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Article

Adaptive Governance of Disaster and Systemic Risks in Critical Energy Infrastructure: A Complex Adaptive Systems Perspective

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ABSTRACT

Critical energy infrastructure operates in an increasingly complex environment characterized by disaster risks, systemic risks, interdependencies, and uncertainty. Traditional approaches emphasizing regulatory compliance and technical protection are no longer sufficient to explain how infrastructure resilience is achieved under rapidly changing conditions. Drawing on Complex Adaptive Systems Theory, this study examines how adaptive governance contributes to managing disaster and systemic risks within critical energy infrastructure. A qualitative instrumental case study was conducted in Naftna Industrija Srbije (NIS), using semi-structured interviews with ten experts responsible for corporate security and critical infrastructure protection, complemented by document analysis. Data were analyzed through reflexive thematic analysis. The findings identify four interrelated governance dimensions: institutional coordination, public-private collaboration, adaptive organizational learning, and governance adaptation. Building on these findings, the study develops the Adaptive Governance Capacity Framework, conceptualized as the collective capability of interconnected public and private actors to coordinate, learn, exchange knowledge, and adapt governance processes in response to evolving disaster and systemic risks. The study contributes to the literature by integrating Critical Infrastructure Theory, Disaster Risk Governance, Collaborative Governance, Organizational Resilience, and Complex Adaptive Systems Theory into a coherent conceptual framework. The findings also provide practical implications for policymakers, infrastructure operators, and emergency management authorities responsible for strengthening resilience in complex critical infrastructure systems.

KEYWORDS

adaptive governance capacity; disaster risk governance; critical energy infrastructure; complex adaptive systems.

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1. Introduction

The protection of critical infrastructure has undergone a profound conceptual transformation over the past decade. Once primarily concerned with safeguarding strategically important physical assets against identifiable threats, critical infrastructure protection is now increasingly understood as a governance challenge shaped by interdependence, uncertainty, and continuous adaptation. Contemporary critical infrastructures operate as interconnected socio-technical systems in which localized failures may rapidly propagate across sectors and national borders, creating cascading effects that challenge conventional approaches to infrastructure protection and risk management (Arvidsson, Johansson, & Guldåker, 2021; Klinke & Renn, 2021; Linkov & Trump, 2019). Recent disaster risk research further emphasizes that these infrastructures are increasingly exposed to disaster and systemic risks whose consequences extend beyond individual organizations and sectors, requiring governance approaches that integrate resilience, adaptation, and cross-sector coordination (United Nations Office for Disaster Risk Reduction [UNDRR], 2022).

Among all critical infrastructure sectors, energy infrastructure occupies a particularly strategic position because disruptions in oil and gas production, refining, transportation, storage, or distribution may rapidly cascade across transportation, healthcare, telecommunications, finance, manufacturing, and public administration. At the same time, digitalization and the convergence of operational and information technologies have expanded the spectrum of vulnerabilities, making governance considerably more complex than traditional protection paradigms assumed. Consequently, resilience is increasingly understood as the capacity of interconnected systems to anticipate, adapt to, and recover from evolving threats while maintaining essential societal functions (Linkov & Trump, 2019; Klinke & Renn, 2021).

These developments have fundamentally transformed governance arrangements. Whereas critical infrastructure protection was traditionally regarded as a governmental responsibility, contemporary infrastructure systems increasingly depend on continuous coordination among governments, infrastructure operators, regulatory authorities, emergency management organizations, technology providers, and private security organizations. Consequently, risk governance is no longer concerned solely with managing individual threats but with coordinating relationships among multiple actors responsible for sustaining infrastructure resilience under conditions of uncertainty (Klinke & Renn, 2021). Public-private collaboration has therefore evolved beyond contractual cooperation into broader governance arrangements that facilitate information exchange, joint decision-making, organizational learning, and coordinated responses to disaster and systemic risks.

Despite the growing body of research on critical infrastructure resilience, disaster risk governance, organizational resilience, and collaborative governance, limited attention has been devoted to explaining how adaptive governance capacities emerge through interactions among public and private actors responsible for managing disaster and systemic risks within critical energy infrastructure. Existing studies predominantly examine these perspectives separately, leaving insufficient understanding of the governance mechanisms that generate resilience in complex socio-technical systems. Empirical qualitative studies exploring practitioners' perspectives remain particularly scarce, especially in Southeast European countries, where governance structures and institutional contexts differ from those typically examined in Western Europe and North America.

Serbia provides a valuable empirical setting for addressing this gap because its critical energy infrastructure combines strategic national importance with intensive interaction among governmental institutions, infrastructure operators, and private security organizations. The selected case therefore enables the exploration of broader governance mechanisms shaping disaster and systemic risk governance within complex socio-technical systems.

To explain these governance dynamics, this study adopts Complex Adaptive Systems Theory (CAS), conceptualizing critical energy infrastructure as a dynamic socio-technical system in which resilience emerges through continuous interaction, institutional learning, adaptive coordination, feedback, and collaborative decision-making (Hanspal et al., 2026). Within this perspective, Adaptive Governance Capacity is defined as the collective capability of interconnected public and private

actors to coordinate, collaborate, learn, exchange knowledge, and continuously adapt governance processes in response to evolving disaster and systemic risks while sustaining infrastructure resilience. Drawing upon document analysis and semi-structured interviews with experts responsible for corporate security and critical infrastructure protection within Naftna Industrija Srbije (NIS), the study explores how Adaptive Governance Capacity develops in practice through institutional coordination, public-private collaboration, organizational learning, and adaptive governance.

Accordingly, the aim of this study is to explore how Adaptive Governance Capacity develops in the governance of disaster and systemic risks within critical energy infrastructure from the perspective of Complex Adaptive Systems Theory.

The study addresses the following research question:

How does Adaptive Governance Capacity emerge through institutional coordination, collaboration, organizational learning, and adaptation in the governance of disaster and systemic risks within critical energy infrastructure?

The study makes two principal contributions. First, it integrates insights from Disaster Risk Governance, Critical Infrastructure Theory, Collaborative Governance, Organizational Resilience, and Complex Adaptive Systems Theory into a coherent conceptual perspective centered on Adaptive Governance Capacity. Second, based on qualitative empirical evidence, it develops an empirically grounded Adaptive Governance Capacity Framework that explains how governance capabilities emerge through coordination, collaboration, learning, adaptation, and interdependence, while offering practical implications for policymakers, regulatory authorities, infrastructure operators, and security professionals.

2. Theoretical Background

2.1. Disaster Risks and Systemic Risks in Critical Energy Infrastructure

The risks affecting critical infrastructure have become increasingly complex due to growing interdependencies among physical assets, digital technologies, organizational processes, and institutional arrangements. Contemporary disaster research distinguishes between disaster risks, arising from the interaction of hazards, exposure, vulnerability, and coping capacities, and systemic risks, which emerge through the interconnectedness of complex socio-technical systems (Klinke & Renn, 2021; UNDRR, 2022; Vuletić, 2026).

