GLOBAL COOPERATION, HYDROGEN STRATEGIES AND INFORMATION PROCESSES AS PILLARS OF ENERGY CRISIS MANAGEMENT

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Abstract: *The current global energy crisis should not be understood merely as a technological or economic challenge, but rather as a crisis that touches upon fundamental questions of global governance and information management. This article examines the role of information processes in global energy policy, focusing its analysis on hydrogen as a strategic energy carrier. Based on an interdisciplinary literature review of scientific publications, international strategy documents, and reports from multilateral organizations, the article analyzes transnational hydrogen strategies, governance agreements, and digital energy infrastructures. The findings demonstrate that hydrogen-based energy systems can only be functional, resilient, and socially acceptable in the long term if they are supported by robust information architectures that enable coordination, transparency, and trust among the stakeholders involved. The article thus makes a conceptual contribution at the intersection of energy policy and information science, underscoring the central importance of information processes for managing global energy crises.*

Keywords: *global energy crisis, hydrogen economy, information processes, international cooperation, energy governance*

1. Introduction

The global energy crisis has intensified considerably in recent years. Geopolitical conflicts, climate-related extreme events, and the growing demand for energy-intensive technologies have exposed structural weaknesses in existing energy systems. In particular, infrastructures based on fossil fuels are proving vulnerable to supply disruptions, price fluctuations, and geopolitical influences. These vulnerabilities are deeply rooted in historically developed energy infrastructures and institutional arrangements, limiting the scope for political action at both national and international levels. In light of these developments, renewable energies and alternative energy sources are increasingly becoming central to long-term strategies for decarbonization and energy security.

In this context, hydrogen is increasingly being discussed as a strategic energy source. It is believed to have the potential to link renewable electricity generation with industrial use, mobility, and long-term energy storage, thereby decarbonizing sectors with limited access to direct electrification. However, hydrogen's role is not limited to the technological replacement of fossil fuels. Its large-scale deployment requires complex transnational coordination processes, the harmonization and adaptation of regulations, and long-term policy commitments.

Hydrogen-based energy systems should therefore be understood as socio-technical and state-intensive systems whose functionality largely depends on political, institutional, and informational frameworks. Decisions regarding certification systems, supply chains, and sustainability standards are the result of political negotiation processes shaped by the availability of information, knowledge asymmetries, and communication structures.

Consequently, this article analyzes the role of information-based governance structures in transnational hydrogen strategies. The aim is to examine the institutional conditions under which information processes can contribute to the resilience, stability, and social acceptance of hydrogen-based energy systems. Hydrogen is thus conceived not primarily as a technological innovation, but as an information-dependent transformation project of global energy policy.

2. Theoretical Background

The increasing interconnectedness of the global economy and the steadily growing global energy demand have fundamentally altered the relationship between energy, political governance, and power dynamics. Energy systems can hardly be understood today as primarily nationally organized infrastructures, but are increasingly structured as highly networked, transnational systems. This development has significantly intensified the interdependencies between states, markets, and institutions, leading to energy security being increasingly discussed as a cross-border challenge (Yergin, 2006; Cherp and Jewell, 2011).

This increases the importance of governance issues in energy policy. While energy governance describes the institutional and political frameworks for managing energy systems, information governance refers to the normative, organizational, and technical arrangements that structure access to, use of, and control of energy-related information. Information processes, in turn, denote the operational practices of collecting, processing, standardizing, and disseminating data and knowledge within these governance structures. This article assumes that current energy crises are less attributable to technological bottlenecks than to

deficits in institutional coordination, governance structures, and information-related management. Information processes are therefore understood as constitutive elements of energy policy decision-making, coordination, and legitimacy.

While existing approaches to energy governance primarily focus on institutional coordination, regulatory arrangements, and market mechanisms, they often implicitly treat information as a technical or administrative tool. Information-related aspects typically appear as supporting infrastructure, not as an independent political resource.

This article distinguishes itself from this perspective by understanding information governance not as a supplement to existing governance structures, but as a constitutive dimension of energy policy steering. Information is conceptualized here as a resource relevant to power and distribution, the organization of which structures access, scope for action, and opportunities for cooperation in global energy systems.

2.1 Global Cooperation and Energy Governance

In recent decades, energy policy has increasingly shifted from nation-state-oriented approaches to multi-stage and transnational forms of cooperation. Energy policy research largely agrees that unilateral national actions are of limited use in addressing systemic risks such as supply disruptions, price fluctuations, or geopolitical conflicts, given globally interconnected energy systems (Yergin, 2006; Cherp and Jewell, 2011). Global energy systems are characterized by spatially decoupled production, transport, and consumption structures, creating systemic vulnerabilities that necessitate institutional coordination beyond the nation-state.

