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Coal Dependency to Net Zero: Evaluating the Strategic Role of the National Grid in Driving the UK's Sustainable Energy Future

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ABSTRACT

The United Kingdom's transition from coal dependency to a net-zero energy system marks a critical evolution in its energy landscape, driven by climate imperatives, policy reforms, and technological advancements. Historically, coal fueled the nation's industrial growth, leaving profound socio-economic and environmental impacts. However, the shift toward renewables, such as wind and solar, has necessitated a transformation in energy governance, infrastructure, and market mechanisms. Central to this transition is the strategic role of the National Grid as a Transmission System Operator (TSO), tasked with integrating renewable energy, ensuring grid stability, and enabling the decarbonization of the electricity and gas sectors. This paper examines the historical reliance on coal, the challenges of integrating renewables, and the governance reforms required for effective energy transition, including establishing the National Energy System Operator (NESO). The study highlights the National Grid's pivotal contributions to achieving the UK's net-zero targets by evaluating the operational, regulatory, and policy dimensions. It further explores the opportunities presented by innovative technologies, market adaptations, and public engagement in fostering a resilient and sustainable energy future. The findings underscore the need for coordinated policy action, stakeholder collaboration, and infrastructure modernization to address the complexities of energy transition and secure a cleaner, more equitable energy system.

Keywords: Energy Transition, Net-Zero Emissions, National Grid, Renewable Energy Integration, Coal Dependency, Sustainable Energy Governance

1. Introduction

The UK is strategically moving away from coal dependency and embracing a future based on sustainable energy practices that drive down pollution. This transition necessitates critical scrutiny, indicating that reducing emissions requires moral and social justice and ever-increasing global urgency. The UK government has recently implemented new policies to establish a confidence-building and significant policy framework for limiting and eliminating total carbon emissions. Research highlights that economic policy uncertainty significantly influences energy consumption patterns and CO2 emissions, emphasizing the need for stable policies to support this transition [1]. Consequently, evaluating the ongoing strategic role of organizations within these shifting energy markets is timely. The primary aim of this report is to examine the role of the National Grid in formulating a broader energy transition within the UK. The industrial specifics include a glimpse of the energy consumption figures and an overview of strategic objectives incorporated within extant UK energy policies. Studies have identified energy demand reduction as a critical factor in achieving net-zero targets, underscoring the importance of efficiency measures and their integration into national energy strategies [2].

Since the early 1990s, both society and regulators have gradually begun to accept the future energy system for the UK based on an obligation of market forces, and it is our central assumption that, of necessity, this emerging frontier may now assume the pressing need for some form of sustainable 'carbon-detriment' cost. The energy sector is continuously characterized by some of the grandest and most ramifying challenges facing the UK. Energy is an underpinning requirement for a contemporary age of effervescent economies and environmentally sustainable societies. Historical data has shown that economic growth, financial development, and R&D investments are critical drivers for achieving net-zero carbon targets, further supporting the role of innovation in facilitating this transition [3]. Given these aspects, the National Grid itself will be shown to occupy a strategic role of considerable size in the transition being undertaken within the UK today. In sum, it will display how it integrates these two forms of sustainability operationally and in its longer-term strategic planning. The National Grid's efforts to modernize infrastructure and incorporate renewable energy sources are essential to the UK's broader energy transition, reflecting immediate operational priorities and strategic planning goals for a sustainable energy future.

2. Historical Context: Coal Dependency in the UK

The UK's heavy reliance on coal has historically defined its industrial growth and economic development since the late eighteenth century, serving as a cornerstone for nation-building and economic expansion. This dependency was rooted in the perception of coal as a competitive advantage and an abundant resource, integral to the UK's transition from early modern to modern societies [4]. The strategic use of coal shaped the nation's energy policy frameworks. It influenced labour systems, as vertical indentured programs for apprentices proved more effective than labour recruitment in driving the efficiency of mining and transport infrastructure. Before the advent of oil following the First World War, coal was irreplaceable, even necessitating imports to meet domestic energy demands. Expanding power infrastructure, such as railways, further solidified this dependency, which relied heavily on coal production [5]. Although the UK's reliance on coal has significantly decreased with the integration of other energy sources, its historical usage has left an indelible mark on environmental quality, mainly through carbon emissions. Research indicates that transitioning from coal to sustainable energy sources, while essential, must be conducted with attention to potential environmental hazards associated with renewable energy sources, such as improper commissioning of wind farms [4][5]. Figure 1 shows the pie chart that visualizes the historical context of coal dependency in the UK. It breaks down the significance of coal across different historical phases, with the largest share (40%) attributed to the industrial growth of the 18th and 19th centuries.

