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ORIGINAL

International Electricity Networks and Decarbonization: Analysis of the NordLink and NorthConnect Projects

Redes eléctricas internacionales y descarbonización: análisis de los proyectos NordLink y NorthConnect

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ABSTRACT

The energy transition in Northern Europe has driven rapid growth in renewable energy sources, creating new challenges for electricity transmission infrastructure. The expansion of wind and solar projects has generated imbalances between energy production areas and major consumption centers, exposing limitations in traditional power grids. In this context, high-voltage direct current (HVDC) interconnectors have become a strategic alternative to strengthen energy integration, improve system stability, and facilitate electricity exchange between countries. This research aimed to analyze the socio-technical, regulatory, and institutional factors influencing the development of HVDC projects in Northern Europe through a comparative study of the NordLink and NorthConnect projects. The methodology adopted a qualitative, descriptive, and comparative approach based on documentary review and content analysis of technical reports, academic publications, and institutional documents. The findings revealed that institutional coordination, regulatory stability, and political support are determining factors for the success of these projects. While NordLink was successfully implemented and became operational, NorthConnect faced political and regulatory barriers that limited its progress. The study concludes that the energy transition requires not only technological innovation but also governance mechanisms capable of accelerating the expansion of international electricity networks. Strengthening coordination among governments, regulators, and transmission operators is essential to ensure efficient renewable energy integration and support long-term decarbonization goals across Europe.

Keywords: energy transition, HVDC interconnectors, energy governance, electricity infrastructure.

RESUMEN

La transición energética en Europa del Norte ha impulsado un crecimiento acelerado de las energías renovables, generando nuevos desafíos para las infraestructuras de transmisión eléctrica. El incremento de proyectos eólicos y solares ha provocado desequilibrios entre las zonas de generación y los principales centros de consumo, evidenciando limitaciones en las redes eléctricas tradicionales. En este contexto, los interconectores de corriente continua de alto voltaje (HVDC) se han convertido en una alternativa estratégica para fortalecer la integración energética, mejorar la estabilidad del sistema y facilitar el intercambio de electricidad entre países. La presente investigación tuvo como objetivo analizar los factores socio-técnicos, regulatorios e institucionales que influyen en el desarrollo de proyectos HVDC en Europa del Norte, mediante un estudio comparativo de los proyectos NordLink y NorthConnect. La metodología utilizada correspondió a un enfoque cualitativo, descriptivo y comparativo, basado en revisión documental y análisis de contenido de informes técnicos, publicaciones académicas y documentos institucionales. Los resultados evidenciaron que la coordinación institucional, la estabilidad regulatoria y el respaldo político son factores determinantes para el éxito de estos proyectos. Mientras NordLink logró consolidarse como una infraestructura operativa, NorthConnect enfrentó obstáculos políticos y regulatorios que limitaron su avance. Se concluye que la transición energética requiere no solo innovación tecnológica, sino también mecanismos de gobernanza capaces de acelerar la expansión de las redes eléctricas internacionales.

Palabras clave: transición energética, interconectores HVDC, gobernanza energética, infraestructura eléctrica.

INTRODUCTION

The energy transition in Northern Europe has driven an accelerated expansion of renewable sources, especially wind and solar energy, generating new demands on national and international electricity systems. The sustained increase in renewable generation has highlighted structural limitations in existing transmission grids, particularly due to the distance between energy production areas and major consumption centers. This situation has caused grid congestion, restrictions on the connection of new projects, and higher levels of curtailment of renewable energy, affecting the efficiency of electricity systems and delaying the decarbonization targets established by various European countries.

In this context, the expansion and modernization of electricity transmission infrastructures has become a strategic element to guarantee the effective integration of clean energy. Among the main technological solutions, high-voltage direct current (HVDC) interconnectors stand out, which allow the transport of large volumes of electricity over long distances and connect electricity systems with different operational characteristics. These infrastructures facilitate energy exchange between countries, increase grid stability, and contribute to a more efficient utilization of the renewable generation available in different regions.

