ENERGY BALANCE AND EFFICIENCY ANALYSIS OF A HYBRID SOLAR-BASED HYDROGEN PRODUCTION-STORAGE SYSTEM

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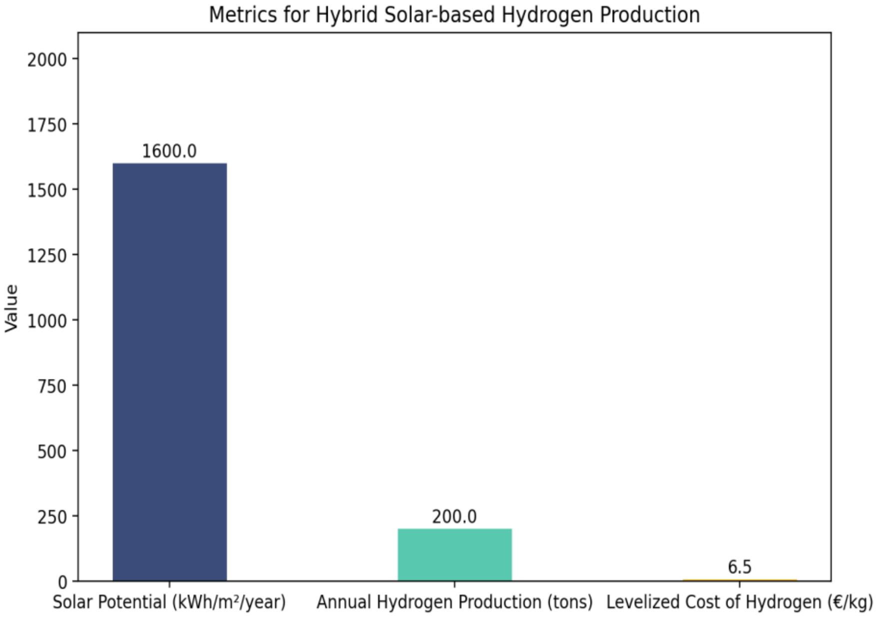
DOI: https://doi.org/10.5281/zenodo.21912215

Abstract. This article analyzes the energy balance and efficiency of a hybrid solar-based hydrogen production and storage system. The study evaluates solar energy conversion, hydrogen production through electrolysis, storage processes, and overall system efficiency. The results highlight the potential of integrated solar–hydrogen systems for efficient energy storage and sustainable energy supply.
Keywords: solar energy, hydrogen production, energy storage, energy balance, energy efficiency, electrolysis, hybrid energy system.
Аннотация. В статье проведен анализ энергетического баланса и эффективности гибридной системы производства и хранения водорода на основе солнечной энергии. Рассмотрены процессы преобразования солнечной энергии, производства водорода методом электролиза, его хранения и общая эффективность системы. Результаты показывают перспективность солнечно-водородных систем для эффективного накопления энергии и устойчивого энергоснабжения.
Ключевые слова: солнечная энергия, производство водорода, хранение энергии, энергетический баланс, энергоэффективность, электролиз, гибридная энергетическая система.
Annotatsiya. Ushbu maqolada quyosh energiyasiga asoslangan gibrid vodorod ishlab chiqarish va saqlash tizimining energiya balansi hamda samaradorligi tahlil qilingan. Quyosh energiyasini o‘zgartirish, elektroliz orqali vodorod ishlab chiqarish, uni saqlash jarayonlari va tizimning umumiy samaradorligi baholangan. Natijalar quyosh–vodorod tizimlarining energiyani samarali saqlash va barqaror energiya ta’minotidagi istiqbollarini ko‘rsatadi.
Kalit so‘zlar: quyosh energiyasi, vodorod ishlab chiqarish, energiyani saqlash, energiya balansi, energiya samaradorligi, elektroliz, gibrid energetika tizimi.