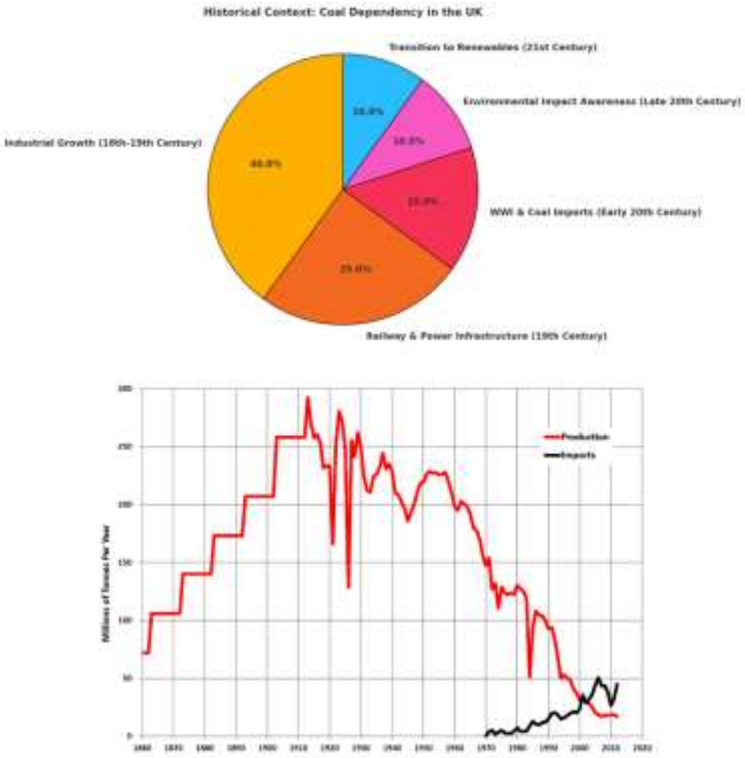

Figure 1: Historical Coal Dependency and Annual UK coal production

As societal attitudes and public perceptions of coal have evolved, its role in the energy mix has diminished. Once seen as indispensable to daily life, coal is now recognized for its environmental detriments, particularly in light of modern alternatives such as hybrid cars and renewable energy technologies [6]. The introduction of sustainable energy policies, including the Energy Act, reflects the political and regulatory efforts required to steer the UK towards carbon neutrality while addressing environmental risks [7]. However, comparative studies suggest that coal phase-out pathways vary significantly across nations, highlighting the unique challenges and strategies in transitioning to sustainable energy systems [5]. The UK's journey from coal dependence to sustainable energy sources provides valuable insights into the intersection of historical dependency, policy evolution, and environmental awareness. By understanding this transition's socio-economic and ecological impacts, policymakers can better anticipate the challenges and opportunities associated with achieving carbon neutrality. This evolution also underscores the importance of public engagement and adaptive policy measures in securing a sustainable energy future.

3. Transitioning to Sustainable Energy Sources

Given the scientific consensus on climate change, domestic imperatives, and commitments within the EU's Energy White Paper, the UK must find a balance that moves towards decarbonizing technologies and establishing a sustainable domestic energy supply [8]. This involves a strategic approach to renewable energy, incorporating wind, wave, tidal, water, and biomass options into the energy mix. Wind, wave, and tidal power are the most viable options due to their availability and technological feasibility [9]. According to the UK National Grid, wind energy is the only truly renewable resource available in significant quantities and with the necessary technological advancements to meet current energy demands [9]. Its scalability and cost efficiency make it an ideal choice for the UK's decarbonization strategy. However, the potential contribution of domestic renewables is estimated to range between 50 and 190 TWh per year, indicating the need for a diversified energy mix to reduce dependency on any single source [8]. Though less explored in the UK, hydropower presents a feasible option, with significant development costs potentially offset by its long-term sustainability. Despite the promising role of domestic renewable sources, challenges remain, particularly in public buy-in and developing low-carbon technologies. Public acceptance is being addressed through government initiatives such as the Renewable Energy Road Map, which seeks to align public perception with the urgency of transitioning to a sustainable energy system [10]. Moreover, the success of a secure and sustainable energy mix depends heavily on political guarantees for long-term investment in energy infrastructure. These investments are necessary to enhance energy storage capabilities, customize demand, and ensure the integration of renewable energy into the Grid. Addressing technological challenges, such as expanding wind and biological hydrogen production capacities, is critical for achieving the UK's carbon neutrality goals [9][10].