According to UNDRR (2022), disaster risk refers to the potential loss of life, injury, or damage resulting from the interaction between hazards, exposure, vulnerability, and insufficient coping capacity. Within critical energy infrastructure, such risks originate from natural hazards, industrial accidents, technological failures, cyberattacks, terrorism, and hybrid threats (Organization for Economic Co-operation and Development [OECD], 2019; Pescaroli & Alexander, 2016). In contrast, systemic risks are characterized by nonlinearity, interdependence, and cascading effects that propagate across sectors and governance levels through dynamic interactions among infrastructure networks, institutions, and societal processes (Klinke & Renn, 2021; Linkov & Trump, 2019).

Critical energy infrastructure exemplifies a system simultaneously exposed to disaster and systemic risks because disruptions in energy production, transmission, or distribution rapidly affect transportation, healthcare, telecommunications, finance, manufacturing, and public administration (Knodt, Fraune, & Engel, 2022; OECD, 2019; Vidović, Beriša, & Cvetković, 2024). Consequently, resilience depends not only on protecting physical assets but also on governance arrangements capable of anticipation, coordination, learning, and adaptation under conditions of uncertainty (Comfort, 2019; Klinke & Renn, 2021).

Rather than representing separate analytical categories, disaster and systemic risks reflect complementary dimensions of complexity within critical energy infrastructure. Understanding and

governing these risks therefore requires theoretical perspectives capable of explaining adaptation, feedback, interdependence, and emergence—the defining principles of Complex Adaptive Systems Theory (Holland, 2006; Levin, 1998).

2.2. Critical Energy Infrastructure as a Complex Adaptive System

The increasing interconnectedness of critical infrastructure has challenged traditional engineering perspectives that viewed infrastructure as a collection of discrete technical assets. Contemporary research instead conceptualizes critical energy infrastructure as a Complex Adaptive System (CAS) composed of interdependent organizations, technologies, institutions, and governance arrangements whose interactions continuously shape system resilience (Holland, 2006; Levin, 1998; Linkov & Trump, 2019).

CAS theory argues that system behavior cannot be understood by analyzing individual components in isolation. Instead, resilience emerges through interdependence, feedback, adaptation, self-organization, and emergence. Within critical energy infrastructure, these dynamics are reflected in the interactions among governmental institutions, regulatory authorities, infrastructure operators, emergency management organizations, technology providers, private security organizations, and local communities.

Interdependence explains how disruptions in one infrastructure sector generate cascading effects across transportation, healthcare, telecommunications, finance, water supply, and digital communication systems (Arvidsson et al., 2021; Pescaroli & Alexander, 2016). Feedback processes enable organizations to exchange information, evaluate outcomes, and continuously adjust governance arrangements, while self-organization supports collaborative action beyond formal institutional structures. Consequently, resilience is not produced by any single organization, regulation, or technology but emerges through the adaptive interaction of multiple governance actors (Comfort, 2019; Holland, 2006; Levin, 1998).

From this perspective, Adaptive Governance Capacity represents the governance mechanism through which Complex Adaptive Systems maintain resilience under conditions of disaster and systemic risks. Institutional coordination, knowledge integration, adaptive decision-making, and public-private collaboration enable governance actors to continuously learn, coordinate, and adjust their responses to changing conditions while sustaining essential societal functions.

To translate these theoretical principles into an empirical framework, this study operationalizes Adaptive Governance Capacity by linking the core characteristics of Complex Adaptive Systems Theory with governance dimensions identified in the literature on risk governance, collaborative governance, and organizational resilience (Comfort, 2019; Duchek, 2020; Emerson & Nabatchi, 2015; Klinke & Renn, 2021). The resulting operationalization, presented in Table 1, provides the analytical framework for interpreting the empirical findings.

Table 1. Operationalization of Adaptive Governance Capacity from a Complex Adaptive Systems Perspective.

CAS Principle	Meaning in Critical Energy Infrastructure	Adaptive Governance Capacity Dimension
Interdependence	Cross-sector dependencies	Institutional coordination
Feedback loops	Continuous information exchange	Knowledge integration
Adaptation	Governance adjustment	Adaptive decision-making
Self-organization	Collaborative action among actors	Public-private collaboration
Emergence	System resilience arising from interactions	Adaptive Governance Capacity

Note. CAS = Complex Adaptive Systems.

The resulting operationalization provides the analytical framework for interpreting the empirical findings (Table 1). As shown in Table 1, Adaptive Governance Capacity is conceptualized as a multidimensional governance construct rather than a single organizational capability. During the reflexive thematic analysis, these dimensions served as sensitizing concepts while remaining open to the emergence of new empirical insights (Braun & Clarke, 2021). Consequently, the Adaptive Governance Capacity Framework presented later in the paper represents an empirically refined conceptual model developed through the interaction of theory and qualitative evidence.

2.3. From Risk Management to Adaptive Risk Governance

The growing complexity of critical energy infrastructure has fundamentally transformed the way risks are governed. Traditional risk management, primarily concerned with identifying and mitigating individual threats, is increasingly insufficient for addressing uncertainty, interdependence, and cascading effects that characterize contemporary socio-technical systems. As infrastructures become more interconnected, effective governance depends less on hierarchical control and more on coordination among multiple public and private actors operating across organizational boundaries (Comfort, 2019; Klinke & Renn, 2021).

This shift has contributed to the emergence of adaptive risk governance, which extends beyond conventional risk management by emphasizing stakeholder participation, institutional coordination, organizational learning, and adaptive decision-making under conditions of uncertainty. Rather than focusing solely on preventing disruptions, adaptive risk governance seeks to strengthen the capacity of governance systems to anticipate, respond to, and learn from evolving disaster and systemic risks (Klinke & Renn, 2021).

Within this context, collaborative governance provides the institutional mechanism through which adaptive risk governance is realized. It brings together governmental agencies, infrastructure operators, regulatory authorities, emergency management organizations, technology providers, and private security organizations in processes of joint decision-making, information exchange, resource coordination, and collective problem-solving (Ansell & Gash, 2008; Bryson, Crosby, & Stone, 2015; Emerson & Nabatchi, 2015; Islam et al., 2026). Such collaboration is particularly important in critical energy infrastructure, where no single organization possesses sufficient authority, information, or operational capacity to manage disaster and systemic risks independently.

Research further suggests that the effectiveness of collaborative governance depends not only on formal institutional arrangements but also on relational capabilities, including trust, shared situational awareness, transparent communication, and continuous knowledge exchange (Bryson et al., 2015; Emerson & Nabatchi, 2015). These capabilities support collective learning, improve coordinated responses to disruptions, and reduce the likelihood of cascading failures across interconnected infrastructures.

Consequently, this study argues that collaborative governance represents a necessary but not sufficient condition for resilience within critical energy infrastructure. While collaboration enables coordination and knowledge sharing, resilience ultimately depends on the collective capability of governance actors to transform these interactions into continuous adaptation (Vidović et al., 2024). This capability is conceptualized here as Adaptive Governance Capacity, integrating insights from risk governance, collaborative governance, organizational resilience, and Complex Adaptive Systems Theory into a coherent framework for understanding how resilience is generated under conditions of uncertainty and complexity.