Against this backdrop, international agreements, the harmonization of regulatory frameworks, and joint infrastructure projects have become established as key instruments for ensuring energy security and system stability. However, these cooperation mechanisms not only fulfill coordinating functions but also reflect and perpetuate political power relations. States with high economic and technological performance often possess disproportionate influence over regulatory processes, technical standards, and market access. Information asymmetries further amplify these dynamics, as unequal access to data, knowledge, and institutional resources structurally favors the power of individual actors.

2.2 Hydrogen as a Strategic Energy Carrier

Current research views hydrogen as a key technology for far-reaching decarbonization processes, particularly in the context of sector coupling and the substitution of fossil fuels in

areas difficult to decarbonize. Accordingly, national and supranational hydrogen strategies assign hydrogen a central role in the transformation of future energy systems (Töpler and Lehmann, 2017; Smil, 2017; Das, 2024). At the same time, numerous studies point to significant economic, infrastructural, and regulatory challenges associated with the implementation of hydrogen-based solutions.

Hydrogen is particularly well-suited as an analytical example because its value chains are structurally transnational. Production sites, transport corridors, storage infrastructures, and consumption centers are often geographically separated, necessitating long-term political commitments as well as coordinated institutional and informational governance mechanisms. While much of the existing literature focuses on technological feasibility, cost developments, and supply chain optimization, issues of institutional governance and informational coordination are often only addressed implicitly. This paper, however, argues that these very dimensions are constitutive for the functionality, stability, and political acceptance of hydrogen-based energy systems.

2.3 Information Processes in Energy Transitions

From an information science perspective, it can be stated that modern energy systems are structurally dependent on data- and knowledge-based processes. Digital infrastructures such as smart grids, digital monitoring systems, and AI-supported optimization tools have led to energy infrastructures increasingly operating as complex socio-technical systems whose stability depends on continuous data collection, processing, and communication (Smil, 2017). Information processes form the basis for the real-time control of energy flows, for predictive infrastructure planning, and for coordination between a multitude of diverse stakeholders.

At the same time, empirical studies show that information asymmetries, a lack of transparency, and inadequate communication can undermine trust in energy technologies and significantly impair the public acceptance of transformation projects (Crossland, 2017). Transparent information flows, common standards, and strategically aligned communication processes are therefore of particular importance, especially in the context of international cooperation in the hydrogen economy. Unequal access to data, technological knowledge, and institutional capacities, particularly between the Global North and the Global South, can contribute to the reproduction of existing power imbalances and thus influence the structure of international decision-making processes.

Despite their growing importance, information processes have so far received only limited systematic consideration in energy policy research. A stronger integration of

information science perspectives therefore appears necessary in order to grasp the governance challenges of future energy systems in a more nuanced way and to better understand the informational foundations of global energy crises.

2.4 Information Governance and Power Asymmetries in Global Hydrogen Systems

While previous sections examined global cooperation, hydrogen as a strategic energy carrier, and information-related processes within the context of the energy transition, this section focuses on information governance itself. In this context, information governance refers to the entirety of institutional, normative, and technical regulations that structure access to, use of, and control of energy-related data and knowledge, thereby shaping energy policy decision-making processes (Roehrkasten, 2015; Crossland, 2017). Information governance is of particular importance in the context of hydrogen-based energy systems, as their transnational value chains are associated with high coordination requirements.

The transnational organization of production, transport, and consumption chains means that numerous actors with heterogeneous institutional backgrounds, regulatory frameworks, and varying levels of knowledge and expertise are involved. Coordinating these actors requires reliable information infrastructures, common data standards, and transparent communication mechanisms that extend beyond national jurisdictions (International Energy Agency, 2023; Quitzow *et al.*, 2024).

The literature on energy security increasingly emphasizes that the resilience of modern energy systems is not solely ensured by physical redundancies or the diversification of supply sources, but depends significantly on the ability to efficiently generate, process, and disseminate relevant information under crisis conditions (Yergin, 2011; Heffron and Sokołowski, 2024). Information-based governance structures help reduce uncertainty, establish early warning mechanisms, and enable coordinated policy responses.

