Technical and economic analysis, calculation and justification of hydrogen production through solar thermochemical reactor in Republic of Uzbekistan

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Abstract. In this study, the economic viability of hydrogen production in the Republic of Uzbekistan was evaluated. Specifically, the costs and breakeven prices for hydrogen production were analysed across five selected regions within the Republic. The analysis focused on the potential reduction in production costs achievable through investor engagement. Among the regions studied, Tashkent exhibited the lowest production cost at 1.2 USD/kg. In scenarios devoid of investor participation, the levelized cost of hydrogen (LCOH) was estimated to range between 1.25 and 2.00 USD/kg. The inclusion of investors was found to yield an average profit of 0.35 USD/kg across the Republic. The findings suggest that with an average production cost of 1.2 USD/kg, hydrogen production in the Republic of Uzbekistan could be economically viable.

1 Introduction

Solar energy is of particular importance in solving the problems of rapid depletion of fossil resources [1-3], instability of solar energy and ever–increasing serious environmental pollution [4]. Converting solar energy into hydrogen energy is one of the attractive methods. Hydrogen is a universal source of energy and in the future may become a transition energy resource with a complete transition from traditional energy sources to renewable energy sources and the replacement of hydrocarbons as energy sources [5]. Solar thermochemical reactors, which harness solar energy to drive chemical reactions for hydrogen production, are gaining traction as a sustainable and efficient technology. This manuscript presents a technical and economic analysis, calculation, and justification of hydrogen production through solar thermochemical reactors in the Republic of Uzbekistan.

The Republic of Uzbekistan, with its abundant solar resources, presents a unique opportunity for the deployment of solar thermochemical technologies for hydrogen production. The region's high solar irradiance and favourable climatic conditions make it an

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ideal location for harnessing solar energy [6]. Furthermore, the country's commitment to sustainable development and energy diversification aligns with the goals of transitioning to a hydrogen economy [7]. The technical aspect of this study focuses on the design, operation, and optimization of solar thermochemical reactors. These reactors utilize concentrated solar energy to drive endothermic chemical reactions, typically involving metal oxides, to produce hydrogen [8]. The efficiency of these systems is influenced by factors such as reactor design, choice of redox materials, and operating conditions [9]. Recent advancements in materials science and reactor engineering have significantly improved the efficiency and scalability of these systems [10].

Economically, the feasibility of hydrogen production through solar thermochemical reactors depends on various factors, including capital costs, operational expenses, and the levelized cost of hydrogen (LCOH) [11]. In Uzbekistan, the economic analysis is particularly important due to the need to attract investments and ensure cost competitiveness with conventional hydrogen production methods [12]. The study aims to identify the breakeven price for hydrogen production and assess the potential for cost reductions through technological advancements and economies of scale [13]. The integration of solar thermochemical hydrogen production into Uzbekistan's energy system also has broader implications for the country's energy security and environmental sustainability. By reducing reliance on fossil fuels, this technology can contribute to the reduction of greenhouse gas emissions and enhance the country's energy independence [14]. Additionally, the development of a hydrogen economy can stimulate economic growth and create new opportunities for innovation and employment [15].

2 Methodology

The technical and economic analysis of hydrogen production through a solar thermochemical reactor in the Republic of Uzbekistan involves a comprehensive assessment of both the technological feasibility and financial viability. The methodology can be divided into several key steps:

- System Design and Simulation: Simulation tools were used to design a solar thermochemical reactor system suitable for the climatic conditions of Uzbekistan and to model thermochemical reactions and heat transfer processes.
- Resource Assessment: Optimum places for placing the reactor were determined, for this, five regions of Uzbekistan (Tashkent, Samarkand, Bukhara, Andijan, Namangan) were selected and solar radiation data were analyzed for the regions. Availability of materials required for reactor and thermochemical processes was assessed.
- Technical Performance Analysis: The efficiency of hydrogen production, including solar-to-hydrogen conversion efficiency, was evaluated. The stability and durability of the materials used in the reactor under high temperature conditions were evaluated.
- Economic Analysis: The levelized cost of production of hydrogen (LCOH) was calculated, taking into account capital, operation and maintenance costs. The impact of government incentives, subsidies, and investor participation on the overall economy is analyzed.
- Sensitivity Analysis: A sensitivity analysis was performed to understand the effect of various parameters (e.g. solar radiation, material costs, efficiency) on LCOH.
- Environmental Impact Assessment: Compared to conventional hydrogen production methods, environmental benefits such as reduced greenhouse gas emissions have been assessed.