2.4. Collaborative Governance as a Driver of Organizational Resilience

The literature reviewed in the preceding sections demonstrates that no single theoretical perspective sufficiently explains how resilience emerges within contemporary critical energy infrastructure. Critical Infrastructure Theory highlights interdependence and cascading effects; Risk Governance

emphasizes coordination under conditions of uncertainty; Collaborative Governance explains multi-actor decision-making and institutional cooperation; and Organizational Resilience focuses on learning, adaptation, and recovery. Although these perspectives offer complementary insights, they have largely developed independently, providing only partial explanations of resilience within increasingly complex socio-technical systems.

To address this limitation, the present study adopts Complex Adaptive Systems Theory (CAS) as the overarching analytical perspective. CAS conceptualizes critical energy infrastructure as a dynamic socio-technical system in which resilience is not an inherent organizational attribute but an emergent property arising from continuous interactions among organizations, institutions, technologies, and governance processes. Through interdependence, feedback, adaptation, and self-organization, governance actors collectively generate the capacity to anticipate, respond to, and recover from evolving disaster and systemic risks (Comfort, 2019; Holland, 2006; Levin, 1998).

Building upon this theoretical integration, the study introduces Adaptive Governance Capacity as its central analytical construct. Adaptive Governance Capacity is defined as the collective capability of interconnected public and private actors to coordinate decision-making, integrate knowledge, support organizational learning, and continuously adapt governance processes in order to sustain the resilience of critical energy infrastructure. Rather than replacing existing theories, this concept synthesizes their complementary contributions into a coherent framework for explaining how resilience emerges through governance.

Within this framework, resilience is understood as the outcome of dynamic governance processes rather than isolated organizational capabilities or technical protection measures. Institutional coordination, collaborative decision-making, knowledge integration, and adaptive learning constitute the governance mechanisms through which complex adaptive systems maintain continuity under conditions of uncertainty and disruption.

The resulting theoretical framework forms the basis for the empirical investigation presented in this study. It guides the qualitative analysis of governance practices within critical energy infrastructure. It provides the conceptual foundation for the development of the Adaptive Governance Capacity Framework proposed in the concluding sections.

The theoretical perspectives integrated into the analytical framework and their respective contributions to the study are summarized in Table 2.

Table 2. Theoretical Foundations of the Study.

Theoretical Perspective	Core Concepts	Contribution to This Study
Critical Infrastructure Theory	Interdependence, cascading effects, socio-technical systems	Explains the transformation of critical infrastructure from isolated assets to interconnected socio-technical systems.
Risk Governance	Uncertainty, coordination, stakeholder participation, adaptive decision-making	Explains governance processes required for managing systemic risks beyond organizational boundaries.
Collaborative Governance	Multi-actor collaboration, trust, shared decision-making, institutional coordination	Explains how collaboration among public and private actors supports resilience.
Organizational Resilience	Adaptation, anticipation, learning, recovery	Explains resilience as a dynamic capability emerging through continuous adaptation.
Complex Adaptive Systems Theory	Emergence, feedback loops, adaptation, self-organization	Provides the overarching theoretical perspective integrating the previous approaches.
Adaptive Governance Capacity (This Study)	Coordination, institutional learning, knowledge integration, collaborative adaptation	Integrates the preceding theories into a unified framework explaining how resilience emerges within critical energy infrastructure.

Table 2 summarizes the complementary theoretical perspectives underpinning this study. Their integration is illustrated in Figure 1, which presents the conceptual architecture adopted for the empirical investigation.

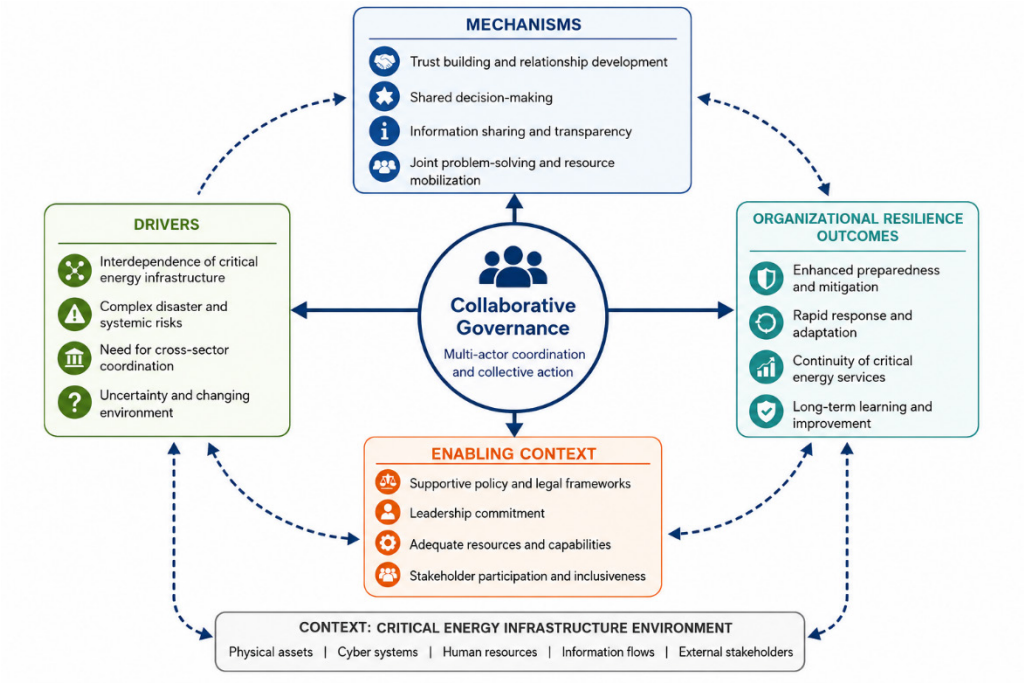

Figure 1. Theoretical Framework for Adaptive Governance Capacity in Critical Energy Infrastructure.

Figure 1 illustrates how Critical Infrastructure Theory, Disaster Risk Governance, Risk Governance, Collaborative Governance, and Organizational Resilience contribute complementary explanations of governance and resilience, while Complex Adaptive Systems Theory provides the overarching analytical lens that integrates these perspectives. Together, they establish the conceptual foundation for examining Adaptive Governance Capacity as the governance mechanism through which resilience emerges within critical energy infrastructure.

3. Methodology

3.1. Research Design

This study adopts a qualitative exploratory instrumental case study to investigate how Adaptive Governance Capacity develops within critical energy infrastructure operating under conditions of complexity, uncertainty, and institutional interdependence. A qualitative approach was selected because the study seeks to develop an in-depth understanding of governance processes, institutional interactions, and organizational practices rather than test predefined hypotheses or establish statistical relationships. Such an approach is particularly appropriate for exploring context-dependent governance phenomena shaped by the experiences and perspectives of multiple stakeholders (Merriam & Tisdell, 2016).

The research is grounded in an interpretivist paradigm, assuming that governance processes are socially constructed through interactions among organizations and institutions. Accordingly, Adaptive Governance Capacity is understood as an emergent phenomenon that develops through coordination, organizational learning, collaborative decision-making, and adaptive responses rather than through formal organizational structures or predefined performance indicators.