Coal was pivotal in the UK's industrial and economic development but left significant social, economic, environmental, and political impacts [9][10]. During its peak in the late 19th and early 20th centuries, coal mining employed over 1.1 million people, supporting thriving communities around coalfields [8][9]. However, miners faced severe health risks, including pneumoconiosis, and accidents caused thousands of fatalities annually [9]. As coal declined, unemployment and economic deprivation plagued former mining regions [10]. Culturally, coal shaped the industrial identity of areas like South Wales, where mining traditions built community resilience [8]. Coal powered the Industrial Revolution economically, driving factories, railways, and trade [9][10]. However, reliance on coal diminished with the rise of oil, gas, and renewables by the mid-20th century, leading to widespread mine closures and environmental remediation costs [9][10]. Environmentally, coal was a major contributor to greenhouse gas emissions, with combustion degrading air quality and causing events like the 1952 Great Smog, which spurred the 1956 Clean Air Act [8][9]. Mining also causes land degradation and water pollution from acid mine drainage [10]. Politically, coal's environmental consequences drove legislation like the 2008 Climate Change Act and the 1990s "Dash for Gas" policy, which reduced coal dependence [9][10]. Labour movements like the 1984-1985 miners' strike highlighted socio-political challenges in transitioning from coal [9]. Today, the UK's shift from coal serves as a model for nations like China and India, showcasing the need for sustainable alternatives while balancing economic and environmental priorities [9][10]. Table 1 provides a clear overview of the UK's transition from coal dependency to sustainable energy with references for further verification.

Table 1: Timeline of UK Coal Use

Period	Event/Development	References
1700s	Early coal use begins to replace wood for heating and industrial processes.	Freese, B. (2004); Pollard, S. (1981)
	The Industrial Revolution drives demand for coal to power steam engines and iron production.	Allen, R. C. (2009); Church, R. (1986)
	Coal has become central to the UK's economy and energy supply.	Wrigley, E. A. (2010)
1800s	Expansion of coalfields in South Wales, Yorkshire, and Scotland.	Church, R. (1986)
	Railways and urban lighting increase coal demand.	Allen, R. C. (2009)
	By 1850, coal accounts for over 90% of the UK's energy supply.	Pollard, S. (1981)
	Electricity generation emerges, further solidifying coal dominance.	Wrigley, E. A. (2010)
1913	UK coal production peaks at 292 million tonnes, employing over 1.1 million miners.	Taylor, A. J. (1967)
1914-1918	Coal shortages during World War I necessitate imports to meet domestic demand.	Church, R. (1986)
1930s	Mechanization reduces reliance on manual labour in mining.	Church, R. (1986)
1940s-50s	Coal continues to dominate post-WWII but faces growing competition from oil and gas.	Taylor, A. J. (1967); Helm, D. (2017)
1956	Clean Air Act combats pollution, reducing urban coal use.	UK Government (1956)
1960s	North Sea oil and gas discoveries provide alternative energy sources.	Department of Energy & Climate Change (2013)
1970s	Environmental awareness rises, with carbon emissions gaining attention.	Helm, D. (2017)
1984-1985	UK miners' strike underscores economic and political challenges of coal reliance.	Taylor, A. J. (1967); Wrigley, E. A. (2010)
1990s	The "Dash for Gas" policy accelerates the transition to gas-fired power plants.	Department of Energy & Climate Change (2013); Helm, D. (2017)
2008	Climate Change Act commits the UK to reducing greenhouse gas emissions.	Climate Change Act (2008); UK
2013	The government announces plans to phase out unabated coal power by 2025.	UK Government (2021)
2015	Multiple coal-fired power plants are shut down.	National Grid ESO (2020)
2016	Renewable energy surpasses coal in electricity generation for the first time.	Renewable Energy Institute (2020)
2019	UK records its first "coal-free day," with no coal used for electricity.	National Grid ESO (2020)
2020	Coal accounts for less than 2% of electricity generation.	International Energy Agency (2020)

