews and one interview that was conducted via telephone. A guide with open-ended questions was employed to ensure a similar structure across interviews and allow participants to report individual experiences and perceptions. Follow-up questions were posed to achieve more clarity and richness of detail. The interviews lasted for one hour on average and were recorded and transcribed. The proceedings further entailed anonymising and aggregating the material and results to secure sensible information with regard to both privacy and confidentiality. Moreover, participants were always permitted to discuss issues without being recorded. In such circumstances, the researcher's notes completed the data collection. The subsequent in-depth content analysis of the interview transcriptions produced a deeper understanding of nuances in meaning and verbal expressions by replaying the recordings alongside the analysis. Furthermore, the data analysis applied a hermeneutic approach to policies and interviews, which necessitated deliberate, reflected subjectivity of the analyst to interpret data and results that could yield novel insights (Breuer et al. 2002; Reichertz 2015).

Third, throughout the study, the findings from the textual material and interviews informed subsequent activities, such as the survey. To broaden the view of particular issues, the survey encompassed all 21 counties in the first step and, in the second step, considered the 10 PGOs that stabilise the power grid during the initial phase of a power shortage. Table 4 indicates the number of responses. The survey posed 34 questions about the respondents' perceptions of the effectiveness and efficiency of *STYREL* in general and the proceedings of the planning process within their respective areas of responsibility in particular. Although the majority of respondents shared their perceptions in the general part of the survey, the rate decreased to around half of the respondents when addressing knowledge of the concrete proceedings of the respective actor. The overall frequency of answers to the survey questions was 63.1%. The answers to the remaining questions were 'do not know (N/A)' or even omitted in some cases.

Finally, this study developed several models that support the communication process towards a shared understanding of the complex implications of planning environments, such as the Swedish case for CIP, for both governance and research. Essential characteristics of a model are mapping, abstraction and pragmatism. A modeller maps an original, such as the complex system that encircles *STYREL*, with a specific intention. Thus, certain abstraction occurs within the modeller's individual-cognitive model; however, a goal-oriented abstraction deliberately removes complexity from the original when creating the model. To be meaningful for a future user, such model must address the perspective of the intended target audience (Stachowiak 1973:131-133).

Since these characteristics of a model require evaluation of its features, scholars have suggested various approaches for assessing models in information systems research (Fettke, Loos 2003; Hevner et al. 2004). PAPER I demonstrates the application of a model, namely the multi-perspective kaleidoscope, as method for complex and interdisciplinary research. The application to the Swedish context illustrates how this model arranges theories and methods that relate to the complex planning case. PAPER II applies an evaluation by experts that entailed asking experts who perform the *STYREL* planning about their perceptions of this system model. Their comments informed further improvements of the model, which in turn enhanced communication about the nexus of the case in further interviews. PAPER IV elucidates the context for a constructive dialogue about strategic objectives through examples from empirical material on the *STYREL* case.

PART C – Synthesis. The final part of this thesis departs from the theoretical concepts that crystallised in the literature review as well as the applications and experiences in praxis that came to light during the study of the Swedish case. Thereby, the method of synthesis constitutes a complementary course of action to the preceding analyses. The synthesis in this dissertation predominantly develops the concept of systemic governance as the nexus of governance, management and leadership in the context of CIP.

This synthesis connects theoretical concepts with practical experiences and intertwines perceptions and statements to define a new worldview by a certain cognitive performance (see e.g. Kant 1956). In chemistry, the term 'synthesis' emerged from descriptions of purposeful connections between elements (Kolbe 1845). In technical contexts, 'synthesis' refers to the design and creation of novel systems that meet certain requirements (see e.g. Berek 1930; Friedrich 1990; Sanden 1912). Thus, the result of synthesis is a new system. In an epistemological context, Kant has characterised a system as 'unity of manifold recognitions under an idea' [*die Einheit der mannigfaltigen Erkenntnisse unter einer Idee*] (Kant 1956, A 832). The unity of such system elements is determined by a purpose, which also determines the synopsis of the key elements that substantiate a synthesis (Kant 1956, A 95). Other scholars have employed the term 'synthesis preparation' for this initial process of summarising theories and knowledge (Pound, Campbell 2015). In this thesis, PART A elaborates on the concepts and theories that relate to the thesis' main focus on systems, infrastructure and governance during such preparatory process. The process of synthesising through cognitive performance—even referred to as 'synthesis' (Kant 1956, B 137–138; Pound, Campbell 2015)—creates the new system by connecting the multitude of elements while considering the intended purpose. However, synthesis as a cognitive process can be conceived of as multi-step proceedings that are inspired by the interplay of conflicts and solutions, realised at the intersection of action and reaction, and driven by perpetuating interaction with the elements and the creativity of mind (Harvey 2014; Kant 1956; Pound, Campbell 2015).

The cognitive process of synthesis creation accompanied the whole research process for this thesis and, therefore, cannot be viewed as one single activity. Iterative reflections on theory and empirical evidence alongside the cumulative approach of the thesis ultimately yielded the synthesis, which PART C explicates in more detail. The insights from studying the Swedish case for CIP, which PART B presents, inform an iterative refinement that clarified the proposed synthesis (Pound, Campbell 2015). The apperception of the synthesised unity (i.e. the system that results from the cognitive process) completes the synthesis (Kant 1956, A 95). In sum, PART C delivers the results of an idealised process and finally proposes the ultimate outcome of the synthesis: systemic governance in the context of CIP.

2.3.3 Treatment of Limitations

Apart from the researcher's cognitive conditions, several aspects imposed constraints on this study. These aspects include the time frame, the access to data, and the selection of the research focus, the methods and the case.

In association with the review, the literature selection and analysis were subject to certain limitations. Since the selection process affects the possible results of a literature review, the previous section has detailed this process (vom Brocke et al. 2009). In addition, the literature review sought not only to summarise the content of the included research as a basis for this study but also to originate a solid foundation for other members of the CIP community (Paré et al. 2015). Therefore, the analysis reviewed key concepts and their application in current research with the aid of categories. Emerging issues, if any, were acknowledged, and missing aspects were clarified.

The research project from which this study departed proceeded over a period of slightly longer than three years. This period covers the interval between the two iterations of the *STYREL* process. As Section 4 describes, staff changes and information loss occurred during such interval and impacted the empirical material that was collected during this period. Due to time constraints, not all key stakeholders could be involved in the study. To address this limitation, participants were gradually selected to appropriately represent the diversity of the investigated complex system. Since CIP relies on sensible data and targets weaknesses in systems, access to data was restricted, which introduced further obstacles to the policy and interview study (Große et al. 2019). Consequently, the data collection relied predominantly on publicly available Swedish documents and personal interviews. Confidential information that was acquired through data collection was handled with care. Sensitive information was omitted, condensed or anonymised during analyses with respect to relevance to the study's focus. Nevertheless, the inclusion of all intended material, such as real documents from the municipal, regional, and national levels to assess the proceedings of the planning process, was not possible in view of concerns regarding information security or loss.

To counter this limitation, the study aimed for data triangulation, which consists of the application of several methods to obtain a form of saturation or information power in the empirical material (Denzin 2012; Gerring 2007; Malterud et al. 2016; Saunders et al. 2018). Besides the document analysis, the conducted interviews enhanced the understanding of the Swedish case and informed the derivation of meta-themes for partial studies (Guest et al. 2006). This process of data analysis and interpretation also took the interview situation into account, as the researcher's perceptions of nonverbal communication, if any, may have influenced the interaction with the material.

The attendance of several workshops with stakeholders of the Swedish case and discussions with the other researchers in the project facilitated a nuanced understanding with consideration to different perspectives. Furthermore, the survey focused on the interactions between actors in the case, which limited the number of possible observations (Lieberson 2012). The survey is an example of a small-n study, which emphasises the need for carefulness in formulating conclusions. Given the limited experiences of the participants with regard to *STYREL*, the establishment of general conclusions is not at the forefront of this study, which instead highlights driving forces with respect to the CIP system and the interactions between actors in the planning process.

Moreover, the investigation needed to account for time and structure limitations to fulfil the institutional requirements for a cumulative dissertation within a predetermined period. Therefore, the acquired data were continuously analysed through the lens of the stated research questions to examine various aspects of the presented problem. The aim was to complete this thesis with separate scientific publications that all thematically interrelate to the case study. PAPERS I-VI indicate any particular limitations in greater detail.

This methodical proceeding imparted a deeper understanding of the theoretical concepts and complex structures in the Swedish case, which ultimately facilitated the synthesis of both elements. In turn, the results of the synthesis signify a point of departure for future studies in the contexts of CIP and other circumstances.

2.4 Ethical Considerations

Ethics in research accounts for a large field of tensions through attention to many issues, such as the research process, the researcher and the research subject. Relationships between individuals as well as their actions and subjectivities are particularly important. Hence, research that involves humans—as subjects or conductors of studies or as consumers of the results—must incorporate several questions concerning responsibility, adequate objectivity and independence. Such questions can involve both legal questions of privacy and philosophical questions of applied, activity-oriented ethics. In addition, political and theoretical questions of positioning research and researchers in certain societal and methodical circumstances can provoke further consideration of, for example, a researcher’s (self-)reflexivity (Unger 2016). All of these questions address the mentioned issues with regard to the entire research process and the relation between the researcher and the subject of their research.

Therefore, ethical considerations in research strongly connect to the research persona who prepares and performs the process. Although relations between a researcher and a research subject are mostly central to discussions, each methodical component of a research process can have consequences for researchers as well as research subjects. In regard to ethical behaviour, Kant has suggested that morally good conduct is based on practical reason (1788:54-56). He has argued that an individual must behave in a morally good way to obtain credibility within a society or group, which implies that only morally good conduct could be a reasonable behaviour. Although reasonability renders morally good conduct advisable, it is relevant to discuss how individual experiences and learned patterns may influence free will and, thereby, such practical reasoning (Schultze-Kraft et al. 2016). Morally good behaviour of a researcher necessitates maximum transparency, as it may affect numerous aspects of the research process (see e.g. APA 2010; Breuer 1996:36-40; Gustafsson et al. 2011; Wissenschaftsrat 2015). Table 5 indicates these aspects and explains how this study addresses them.

Table 5: Ethical Aspects Addressed during the Dissertation

Aspect	*Description*	*Application*
Veridicality	Establish openness by presenting methods, materials, results and conclusions. Appropriate efforts reveal integrity of the research that supports credibility.	This dissertation (i.e. the thesis and the embedded papers) details the methods for data collection, analysis and synthesis as well as the results and conclusions.
Disclosure of interests	Distinctly present interests to encourage adequate interpretation of research. Emphasise interests that relate to particular principals or may pose conflicts.	It is gratefully acknowledged that the EA financially supported parts of the research. No conflicting interests were disclosed that related the support to predetermined results.
Replicability	Explain the performed actions and applied methods and theories. Readers should be in a position to understand and follow the research process and results.	This dissertation seeks to offer adequate information about actions, methods and background as well as interpretations.
Application of good standards	Involve reflection on common norms and expectations regarding the research process and proper method selection that is inclusive of the treatment of informants.	Chapter 2 of this thesis addresses these particular reflections. Other sections and the papers also discuss this issue to varying extents.
Publication of results	Reflect on the researcher's self-censorship, which may occur during topic selection and the determination of the completeness of a study. Effects of principal's interests may also be considered.	All of the included papers have been published. Material and results concern the examined topic. Section 6.4 notes remaining issues for further research.

2.5 Summary

This chapter has explicated the epistemological, methodical and ethical basis of this dissertation. The extent of the interdisciplinary research field, the complexity of the Swedish case of CIP governance, the heterogeneity of the related information systems and the variety of actors in this complex SoS necessitated deliberate limitations to meet time and budget constraints.

This thesis applies three main approaches: a literature review, a case study and a synthesis. PART A of this thesis conducts a systematic literature review that summarises the content of the included literature as a framework for this study and also originates a solid foundation for other members of the CIP community (Paré et al. 2015). This literature review involved a search for relevant scientific articles (vom Brocke et al. 2009) and content analysis of a selection of articles. The main categories of system, infrastructure and governance directed the selection, reading and textual analysis of the literature. Complementing literature filled gaps in knowledge of certain aspects. PART B studies the Swedish case of *STYREL* in detail and employed several methods for data collection and analysis as well as the design of conceptual models. The research entailed investigating publicly available textual material on *STYREL* before selecting three counties for interviews with a total of 66 participants from CABs, municipalities and PGOs. The findings from the textual material and interviews informed subsequent activities, such as a survey that encompassed all 21 counties and the 10 PGOs that are responsible during the initial phase of a power shortage. Finally, several models were developed to support communication towards a shared understanding of the implications of a complex SoS, such as that in the Swedish case for CIP, for both governance and research. PART C applies the method of synthesis as a complement to the preceding analyses to elaborate on the concept of systemic governance in the context of CIP. This synthesis connects the theoretical concepts in PART A with the practical experiences from the case study in PART B and intertwines perceptions and statements into a new worldview (see e.g. Kant 1956). Figure 4 illustrates this proceeding.

Some limitations of this study highlight prospects for further research. For example, this research was conducted during the interval between the two iterations of the policy-making process. Staff changes and information loss that occurred during such interval may have impacted the empirical material. Hence, further research could focus on real decision-making situations for specific stakeholders during the next process iteration. The next three chapters provide the results of the study that this chapter has detailed, and the subsequent discussion specifies further areas for research.

3

Part A – Theory: Integrated System Perspective

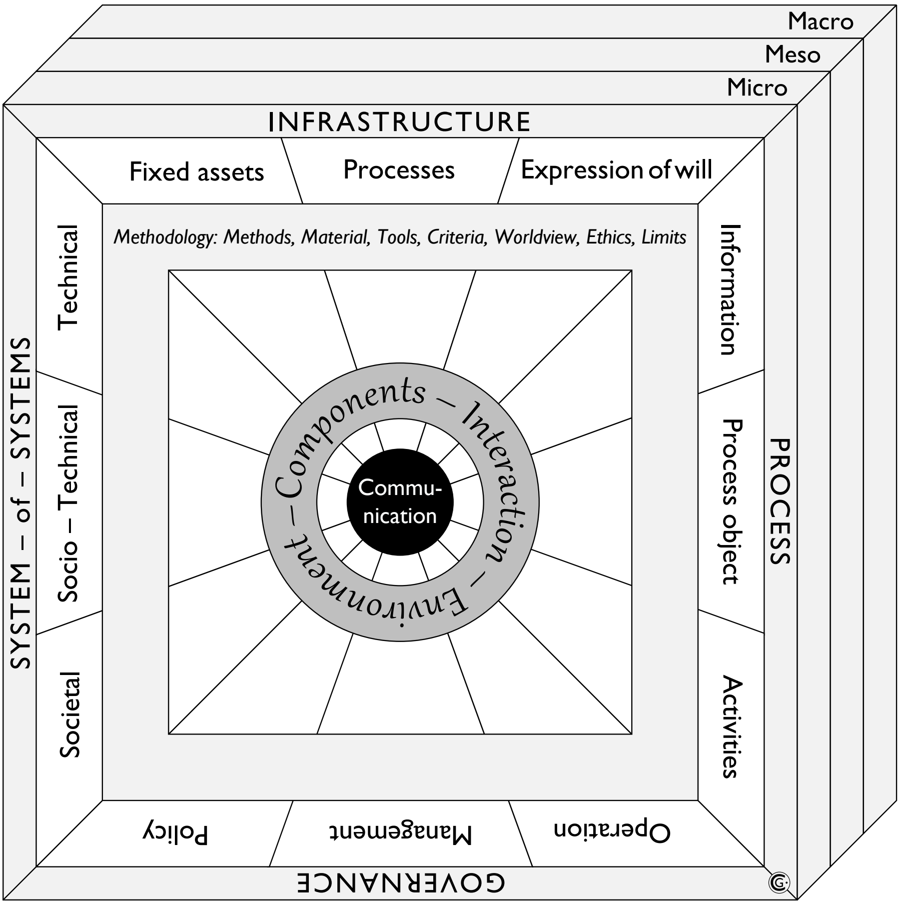

Figure 5: Kaleidoscope for Integrative System Analysis (KISA)

3.1 Part A – Outline

As indicated by the brief overview of the origins and applications of the fundamental concepts in the introductory chapter, the use and meanings of the terms 'system', 'critical infrastructure' and 'governance' are various, multi-faceted and shifting. Therefore, this chapter reviews recent and historic scientific literature to examine the definitions, properties and applications of the concepts in the research field of CIP.

PART A conducts a systematic literature review that not only summarises the content of the included literature to frame the study but also originates a solid foundation for other members of the CIP community (Paré et al. 2015). Thus, in providing the theoretical framework for this dissertation, the aim of this chapter is twofold. First, it seeks to formulate an overview of the concepts and theories that substantiate an understanding of CIP and its governance; second, it intends to create a multi-perspective view of systems that integrates several disciplines and research areas.

In concrete terms, the investigation supports the research through both a literature review of 30 scientific articles, which were published over the past 15 years, and an origination of a theoretical frame of reference in the context of systems, critical infrastructure, protection, governance and their processes.

Section 3.2 conveys the essence of the literature review, which Section 2.3.2 has described in more detail. The main categories—namely system, (critical) infrastructure and governance—structure the presentation and discussion of the findings regarding inherent and articulated meanings, common elements and properties, and remaining gaps. This section contributes a foundation and specific insights for common understandings of the investigated concepts, the maturity of the research field and the ontological challenges that warrant further consideration.

Section 3.3 applies the multi-perspective kaleidoscope, which PAPER I originates and Section 2.3.2 has described. The study uses this approach to develop the integrative system perspective that Figure 5 depicts and which could be a valuable tool even beyond the context of CIP. This ensuing multi-focal lens not only guides the subsequent research (i.e. the case study in PART B and the theory development in PART C) but also constitutes a frame of reference for future, multidisciplinary research in the field of critical infrastructure, CIP and their governance.

The last section of the chapter summarises the outcomes of this deductive part of the thesis. To this end, it highlights the main findings, condenses the key elements of relevance for the subsequent case study and indicates several aspects for further fundamental research in the field.

3.2 State-of-the-art: System, Infrastructure and Governance

This section presents the results of the literature review and discusses the findings that connect the corner stones of the triangle of systems, CIP and governance. It concentrates on definitions, common elements and emerging issues that are explicitly articulated or implicitly incorporated in the articles.

3.2.1 The Spectrum of System Concepts

None of the reviewed articles contains a definition that derives from system theory. Furthermore, less than one-third of them makes any reference to previous research in this context when describing the elements of a system (Coaffee, Clarke 2017; Gonzva et al. 2016; Große, Olausson 2019; Katina, Keating 2015; Liu et al. 2017; Lykou et al. 2017; Normandin, Therrien 2016; Ouyang 2014; Sajeva, Masera 2006). Apart from the possibility that such absence stems from the immaturity of the research field of CIP, as Seager et al. (2017) and Katina et al. (2015) have recognised, the insufficient anchoring in theory implies that the inherent meaning of the term 'system' constitutes common knowledge. However, closer textual analysis reveals that the articles incorporate a broad spectrum of meanings. The lowest common denominator consists of three key elements that form a 'system': some **components** that have a kind of **interaction** and are surrounded by a certain **environment**. Although this general understanding is present in earlier history, von Bertalanffy (Bertalanffy 1950, 1968:33) first formulated the General System Theory and discussed these elements in contrasting biological and physical phenomena. These key elements of any system have specific properties, which can be used to characterise a system type. Lists and descriptions of such properties dominate the usage of the system concept in the reviewed articles; however, the type of system of interest is often unclear. The abstraction level in the articles covers systems ranging widely from those of an all-encompassing character (Prelipcean 2010) or global impact (Schaberreiter et al. 2016) to purely technical systems, which, for example, have been considered in the modelling and simulation of a small gas-power-distribution network (Liu et al. 2017).

To label specific systems, the articles use a vast number of aspects, such as a focus on the key elements of a system, particular system behaviours or properties, or the main purpose of a system of interest. The discussion following Table 6 considers some labels of the former two types, namely technical/technological, socio-technical, social, political, complex adaptive and SoS labels as well as open, closed and interdependent labels. Those of the latter type, which regard the systems' key functions, recur in Section 3.2.2.

Table 6: Appearance of System as Concept (* C: Components, I: Interrelations, E: Environment)

Author (Year)	*Definitions / Descriptions*	*System of interest's nature*	*Elements** C	I	E
Abedi et al. (2019)	'*Real systems consists of thousands to then thousands of components*' (p. 27)	- Known components - Mathematically modellable - Technical and measurable - Interdependent	X	X	X
Cedergren et al. (2019)	'*the resource system represents the stock of the resource, resource units represent what users withdraw from the resource system*' (p. 2)	- Known components - Interactions with the system's environment or stakeholders - Technical and measurable - Constitutes a limited resource	X	X	X
Große, Olausson (2019)	'*interactions between components in a system cause system behaviour, which is not easily explained by the properties of components*' (p. 426)	- Emergent behaviour - Interdependent - Entropic and adaptable - Large and dynamic	X	X	X
Katina et al. (2019)	'*blockchaining systems*' in which blockchain has the '*potential to revolutionise internal, external and intra systems and their transaction processes at different levels*' (p. 131)	- Based on virtual currencies (e.g. bitcoin) - Physical/information technology - Values and beliefs	X	X	X
Große, Olausson (2018)	'*Multilevel planning system consists of three hierarchical levels—the local, the regional and the national level*' (p. 1896) and '*co-operation between system components*' (p. 1899)	- Large number of participants - Interdependent - Unknown components and interrelations are possible - Hierarchical and reticular	X	X	X
Tehler et al. (2018)	'*they are becoming increasingly interconnected growing into 'system of systems' and thereby increasing the risk of transboundary crises*' (p. 1865)	- Feedback loops - Interdependent - Large extent - Physical and technical	X	X	X
Gheorghe et al. (2018)	'*space systems, mainly satellites orbiting the Earth*' (p. 555) '*are an unalienable component of high-functioning system-of-systems*' (p. 559)	- Physical/information technology - Interdependent - Functionally expansive	X	X	X
Antonsen et al. (2017)	'*Dealing with interconnectivity requires good system descriptions*' (p. 1840)	- Interconnected - Smart - Communication	X	X	X
Coaffee, Clarke (2017)	'*complex adaptive systems with* [...] *ability to adapt to such conditions of uncertainty and volatility' (p. 365)* and '*a near exclusion of social and human factors*' (p. 367)	- Interdependent - Large and interconnected - Uncertain and volatile - Non-linear and dynamic - Socio-technical and integrated	X	X	X
Katina et al. (2017)	'*Physical (hard) systems such as roads* [...], *hospitals, electrical* [...] *and water systems as well as soft systems, e.g. SCADA and ICT*' (p. 172)	- Face operational factors - Interdependent - Technical, controllable - Large and dynamic	X	X	X
Liu et al. (2017)	Systems-of-systems '*are made by many physically and functionally heterogenous components* […] *organized in a hierarchy of subsystems that contribute to the system function*' (p. 1)	- Technical - Interdependent - Mathematically modellable - Linear-dynamic - Network structure	X	X	X
Lykou et al. (2017)	'*fixed installations* [...], *vehicles* [and] *operations (people, institutions, laws, policies, and information systems)*	- Mainly physical, fixed - Extensive network - Transboundary	X	X	X

	that convert [the former two] *into working* [...] *networks*' (p. 2)	- Interconnected - Long life span and high costs			
Seager et al. (2017)	'*characterized by empirical relationships between and among people, objects, and other systems*' (p. 88)	- Interdependent - Interobjective - Has boundaries and purpose	X	X	X
Gonzva et al. (2016)	'*Socio-technical systems link physical systems with actors and rules to provide a particular function*' (p. 2)	- Large number of dynamically interacting, diverse elements - Unanticipated variability	X	X	X
Häring et al. (2016)	'*socio-technical systems like critical infrastructure*' (p. 273) that serve '*functions of critical interest*' (p. 274)	- Technical and quantifiable - Context and conditions - Interdependent behaviour		X	X
McGee et al. (2016)	'*cannot be completely understood or effectively resolved by addressing parts in isolation*' (p. 147)	- Technical and interdependent - Causal relationships - Non-linear effects	X	X	X
Normandin, Therrien (2016)	'*any social system* [...] *is composed of a large number of parts that interact non-linearly*' (p. 110)	- Emergent behaviour (macro) - Interaction (micro) - Order/disorder (neg-/entropy)	X	X	X
Schaberreiter et al. (2016)	'*composed of many components that are interacting to provide a service* [...] *not* [...] *in isolation*' (p. 672)	- Socio-technical and diverse - Interdependent and global - Technology-based and cyber	X	X	X
Katina, Keating (2015)	'*a set of interrelated components working together toward some common objective or purpose*' (p. 332)	- Physical (hard) and soft (ICT) - System-of-systems - Integrated and co-ordinated	X	X	X
Di Maio (2014)	'*not limited to the IT infrastructures, Data Base and Network but extend to facilities, utilities and support services; policies, procedures, and people*' (p. 5)	- Interoperable - Plurality of actors - Interdependent - Virtually no-boundary	X	X	X
Ouyang (2014)	'*hierarchical structures where each level imposes constraints on the activity of the level beneath*' (p. 55)	- Interdependent - Feedbacks and controls - Not static but evolving	X	X	X
Spyridopoulos et al. (2014)	'*various assets, interactions with the internal and external environment*' (p. 438)	- System-of-systems - Proprietary - Having boundaries	X	X	X
Johnsen, Veen (2013)	'*is an international wireless communications standard for railway communication*' (p. 1)	- Technical - Distributed - Single point of failure	X	X	X
Prelipcean (2010)	'*social systems with* [...] *contributions to the entire global system*' (p. 220)	- Universal and all-embracing - Socio-economic	X	X	X
v. d. Vleuten, Lagendijk (2010a, b)	'*consist of interconnected yet separately managed networks*' (p. 2055)	- Mainly technical - Transnational - Feedback and causal loops	X	X	X
Eusgeld, Kröger (2008)	'*interdependent structures of components*' with a '*dependence on natural and operational environment*' (p. 476)	- System-of-systems - Interdependent - Dynamic and non-linear	X	X	X
Robert et al. (2008)	'*networks are interdependent on each other. Each one uses resources that the others produce*' (p. 393)	- Dynamic - Socio-economic environment - Mainly technical	X	X	X
Sajeva, Masera (2006)	'*composed of multiple, heterogeneous, distributed systems, interconnected among themselves at various levels*' (p. 381)	- System-of-systems - Emergent - Chaotic (i.e. non-linear) - Socio-technological	X	X	X
Gheorghe (2004)	'*relations exhibited today by complex technical and societal systems*' (p. 123)	- Technically designed - Genuine uncertain and ambiguous conditions		X	X

The majority of the articles rather vaguely characterise the system under investigation, which radiates confidence—intended or not—that the *Weltanschauung* of the authors is similar to that of a reader regarding the interpretation of the distinct system constituents. Departing from the literature review, six main types can be deduced: technical/technological, socio-technical, social, political, complex adaptive and SoS.