The exploration of hybrid solar-based hydrogen production systems represents a pivotal advancement in the pursuit of sustainable energy solutions. These systems leverage the abundant solar energy potential by integrating photovoltaic (PV) technology with hydrogen production, typically through electrolysis, allowing for the conversion of solar electricity into hydrogen gas. Such hybrid setups not only generate hydrogen but also serve as energy storage mechanisms, which mitigate the inherent intermittency associated with solar power production. Furthermore, the combination of solar energy with wind resources offers a complementary approach that enhances the reliability and stability of hydrogen generation. According to findings, these hybrid systems can achieve a marked reduction in the levelized cost of hydrogen, making them economically viable alternatives to traditional fossil fuel-based production methods (S G Nnabuife et al., 2024) .



The chart displays key metrics for hybrid solar-based hydrogen production systems in Constanța County, Romania, highlighting solar potential, hydrogen production, and associated costs.

Energy balance considerations in hydrogen production and storage

The energy balance in hydrogen production and storage systems is a critical consideration, especially when examining the hybrid solar-based frameworks designed to optimize renewable energy utilization. In assessing these systems, it is essential to evaluate both the efficiency of hydrogen production through electrolysis and the subsequent storage methods that minimize energy losses. The integration of photovoltaic (PV) technologies into hydrogen generation facilitates efficient conversion of solar energy while addressing grid stability. However, challenges remain, particularly in balancing energy input versus output efficiencies. Traditional reliance on fossil fuels offers a contrast, wherein the inefficiencies inherent in these processes highlight the advantages of transitioning to renewables (Strejoiu C-V et al., 2025). Moreover, the hybrid systems combining batteries and hydrogen storage provide a multifaceted approach to meet increased energy demands, each technology bringing its own strengths and weaknesses (Yang Y et al., 2024). Such systems must achieve a seamless interplay between rapid response capabilities of batteries for short-term storage and the long-duration capacity of hydrogen. The comparative analysis of these technologies is crucial in developing effective strategies for optimizing energy management, with visual frameworks like that in providing valuable insights into the energy flows that underlie the hydrogen production and storage process.

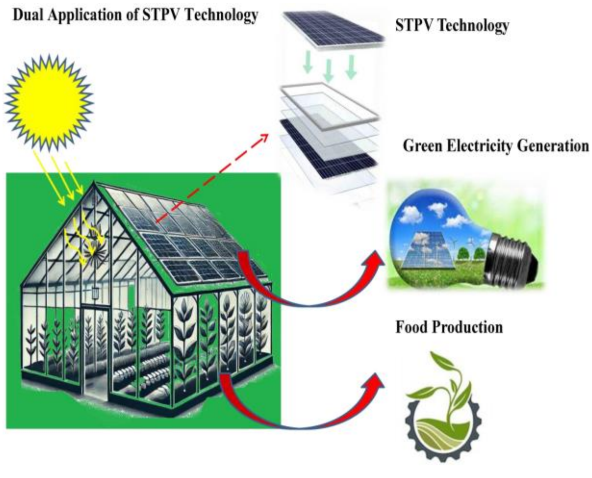


Image1: Integration of STPV Technology in Sustainable Agriculture

Production Method	Efficiency (%)
Steam Methane Reforming	75-85
Electrolysis (with renewable energy)	60-80

Gasification of Coal	50-70
Thermochemical Water Splitting	30-50

Energy Efficiency in Hydrogen Production Methods

Efficiency analysis of hybrid solar-hydrogen systems

The efficiency of hybrid solar-hydrogen systems is paramount to optimizing energy production and storage, particularly as society shifts toward sustainable practices. These systems exploit the synergy between solar energy generation and hydrogen production through electrolysis, converting excess renewable energy into a storable form. A comprehensive life cycle assessment is crucial for understanding the efficiencies at play and identifying areas for improvement. For instance, while solar photovoltaic systems offer high electrical efficiency, they experience output fluctuations due to weather conditions, necessitating robust hydrogen storage solutions to bridge energy supply gaps. Recent studies emphasize that integrating battery systems could enhance efficiency by addressing short-term energy demands while hydrogen systems cater to long-duration storage needs, thus presenting a complementary relationship between the two technologies (Yang Y et al., 2024) . The findings illustrate that such hybrid frameworks not only improve energy balance but also augment the resilience of energy infrastructures (Strejoiu C-V et al., 2025) . The intricacies involved in this efficiency analysis underscore the potential of hybrid solar-hydrogen systems to play a critical role in a sustainable energy future. Additionally, the visual representation in clearly demonstrates the increasing share of renewable electric energy across various sectors, effectively contextualizing the importance of energy diversification strategies in modern systems.