2024 (Planned)	The remaining coal-fired power plants are to be permanently closed.	UK Government (2021)

4. The Role of the National Grid in Energy Transition

Energy systems are on the cusp of a dramatic transformation driven by the intersection of climate change, peak fossil fuel extraction, and national carbon targets. This shift prioritizes renewable energy sources over traditional coal and gas reliance, aligning with the UK's ambition for a net-zero carbon electricity system. Central to this transition is the National Grid, which, as the Transmission System Operator (TSO), oversees the high-voltage electricity transmission grid in England, Wales, and Scotland and the gas transportation system [11]. The National Grid's role is pivotal in balancing the system and ensuring flexibility as distributed and renewable generation sources become increasingly integrated into the nation's energy infrastructure. Its proactive strategic and investment plans support the UK's evolving socio-technical energy system. The National Grid facilitates this transition by managing a variety of energy sources, including renewable ones whose output can be intermittent—affected by changing weather patterns such as clouds or wind shifts [12]. The TSO must also address geographic decentralization to manage the complexities of integrating distributed generation, such as rooftop solar panels and offshore wind farms. This involves securing legal rights to connect, disconnect, dispatch, and curtail energy sources when necessary, ensuring the Grid's stability and reliability. Additionally, the Grid must accommodate cross-border interconnections, enabling collaboration with European and international TSOs to optimize energy flows and enhance system resilience [12][13]. Moreover, integrating renewable energy systems increasingly relies on advancements in information technologies. These innovations facilitate real-time monitoring, demand forecasting, and the seamless operation of distributed energy systems. By prioritizing technical infrastructure upgrades and regulatory frameworks, the National Grid adapts to current challenges and prepares for the long-term sustainability of the UK's energy transition [13]. Table 2 summarises the key areas where the National Grid must overcome challenges and leverage opportunities to ensure a secure, modern, and sustainable energy system.

National Grid's report outlines five key actions to accelerate the energy transition:

1. **Reform the Planning System with a Strategic Clean Energy Vision**:

Finalize the National Policy Statements by summer to provide clarity and certainty, supporting the rapid deployment of net zero infrastructure.

2. **Align Regulatory and Governance Frameworks for Effective Delivery**:

Review and refine regulators' objectives and duties, ensuring roles and responsibilities are clearly defined across institutions involved in the energy transition.

3. **Modernise Grid Connection Processes to Accelerate Net Zero Projects**:

Transition from a 'first come, first served' model to a more dynamic 'connect or move' approach. Establish strategic 'capacity hubs' for innovative and coordinated grid connections and implement fast-track routes for critical net zero projects, focusing on areas with the highest economic potential.

4. **Prioritise Communities and Consumers in the Transition**:

Develop a unified community benefits framework to ensure residents gain tangible advantages from hosting net zero infrastructure.

5. **Expand Supply Chain Capacity and Build a Skilled Workforce**:

Introduce targeted incentives to attract clean energy manufacturers and training providers, fostering growth and expansion in the UK clean energy sector.

Table 2: Challenges and Opportunities for the National Grid

Category	Challenges	Opportunities
Infrastructure	Ageing grid infrastructure requires modernization.	Expanding grid capacity for renewable integration.
	Increased electrification of transport and heating demands higher capacity.	Building cross-border interconnections to trade renewable energy and enhance security.
Integration of Renewables	Managing intermittency of wind and solar energy.	Energy storage technologies like batteries and pumped hydro to stabilize the Grid.
	Delays in connecting renewable projects to the Grid.	Strategic storage hubs to improve flexibility and resilience.
Decentralized Systems	Transitioning from centralized to decentralized models with local energy systems.	Empowering local communities with vehicle-to-grid (V2G) and peer-to-peer energy trading.
	Adapting to two-way power flows and managing distributed energy.	Reducing transmission losses through localized energy generation.
Regulatory Barriers	Outdated regulatory frameworks and slow planning processes hinder project timelines.	Simplifying and streamlining regulatory processes for faster infrastructure deployment.