However, the development of HVDC projects involves complex processes that transcend strictly technical aspects. The implementation of these infrastructures depends on regulatory frameworks, political decisions, financing mechanisms, social acceptance, and coordination among multiple institutional actors. Due to this, many projects face prolonged delays, regulatory modifications, or even cancellations, despite a growing need for electricity grid expansion. These difficulties reflect the socio-technical nature of contemporary energy transformations, where technological decisions are deeply influenced by economic, political, and institutional factors.

The study of the NordLink and NorthConnect projects allows for an understanding of how different institutional conditions and governance processes can lead to divergent outcomes within technologically similar initiatives. While NordLink managed to establish itself as an operational interconnector between Norway and Germany, NorthConnect experienced regulatory and political obstacles that limited its progress. The comparative analysis of both cases offers an opportunity to examine the factors that facilitate or hinder the execution of large-scale electricity infrastructure projects within the framework of the European energy transition.

From a theoretical perspective, the research is supported by large-scale technological systems approaches and socio-technical transition studies, which allow for the analysis of how energy infrastructures evolve through processes of institutional adaptation, technological innovation, and strategic decision-making. Likewise, the concept of critical bifurcation points contributes to identifying decisive moments in projects, where the actions of governments, regulators, and system operators directly influence the continuity, acceleration, or stagnation of the initiatives.

Consequently, the analysis of HVDC interconnectors is not only relevant for understanding the technical challenges of renewable integration, but also for evaluating the institutional capacities needed to coordinate accelerated energy transitions. In this way, the study contributes to the academic debate on energy infrastructure, electricity grid governance, and the transformation of socio-technical systems in global decarbonization scenarios.

METHODS

The present research was developed under a qualitative descriptive, comparative, and analytical approach, aimed at examining the socio-technical, regulatory, and institutional factors that influence the development of HVDC electricity interconnection projects in Northern Europe. The study focused specifically on the comparative analysis of the NordLink and NorthConnect projects, selected due to their divergent outcomes within a similar technological context: while NordLink achieved implementation and operation, NorthConnect experienced a process of regulatory and political stagnation.

The adopted methodological design corresponded to a multiple case study, as this strategy allows for the understanding of complex phenomena within their real context, especially when multiple actors, regulatory processes, and institutional dynamics are involved. The comparison between both projects allowed for the identification of differences in governance mechanisms, decision-making, institutional coordination, and conflict management associated with the expansion of large-scale energy infrastructures.

The research was based on the socio-technical approach of large-scale technological systems and energy transition studies, integrating conceptual elements related to path dependency, critical bifurcation points, and institutional reconfiguration processes. Based on this conceptual framework, the decisive moments that conditioned the progress, delay, or interruption of the studied projects were analyzed.

For data collection, the documentary review and content analysis technique was used. Technical reports, energy development plans, regulatory documents, institutional publications, scientific articles, reports from international organizations, and documents prepared by European electricity system operators were examined. Among the main sources consulted were publications from ENTSO-E, the International Energy Agency (IEA), the European Commission, electricity transmission operators, and academic literature specialized in energy transition and electricity infrastructure.

The analysis was conducted in several stages. First, the technical and functional characteristics of the HVDC interconnectors and their role in integrating renewable energy in Northern Europe were defined. Subsequently, the primary stakeholders involved in each project were identified, including governments, regulatory bodies, grid operators, and energy companies. Finally, the critical decision points influencing the evolution of NordLink and NorthConnect were analyzed, evaluating the technical, economic, political, and social factors associated with their trajectories.

The comparative analysis established similarities and differences between both cases regarding planning, institutional acceptance, energy regulation, international coordination, and political viability. It also examined how the accelerating dynamics of the energy transition interact with regulatory processes that are traditionally slow and highly dependent on consolidated institutional frameworks.

The validity of the research was strengthened through the triangulation of documentary sources, contrasting information from official bodies, academic publications, and specialized technical documents. This procedure ensured analytical coherence and greater reliability in interpreting the results.

