Desktop Feasibility to Evaluate Commercial Aspects of Utilizing Green Hydrogen by Decarbonization and Techno Economic Analysis

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Abstract— The increasing demand for sustainable and clean energy sources has led to a growing interest in the utilization of green hydrogen as a potential solution. Green hydrogen, produced through electrolysis using renewable energy sources, has the potential to significantly reduce greenhouse gas emissions and contribute to a more environmentally friendly energy sector. However, before implementing large-scale green hydrogen projects, it is crucial to assess their commercial viability and economic feasibility. This study focuses on evaluating the commercial aspects of utilizing green hydrogen through a techno-economic analysis conducted on desktop feasibility. The research aims to assess the economic viability of green hydrogen production, storage, and utilization, considering factors such as capital costs, operational expenses, energy efficiency, and market dynamics. The methodology involves collecting data on renewable energy resources, electrolyzer technologies, hydrogen storage options, and potential market scenarios. Various techno-economic models and software tools are employed to simulate different scenarios and evaluate the financial implications of green hydrogen projects. Sensitivity analyses are conducted to assess the impact of variables such as electricity prices, government policies, and infrastructure development on the economic feasibility of green hydrogen solutions. The findings of this study provide valuable insights into the commercial aspects of utilizing green hydrogen, helping policymakers, investors, and industry stakeholders make informed decisions. The research highlights the potential benefits and challenges associated with green hydrogen projects, identify key economic indicators, and propose strategies for cost optimization and market integration. By analyzing the techno-economic feasibility of green hydrogen on a desktop scale, this research contributes to the understanding of the economic viability of green hydrogen projects. A sensitivity analysis may reveal that a 10% increase in electricity prices reduces the profitability of the green hydrogen project by 15%. A reduction of subsidies by 20%, decreases the project's internal rate of return (IRR) by 8%, emphasizing the importance of policy stability for project success. Cost optimization efforts might identify alternative equipment suppliers that offer a 15% reduction in the cost of electrolyzers or storage systems, leading to substantial savings in the overall project budget. It supports the transition towards a more sustainable energy landscape by providing guidance on the commercial aspects of utilizing green hydrogen and facilitating the development of efficient and profitable green hydrogen systems.

Index Terms— Green hydrogen, Techno-economic solution, Sustainable energy, Renewable energy, Energy efficiency.

I. INTRODUCTION

The increasing global concern for environmental sustainability and the transition towards a low-carbon economy have fueled the interest in green hydrogen as a potential solution for clean energy production. Green hydrogen, produced through the process of electrolysis using renewable energy sources, offers a promising pathway to decarbonizes various sectors, including transportation, industry, and power generation. However, before implementing large-scale green hydrogen projects, it is essential to evaluate their feasibility and economic viability.

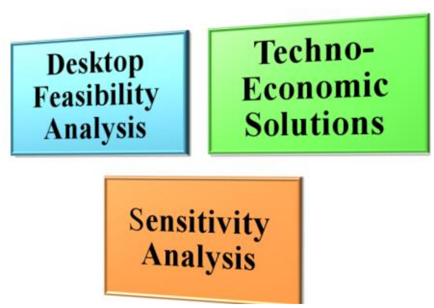

Figure 1: Steps Prior to implement large-scale green hydrogen projects

Desktop feasibility analysis, coupled with techno-economic solutions, plays a crucial role in assessing the commercial aspects of utilizing green hydrogen. This approach allows for a comprehensive evaluation of the technical and economic factors involved in green hydrogen production, storage, and utilization, without the need for physical prototyping or extensive field studies. The desktop feasibility analysis begins by collecting and analyzing relevant data related to renewable energy resources, electrolyzer technologies, hydrogen storage options, and market dynamics. This information provides a foundation for developing techno-economic models and software tools that simulate different scenarios and evaluate the financial implications of green hydrogen projects. Techno-economic solutions enable the assessment of key economic indicators, such as capital costs, operational expenses, energy efficiency, and potential revenue streams. These models take into account factors such as project scale, location-specific parameters, and regional energy market conditions to estimate the economic viability of green hydrogen systems. Sensitivity analysis within the techno-economic solution framework allows for the examination of the project's response to changes in various parameters. It helps identify the critical variables that significantly impact the project's profitability, such as electricity prices, government policies, and infrastructure development. Renewable Energies Available in Nature

Renewable energies, also known as clean or green energies, are energy sources that are naturally replenished and have a minimal impact on the environment. They are considered sustainable because they do not deplete natural resources and produce lower greenhouse gas emissions compared to fossil fuels. Renewable energies play a vital role in combating climate change and reducing reliance on fossil fuels.