	Lengthy grid connection processes for renewables.	Implementing “connect or move” connection models to reduce delays.
Cybersecurity	Increased digitalization exposes the Grid to cyberattacks.	Investing in robust cybersecurity systems to protect operations.
Workforce and Skills	Shortages of skilled workers in engineering, data analytics, and renewable technologies.	Developing a skilled workforce through training programs and academic collaborations.
Costs and Affordability	High costs of infrastructure upgrades and renewable integration may burden consumers.	Targeted investments in clean energy can boost economic growth and reduce long-term costs.
Consumer Engagement	Gaining public support for new infrastructure projects.	Empowering consumers through demand-side response, time-of-use pricing, and community benefits.
Global Leadership	Maintaining competitiveness while adapting to global decarbonization trends.	- Becoming a global leader in renewable integration and energy transition strategies.

4.1 The separation of NESO from National Grid

In 2019, a significant restructuring of the UK’s electricity system governance was implemented, leading to greater operational independence for electricity system management. This change involved separating the management of electricity systems in England, Scotland, and Wales from the National Grid to comply with the EU’s clean energy package legislation. This legislation mandated the creation of an independent Electricity System Operator (ESO) to facilitate the transition towards decentralized, low-carbon energy systems [14]. The ESO operates as a subsidiary company, reflecting the broader commitment to green energy initiatives and enhancing the overall energy governance framework. Separating the ESO from the National Grid enabled a decentralized energy landscape. Economists have pointed out that integrating the roles of energy companies and system operators would have posed significant challenges to preparing the electricity system for the demands of a low-carbon future [15]. By focusing exclusively on the operational reliability and flexibility of the energy system, the ESO plays a critical role in balancing supply and demand, particularly as the integration of renewables and distributed energy systems increases.

Adopting intelligent technologies and expanding transmission capacity have further enhanced the ESO’s ability to coordinate supply and demand effectively. These advancements have enabled the ESO to address the complexities of renewable energy intermittency while maintaining system stability. Furthermore, the separation has brought administrative advantages, allowing the ESO to align its objectives more closely with the goals of the UK’s low-carbon transition [16]. However, significant challenges remain, particularly in coordinating the various components of the energy system. These include ensuring seamless interaction between decentralized generation, transmission infrastructure, and energy storage technologies. As the UK transitions to a sustainable energy landscape, the ESO’s role in managing these complexities will be increasingly vital to achieving reliability, flexibility, and long-term sustainability.

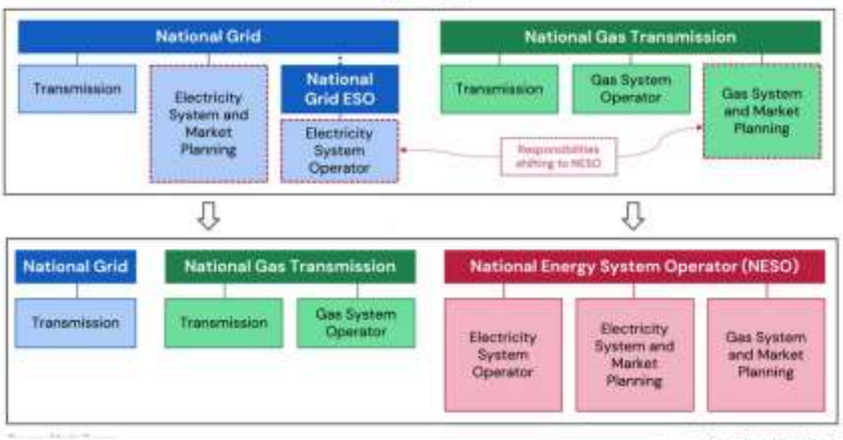

Figure 2: Transition of Responsibilities from National Grid and National Gas Transmission to the National Energy System Operator (NESO)

Role and Structure of the National Energy System Operator (NESO)