Technical/technological. System characterisations in the investigated context are merely oriented towards physical components and technical constructions wherein humans mainly appear in the role of output recipients (i.e. users) or are addressed as an environmental factor (e.g. operator or manager of the technical system). Such type of system bears several additional labels that emphasise, for example,

- The **components**: generator (Abedi et al. 2019), real (Abedi et al. 2019), rail/railway (Cedergren et al. 2019; Seager et al. 2017), resource (Cedergren et al. 2019), computer (Große, Olausson 2019), traditional (Katina et al. 2019), cyber-physical (Katina et al. 2017), hard (Katina et al. 2017; Katina, Keating 2015; Lykou et al. 2017), soft (Katina et al. 2017; Katina, Keating 2015), canal (Seager et al. 2017), sewerage (Antonsen et al. 2017), physical (Gonzva et al. 2016; Katina et al. 2017; Seager et al. 2017), storage (McGee et al. 2016), and router (Katina, Keating 2015);
- The **interaction**: (a) among components—grid (Abedi et al. 2019; Seager et al. 2017), linear (Coaffee, Clarke 2017), wireless (Katina, Keating 2015), network (Cedergren et al. 2019; Coaffee, Clarke 2017; Di Maio 2014; Gonzva et al. 2016; Johnsen, Veen 2013; Katina et al. 2017; Katina et al. 2019; Liu et al. 2017; Lykou et al. 2017; Robert et al. 2008; Schaberreiter et al. 2016; van der Vleuten, Lagendijk 2010a, 2010b), cyber (Abedi et al. 2019; Katina et al. 2017; Katina et al. 2019; Schaberreiter et al. 2016); or (b) with an environment—closed (Katina et al. 2019; Tehler et al. 2018);
- The location in relation to an **environment**: local, regional, national, transnational (van der Vleuten, Lagendijk 2010a, 2010b); distributed (Eusgeld, Kröger 2008; Johnsen, Veen 2013; Ouyang 2014; Sajeva, Masera 2006).

The labelling of a system as 'hard' or 'soft' is particularly interesting. Lykou et al. (2017) have referred to 'hard and extensive infrastructures', such as roads, runways and buildings. Katina et al. (2017; 2015) have extended this description with, among others, 'hospitals', which raises the question of whether the 'hard' part of such a system (e.g. the building or even the medical equipment) is capable of constituting a hospital or if first the inclusion of an interrelated workforce (e.g. healthcare professionals or operational staff) would complete the system as a hospital. Spontaneously, such workforce would emerge as a complementary (i.e. soft) part of the hospital system. However, the description of 'soft' in the articles instead uncovers supervisory control and data acquisition (SCADA) systems and information and telecommunication technologies (Katina et al. 2017; Katina, Keating 2015). In this context, such soft systems can be understood as the technical aspects of an information system, such as its hardware and software. In contrast, according to Checkland (1989; 2008), soft systems are an interrogative concept that is intended to facilitate debate among concerned parties about poorly structured problems (for details, see Avison, Taylor 1997). This example illustrates the ambiguity of such labels and the difficulty of articulating their inherent meanings. Nevertheless, the rapid development of ICT intertwines its components with the former technical systems, which the articles seem to reflect with the usage of the label 'technological'. Infrastructure, which is another vague label that conglomerates components and their interrelation in some sense, deserves particular attention in the context of this thesis and is therefore discussed in more detail in Section 3.2.2.

Furthermore, many articles use labels such as 'linear', 'network' and 'grid', which illustrate the interactions within the technical system components. Thus, from a traditional engineering point of view, the interaction between system components in technical systems occurs via physical connections, such as cables, roads or rails (e.g. Cedergren et al. 2019; Liu et al. 2017; Lykou et al. 2017; McGee et al. 2016), which renders the border between a technical system and its environment relatively obvious and thereby enables its image as a closed system. As noted, the development of ICT (e.g. the Internet) and its global application is diminishing the visible appearance of networks and, thereby, the borders between a system and its environment. Some of the articles reference this point with labels such as 'wireless' or 'cyber', which characterise both types of interactions—within a system and between a system and its environment.

All articles recognise a type of environment that either presents constraints which the system must regard or constitutes a counterpart for interaction. The type of exchange that a system maintains with its environment defines whether the system is considered open or closed. Physics (e.g. the origins of thermodynamics) and physical chemistry have been concerned with closed systems to examine transformation of energy or chemical elements, wherein 'closed' conveys that no element (or only energy) can enter or leave the system, and no material exchange occurs (Bertalanffy 1950). In this regard, Clausius' considerations of the transformation of thermical heat in mechanical work, which resulted in the second law of thermodynamics and the concept of entropy (Clausius 1850a, 1850b, 1865), are of particular interest in the context of this thesis and warrant further investigation in the literature. Clausius (1865:400) has stated that '[t]he entropy of the world is striving towards a maximum' [*Die Entropie der Welt strebt einem Maximum zu*], which suggests a tendency towards decay or maximal disaggregation [Disgregation (ibid p. 388)] that is observable in nature. In short, it implies that entropy is increasing due to irreversible processes, such as friction, a pressure increase or mixing in a closed system. Thus, entropy is a measure of how much energy has transformed from exergy to anergy (i.e. the part of energy that is unavailable for carrying out purposeful work in a system). To lower entropy and obtain a form of restitution of the previous state, a compensation must occur (ibid, p. 398), that is exergi must enter, and anergy must leave the system. Since then, several researchers have investigated the relationship between processes within a system and an external 'demon' for affecting entropy (see e.g. Maxwell 1871; The sorting Demon 1879). This demon possesses the ultimate knowledge of the system, which has further inspired the adoption of entropy by information theory, as coined by Shannon (1948), wherein entropy is considered a measure of uncertainty to address the lack of knowledge in a system. In the context of technical systems, a computer software system that measures and controls another technical system (e.g. a SCADA system) could constitute such demon. However, the memory of the artificial demon is also subject to entropy. Apart from the natural aging of components, which increases entropy at the physical level, the erasure of memory content appears to be necessary to reduce entropy at the knowledge level (i.e. a full memory). As irreversible process, the erasing in turn produces heat during computing (Landauer 1961) that must consequently be dissipated to mitigate entropy at the physical level.

Ultimately, the quality of the system borders has an impact on the system. In the literature that was reviewed, only the article by Eusgeld and Kröger (2008) explicitly acknowledges system boundaries for analysing system vulnerabilities. All other articles imply that the boundaries are rather fluent and invisible. The label 'open' appears in relation to the mentioned ICT, such as in 'open information infrastructures' (Sajeva, Masera 2006:381) and 'open, interoperable and reliable cyberspace' (Schaberreiter et al. 2016:670). In accordance with von Bertalanffy (Bertalanffy 1950; 1968:141), open systems interact across and beyond system boundaries with other systems or with a larger, surrounding environment. Specifically, the interaction involves not only an exchange of material but also a 'change of the components' (Bertalanffy 1950:23). Therefore, the open system concept has been viewed as appropriate for surmounting the limiting perspectives of closed technical systems and approaching enterprises as open socio-technical systems (Emery, Trist 1960).

Socio-technical. Some of the reviewed articles acknowledge the socio-technical character of the system of interest. Table 6 presents a definition by Gonzva et al. (2016) that integrates the technical system, actors and rules into a joint system, which aligns with the claims of Emery and Trist (1960) but simultaneously ignores the openness of the system (i.e. 'that every socio-technical system is embedded in an environment that affects the way it behaves' [Mumford 2006]). The reviewed articles mainly consider the environment in the form of constraints, such as natural events, legal regulations or public values, that frame the course of action.

Despite indications that 'the social and the technical should, whenever possible, be given equal weight' (Mumford 2006), the proportions of the technical and social parts of the system have been and are still challenging a clear characterisation of this type of system. Whereas Emery and Trist (1960) have argued that 'the technological component has been found to play a key mediating role'—and thus must be integrated with the social system of an enterprise into a socio-technical one—Coaffee and Clarke have recently identified a 'near exclusion of social and human factors' (Coaffee, Clarke 2017). An article by Katina and Keating has confirmed this perception in mentioning the difficulty of including 'social-technical dimensions' in modelling and simulating technical systems, which necessitates the involvement of different worldviews (Katina, Keating 2015). Hence, humans are seldom portrayed as a constituent part of the system as in the articles by Große and Olausson (2018; 2019); most of the time, they are addressed as a resource in a production machinery (Di Maio 2014; Eusgeld, Kröger 2008), a cause of failure (Abedi et al. 2019; Gheorghe 2004; Katina et al. 2017) or somehow included in the design or analysis or as part of a system (Cedergren et al. 2019; Häring et al. 2016; Johnsen, Veen 2013; Lykou et al. 2017; Ouyang 2014; Seager et al. 2017). In contrast, Schaberreiter et al. (2016) have emphasised that analyses of complex relations within socio-technical systems must address organisational and human aspects as much as the technical considerations as well as the economic and legal requirements that are provided by the environment. According to Mumford (2006), the technical part covers 'technology and its associated work structure', and the social part encompasses 'grouping of individuals into teams, coordination, control and boundary management' as well as 'the delegation of responsibility to the work group and a reliance on its judgement for many operational decisions' in a socio-technical system. Nevertheless, the majority of the articles lack a clear explanation of the system of interest and its analysis. One example can be found in the article by Johnsen and Veen (2013), which reports the application of 'a broad socio-technical approach to safety that builds on many knowledge areas such as relevant technical issues, psychology, organization knowledge, culture, human factors, and safety'. Still, it remains unclear whether the knowledge base that was used for the analysis can be considered socio-technical, whether the system under investigation is intended to be of a socio-technical type or whether the research system that performed the analysis has been characterised. This example illustrates the difficulties in determining not only the constituting elements but also the system borders for analysis. Interactions between system components or between the system and its environment appear similarly undefined in the majority of the articles. Such ambiguous view of system boundaries consequently overlooks the dependence of a system on its environment; specifically, an open system changes material, energy and information with its environment to maintain a steady state with respect to entropy (Bertalanffy 1950; Clausius 1865; Landauer 1961). This exchange to maintain a balanced open system thus incorporates both a dependency on a substantive support, such as material, workforce and information, and a variation in the internal processes for adapting to different external constraints. While recent research has primarily focused on the latter to investigate the resilience of systems (Coaffee, Clarke 2017; Gonzva et al. 2016; Häring et al. 2016; Johnsen, Veen 2013; Katina et al. 2017; Lykou et al. 2017; McGee et al. 2016; Spyridopoulos et al. 2014), some of the investigated articles also reflect the former, namely the dependency of an adequate resource influx into the system (Große, Olausson 2019; Seager et al. 2017; Tehler et al. 2018).

Despite developments in the perception and design of socio-technical systems—particularly with regard to ICT and its tendency to entangle technical systems and interconnect them with social systems (see e.g. Mumford 2006), it seems that those systems are still threated separately rather than as a unit because of greater heterogeneity and complexity (Bertalanffy 1950; Katina, Keating 2015).

Social. Two out of the 30 articles explicitly mention the social system. One article uses the notation as a container for all types of recipients that are exposed to the effects of physical disasters, but it lacks a more detailed specification (Prelipcean 2010). The second article employs the concept of complexity to characterise a social system as 'a large number of parts that interact nonlinearly' and further cites the examples of 'an organisation or a city' (Normandin, Therrien 2016). This portrayal of a social system in the article is remarkable for several reasons.

First, the given examples are of interest. The first confirms the mentioned separation between technical and social systems in contrast with research that encourages a more complementary perspective (e.g. Emery, Trist 1960; Mumford 2006). The second example, which concerns cities, is subject to a broader discussion in another article within the reviewed literature. Despite acknowledged difficulties in establishing a general definition, Gonzva et al. (2016) have argued that although cities could be understood as socio-ecological systems, which would allow for 'even include humans as components of these ecosystems', the authors perceive it 'more relevant to approach city as a technical object'. Thereby, the human factor becomes an environmental constraint. In a puzzling argument, the authors refer to the concept of complexity as means that ease 'the understanding of cities because it allows to divide it into elementary, constitutive, and especially independent subsystems in a transitory manner' (Gonzva et al. 2016:2). However, this description is contradictory and refers to the concept of abstraction that is considered a means of handling complexity when modelling a system by 'zooming out' of the considered real system, which is accompanied by a lesser richness of detail (Stachowiak 1973). To this end, the city as a specific system concept illustrates the hitherto outlined spectrum of perceptions with regard to the key elements of a system and their character.

Second, although Normandin and Therrien have claimed that interactions, 'such as organizational learning', between components at a micro-level cause macroscopic properties of a social system, such as emergence, the article omits any specification (Normandin, Therrien 2016). The human actors appear vaguely in the periphery as, for example, 'members of a multidisciplinary team' or 'organizational and interorganizational' and 'community' factors, which leaves ample room for interpretation in terms of whether they are part of the system or belong to an environment. Although interaction is visible in the article as the bearing element, it remains similarly ambiguous to the system components, whereas favourable interactions and relations are labelled as 'sense-giving, good', 'respectful', 'good working' and 'harmonious' elements that also involve feedback. This view of interaction reflects the underlying system perspective of the authors, which is consistent with sociological system theory. Without claiming to be exhaustive, interactions are viewed as the main element of social systems in the sociological context. A few scholars have approached interactions between individuals during communication processes within small groups (e.g. Bräuer 2005; Kelley et al. 2003; Kelley, Thibaut 1978; Neidhardt 2017); nevertheless, research in the context of social systems has more commonly addressed communication processes between an idealised sender-receiver pair. The focus is on, among others factors, the understanding and acceptance of messages by a receiver and the concept of mutual dependence and interference of the interaction partners, which is called interdependence (e.g. Becker-Beck 1997; Bierhoff, Frey 2017; Bräuer 2005). Luhman has explicated an understanding of a social system that completely abstracts from humans in an all-comprehending media system (Luhmann 1984). His perspective has been criticised for several reasons; for example, it projects a radical renunciation of social aspects in societies, and it obscures the human capacity for deliberating and pursuing rational interests (Habermas 1981, II:422f). However, this more societally based view of a social system starkly differs from the understanding within that of a socio-technical system.

Third, the article employs a pair of contrasting concepts, namely negentropy and entropy, to classify resilience factors that emerge from interaction within a social system. The authors define negentropy as 'order, homogeneity, stability' and entropy as 'disorder, heterogeneity, change' (Normandin, Therrien 2016:110). Such a bureaucratic perception of these concepts is problematic in several ways. First, the authors' use of homogeneity and heterogeneity is an inaccurate interpretation of entropy as concept. Instead, a homogeneous system is uniform in its composition or character, which implies a low information content and incapacity for further disaggregation (i.e. high entropy). The opposite applies for heterogeneity, which relates to a high information content and inherent capacity for further adaption (i.e. low entropy). Second, the misinterpretation by the authors can explain their argument in support of 'favourable disorder' with regard to innovation and creativity to enhance the resilience of a social system. 'Unfavourable disorder' then addresses entropy in a proper manner (e.g. 'conflicting rules paralysing the functioning of the system'). This latter category should also comprise that of 'unfavourable order', which, on the basis of the given description, can be viewed as a lack of capacity for purposeful action (i.e. entropy). Third, favourable order, such as the 'development of a common language between members of a multidisciplinary team from several different departments', indicates both low entropy and a process of purposeful change, which contradicts the authors' definitions of the categories. Such low entropy level complements a high degree of free energy that allows for the survival, adaption and progress (or evolution) of a social system—and thereby creates resilience—through a purposeful mix of continuous work, innovation and creativity as well as the recreation and renewal of energy. Nevertheless, these processes consequently increase entropy in the system, which, as noted, must somehow leave the system and be replaced by new energy. This exchange with the environment, which lowers entropy to perpetuate a steady, permanently changing state, can be associated with negentropy. However, negentropy is not available within a system, as the investigated article proposes; rather, it enters a system through an exchange with its environment. To this end, negentropy causes entropy in another system, which, apart from the mentioned demon, indicates the finite nature of existence.

Political. Several of the investigated articles acknowledge the importance of political activities as drivers or constraints of the system of interest (Abedi et al. 2019; Antonsen et al. 2017; Coaffee, Clarke 2017; Große, Olausson 2019; Johnsen, Veen 2013; Katina et al. 2019; McGee et al. 2016; Sajeva, Masera 2006; Schaberreiter et al. 2016; Seager et al. 2017; van der Vleuten, Lagendijk 2010a, 2010b). However, the majority of the articles abstain from a more precise definition of a political system because it is considered merely an environmental factor that is not as central in these studies. In accordance with Easton (1965), a political system as part of a surrounding societal system can be envisioned as a 'black box' that encompasses institutions, processes and actors that yield binding decisions for society. It involves questions of who possesses authority and which influences impact its society and economy. In this sense, a political system is mainly associated with government but can also be applied to any kind of organisation, multi-stakeholder group or multi-level system that involves man-made steering mechanisms.

Similarly to other types of system, a political system relates to borders, such as national boundaries or a common framework for action. Seager et al. (2017) have exemplified such political borders with 'city, county, or state lines' or regulatory boundaries. Furthermore, Katina and Keating (2015) have recalled the boundaries in the European Union when considering cross-border effects in the context of CIP.

The indistinct boundaries of an open political system are imagined in the article by Schaberreiter et al. (2016), which notes that the task of preserving the openness and freedom of the Internet while improving privacy and security has become an issue for the global forum. Van der Vleuten et al. (2010a, 2010b) have detailed how political systems have affected technical development in the context of European power distribution networks over decades as well as how technical and societal requirements can transform from local and regional to national and transnational issues and thereby stimulate evolution of the concerned systems.

In prolongation of the previous discussion on the power for change, such perception of disorder may be influenced by changes in political systems throughout history. However, a more consistent adoption of the concept of entropy mainly relates it to the decay of a system, which either engages in an exchange with its environment to obtain capacity for further activity or uses certain isolation to reach a maximum of entropy (i.e. an indelible incapacity to act). Such termination of the purpose-giving processes within a system signifies the termination of the system itself, which does not necessarily apply to its components. Thus, the disaggregation of one system can free energy to develop another system, and so on. This connection illustrates both the interdependency between systems and the relation of entropy to a certain process (or purpose).

Complex adaptive. Because of the search term that was used, all articles in the literature review label the system under investigation as 'complex'. Viewing a system as complex adaptive further emphasises its 'ability to adapt to such conditions of uncertainty and volatility', according to Coaffee and Clarke (2017). Spyridopoulos et al. (2014) have noted that such systems consist of 'large sets of components that interact with each other while synergies emerge through those interactions'. Particularly, such systems feature components that interact in parallel, base actions on conditional reasoning, build subroutines and use adaption to improve performance (Holland 2006). Among the articles, there is wide recognition that the components of complex (adaptive) systems are interconnected and autonomous agents that, due to individual adaption to interactions and particular environmental conditions, display non-linear behaviours, which can lead to emergence and unpredictable outcomes (Abedi et al. 2019; Coaffee, Clarke 2017; Eusgeld, Kröger 2008; Große, Olausson 2019; Katina et al. 2017; Katina, Keating 2015; Liu et al. 2017; McGee et al. 2016; Normandin, Therrien 2016; Sajeva, Masera 2006; Seager et al. 2017). The articles provide examples of emergent properties, such as resilience (Normandin, Therrien 2016), self-organisation (Coaffee, Clarke 2017; Katina et al. 2017; Katina et al. 2019), self-healing (Schaberreiter et al. 2016), system adaption and (co-)evolution (Cedergren et al. 2019; Eusgeld, Kröger 2008; Gheorghe 2004; Katina et al. 2017; Katina et al. 2019; Katina, Keating 2015; Ouyang 2014; Prelipcean 2010; Sajeva, Masera 2006). The latter further indicates that complex adaptive systems are not single systems but are often concerned with SoS. In the interest of completeness, the difference between the properties 'complicated' and 'complex' warrants acknowledgement. According to Sajeva and Masera (2006), the label 'complicated' distinguishes between 'large systems [that] can be described as merely complicated' and systems that are complex. However, such distinction depends on the point of view. A system is complicated from the perspective of an observer or user, which relates to his or her level of experience and knowledge. Meanwhile, complexity is a property of the system and persists independently of a particular observer or user.

Furthermore, the appearance of the system element 'environment' remains ambiguous in both the articles and the theory, which reflects the openness of the systems under investigation. On the one hand, the agents reside and act within a space that is known as the environment, wherein they interact and influence each other. Therefore, the system emerges as a set of agents and their interactions that fit together optimally in a joint environment, which is called a fitness landscape (see e.g. Onik et al. 2016) and can be viewed as the constituting system process or purpose. On the other hand, this emergent system interacts competitively with other complex adaptive systems, which are called landscapes, which makes it difficult to clearly distinguish between the internal and external environment of the system(s) and each agent.

However, the interactions with other systems yield information that, consistent with the previous statements, can be interpreted as an exchange that reduces a system's entropy and allows for further progress. Consequently, the complex adaptive system reorganises its network structure among the constituting and available agents to improve the performance of its key process (i.e. to maintain best fitness). This adaptive reorganisation initiates further changes in both the agents' cognitive model and the number of interactions in the fitness landscape by adapting to the returning information through the layers of the system (Ellis, Herbert 2011). These adaptions at several levels induce further interferences back and forth through the system(s) and environment(s). The consequence is a set of effects that are spontaneous, uncertain and highly difficult to predict; such effects are collectively referred to as 'emergence'.

Concepts regarding complex adaptive systems have mainly been used for modelling and simulating non-deterministic and dynamic phenomena in complex systems by way of mathematical and computational models (for an overview of key concepts, see Onik et al. 2016). Furthermore, these concepts have been applied 'to model complex social systems' (Onik et al. 2016), which indicates a perception of social systems in the manner as in socio-technical systems. Indeed, while the specific modelling of an agent's reasoning through a kind of cognitive structure is considered rational for optimising its performance (i.e. fit into a landscape) towards an overall system goal, it aims to emulate human decision-making and adaption. In addition, the strong focus on interactions and interdependencies both among system components and between those components and their particular environment as well as on mutual influences is apparent in the sociological view of social systems. In sum, the understanding of systems as complex adaptive provides valuable concepts for integrating several perspectives to approach complex systems in a multi-disciplinary manner.

Systems of systems. Around one-third of the reviewed articles mention a specific type of system, namely SoS, in the context of CIP (Abedi et al. 2019; Eusgeld, Kröger 2008; Gheorghe et al. 2018a; Gonzva et al. 2016; Katina et al. 2017; Katina, Keating 2015; Liu et al. 2017; Ouyang 2014; Sajeva, Masera 2006; Spyridopoulos et al. 2014; Tehler et al. 2018). The authors have emphasised the interconnected nature of systems, which permits the relation of SoS to the noted key elements of a system: the components (in this case, systems); interactions (relations between the systems); and an environment that surrounds the SoS and therefore must also concern the individual environments of each subsystem and the space between them. Each subsystem is considered 'open', which, as discussed above, involves a dependency of exchange with its particular environment that, in turn, somehow contains the other components (i.e. subsystems) of the system. The majority of the articles acknowledge this openness of the subsystems by labelling the components and their interactions as 'interdependent' on each other, which indicates the close relationship of SoS with complex adaptive systems.

Several concepts were prominent in the review of the articles. Ouyang (2014) has referenced the definition of SoS by DeLaurentis (2007), which asserts that SoS 'consist of multiple, heterogeneous, distributed, occasionally independently operating systems embedded in networks at multiple levels that evolve over time'. In addition, Sajeva and Masera (2006) have noticed a 'high complexity, plurality of stakeholders and neither is it a clear definition of roles and responsibilities' as characteristics. Considering the aforementioned interdependencies, Tehler et al. (2018) have anticipated an increasing risk of a transboundary negative impact. Similarly, Gheorghe et al. (2018a) have contended that negative effects (e.g. triggered in space) could easily transcend geographic or jurisdictional boundaries because of the interconnected structure of SoS. Accordingly, Eusgeld and Kröger (2008) have argued that analyses of SoS should consider 'interdependent structures of components, which result in an often spatially distributed 'system-of-systems', [which] may show strong interdependencies, dynamic and non-linear behaviour, rippling effects, dependence on natural and operational environment, etc'.

Owing to the openness and interdependency of the subsystems, the concept of entropy warrants further attention in the specific context of SoS. As indicated, entropy within a system can be reduced only by an exchange with its environment. In turn, this reduction (i.e. negative in a mathematical sense) is accompanied by an increase in entropy within another system in a rather dynamic relation. When applied to a system of two subsystems, this relation implies that when one subsystem depends on substantive support from the other, then the entropy of the SoS increases as a result of the process of exchange. Further exchange with the environment outside of the SoS must occur to reduce the entropy of the SoS. An abstracted example to illustrate this relation is that of specialists who change jobs. One subsystem that is in need of an engineer to maintain its business might hire one that originated from a second subsystem. Now, the second subsystem needs an engineer and must devote extra energy, such as working hours or money, to find a substitute. This example demonstrates two aspects. First, the entropy as an inhibitory effect moves from one subsystem to the other; in this way, the entropy reduction at the first subsystem (hiring) is compensated with an entropy increase at the other subsystem (loss of employee). Second, an investment of energy for recruitment is required not only from the first subsystem but from both subsystems, which increases the overall entropy of the SoS. When this process recurs, the entropy of the SoS increases further. Only the appearance of an engineer from the environment of the SoS could lower the entropy of the second subsystem, which can nonetheless not fully compensate for the accrued entropy in the SoS. Hence, the activities of one subsystem can have both positive and negative effects on other subsystems but tend to contribute to a growth in entropy within the system.