II. TYPES OF RENEWABLE ENERGIES

Renewable energy sources are forms of energy derived from naturally replenished resources. Here are some of the main types of renewable energies available in nature:

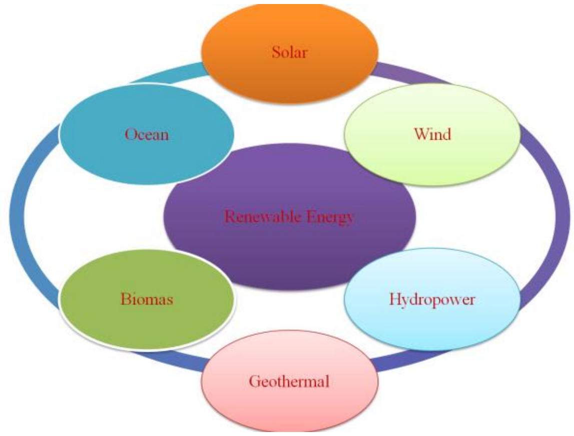

Figure 2: Types of Renewable Energy

Comparing these Renewable Energy sources on basis of some key factors

Table 1 for this comparison is presented below

Renewable Energy	Availability and Scalability	Power Generation Potential	Environmental Impact	Technological Maturity and Costs
Solar	Abundant and Available	High Potential For Electricity Generation	Minimal Direct Environmental Impact	Mature and Cost-competitive
Wind	Abundant and Available	High Potential For Electricity Generation	Minimal Direct Environmental Impact	Mature and Cost-competitive
Hydro	Depend on Suitable Water Sources	Well-established and Efficient Renewable Energy Source	Minimal Direct Environmental Impact	Limited Growth Potential
Geothermal	Location-specific	Reliable Base Load Potential	Low Emissions	Higher Upfront Costs But Long-term Cost Stability
Biomas	Based on Local Agricultural Practices	Flexibility For Heat and Electricity Production	Depend on the Feedstock and Combustion Technologies	Maturity and Costs Depending on the Conversion Process
Ocean	Can Be Site-specific	Still Is in Early Stages of Development	Localized Environmental Impacts on Marine Ecosystems	Still Evolving and Generally Have Higher Costs

3. Tools and Techniques to Achieve Green Hydrogen

Achieving the production and utilization of green hydrogen requires the use of various tools and techniques. These tools and techniques can be used to increase the production of green hydrogen and its utilization as well. It includes below mentioned fundamental tools and techniques:

Electrolysis: Electrolysis is the primary technology used to produce green hydrogen. It involves the use of an electrolyzer, which uses electricity to split water (H_2O) into hydrogen (H_2) and oxygen (O_2). There are different types of electrolyzers, including alkaline electrolyzers, proton exchange membrane (PEM) electrolyzers, and solid oxide electrolyzers, each with its own advantages and applications.

Renewable Energy Sources: Green hydrogen production relies on the use of renewable energy sources to power the electrolysis process. Solar, wind, and hydroelectric power are commonly employed as clean and sustainable sources of electricity. These sources ensure that the hydrogen produced is free from carbon emissions, contributing to its "green" status.

Energy Storage Systems: Green hydrogen can play a crucial role in energy storage. Excess renewable energy generated during periods of high production can be used to produce hydrogen, which can then be stored and later converted back to electricity when renewable energy generation is low. This helps to balance the intermittent nature of renewable energy sources and ensure a stable energy supply.

Hydrogen Infrastructure: To utilize green hydrogen effectively, a well-developed infrastructure is necessary. This includes hydrogen production facilities, storage systems, transportation networks (pipelines or compressed gas), and distribution networks. Infrastructure development is crucial for enabling the widespread adoption of green hydrogen in various sectors.