The **National Energy System Operator (NESO)** is a proposed organization in the UK energy sector designed to take on an integrated and independent role in overseeing both electricity and gas systems. NESO aims to centralize and streamline the UK’s energy infrastructure operation, ensuring a coordinated, efficient, and secure energy transition toward a net zero future. Below is a detailed explanation of its role and structure:

Role of NESO

1. **System Operation**:
    - NESO will manage the real-time operations of electricity and gas transmission systems, ensuring the energy supply's stability, security, and reliability across the UK.
2. **Integrated Energy Planning**:
    - It will be responsible for long-term strategic planning for gas and electricity markets, ensuring they align with the UK's net zero targets.
    - By consolidating planning for electricity and gas systems, NESO will promote a holistic approach to managing the transition to low-carbon energy.
3. **Market Development**:
    - NESO will facilitate and develop electricity and gas markets, ensuring fairness, competition, and efficiency.
    - It will work to enhance market conditions that attract investments in renewable energy and low-carbon technologies.
4. **Enabling Net Zero**:
    - A core focus of NESO is to drive the decarbonization of the UK's energy systems by enabling the integration of renewable energy sources, such as wind and solar, alongside cleaner gas technologies like hydrogen.
    - It will coordinate critical projects like grid modernization and interconnections to support the energy transition.
5. **Independence and Accountability**:
    - NESO is envisioned as an independent organization that removes conflicts of interest and ensures neutrality in managing energy networks. It will be accountable to the government and industry stakeholders for delivering a secure and sustainable energy system.

Structure of NESO

1. **Electricity System Operator (ESO)**:
    - The electricity system operator function will be transferred to NESO from the National Grid ESO.
    - Responsibilities include managing electricity grid operations, balancing supply and demand in real-time, and integrating renewable energy sources.
2. **Gas System Operator (GSO)**:
    - The gas system operator function will shift from National Gas Transmission to NESO.
    - NESO will oversee the operation and planning of the gas transmission network, ensuring the transition from natural gas to hydrogen or other low-carbon alternatives.
3. **System and Market Planning**:
    - NESO will consolidate system and market planning for electricity and gas under one umbrella. This integration will enhance long-term planning for infrastructure investment and ensure coordination between the two energy systems.
4. **Key Organizational Features**:
    - **Independence**: NESO will be separate from National Grid and National Gas Transmission to avoid conflicts of interest and ensure fair operation across the energy market.
    - **Integrated Governance**: By overseeing gas and electricity, NESO will create a unified governance structure, allowing better resource allocation, risk management, and policy implementation.

Benefits of NESO

- **Holistic Approach**: Uniting electricity and gas operations under one entity will promote better coordination between these systems, reduce inefficiencies, and enhance resilience.
- **Accelerating Decarbonization**: With a centralized focus, NESO can streamline projects integrating renewables, hydrogen, and other low-carbon technologies.
- **Independence**: Ensuring operational neutrality fosters trust among stakeholders and helps drive competitive markets.
- **Future-Ready Systems**: NESO will be positioned to address emerging challenges in energy transition, such as balancing intermittent renewables and supporting the hydrogen economy.

The creation of NESO represents a significant step forward in modernizing the UK's energy system. It will enable the country to meet its net zero goals while ensuring energy security and operational efficiency in the evolving energy landscape.

4.2 Challenges and Opportunities for the National Grid

Several challenges pose potential obstructions for the National Grid as the energy transition develops. In the United Kingdom, the costs of maintaining an antiquated electricity grid are forecasted to double, skyrocketing from £4 billion per year to a staggering £8 billion per year for the next decade, despite the pressures to reduce energy bills that are prevalent in energy policy agendas [17]. This upward spiral in costs can be attributed, once again, to the continuous advancements in technology, most notably the increasing penetration of distributed generation, which is driving energy companies to invest heavily in new and innovative technologies [18]. However, the National Grid finds itself constrained by the income it can earn from its customers, which restricts its ability to invest in upscaling and renewing the existing infrastructure to the level required to meet the current demands. The available funds only cover around one-fifth of the necessary investment [19]. Therefore, collaboration with the broader industry is not just desirable but essential. This collaboration becomes even more crucial during financial constraints within the power sector [20]. The National Grid finds itself heavily dependent on stakeholders from both the public and private sectors. Forming partnerships with these stakeholders becomes a paramount objective, as it allows for sharing resources and expertise and reciprocal benefits. However, for these partnerships to be successful and mutually advantageous, the strategic investment proposed by the National Grid must be highly persuasive and compelling for all parties involved. By formulating a compelling strategic investment plan and fostering collaboration with the broader industry, the National Grid can overcome the challenges and obstructions that lie ahead. This will enable the Grid to navigate the shifting landscape of the energy transition more effectively, ensuring a smooth and resilient transition to a more sustainable and efficient energy system for the entire nation [21].