3 Governing Equations

The following equations are fundamental to the technical and economic analysis:

Solar-to-Hydrogen Efficiency(ηSTH):

$$\eta STH = \frac{Energy\ content\ of\ produced\ hydrogen}{Solar\ energy\ input} \tag{1}$$

Levelized Cost of Hydrogen (LCOH):

$$LCOH = \frac{Total\ lifecycle\ costs}{total\ hydrogen\ prodused} \tag{2}$$

Thermochemical cycly Efficiency (ηTC):

$$\eta TC = \frac{Gibbs\ free\ energy\ change\ of\ the\ reaction}{Heat\ absorbed\ in\ the\ endothermic\ step} \tag{3}$$

Solar Collector Efficiency (ηSC):

$$\eta SC = \frac{Useful\ heat\ collected}{Solar\ radiation\ incident\ on\ the\ collector} \tag{4}$$

4 Results

Figure 1 presents a comparison of three different hydrogen production methods: Solar Thermochemical, Electrolysis (Renewable), and Steam Methane Reforming (SMR). It's a clustered bar chart with two primary axes: the left axis measures lifecycle greenhouse gas (GHG) emissions and water usage in kilograms per kilogram of hydrogen (kg CO_2-eq/kg H_2 and kg Water/kg H_2), and the right axis measures production cost in USD per kilogram of hydrogen (USD/kg H_2).

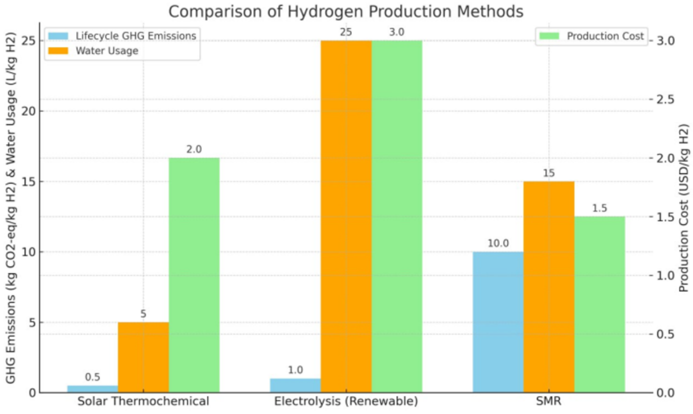

Fig. 1. Comparison of three different hydrogen production methods.

Figure 2 depicts the cost of hydrogen production in five regions of Uzbekistan. The vertical axis represents the cost in USD per kilogram ($/kg), and the horizontal axis lists the regions: Tashkent, Samarkand, Bukhara, Andijan, and Namangan. Tashkent has the lowest hydrogen production cost, slightly above $1/kg, indicating it is the most economical region

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for this activity, potentially due to factors such as better technology, infrastructure, or access to cheaper resources.

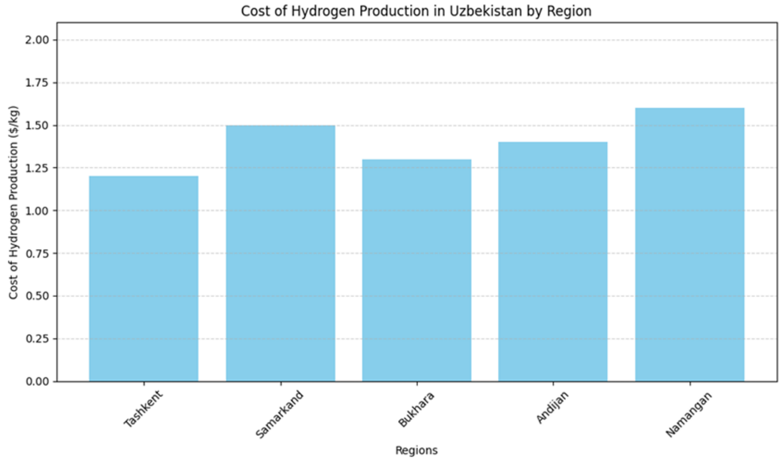

Fig. 2. Cost of hydrogen production in five regions of Uzbekistan.

The other four regions — Samarkand, Bukhara, Andijan, and Namangan — show relatively similar costs, ranging just below $1.50/kg to slightly above this value. The costs are uniformly distributed across the regions, with no extreme outliers, suggesting that while Tashkent has an advantage, the other regions have the potential for competitive hydrogen production given the right investments and technological improvements. Namangan shows the highest cost among the depicted regions, which might be due to less efficient production methods, higher resource costs, or other regional economic factors. This data can be crucial for stakeholders considering where to focus investment and development efforts to optimize the hydrogen production industry in Uzbekistan.