Ackoff (1971) has compiled some key concepts regarding systems to develop an understanding of SoS. Apart from a distinction between abstract and concrete systems and a different view of closed systems, he has explained the subjectivity of a particular system configuration with the example of a house, which could extend the discussion of the concept of 'city' (see the paragraph on social systems [page 40 et seq.]). Moreover, he has differentiated between organisations and organisms as concepts for approaching an SoS with the aid of the label 'purposeful', which signifies the ability of a system to choose both goals and means. In this sense, an organisation is an SoS which consists of at least two systems that 'have and can exercise their own wills' for a common purpose, wherein 'at least one subsystem has a system-control function' (Ackoff 1971). This definition implies that an organisation can be comprised of two persons (i.e. organisms) or of several organisations. Whereas some of the articles implicitly adopt a similar perspective of systems, the conceptual paper by Normandin and Therrien (2016) reflects Ackoff's perspective discernibly. However, as indicated, this view of organisations hardly accounts for the impact of technical/technological systems on the performance of the SoS. Furthermore, by claiming that 'in an organism only the whole can display will, none of the parts can', Ackoff (1971) has rejected the treatment of organisations as organisms in both research and practice. Nevertheless, such anthropomorphic perception of systems is evident in complex adaptive systems, wherein agents use reasoning to organise themselves in systems. The rule-based reasoning of these agents is realised by algorithms, which can, to some extent, be called artificial intelligence. Still, the extent to which a technical system in combination with a reasoning artificial demon can be viewed as an 'organism' remains uncertain.

With reference to Maier's (1996) principles, Katina and Keating (2015) have presented characteristics of SoS, such as operational and managerial independence of constituent systems, evolution, emergence and geographical distribution when mapping these features to the critical infrastructure field. However, Maier (1998) has deviated from the latter and adjusted the focus on the former two. He has stated that 'a system that has operational and managerial independence of its elements is a system-of-systems'. This assertion stresses the deliberate decision of systems to collaborate in an SoS for a common purpose. In this sense, Maier's perception of an SoS is similar to Ackoff's view of an organisation and the agents in a complex adaptive system. However, Maier's fixation on ICT obscures his main argument that a system which is a component of an SoS is simultaneously a subsystem of another system, which necessitates collaboration among the latter to align strategic objectives in policies, common standards for technical interfaces, and specific goals and means for operations and development.

The components of an SoS are subsystems in two ways, and each has interactions with the SoS, its parent system and its particular environment. *Hence, an SoS is a system of subsystems of other SoS.* This monstrous term is analogically cumbersome, as it illustrates the entangled nature of SoS, which involves differences in environmental conditions and a diminished opportunity for the parent system to exercise control over its subsystems that are also part of another SoS. This conceptual construct is likewise applicable to organisations, political and social systems of societies and socio-technical systems. In Maier's contribution, the SoS have a primarily technical nature, and the purpose of information sharing in the subsystems' operations is socio-technical, while the managerial control of each subsystem remains, to some extent, out of reach of the SoS. Moreover, it indicates three types of direction of the SoS—directed, collaborative and virtual—and a shared information system as the backbone of an SoS.

Liu et al. (2017) have expressed a similar perspective in considering the interconnected system of a natural gas distribution network and a power grid. While such network can, in reality, be considered an SoS—for example, if the various parts are operated by different providers—the investigated model then appears as a simplified network with linear dependencies, which may diverge excessively from the nature of the original SoS.

Spyridopoulos et al. (2014) have provided another perspective that is remarkable in two respects. First, it positions an industrial control system, namely a generic SCADA system, as an SoS. In accordance with Maier (1998), neither the sheer complexity of such systems as a SCADA nor the connection with the Internet alone innately justifies classification as an SoS. Second, the linguistic imprecision with regard to a system of systems or a system-of-systems according to the SoS concept is apparent in the article's application of Beer's Viable System Model (see e.g. Beer 1995; Espejo, Harnden 1992), which approaches a system as a set of systems that, as a unit, is autonomous and capable of surviving. Although the Viable System Model conceptually enables an analyst to model an SoS, which recursively involves the SoS itself, the interrelations between the subsystems and their individual 'parent' systems, the interrelations between the latter and the various environmental settings, and the inherent complexity of such attempt reasonably necessitates a deliberate limitation of its application. In the discussed article (Spyridopoulos et al. 2014), the authors restrict the view to one organisation, which is further recognised as an 'organism' to abstract from complex interactions and adaption processes. In extension of former considerations, electronic devices regulate a physical process, while a SCADA constitutes the artificial demon that ensures the system's steady state.

However, since all parties which are concerned with an SoS can be acknowledged as having and exercising their own will, the integrative design, direction and control of an SoS requires a new type of steering (Ackoff 1971; Maier 1998). Therefore, Katina and Keating (2015) have emphasised a holistic worldview with respect to SoS that concerns 'not only the technical aspects of the domain, but also the human, social, organisational, managerial, policy and political aspects'. In addition, they have signalled 'the need to consider coordination and integration beyond individual constituent systems'. Nevertheless, the influence of the various parent systems on an SoS is an underrepresented issue. It must be involved in such considerations in view of the mutual interdependencies that impact the system's behaviour. In their article, Katina et al. (2017) propose complex systems governance for a specific SoS, which consists of cyber-physical systems. Similarly to Spyridopoulos et al. (2014), they consider a cyber-physical-system as an organism wherein a software system (as the artificial demon) ultimately controls a physical process in the respective technical system. The authors have argued that the emergence of this type of SoS is due to the increasing interconnectedness of subsystems that organisations comprise, and they have applied the notation of a 'metasystem' to differentiate management processes from operations, which is comparable to the scheme of Beer's Viable System Modell (Beer 1995; Katina et al. 2017). However, the article does not succeed in maintaining a separation of the concepts; it struggles with the hierarchies of the model in terms of planning and operation and finally confuses the 'metasystem' with the SoS, which was also labelled as 'overall' (cf. Katina et al. 2017). This article demonstrates the difficulty of preserving a distinction between the discussed concepts, especially when an investigation concerns several hierarchical levels, different types of system and components, and a broad spectrum of interrelations, interdependencies and processes.

Purpose and Process. Beer (2002) has provided the widely cited heuristic that '[t]he purpose of a system is what it does'. Although man-made systems are developed under various perceptions to facilitate a key process—for example, power supply or information exchange—such intended functionality does not necessarily explain patterns of behaviour that emerge from a system's existence (i.e. the independent and interdependent activities of the particular system elements). Unfortunately, if this perspective of purpose and behaviour is not properly considered, it may be equated with the execution of a certain process in the context of technical systems. On the contrary, discrepancies between the intended purpose and system properties become apparent in forms of system behaviour, such as adaption, emergence and entropy, which are recognisable when performing the purpose-giving process. The majority of the reviewed articles assume that the system of interest continuously fulfils its function, and they thus consider deviant behaviour that requires particular action, such as the 'failure process' (Gonzva et al. 2016; Liu et al. 2017), 'process control' (Katina et al. 2017), 'the recovery process' (Liu et al. 2017; McGee et al. 2016; Prelipcean 2010) or 'the integration process' (van der Vleuten, Lagendijk 2010a). Apart from the intended purpose (i.e. functionality), a system can change its state through reaction or response to a particular event and autonomous action (e.g. Ackoff 1971), which implies that systems can perform several processes. Therefore, a conceptual clarification is suggested.

Whereas the existence of a system in general can be independent of the process that it was intended to facilitate, the process itself relies on an executing system. Furthermore, a process has a determined start and end, which can in turn relate to the determination of a system, though this consequence is not mandatory. A process is a content-related and self-contained sequence of timely and logically consistent events and activities that processes a central, process-characterising object (see e.g. Becker, Schütte 2004; Davenport 2017; Davenport, Short 1990; Scheer 1991). A process can be performed through parallel instances or in rapid succession, which may feign continuity. Aside from demanding a trigger, each process iteration differs from previous and subsequent ones because of several changes regarding, for example, the process object, the properties of materials or the state of the executing system. The term 'process' can have two interpretations. In the first, it relates to a blueprint of such sequence, which is often referred to as a reference process (see e.g. vom Brocke 2002). In the second, it can concern a particular execution of a reference process. Many of the reviewed articles subsume regular iterations of a reference process as an operation; however, a few articles consider particular processes and their impacts on the evolving systems, such as the development of the European power grid and its properties (van der Vleuten, Lagendijk 2010a, 2010b), the process of developing and generating resilience (Häring et al. 2016) and the planning process for CIP in the Swedish context, which relies on an SoS (Große, Olausson 2018; Große, Olausson 2019). Ultimately, Coaffee and Clarke (2017) have argued that a more process-based viewpoint could facilitate the orchestration of a coherent, socio-technical and integrated approach in SoS.

3.2.2 Critical Infrastructure and Protection

The term 'infrastructure' stems from the Latin words *infra*, meaning 'underlying', and *structura*, meaning 'assemblage'. Therefore, infrastructure is defined as an underlying base or framework. Generally, the reviewed articles apply such view of infrastructure, as they commonly perceive it as a common good that already and forever exists. In the majority of the articles, infrastructure has a physical nature and long durability. Table 7 presents typical examples, such as roads, railways, power grids and buildings (Antonsen et al. 2017; Cedergren et al. 2019; Große, Olausson 2018; Große, Olausson 2019; Johnsen, Veen 2013; Katina et al. 2017; Katina, Keating 2015; Liu et al. 2017; Lykou et al. 2017; McGee et al. 2016; Prelipcean 2010; van der Vleuten, Lagendijk 2010a, 2010b). Research has also identified emerging infrastructures in space, under the sea and below the ground (see Gheorghe et al. 2018b; Gheorghe et al. 2018a). Sometimes, the term infrastructure involves established organisational structures and collective knowledge (e.g. Coaffee, Clarke 2017; Katina et al. 2019; Seager et al. 2017). Developments in ICT and their entanglement with industrial processes have forced a perception of ICT as either a particular type of infrastructure or as infrastructure that is incorporated into other types of infrastructure (Di Maio 2014; Johnsen, Veen 2013; Katina et al. 2019; Schaberreiter et al. 2016; Spyridopoulos et al. 2014). However, the unconscious assumption that these physical assets are permanent involves a certain level of abstraction, which implies that there is no need to wonder where they came from or how they came into being. Although this perspective may be helpful for assessing a particular system level or process by abstracting from certain details, the specific applications of the concept of infrastructure often remain ambiguous in the articles. Moreover, some authors have explained 'infrastructure' by the concept of 'infrastructure' (Lykou et al. 2017) or the aid of several system concepts (e.g. Häring et al. 2016; Katina et al. 2017; Katina, Keating 2015; Spyridopoulos et al. 2014), which highlights that infrastructure should be approached as a system but does not necessarily bring more clarity due to complex system characteristics, such as adaption, emergence and entropy. Thus, two questions remain: which elements constitute infrastructure, and which functions can it serve (for an observer or user).

With regard to the first inquiry, several authors have addressed the system elements of infrastructure. One issue is that there is no precise designation of the level of abstraction regarding systems or infrastructure. Descriptions by Lykou et al. (2017) illustrate the dilemma of de-/composition. A detailed discussion of this example follows the presentation of descriptions and examples of critical infrastructure in Table 7.

Table 7: Characterisations and Examples of Infrastructure and its Criticality

Author (Year)	*Definitions / Descriptions*	*Critical Infrastructures*
Abedi et al. (2019)	'*large-scale man-made systems that operate inter-dependently to provide and deliver essential goods and services. Failure or destruction affects the safety, security, economy, health, and well-being of a community*' (p. 2)	- Energy and communication networks - Transportation systems - Water and gas distribution systems
Cedergren et al. (2019)	'*Many of society's essential functions and services are provided by critical infrastructures*' (p. 1)	- Electrical power supply - Communication systems - Rail infrastructure
Große, Olausson (2019)	'*their continuity during disturbances is crucial for the survival and progress of a depending society*' (p. 424)	- Power supply - Railway - Electric vehicles
Katina et al. (2019)	'*systems serving the welfare of the public and their services*'' (p. 122)	- Blockchain - Financial transactions
Große, Olausson (2018)	'*important users in society [that are] crucial for private households, businesses, and public operations to function and survive*' (p. 1893)	- Power supply - Railway - Electric vehicles
Tehler et al. (2018)	'*functioning of modern societies is dependent on the services provided by an interconnected web of critical infrastructures*' (p. 1865)	- Telecommunication - Electric power supply - Transportation - Water supply
Gheorghe et al. (2018)	'*capacity for the provision of unique services or of services that are difficult to substitute sustainably through* [...] *alternatives*' (p. 555)	- Space systems - Global navigation satellite system
Antonsen et al. (2017)	'*modern critical infrastructures are becoming increasingly 'smarter''* (p. 1837) *and are 'required to meet the population and society's basic needs such as food, water, heating, security and the like'* (p. 1840)	- Harbour / cargo port - Industries - Fuel supply - Societal functions
Coaffee, Clarke (2017)	'*a larger, more complex and an increasingly interconnected amalgamation of social, technical and economic networks*' (p. 365)	- Physical / informational - Energy, water, transport
Katina et al. (2017)	'*system of systems that provides essential goods and services necessary for public well-being with the aid of control systems in the form of information and telecommunications*' (p. 173)	- Roads, highways, hospitals - Electrical systems - Water systems - SCADA and ICT systems
Liu et al. (2017)	'*engineered systems which provide continuous flows of goods (e.g. energy, water, gas) and services (e.g. transportation, information), that are used for industrial productions and people living [and] are interconnected to each other*' (p. 1f)	- Power grids - Energy/gas/water supply systems - Telecommunication networks
Lykou et al. (2017)	'*greatly supports the smooth functioning of society's prosperity and viability of economies worldwide; services that are vital for business and for the quality of life of citizens*' (p. 1)	- Fixed installations (e.g. roads, railways, terminals [airports, railway and bus stations, seaports])
Seager et al. (2017)	'*those* [services] *which are vital for protecting or providing essential human capabilities*' (p. 91)	- Organisations - Physical equipment
Gonzva et al. (2016)	'*complex socio-technical systems in which the components are particularly interdependent* [and] *constitute the backbone of modern societies*' (p. 1)	- Physical structures - Transportation - Rail transport network
Häring et al. (2016)	'*complex and interdependent* […] *socio technical systems*' (p. 272f)	- Technical and societal

McGee et al. (2016)	'*risk relationships and resultant cascading effects*' (p. 146) and '*some may potentially be more "critical" than others*' (p. 151)	- Electric power - Communication network - Transportation systems - Water systems - SCADA and ICT systems
Normandin, Therrien (2016)	'*access to networks of resources; diverse components; skills and infrastructure in communication*' (p. 116)	- Housing/shelter - Medical capacity - Access/evacuation
Schaberreiter et al. (2016)	'*provide services that are at the core of our modern society and a disruption or destruction of these services would have severe consequences for society and the economy*' (p. 668)	- Energy - Telecommunication - Information systems
Katina, Keating (2015)	'*provide goods and services that enable the maintenance and sustainment of public wellbeing including public safety, economic vitality, and security*' (p. 317)	- Roads, highways, hospitals - Electrical systems - Water systems - SCADA and ICT systems
Di Maio (2014)	'*aircraft (airborne or on the ground), airports – considered "soft targets" – and in general the infrastructures serving civil aviation*' (p. 1)	- Air traffic management - Air navigation service - Air transport
Ouyang (2014)	'*network of independent, mostly privately-owned, man-made systems and processes that function collaboratively and synergistically to produce and distribute a continuous flow of essential goods and services*' (p. 44)	- Telecommunications - Electric power systems - Natural gas and oil - Banking and finance - Transportation - Water supply systems - Government services - Emergency services
Spyridopoulos et al. (2014)	'*interconnected networks* [whose] *essential service provision* [is] *of critical importance*' (p. 438f)	- Power production - Telecoms
Johnsen, Veen (2013)	'*railway tracks and signaling equipment [and] key communication infrastructure* "(p. 2f)	- Communication system - Railway
Prelipcean (2010)	'*deliver special services to clients*' (p. 220) "*assets* […] *critical to household's welfare*' (p. 223)	- Town halls, roads - Border police offices - Civil protection facilities
v. d. Vleuten, Lagendijk (2010a, b)	'*electric power grids count among the most 'critical' of all modern infrastructure*' (p. 2053) due to '*the massive societal and economic dependency on uninterrupted energy infrastructure services*' (p. 2042)	- Electric power grid - Gas supply networks
Eusgeld, Kröger (2008)	'*highly integrated and interdependent* […] *large scale interconnected* […] *system-of-systems (or meta-infrastructure system* […] *supplying goods and services* […] *perceived as common good*' (p. 1-2)	- Electric power supply
Robert et al. (2008)	'*everyone is extremely dependent on Lifeline Networks, providing vital resources*, [that] *are interdependent on each other* [and] *increasingly automated and interlinked*' (p. 392f)	- Telecom system - Electricity system - Drinking water system - Transportation
Sajeva, Masera (2006)	'*composed of many constituent systems with multiple operators, but characterised by high levels of structural, functional, administrative and jurisdictional complexity*' (p. 380)	- Market and technical - Electric power supply - Oils, gas, water storage and delivery - Finance and insurance - ICT - Health end emergency - Law enforcement
Gheorghe (2004)	'*vital*' (p. 120) and '*complex and interdependent systems*' (p. 122)	

Lykou et al. (2017) have noted that '[t]ransport is a[n] [...] infrastructure that greatly supports' a society. Subsequently, they have stated that 'transport is the movement of people and goods from one location to another', which represents the service that the infrastructure enables or provides. This infrastructure has been further decomposed into transport infrastructure, vehicles and operations, the latter of which includes 'people, institutions, laws, policies, and information systems that convert infrastructure and vehicles into working transportation networks' (ibid, p. 2). This example reveals that the particular meaning of the term 'infrastructure' depends on the context in which it is used and the perspective of an observer or user. The same applies with respect to ICT. Whereas Schaberreiter et al. (2016) have indicated that 'infrastructures are *driven by* complex and interacting systems' (emphasis added), Spyridopoulos et al. (2014) have reported that 'Industrial Control Systems [...] are of the most important components of National Critical Infrastructure'. Furthermore, Katina et al. (2017) have acknowledged that ICT is both a prevalent controlling system for physical processes and an emerging infrastructure, and it is therefore becoming increasingly critical. Although the literature recognises workforce and institutional or legal regulation in the context of infrastructure, these elements are mainly considered operators or environmental factors of infrastructure. For example, Gonzva et al. (2016), have perceived infrastructures as socio-technical systems, which entail the provision of a service and an amalgamated character of all customers. Eusgeld and Kröger (2008) have encouraged further research on 'whether or not the operating environment (in the wide sense, incl. socio-economic and institutional factors) needs to be considered'. However, this operative perspective of systems obscures the view of infrastructure as a necessary precondition for the production process of an intended service. For instance, many articles identify 'energy' and the power system as infrastructure (Abedi et al. 2019; Cedergren et al. 2019; Coaffee, Clarke 2017; Eusgeld, Kröger 2008; Gonzva et al. 2016; Große, Olausson 2018; Große, Olausson 2019; Katina, Keating 2015; Liu et al. 2017; McGee et al. 2016; Ouyang 2014; Schaberreiter et al. 2016; Seager et al. 2017; Spyridopoulos et al. 2014; van der Vleuten, Lagendijk 2010a, 2010b). From the perspective of a consumer of electricity, power in the socket is a precondition for business, heating or charging a mobile phone, for example. Moreover, for the power to emerge from the socket, installation of the socket is a precondition. Similarly, for the transmission of power, the established power grid is a precondition. For the power grid, the production and delivery of components are preconditions, and so on. Hence, all of these preconditions that are subsumed as infrastructure incorporate a *physical* layer of material, an *operative* layer of (man-)power and knowledge, and a *strategic* layer as an expression of will (i.e. strategic objectives about the purpose of the construction).

Thus, further relationships can be established: operations are concerned with executing a process upon infrastructures, management is concerned with the control of input and output of the operation process, and governance is concerned with both the processes within the system and the integrity of the system itself. At all system levels, the entropy that accompanies activity must be handled with regard to two complements. First, it can be moved outwards by entities that have information and can exercise system adaption, such as human process operators or ICT systems that embody the depicted demon. Second, it must be replaced by suitable energy and information flows inwards.

With consideration to the second aspect, infrastructure provides a structure or tool upon which a user acts, which confirms that the user's perspective determines the critical process that infrastructure as a system executes and the product of the process which emerges as a precondition for a particular user. With the nature of infrastructure in mind, the establishment of infrastructure can be considered a preceding process that is performed by another system, which also underlines the dependency of the subsequent processes on the preceding ones. All of the reviewed articles emphasise the dependency of the well-being of the final consumer—mostly aggregated to a regional society or national population—on the services that are provided upon and by infrastructures (see Gheorghe et al. 2018b). As illustrated above, goods and services are framed as common goods similarly to the underlying infrastructures (Eusgeld, Kröger 2008). Seager et al. (2017) have further broadened this perspective by acknowledging 'infrastructure as the principal mechanism by which human rights are realized as human capabilities'. Accordingly, the authors have expressed the critique that, in many cases, the 'approach to critical infrastructure suffers from a misplaced emphasis on the physical condition of the infrastructure, rather than the services provided' (Seager et al. 2017). With regard to the deliberations above, the physical conditions of infrastructure are arguably often ignored; instead, the physical conditions of the operation process are considered. However, the key point of the discussion in Seager et al. (2017) is that the resilience of infrastructure must take into account the various perspectives and capabilities of users, and it thus extends beyond the physical components, which necessitates both 'multiple adaptive pathways' and holistic, interdisciplinary research.

The indicated interdependency of systems and processes as well as of produced services and goods and their consumers has accelerated alongside societal development. Interdependency refers to the inherent uncertainty about mutual dependencies that emerge from the intertwined character of infrastructures, systems and processes in a developed society. Such interdependency has two implications. First, if one process fails, then the subsequent processes are affected; this outcome is often referred to as that of cascading failures (Abedi et al. 2019; Große, Olausson 2018; Katina, Keating 2015; Seager et al. 2017; van der Vleuten, Lagendijk 2010a). Second, it is difficult to identify the correct order of processes and the degree of dependence (i.e. the criticality of a delivering process under consideration of the potential consequences for customers). The review of the selected articles reveals several types of interdependency among infrastructures and between infrastructures and the environment. Many of the articles follow the classification of Rinaldi et al. (2001), which is reportedly the only self-contained classification (Ouyang 2014). It states four types of interdependencies: physical (exchange of goods), cyber (exchange of information), geographic (effects that emerge from close spatial proximity) and logical ('if the state of each infrastructure depends on the state of the other via a mechanism that is not a physical, cyber, or geographic connection' [Rinaldi et al. 2001]). Gheorghe et al. (2018a) have expanded this list by extracting two aspects from the latter type: policy (regulation and procedural changes) and societal (effects of public opinion).

As a consequence of the increasing dependence of societies on their underlying infrastructure for survival and progress (Cohen 2010), official institutions have acknowledged a need to identify and protect such critical infrastructure. Several definitions of critical infrastructure and the services that it enables can be identified in public policies (see e.g. Gheorghe et al. 2018b:5; Große 2018:13f) which many of the articles adopt. For example, Gonzva et al. (2016) have simply stated that 'critical infrastructures are considered as critical in view of populations' increasing dependence on them', whereas Coaffee and Clarke (2017) have stressed their 'potential to significantly affect public safety, security, economic activity, social functioning or environmental quality'. A similar view of (national) sovereignty has been adopted by Ouyang (2014) in noting that '[s]ystems whose incapacity or destruction would have a debilitating impact on the defense and economic security are regarded as critical'. In addition, Sajeva and Masera (2006) have mentioned that infrastructure 'is considered to be critical when its partial or total inability would affect the security and social welfare of a given context, sometimes at the national or the international level'. The label of 'critical' indicates the existence of its counterpart—namely infrastructure that is less or non-critical—which in turn implies that a classification scale can be used to assess criticality (see e.g. Fekete 2011; Fekete et al. 2012). Table 11 presents the example of the classification scheme that is used in Sweden for the identification and classification of critical infrastructure. In addition, several authors have noted that each stakeholder tends to concentrate on his or her own values and their relation to the potential risk (Antonsen et al. 2017; Gheorghe et al. 2018b; Große, Olausson 2018; Große, Olausson 2019; Sajeva, Masera 2006; van der Vleuten, Lagendijk 2010a).

The notations of key resources and key assets emerged from the literature review and are interrelated with critical infrastructures and the essential goods and services that are produced and delivered by them. Although damage or destruction of a key asset would not necessarily affect human existence, its symbolic, economic or societal value suggests that severe disturbances or loss of life could occur in society if such key asset is the target of an attack (Fekete et al. 2012; Gheorghe et al. 2018b; Gheorghe et al. 2018a; Katina et al. 2019). Key resources are those that are necessary for a process but which, because of their scarcity, limit the capacity of processes (e.g. those whose results are critical for a subsequent consumer, such as further processes or society). Depending on the type of process, such key resource can be natural, material, computational, informational, organisational, or related to people and services. The reviewed articles cite examples of key resources with respect to their limited availability, such as railways (Cedergren et al. 2019), electricity (Große, Olausson 2019; Robert et al. 2008), drinking water (Robert et al. 2008), telecommunications (Robert et al. 2008) and orbital bands (Gheorghe et al. 2018a).

The majority of the articles stress the need to protect critical infrastructure from disturbances and safeguard the dependent society from potentially disastrous consequences. Robert (2008) has noted that 'it is crucial to protect interdependent networks' since 'the loss of an LN [lifeline network] is […] likely to result in major crises'. Although the common label of such networks has changed to 'critical infrastructures', as previously discussed, such protection can involve many challenges, especially given the scarcity of resources and the interdependencies of infrastructures (Gheorghe et al. 2018a) as well as the ambiguity of concepts and policies. Gheorge (2004) has stated that '[p]roblems come from solutions', which indicates that recent developments in society with regard to technology, population, politics and environmental factors are likely to broaden the spectrum of challenges in the context of CIP.