Decarbonization: It is an essential aspect of achieving green hydrogen production. Green hydrogen is characterized by its low carbon footprint, as it is produced using renewable energy sources and does not contribute to greenhouse gas emissions during its production process.

Fuel Cells: Green hydrogen can be used in fuel cells to generate electricity for various applications. Fuel cells convert hydrogen into electricity through an electrochemical reaction, with water as the only byproduct. Fuel cells have applications in transportation, stationary power generation, and portable devices, offering efficient and clean energy conversion.

Carbon Capture and Utilization (CCU): Green hydrogen can be used in combination with carbon capture and utilization technologies to achieve even greater emissions reductions. By capturing and utilizing carbon dioxide (CO2) emissions from industrial processes, the carbon footprint of hydrogen production and utilization can be further minimized, enhancing its environmental benefits.

Techno-economic Analysis: Techno-economic analysis tools and methodologies are essential for assessing the feasibility and economic viability of green hydrogen projects. These tools help evaluate the capital costs, operational expenses, energy efficiency, and revenue potential of green hydrogen production and utilization systems. They aid in decision-making, optimization, and risk assessment for green hydrogen projects.

Due to simplicity and hazel free operation main focus of this paper is on two tools and techniques i.e. Decarbonization and Techno-economic Analysis.

III. DECARBONIZATION

Decarbonization process involves reducing or eliminating carbon emissions from various sectors, including energy production, transportation, and industry. Green hydrogen plays a significant role in decarbonization efforts by serving as a clean and sustainable energy carrier that can replace carbon-intensive fuels and processes. By utilizing renewable energy sources such as solar, wind, or hydroelectric power for electrolysis, the production of green hydrogen avoids the emissions associated with fossil fuel-based hydrogen production methods. This eliminates or greatly reduces the carbon emissions that would occur if hydrogen were produced from fossil fuels, such as natural gas or coal. Furthermore, green hydrogen can be used as a decarbonization tool in other sectors. Few sectors have been mentioned below:

Transportation: Green hydrogen can be used as a fuel for fuel cell electric vehicles (FCEVs), replacing conventional fossil fuel-powered vehicles. FCEVs powered by green hydrogen emit only water vapor, contributing to significant reductions in transportation-related greenhouse gas emissions.

Industrial Processes: Green hydrogen can replace fossil fuels in industrial processes that require high-temperature heat, such as steel production or chemical manufacturing. By using green hydrogen as a clean energy source, these processes can reduce their carbon emissions and contribute to overall decarbonization efforts.

Energy Storage and Grid Flexibility: Green hydrogen can be utilized as an energy storage medium, enabling the integration of renewable energy sources into the electricity grid. Excess renewable energy can be used to produce green hydrogen, which can be stored and later converted back to electricity when demand exceeds supply. This helps balance the intermittent nature of renewable energy and provides grid flexibility, supporting the decarbonization of the energy sector.

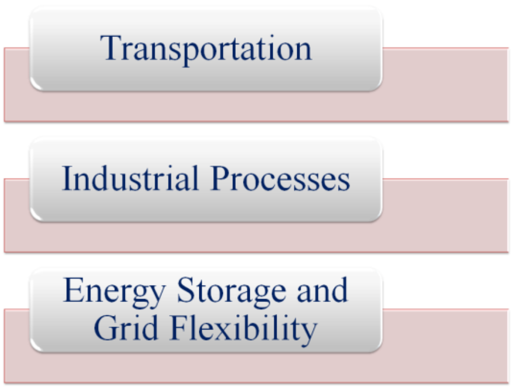

Figure 3: Decarbonization can be used as green hydrogen in different sectors

IV. TECHNO-ECONOMIC ANALYSIS

Techno-economic analysis is a valuable tool for achieving green hydrogen. Techno-economic analysis allows for a comprehensive evaluation of the technical and economic aspects of green hydrogen production, helping to assess its feasibility, optimize processes, and guide decision-making.

- Process applied to achieve green hydrogen via techno-economic analysis method:

Feasibility Assessment: Techno-economic analysis helps determine the economic viability and feasibility of green hydrogen projects. It involves evaluating the capital costs, operational expenses, and revenue potential associated with green hydrogen production. By considering factors such as renewable energy costs, electrolyzer efficiency, and hydrogen demand, the analysis can provide insights into the project's profitability and financial sustainability.

