Techno-Economic Study of Adding Hydrogen Storage to PV Plant in Neom City

Mashael A. Rajeh
College of Engineering Effat University
Jeddah, Saudi Arabia
marajeh@effatuniversity.edu.sa

Mohamed F. El-Amin
College of Engineering Effat University
Jeddah, Saudi Arabia
momousa@effatuniversity.edu.sa

Abstract

Based on its 2030 vision Saudi Arabia seeks future renewable clean energy as an essential input into most industrial sector production processes. As a model, Neom city is targeted 100 % dependent on renewable energy, limiting climate change caused by CO2 emissions. On the other hand, hydrogen as a clean energy source has gained much attention in recent years. Moreover, hydrogen storage is considered a promising energy carrier that can be merged in the renewable energy system to store a large amount of energy. The research focuses on adding hydrogen storage in a photovoltaic (PV) plant in Neom city represents the vision "2030" to limit CO2 emission. Hydrogen storage could provide a fully renewable and clean power source for fixed and mobile applications. Must scaled-up hydrogen production and the legislative framework needed to define commercial deployment models explicitly. More technology advancements are expected to minimize the associated costs of extraction, storage, and transportation and more investment in the infrastructure supporting Neom city. This work presents a techno-economic study of adding hydrogen storage to a photovoltaic (PV) plant in Neom city. Utilizing the System Advisor Model (SAM) software to calculate the payback period (PP) and the intern rate of return (IRR), and other economic parameters of the project with and without adding the hydrogen storage. The net present value of PV plant with hydrogen storage is considered $6,887,662, which means more time value of money from the supplied value. The techno-economic assessment of this study was limited to a PV plant with a total capacity of 30 MW on-grid.

Keywords
Neom city, Techno-economic, Photovoltaic (PV), Hydrogen storage, and Metal hydride hydrogen storage.

1. Introduction
NEOM City is in the Tabuk region, Saudi Arabia, northwest of the country (Figure 1). According to Saudi Arabia's vision 2030, it would be the world's first environmentally friendly city. The country's ample area for renewable energy especially solar energy projects offers an even stronger case for the government to use hydrogen storage (Carpenter 2021).

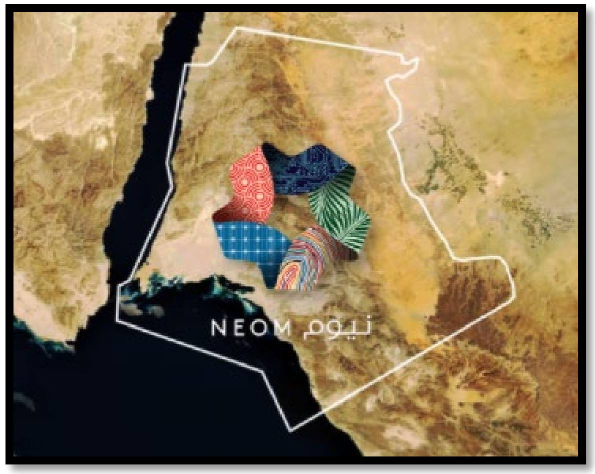

Figure 1. The Neom city (Farag 2019).

Nowadays, hydrogen (H) could be one of the solutions for future energy transition if produced by green energy using solar power, one of the most renewable energy sources in KSA. A growing body of research shows that hydrogen (H) storage is an appealing alternative for the deep decarbonization of global energy systems. Recent cost and performance improvements point to economic feasibility (Mirza 2021).

Moreover, the expansion of renewable energy, especially solar energy projects in Saudi Arabia as shown in table 1, gives a new opportunity to establish a new renewable energy technology industry. Hydrogen storage may play a role in providing a power, heat, industry, transportation, and energy storage in a low-carbon energy system, as well as an appraisal of hydrogen's current state of readiness to fulfill that potential in Neom city.

Table 1. Solar projects under the National Renewable Energy Program (NREP) (Amran et al. 2020).

