EVALUATING ECONOMIC, ENVIRONMENTAL, AND SOCIAL IMPACTS OF ADOPTING FUSION ENERGY IN SAUDI ARABIA

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1. INTRODUCTION

As global energy demands increase and environmental concerns escalate, Saudi Arabia's interest in sustainable and innovative energy sources, such as fusion energy, has grown significantly. The current study explores the potential impacts and future scenarios of adopting fusion energy in Saudi Arabia. The paper begins by outlining the basic principles of fusion energy, emphasizing its advantages over traditional energy sources. Introducing fusion energy in Saudi Arabia is posited as a transformative step towards energy diversification and sustainability, potentially revolutionizing the country's energy landscape.

This research forecasts the economic, environmental, and social impacts of fusion energy adoption. Economically, the study suggests that fusion energy could decrease Saudi Arabia's dependence on oil exports, stabilize its economy against fluctuating oil prices, and foster new industries and job opportunities in high-tech sectors. Environmentally, the transition to fusion energy is projected to significantly reduce carbon emissions, aiding Saudi Arabia in meeting its commitments under international climate accords. Socially, the adoption of fusion energy could enhance the quality of life by reducing air pollution and promoting technological education and research. The research also discusses potential challenges, such as the high initial costs of fusion energy infrastructure, the need for substantial investment in research and development, and the geopolitical implications of shifting from a fossil-fuel-dominated economy.

2. METHODOLOGY

The study employs a mixed-methods from technology foresight approach, integrating quantitative predictive models with qualitative analyses. This design facilitates a comprehensive evaluation of the potential economic, environmental, and social impacts of adopting fusion energy in Saudi Arabia [1]. The research is divided into the following main phases: theoretical framework development, data collection and analysis, scenario and policy analysis [2]. Different adoption scenarios are developed to explore various pathways for integrating fusion energy into Saudi Arabia’s energy mix. Each scenario considers different speeds of adoption, levels of investment, and technological advancements. This methodology is reflected by applying Technology Foresight Tools (Horizon Scanning, Trend Analysis, Stakeholder Mapping and Analysis, PESTLE Analysis and Scenario Planning) as detailed in the subsequent section.

3. RESULTS

The objective here is to develop multiple future scenarios to explore different pathways of fusion energy adoption and its impacts under various conditions (e.g., rapid adoption, gradual integration, limited use). This will help addressing uncertainty in fusion technology development timelines. Table 1 shows three scenarios (Optimistic, Moderate and Conservative) outlining potential paths for Saudi Arabia's adoption of fusion energy. The following assumptions were made:

1. Total electricity consumption grows to 500 TWh by 2050.
2. Renewable and fusion contributions replace hydrocarbon-based electricity in varying degrees depending on the scenario.

Taking into consideration that Fusion Energy's large-scale deployment (especially >10% of the grid) requires not only technological breakthroughs but also significant political and financial commitment, the numbers provided in Table 1 are estimates and depend on multiple assumptions about Saudi Arabia's energy growth, technological advancements, and policy commitments. Below is a breakdown for the realism of these scenarios. Fig. 1 demonstrates a visualization of the energy mix contributions under the three scenarios, showing the relative shares of fusion, renewables, and hydrocarbons in Saudi Arabia's electricity generation.

TABLE 1. THREE SCENARIOS (OPTIMISTIC, MODERATE AND CONSERVATIVE) OF POTENTIAL PATHS FOR SAUDI ARABIA'S ADOPTION OF FUSION ENERGY.

Scenario	Fusion Energy Contribution to Grid (%)	Impact on Energy Mix (%)	Numerical Impact on Energy Mix (TWh)
Optimistic Scenario	10–15% by 2045	Hydrocarbons: 40–45%; Renewables: 40–50%; Fusion: 10–15%	Fusion: 50–75 TWh; Renewables: 200–250 TWh; Hydrocarbons: 175–225 TWh
Moderate Scenario	5–10% by 2050	Hydrocarbons: 50%; Renewables: 40–45%; Fusion: 5–10%	Fusion: 25–50 TWh; Renewables: 175–225 TWh; Hydrocarbons: 200–250 TWh
Conservative Scenario	<5% by 2060	Hydrocarbons: 55–60%; Renewables: 40–45%; Fusion: <5%	Fusion: <25 TWh; Renewables: 175–225 TWh; Hydrocarbons: 275–300 TWh

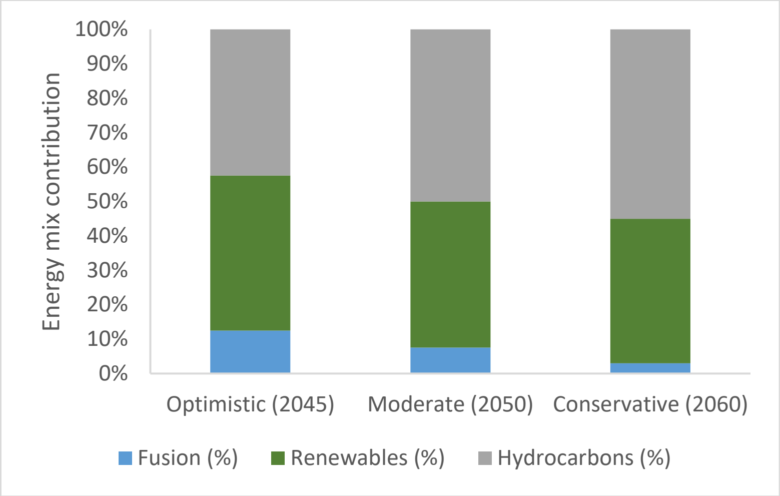

FIG. 1. Energy mix contribution (%) for three scenarios in Saudi Arabia.

The scenarios presented in Table 1 outline potential pathways for Saudi Arabia's fusion energy adoption, but their realism varies significantly. The Optimistic Scenario (10–15% by 2045) is highly ambitious, requiring fusion commercialization, large-scale deployment, and grid integration within a very short timeframe—challenges that make it moderately unrealistic given current technological and economic constraints. The Moderate Scenario (5–10% by 2050) is plausible if Saudi Arabia invests heavily in fusion R&D, infrastructure, and regulatory frameworks over the next two decades, positioning itself as an early adopter. The Conservative Scenario (<5% by 2060) is the most realistic, as it aligns with the cautious adoption of emerging energy technologies, especially given the uncertainties surrounding fusion's commercial viability [3]. Overall, while early investment could accelerate fusion adoption, a gradual and complementary integration with renewables and hydrocarbons is the most probable outcome in the mid-to-late 21st century [4].

4. CONCLUSION

Fusion energy offers an ideal carbon-free energy source with high-power density, unlimited fuel availability, and low environmental impact. This aligns with global goals for sustainable and decarbonized energy production [5]. Saudi Arabia would need to establish a robust infrastructure, including specialized grids, advanced cooling systems, and domestic manufacturing capabilities for reactor components. Integration with existing energy systems would also require upgrades to transmission networks and energy storage solutions to effectively balance fusion-generated power with intermittent renewable energy sources. If successfully adopted, fusion energy could reshape Saudi Arabia's energy mix, significantly reduce greenhouse gas emissions, and position the Kingdom as a leader in next-generation energy technologies. However, the main barriers in adopting fusion energy are the high initial cost, technical feasibility and the timeline for deploying power plant demonstrations, which are critical for assessing its adoption in Saudi Arabia's energy strategy. The megafund financing model can serve as a framework to overcome high upfront costs and risks. Saudi Arabia could explore similar securitization approaches to attract diverse investors, leveraging government-backed guarantees or sovereign wealth funds.

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