Cedergren et al. (2019) have recently discovered that 'restructuring of the [railway] sector has created long-term challenges related to balancing the use of the infrastructure with a sufficient level of maintenance', which confirms the above argument that infrastructure is frequently overlooked in both theory and practice for the benefit of a higher efficiency of operation. Katina et al. (2019) have called for more comprehensive problem formulations beyond technology-only solutions that also expand the boundaries of the investigated system and involve 'the wider array of human/social, organisational/managerial and policy/political aspects influencing' developments in critical infrastructure and technology. Research has highlighted additional emerging aspects that deserve consideration in the context of CIP, such as legal regulation and economic calculation and information security in a comprehensive sense (Antonsen et al. 2017; Di Maio 2014; Gheorghe et al. 2018a; Große, Olausson 2018; Große, Olausson 2019; Johnsen, Veen 2013; Schaberreiter et al. 2016; Spyridopoulos et al. 2014). Many of the investigated articles emphasise a focus on resilience as a complement to or substitute for technology-focused CIP. In contrast, Häring et al. (2016) have adopted the opposite position with the advice 'to deliberately limit the scope of Resilience Engineering towards engineering, i.e. mainly technological solutions'. According to these findings, there is a heightened demand for multidisciplinary research to obtain more integrated solutions, yet scholars and practitioners are still challenged by the complexity of the task, institutional and disciplinary boundaries and limitations regarding methodologies, and issues of long-term funding and imagination (see Seager et al. 2017).

Coaffee and Clarke (2017) have contrasted protection and resilience as the poles of the CIP spectrum. Thereby, protection is portrayed in a 'hard', technical sense, while resilience is assigned a 'flexible', socio-technical character. Although this classification seems enticing, it presents two flaws. First, it still neglects the purpose of both topics for society, which entails how the functionality of critical infrastructure affects dependent people. Second, it improperly meshes perspectives of systems and infrastructures, as the previous discussions have explained. However, *protection* is an expression of will (i.e. a strategic objective) under which a system is approached from the outside through activities such as risk and vulnerability analyses, planning, implementation of measures, and monitoring of realised and emerging effects. In accordance with the key points of the article, this CIP must concern the socio-technical system that executes processes upon infrastructures, apply a multi-focal perspective of both short- and long-term goals and develop adequate margins to balance disturbances in a flexible manner. Thus, *protection* actively aims to influence the *adaption*, *emergence* and *entropy* of a system by mediating hardening and awareness, efficiency and redundancy, and dependence and autonomy. Consequently, *resilience* is a behaviour of the system itself that results from its capability to handle its vulnerabilities through adaption and emergence.

This thesis focuses on CIP and its governance; therefore, it does not exhaustively engage with the concepts of resilience, risk and vulnerability. For further discussion of these concepts, this thesis recommends related research (e.g. Birkmann et al. 2010; Fekete 2018; Högselius et al. 2013; Månsson 2018).

3.2.3 Expressions of Governance

The literature review discovered a broad range of applications with regard to the concept of governance. Table 8 illustrates the usage of the term 'governance' as it appears in the reviewed articles and excludes those that do not use the concept. In their article, Sajeva and Masera (2006) extensively explore the concept of governance in terms of the risk of infrastructures in the European context. They notice the difficulty of simply defining governance given that 'it has different meanings for different people, according to the level at which it is applied, the goals to be achieved and the preferred approach' (Sajeva, Masera 2006). Such difficulty has also been acknowledged by other authors (Coaffee, Clarke 2017; Gheorghe 2004; Gheorghe et al. 2018a; Große, Olausson 2018; Große, Olausson 2019). Moreover, Sajeva and Masera (2006) have remarked that governance entails the inclusion and co-operation of public and private stakeholders to approach complex problems, which are labelled 'systemic risks' (Eusgeld, Kröger 2008; Gheorghe 2004; Prelipcean 2010). In contrast with traditional government, many of the articles indicate that governance implies broader participation, informed decision-making and a commitment of participants to deliberate action for governing. Such approach has a multitude of applications to, for example, organisational, public-private, national or transnational contexts as well as complex, socio-technical SoS, such as societies or critical infrastructures. Sajeva and Masera (2006) have further opined that governance acts 'as an interface among the stakeholders, as the source of information and support for strategic decisions, and as the instrument through which the principle of accountability can be properly implemented'.

Table 8: Appearance and Definitions of Governance in the Reviewed Articles

Author (Year)	*Usage of the term governance*	*Nature / Tasks*
Cedergren et al. (2019)	'*the governance system* […] [is] (*overly) generous with allowance of train operation at the expense of granting access to maintenance operations*' (p. 6)	- Resource allocation - Co-ordination
Große, Olausson (2019)	'*The concept of governance is the common element of the continuum that extends from traditional top-down control on one end to self-organisation and networks on the other [regarding] the management of society*' (p. 425)	- Network management - Control/co-ordination - Information and communication - Integration
Katina et al. (2019)	'*a mechanism for providing oversight, accountability and congruent direction*' (p. 123)	- Identity and vision - Communication and integration - Management
Große, Olausson (2018)	'*The concept of governance describes how a society is organized, governed and who is involved in dialogue, participation, and networking*' (p. 1894)	- Policy and identity - Network for steering - information and communication - Management

Gheorghe et al. (2018)	'*relates not just to decision making, but also to the tools, mechanisms, organizations, and mental modes that influence that decision making*' (p. 558)	- International - Public-private policies - Management
Antonsen et al. (2017)	'*Risk governance processes are usually focused on individual enterprises, overlooking important interorganizational issues*' (p. 1837)	- Governmental supervision - Policies and regulation
Coaffee, Clarke (2017)	'*the changing material politics, geographies and governance arrangements associated with critical infrastructure* [are] *the 'collective equipment' of state power* […] *by which control might be exerted, socio-economic restructuring advanced and inequity concretised*' (p. 364)	- Organisational - Governmental - Policies and principles - Management - Risk analysis
Katina et al. (2017)	'*is focused on design, execution, and evolution of 'metasystem' functions necessary to provide for [sic] communication, control, coordination, and integration (C3I) in CPS* [cyber-physical systems]' (p. 168)	- Cybernetic - Management - Organisational - Integration
Lykou et al. (2017)	'*governance (i.e. regulations, legislations, and guidance)*' (p. 5); '*effective transport governance for adaptation are 'soft' type* […] [i.e.] *creating the appropriate framework to enable adaptation action at local and regional level*' (p. 9)	- Governmental policy - Resource allocation - Planning/co-ordination - Management
Seager et al. (2017)	'*refers to the combination of laws, protocols, and norms that dictate decision-making activities taken for service provision*' (p. 99)	- Policy - Administrative structures - Functional layering
Gonzva et al. (2016)	'*the city is composed of different elements* […] *organized by governance*'(p. 2)	- Steering and organising - Holistic understanding
Normandin, Therrien (2016)	'*governance role played by local governments*' (p. 112)	- Government
Schaberreiter et al. (2016)	'*is organized using a multi-stakeholder approach, complemented by a global forum to address core Internet decisions*' (p. 670)	- Policy - Norms and laws
Katina, Keating (2015)	'*private-public governance policies*' (p.318)	- Governmental action
Di Maio (2014)	'*means the importance of coordinate people, processes and technology to govern security "end to end"*' (p. 6)	- Policy - Management - Control & integration
Spyridopoulos et al. (2014)	'*establishing a baseline of the current information security operations system*' (p. 441)	- Policy - Goal setting
Prelipcean (2010)	'*The governance* [of] *risk should avoid a inadequate/ poor governance*' (p. 222)	- Official action - Communication
v. d. Vleuten, Lagendijk (2010a, b)	'*the very perception of Europe's decentralized power infrastructure and governance as "vulnerable" is contested and bound up with current re-negotiations of transnational electricity infrastructure governance*' (p. 2046)	- Political influences - Governmental rules - Steering networks - Management
Sajeva, Masera (2006)	'*is a decision-oriented management process by which public and private actors jointly deal with societal sensitive and complex issues*' (p. 384)	- Public-private - Management - Co-operation
Gheorghe (2004)	'*asks for 'scientific analysis of risks, integration of societal perception and amplification of risk into the risk assessment process, structuring decision making in a consistent rational and democratic way (with a multitude of 'abstract' societal values involved) to transparent and open communication''* (p. 123)	- Policy - Management - Public-private - Trans-cultural

In general, the presence of the term 'governance' in the articles creates a close relationship to manifestations of will in the form of policy documents. Although the literature often directly or indirectly addresses the political/public will and official policies, some of the articles focus on organisational or corporate governance, the management of public-private partnerships or processes of decision-making (Antonsen et al. 2017; Di Maio 2014; Große, Olausson 2018; Große, Olausson 2019; Katina et al. 2019; Katina, Keating 2015; Prelipcean 2010; Sajeva, Masera 2006). In addition, Sajeva and Masera (2006) have provided an overview of principles for good governance that public policies have stated. Considering such policy documents, there is evidently a strong focus on operative processes of policy-making and implementation that aim to be open, participatory, transparent, accountable and coherent (see Grzeszczak 2015; Sajeva, Masera 2006). However, the strategic perspective of visions, strategic objectives and long-term goals is underrepresented. From such a strategic view, visions would imagine future worlds with consideration to historical, cultural and social complexities. Strategic objectives can then emerge from such imagination—both consciously and subconsciously—and thereby constitute a precondition for further planning, regardless of whether it concerns issues in the personal sphere or in business or public environments. Such strategic objectives precede the operational objectives of a complex system, while both precede process goals (Bouckaert, van Dooren 2010; Große 2018). Hence, a more comprehensive governance must also consider the alignment of a multitude of goals and objectives, especially when it concerns the well-being of people and the protection of critical infrastructure.

Gheorghe (2004) has emphasised a need for appropriate governance that accounts for the complexity of critical infrastructure and societal systems. Likewise, Coaffee and Clarke (2017) have requested 'new modes of equitable governance across multiple systems, networks and scales'. Some authors have suggested concrete targets and measures, such as planning for adaption to climate change (Lykou et al. 2017), governing technology development (Katina et al. 2017; Katina et al. 2019), managing public resources (Cedergren et al. 2019; Gheorghe et al. 2018a; Johnsen, Veen 2013; Prelipcean 2010), simultaneously ensuring openness and freedom of the Internet and information security (Schaberreiter et al. 2016) and considering centralised or decentralised approaches (Di Maio 2014; Normandin, Therrien 2016; Seager et al. 2017; van der Vleuten, Lagendijk 2010a, 2010b).

Many of the reviewed articles recognise that it is difficult for governance to effectively implement measures that impact the private sphere, which is encouraged to comply with public policies. To enhance adherence, several authors have promoted incentives as a means of managing such implementations (Cedergren et al. 2019; Gheorghe et al. 2018a; Lykou et al. 2017; Sajeva, Masera 2006; Schaberreiter et al. 2016; Seager et al. 2017; Tehler et al. 2018).

Apart from presenting several perspectives on governance, Katina et al. (2019) have concluded that governance not only relates to the nature of a system of interest but also 'involves three essential aspects: direction, oversight and accountability'. This perception of governance seems to adopt the concept of the 'organism' (see page 47), wherein governance constitutes the head of the system, and is referred to as a meta-system (see Beer 1995; Katina et al. 2017). As mentioned, the original concept allows for a recursive application, which easily confuses a concrete usage of the concept, especially with regard to SoS (cf. Katina et al. 2017). The meta-system intends to govern a complex system and unites the management of an operating system and strategic development. However, a tripartite structure of the recursive concept could achieve more clarity. Such triad consists of operation, management and strategic development (e.g. through policy-making). However, the aforementioned perspective of governance as the head of a system has blurred the transparent and participatory nature of governance, as already described, which can be ascribed to the fact that transparency and participation are acknowledged as resource-consuming (Sajeva, Masera 2006). Sajeva and Masera (2006) have further remarked that in specific contexts, such as that of Sweden, co-operative and participatory decision-making may be expected, while steering in the form of rigid directing is considered rude and disrespectful.

One-third of the articles do not contribute to a deeper understanding of the concept of governance, which may reflect the perception of governance as a peculiarly subject-less phenomenon (Offe 2008). Whereas the term 'government' clarifies the body that governs society, the term 'governance' nebulises the governing actor, which can explain the popularity of the term in a variety of contexts even beyond the public sphere, as indicated above. Other scholars have noted that governance is an 'elusive and much debated concept' (Griffin 2010:365) and a 'significant expansion, broader than management' of society (Ison et al. 2018). Since the ambiguity of the term tends to complicate analyses in the social sciences, it has been questioned whether governance marks the contraposition (*Gegenbegriff*) or the *genus proximum* (*Oberbegriff*) to government (Colebatch 2014; Offe 2008). The majority of the reviewed articles reflect this ambiguity. On the one hand, they view governance as *Gegenbegriff* to government concerning the entire continuum of modes of steering that deviate from rigid, top-down steering towards self-organising networks; on the other hand, they perceive governance as *Oberbegriff* with reference to all types of steering in which the governing body is not clearly identified and addressed.

Therefore, the structure and multilateralism of governance as the contraposition to government hamper the imputability of decision-making and its consequences for a responsible actor (Offe 2008) similarly to the usage as a general concept, which complicates the application of the term as an analytic construct (Colebatch 2014).

However, the lowest common denominator characterises governance as a departure from traditional ruling towards participative forms of policy-making, in which, according to Rhodes (1996), 'self-organizing, interorganizational networks' […] complement markets and hierarchies as governing structures for authoritatively allocating resources and exercising control and co-ordination'. This characterisation positions governance at the intersection of governmental control, competitive market dynamics and the private sphere of citizens (Offe 2008). In this space, an interorganisational network, which corresponds to the concept of an SoS, governs (public) service delivery of, for example, CIP and undisturbed power supply. However, this position necessitates a new, systemic approach to governing that considers the extent and complexity of developed societies' concerns, such as CIP.

Research has emphasised that large-scale problems, such as climate change and an increasing dependency on critical infrastructure, challenge society and governments because they transcend political domains (Griffin 2010; Ison et al. 2018). In view of this, Ison et al. (2018) have recalled cybernetics to contend with complexity in society and introduced the concept of cyber-systemic governance. This approach stresses the dynamic and systemic relationships among stakeholder groups in society and common concerns regarding, for example, the biosphere and the technosphere. The authors have particularly highlighted the relevance of negotiating and pursuing social purpose as it develops within an unfolding context. Although this social purpose is set to be prior to the governing activity, the authors have struggled with logics in the multi-dimensional system. This conflict could relate to the impression that traditional government, similarly to system control, is saddled with negative associations, while governance is thought to be oriented towards the common good (see Offe 2008). Since the proposed cyber-systemic governance approach evolves from the cybernetics of Wiener (1948), it involves a structure of control and a controlled system interconnected by relations of governing and feedback, which enables the governing body to adapt governance. Nevertheless, the authors have contradicted this systematic loop of action and reaction within their approach by contrasting 'systematic' and 'systemic' similarly to how 'government' and 'governance' are polarised as negative or positive. Processes and systems are not necessarily interchangeable; thus, 'systematic' must relate to processes, while 'systemic' concerns systems.

In this regard, systematic processes facilitate transparency and evaluability of activities and processes, which in turn enables constructive feedback for the governing actors and systems, regardless of the system's particular structure. Problems can arise if the receiver of the feedback is not identifiable, which can be the case in networks. Another concern is a lack of proper feedback relations, which is the major critique of the cyber-systemic governance approach towards dominating approaches. Systemic thinking in establishing processes must thus not only include proper systematics in the particular processes but also consider the dynamics within the governing and governed system, and the relations between them and their environments.

McIntyre-Mills (2006) has applied such shift in thinking to characterise systemic governance as a bottom-up approach that starts at the local level and, through adaption to circumstances and the emergence of new forms, is able to span multiple areas. This perspective is *Gegenbegriff* to traditional forms of government; however, it struggles with the systemic perspective, which would also encompass larger concerns from the local perspective, and vice versa. Apart from power directions, a systemic governance approach needs to address processes and structures at several levels of concern in society and mediate among them. Thus, the challenge is still to establish the balance between control and flexibility, complexity and capability to act, dispute and dialogue, participation and self-indulgent publics, common structure and local variety, and systematic and ad-hoc proceedings.

The deliberations above illustrate that governance is a multi-faceted, multi-layered and recursive concept that is similar to those of systems and infrastructure. Specifically, it mainly concerns the steering of another system with the aid of policies, wherein their implementation and the execution of measures relate to the managerial and operational functions of subordinate systems. However, the process of policy creation is an operational task which also entails the management of this process and the existence of higher-level visions, strategic objectives and process goals.

In sum, governance integrates a system perspective into *systemic governance* with a tripartite structure. First, the ability to oversee a system enables governance to align visions, strategic objectives and goals to find direction and contend with the system's entropy. Second, management effectuates this direction through the integration of systems and processes to treat emergence. Third, due to its focus on management (i.e. rule-based, quantitative steering), the reviewed literature consistently overlooks the necessary element to overcome ambiguity and uncertainty because of the inherent lack of knowledge and to consider adaption Hence, system leadership must consider qualitative aspects to complete systemic governance.

3.3 Kaleidoscope for Integrative System Analysis – KISA

3.3.1 Key Elements of the KISA Model

Integrative system analysis requires a tool that facilitates both an investigation of systems from a holistic perspective and research that scrutinises particular aspects of a specific system while retaining a holistic understanding. Figure 5 presents such a tool. The depicted kaleidoscope constitutes a conceptual framework for integrative system analysis.

The content of the kaleidoscope results from the considerations from the literature review, as presented in Section 3.2. Methodologically, the KISA derives from the method for complex and interdisciplinary research that PAPER I develops. The KISA model uses a radial representation of the pertinent perspectives as triangles, which symbolises how a specific research focus can be gradually narrowed while maintaining a holistic setting. In addition, the neighbouring triangles demonstrate a close relationship between their respective concepts.

Four perspectives are arranged radially: system, infrastructure, process and governance. First, *system* embraces concepts with regard to various types of system, such as societal, socio-technical and technical. This perspective concerns a particular snapshot of a system, which captures a certain state at a particular moment in time. Second, *infrastructure* regards the conglomerate of fixed assets, processes and expressions of will that is (or can become) critical if the survival, well-being and progress of a society depend on its maintained functionality. Third, *process* considers the key process(es) that a system of interest performs. Thus, its contemplations include related information, process objects as materials and activities that are performed by persons, tools and technologies. Finally, *governance* focuses on concepts and activities with respect to operation, management and politics/policies, which occur in not only public contexts but also non-governmental, public-private or private organisations. These four perspectives are founded on three layers that mirror the ability of the perspectives to adjust the special focus on the micro, meso or macro level of a system of interest.

Figure 5 illustrates that the KISA's outermost ring contains the mentioned perspectives, and the second ring represents areas of particular interest under one perspective. As indicated above, theories from the respective area substantiate the conceptual frame of each triangle. A deliberate exchange between perspectives facilitates a mutual influence among theories from adjacent areas. The innermost ring refers to methodologies, particular methods and limitations. Since research must contend with ontological, epistemological and ethical considerations, different fields can have distinct traditions and paradigms for gaining knowledge. Thus, the innermost ring enables a conscious choice of methods, tools and measures with respect to materials, possible limitations and research questions. The design of a particular research methodology can therefore select from several methods for collection and analysis of material as well as combinations of them. In contrast to the example in PAPER I, the KISA does not specify particular methods or components for two main reasons. The first regards the methodological proceedings that this thesis applies, which have been discussed in detail in Section 2. Since this setting has been adapted to the specific conditions of this study, it may not perfectly fit another research design. Second, the previously presented literature review reflects significant diversity among the research fields that utilise system-theoretical concepts; accordingly, there are substantial differences in not only methods and tools for analysis but also perceptions regarding knowledge, assumptions, interpretations and understandings. Hence, each single application of the KISA requires a careful assessment of the constraints that a particular research project has to manage, such as access to data or participants, limits due to capacity, time or funding, or even legal, ethical or technical restrictions. The KISA encourages an integrative approach that includes the composition of a proper methodology for a particular study with consideration of the adjacent perspectives that shape the model.

Communication is the central hub of the KISA model, as proposed in PAPER I and visualised in Figure 5. This communication hub constitutes a means of enabling exchange among research fields as well as between research and practice. This exchange concerns clarifications and development of theories, methodologies and results in addition to discussions of involved *Weltanschauungen* and the particular system of interest and its components, interactions and environment.

3.3.2 Contribution of the KISA Model and Further Advancements

The proposed KISA contributes a systemic perspective that research and practice can apply throughout investigations of complex issues in society for the purpose of developing a multi-perspective understanding.

The adjustability of this holistic system perspective is a feature of particular value. Studies can choose the way in which they view a certain problem with regard to a particular system of interest by zooming in and out to vary the level of detail. Such adjustments of a zoom factor allow for scrutiny of a selected problem or segment in different degrees of detail and a spectrum of theories and methods that are appropriate for each level. Simultaneously, the holistic perspective is maintained, which enables researchers to transfer results from one level of detail to another while taking into account the interrelated conditions at the higher or lower level. Moreover, the KISA contributes a conceptual framework that is suitable for several disciplines; therefore, it supports the transfer of theories, methods and results among a variety of research areas. An enhanced transfer of knowledge and understanding is important—especially for the development of technologies and interrelated societal issues, such as CIP—which emphasises the relevance of the KISA for multi-disciplinary research.

In addition, the KISA model adheres to an underlying tripartite structure. This structure, which emerges from the key elements of a system, is reflected in the breakdown of both the different perspectives and the research strategy of a selected triangle. Moreover, the structure permits a research strategy to adjust systematically to a particular problem, setting or audience. Thereby, the tripartite structure encourages a multi-focal perspective; although extremes may be sharply focused during an investigation (e.g. the near focus on individual perceptions or the far focus on systems at a high level of abstraction), these endpoints must be interrelated not only to each other but also to a middle level for providing a systemic view.

Future developments of the KISA can depart from the conditions of a particular research problem or frequent application of the model. First, a specific research problem may inform the creation of either an adapted version of the KISA (e.g. in another research discipline) or, preferably, a specialised cube that fits into a segment of the KISA, which can thereby advance to a universe of theories and methods for CIP research and practice. Integrating a systemic view of multi-disciplinary research may also produce another dimension. Second, through adherence to the KISA, future research can establish a supporting spectrum of theories and concepts, methods and specific cases. Such knowledge base can accelerate both discussions among scholars and practitioners and the alignment of definitions and designations. Consequent application of the KISA to various research problems can promote cumulative and additive developments of knowledge as well as their incorporation into a truly multi-disciplinary canon of systems research.

3.4 Further Reading

Additional concepts are interrelated with systems, infrastructure and governance but not considered by this study. Current discussions of concepts, theories and applications highlight their importance for CIP, systems science, and information systems research and engineering (see e.g. Bichler et al. 2016a, 2016b; Demetis, Lee 2016, 2017; Hassel et al. 2014; Mingers 2017; Robey, Abdalla Mikhaeil 2016; Schneider, Bauer 2007; Schultze 2017; Whitney et al. 2015).

3.5 Summary

PART A has examined relevant scientific literature and revealed that the concepts of systems, infrastructure and governance encounter a common challenge: the characterisation of their key elements, namely the components, interactions and environment(s). Since the common parlance is ambiguous about these terms, it follows that their appearances in the literature cover a broad spectrum of understandings. However, the perspective in approaching a system—even that of infrastructure or governance—reveals the system's nature and properties and attributes its purpose and main process(es).

Briefly summarised, a *system* is an assemblage of components with properties that, through certain interactions within an environment, fulfil a common (i.e. critical) *process* that strongly depends on the simultaneous and proper functionality of the majority of components, which can *adapt* to their conditions. In this form, a system has properties, can exhibit behaviour (e.g. *emergence*) and may interact with its environment. To maintain the critical process, a system must master *entropy*, which necessitates a *control* mechanism, such as artificial reasoning or human decision-making. Considering the constituting components, the system can be classified as technical, socio-technical, social, political or *organism*, which implies that it has and exercises some kind of will only at the system level. An SoS evolves when constituting, independent systems interact to achieve a common purpose, and each system gains some benefit from its participation. In this configuration, an SoS can be viewed as an *organisation*, which may also be in need of *steering* mechanisms. When zooming out another level, organisations, which shrink to organisms due to a higher level of abstraction, may then coalesce particular forces to accomplish an overarching purpose within a *complex* super-system, such as that of CIP, by exchanging certain benefits. *Infrastructure* is perceived as an always-existing, long-lasting common good that unites material, (building) processes and an expression of will. Nevertheless, even such an SoS requires governance to contend with decaying forces. This *systemic governance* must be able to ensure accountability and integrity of the governed system—both horizontally alongside processes and vertically through hierarchies while accompanying system dynamics. Hence, indirect steering through policies and quantitative process control by management need complementation by direct system leadership to lift qualitative aspects and create systemic governance.

The review informed the proposal of the KISA model, which contributes a systemic perspective that can guide the exploration of complex issues in society to acquire beneficial, multi-faceted knowledge and a multi-perspective understanding. Further research can target the cultivation of a multi-disciplinary canon of theories and concepts, methods and specific cases.