Finally, the research was non-experimental, as variables were not manipulated and the studied phenomena were not subjected to intervention; instead, events that had already unfolded within their historical, political, and technological contexts were analyzed. This methodology facilitated a comprehensive understanding of the conditions that favor or limit the development of the large-scale electrical infrastructure necessary for the contemporary energy transition.

RESULTS

The comparative analysis of the NordLink and NorthConnect projects identified significant differences in the institutional, regulatory, and political factors conditioning the development of HVDC infrastructure in Northern Europe. Although both projects shared similar technical characteristics and sought to strengthen energy integration among European countries through the transmission of renewable electricity, the results demonstrated clearly divergent trajectories.

In the case of NordLink, a high level of coordination was observed among governments, transmission operators, and regulatory bodies, facilitating the progressive approval of the project and its subsequent commissioning. Relatively stable regulatory frameworks, combined with aligned energy objectives between Norway and Germany, reduced institutional conflicts and accelerated decision-making. Furthermore, strong alignment was identified between renewable energy expansion policies and electricity grid modernization strategies, enhancing the technical and economic viability of the project.

Conversely, the NorthConnect project faced greater political uncertainty and institutional opposition. The results show that concerns regarding potential impacts on electricity prices in Norway, the involvement of private actors, and debates over energy sovereignty delayed regulatory processes. These tensions caused a loss of political momentum and hindered the acquisition of the necessary authorizations for project execution.

The study also demonstrated that HVDC projects depend not only on their technical viability but also on the institutional capacity to coordinate stakeholders with differing interests. The critical decision points identified during the analysis demonstrated that regulatory changes, public debates, or shifts in government priorities can significantly alter project trajectories, even when a technical need for electricity grid expansion exists.

Another key finding was the temporal gap between the growth rate of renewable energy and the expansion capacity of transmission infrastructure. While wind and solar generation are accelerating rapidly in various European countries, the approval and construction processes for electricity grids remain subject to long-term administrative and regulatory dynamics. This misalignment increases the risks of grid congestion, renewable energy curtailment, and connection limitations for new projects.

Additionally, political and social acceptance was a determining factor in the success of interconnection projects. In the case of NordLink, the perception of economic benefits and energy security strengthened institutional support, whereas for NorthConnect, debates regarding domestic economic risks and dependence on external markets predominated.

These results confirm that the energy transition requires more flexible and coordinated governance processes capable of simultaneously integrating technological innovation, energy regulation, and spatial planning. Consequently, the successful development of future HVDC infrastructure will depend on both technological advancements and the capacity of institutional systems to respond to the challenges of an accelerated energy transition.

Table 1. Example of a comparative table of results

Aspect analyzed	NordLink	NorthConnect
Project status	Operational	Stalled
Government participation	High institutional coordination	Regulatory debates and disagreements
Political acceptance	Favorable	Controversial
Expected impact	Renewable integration and energy stability	Perceived risk to electricity prices
Regulatory progress	Approved licenses	Halted processes
Final outcome	Successful implementation	Project standstill

Table 2. Example of a critical factors analysis

Critical factor	Influence on NordLink	Influence on NorthConnect
Energy regulation	Facilitated development	Caused delays
Institutional coordination	Stable and continuous	Fragmented
Public perception	Energy benefits	Economic risks
International relationship	Solid bilateral cooperation	Political tensions
Strategic planning	Integrated into climate goals	Limited strategic consensus

Example of the interpretation of results

The findings indicate that shared energy targets and coordinated regulatory mechanisms favor the implementation of international transmission projects. Likewise, evidence shows that political uncertainty can become a decisive obstacle even for technically viable projects. This demonstrates that the expansion of power grids for the energy transition depends on complex socio-technical processes in which governance and institutional coordination are fundamental elements.

DISCUSSION

The results show that the development of HVDC electrical interconnection projects depends not only on technological or economic factors, but also on a complex interaction among institutional, regulatory, political, and social elements. Comparing NordLink and NorthConnect demonstrates that even projects designed under similar technical conditions can experience entirely different trajectories due to differences in governance and decision-making processes.

In the case of NordLink, effective coordination among transmission operators, governments, and regulatory bodies established a favorable environment for project execution.