A single instrumental case study was selected because it enables the investigation of contemporary governance phenomena within their real-life institutional context, where the boundaries between the phenomenon and its environment cannot be clearly separated (Stake, 1995; Yin, 2018). Rather

than representing an exceptional organization, the selected case provides an information-rich setting for examining governance processes within critical energy infrastructure, supporting analytical rather than statistical generalization.

The study follows a theory-informed, empirically grounded research strategy, integrating insights from Critical Infrastructure Theory, Risk Governance, Collaborative Governance, Organizational Resilience, and Complex Adaptive Systems Theory throughout data collection and interpretation. Consistent with Eisenhardt (1989) and Eisenhardt and Graebner (2007), theoretical perspectives informed the analysis, while qualitative evidence was used to refine the proposed Adaptive Governance Capacity Framework.

3.2. Research Context

The empirical research was conducted within Naftna Industrija Srbije (NIS), one of the largest integrated energy companies in Southeast Europe and a key operator of Serbia's critical energy infrastructure. Operating across the entire oil and gas value chain—from exploration and production to refining, distribution, and energy supply—NIS represents a strategically important component of the national energy system. Because disruptions within its operations may generate cascading effects across multiple critical sectors, the company provides an information-rich setting for examining governance mechanisms for managing disaster and systemic risks.

The Serbian energy sector has undergone significant transformation through market liberalization, digitalization, regulatory harmonization with the European Union, and increasing cybersecurity requirements. At the same time, energy operators face interconnected risks associated with geopolitical instability, cyber threats, climate-related hazards, technological modernization, and cross-sector dependencies. These developments have increased the importance of governance mechanisms that support institutional coordination, organizational learning, and adaptive responses across organizational boundaries.

NIS was selected through purposive sampling based on four criteria: (1) its strategic importance within Serbia's critical energy infrastructure; (2) extensive interaction with governmental institutions and regulatory authorities; (3) organizational complexity requiring continuous coordination among multiple stakeholders; and (4) access to experienced professionals directly involved in corporate security and critical infrastructure protection.

The principal characteristics of the selected case, the research strategy, data sources, and analytical approach are presented in Table 3.

Table 3. Overview of the Case Study.

Characteristic	Description
Case organization	Naftna Industrija Srbije (NIS)
Sector	Critical Energy Infrastructure
Country	Republic of Serbia
Research strategy	Qualitative instrumental case study
Sampling strategy	Purposive sampling
Participants	Experts in corporate security and critical infrastructure protection
Data sources	Semi-structured interviews; organizational and regulatory documents
Data analysis	Reflexive thematic analysis
Research objective	Development and refinement of the Adaptive Governance Capacity Framework

As indicated in Table 3, the unit of analysis comprises governance processes operating across organizational and institutional boundaries.

3.3. Data Collection

Empirical data were collected through semi-structured expert interviews and document analysis, enabling methodological triangulation and a comprehensive understanding of governance processes related to disaster and systemic risks within critical energy infrastructure. Combining multiple data sources enhanced the credibility of the study by allowing participants' perspectives to be interpreted alongside organizational procedures, regulatory requirements, and the broader institutional context (Bowen, 2009; Yin, 2018).

The primary source of empirical evidence comprised ten semi-structured interviews with professionals directly involved in corporate security, critical infrastructure protection, crisis management, and governance within Naftna Industrija Srbije (NIS). Participants were selected through purposive criterion sampling (Patton, 2015) based on four criteria: (1) direct responsibilities related to critical infrastructure protection and security governance; (2) substantial professional experience in corporate security, crisis management, or risk governance; (3) active cooperation with governmental institutions or other organizations responsible for critical infrastructure protection; and (4) willingness to participate voluntarily in the research.

The interviews were conducted in March 2025, each lasting approximately 30 minutes, resulting in about five hours of recorded material. All interviews were audio-recorded with informed consent, transcribed verbatim, and conducted in Serbian. Quotations presented in this article were translated into English by the authors while preserving their original meaning. To preserve conceptual equivalence, the translations were independently reviewed by the co-authors before inclusion in the manuscript.

Following the concept of information power (Malterud et al., 2016), ten expert interviews were considered sufficient because participants possessed highly specialized expertise, the study addressed a narrowly defined research aim, and the final interviews generated no substantially new conceptual insights.

The interview protocol was informed by the theoretical framework and explored five thematic areas: (1) governance and institutional coordination; (2) disaster and systemic risk management; (3) collaboration with public and private stakeholders; (4) organizational learning and adaptive governance; and (5) opportunities for strengthening the resilience of critical energy infrastructure. The semi-structured format ensured consistency across interviews while allowing participants to elaborate on issues they considered particularly relevant.

To complement the interview data, the study also employed document analysis. The analyzed materials included Serbian legislation on critical infrastructure, national strategic documents related to disaster risk reduction and security governance, publicly available corporate governance policies, organizational procedures concerning security and resilience, and other relevant documents published between 2019 and 2025. These documents provided contextual information and supported triangulation between formal governance arrangements and participants' perspectives (Bowen, 2009).

The principal characteristics of the interview sample and the data-collection procedure are summarized in Table 4.

Table 4. Documentary Sources Used for Triangulation.

Document category	Examples	Analytical purpose
National legislation	Law on Critical Infrastructure, Law on Private Security	Regulatory framework
National strategic documents	DRR strategies, security strategies	Governance context
Corporate governance documents	Internal procedures, resilience policies	Organizational governance

Document category	Examples	Analytical purpose
Public reports	Annual reports, public information	Triangulation of interview findings

Table 5. Participant Characteristics.

Characteristic	Distribution
Senior management	3
Middle management	5
Operational experts	2
10–15 years of experience	4
More than 15 years	6

The research was conducted in accordance with established ethical principles for qualitative research. Participants were informed about the purpose of the study, the voluntary nature of participation, their right to withdraw at any stage, and the measures adopted to ensure confidentiality and anonymity. Written informed consent was obtained prior to each interview. Given the strategic importance of critical energy infrastructure, the analysis focuses exclusively on governance processes and institutional interactions while deliberately excluding operationally sensitive information that could compromise organizational or national security.

The characteristics of the Interview Sample Are summarized in Table 6.

Table 6. Characteristics of the Interview Sample

Characteristic	Description
Number of participants	10
Sampling strategy	Purposive sampling
Organizational affiliation	Naftna Industrija Srbije (NIS)
Professional profile	Experts in corporate security and critical infrastructure protection
Interview type	Semi-structured
Period of data collection	March 2025
Average interview duration	Approximately 30 minutes
Total recorded material	Approximately 5 hours
Recording	Audio-recorded
Transcription	Verbatim
Interview language	Serbian (translated into English for publication)

The interview protocol covered several governance-related topics concerning critical infrastructure protection, disaster and systemic risks, public-private collaboration, and adaptive governance. Rather than treating interview questions individually, Table 7 synthesizes the dominant empirical insights that informed the subsequent reflexive thematic analysis.

Table 7. From Interview Protocol to Analytical Themes.