4

PART B – PRAXIS: THE SWEDISH CASE OF *STYREL*

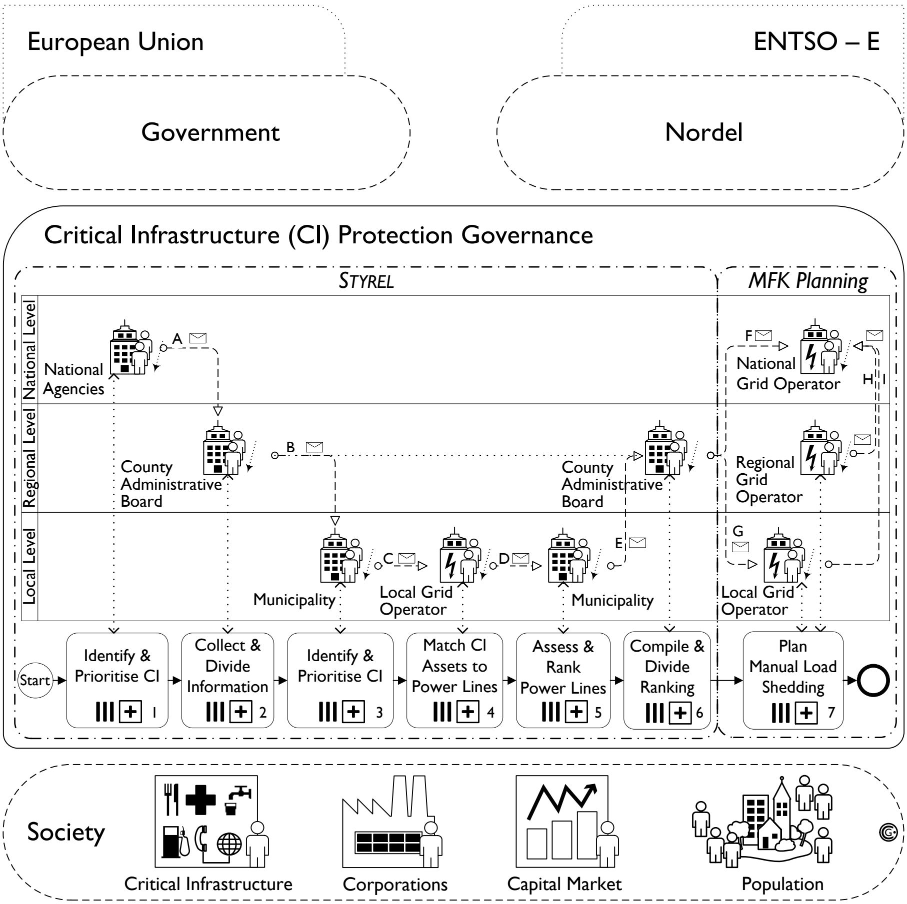

Figure 6: The Planning Process of *STYREL* in the Swedish CIP Context (adapted from PAPER IV)

4.1 Part B – Outline

Critical infrastructure protection has been introduced as a purpose that a complex super-system pursues by coalescing forces of its constituting systems to derive benefits, which may include the creation of value for society.

This chapter departs from the theoretical underpinnings in PART A to concentrate on the practical application of one specific approach in the Swedish context, namely *STYREL*. Figure 6 depicts the central planning process. PART B investigates the first research question:

How does Sweden organise and govern critical infrastructure protection?

The aim of this chapter is threefold. First, it seeks to provide an extensive representation of the unique Swedish case. Second, it intends to deepen the investigation of *STYREL* in accordance with the perspectives of systems, CIP and governance in the Swedish context. Third, it strives to highlight areas for development and provide recommendations for integration and alignment.

The subsequent exploration of the research question in this chapter is mainly based on the included papers. In addition, this thesis conducts a meta-analysis of the papers as well as some unpublished material. This analysis applies the KISA model of PART A to examine the inter-organisational co-operation during emergency response planning for power shortages and the application of the preparatory plan for CIP in Sweden.

The following section provides an overview of the papers that are included in this dissertation. First, a brief synopsis presents the main contributions of each paper and their relation to the research question. Second, concise summaries of the papers demonstrate their respective approaches, results and contributions.

The subsequent section details the Swedish governance approach to CIP against power shortages, which is called *STYREL*. First, it elaborates on the SoS that surrounds and executes the planning process. To this end, it focuses on the particular components, such as the actors in the system, their interactions during the planning and considerations regarding the system environment. Then, it targets the usage and implementation of the resulting plan for CIP in Sweden. Finally, it delivers insights into the governance of the multi-level planning, including issues regarding policies, the management and operation of *STYREL*, and accelerating problems in the adaption, emergence and entropy of the governance system during and between process iterations.

The chapter concludes with a discussion of the implications for the Swedish case and elucidates areas for improvement. In addition, a summary condenses the key findings of the studies on the complex Swedish case.

4.2 Essence and Contribution of the Papers

The research question that guides PART B can be divided into three aspects: (a) the particular system and its key process, (b) the context of CIP in Sweden and (c) the governance of both. Table 9 summarises the results and demonstrates their relation to the research question with an indicator.

Table 9: Overview of the Results and their Contribution to the Research Question

	Key contributions of the included papers
PAPER I (b)	▪ Method for designing a research strategy for complex and multi-disciplinary research problems with consideration of paradigms, theories and methods ▪ Demonstration of usability through application of the conditions in *STYREL*
PAPER II (**a**, c)	▪ Model of the SoS that surrounds and executes the *STYREL* process: o Rich Picture that identifies actors as system components, including their concerns, roles and interrelations o Root Definition that represents a generic system to support decision-making in the case of a power shortage o Action Model that specifies relevant actions during the planning ▪ Empirical model evaluation that suggests actions to improve *STYREL* regarding (1) the usage of the resulting plan, (2) better communication, (3) improvement of feedback loops and (4) adapted guidelines and decision aid
PAPER III (a, b, c)	▪ Portrayal of the central role of the CABs in the *STYREL* process and the multi-level, multi-agency planning system ▪ Evidence that the CABs lack awareness, knowledge, information and resources to fulfil their core function in *STYREL* and Swedish CIP ▪ Discussion of implications for policies, management, information processing and communication to improve co-operation, participation and reliability
PAPER IV (a, b, c)	▪ Knowledge of blind spots in *STYREL* and the multi-level system of CIP, including the reference process, its implementation, the proceedings and results ▪ Demonstration of the chain of policy, interaction and learning ▪ Aspects of the design, execution and evolvement of the Swedish system that are likely to affect the predictability of its behaviour and thereby generate further properties, such as entropy, emergence and adaptability
PAPER V (a, **c**)	▪ Four classification parameters of strategic objectives: (1) *manifestation* (implicit or explicit), (2) *sequence* (intermediate or advanced), (3) *logic* (identical, compatible or antinomic) and (4) *side effect* (beneficial, neutral or conflicting) ▪ Three main challenges for governance that strategic objectives provide, which emerge from SoS: (1) opportunities, (2) indefinites and (3) risks
PAPER VI (a, b, c)	▪ Multi-level planning concept applied to emergency response for CIP ▪ Necessary insight for systemic governance to align strategic objectives, process management and leadership issues at each level ▪ Characterisation of the different planning levels from strategic planning to application of the resulting plan and integration of *STYREL* into Swedish CIP ▪ Specification of sources of uncertainty with regard to lack of knowledge: (1) the complex planning (reference) process, (2) the decision-making process and (3) the direction and guidance ▪ Parameters to address by systemic governance regarding the sources of uncertainty (1) – (3) and (4) further factors.

The preceding synopsis specifies the most significant contributions of the included papers. The section below elaborates on the papers and their essential insights in the context of this dissertation. Section 4.3 presents the results of the papers that belong to the meta-analysis of this thesis.

PAPER I. The article entitled '*Research in Complex Planning Situations: Dimensions and Challenges from Swedish Response Planning*' used the research process of design-oriented information systems research (Österle et al. 2011) to compose a multi-perspective kaleidoscope for complex and inter-disciplinary research. By utilising this kaleidoscope, researchers can design an individual research strategy that is adequately adapted to a complex problem. The article evaluates the multi-perspective kaleidoscope by applying it to the research problem depicted by the *STYREL* case.

Although the article applies a mostly theoretical meta-perspective, it also indicates conditions which can impact a research strategy design in a particular context. For instance, different research fields can approach systems and their properties by using various theoretical concepts, or interrelations between research fields can lead to overlapping areas that may employ similar terms with different meanings. Moreover, research projects on complex problems, such as *STYREL*, are subject to specific conditions with regard to time, financing and capacity, for example. Such conditions can affect the scope and comprehensiveness of the particular research project.

PAPER I focuses on how to integrate separate research fields and sub-areas; thereby, it contributes not only to the orchestration of proper theoretical frameworks but also—and elaborately—to method development. PART A of this thesis has used the presented method to develop the KISA. This multi-perspective kaleidoscope enables scholars from separate disciplines to create a joint strategy for approaching a complex problem from multiple angles while still retaining a holistic perspective. In addition, this method facilitates communication about the selection process of a research methodology within a project group, among the research community or to third parties.

PAPER II. The article entitled '*Applying Systems Thinking onto Emergency Response Planning: Using Soft Systems Methodology to Structure a National Act in Sweden*' investigates the case from a soft operations research perspective. It adapts the Soft Systems Methodology (Checkland 1989) to design-oriented information systems research (Österle et al. 2011). Departing from the study of documents on *STYREL*, this partial study develops a conceptual system model that consists of three sub-models: the Rich Picture (see Figure 7), a core root definition of a generic system model and an action model. Ten security officials at municipalities and representatives from local PGOs that were involved in *STYREL* evaluated this system model.

The conceptual system model emphasises components, interactions and surrounding conditions in the SoS with regard to *STYREL*. First, the Rich Picture visualises the problem situation, including actors, interrelations and focal areas. Based on this segment of the real-world phenomenon, the core root definition then enhances the understanding of involved actors and their roles in the complex planning system for CIP. This generic system model indicates preconditions and constraints, such as the prevailing *Weltanschauung*, legal regulations and technical limitations in the particular context. Advancing from this generic model, additional abstraction from the underlying case yields an action model that contains relevant actions in the context of response planning for power shortages. This action model conveys relations between actions and helps to identify interactions and adequate controlling activities.

The interviewees appreciated the visualisation of the system and the concretised structure, and they expressed further concerns regarding the conditions and requirements of *STYREL*. PAPER II evidences that short-term management and the execution of emergency response planning are complex endeavours that require target-group-oriented communication and governance. The interviewees noted further changes and actions for the context of *STYREL*. The results imply that the distributed environment of *STYREL* challenges governance with regard to alignment and achievement of strategic objectives and continued motivation of responsible persons. This study thereby offers an informal basis for the development of adequate information paths and assists with visualising the complexity of emergency response planning for CIP for power shortages in Sweden. Additionally, the conceptual model facilitates a future dialogue on work flows, responsibilities, governance and collective learning.

PAPER III. The article entitled '*Swedish multi-level planning system for critical infrastructure protection: The regional core*' examines the role of the regional hub of *STYREL* and the collaboration and interaction between planning levels. The article focuses on the co-ordinators' perspective and presents evidence from interviews and a survey among planners at the CABs who are entrusted with supervision and execution of *STYREL* within their regional area of responsibility.

PAPER III outlines the main principles of the Swedish crisis management system and notes the actors who share responsibility for the energy supply in Sweden. The article further demonstrates that the CABs have a central role in not only the Swedish crisis management system but also the SoS that interrelates with *STYREL*. The study departs from the theoretical background of complex systems governance to portray the CAB's central position in the process, emerging problems during its execution, the integration in the context of CIP and the interlinked governance issues, such as information scarcity and a lack of decision-support, guidance and direction.

In association with their role in *STYREL*, the paper reveals that the CABs bear a double burden as participants in the process and as regional co-ordinators. Additionally, the participants questioned the usefulness of *STYREL*'s outcomes for crisis management and expressed considerable doubt about whether *STYREL* can substantially support CIP during a power shortage. Because of these potential shortcomings and other practical issues within the process, the CABs requested a more structured process with other actors. Further issues that necessitate improved governance are an absence of measures to evaluate the received information and their own decisions, a lack of feedback from the PGOs regarding next-level planning of manual load shedding due to national information security concerns and a general insufficiency of knowledge and experience, for example.

PAPER III contributes a detailed portrayal of the role of CABs in *STYREL* and the multi-level system that maintains a multi-agency planning process. The article also provides insights into concrete techniques, perceived difficulties and the relation of *STYREL* to Swedish CIP. In addition, it reveals areas for further development through its discussion of implications for policy development, information management and communication within the system and to external stakeholders.

PAPER IV. The article entitled '*Blind Spots in Interaction between Actors in Swedish Planning for Critical Infrastructure Protection*' expands the perspective of PAPER III to examine the chain of policy, interaction and learning among key actors as well as their roles in *STYREL,* in the Swedish crisis management system and in the event of a power shortage. With evidence from 66 interviews and a survey among all 21 CABs and the 10 PGOs that are responsible for effectuating a manual load shedding in accordance with Swedish regulations, the analyses indicate blind spots in the current proceedings.

PAPER IV discusses three considerations. First, the levels of fact and relation indicate an interrelation with system entropy. Second, motives and objectives can account for emergent behaviour. Finally, experience results in learning that transforms into an adaption through development and maturation to suit certain circumstances. Examples of blind spots in *STYREL* include vague instructions, a reference process model with poor specification of concrete proceedings, a lack of feedback and knowledge management, staff changes, weak collaboration, differences in interpretations of critical infrastructure's criticality, inadequate knowledge and varying maturity of the activities of actors.

By highlighting blind spots in Swedish CIP, PAPER IV concludes the need for a more integrated and standardised system that considers the wider context of CIP in normal and crisis conditions at national and international levels. The article contributes knowledge of the variety in participation, experience, understanding and proceedings among the key actors. These aspects in combination with a growing system of critical infrastructure necessitate appropriate *systemic governance* with governance, management and leadership efforts to channel the dynamism of the complex system of CIP and address entropy, emergence and adaption.

PAPER V. The article entitled '*The Systemic Implications of Emergent Strategic Objectives in Complex Planning Situations*' develops a model for analysing systemic implications of strategic objectives in the context of national CIP for the case of a power shortage. Departing from the results of the preceding document and interview studies on *STYREL*, the article addresses the emphasised need for a thorough consideration of the various interests that are involved in such complex systems of multi-level planning.

PAPER V contributes context for a constructive dialogue that supports the analysis of strategic objectives in the SoS. It illustrates the relation between strategic objectives, which emerge from particular system conditions, and their combinations that challenge controlling, governance and leadership efforts. Systemic parameters specify the components, interrelations and environment(s) of a SoS. In addition, four classification parameters characterise strategic objectives: *manifestation* (implicit or explicit), *sequence* (intermediate or advanced), *logic* (identical, compatible or antinomic) and *side effect* (beneficial, neutral or conflicting). Bundles of strategic objectives classify the three main challenges for governance of CIP as opportunities, risks and indefinites. Suggestions for addressing them properly include the following.

- *Opportunities*: find and promote compatible strategic objectives that rely on means with beneficial side effects
- *Indefinites*: monitor and assess strategic objectives to dissolve identical objectives and identify future opportunities or risks
- *Risks*: determine and mitigate antinomic strategic objectives and compatible ones that apply means with conflicting side effects

STYREL similarly ignores conflicting side effects among strategic objectives and beneficial ones. Hence, by proposing the model, PAPER V contributes to future systematic development of Swedish CIP. This model can further assist with analysis of other similar complex planning environments.

PAPER VI. The article entitled '*Sources of Uncertainty in Swedish Response Planning*' focuses on uncertainty in planning and decision-making for CIP. It examines sources of uncertainty that are associated with a lack of knowledge in complex planning environments. In particular, PAPER VI presents theoretical concepts regarding multi-level planning and national emergency response planning. The derived framework for analysis contains several parameters and a model that represent characteristics of multi-level national emergency planning. This framework underpins a comprehensive analysis of *STYREL*. First, the analysis of documentation on the case reveals three sources of uncertainty: the complex planning process, the decision-making process and the direction and guidance in those two processes. In addition, interviews with experts who are entrusted with the planning at municipalities and CABs elicited details about the identified sources of uncertainty.

The contribution of PAPER VI is twofold. First, the review of scientific literature presents interdependencies between different levels in multi-level planning, such as strategic, tactic and operational planning, the execution of planning with decision-making and the usage of the plan. Furthermore, it applies these levels to national emergency response planning. PAPER VI specifically reveals three sources of uncertainty that correlate with lacks of knowledge in SoS, such as *STYREL* (S1-3 in Figure 8).

S1: The complex planning process includes tactical and operative planning of the execution process, which, in *STYREL*, addresses the reference process model (development) with resource planning and allocation.

S2: The decision-making process relates to the execution of the planning, which, in *STYREL*, includes the identification and prioritisation of critical infrastructure that depends on the power supply.

S3: The direction and guidance appear alongside *S1* and *S2* to align objectives, goals and means throughout the complex planning environment, which, in *STYREL*, relates to local, regional and national governance.

Further parameters, which the interviews with decision-makers refined, explicitly specify these sources of uncertainty in PAPER VI. Thereby, the article highlights particularly important components and the hierarchical structure of national planning for CIP in response to power shortages.

Second, the empirical results of this study extend the three sources of uncertainty in multi-level planning with more complex interrelations and components. Participant-derived insights emphasise that governance efforts need to focus on many interrelations, such as those between the uncertainties in multi-level planning, the characteristics of a decision-maker and the environment that surrounds such a decision. In particular, decision-makers' experiences expose issues that connect with these sources of uncertainty, such as information technology support, decision aid and collective learning.

4.3 The Swedish Case of *STYREL*

4.3.1 The Systems of Systems associated with *STYREL*

The key actors and stakeholders in the Swedish case can be viewed not only as independent systems within a broader CIP context but also as part of their respective milieus. Within these environments, the actors—as components of the SoS—maintain various interactions. Table 10 details the involved actors and their areas of responsibility in society and *STYREL*.

Table 10: Actors in the Swedish Planning Approach – *STYREL* (adapted from PAPER V)

N°	*Actor*	*Area of Responsibility*
I	Swedish Civil Contingencies Agency	▪ National prevention, contingency and crisis management ▪ *STYREL* – process development
II	Swedish Energy Market Inspectorate	▪ Control of the Swedish energy market, pricing and policies ▪ *STYREL* – process development
III	Swedish Energy Agency	▪ Reliable and sustainable energy supply ▪ *STYREL* – process development, initiation of process execution (national), direction and guidance
IV	National PGO	▪ Maintenance of the national power grid and power supply ▪ *STYREL* – process development, supervision of planning for and execution of manual load shedding (which subsequently implements the results of *STYREL*)
V	National Agencies (ca. 100)	▪ Various tasks affecting societal security ▪ *STYREL* - identification and prioritisation of critical infrastructure that the particular agency operates, distribution of planning documents to the CABs where objects are physically located
VI	County Administrative Boards (n=21)	▪ Representing the government at the regional level ▪ *STYREL* – process execution (regional), distribution and compilation of planning documents, direction and guidance
VII	Municipalities (n=290)	▪ Representing society and acting locally ▪ *STYREL* – process execution (local), identification of critical infrastructure, collaboration with PGO (operating locally) and public and private operators of critical infrastructure (located locally), prioritisation of assets and controllable power lines
VIII	Power Grid Operators (ca. 160)	▪ Grid maintenance and power supply at the regional/local level ▪ *STYREL* – assisting municipalities with information on how critical infrastructure relates to power lines; planning for manual load shedding

Imbalances of power production and consumption require control activities to maintain the power grid in a stable state, as explained in Section 1.3.2. This balancing can lead to power outages for some consumers. A swift response to certain circumstances can be imperative to protect society from negative consequences. The Swedish approach pre-emptively identifies critical power consumers and their importance for society. For this purpose, it uses the eight-point scale in Table 11 (MSB 2010:10). Apart from this scale, no further decision aid is available.

Table 11: Classification Scheme of Critical Infrastructure (Source: MSB 2010:10)

Class	*Score*	*Description*
1	7	Power consumers that have a large impact on life and health in a short time frame (hours)
2	6	Power consumers that have a large impact on vital societal functions in a short time frame (hours)
3	5	Power consumers that have a large impact on life and health in a longer time frame (days)
4	4	Power consumers that have a large impact on vital societal functions in a longer time frame (days)
5	3	Power consumers that represent large economic values
6	2	Power consumers with major importance for the environment
7	1	Power consumers with importance for societal and cultural values
8	0	All other power consumers

Each included paper in this dissertation contains a description of the SoS for CIP and the *STYREL* case. In particular, PAPERS II-IV concentrate on analyses of the system, the roles of key actors in the approach and the interactions during the planning. The *STYREL* reference process is outlined as follows.

First, at the national level, four national authorities (see I to IV in Table 10) commence the planning process. The EA (III), as the government-entrusted actor with overall responsibility for the process, informs other national agencies (V) and all CABs (VI). Many national agencies are requested to document the critical infrastructure for which they are responsible. This inventory identifies key power consumers and prioritises their importance for society according to the scale in Table 11. The national agencies then distribute a separate list of their inventory to the CAB in each county in which the critical infrastructure is physically located.

Second, the CABs initiate the execution of the planning at the regional level and provide information about the proceedings to their municipalities. In addition, each CAB processes the inventories of the national agencies and prepares a particular selection for each municipality (VII).

Third, at the local level, municipalities are encouraged to identify power consumers that are vital for the local society. Responsible individuals at municipalities prioritise these key consumers by applying the aforementioned scale. With respect to the limitations for controlling electrical power, municipalities must further observe technical feasibility. Therefore, local PGOs (VIII) provide information about the relation of the power consumers to controllable power lines at the request of the municipalities. With this information, various consumers—each with a score based on its prioritisation class—aggregate to different power lines. A spreadsheet that performs an additive aggregation constitutes the information technology support for this aggregation. To eliminate possible flaws due to this aggregation, municipalities must manually assess the ranking of the resulting power lines. Upon completion of this assessment, the municipalities forward the resulting list, which contains the ranking of local power lines, as a suggestion to their responsible CAB.

Once the ranking list returns to the regional level, the responsible CAB then prepares a compiled ranking, which involves all lists from their municipalities, by using another spreadsheet that automatically applies another additive aggregation. In co-operation with municipalities and neighbouring CABs, each CAB specifically considers power lines that cross local and regional borders so that the resulting compilation is adequately attentive to the initial classification of key consumers. Each CAB then conveys the completed compilation to the Swedish national PGO (IV) and the respective parts of the ranking list to the interrelated local PGOs (EA 2014c).

This large-scale SoS, which performs the planning for CIP with regard to the power supply, is embedded within a shared environment of societal responsibility. Each of the components of this SoS is simultaneously a component of another SoS as well. Therefore, the *STYREL* planning is only a relatively small part of the total workload for each actor in its daily business, and the particular environment of each actor dominates the interpretation of its role in the planning. Based on the results of the document study, PAPER II clarifies the contexts and derives the following core root definition for the SoS:

> *A government-owned system, staffed by local, regional and national qualified professionals, which, considering legal regulations and technical limitations, supports planning and preparedness. It provides relevant information for decision-making on power supply in the case of power shortage. The system collects and prioritises power consumers that meet the criterion 'important to society' in order to preserve and maintain critical infrastructure during a crisis situation that makes an impact on local, regional or national society.*

The key stakeholders and actors in the system, their relations, and examples of their individual concerns and contexts create the complex situation that is depicted in Figure 7. As the results of this case study repeatedly illustrate, the scant attention to *STYREL* between the process iterations affected both the actors' awareness of the contextual frame and their interpretation of particular roles in this SoS. In addition, the commitment of actors and the knowledge and experience of this planning for CIP gradually diminished.

As part of the Swedish system for crisis management, the regional body operates as a co-ordinator that organises co-operation and interaction among actors from the public and private sectors. The CABs bear a double burden in *STYREL* as participants in the process and as regional co-ordinators. During the execution of the planning, CABs occupy a central role as intermediates between the national, regional and local levels. PAPER III examines this role in more detail. According to the reference process, the CAB's role is directed both from the top down and from the bottom up; however, the latter is incomplete because the national level lacks co-ordination. Regarding process execution, this case study reveals that 58.3% of the responsible persons at the CABs had never participated in *STYREL* before, while 25% had participated once, and 16.7% had taken part twice. The evident lack of knowledge is likely to impact their ability to co-ordinate the proceedings and process information. In addition, between the first and second process iterations, the role of the CABs changed. In the first iteration, the CABs had access to detailed information to participate more actively in assessing and balancing the priorities of the critical infrastructure assets at the county level. In the second, the CABs received limited information to compile the results from the municipalities. As this case study highlights, this change influences the SoS and the relevance of the planning results for CIP.

Such blind spots in the design, execution and evolvement of the Swedish multi-level planning system are the subject of the partial study in PAPER IV. In particular, interactions between the key actors are the focus. Missing feedback, collaboration and knowledge are reoccurring issues, among others, which relate to staff changes at the actors. For example, slightly more than 40% of the officials at the municipalities and the PGOs who participated in the survey had no experience with *STYREL*. Since the reference process only poorly specifies concrete proceedings, many actors found themselves in a situation of conflict to serve the purposes of two or more SoS to which they belonged. At the level of an individual decision-maker who acts on behalf of the key actors in the SoS, this conflict led to adaption, which reflects resignation, fading commitment or learning from hearsay. As such adaptions cumulate over time, the Swedish SoS that identifies and prioritises critical infrastructure is likely to present an emergent behaviour during the next iteration of *STYREL*. Effects can emerge as, for example, changes in participation of the particular actors, the amount of provided information or the dedication of resources. As PAPER IV indicates, contending with the complexity of the SoS and the process creates a substantial level of entropy that compromises the efficiency of the system. In addition, an increase in entropy over time further reduces the effectiveness of the process and the efficacy of its results for CIP.