Perhaps the most significant operational challenge currently facing the National Grid is posed by the heavy system's reliance on coal, which presents many consequences and hurdles that must be addressed. The impacts of coal dependency were particularly felt in 2015 when the energy system margin narrowed considerably—resulting in a critically low Energy Return on Investment (EROI), thereby jeopardizing the stability and resilience of the entire grid infrastructure [17]. Given these circumstances, stakeholders are faced with balancing the ever-increasing demand from industry and consumers for secure and uninterrupted energy supplies while simultaneously developing effective, large-scale, complex power systems. This involves exploring innovative solutions such as microgeneration, intelligent grids, and storage options that present numerous opportunities for improvement [18]. These alternatives not only have the potential to increase system resilience but also to help reduce the exorbitant costs associated with maintaining system security [19]. Looking ahead, it becomes evident that long-term strategies must prioritize the development of new energy islands as a means to distribute energy from multiple sources to meet the escalating demand, effectively countering supply-side intermittency [20]. This proactive approach ensures a reliable supply and allows sustainable energy distribution across different regions. In addition to the energy islands, the successful implementation and utilization of high-voltage direct current interconnectors are a vital component of the National Grid's growth and optimization. However, to maximize the benefits derived from these interconnectors, it is essential to have access to close-to-real-time data that facilitates swift and accurate decision-making. This, in turn, opens up many possibilities for predictive analytics and enables stakeholders to make informed choices that positively impact the efficiency of the Grid [21]. Despite these advancements and opportunities, it is essential to acknowledge that an era of unprecedented uncertainty mars the current energy landscape with changing policies and evolving investment preferences. Many technologies offered as potential solutions face the challenge of navigating this intricate web of risks and uncertainties. Nevertheless, it is crucial to pursue these avenues as they have the potential to transform the National Grid into a more resilient, reliable, and sustainable energy infrastructure that will meet the needs of future generations.

5.0 Policy Recommendations for a Sustainable Energy Future

Comprehensive strategic planning is essential and critical to coordinate and align amongst seemingly disparate elements that collectively compose the energy and climate models underpinning broader climate goals [22]. When the UK leaves the European single market and consensus on the collective European environment—drivers of many environmental policies, including energy policy—it may be necessary to reconsider these frameworks, especially if repeals of ownership rules or unbundling result in profits being spent abroad. Improvements to the regulatory framework could be made to encourage renewable investment, including attempts to resolve thorny issues in Grid charging [23]. The growth of renewables could be further facilitated through government investment in grid modernization, combined heat and power, or more diverse local generation schemes and improvements in energy efficiency [24]. These policy recommendations thread through the governance archetype proposed. The UK should play a pivotal role in furthering and coordinating the development of renewable energy and alternative, more sustainable infrastructures, with ambition commensurate with its climate targets. The government should, for example, support and promote growth in sustainable technology, including research and development, and be an early adopter of new technologies [22]. Researchers may lead the development of such transformational infrastructures and could include features such as the deliberate co-support of critical sustainable infrastructures that are intrinsically interdependent.

In such a systems-thinking approach, complex issues are best resolved through participatory means; thus, representations of local communities and other stakeholders through physical views indicated by shared visualizations are a valuable, empathetic tool for policymakers and others with fiduciary roles [23]. Lastly, while participation will also be in the form of engagement—i.e., local and other stakeholders as collaborators in community and civic development—participation stands, in this case, as an overall term meaning involvement at every level of decision-making [24]. Finally, energy policy can be explicitly directed at altering the energy use of residential and commercial customers, creating the economic incentive to "do the right thing," and providing environmental services [22]. Table 3 states the policy recommendations for a sustainable energy future in the UK and the year they were formulated, providing a timeline of progress toward achieving net-zero goals.