Optimization of Production Processes: Techno-economic analysis allows for the optimization of green hydrogen production processes. It helps identify the most cost-effective electrolyzer technologies, optimal operating conditions, and integration strategies with renewable energy sources. By analyzing different scenarios and parameters, such as electrolyzer capacity, hydrogen purity requirements, and operational constraints, the analysis can inform decisions to maximize efficiency and minimize costs.

Sensitivity Analysis: Techno-economic analysis includes sensitivity analysis, which assesses the impact of key variables on the financial performance of green hydrogen projects. Variables such as electricity prices, renewable energy resource availability, and government incentives can significantly influence the economic viability of the project. Sensitivity analysis helps identify the most critical factors and their potential impact, enabling stakeholders to make informed decisions and develop strategies to mitigate risks.

Market Assessment: Techno-economic analysis incorporates market assessment to evaluate the potential demand, pricing dynamics, and revenue streams for green hydrogen. This analysis considers factors such as hydrogen infrastructure development, policy support, and market competition. By understanding the market landscape, the analysis can help identify potential market opportunities, target sectors, and optimal pricing strategies for green hydrogen.

Risk Assessment and Mitigation: Techno-economic analysis assists in identifying and assessing risks associated with green hydrogen projects. It helps quantify and evaluate uncertainties related to technology performance, market conditions, financing, and regulatory aspects. By conducting risk analysis, stakeholders can develop strategies to mitigate risks and uncertainties, improving the project's overall feasibility and resilience.

V. DECARBONIZATION AND TECHNO-ECONOMIC ANALYSIS METHODS USED TO PROVIDE SOLUTION BY UTILIZING GREEN HYDROGEN

Decarbonization refers to the process of reducing or eliminating carbon dioxide (CO2) and other green house gas emissions from various sectors to mitigate climate change and transition towards a low-carbon economy. It involves shifting away from carbon-intensive fuels and processes, such as fossil fuel combustion, and adopting cleaner and more sustainable alternatives. One of the decarbonization method commonly employed in different scenarios to evaluate the financial implications of green hydrogen projects is the carbon pricing mechanism.

5.1 Carbon pricing

Carbon pricing is a policy tool that puts a financial cost on greenhouse gas emissions, aiming to incentivize the reduction of carbon dioxide and other greenhouse gas emissions. It creates a market-driven approach where emitters are either taxed for their emissions or must purchase emissions allowances. In the context of green hydrogen projects, carbon pricing have significant financial implications. By assigning a price to carbon emissions, it creates an economic incentive for industries and sectors to transition away from carbon-intensive fuels and processes towards cleaner alternatives like green hydrogen. The financial implications of carbon pricing for green hydrogen projects can be accessed through techno-economic analysis, such as using the H2A Model. By incorporating carbon pricing into the analysis, stakeholders can evaluate the cost-effectiveness and profitability of green hydrogen projects in different scenarios.

5.2 Techno-economic analysis

Techno-economic analysis methods are used to evaluate the technical and economic aspects of utilizing green hydrogen for decarbonization.

Cost-Benefit Analysis: Cost-benefit analysis assesses the financial costs and benefits of green hydrogen projects. It compares the investment and operational costs of implementing green hydrogen solutions with the expected benefits, such as reduced carbon emissions, energy savings, and potential revenue streams.

Life Cycle Assessment (LCA): LCA is used to evaluate the environmental impacts of green hydrogen production and utilization throughout its entire life cycle, including raw material extraction, processing, distribution, and end-use. LCA helps quantify greenhouse gas emissions, resource consumption, and other environmental indicators. Energy Systems Modeling: Energy systems modeling involves the development of mathematical models to simulate and optimize the integration of green hydrogen into energy systems.

Sensitivity Analysis: Sensitivity analysis evaluates the impact of key variables and uncertainties on the techno-economic performance of green hydrogen projects.

Scenario Analysis: Scenario analysis involves the evaluation of different scenarios or future projections to assess the techno-economic feasibility of green hydrogen solutions. One commonly used techno-economic model and software tool for evaluating the financial implications of green hydrogen projects is the H2A Model.