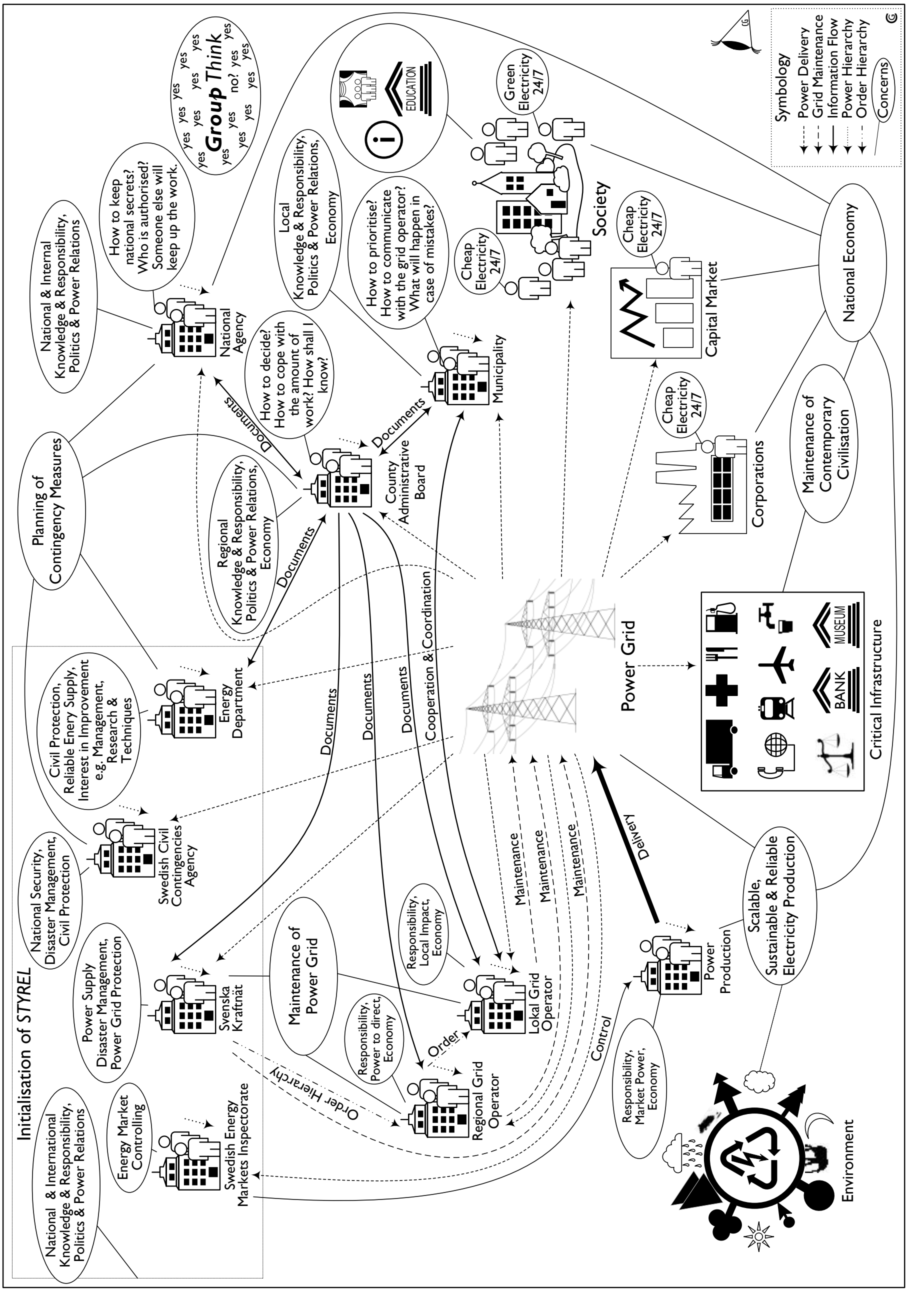

Figure 7: Rich Picture of the System-of-systems Interrelated with *STYREL* (Source: PAPER II)

4.3.2 Critical Infrastructure Protection with the Aid of *STYREL*

One objective of *STYREL* is to 'alleviate consequences for society that emerge when manual load shedding must be executed' (EA 2014c:7). Another objective of the planning process is to achieve a plan that 'PGOs can use as basis for their response planning' (EA 2014c:25). The EA website communicates a third objective: 'to prepare data to be able to prioritise societal important power consumers in the case of manual load shedding' (EA 2014d). These objectives convey the intended use of the *STYREL* plan as a means for subsequent planning for CIP, including both the Swedish crisis management system, which addresses the consequences of disturbances in societal functions, and the electrical power system, which is of vital importance for other critical infrastructure. While the former usage is not clearly defined, the maintenance of power grid stability is at the forefront of the Swedish approach. The official handbook mentions this utilisation of the results for the planning of load shedding as a final step in *STYREL* (see PAPER IV). However, the case study demonstrates that the PGOs instead viewed this step as a subsequent planning that involves the results of *STYREL* where it appears possible. A similar view emerged regarding the effectuation of the results of both plantings during a power shortage or outage.

Since CIP for the power supply is the central concern of *STYREL*, the PGOs are main users of the results. At the next level of planning concerning measures for ensuring stability of the power transmission system, all PGOs are legally obligated to use the allocated ranking lists to plan their response in the event of a power shortage. Whereas the national PGO only stores this information, planning for load shedding at the local level allows for maximum adherence to the ranking list of *STYREL* during an emergency.

As mentioned, the Swedish power grid must manage the grid frequency to prevent blackouts (see e.g. Bömer et al. 2011). When the frequency is low, and no reserve can be activated or imported, load shedding is a measure to stabilise the power grid. The planning for load shedding is twofold.

The first part concerns a plan for manual disconnection of demanded power. In Sweden, all PGOs are legally obligated to independently perform this planning, which must permit each operator to disconnect at least 50% of the actual load. Since the current load can vary considerably during a particular period based on, for example, the season, weather conditions or time of day, the planning of PGOs departs from the maximum load that occurred in the last year. The resulting plan for disconnecting power consumption involves the results of *STYREL* to ensure that critical infrastructure receives electricity that is as undisturbed as possible.

The second part addresses a plan for automatic disconnection of demand. This planning, which only PGOs that are directly connected to the national grid must perform in the southern part of Sweden, considers at least 30% of the actual load for sites in the southern part of Sweden, while the manual and automatic disconnection schemes may overlap by only one-fifth. The latter planning also involves larger boilers and heating pumps, which is similar to that of continental Europe. (SvK 2012)

Manual load shedding occurs in situations in which the electricity demand slowly increases until the production and transmission are finally unable to fulfil the demand. In contrast, automatic load shedding takes place mainly in situations in which a sudden imbalance emerges due to, for example, a failure in a power plant. In general, the PGOs strive to plan for such measures with minimal negative societal consequences. However, the study of *STYREL* reveals several obstacles for the PGOs with regard to the usage of the received information, such as the completeness and level of detail in the documents and insufficient knowledge of the planning for load shedding at other PGOs.

The first obstacle concerns the completeness of the critical infrastructure ranking. During the third step of the *STYREL* process at the local level, PGOs receive detailed information about the identified critical consumers. As described in PAPER IV, municipalities maintain closer interaction with smaller, locally based PGOs than with larger providers who operate many local grids. In some cases, the representative of a locally based PGO was completely involved in the identification and prioritisation of critical infrastructure, which may influence the completeness and usability of the process outcomes. In contrast, the three larger PGOs operate local grids in up to 120 municipalities. The sheer amount of data that these companies had to process pose an obstacle to closer collaboration. In addition, the recent *STYREL* planning hardly involved larger parts of civic society and neither non-governmental nor private organisations. This case study reveals that such proceeding stipulates a workload that surpassed the capabilities of the municipalities. This absence implies that the majority of privately operated critical infrastructure is not represented in the plan that the PGOs applied in their planning of load shedding.

The second obstacle relates to the level of detail in the received documents. During the execution of *STYREL*, the PGOs receive detailed information about the critical infrastructure assets and provide information about the relation of critical infrastructure assets to power lines. However, in the final ranking of power lines that the PGOs ultimately receives, the asset information is omitted. The ranking thus contains a level of specificity that precludes a detailed assessment. A consequence is that the PGOs have difficulties finding appropriate non-prioritised power lines to install automatic load shedding without affecting critical infrastructure. In addition, the power grid is constantly under development to not only adapt to a growing demand for electricity but also maintain the physical transmission system. Therefore, changes in the grid's structure can cause the power supply to a particular power consumer to be realised via another power line than was assigned to this consumer during step three of *STYREL*. Because of such changes over time and the lack of detail in the final documents, the PGOs cannot assure the intended implementation in the regular planning of load shedding, especially between iterations of the *STYREL* process.

The third obstacle relates to the absence of knowledge of the load-shedding plans at other PGOs. The poor alignment of these plans implies that the PGOs can handle their own grids but otherwise have no knowledge of the consequences of their measures for sub-grids. This obstacle can hamper the fulfilment of the planning of load shedding, as PAPER IV discusses in more depth, and it is likely to have an impact on critical infrastructure at the local level in the case of a power shortage.

These three obstacles exemplify the interdependencies between the system of *STYREL*, its reference process, the decision-making in its execution, the subsequent implementation of results in further planning and the effects for critical infrastructure during effectuation in a crisis situation.

When a power shortage occurs, the national PGO is primarily responsible for manual load shedding in Sweden. Apart from the national PGO, nine out of all PGOs in Sweden are delegated certain responsibilities during the initial phase of managing power supply disturbances. These PGOs maintain preconditions that allow them at any time—by order of the national PGO—to reduce the power consumption in accordance with a demanded volume. This consumption reduction shall be effectuated within 15 minutes of receiving the order (EA 2012a; Veibäck et al. 2013), and it should adhere to the prioritisation of the *STYREL* process as much as possible. PAPER IV reveals several difficulties due to the brevity of this period. For example, severe circumstances can force regional PGOs to reduce the demand at the regional level without knowing which critical infrastructure such cut will affect. *STYREL* intends to mitigate this problem, but very few PGOs are currently able to effectuate manual load shedding at the local level within this time frame. The mentioned absence of alignment during the planning of load shedding between regional and local PGOs still hampers a more precise effectuation.

Even in cases in which these PGOs are able to effectuate a manual load shedding while fully complying with the received *STYREL* plans, the lack of details in these documents in combination with the grid development over time endangers the reliable power supply to societally important consumers. Since the PGOs have no means of tracing such changes in advance, the consequences are first observable during emergencies, such as that of a national power shortage.

Another fact aggravates the risk and reduces *STYREL*'s efficacy: not all affected stakeholders are included in the process (e.g. the private sector is not meaningfully involved, and the civic society is practically unrepresented). On the one hand, this exclusion implies that a considerable portion of privately operated infrastructure can be affected. *STYREL* fails to analyse the consequences of such outages, which demonstrate the conflicts of the system with the intended objectives. On the other hand, it can further indicate that a substantial part of the society may experience a blackout without appropriate preparation, which requires further consideration by the crisis management system.

However, this case study evidences that a majority of the public actors treat *STYREL* largely separately for several reasons. One issue that recurred during several studies on the Swedish case is the lack of feedback. For example, municipalities emphasised that they require more feedback during and after the process to successfully integrate *STYREL* into local risk assessments and emergency response planning. The CABs noted that the removal of information during the process rendered it impossible for them to evaluate the received documents and the extent to which initial preferences for national or regional critical infrastructure were preserved during the planning. This information scarcity hampers the integration of *STYREL* into other efforts of CIP and crisis management. Since the process sequentially removes information, the PGOs receive a plan that significantly restricts their ability to ensure a power supply to societally important power consumers during disturbances. Moreover, the only situation in which adherence to *STYREL* is legally obliged is when the national PGO identifies a national power shortage situation and decides that a co-ordinated manual load shedding must be effectuated. This limited focus is likely to impact the implementation of the *STYREL* results in other situations, for example during restoration after a major blackout or for the planning of regular power grid maintenance.

Although this case study indicates side effects for local risk assessments, CIP and crisis management, tracing the potential of *STYREL* for CIP illuminates conflicts with the objectives, as stated at the beginning of this section. Although the level of fulfilment remains questionable, the approach mostly contributes to the second objective. The first is not evaluable in the current setting; it signifies a general vision for CIP as opposed to an objective for *STYREL*. The third is hardly possible to fulfil in view of the changes to information proceedings between the first and second iterations.

4.3.3 Governance of *STYREL* in the Context of Swedish CIP

The Swedish government entrusted the EA with establishing emergency response to ensure the power supply. After a pre-study (EA 2004), the *STYREL* approach began development in 2004. A pilot was carried out in 2009, and the first national execution in 2010/2011 completed its implementation (EA 2012a). Since the planning stipulates new iterations at four-year intervals, the second execution of the process was performed in 2014/2015. The schedule for the third iteration collided with elections and other tasks at the municipalities, such as risk and vulnerability analyses, so this iteration was postponed for one year, and the timeframe of the process was extended. It was intended to run between 2019 and 2021. Due to the ongoing SARS-CoV-2 pandemic, the process is now adjourned for one year (EA 2020).

Against the background of national regulations, the EA possesses overall responsibility for the governance of *STYREL*, including its process, results and development. However, the approach delegates responsibility among the actors of the SoS, as apparent from the national regulation and Table 10. During the multi-agency process, the EA provides the following support:

- A handbook that describes the national policy for the approach;
- A user guideline that dictates the main functions of the planning spreadsheets and which actor should fill in which kind of data;
- Preparatory meetings with general information for key actors;
- Short movies that exemplify the usage of the spreadsheets.

Apart from these contributions in the initial phase of the process iteration, the EA performs neither system or process management and leadership activities nor co-ordination at the national level of the process.

As PAPERS III and IV clarify in more detail, the CABs are responsible for co-ordinating work with the system at the regional level. This role of the CABs proceeds alongside the major part of the planning process until the distribution of the results to the PGOs. Each CAB is expected to guide and mediate *STYREL* among the municipalities, though the policy allows each CAB to determine the actual structure and organisation of the regional proceedings. As mentioned, more than half of the responsible persons at the CABs have not previously participated in *STYREL*, which suggests that knowledge within the system is stunted and that the CABs struggle within this role. Criticism focused on the design of the reference process and process execution as well as on the limits to the usefulness of the resulting plans. During the case study, the evidence from the empirical investigation was dominated by several issues, such as an absence of feedback, the interpretation and application of the classification scheme in Table 11, the extent and quality of the resulting plan, the handling of information during the process and a feeling of insufficient support during and between the planning iterations. Although the EA encourages municipalities to anchor the process at the top-level management, officials at municipalities reported difficulties with local governance of the process. Similarly to the CABs at the regional level, the municipalities must adapt the general policy to the local conditions to create a local setting and establish sufficient information paths. The *STYREL* handbook recommends involving private organisations, as these organisations operate a substantial part of critical infrastructure; however, the concrete proceedings are otherwise left to each public actor. As the interviewees reported, dedicated resources and geographical conditions are examples of the constraints that affected the concrete form of this time-consuming process. In consequence, many municipalities were challenged by the involvement of the private sector as well as the integration of *STYREL* into other local crisis preparation. In addition, the classification scheme was subject to extensive discussion and diverse interpretations and adaptions. For example, some actors developed their own lists of critical infrastructure assets that fit into each class or applied further sub-criteria, such as the turnover and number of employees of a classified operator of critical infrastructure or risk-enhancing geographical issues.

This case study demonstrates that the main role of PGOs is that of an information provider in *STYREL*. In this role, many of them perceived drastic differences among municipalities regarding the identification and prioritisation of critical infrastructure. This experience in combination with the information scarcity in the final documents affected the application of the resulting plan. Although the regional PGOs have established contacts with their subcontractors in regard to the power supply, the planning for load shedding and grid maintenance is performed by each PGO independently. As PAPER IV presents, each PGO is legally obligated to plan for load shedding and to inform the national PGO and related CABs when it is due. However, the study findings reflect both a low rate of ready messages and poor alignment of the subsequent planning for load shedding.

In general, *STYREL* lacks proper a means of assessing and comparing processed information, which in turn hampers future improvement. The perceived lack of feedback in combination with staff turnover during and between this large-scale and long-term planning aggravates the problem and causes adaption, emergence and entropy in the multi-level SoS. Moreover, the absence of criteria for assessment, selection, success, quality, information security and performance complicates the evaluation of the entire process and its results. Although the few evaluations of the process development have already emphasised some of these issues, only slight changes have been made to the following policies. In addition, documentation of this improvement process or evaluations of the second round is absent, which suggests that such documents either do not exist, are classified or have not had their information released by the owner. None of the co-ordinating organisations or any central instance collects any documentation or evaluation from the participating actors. The regulation explicitly refers to the EA, the MSB and the national PGO as key actors that are responsible for further development of the Swedish approach. However, the highly limited dedication of resources, the staff turnover and the weak system design also challenge the national actors. These issues obstruct not only improvements at the national level of the decision-making process but also further development of the reference process and the alignment of strategic objectives among the actors in society.

Today, the approach is not well-integrated; therefore, many of the key actors regret the absence of a holistic, integrated view of *STYREL* and envision that integration and transition of the planning process is a crucial pay-off to the Swedish crisis management system at subsequent planning levels, such as those for preparedness and contingency planning. PAPER II contributes a system model and indicates starting points for enhanced system monitoring and process development. In addition, PAPERS III and IV provide detailed knowledge of the various challenges for governance during the previous proceedings of *STYREL* and the consequences for CIP.

The findings from studying the Swedish case highlight the need for thorough consideration of the various interests that are involved in such a complex system of national multi-level planning. Therefore, PAPER V provides a model for analysing strategic objectives in such SoS. The novel approach offers a context for constructive dialogue about strategic objectives, reachable goals and appropriate means. This approach enables the involvement of both key actors who are involved in such system and the stakeholders it affects. The approach departs from an analysis of the systemic conditions, which can enhance the understanding of the need for a structured dialogue in complex systems. One example regards decision aid for decision-makers in identifying infrastructure assets and assessing their criticality in accordance with common understandings. In PART B, the analysis highlights ambiguity in several steps of the process; for example, the designation of information paths, expected efforts and responsibilities remains unclear. The results indicate that different interpretations of vague descriptions and implicit objectives prompt different proceedings. Thus, uncovering tacit content and its significance can assist with converting objectives, which can in turn facilitate the development of the SoS. Because of the number of actors and stakeholders in the Swedish CIP, strategic objectives are numerous, highly diverse and will occur simultaneously. Besides exploring the system conditions and strategic objectives, the model encourages a thorough analysis of the challenges for governance that emerge from the bundles of strategic objectives and their influence on governance activities as well as further adaption of the SoS.

Departing from objectives and strategies, PAPER VI proposes a multi-level system of national emergency response planning (NERP) in general and identifies the position of *STYREL* in Swedish CIP and crisis management in particular, as Figure 8 presents. The recursive concept of multi-level planning applies three hierarchical levels: planning in a narrower sense, planning in a broader sense and utilisation of the planning results. This structure is applicable to both the entire planning for CIP from an aggregated perspective and each hierarchical level within a decomposed multi-level-planning (MLP), such as the Swedish *STYREL* approach.

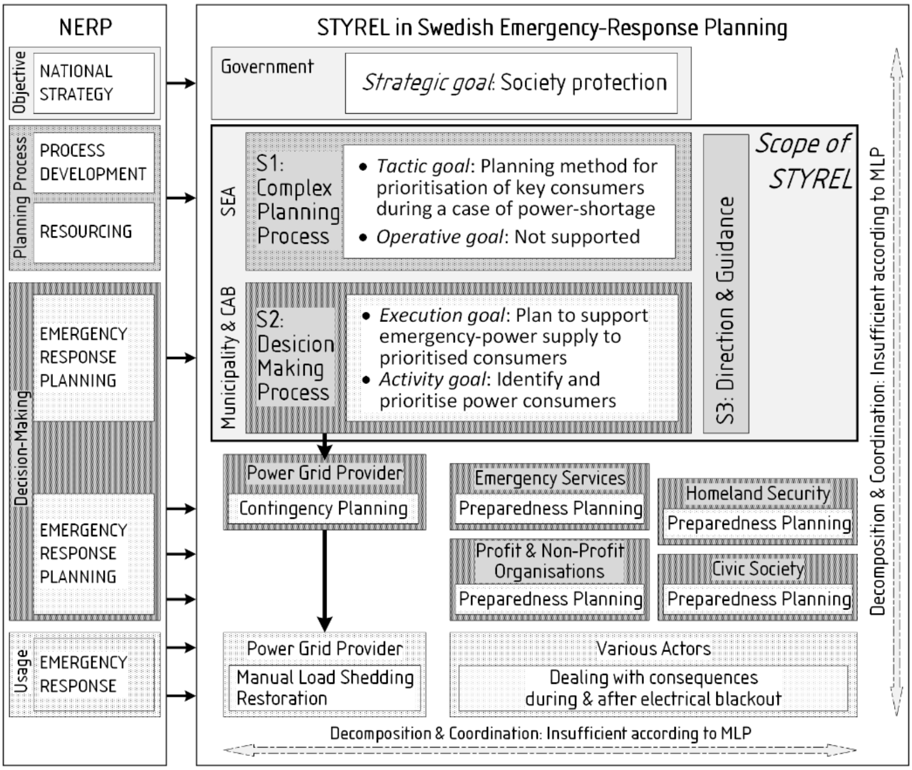

Figure 8: The Position of *STYREL* in National Emergency Response Planning (Source: PAPER VI)

Furthermore, PAPER VI refines several parameters and influencing factors that associated governance efforts need to address. The case of *STYREL* helps to specify sources of uncertainty in SoS due to a lack of knowledge, the characteristics of a decision-maker and the surrounding work environment.

4.4 Implications for Swedish CIP

This case study has explored and decomposed the SoS that surrounds and executes *STYREL* in Sweden. The inquiry clarifies the system as well as the anchorage of the planning process in local society through the request of local knowledge. Although this approach is intended to be enclosing and participative, the results indicate that the planning procedure only partly extends to society. In addition, the resulting plan is formally used only to serve PGOs during an especially limited situation. Therefore, the process cannot be considered fully developed. Instead, the procedure appears to be a well-established starting point for a more far-reaching approach that would include operators of critical infrastructure and various societal stakeholders that contend with the consequences of emergencies.

This study assists with a conceptual system model (see PAPER II) to identify relevant stakeholders. Such a proceeding can also facilitate analysis of risks and consequences that a critical event can pose to particular groups, which could in turn inform appropriate preparation of a target-oriented response. The CAB is prominent as one key actor with a central role in the Swedish SoS. However, the findings reflect that this regional level lacks awareness of its function as a core player in the Swedish approach. In addition, the regional hub does not possess the knowledge or resources to adequately fulfil its dedicated function in the national planning for protecting critical infrastructure from the consequences of power supply disturbances. The analyses conclude that the results of the *STYREL* process rely on the commitment of the CABs to achieve a common understanding of the criticality of infrastructure and for mediating collaboration in their geographical area of responsibility (see PAPER III). The level of trust between the different actors as components in the Swedish SoS for CIP seems likely to further influence the resulting emergency response plan.

This study of the *STYREL* case also signifies the chain of policy, interaction and learning between the public and private actors, such as national agencies, CABs, municipalities and PGOs, alongside the planning process. The current approach causes blind spots to emerge in the form of, for example, vague instructions, a reference process model with poor specification of concrete proceedings, insufficient feedback and knowledge management, staff changes during and between process iterations, and weak collaboration. Such circumstances introduce additional uncertainties due to a lack of knowledge of CIP that includes poor awareness of activities, differences in interpretations of the criticality of infrastructure and varying maturity of the activities of actors. Such flaws intensified individual prejudices rather than alleviating them, which led to extensive variation in levels of mutual trust and respect between actors. The consequent increasing entropy in combination with a growing system of critical infrastructure necessitates appropriate governance, management and leadership efforts to channel the dynamism of this SoS. Moreover, the findings indicate that the Swedish planning system is likely to present an emergent behaviour during the next iteration of *STYREL* in view of the diversity of perceptions of strategic objectives, motives and experiences. According to this study, addressing learning and subsequently transforming the experience in future behaviour appears to be a significant task for governance. Otherwise, the shared reality based on experiences of other group members could profoundly influence individual judgements and thereby lead to undesired adaption. Moreover, the planners' perceptions of the significance of the process, the likelihood of a power shortage situation and the crisis management capability of a county may impact the effectiveness of the complex multi-level planning system during a crisis. The results suggest the establishment of a consistent overall system framework in terms of scope, level of granularity and participation, and particular parameters, such as selection criteria and success factors. Moreover, further development of *STYREL* must consider stronger integration into the larger CIP context to facilitate more extensive usage of planning results in other interrelated public-private collaborations. In particular, there is a need to prioritise the formation and maintenance of relevant information channels between the actors who participate in a planning process for CIP, such as *STYREL*, and those who this process affects (see PAPER IV).

As the case study has indicated, the Swedish approach does not yet comprehensively include all strategic objectives which the systemic parameters of the SoS pose for CIP; therefore, more effort is needed to identify hidden stakeholders and objectives. Additionally, the findings evidence that the analysis of these objectives is also incomplete. Although certain actors follow an internal logic, systemic governance appears to be underdeveloped with regard to management of the complexity, ambiguity and uncertainty that are involved in the approach. The proposed context for analysing strategic objectives (see PAPER V) can assist governance efforts through the continuous process of identifying strategic objectives, analysing their properties and determining the direction of activities. In addition to dissolving identical objectives and eliminating antinomic strategic objectives, this measure also requires close consideration of the challenges which result from bundles of strategic objectives and may pose consequences for Swedish society in an urban context, under rural circumstances or in both situations.

Moreover, the framework for analysing the multi-agency, multi-level planning (see PAPER VI) specifies sources of uncertainty by various parameters that reveal a need for knowledge that is associated with the process, the decision-makers and other stakeholders. Thereby, this case study provides another valuable tool for nuancing the approach and addressing the particular issues seriatim. The development of more breadth and depth will position *STYREL* as a strong planning approach that imparts value to both public crisis management, PGOs and national society. The presented models visualise the current situation and surroundings of *STYREL* and can accordingly be used to explore information pathways to identify critical interrelations and responsibilities between concerned actors. Evidence from this study indicates, for example, that informal information paths may exist between local planners and emergency services which support local preparedness planning. Such experiences from local instantiations can highlight the shortcomings of the procedure and the creativity of local planners to add value to their local community. Such insights also support a formal refinement of *STYREL*. The study results provide visualisation and structure for this refinement to horizontally and vertically explore the complex planning environment in terms of policy development, process management, structural organisation and other aspects. This contribution may in turn support the invention and alignment of strategic objectives and responsibilities as well as the concretisation of measures for information security in the complex system of planning for CIP. Moreover, clearance in horizontal and vertical structures could reduce knowledge gaps (see PAPER VI).