System Type	Efficiency (%)
MIT Solar Thermochemical Hydrogen	40
University of Michigan Solar Water Splitting	9
Cornell Solar Seawater Electrolysis	12.6
UIC Agricultural Waste Method	600% reduction in energy required

Efficiency of Hybrid Solar-Hydrogen Systems

Conclusion. In conclusion, the implementation of a hybrid solar-based hydrogen production-storage system illustrates a critical advancement in the quest for sustainable energy solutions. By harnessing renewable solar energy, this system not only addresses the pressing need for green alternatives to fossil fuels but also enhances energy efficiency and self-sustainability, as evidenced by the microgrid model employed in the analysis. The research underscores the potential of integrating photovoltaic panels with hydrogen production, which facilitates grid stability and promotes a cleaner environment. The insights gathered from simulations, particularly those modeling energy dynamics and efficiency over a one-week period, validate the feasibility of such systems in real-world applications. Furthermore, the analysis corresponds with findings from existing studies, advocating for the integration of renewable sources in hydrogen economy frameworks (Strejoiu C-V et al., 2025) (Barlaz F et al., 2025) . To solidify this conclusion, the examination of energy distribution and renewable adoption across sectors, as portrayed in the relevant images, highlights the broader context of energy transition. Among these, effectively encapsulates the progress in renewable electricity share, reinforcing the argument for innovative energy solutions that foster ecological balance and economic viability.

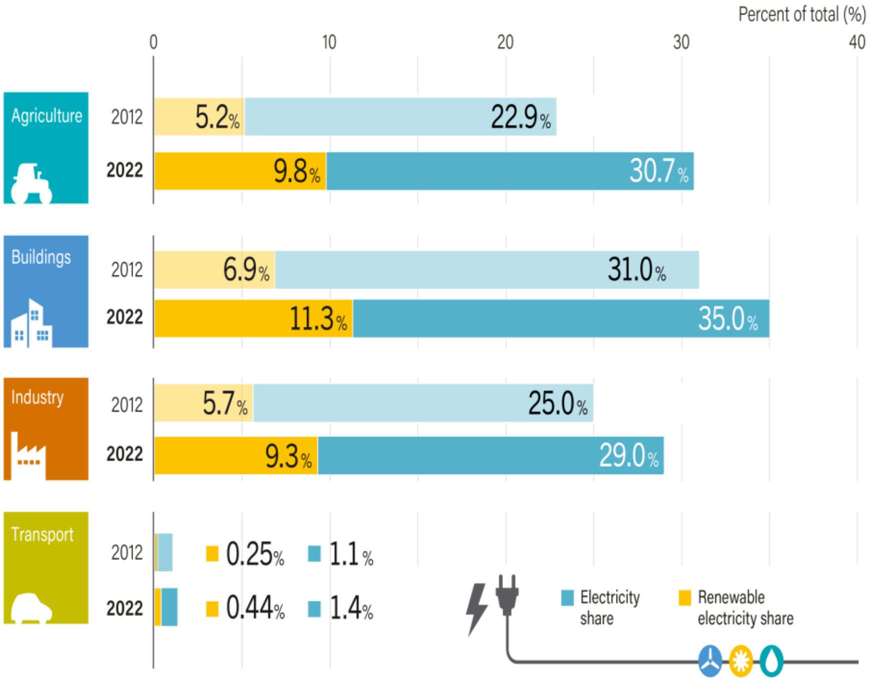


Image2: Electricity and Renewable Energy Shares by Sector (2012-2022)

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