At the same time, information governance is closely linked to issues of political power and global inequality. Actors with privileged access to data, technical standards, and digital platforms have structural advantages in international negotiation processes (Sadik-Zada, 2021; Plank *et al.*, 2023). Unequal information capacities can foster asymmetric decision-making processes and reproduce existing dependencies. From this perspective, information governance should not be understood as a supplementary dimension of existing energy governance structures, but rather as a constitutive prerequisite for transnational coordination and the systemic resilience of hydrogen-based energy systems.

Empirically, this approach offers the possibility of investigating information governance through qualitative document analysis, expert interviews, or comparative case studies of international hydrogen projects. For example, differences in data access, the definition of technical standards, or the institutional anchoring of information-related responsibilities, and their impact on coordination, trust, and crisis response capabilities, can be analyzed.

3. Methodology

This work is based on a qualitative, literature-oriented analysis of scientific publications, strategy papers, and reports from international organizations (including the IEA, the EU, and national hydrogen strategies). The aim was not a comprehensive systematic review, but rather a theory-driven selection of relevant documents that reflect key discourses and institutional frameworks of global hydrogen policy. The literature selection focused thematically on global cooperation, the hydrogen economy, and information management.

The documents were analyzed using thematic content analysis. This analysis was guided by the dimensions of global cooperation, information processes, and information governance developed in the theoretical section and aimed to identify recurring patterns, dominant lines of argumentation, and conceptual gaps. This methodological approach appears particularly suitable for analyzing new governance frameworks in the field of hydrogen policy and for further developing existing theoretical approaches.

The selection of literature follows a theory-driven approach and comprises three key corpora:

(1) energy policy and geopolitical works on energy security and global energy governance,

(2) studies on the hydrogen economy and transnational energy systems, and

(3) information science and political economy contributions on information governance, power, and knowledge structures.

In particular, works dealing with cross-border energy systems, institutional coordination, and information-related control mechanisms were selected. The aim was not to create a comprehensive systematic literature review, but rather to bring together and conceptually integrate key theoretical strands.

Therefore, the selection does not claim to be exhaustive, but serves to analytically condense relevant perspectives at the intersection of energy policy, globalization, and information research.

4. Results

The analysis of the hydrogen strategies examined shows that they are predominantly transnational in nature. The production, transport, and use of hydrogen frequently cross national borders and therefore require close cross-border cooperation. Establishing stable and reliable hydrogen value chains necessitates common technical standards, harmonized regulatory frameworks, and long-term political commitments. Given the high infrastructural and economic costs involved, unilateral national approaches often prove ineffective in this context.

The analyzed strategy documents suggest that information processes implicitly function as critical infrastructure, particularly with regard to coordination, monitoring, and crisis response. Digital platforms, reliable data and information exchange mechanisms, and transparent communication structures play a central role in coordinating international hydrogen projects and ensuring the reliability of complex energy systems. Information flows contribute to both operational management and building trust between participating states, companies, and institutions.

The analysis also shows that the design of information governance structures has a decisive influence on the resilience of hydrogen-based energy systems. The strategy documents and policy frameworks examined illustrate that issues of data access, standardization, and institutional responsibility for information flows are often addressed implicitly, even though they play a central role in the coordination and functioning of transnational hydrogen projects.

Particularly in multinational cooperation projects, fragmented information architectures prove to be potential risk factors. A lack of common data standards, insufficient transparency along value chains, and unclear responsibilities within information-related governance structures can exacerbate coordination problems and impair the crisis response capabilities of the actors involved.

At the same time, the results indicate that information-based governance mechanisms, such as joint monitoring systems, transparent certification procedures, and coordinated communication strategies, can make a significant contribution to stabilizing international hydrogen cooperation. The findings show that information governance structures act as a link between technological infrastructure and political control, thus influencing the resilience and legitimacy of hydrogen-based energy systems.

Another finding of the analysis concerns the public acceptance of hydrogen technologies. The evaluation of the strategy papers examined suggests that this depends

significantly on information-related factors such as transparency, risk communication, and participation. Transparent communication, an understandable presentation of risks, and participatory information processes can significantly contribute to reducing uncertainty and promoting public acceptance. Without these elements, even technically sophisticated projects risk encountering public resistance.

Overall, the results clearly show that technological maturity alone is not sufficient for the successful establishment of hydrogen-based energy systems. Crucially, robust government structures and professional information management are essential, fostering cooperation, building trust, and ensuring societal legitimacy.

5. Discussion

The results of this analysis suggest that the hydrogen transition should be understood as a fundamentally information-dependent socio-technical transformation. While much of the existing literature focuses on technological efficiency, cost development, and market design, this article demonstrates that the institutional design of information-related structures plays an independent and, to date, insufficiently conceptualized systemic role in the stability and resilience of hydrogen-based energy systems.