Further development could clarify the activities and responsibilities within the SoS as well as improve resource allocation at the local, regional and national levels. The insights from this case study uncover the complex and quickly changing environment of national planning for emergency response for the case of a power shortage. The findings testify that systemic governance of the SoS for CIP is necessary to integrate the maintenance of the SoS, the co-ordinated management of the *STYREL* reference process and its execution and the development of adequate leadership efforts alongside the former two, including regular adaption of the SoS to changing requirements and demands. The conceptual system model represents the complex planning environment, as limited to the *STYREL* context, from an overall perspective. This entry point to the SoS encourages in-depth analyses of certain parts while maintaining a holistic perspective, and it offers information about the development of *STYREL* and the related means for emergency response. Evidence from the empirical inquiry into the Swedish case can direct such governance efforts since the experienced conditions of the current setting indicate areas for improvement, such as collaboration within and between organisations, interaction and communication alongside the planning, and comprehension of the possible situations which the planning targets. Hence, the insights that were obtained through this inquiry inform significant perspectives of the complex system for protecting society from the negative effects of a power shortage to critical infrastructure. This knowledge can support systemic governance to enhance a shared understanding of the planning context among stakeholders who are involved in and affected by *STYREL*.

In view of the discussion above, such governance efforts in the context of the *STYREL* case are encouraged to address the following.

- Raising awareness of the complexity of the SoS
- Assessment of key actors and their roles, responsibilities and accountability
- Identification and analysis of the interdependencies and structures for tasks, processes and organisation
- Establishment and maintenance of a consistent overall system framework in terms of scope, level of granularity and participation
- Identification of strategic objectives and hidden perceptions in the SoS
- Assessment of strategic objectives in terms of relevance and feasibility
- Involvement of further societal actors and co-ordination of all actors
- Risk and consequence analysis (also further emergency power supply)
- Prioritisation and integration of objectives, goals and means
- Communication and control of preferred strategic objectives
- Visualisation of structures, interrelations and individual conditions
- Alignment of responsibilities and information security measures
- Development of the reference process and resource allocation
- Development of the decision-making processes
- Assessment of the suitable granularity of the processed information, the adequacy of access rights and the appropriate information paths
- Collect and provide learning cases of good practices and pitfalls
- Collective learning: training, feedback and knowledge exchange
- Establishment of particular parameters to enable regular evaluation of particular aspects, such as selection criteria and success factors
- Transition of the *STYREL* planning results to next-level planning
- Integration of *STYREL* into the Swedish crisis management system
- Alignment with preceding analyses and subsequent planning, such as risk and vulnerability analyses and contingency planning
- Enhancing mutual trust, respect and understanding between actors
- Development of policies, process management and system leadership

4.5 Summary

PART B has pursued the first research question and presented the SoS for CIP in Swedish practice in detail. Furthermore, it has demonstrated that the Swedish approach encounters several challenges. Evidence from public policies, interviews and a survey with actors from both public and private organisations highlights issues in the design, execution and evolvement of the Swedish multi-level planning for CIP. *STYREL* has been executed in full scale in Sweden on two occasions and can therefore be viewed as implemented. The approach engages a large number of actors, such as all municipalities, CABs and PGOs as well as national agencies, to perform identification and prioritisation of electricity-dependent critical infrastructure, which subsequently constitutes the foundation on which PGOs can plan for and ultimately execute load shedding in the event of a power shortage. One of the challenges that this study of the Swedish case has discovered is the difficulty of estimating the intended benefit for the actors in the SoS that perform the planning and the society that *STYREL* affects. Examples of the reasons for this difficulty include the following:

- A lack of knowledge about the specific needs of the constituting systems, the individuals who are entrusted with decision-making, the infrastructure that the protection concerns and the society that it serves;
- The absence of consequence analyses, including relevant measures, to evaluate the impact of the decisions that are made in each process step;
- Weak integration into crisis management for further usage of the collected information about the infrastructure and the ultimately produced plan

A second challenge is to coalesce forces in and around the SoS for CIP to maintain societal security and provide a basis for sustainable development. In the current approach, a subsequent actor in the process must rely on the expertise and dedication of the preceding actor. For example, CABs depend on the commitment of the municipalities and their assessment of infrastructure; likewise, PGOs rely on the commitment of both and their understanding of the importance of infrastructure assets and proper collaboration. Moreover, the actors lack measures to evaluate the quality of information that the system processes. Information flaws and impersonal interactions intensified individual prejudices rather than alleviating them, which also reflects the variation in understandings and lack of consensus within the SoS.

This study of the Swedish case emphasises that the immense scope and dynamics of the complex system of CIP involve many aspects that are ambiguous and uncertain. In view of this, there is a need for the development of appropriate systemic governance that integrates policy, management and leadership efforts to channel the dynamism of the complex system of CIP.

5

Part C – Synthesis: Systemic Governance of CIP

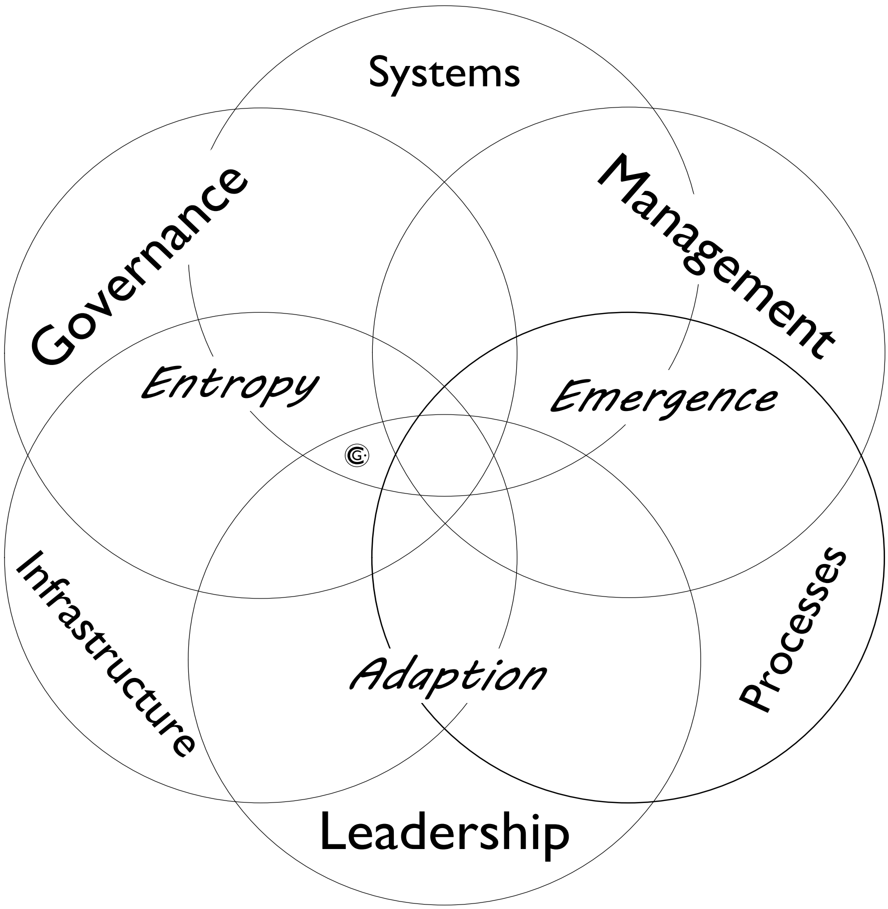

Figure 9: The Concept of Systemic Governance

5.1 Introduction

The concept of governance describes how a society is organised and governed and who is involved in dialogue, participation and networking. Thus, governance constitutes a multi-faceted, multi-layered and recursive concept that is similar to those of systems and infrastructure, as PART A has extensively discussed.

This chapter synthesises the theoretical concepts from PART A with the practical experiences in PART B alongside several perspectives, interactions and boundaries that emerged during this study. The theory-building process in PART C addresses the second research question:

What are the fundamentals for understanding the state and the relevance of critical infrastructure protection governance?

The objective of the chapter is twofold. First, it seeks to provide an integrated notion of critical infrastructure that emphasises its character as a multi-level system and considers properties that relate to this character and its protection. Second, it aims to deliver a novel worldview of systemic governance of CIP.

The research that explores the above question includes the findings of the literature review on systems, infrastructure and governance and the study of the Swedish case for CIP. Moreover, the synthesis adheres to the underlying tripartite structure and revolves around multiple perspectives, certain interactions or interdependency, and particular boundaries.

The following two sections synthesise concepts and practices of CIP against the Swedish background. The first section focuses on the trinity of systems, processes and control; thereby, it contributes to an elaborated understanding of the multi-level structure of critical infrastructure and the interdependent society. The second section concentrates on three properties—namely adaption, emergence and entropy—that warrant proper consideration in CIP. This section imparts further knowledge by demonstrating the connection of the theoretical concepts to perceptions and statements in the Swedish practice.

The subsequent section departs from the presented findings to synthesise the multitude of findings and knowledge. Ultimately, the third section proposes the concept of systemic governance of CIP that is condensed in Figure 9. In particular, it outlines the nexus of governance, management and leadership that is vital to ensuring accountability and integrity of the SoS for CIP alongside the processes, hierarchies and dynamics of this complex system.

The final section of this chapter summarises key insights from the synthesis that elevate the empirical findings from the Swedish case to theory development on systemic governance for CIP. As the inductive part of this thesis, PART C completes the research circle of the dissertation.

5.2 Critical Infrastructure – The Trinity of Systems, Processes and Control

The analyses of the definitions of critical infrastructure and the practical evidence in this thesis reveal its multi-level character. On the one hand, infrastructure is perceived as always-existing, long-lasting and fixed common goods. On the other hand, it is considered an operative process that, through control of the former, provides essential goods and services for public well-being. In addition, infrastructure involves several types of control, such as for the maintenance of the fixed structures, the monitoring of the operative process or even the strategic development of both.

In accordance with this multi-level character, several issues emerged from the case study. Such issues include differences in time horizons, stakeholders and objectives at the various levels, and a lack of alignment among them.

Considering the time horizon, fixed-installed infrastructure provides a long service life. For example, the expected lifespan of electrical components is at least 50 years, which implies that maintenance and regular replacement can be postponed when the operative business takes precedence. The national grid in Sweden is one example: more than 800 km of the high-voltage transmission system is older than 70 years at present and will be over 80 years old at the time of its planned replacement (SvK 2017a). This issue relates to not only the age of the components but also the differences in needs that the grid served between the 1940s and 1950s and the presently developed society, which include a heightened demand due to digitalisation and electrified mobility. In contrast, the operative process that provides essential goods and services has a considerably shorter time horizon. In addition, business accelerates and shifts from annual to quarterly and daily figures, and it focuses on real-time monitoring and reduction of redundancies to increase effectiveness. The process of electricity transmission, for example, is particularly time-critical because the PGOs need to balance production and consumption of power at all times to ensure an undisturbed supply of electricity, for which availability and demand determine the market price. Consequently, the control activities in the multi-level system of critical infrastructure regard both the long-term aspects of the underlying infrastructure and the short-term demands of the critical process. Nevertheless, several risks can relate to the time horizon of this level, such as changes to the political landscape and regulation, the ownership of critical infrastructure or the societal needs that the infrastructure serves.

In association with stakeholders, three key groups can be characterised in the context of critical infrastructure. The first group is responsible for critical infrastructure and includes all actors that are responsible for both the underlying physical structures and the related processes upon these structures to finally provide the critical service to society. Since strategic decision-making about public infrastructure, such as the power grid, is mainly a responsibility of public authorities, this group also encompasses governmental actors that exercise public will. In the context of this study, Table 10 describes some of the stakeholders who belong to this group (e.g. the PGOs at the local, regional and national levels, the EA, the Swedish Energy Market Inspectorate and other national agencies). The second stakeholder group is responsible for public crisis preparedness and management. In this case study, municipalities, CABs and the MSB mainly represent this group at the local, regional and national levels, respectively. In the context of the power supply in Sweden, the PGOs are legally obliged to prepare a plan for load shedding. In such understanding, the PGOs are also part of this stakeholder group. However, only 10 PGOs meet the technical requirements to ensure crisis management at any time, which weakens the role of PGOs as actors in public crisis management. Similarly to the first group, the second group involves national authorities and expressions of public will even though the findings of this case study indicate weak integration of *STYREL* into Swedish emergency response planning and crisis management. Other studies in the Swedish context have further substantiated the view that weak governance and a lack of continuity characterise Swedish crisis management (e.g. Olausson, Nyhlén 2017; Wimelius, Engberg 2015). Although this case study of *STYREL* reveals that the execution of the planning process has rarely involved civic society and non-governmental or private organisations, they may nevertheless have a role in crisis management (Nohrstedt et al. 2018). These stakeholders represent the third group, which is comprised of all consumers of critical services (e.g. the power supply), including other critical infrastructure, public operations, private businesses, households and individuals. Apart from the underrepresentation of end consumers in the policy-making process, the decisions of the former two groups affect the stakeholders of this third group. In addition, stakeholders of the former two groups expect those of the third to be prepared; however, experiences from local power outages in the aftermath of two storms in Sweden evidence that the consumers did not recognise such responsibility to establish preparedness (Heidenstrøm, Kvarnlöf 2018; Palm 2009).

Regarding strategic objectives, this study of the Swedish case has uncovered the need for a structured dialogue about strategic objectives within the complex system that targets CIP. Some examples from *STYREL* can illustrate the issue. First, the physical infrastructure of the power grid is permanently under development to meet the increasing demand for electricity, which accompanies, for example, the growing digitalisation of society or electrification of transportation. However, such dynamic development is overlooked in the Swedish planning process for CIP. Second, the critical service process (i.e. supply power to society) relies on a proper balance between production and consumption. Yet, neither production nor consumption is appropriately considered during the planning for CIP, which merely targets the case of a power shortage that requires manual load shedding to stabilise the transmission process. Balancing the power grid during a power shortage does not primarily require a ranking of critical infrastructure. Otherwise, if the objective (i.e. the protection of society) is involved in the decision-making, such ranking can help to reduce the impact of power disturbances on society. Unfortunately, the current process cannot ensure adherence to this objective because PGOs do not receive adequate information. Considering the mentioned second stakeholder group in turn, the lack of feedback in the long-term planning process hampers the improvement of measures for societal security and crisis management. In addition, the reference process cannot assure that the final ranking properly represents critical infrastructure of national or regional importance because of difficulties in information sharing and collaboration among the actors. In the Swedish case, the management of information security is left to each actor without any specification. This proceeding causes barriers to co-operation and further usage of planning results among the actors due to the sensitivity of information about critical infrastructure and vulnerable consumers in society. The ambiguity of objectives within the SoS also challenges Swedish CIP and illustrates the poor representation of governance in the context of *STYREL*.

Moreover, a lack of alignment pervades the Swedish approach. For example, the planning for CIP prescribes neither an over-regional nor a national alignment of critical infrastructure and power lines. In addition, there is no alignment between the PGOs regarding their load shedding plans or between PGOs and municipalities or CABs with respect to results that could facilitate local, regional or national risk and crisis management. Despite these shortcomings in co-ordination and alignment in the Swedish case, the existing system structure can serve as a stable starting point for improving the usefulness and use-worthiness of the planning. Proper consideration of the SoS, the involved critical processes and control activities, and a constructive dialogue regarding the involved interests can facilitate an alignment of goals and means towards a shared understanding among concerned parties.

5.3 System Protection – The Triad of Adaption, Emergence and Entropy

The concepts of adaption, emergence and entropy adhere to the multi-level character of the SoS for CIP since this triad is similarly recursive. In this understanding, adaption occurs at the organism level of the SoS and is experienced as emergence at the organisation level if such level lacks knowledge of the factors that prompted adaption at the sub-level. Moreover, interactions, frictions and interdependencies within the system can increase entropy, which necessitates a compensation from outside the system as well as a steering mechanism to maintain the system's capability to act.

In the Swedish case, adaption occurs through learning from individual experiences. A shared reality is based on experiences of other group members that profoundly influence individual judgements and thereby induce adaption to suit certain circumstances. For example, the lack of dedicated resources among several actors prompted adaption of the activities to local restrictions. One consequence was that many of the individuals had to contend with a multitude of tasks within their parent organisations, which can lead to adapted efforts for the SoS for CIP. In some cases, municipalities engaged retired public officers as consultants to prioritise critical infrastructure and assist in local proceedings to mitigate the knowledge gaps. In a few cases, the obtained knowledge of critical infrastructure entered local crisis management because the security officer was assigned both tasks.

Emergent system behaviour can emerge from such adaption. For instance, the PGOs experienced unexpected errors in the final planning documents even though some of them had been resolved in previous process steps. However, these changes did not survive the information processing through the aid of the different planning documents; instead, these errors seemed to result from time-saving behaviour (i.e. 'copy-and-paste' of local and regional results from the previous planning round). Since the feedback process among the actors is underdeveloped in the reference process, such adaptions cannot be traced, and they consequently appear as emergence in the next level.

The CIP as well as the mitigation of system entropy needs an expression of will (i.e. the SoS of CIP requires proper governance that integrates the strategic, process and individual levels). As this case study has discussed in detail, the Swedish SoS lacks system leadership and process management. Although policies and regulations exist that can represent governance, they are general and vague. Therefore, the local and regional interpretations of unclear and implicit strategic objectives result in different proceedings, including equally ambiguous means and guides for the decision-makers.

5.4 Systemic Governance – The Nexus of Governance, Management and Leadership

The results of the literature review reveal a need for appropriate governance that considers the complexity of critical infrastructure and societal systems (Coaffee, Clarke 2017; Gheorghe 2004). The presented study of the Swedish case of CIP confirms this view. The investigation highlighted several challenges for governance in the context of CIP, such as the following: insufficient knowledge; poor alignment, integration and co-ordination of objectives, processes and activities; an absence of quality and performance indicators; and inadequate information and knowledge transfer. These challenges demonstrate that the current approach of indirect steering through existing networks and vague suggestions in policies is overwhelmed by the complexity of the governed system of CIP.

As indicated, the control system must possess ultimate knowledge of the system to be able to control that system, which implies that the system that governs CIP can be considered at least a similarly complex system (Ashby 1956). Hence, governance of CIP is not a simple concept or task. On the one hand, it involves a considerable number of individuals and technical or parent systems, which encompass a variety of perspectives, in the SoS for CIP. On the other hand, it must account for the often non-linear interrelations among individuals and organisations and the social, political and technical systems that are interconnected. In addition, governance must concern the interaction of the SoS with the system environment, which can, for example, address the needs of civic society or other nations or the mounting threat of climate change or cyber-attacks. Since the scope of this task questions the controllability of such an SoS, systemic governance for CIP should mainly address the decaying forces and channel the dynamism of the complex system of CIP. The central aim is to ensure accountability and integrity of the multi-level system alongside processes, hierarchies and dynamics. Hence, systemic governance should integrate indirect steering through policies with indicator-based process management and direct system leadership that lift qualitative aspects for future integration.

First, indirect steering that is expressed by policies has a central position in public governance and society management, wherein policies support direction and identity for the system components, such as the actors in CIP. Despite tendencies towards liberalisation of the energy market and power supply, the energy sector is one of the critical infrastructure sectors that is strongly regulated by the state. Research has indicated that societal developments necessitate more open access and tariffs (van der Vleuten, Lagendijk 2010a). However, policies and regulations with regard to CIP are ambiguous and vague in Sweden. As this case study demonstrates, the decision-makers experienced insufficient clarity of responsibilities and instructions to properly implement the policy in practice. Moreover, the publicly available policies do not provide stakeholder-dedicated specifications, a clear statement of objectives, goals or means at the local, regional or national levels, or proper suggestions for integration in risk and crisis management. Thus, policies as instrument for indirect steering must regularly evolve, which entails adaption to the demands of the governed SoS and its systems and subsystems. Such policy development should incorporate insights and experiences of the process execution as well as ongoing changes in society.

Second, indicator-based process management could facilitate an evaluation and comparison of approaches not only between similar actors, such as municipalities, but also among different sectors or countries with similar environmental or societal conditions. Some of the recurring issues in the Swedish approach concern the identification, selection and prioritisation of electricity-dependent infrastructure and its critical services. In this context, the officially provided decision aid in Table 11 is insufficient to evaluate the completeness and quality of the results. In addition, it is not applicable to differentiate between several objects of the same type that have different properties or to evaluate the final ranking as well as its consequences for society. The Swedish approach hardly maintained process management at the time of the study. Although the handbook as a policy instrument has been updated with a new schedule for the third iteration, no central management of the current process iteration will occur (cf. EA 2018). The regional level provides some co-ordination in its area of responsibility but rarely processes management; thus, the development of process management should introduce indicators that can facilitate a dialogue among the actors about their results and enable self-evaluation. In addition, the reference process should stipulate regular feedback among the actors to promote collective learning (Ison et al. 2018). However, active process management must accompany the policy-making to monitor the process and encourage co-operation and collaboration. The obtained results from such process monitoring should subsequently inform the improvement of both the policies, including the reference process, and the process management during execution.

Third, direct system leadership is necessary to treat the decaying forces in the SoS for CIP. Since the complexity of such an SoS limits the ability of the control system to govern all possible system states, policies and process management need additional support to channel dynamic changes in the SoS.

Therefore, system leadership should accompany the former two to identify emerging issues, such as those relating to adaption at another level of the system or deriving from societal developments that the process not yet has considered. An additional aim is to handle the ambiguity that is inherent to the complex task of CIP. The main challenge for leadership in SoS is that the actors in the SoS are simultaneously part of another SoS, which involves goal conflicts and differing worldviews. Under such circumstances, system leadership is separated from direct managerial authority and instead assumes the role of an attractor and moderator. One actor, who is the system leader, constitutes a central point of contact in the SoS for individuals and organisations mainly within the SoS for CIP but also for the wider public. One important task is to maintain an overview of the system components and the expertise of the involved individuals and organisations. This case study confirms the finding of previous research that the knowledge that PGOs hold is largely unknown by those who administer crisis management (Seager et al. 2017). Likewise, knowledge of needs and activities for proper public crisis management is limited among PGOs. Thus, linking expertise and moderating dialogue among the actors is imperative to contend with entropy in the SoS. Another task for the system leader is to affect undesired adaption and decreasing commitment, which can cause emergent effects in a crisis. Thus, system leadership includes a moderation of constructive discussions of the process object (i.e. information), the process itself and interpretations of local, regional and national requirements and experiences among the stakeholders. In this way, system leadership completes policies and standards as well as system and process management by providing an interface among stakeholders (cf. Sajeva, Masera 2006).

Thus, systemic governance occupies a significant role in the SoS of CIP in, for example, establishing two-way communication, structured knowledge exchange, process moderation and an enhanced, holistic view of CIP among the various actors. The variety of participation, knowledge and proceedings in the context of CIP in combination with a growing system of critical infrastructure necessitates appropriate systemic governance with policy, management and leadership efforts to channel the dynamism of the system. In that sense, policy appliances must concern strategic objectives that address people, processes and technology to align action(s) that must be performed to reach a preferred future state. Moreover, system management needs to concretise 'what' with the 'how, when and by whom', and system leadership should alleviate uncertainty and ambiguity by discussing reasons and means for moving forward among actors in the SoS while interacting with management and policy developments.

5.5 Summary

PART C has pursued the second research question and synthesised the theoretical concepts and empirical findings into the concept of systemic governance for CIP. Since the concepts of system, infrastructure and governance have been introduced and discussed as recursive concepts in this thesis, systemic governance for CIP has a similarly recursive and tripartite structure.

This chapter recalls critical infrastructure as an SoS that is comprised of long-lasting and partly fixed common goods upon which operative processes provide essential goods and services for public well-being and wherein several types of control aim to ensure perpetual existence and supply. Although infrastructure is perceived as an always-existing common good, its ostensibly permanent functionality is illusory. Instead, systemic governance of CIP is necessary to address the decaying forces at the fixed infrastructure level as well as the process and strategic development levels. In particular, the alignment of time horizons, stakeholder interests and strategic objectives demands consideration in the context of CIP.

Three key properties, namely adaption, emergence and entropy, are tightly intertwined with the multi-level character of the SoS for CIP and the recursive and tripartite structure of its conceptual representation. Adaption occurs at the sub-level of the system but is perceived as emergence by the higher level if the latter level lacks knowledge of the factors that caused the adaption at the former. Interactions, frictions and uncertainties within the system can increase entropy, which necessitates a compensation from outside the system and a steering mechanism to maintain the system's capability to act. The inherent complexity and non-linearity in the context of CIP necessitate a new worldview of system control in the form of systemic governance of CIP.

Therefore, a system perspective of critical infrastructure and governance is integrated into systemic governance of CIP with a tripartite structure. First, the ability to gain an overview of a system enables governance to align visions, strategic objectives and goals to create direction (e.g. through policies) and, thus, to contend with the system's entropy. Second, system and process management effectuate this direction to treat emergence through the integration of systems and processes and the establishment of rule-based, quantitative measures for feedback and self-control. Third, system leadership addresses adaption; therefore, it mitigates ambiguity and uncertainty due to the lack of knowledge that accompanies complexity in CIP. This nexus, which constitutes systemic governance of CIP, aims to ensure accountability and integrity of the system horizontally (alongside processes), vertically (with multi-layered hierarchies) and holistically (accompanying the dynamics of the SoS).