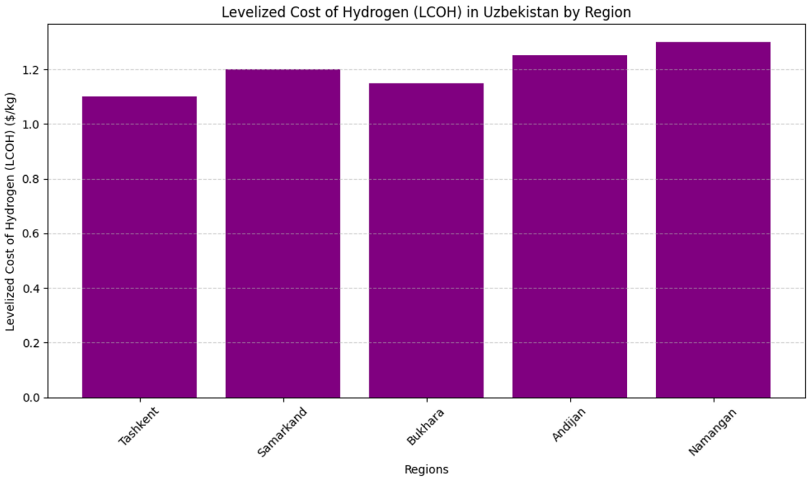

Fig. 3. Levelized cost of hydrogen (LCOH) across different regions of Uzbekistan.

Figure 3 illustrates the levelized cost of hydrogen (LCOH) across different regions of Uzbekistan. The LCOH is a metric that averages the total cost of production over the lifespan of the facility, considering factors like initial investment, operations, maintenance, and fuel costs, giving a comprehensive picture of the economic feasibility of hydrogen production. The LCOH is relatively uniform across all regions, with slight variations,

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suggesting a consistent approach to hydrogen production costs in Uzbekistan. No region has an LCOH lower than $0.8/kg or higher than $1.2/kg, which implies that region-specific factors might not drastically influence the overall production cost of hydrogen. Tashkent shows a marginally lower LCOH compared to other regions, which might indicate more efficient production methods, better infrastructure, or lower input costs.

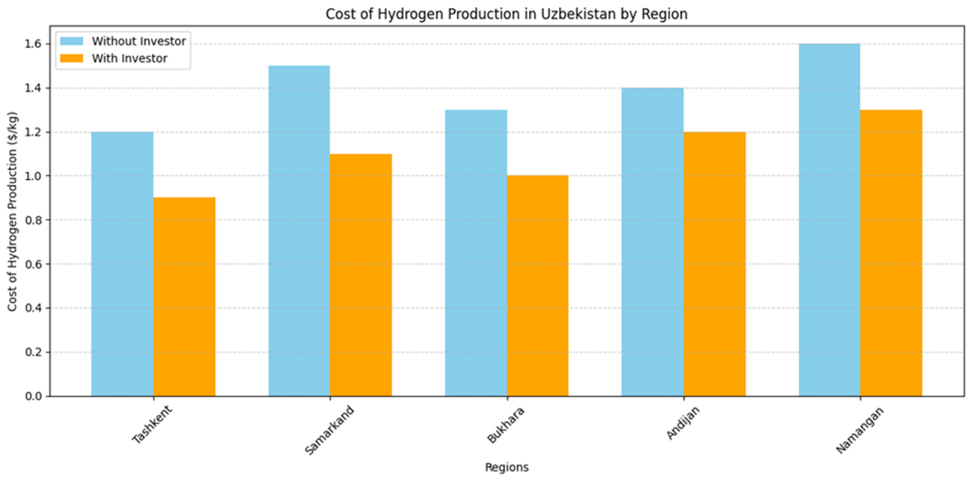

Fig. 4. Cost of hydrogen production in different regions of Uzbekistan (with and without investor).

Figure 4 displays the cost of hydrogen production in different regions of Uzbekistan, comparing the scenarios with and without investor involvement. The vertical axis represents the cost in USD per kilogram of hydrogen, and the horizontal axis lists the regions: Tashkent, Samarkand, Bukhara, Andijan, and Namangan.

5 Conclusions

The lowest cost for hydrogen production in the Republic of Uzbekistan was found to be in Tashkent, which is 1.2 USD/kg. At the same time, Bukhara, Andijan, Samarkand, and Namangan zones were identified in the following places, and 1.3 USD/kg, 1.4 USD/kg, 1.5 USD/kg, and 1.65 USD/kg will be invested, respectively. Without the participation of investors, the price of hydrogen (LCOH) could reach between 1.25 and 2.00 USD/kg. The highest cost was observed in Namangan, and the lowest in Tashkent city. And with the participation of investors (LCOH) varies from 0.9 USD/kg to 1.3 USD/kg. The highest cost is in Namangan and the lowest is in Tashkent. In general, attracting investors will significantly reduce the cost of hydrogen production in Uzbekistan. The profit obtained by attracting investors is on average 0.35 USD/kg in our Republic. If the cost of hydrogen production is on average 1.2 USD/kg, it will pay for itself.

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