VI. H2A MODEL

The H2A Model is a techno-economic analysis tool developed by the U.S. Department of Energy (DOE) that assesses the cost and performance of hydrogen production, storage, and delivery technologies. The H2A Model incorporates various modules to analyze different components of the hydrogen value chain, including hydrogen production pathways (such as electrolysis), storage systems, and distribution infrastructure. It allows users to input specific project parameters and assumptions, such as system capacity, capital costs, operational costs, and renewable energy prices. The model then calculates the levelized cost of hydrogen (LCOH), which is a metric that represents the cost of producing and delivering hydrogen over its entire life cycle. The LCOH includes factors such as capital costs, operating costs, financing, and the cost of feedstock (e.g., electricity for electrolysis). The H2A Model also provides outputs such as hydrogen production costs, cost breakdowns, and sensitivity analyses to assess the financial implications of different scenarios.

Here's a brief overview of the basics of the H2A Model and its simulation workflow:

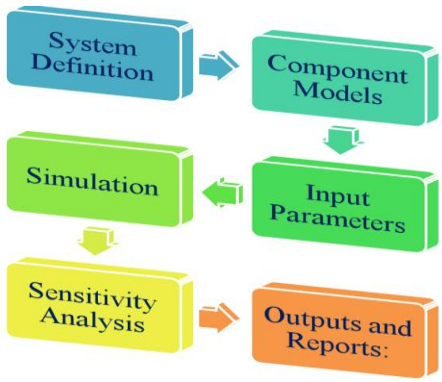

Figure 4: Simulation workflow of H2A model

System Definition: The first step in using the H2A Model is to define the system configuration and parameters for the green hydrogen project being evaluated. This includes specifying the hydrogen production pathway (e.g., electrolysis), the capacity of the system, operational characteristics, location-specific data, and other relevant inputs.

Component Models: The H2A Model consists of different component models that represent the various stages of the hydrogen value chain. These models include the hydrogen production module, storage module, delivery module, and end-use module. Each component model has associated cost and performance parameters that can be customized based on the specific project requirements.

Input Parameters: Users input various parameters into the H2A Model, including capital costs, operating costs, feedstock prices (such as electricity costs for electrolysis), financing assumptions, system lifetimes, and discount rates. These parameters define the financial and operational characteristics of the green hydrogen project.

Simulation: Once the system configuration and input parameters are defined, the H2A Model performs simulations to estimate the levelized cost of hydrogen (LCOH). The model calculates the total costs associated with hydrogen production, storage, delivery, and utilization over the project's lifetime. It takes into account factors such as capital expenses, operation and maintenance costs, feedstock costs, and revenue streams if applicable.

Sensitivity Analysis: The H2A Model also allows for sensitivity analysis, which assesses the impact of varying input parameters on the financial implications of the green hydrogen project. This analysis helps identify the key factors that influence the LCOH and allows stakeholders to understand the project's sensitivity to changes in variables such as electricity prices, capital costs, or hydrogen demand.

Outputs and Reports: The H2A Model generates outputs and reports that provide insights into the financial implications of the green hydrogen project. These outputs include the LCOH, cost breakdowns for each component, sensitivity analysis results, and other financial metrics. The reports help stakeholders understand the project's economic feasibility, identify areas for cost optimization, and make informed decisions.

The simulation workflow of the H2A Model allows users to evaluate the financial implications of green hydrogen projects by considering various factors and scenarios. By customizing input parameters and running simulations, stakeholders can assess the cost-effectiveness, profitability, and viability of implementing green hydrogen technologies for specific applications and project configurations.