Interview topics	Representative empirical findings	Analytical theme	Adaptive Governance Capacity dimension
Perceived strategic importance of the organization; implementation of the Law on Critical Infrastructure; institutional support	Participants consistently perceived NIS as a strategically important component of Serbia's critical energy infrastructure (average rating 9/10). Although the organization implemented the main legal requirements, respondents emphasized the lack of systematic monitoring, institutional feedback, and continuous coordination by competent public authorities.	Institutional coordination	Institutional coordination
Alignment of legislation; role of private security; public-private partnerships	Respondents considered the existing legislative framework generally adequate but only partially harmonized across sectors. They stressed that the contribution of private security providers remains insufficiently recognized despite their essential operational role in protecting critical infrastructure.	Public-private collaboration	Public-private collaboration
Risk management; prevention; integrated protection; organizational preparedness	Participants emphasized that resilience depends primarily on prevention, strategic planning, organizational learning, and integrated protection rather than on physical protection measures alone. External crises, particularly the war in Ukraine, stimulated organizational adaptation and reassessment of security risks.	Adaptive risk management and organizational learning	Adaptive organizational learning
Governance challenges; cooperation among institutions; future development	Respondents described resilience as emerging through continuous interaction among infrastructure operators, governmental institutions, regulatory bodies, emergency management organizations, and private security providers. Communication, trust, knowledge exchange, and adaptive coordination were identified as prerequisites for effective governance.	Emergence of Adaptive Governance Capacity	Governance adaptation

3.4. Data Analysis

The empirical material was analyzed using reflexive thematic analysis (Braun & Clarke, 2021). This flexible yet theoretically rigorous qualitative method enables the systematic identification, interpretation, and development of patterns of meaning within qualitative data. This analytical approach was considered particularly appropriate because the study sought not only to describe governance

practices but also to develop an empirically grounded conceptual understanding of Adaptive Governance Capacity within the context of disaster and systemic risk governance.

The analysis followed a theory-informed, interpretive strategy. Existing theoretical perspectives—including Disaster Risk Governance, Critical Infrastructure Theory, Collaborative Governance, Organizational Resilience, and Complex Adaptive Systems Theory—served as sensitizing concepts that informed the interpretation of the empirical material without predetermining the findings. This approach combined deductive sensitivity to established theoretical constructs with inductive openness to new themes emerging from participants' experiences (Braun & Clarke, 2021; Eisenhardt & Graebner, 2007).

The analytical process followed the six phases of reflexive thematic analysis proposed by Braun and Clarke (2021): (1) familiarization with the data through repeated reading of the interview transcripts; (2) generation of initial codes by systematically identifying meaningful text segments; (3) grouping related codes into preliminary categories; (4) reviewing and refining categories into higher-order themes through continuous comparison with both the empirical material and the theoretical framework; (5) defining and naming the final themes; and (6) integrating the themes into an explanatory interpretation of Adaptive Governance Capacity within critical energy infrastructure.

Coding was conducted manually by the authors, without the use of qualitative data analysis software. This decision was consistent with the principles of reflexive thematic analysis, which emphasize continuous engagement with the empirical material and the interpretive role of the researchers throughout the analytical process (Braun & Clarke, 2021). Manual coding facilitated repeated comparison between interview transcripts, documentary evidence, and emerging theoretical interpretations, allowing the researchers to refine codes and themes iteratively rather than treating coding as a purely technical procedure.

3.4.1. Researcher Positionality and Reflexivity

The interviews were conducted by one of the authors, whose professional expertise includes research in critical infrastructure governance, security management, and organizational resilience. The researchers had no managerial or employment relationship with NIS during the study. Consistent with reflexive thematic analysis, the researchers continuously reflected on their theoretical assumptions throughout coding and interpretation to ensure that emerging themes remained closely grounded in the empirical material while acknowledging the interpretive nature of qualitative analysis.

To enhance analytical rigor, coding and theme development were conducted through repeated discussions among the authors. Emerging interpretations were continuously compared with the empirical evidence and relevant theoretical concepts to ensure that the final themes remained firmly grounded in participants' accounts while contributing to theory development. This iterative process ultimately resulted in four overarching themes that explain how Adaptive Governance Capacity emerges through institutional coordination, collaborative governance, organizational learning, and adaptive decision-making.

Rather than treating themes as isolated analytical categories, the analysis focused on the dynamic relationships among governance mechanisms, institutional interactions, and adaptive processes. In line with the principles of Complex Adaptive Systems Theory, particular attention was devoted to identifying patterns of interdependence, feedback, collaboration, and adaptation across organizational boundaries. This interpretive strategy enabled the development of the Adaptive Governance Capacity Framework, which constitutes the principal theoretical contribution of this study by explaining how adaptive governance capacity emerges through the interaction of institutional coordination, public–private collaboration, organizational learning, and continuous adaptation.

3.5. Trustworthiness and Research Quality

The trustworthiness of the study was ensured by applying the criteria of credibility, transferability, dependability, and confirmability proposed by Lincoln and Guba (1985). Credibility was strengthened through methodological triangulation, combining semi-structured interviews with document analysis, thereby enabling the comparison of participants' perspectives with organizational and institutional sources. The purposive selection of experienced professionals further enhanced the richness and relevance of the empirical data.

Transferability was supported through a detailed description of the research context, the case organization, and participant characteristics, allowing readers to assess the applicability of the findings to other critical infrastructure settings. Dependability was enhanced by documenting each stage of the research process, including data collection, coding, theme development, and interpretation.

Confirmability was addressed through continuous comparison between empirical evidence and theoretical concepts during the analytical process. Rather than seeking researcher neutrality, the reflexive thematic analysis acknowledged the interpretive role of the researchers while ensuring that all analytical conclusions remained firmly grounded in the empirical material. The integration of interview data with documentary evidence further strengthened the consistency and credibility of the findings.

Ethical principles were observed throughout the research process. Participation was voluntary, informed consent was obtained from all participants, and confidentiality and anonymity were maintained. Given the strategic importance of critical energy infrastructure, no operationally sensitive information is disclosed in this article.

According to institutional and national regulations applicable to this study, formal approval by an ethics committee was not required because the research involved voluntary interviews with adult professionals and did not collect sensitive personal data. Organizational authorization was obtained prior to data collection.

The trustworthiness of the study was assessed using the criteria proposed by Lincoln and Guba (1985): credibility, transferability, dependability, and confirmability.

The semi-structured interview protocol addressed a broad range of governance issues related to critical infrastructure protection, disaster and systemic risks, institutional coordination, public-private collaboration, and adaptive governance. Rather than presenting individual interview questions, Table 8 summarizes the dominant empirical insights and demonstrates how they informed the development of the analytical themes through reflexive thematic analysis.

Table 8. Strategies for Ensuring Research Trustworthiness.

Criterion	Strategy Applied in This Study
Credibility	Methodological triangulation through semi-structured interviews and document analysis; purposive sampling of experienced professionals; iterative interpretation of empirical data.
Transferability	Rich description of the organizational, institutional, and governance context to support analytical transferability to similar critical infrastructure settings.
Dependability	Transparent documentation of the research design, data collection, transcription, coding, theme development, and analytical procedures.
Confirmability	Reflexive thematic analysis supported by continuous comparison between empirical evidence, documentary sources, and the theoretical framework to ensure that interpretations remained grounded in the data.