Table 3: Policy recommendations for a sustainable energy future in the UK

Policy Area	Recommendations	Year Formulated	Objectives
Planning System Reform	Finalise National Policy Statements to accelerate net-zero projects.	2022 (Draft)	Provide clarity and certainty for infrastructure planning.
	Develop a strategic clean energy vision for long-term coordination.	2021	Enable consistent and goal-oriented energy planning.
Regulatory and Governance	Review regulators' objectives to prioritise decarbonization and innovation.	2023	Align regulatory frameworks with net-zero goals.
	Clarify roles and responsibilities across energy institutions.	2020	Improve accountability and reduce administrative delays.
Grid Connection Modernization	Transition from "first come, first served" to "connect or move" connection processes.	2022	Expedite integration of renewable energy projects.
	Establish strategic "capacity hubs" for coordinated grid connections.	2022	Enhance grid flexibility and support renewable energy scaling.
	Fast-track grid connections for critical net-zero projects.	2022	Accelerate projects with the highest economic and environmental impact.
Community Engagement	Implement a community benefits framework to share the socio-economic gains of hosting energy infrastructure.	2022	Build public support for net-zero energy initiatives.
Supply Chain Development	Introduce incentives for clean energy manufacturers to establish operations in the UK.	2021	Boost domestic supply chain resilience and reduce reliance on imports.
	Develop a national skills pipeline with education and retraining programs.	2021	Equip the workforce with the skills needed for renewable energy industries.
Decarbonization of Energy Use	Promote electrification of transport and heating sectors.	2019 (Accelerated 2020)	Reduce emissions in traditionally high-carbon sectors.
	Scale up hydrogen and carbon capture, utilization, and storage (CCUS).	2020	Support hard-to-decarbonize industries and diversify the energy mix.
Infrastructure Investment	Expand international interconnectors for energy security and trade.	2020	Strengthen energy system resilience and facilitate cross-border renewables.
	Modernise grid infrastructure to handle renewable energy and growing electricity demand.	2022	Future-proof the Grid for reliability and capacity expansion.
Digital and Smart Technology	Invest in innovative grid technologies for efficient energy management and demand-side response.	2021	Optimise energy usage and integrate distributed energy resources (DERs).
	Leverage advanced data analytics to enhance grid monitoring and predictive maintenance.	2021	Improve grid reliability and operational efficiency.

6. Conclusion

This paper has aimed to shed new empirical light on the role of National Grid Company in the British energy transition from coal dependency to a determination to reach net zero. Strategic use of its role and authority as a systems operator has allowed National Grid Company to define and drive the UK's coal phase-out, particularly affecting it just as much as reflecting broader societal shifts. It also benefited from support from other stakeholders, such as commercial groups, the public and government, in its efforts to coordinate and act. However, the more comprehensive comparative analysis of governance perspectives and expectations is truncated by resistances and uncertainties as they continue to play out. National Grid Company's role in navigating and managing change is seen as vital as it becomes clear that the joint objectives of what comes to be known as the Electricity Market Reform, the Capacity Market and the Emissions Performance Standard may prove to be self-defeating counterproductive when read across national, European and global policy-making. Policy coherence is essential because it affects climate objectives rather than simply being about the energy industry's preferences. It provides more room to 'let go' rather than be sponsored into a change in direction or expectations. The case of the National Grid provides an alternative interpretation of what orchestrating a transition and sustainability rather than future energy dynamics means or might be construed as an offering. Indeed, the case studies also show a more engaged and delightful formation of new and differentiating responses to the situation. The climate breakdown is frightening. All other things pale insignificance in the context of what it can bring—it already does bring and will bring only more grave consequences—for our children's future.

Nevertheless, we do have solutions. Areas of real dynamism and creativity or innovation were witnessed in providing network services, grid balancing, new markets for flexibility account support and Non-Transmission Network Operators, for example. The renewables sector is leading the way in investment, R&D and innovation. These alternatives give cause for hope and show a way ahead is possible. Given the current energy, the regime is not static, and it is being challenged or re-imagined and designed differently by all sorts of actors in the play, which supports the energy transformation. All actors must play their role in this new system, propose who ought to and why, and prove their worth.

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