Hydrogen-based energy systems operate across borders and sectors and are therefore particularly dependent on coordinated, reliable, and transparent information flows. The results presented show that fragmented or opaque information architectures can exacerbate coordination deficits, increase uncertainties, and undermine trust among the actors involved. Robust and interoperable information infrastructures, on the other hand, contribute to structuring decision-making processes and enable collective action within complex political and institutional frameworks.

Furthermore, the results show that information-related structures are closely linked to issues of political power and global inequality. Actors with privileged access to data, technical standards, and digital platforms have expanded their influence on global hydrogen governance. Without targeted institutional balancing mechanisms, there is an analytical risk that hydrogen-based energy systems will reproduce or exacerbate existing dependencies.

Another key finding concerns the social acceptance of hydrogen-based technologies. The analysis confirms findings from existing literature that transparent information provision, comprehensible decision-making processes, and participatory communication formats are essential prerequisites for political legitimacy. Information-related governance mechanisms

act as a link between technical implementation and public perception and significantly influence the extent to which transformation processes are perceived as credible and fair.

Overall, the discussion underscores that hydrogen cannot be understood as a purely technological solution to the energy crisis. Rather, it is a governance-intensive transformation whose success depends significantly on the targeted design of institutional and informational frameworks. Information-related structures form a crucial link between technical infrastructure, political coordination, and societal legitimacy.

5.1 Policy and Governance Implications

Several conclusions for energy and information policy can be drawn from the results of the analysis. First, the study suggests that hydrogen strategies should be understood more as governance projects than is currently the norm. Policymakers are therefore urged to invest not only in physical infrastructure such as electrolyzers, pipelines, and storage facilities, but also in digital and institutional infrastructure that enables and structures the cross-border exchange of data, knowledge, and information.

Second, the findings underscore the importance of internationally coordinated information and data standards for the functioning of global hydrogen markets. Uniform certification systems, transparent sustainability criteria, and interoperable data platforms can help reduce market fragmentation, lower coordination costs, and build trust among the participating states, companies, and institutions. International organizations and multilateral forums could play an important moderating role in this process, particularly in mitigating power imbalances and promoting more inclusive governance structures.

Third, the results show that societal acceptance of hydrogen-based technologies should not be considered a secondary variable in energy policy decisions. Early, transparent, and participatory information processes are crucial to reducing uncertainty, minimizing public resistance, and ensuring political legitimacy. This is particularly true for large-scale infrastructure projects, whose local impacts are immediately visible, while their economic or climate benefits often materialize at different times and in different locations.

The analysis suggests explicitly anchoring information management as a component of future energy security strategies. In times of geopolitical uncertainty, increasing digital vulnerabilities, and growing system complexity, the ability to reliably generate, process, and communicate energy-related information acquires an independent security policy dimension. Hydrogen-based energy systems can only contribute to the stabilization of global energy systems if their informational foundations are as resilient as their technical components. This

expands classical energy security concepts to include an explicitly informational perspective. The implications formulated here are based on a conceptual analysis and do not claim immediate or direct political feasibility.

6. Conclusion

This analysis shows that addressing the global energy crisis cannot be achieved solely through technological innovation. Hydrogen can only play a key role in future energy systems if its use is embedded in cooperative and transnational governance frameworks based on robust, transparent, and inclusive information processes. Information management thus proves to be a strategically central, yet hitherto underestimated, component of global energy policy.

By conceptualizing hydrogen-based energy systems as information-dependent socio-technical infrastructures, this contribution offers a more comprehensive theoretical approach to energy transition research. Information processes are understood not as supporting tools, but as constitutive elements of political governance, societal legitimacy, and systemic resilience. This underscores that information infrastructures are of comparable importance to the functioning of future energy systems as physical energy infrastructures.

This underscores the need for future research to examine the information policy dimensions of the energy transition in greater depth using empirical methods. In particular, international hydrogen projects, transnational data platforms, and digital governance mechanisms offer considerable potential for the systematic analysis of the interplay between information, power, and energy security.

In summary, the success of the hydrogen transition depends not only on technical feasibility and economic viability, but also crucially on the ability to shape global information processes consciously, in a coordinated manner, and responsibly. Strengthening the informational foundations of global energy policy could therefore prove to be a decisive factor in transforming hydrogen from a strategic option into a stabilizing element of future energy systems.

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