The analytical themes presented in Table 8 served as the conceptual bridge between the empirical material and the subsequent thematic analysis. Although the interview protocol comprised several

distinct questions, participants' responses converged around four interrelated governance themes that collectively explain the emergence of Adaptive Governance Capacity within critical energy infrastructure.

4. Findings

The reflexive thematic analysis resulted in four interrelated themes explaining how Adaptive Governance Capacity develops within critical energy infrastructure. Although presented separately for analytical clarity, the themes are mutually reinforcing and collectively illustrate the governance processes through which resilience emerges across organizational and institutional boundaries. The findings are supported by representative quotations from interview participants and interpreted in relation to the theoretical framework developed in the previous sections.

The four analytical themes identified through reflexive thematic analysis are summarized in Table 9.

Table 9. Overview of the Analytical Themes.

Theme	Empirical Focus
Institutional coordination across organizational boundaries	Public-private interaction
Adaptive decision-making	Crisis response and coordination
Learning and knowledge integration	Continuous improvement
Emergence of governance capability	System resilience

4.1. Institutional Coordination as the Foundation of Infrastructure Resilience

The thematic analysis identified institutional coordination as the principal governance mechanism shaping the resilience of critical energy infrastructure. Across all interviews, participants consistently emphasized that infrastructure protection depends not only on internal organizational capabilities but also on effective coordination between infrastructure operators, governmental authorities, and other stakeholders responsible for disaster and systemic risk governance. While the implementation of the Serbian Law on Critical Infrastructure has strengthened formal regulatory arrangements, respondents highlighted persistent shortcomings in institutional coordination, particularly regarding governmental oversight, implementation monitoring, and continuous feedback.

Participants repeatedly described governance as predominantly compliance-oriented rather than adaptive. Although infrastructure operators invested considerable effort in aligning internal procedures with legal requirements, they reported receiving limited institutional guidance regarding the adequacy of these measures. As one participant explained:

"We implemented the key requirements of the Law on Critical Infrastructure, but we have never received clear feedback from the competent authorities regarding whether these measures fully meet institutional expectations." (P3)

Several respondents further noted that communication between public authorities and infrastructure operators remains largely episodic and reactive, rather than institutionalized through regular coordination mechanisms. Increased governmental engagement was frequently associated with the outbreak of the war in Ukraine, suggesting that external crises, rather than established governance structures, continue to drive interorganizational cooperation.

Another recurring finding concerned the importance of institutional trust. Participants emphasized that effective governance depends on mutual understanding between regulatory authorities and infrastructure operators. NIS was frequently identified as a positive example because several senior

security professionals had previously served in state security institutions, facilitating communication, trust, and interorganizational cooperation.

Overall, the findings indicate that institutional coordination extends beyond regulatory oversight and should be understood as a continuous governance process based on communication, mutual learning, trust, and shared responsibility. These findings support the view that resilience within critical energy infrastructure is strengthened not simply through legal compliance but through governance arrangements capable of fostering adaptive coordination under conditions of disaster and systemic risk. In this sense, institutional coordination represents the first core dimension of Adaptive Governance Capacity, enabling organizations to anticipate disruptions, exchange knowledge, and coordinate collective responses across institutional boundaries.

4.2. Public-Private Collaboration Beyond Regulatory Compliance

The second major theme concerns the role of public-private collaboration in strengthening the resilience of critical energy infrastructure. Although participants acknowledged the importance of the existing legislative framework, they consistently emphasized that effective infrastructure protection depends less on formal regulation than on the quality of operational cooperation among public authorities, infrastructure operators, and private security organizations. Collaboration was therefore described not merely as a legal obligation but as a governance mechanism essential for ensuring service continuity under conditions of disaster and systemic risk.

Participants stressed that the increasing complexity of contemporary security threats has fundamentally reshaped the traditional division of responsibilities between public and private actors. According to the respondents, critical infrastructure protection can no longer rely exclusively on state security institutions because of the scale, continuity, and specialization required for safeguarding energy systems. As one participant explained:

"There is no realistic alternative. Police or military forces cannot provide continuous protection of critical infrastructure twenty-four hours a day. Private security has therefore become an indispensable part of the protection system." (P6)

The interviews further revealed that Naftna Industrija Srbije (NIS) operates through an extensive collaborative governance network involving specialized private companies responsible for physical protection, technical security systems, patrol services, cash transportation, and facility security. Rather than viewing these arrangements as conventional outsourcing, participants described them as long-term partnerships built upon clearly defined responsibilities, continuous communication, and mutual trust.

Despite these positive experiences, respondents identified important institutional barriers limiting the effectiveness of public-private collaboration. The most frequently cited challenge was the insufficient recognition of the strategic role that private security organizations can play in protecting critical infrastructure. Participants argued that private security providers generate valuable operational knowledge and field-based intelligence that could significantly strengthen situational awareness and support disaster and systemic risk governance if more effectively integrated into public decision-making processes. As one respondent noted:

"The private sector is often present where public institutions are not. We collect information every day that could be valuable for public authorities, but these capacities are still insufficiently recognized." (P8)

Although most participants emphasized the benefits of public–private collaboration, a small number of respondents also expressed reservations regarding inconsistent institutional recognition of private-sector expertise and the uneven implementation of existing coordination mechanisms. These observations illustrate that collaboration remains contingent upon broader institutional commitment rather than formal regulatory provisions alone.

Interestingly, respondents generally viewed the existing legislative framework as an adequate foundation for cooperation. Rather than advocating substantial legal reform, they emphasized the need for stronger institutional commitment, clearer coordination mechanisms, and more consistent implementation of existing regulations. Some participants nevertheless suggested that a dedicated legal framework governing public-private partnerships in critical infrastructure protection could further clarify responsibilities and strengthen long-term cooperation.

Overall, the findings demonstrate that effective collaboration extends well beyond regulatory compliance. Resilience emerges through governance arrangements that promote continuous information exchange, operational coordination, mutual trust, and shared responsibility among public and private actors. These findings reinforce collaborative governance theory while extending it to the context of critical energy infrastructure, where collaboration functions as a dynamic governance capability. As such, public-private collaboration represents the second core dimension of Adaptive Governance Capacity, complementing institutional coordination by strengthening collective learning, resource integration, and coordinated responses to disaster and systemic risks.

4.3. Adaptive Risk Management Through Prevention and Organizational Learning

The third theme highlights the role of adaptive risk management in strengthening the resilience of critical energy infrastructure. Participants consistently emphasized that resilience depends not only on protective measures but also on continuous learning, preventive action, and the capacity of organizations to adapt governance practices in response to evolving disaster and systemic risks. Rather than focusing primarily on crisis response, respondents described prevention as the cornerstone of effective infrastructure protection.

Several participants argued that the greatest vulnerabilities within the Serbian energy sector stem not from deficiencies in physical protection systems but from insufficient preventive planning and limited strategic coordination among responsible institutions. As one participant explained:

"The greatest challenge is not physical protection itself. Our facilities are well protected. The real challenge is prevention and long-term strategic management." (P4)

This perspective was consistently reinforced throughout the interviews. Although respondents expressed confidence in the effectiveness of existing physical and technical protection measures, they emphasized that resilience cannot be achieved through technological safeguards alone. Instead, organizations must continuously anticipate emerging threats, reassess existing protective measures, and adapt governance practices to changing security conditions.