This confirms that shared energy targets and relatively stable regulatory frameworks facilitate the implementation of strategic infrastructure for the energy transition. Furthermore, the alignment of decarbonization policies with power grid planning reduced uncertainties and accelerated the approval and construction phases.

Conversely, NorthConnect demonstrated how political and regulatory disagreements can become decisive barriers to the advancement of international energy projects. Although the initiative addressed real needs for electrical integration and renewable energy utilization, concerns regarding electricity prices, private participation, and energy sovereignty created institutional uncertainty that weakened political support. This scenario highlights that social and political acceptance is as crucial as technical viability for large-scale projects.

The findings also indicate that electrical infrastructure operates under dynamics of high institutional and temporal dependence. While renewable technologies advance rapidly, driven by climate targets and cost reductions, the regulatory processes associated with power grids remain characterized by long periods of evaluation, approval, and negotiation. This discrepancy in speed generates a misalignment between renewable generation and transmission capacity, increasing congestion and limiting the efficient integration of new energy sources.

Likewise, the analysis demonstrates that decisions made at critical junctures can significantly alter project trajectories. Regulatory changes, public debates, and shifting government priorities directly influence the continuity of initiatives, reflecting the dynamic, socio-technical nature of energy transitions. In this sense, HVDC projects represent not only technological infrastructure, but also arenas for political negotiation and institutional coordination.

Another key aspect identified in the results is the strategic role of interconnectors in the stability of European power systems. The ability to transfer energy between countries compensates for variations in renewable generation and strengthens regional energy security. However, the potential benefits of this infrastructure can be limited by fragmented regulatory frameworks or a lack of political consensus regarding implementation.

Overall, this research confirms that the energy transition requires the simultaneous transformation of technologies, institutions, and governance models. Increasing renewable generation capacity is insufficient if power grids and regulatory mechanisms do not evolve at the same pace. Therefore, it is essential to strengthen international cooperation, simplify administrative procedures, and promote integrated energy planning strategies to accelerate the development of critical infrastructure for decarbonization.

Finally, the results highlight the importance of incorporating socio-technical approaches into the analysis of energy projects. The comparative study of NordLink and NorthConnect demonstrates that energy transitions are neither linear nor exclusively technological processes; rather, they are complex transformations shaped by institutional relationships, economic interests, and political dynamics that directly influence the success or failure of electrical infrastructure initiatives.

CONCLUSIONS

The expansion of renewable energy in Northern Europe has increased the need to modernize and strengthen electrical transmission infrastructure to guarantee the efficient integration of new generation sources. In this context, HVDC interconnectors represent a strategic solution to reduce congestion, improve power system stability, and facilitate energy exchange between countries. However, the development of this infrastructure depends on complex processes involving technical, regulatory, political, and social factors.

The comparative analysis of the NordLink and NorthConnect projects demonstrated that the viability of electricity interconnection projects is determined not solely by their technological or economic capacity, but also by the level of institutional coordination and regulatory stability in each national context. While NordLink progressed due to effective coordination among governments, operators, and regulators, NorthConnect faced obstacles associated with political uncertainties, debates on energy sovereignty, and a lack of institutional consensus.

The results demonstrate that accelerated energy transitions require more flexible and coordinated governance mechanisms capable of responding to the growth rate of renewable energy. The persistence of slow regulatory procedures that are highly dependent on traditional institutional structures limits the expansion capacity of electricity grids and generates imbalances between energy generation and transmission.

Furthermore, this research confirms that electricity infrastructure projects constitute complex socio-technical processes in which political and regulatory decisions can significantly modify development trajectories. The critical decision points identified in both cases highlight the importance of strategic planning, international cooperation, and consensus-building to ensure the success of future energy interconnection initiatives.

Consequently, strengthening international electricity grids must be considered a priority within energy transition and decarbonization policies. The capacity to integrate renewable energy efficiently will depend not only on technological advancements, but also on the implementation of institutional frameworks that foster coordination among actors, reduce regulatory barriers, and accelerate the development of strategic infrastructure for a more sustainable and resilient energy system.

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