6

Discussion

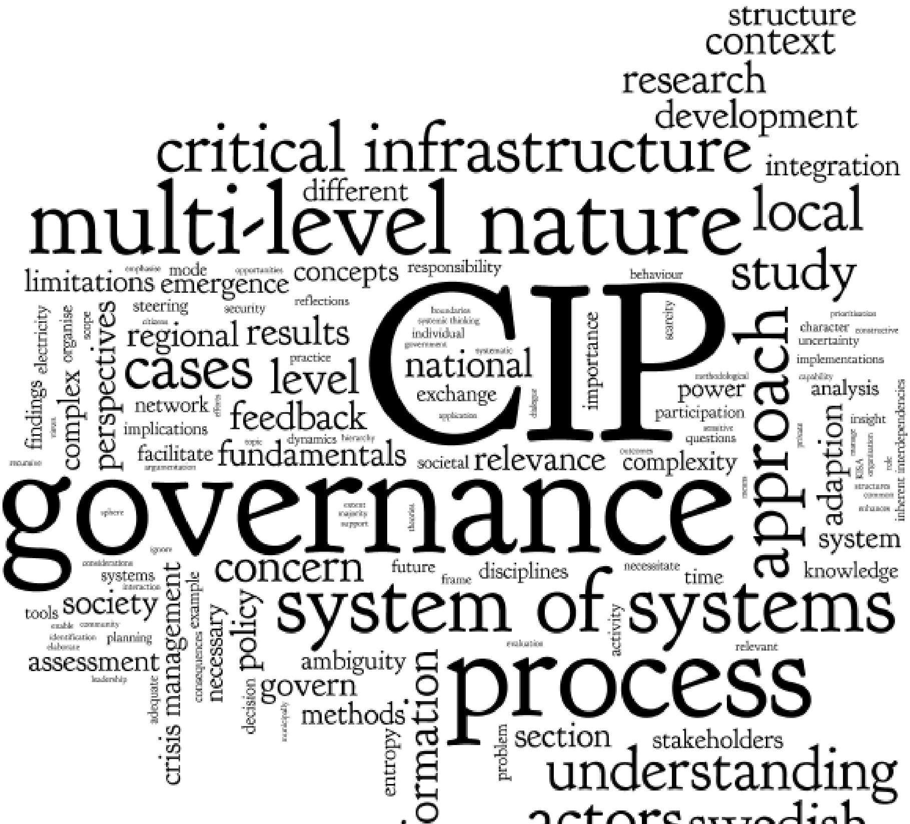

Figure 10: Reflection of CIP and its Governance in Research and Practice

6.1 Introduction

The aim of this chapter is twofold. First, it aggregates the theoretical and empirical findings of this dissertation in accordance with the stated research questions. Second, it addresses a few methodological considerations of the investigation to highlight opportunities for further research.

As Figure 10 symbolises, this chapter reflects on the conducted study and emphasises the academic implications of the study's results as well as their practical relevance in the CIP context. The discussion revolves around perspectives, interactions and boundaries in the context of complex systems, critical infrastructure and governance. The argumentation also situates the major insights of this study within the larger context of risk and crisis management in society.

Section 6.2 discusses the contributions of the case study to an understanding of how CIP is organised and governed in practice. Against the backdrop of the multi-level structure of systems, infrastructure and governance, the section accentuates key findings from the investigation of the Swedish case. It delivers reflections on the relevance of participation with consideration to different levels of concern, proper means of supporting assessments and decisions, and the importance of integration into local, regional and national structures of risk and crisis management.

Section 6.3 shifts the argumentation towards a more general discussion of the thesis topic and reflects on the fundamentals of understanding the state and relevance of CIP governance. This section contributes considerations of the positioning of the topic in society, the infelicitous blending of systems and processes, and the importance of adequate feedback exchange. Thereby, it highlights how systemic thinking can develop an understanding of CIP and its governance.

Section 6.4 completes the methodological reflections of this study and designates some areas for future research. It particularly identifies research directions that use this study as a point of departure to broaden and deepen knowledge and understanding in the context of CIP governance. These prospects implicate several research disciplines within the social, natural and applied sciences to suit the multi-disciplinary nature of CIP.

The final section of this chapter summarises the main points of the discussion and closes the loop of investigation within this dissertation. In addition, it outlines the following chapter, which ultimately completes this thesis.

6.2 Organisation and Governance of CIP

This study has obtained results from a Swedish approach for governing CIP to handle cases of power shortages and their consequences for society. Analyses of documentation on the Swedish case and interviews with participating actors have yielded findings on the complex SoS, its components and their interrelations as they are embedded in certain environments. Thus, the findings offer new insights for improving not only the Swedish system and interrelated processes but also similar complex governance approaches. During the investigation, this study closely adhered to perspectives, interactions and boundaries with regard to the organisation and governance of CIP.

The case study in PART B has decomposed the SoS of CIP that seeks to manage the societal consequences of power shortages in Sweden by identifying and prioritising critical infrastructure. The results reveal several stakeholder groups that such crisis would affect. However, many implementations of the approach ignore the majority of society. On the one hand, many adaptions of the proposed policy-making process almost exclusively consider infrastructure and interrelated services that are municipally operated. Although these assets and services constitute a relevant part of critical infrastructure, this limitation of the approach disregards the mostly privately operated systems and processes that produce and distribute a flow of essential goods and services. In addition, it overlooks the capability and capacity of citizens to cope with power shortages, which leads to misjudgements about their consequences. On the other hand, participation in the policy-making process is similarly incomplete. The process basically involves national, regional and local authorities as decision-makers as well as PGOs as advisers and final receivers of the policy. Although the approach allows for individual settings within each actor’s area of responsibility, this study identified only a few implementations in which further stakeholders were included or the local PGO was part of the entire process. Moreover, only a highly limited group of stakeholders was involved in the creation of the governance approach. The results of this study indicate that even less participation is occurring in further development of the governance approach.

One explanation for these limitations interrelates with the structure of the problem and the solution approach. The results of this study demonstrate that the structure of the approach was challenged by the multi-level character of the problem. For example, the local level was expected to not only assess the local circumstances but also include the regional and national perspectives, which often exceeded local capabilities. Since the approach deliberately limits the information exchange between the local and regional levels, the latter had to contend with an information scarcity that rendered it practically impossible to assess local, regional or national perspectives. Moreover, the implementation underrepresents the national perspective. Although the Swedish approach seems to transform the top-down hierarchy of traditional government into a flexible network structure, it fails to adapt to the multi-level character of the problem. Such character is evident from the multiple levels of the power transmission network and the infrastructure and services, which produce and provide services that may be of interest for not only one local community but also a regional, national or global society. In addition, the Swedish governance approach does not stipulate feedback structures with regard to the results of the identification and prioritisation or further development of the process and the interrelated SoS of CIP. This study has illustrated that such absence of feedback affects the actors in the system, which in turn induces individual adaption and emergent system behaviour.

The accompanying means, which are tightly intertwined with the structure of the governing system and its processes for facilitating CIP, have an effect on the outcomes. The results in PART B highlight a need for particular attention to the tools and methods for assessing infrastructure and services to identify and prioritise the critical portion of them in local, regional and national contexts as well as the timeframe of a possible crisis situation. First, such assessment involves a vast amount of partly sensitive data, which necessitates systematic data management that includes proper levels of information security. Second, the collection and analysis of relevant data require not only a clarification of data sources, methods and the scope for interpretations but also the dedication of resources and tools as well as a constructive dialogue about the implications of the particular outcomes for society and interrelated risk and crisis management.

This study particularly stresses the importance of integrating the planning process into the larger context of national emergency response planning and crisis management to account for interdependencies. For example, although the electricity sector is acknowledged as central to critical infrastructure, some critical services also depend on electricity-independent infrastructure, which is *a priori* excluded from the Swedish approach. If an application of the final plan in local risk analysis and crisis management is not properly considered, it could insinuate that such dependency does not exist. While many actors in the Swedish case could benefit from the integration of the planning into their day-to-day work, only a few have made progress since the governance approach neglects to explicitly address and properly support such integration.

6.3 Fundamentals of CIP Governance

This study views CIP as a common, societal concern that is located in the field of governance between governmental control and competitive market dynamics as well as the private sphere of citizens (Offe 2008). Protection is thereby an expression of will (i.e. strategic objective) under which the system of critical infrastructure is approached from outside. Thus, CIP actively aims to influence adaption, emergence and entropy of the SoS by mediating between hardening and awareness, efficiency and redundancy, and dependence and autonomy. In turn, the governance of CIP similarly concerns the SoS of public and private actors that effectuates CIP, which consequently involves relations to and between the sub-levels of the governed system.

The literature review in PART A has elaborated on the fundamental concepts of CIP, namely systems, infrastructures and governance. Apart from a substantial discussion of the concepts and their properties, it has contributed a frame of reference for understanding the state and relevance of CIP and its governance. It integrates the tripartite structure of systems, infrastructure and governance as well as their processes and different levels of concern, which regard the granularity of understanding. An adaption of the proposed KISA (see Figure 5) can guide the analysis of the state of a particular SoS, as conducted in PART B. In addition, the kaleidoscope facilitates a similar analysis at another point in time, which enhances comprehension of the effects of time on the investigated SoS and the relevance of CIP governance to address adaption, emergence and entropy of the governed system.

However, the recursive and multi-level nature of the involved systems of infrastructure and governance provides degrees of complexity, ambiguity and uncertainty that are difficult to manage, as the Swedish case illustrates. One explanation of such limitations refers to the interdependency between the extent of the problem and its solution. As outlined, the complexity of the SoS of critical infrastructure requires similarly complex systems to organise and govern CIP. In contrasting government and governance as the two ends of the spectrum of steering modes, research has attributed rigid hierarchy and bureaucratic processes to the former while viewing the latter as a 'knight in shining armour' that is fully capable of steering the dynamics of the complex SoS through self-organising networks. Nevertheless, the results of this study indicate that both steering modes present advantages and disadvantages. As elaborated in PART C, the findings from the Swedish case emphasise that a proper balance between these contrapositions can enable a systemic mode of steering that actively addresses ambiguity and uncertainty, which are inherent to the context of CIP, by integrating governance, management and leadership efforts.

Another fundamental aspect for understanding the state and the relevance of CIP governance is the difference between system and processes. The existence of a system can be independent of the process that it is intended to facilitate, whereas a process relies on an executing system. This difference implies that they are not easily interchangeable, particularly when the executing system is an SoS, and sub-levels relate to different parent systems. The results of the study demonstrate that conflicts emerged in the sphere of the various actors in the form of, for example, other tasks or competing goals. In addition, the Swedish case illustrates that a process can contain one or more sub-levels, while each process activity can be decomposed into a sub-process (e.g. at a certain actor). Complexity intensifies if an activity is part of multiple processes and involves a specific executing system which also interrelates with the mentioned SoS. Hence, CIP governance needs to drive an understanding of the CIP system and its processes at both the general and sub-levels to facilitate alignment.

As this study has noted, feedback has an important role in complex systems to channel adaption, emergence and entropy. However, the complexity of CIP can pose obstacles to appropriate feedback loops, which signifies the relevance of CIP governance. PART B has discovered instances in which actors missed feedback from other actors, such as during the policy-making process with regard to particular activities or between process iterations with respect to further developments. As stated, the investigated approach ignores the levels of concern that are involved in the task of CIP as well as the various levels of governance that are necessary to govern the activities and processes of the SoS of CIP. Any feedback exchange occurs in the area of responsibility of each actor and involves only the directly subordinate actors. Since such understanding of self-organising networks limits the perspective of each actor in the SoS, CIP governance must secure mechanisms for ensuring proper bi-directional feedback that enable evaluation and constructive dialogue between actors that directly interact as well as among other concerned stakeholders of the SoS of CIP and the wider society.

Therefore, adequate information and pathways are necessary to facilitate CIP governance and its development. To address adaption, emergence and entropy of the SoS of CIP, governance must consider policy-making from a systemic perspective that acknowledges the inherent multi-level character. Knowledge of the extent to which governance aligns goal-finding with management and leadership of the system of policy-making processes for CIP can thus enhance understandings of the state and the relevance of CIP governance.

6.4 Indications for Further Research

The research for this dissertation has been subject to several limitations, as detailed in Section 2.3.3. In particular, the multi-disciplinary and complex nature of the investigated approach for CIP with regard to the power supply provides a wide range of promising prospects for future research beyond the scope of this study. Such efforts can contribute to the multi-disciplinary canon of theories and concepts, methods and specific cases.

One course of research could link to the case study in PART B. Since this study is partly based on the retrospective views of the interviewees, a replication could examine the concrete proceedings alongside the decision-making process at different stakeholders. In addition, such investigation could analyse the current state of the SoS and thereby reveal the effect of time on the state and relevance of the approach. An application of complementary methods could further improve the comprehensiveness of the representation, and research on similar cases in other sectors of CIP or other countries can broaden understandings of the scope and the context of this societal concern.

Another research direction can address the conceptual universe to develop both cumulative and additive knowledge that is associated with theories and concepts in the field of CIP. The elaborations in PART A originate a solid foundation for the CIP community with regard to the concepts of system, infrastructure and governance. Subsequent research could interrelate other concepts, such as vulnerability, resilience or materiality, with the proposed multi-perspective frame of reference.

Additional research could concentrate on the development of methods and tools to facilitate both research and practice in the context of CIP. The research for this study had to contend with information scarcity mainly due to information security concerns and a low level of trust among the actors in the CIP context. Future development of methods and tools would require improved collaboration between research and practice even across research disciplines and critical infrastructure sectors. The refinement of research and assessment methods could involve integration with the KISA model to concretise the fundamentals of the CIP field.

Finally, the study characterises CIP as a common societal concern. This view implies a variety of perceptions of the value of infrastructure and services for affected stakeholders in decision-making. For many participants in the study, ethical questions about identification and prioritisation of critical infrastructure were matters of concern. Therefore, future research could revolve around aspects of equality and solidarity, self-responsibility and capability of the citizen ideal as well as uniformity and group behaviour in policy networks.

6.5 Summary

This discussion chapter has aggregated the theoretical and empirical findings of this study in light of the stated research questions. It has particularly accentuated how systemic thinking can advance understandings of CIP and its governance. The chapter has also delivered a few methodological considerations to highlight opportunities for further research.

In accordance with the question of how to organise and govern CIP, one major insight from the Swedish case is that many local implementations overlook the majority of society because of several constraints, such as the limited participation of relevant stakeholders in the process and assessments that almost exclusively target municipally operated facilities. Another insight is that the focus on end-nodes of the electrical grid and local power lines pose difficulties for integrating local, regional and national levels of concern, including interdependencies among infrastructure and services, into the assessment and decision-making. The sequential order and information scarcity in the policy-making process and the SoS of CIP leads to individual adaption and emergent system behaviour. A third insight concerns the sensitivity of handled information. The Swedish approach deliberately distributes the responsibility for managing information security to each actor, which significantly complicates the information exchange within the SoS. Knowledge management is almost absent, and regular evaluation is neglected.

The fundamentals for understanding CIP governance arise from the recursive and multi-level concepts of systems, infrastructure and governance. The inherent complexity of CIP interrelates with ambiguity and uncertainty, which necessitates a systemic mode of steering that actively accounts for changes over time. Fundamentally, this systemic governance must recognise the non-interchangeability of systems and processes as well as their multi-level nature to understand the interdependencies among systems and processes and their dynamics, which emerge in the form of adaption, emergence and entropy. Thus, feedback exchange has an essential role in the SoS of CIP governance to channel complexity. However, it depends on adequate information and well-established communication paths, which necessitates a certain level of systematic structure, particularly in the sensitive context of CIP.

The following chapter completes this thesis and concludes the dissertation. First, it offers a brief summary that condenses the contents of this thesis. Then, it connects back to the starting point of this thesis and presents the key answers to the research questions. Apart from encouraging future advancements, the final section provides the conclusions of this dissertation.

7

CONCLUDING REMARKS

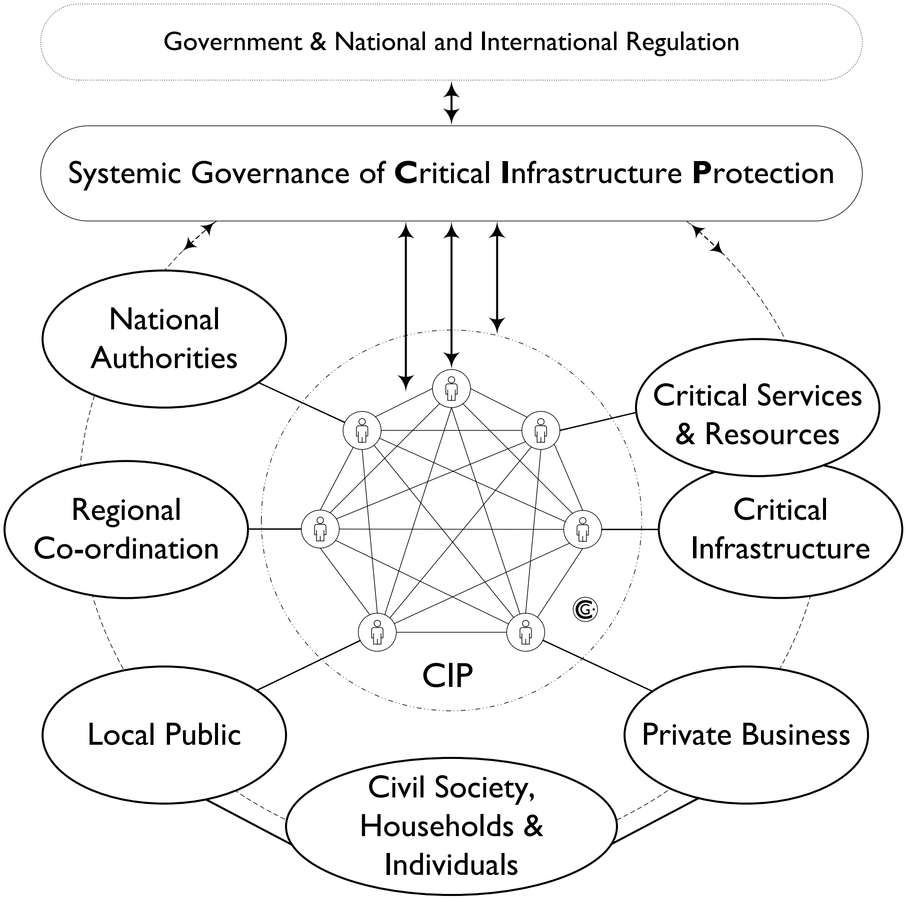

Figure 11: Towards Systemic Governance of CIP Practice

The purpose of this study was to investigate how systemic thinking can develop understandings of CIP and its governance, as aggregated by Figure 11. To contribute to the multi-disciplinary field of CIP, this doctoral dissertation presents a thesis and six scientific papers, which were peer-reviewed and published. The research has applied several methods, such as a literature review in PART A, a case study in PART B and a synthesis in PART C. In addition, Chapters 2 and 6 and the included papers comprehensively discuss the proceedings and implications of this study for research and practice.

This dissertation yields a comprehensive compilation of novel tools and knowledge for gaining a deeper understanding of CIP and its governance. Whereas the included papers (see Appendix) address specific aspects of the Swedish case of *STYREL* as a governance approach to CIP against power shortages, this thesis advances from the particular case to elaborate on the dissertation's scientific contribution to theory development.

First, PART A of this thesis (see Chapter 3) contributes to the fundamentals for understanding the concepts of systems, infrastructure and governance. It has clarified the origins, interpretations and current use of these concepts in scientific literature and emphasised their recursive, multi-level structure. The specific focus was on the properties of adaption, emergence and entropy to describe dynamic effects in complex systems. In addition, interrelations and interdependencies among these concepts, levels and processes reveal the complexity of the examined concepts (see Section 3.2). Hence, the elaborations in PART A originate a solid foundation for the CIP community with regard to the concepts of system, infrastructure and governance.

Apart from examining the state of the art, PART A provides the KISA, which is the kaleidoscope for integrative system analysis (see Figure 5) as a frame of reference, which not only structures the research for this study but also constitutes a new tool for future system analyses (see Section 3.3). The development of KISA applies the multi-perspective kaleidoscope for the complex and interdisciplinary research that PAPER I originates (see page 72).

Second, PART B (see Chapter 4) has investigated the Swedish governance approach for CIP against power shortages and contributed valuable findings on perspectives, interactions and boundaries in the Swedish CIP context. It has illustrated how the perspective of the individual actors in the SoS frames the perception of and the actors' roles in the system and its processes. This study of the Swedish case stresses the immense scope and dynamics of the complex system of national CIP, which involves many aspects of ambiguity and uncertainty that result in limited knowledge. In particular, PAPER II applies the Soft Systems Methodology to propose a conceptual system model with regard to *STYREL* (see page 72f). The visualisation of the complex system (see Figure 7) not only facilitated communication with interviewees and researchers but also enabled them to obtain a more holistic understanding of the problem situation even beyond individual concerns. More specifically, PAPER III provides a detailed portrayal of the central role of the CABs in the multi-level system and the long-term planning process (see e.g. pages 73f and 80ff). It reveals that the CAB, as the regional co-ordinator, lacks the awareness, knowledge and resources to fulfil its core function in the national planning for CIP. Hence, systemic thinking could assist CABs with broadening the perspective to improve regional and interregional co-ordination. In enlarging the focus, PAPER IV indicates blind spots in the design, execution and evolvement of the Swedish multi-level system for CIP alongside the chain of policy, interaction and learning among key actors in *STYREL* (see pages 74f and 80ff). This dissertation encourages further development of *STYREL* to improve its integration into the Swedish crisis management system and the larger CIP context. On the one hand, the various interests that are involved in such a large-scale, complex system need thorough consideration. PAPER V contributes a novel tool for fostering a constructive analysis and dialogue about strategic objectives in such SoS as well as their side effects (see page 75). Furthermore, it exemplifies the challenges for governance that emerge from the bundles of strategic objectives, which are classified as opportunities, indefinites and risks. On the other hand, the complexity of national CIP is accompanied by several sources of uncertainty that prompt biases and challenge governance. PAPER VI demonstrates the application of the recursive concept of multi-level planning to both national emergency response planning and the Swedish *STYREL* (see page 75f). Identified sources of uncertainty due to lacks of knowledge in SoS correlate to the complex planning process, the decision-making process, and direction and guidance alongside the former two, as Figure 8 presents.

Third, PART C (see Chapter 5) has contributed theory development that targets the relevance of a systemic approach to CIP governance for adapting to the recursive, multi-level structure of this complex SoS. This part conceives the argument that such adaption necessitates the development of the concept of *systemic governance* to integrate policy-making, management and leadership efforts for channelling the dynamism of the complex system of CIP. This tripartite structure could facilitate not only the attribution of responsibilities to certain actors in society but also a dialogue about process-related assumptions and expectations. The evidence of the Swedish case suggests that such dialogue must involve strategic objectives and the actors' understandings of their roles in CIP and risk and crisis management in society. In addition, CIP governance must include the establishment and maintenance of appropriate information channels among CIP and society.

This study has examined the research questions posed in Section 1.1. PART B and PART C have detailed the findings that are concluded below.

How does Sweden organise and govern critical infrastructure protection?

Critical infrastructure protection is a societal concern that engages a large-scale system of public and private actors in certain activities to mitigate the negative consequences of disturbances to infrastructure and services that are essential for society. This concern involves, for instance, long-term planning for maintenance, emergency response, and risk and crisis management. Since electricity has become a key prerequisite in society, a main focus of CIP is the undisturbed power supply of critical infrastructure. In Sweden, natural conditions, the geographic extent and historical developments of the power grid frame the technical constraints. Apart from the national PGO, which maintains the national grid and high-voltage power transmission, the EA is entrusted with ensuring a reliable and sustainable energy supply. The Swedish Energy Market Inspectorate controls the energy market, and the MSB considers society's protection and crisis preparedness. In view of a growing dependency of societies on electricity (e.g. due to an increasing digitalisation and the electrification of the transport sector), these authorities were commissioned to develop CIP in this context. The EA is entrusted with the creation and realisation of the Swedish approach, which involves many national agencies, all CABs and municipalities, and regional and local PGOs.

This long-term planning alternates with long stand-by periods between iterations, during which responsible individuals change their working tasks or positions. Organisational knowledge and experience of the proceedings consequently disappear, which has been insufficiently account for by governance. Clarity of objectives, goals and means thereby diminishes and warrants completely new consideration in the next process iteration. Since experience levels have been inadequately addressed, decision-makers in the distributed approach in Sweden must rely on their own perceptions and determinations of proper local proceedings. Individual adaptation can trigger an emergent system behaviour during the next process step or iteration or subsequent preparedness planning. Although the large-scale approach to CIP against power shortages involves many actors, it largely fails to involve the private sector and neglects to stipulate further participation of non-governmental organisations or citizens to enhance the resilience of the society. Thus, this proceeding results in uncalculated consequences. In addition, the current design of the approach hampers transparency and evaluation, which poses obstacles to the cultivation of mutual trust, collective learning and a shared understanding as well as proper risk communication with the wider public.

What are the fundamentals for understanding the state and the relevance of critical infrastructure protection governance?

Critical infrastructure protection is a complex endeavour in view of the multitude of interdependencies among societally important infrastructure and services. This study argues that such aspiration necessitates the development of systemic governance, which integrates policy-making, management and leadership efforts to channel the dynamism of the complex system of CIP.

One fundamental dimension for understanding the state and the relevance of CIP governance is the recursive, multi-level structure that characterises the concepts of system, infrastructure and governance as well as their processes and properties. In addition, recognising the difference between systems and processes facilitates further understanding of the state of CIP. The findings of this study specifically underline the imperative of clarifying the terminology in the CIP area and the role of governance in advancing a common understanding among actors in this complex SoS of CIP.

A second fundamental dimension considers the areas of concern that correspond to local, regional, national and international levels of CIP. Each actor in the SoS is simultaneously part of another SoS and departs from its particular context when defining its role in CIP, which involves different worldviews and conflicts of interest at another level of concern. Thus, governance efforts must develop a strategic framework against which each actor can reflect local proceedings. Constructive dialogue among relevant stakeholders should mediate such establishment of methods to assess criticality, tools for information sharing or underlying objectives, for example.

A third fundamental dimension concerns the impact of time that relates to different states of systems, processes or included activities as well as changes in environmental conditions and strategic objectives over time. In particular, the mentioned interdependencies impart a complexity that may prompt a sense of fatality that pervades the SoS of CIP and its governance. However, mitigating adaption, emergence and entropy within the multi-level system of CIP requires an acceptable balance between common structure and local variety and systematic and ad-hoc proceedings. Thus, a systemic mode of governance that approaches the complexity paralysis should align policy-making, management and leadership efforts within the recursive and multi-level structure over time. Fundamentally, systemic governance should actively address informal and formal feedback exchange among the actors in the SoS of CIP, which would also foster information security and an integrative transfer of the result of one planning process to a subsequent one. In addition, systemic governance must target the attractor role in the SoS to elicit and sustain a keen interest in CIP.

Premature optimization is the root of all evil.

Donald E. Knuth

(Knuth 1974:268)

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