Participants further noted that recent geopolitical developments, particularly the outbreak of the war in Ukraine, substantially influenced organizational learning and risk perception. These events prompted a reassessment of potential threats, including terrorism, sabotage, cyber incidents, and hybrid risks, while simultaneously increasing governmental attention to critical infrastructure protection. External crises were therefore perceived not only as sources of disruption but also as catalysts for institutional learning and governance adaptation.

Another recurring finding concerned the importance of an integrated protection approach. Participants unanimously argued that resilience cannot be achieved through isolated security measures implemented by individual organizations. Instead, effective protection requires integrating preventive planning, physical and technical security, information security, crisis preparedness, interorganizational cooperation, and coordinated recovery mechanisms. As one respondent noted:

"Only an integrated approach allows us to say that everything possible has been done to protect critical infrastructure." (P9)

Overall, the findings indicate that adaptive risk management extends beyond formal procedures and emergency planning. It depends on organizations' ability to learn from operational experience,

revise existing practices, strengthen institutional cooperation, and incorporate lessons from both routine operations and external crises. These findings reinforce contemporary resilience literature by demonstrating that adaptive risk management functions as a dynamic governance capability linking prevention, organizational learning, and institutional adaptation. As such, it represents the third core dimension of Adaptive Governance Capacity, enabling critical infrastructure organizations to anticipate, absorb, and adapt to evolving disaster and systemic risks.

4.4. Adaptive Governance Capacity as an Emerging Governance Capability

The final theme synthesizes the preceding findings by explaining how Adaptive Governance Capacity emerges through the interaction of institutional coordination, public-private collaboration, and adaptive organizational learning. Rather than representing a single organizational capability, participants consistently described resilience as the outcome of interconnected governance processes operating across organizational and institutional boundaries.

The interviews indicate that no individual actor possesses sufficient authority, knowledge, or operational capacity to ensure the protection of critical energy infrastructure independently. Instead, resilience develops through continuous interaction among infrastructure operators, public institutions, regulatory authorities, emergency management organizations, and private security providers. Participants emphasized that effective governance depends not only on technical resources but also on communication, mutual trust, coordinated decision-making, and the capacity to adapt governance arrangements as disaster and systemic risks evolve. These findings suggest that resilience is fundamentally relational, emerging from the collective performance of the governance system rather than from the capabilities of individual organizations.

Participants also consistently described governance as a dynamic process requiring continuous adjustment rather than compliance with fixed procedures. Experiences associated with geopolitical instability, emerging security threats, and the implementation of the Law on Critical Infrastructure demonstrated that governance mechanisms must remain sufficiently flexible to incorporate new knowledge, revise existing practices, and strengthen institutional cooperation in response to changing circumstances. Adaptive capacity was therefore perceived not as a predefined organizational resource but as an evolving governance capability developed through experience, collaboration, and continuous learning.

Importantly, respondents did not perceive institutional coordination, public-private collaboration, and organizational learning as separate governance activities. Instead, these processes were consistently described as mutually reinforcing dimensions of a broader governance system. Institutional coordination facilitated communication and trust, collaboration enabled the mobilization of complementary expertise and resources, while organizational learning strengthened the ability to anticipate, interpret, and respond to emerging risks. Their interaction generated adaptive responses extending beyond individual organizations and contributed to the resilience of the critical energy infrastructure system as a whole.

Building on these empirical findings, this study conceptualizes Adaptive Governance Capacity as the collective capability of interconnected public and private actors to continuously coordinate, collaborate, learn, exchange knowledge, and adapt governance processes to sustain the resilience of critical energy infrastructure under conditions of uncertainty, interdependence, and continuous change. Unlike traditional governance approaches centered primarily on institutional control or regulatory compliance, Adaptive Governance Capacity conceptualizes governance as a dynamic, relational, and adaptive capability emerging through sustained interaction among multiple stakeholders.

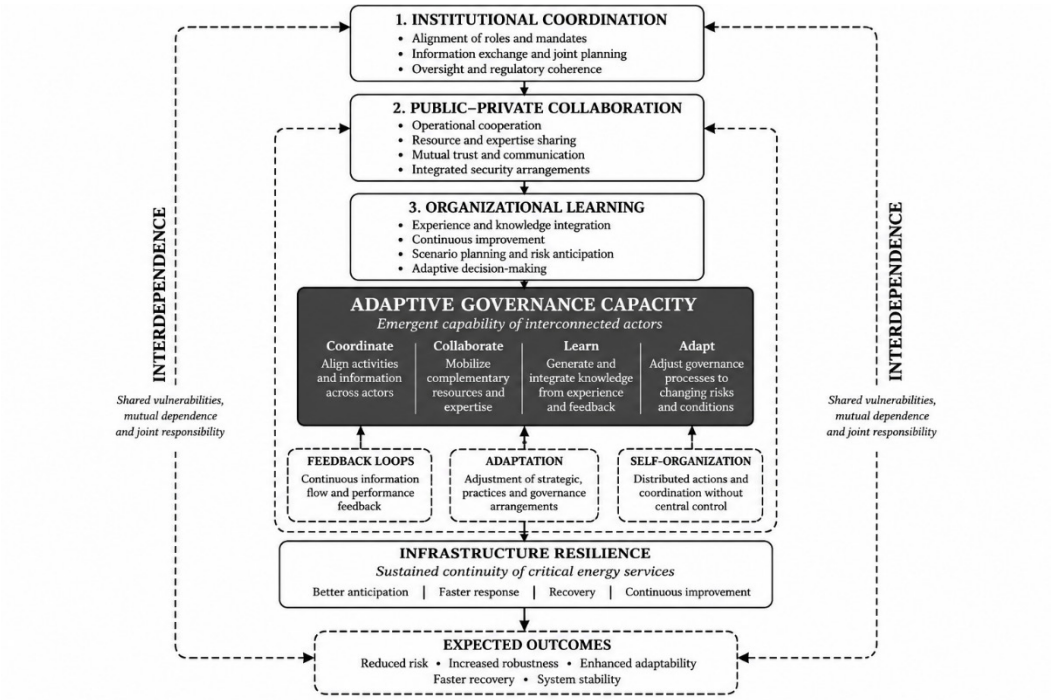

Figure 2. Adaptive Governance Capacity Framework for Disaster and Systemic Risk Governance in Critical Energy Infrastructure.

Figure 2 synthesizes the empirical findings by illustrating how institutional coordination, public-private collaboration, and organizational learning interact through continuous feedback, adaptation, and interdependence to generate Adaptive Governance Capacity. From a Complex Adaptive Systems perspective, governance capacity emerges through self-organization and the dynamic interaction of multiple actors rather than through centralized control. The resulting governance capability strengthens the resilience of critical energy infrastructure by enabling continuous learning, coordinated action, and adaptive responses to disaster and systemic risks.