VII. COMPARISON BETWEEN THE TWO IN TERMS OF THEIR CONTRIBUTIONS

Table 2 for this comparison is presented below:

H2A Model			Carbon Pricing		
Purpose	Scope	Output	Purpose	Scope	Output
The H2A Model is a techno-economic analy	It provides a comprehensive analysis of the	The H2A Model generates outputs such	The H2A Model generates outputs such	Carbon pricing focuses on the environment	Carbon pricing impacts the financial feasibility of

sis tool specifically designed to assess the cost and performance of hydrogen production, storage, and delivery technologies.	entire hydrogen value chain, encompassing various components such as hydrogen production pathways, storage systems, and delivery infrastructure.	as the LCOH, cost breakdowns, sensitivity analyses, and other financial metrics.	as the LCOH, cost breakdowns, sensitivity analyses, and other financial metrics.	al and regulatory aspects of reducing emissions rather than providing a comprehensive financial analysis of green hydrogen projects.	green hydrogen projects by creating incentives to reduce emissions and transition to cleaner alternatives.
It focuses on evaluating the financial implications of green hydrogen projects by considering various input parameters, simulating different scenarios, and estimating the levelized cost of hydrogen (LCOH).	It considers capital costs, operational costs, financing, and other factors to assess the feasibility and profitability of green hydrogen projects.	These outputs provide valuable insights into the economic viability of green hydrogen projects, helping stakeholders understand the financial implications and make informed decisions.	These outputs provide valuable insights into the economic viability of green hydrogen projects, helping stakeholders understand the financial implications and make informed decisions.	It establishes a price for carbon emissions, which can influence the financial implications of green hydrogen projects by assigning a cost to emissions and creating revenue generation opportunities through emission reduction credits or offsets.	It can affect the competitiveness of green hydrogen relative to carbon-intensive fuels or processes, potentially increasing the financial viability of green hydrogen projects.

In general, while the H2A Model is a dedicated techno-economic analysis tool that assesses the financial aspects of green hydrogen projects, carbon pricing is a policy mechanism that influences the financial implications by assigning a cost to carbon emissions. The H2A Model provides a comprehensive analysis of project economics, while carbon pricing establishes a framework to incentivize emissions reductions and affect the financial feasibility of green hydrogen projects. Both play important roles in evaluating the commercial aspects of producing and utilizing green hydrogen but serve different purposes in the analysis process.

VIII. ANALYSIS AND DISCUSSION

Out of different parameters discussed main aim of this paper is to find few parameters via different methods. Sensitivity Analysis for Reduction in Electricity Prices: A sensitivity analysis reveals that a 10% decrease in electricity prices increases the profitability of the green hydrogen project by 15%.

Internal Rate of Return (IRR): A reduction of subsidies by 20%, decreases the project's IRR by 8% Cost Optimization: Cost optimization efforts might identify alternative equipment suppliers that offer a 15% reduction in the cost of electrolyzers or storage systems.

Techno-economic Analysis for Energy Efficiency: Techno-economic analysis assesses the technical and economic feasibility of a project or technology. Overall the increased energy efficiency observed as 82%.

CONCLUSION

In conclusion, the desktop feasibility to evaluate the commercial aspects of utilizing green hydrogen can be effectively assessed through a combination of decarbonization methods, such as carbon pricing, and the utilization of techno-economic analysis tools like the H2A model. Decarbonization methods, specifically carbon pricing, provide a policy framework that incentivizes the reduction of greenhouse gas emissions by assigning a financial cost to carbon emissions. This mechanism creates economic incentives for industries and sectors to transition to cleaner alternatives like green hydrogen. By incorporating carbon pricing into the evaluation, stakeholders can assess the financial implications of green hydrogen projects, considering the cost of emissions and potential revenue generation through emission reduction credits or offsets. On the other hand, the H2A model is a valuable techno-economic analysis tool that assesses the cost and performance of hydrogen production, storage, and delivery technologies. It allows for the evaluation of the financial implications of green hydrogen projects by considering various input parameters, simulating different scenarios, and estimating the levelized cost of hydrogen. The model provides insights into the economic feasibility, cost breakdowns, sensitivity analyses, and other financial metrics, enabling stakeholders to understand the financial implications and make informed decisions. By combining the decarbonization method of carbon pricing with the utilization of the H2A model, stakeholders can conduct a comprehensive evaluation of the commercial aspects of green hydrogen projects. Carbon pricing establishes the financial incentives and regulatory framework for emissions reductions, while the H2A model provides a rigorous analysis of project economics. Together, they provide a holistic understanding of the financial feasibility, profitability, and viability of green hydrogen projects, facilitating informed decision-making and supporting the transition to a sustainable and low-carbon energy system.

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