The findings presented in this chapter provide the empirical foundation for the discussion that follows. The next section interprets these results in relation to Disaster Risk Governance, Collaborative Governance, Organizational Resilience, and Complex Adaptive Systems Theory while examining their theoretical and practical implications for governing disaster and systemic risks within critical energy infrastructure.

5. Discussion

The findings of this study demonstrate that the resilience of critical energy infrastructure cannot be adequately explained through governance approaches centered primarily on regulatory compliance, physical protection, or organizational preparedness. Instead, resilience emerges through dynamic governance processes characterized by institutional coordination, public-private collaboration, organizational learning, and adaptive decision-making. These findings reinforce contemporary perspectives on disaster and systemic risk governance, which emphasize collaboration, learning, and adaptation as essential governance mechanisms for addressing complex and interconnected risks (Aven & Renn, 2010; Klinke & Renn, 2012; UNDRR, 2022).

The empirical findings further extend collaborative governance theory. While previous research highlights trust, shared decision-making, and stakeholder participation as fundamental conditions for collaboration (Ansell & Gash, 2008; Emerson & Nabatchi, 2015), this study demonstrates that, within critical energy infrastructure, collaboration functions as an operational governance capability rather than merely an institutional arrangement. Institutional coordination became effective only

when supported by continuous communication, reciprocal information exchange, clearly defined responsibilities, and mutual trust among infrastructure operators, public authorities, emergency management organizations, and private security providers. These findings suggest that governance relationships must remain adaptive and continuously evolving in order to sustain resilience under conditions of uncertainty.

The results also support recent advances in organizational resilience research, particularly the view that resilience represents a dynamic capability developed through anticipation, learning, and continuous adaptation (Duchek, 2020; Hollnagel, 2014). However, the present study indicates that these adaptive capabilities extend beyond individual organizations. Resilience within critical energy infrastructure emerged through governance networks in which multiple organizations collectively generated adaptive responses to evolving disaster and systemic risks. This interpretation is consistent with Complex Adaptive Systems Theory, which conceptualizes resilience as an emergent property arising from interactions among interconnected actors rather than from the capabilities of isolated organizations (Holland, 2006; Levin, 1998).

The principal theoretical contribution of this study is the conceptualization of Adaptive Governance Capacity as an integrative governance construct linking institutional coordination, collaborative governance, organizational learning, and adaptive decision-making. Rather than proposing a new governance theory, the study synthesizes complementary insights from Disaster Risk Governance, Critical Infrastructure Theory, Collaborative Governance, Organizational Resilience, and Complex Adaptive Systems Theory into a coherent analytical framework. The findings demonstrate that Adaptive Governance Capacity represents the collective capability of interconnected public and private actors to coordinate action, integrate knowledge, continuously learn, and adapt governance processes in response to changing operational conditions. In doing so, the study extends previous governance research by positioning adaptive governance as the principal mechanism connecting collaborative governance with infrastructure resilience (Vidović et al., 2024).

From a practical perspective, the findings underline the importance of strengthening governance arrangements rather than relying solely on additional regulation. Public authorities should reinforce institutional coordination, establish permanent mechanisms for communication with infrastructure operators, and improve the implementation of existing regulatory frameworks (Hanspal, Cvetković, Lipovac, & Popović, 2026). At the organizational level, infrastructure operators should invest in continuous organizational learning, integrated risk management, and long-term collaboration with external stakeholders. The findings also emphasize the strategic role of private security organizations as governance partners whose operational knowledge and field experience can substantially enhance disaster and systemic risk governance.

Several limitations should be acknowledged. The study is based on a single instrumental case study conducted within one major energy company in Serbia, which supports analytical rather than statistical generalization. In addition, the findings primarily reflect the perspectives of professionals working within one organizational context and may not fully capture the views of all actors involved in critical infrastructure governance. Future research should therefore examine Adaptive Governance Capacity across different infrastructure sectors and national contexts using comparative case studies and mixed-method research designs to validate further and refine the proposed framework.

From a Complex Adaptive Systems perspective, Adaptive Governance Capacity emerges through continuous feedback, self-organization, institutional learning, and interdependence among governance actors. Rather than being centrally controlled, resilience develops through the adaptive interactions of multiple organizations responding collectively to evolving disaster and systemic risks.

Although the proposed Adaptive Governance Capacity Framework is informed by empirical evidence from one strategically important energy company, it should be interpreted as a preliminary conceptual framework reflecting how NIS professionals perceive governance processes across the wider critical infrastructure system. Future research incorporating public authorities, emergency management organizations, regulators, and additional infrastructure operators will be essential for further validating and refining the framework.

6. Conclusion

This study examined how Adaptive Governance Capacity emerges within the governance of disaster and systemic risks in critical energy infrastructure through an instrumental case study of Naftna Industrija Srbije (NIS). The findings demonstrate that infrastructure resilience cannot be adequately explained through regulatory compliance, technical protection, or organizational preparedness alone. Instead, resilience emerges through the dynamic interaction of institutional coordination, public-private collaboration, organizational learning, and adaptive decision-making. These interconnected governance processes enable organizations to anticipate, respond to, and adapt to evolving risks within increasingly complex and interdependent operational environments.

The principal theoretical contribution of this study is the conceptualization of Adaptive Governance Capacity as an integrative governance construct that connects Disaster Risk Governance, Critical Infrastructure Theory, Collaborative Governance, Organizational Resilience, and Complex Adaptive Systems Theory. Rather than proposing a new governance theory, the study synthesizes these complementary perspectives into a coherent analytical framework that explains how governance capabilities emerge through continuous interaction, learning, feedback, and adaptation among multiple public and private actors. In doing so, the proposed Adaptive Governance Capacity Framework provides a conceptual foundation for understanding resilience as an emergent property of governance networks operating under conditions of uncertainty, interdependence, and continuous change.

From a practical perspective, the findings suggest that strengthening the resilience of critical energy infrastructure requires governance arrangements that extend beyond regulatory compliance. Public authorities should promote sustained institutional coordination, strengthen mechanisms for knowledge exchange, and foster long-term collaboration with infrastructure operators and private security organizations. Likewise, infrastructure operators should invest in continuous organizational learning, integrated risk management, and adaptive governance practices capable of responding to emerging disaster and systemic risks. The framework proposed in this study may therefore serve as a useful reference for policymakers, regulators, and infrastructure operators seeking to enhance governance resilience within critical infrastructure systems.

This study has several limitations. It is based on a single instrumental case study conducted within one critical energy infrastructure organization in Serbia and therefore supports analytical rather than statistical generalization. Future research should examine the applicability of the Adaptive Governance Capacity Framework across different critical infrastructure sectors, governance systems, and national contexts using comparative and mixed-method research designs. Such research would contribute to further refinement of the framework and deepen our understanding of adaptive governance under increasingly complex risk conditions.

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Informed Consent Statement: Participation was voluntary, and informed consent was obtained from all participants.

Data Availability Statement: The data supporting the findings of this study are not publicly available due to the sensitive nature of the research and confidentiality agreements with the participating organization. De-identified data may be made available by the corresponding author upon reasonable request and subject to organizational approval.

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