Capacity (MW)	Project name
120	Wadi Al Dawasir
300	Skakah
300	Saad
700	Alrass
1500	Sadir
80	Layla Projact

1.1 Objectives

The research's primary target is to compare the economic studies between two PV plants without and with hydrogen storage in Neom City. By use System Advisor Model software calculates the payback period (PP), intern rate of return (IRR), and other financial parameters.

2. Literature Review

The literature review is conducted to summarize the current and previous research on a techno-economic study. Hydrogen storage systems have matured as viable for power system stabilization during generation-demand mismatches and for generating economic rewards from excess hydrogen and oxygen production. Becherif et al. (2015) used hydrogen energy storage as a new techno-economic emergence solution analysis. It drew attention to the novel hydrogen generation and storage technology, its efficacy, and the regulatory context's impact on its development. The techno-economic aspects of hydrogen production and storage were discussed. For a power system rated at 70 kW, MATLAB-Simulink was used. Hydrogen storage systems have matured as viable for power system stabilization during generation-demand mismatches and for generating economic rewards from excess hydrogen and oxygen production (Alshehri et al., 2018).

The Middle East and North Africa (MENA) area was endowed with energy from the sun may be captured from the MENA and stored as hydrogen, which is gaining popularity as a supplementary energy source. The authors looked at cost-efficient of the hydrogen generation and storage. Hydrogen may be produced using photovoltaic solar power and electrolysis devices. Most of the cost of the PV and electrolyzing systems must be paid upfront to produce hydrogen from solar electricity. Because of this, capital efficiency was the essential element to consider. A techno-economic review was carried out by Ran et al. (2018) the major materials of an off-grid solar panel generating model with hybrid power storage were built as mathematical systems. Depending on the material requirements, self-wastage, and system capacity affects. The authors examined the values and developed a modeling framework for an off-grid PV microgrid with hybrid energy storage using MATLAB software. The storage battery, electrolyzer, compressor, hydrogen tank, and fuel cell were all modelled in MATLAB/Simulink. They built a modeling framework for off-grid solar power generation with hybrid energy storage, using the power management method.
A techno-economic evaluation was conducted by Silva et al. (2018) in Sri Lanka to the reliability and economic viability of putting in place hydrogen production, storage, and solar photovoltaic systems Diesel generators were used to power the sites for communications. The scientists analyzed data from 3039 telecom base station sites in order to create and store hydrogen gas by electrolyzing water using solar energy collected. HOMER Grid was utilized to determine the best system composition. Their study's findings indicated that low-demand sites were appropriate for this design, and as the demand increased, more than one point in the system was required. Also, An economic analysis was conducted by Touili et al. (2019) to assess solar hydrogen generation in Morocco between Morocco and Southern Europe via water electrolysis. The authors studied the economy from 2014 to 2016 to model and create hydrogen from a 100 MWp PV power plant system was linked to a PEM electrolyzer. The study's findings highlight hydrogen's solar energy potential generation, providing policymakers and investors with important information to promote them. The findings demonstrated that the suggested idea was technically and economically viable in the majority of situations, but, in some scenarios with higher power consumption, an optimized variant of the standard design was shown to be still economically viable.

Abdin and Mérida (2019) investigated a techno-economic analysis of hybrid energy systems for off-grid power supply and hydrogen synthesis based on renewable energy to investigate power generation and hydrogen production via renewable energy resources (mainly solar and wind) to produce synthetic fuels by capturing CO2 from the atmosphere in five different global locations; Squamish, Canada; Los Angeles and Golden, USA; and Brisbane and Adelaide, Australia. The findings of this study imply that hydrogen has a lower cost of energy storage than batteries in off-grid energy systems. Gu et al. (2020) identifies a comparative techno-economic study of solar energy integrated hydrogen supply pathways for hydrogen refueling stations in China. It was determined the economic, energy, and environmental elements of prospective solar-integrated green hydrogen supply routes in China, including cross-regional and onsite possibilities for hydrogen filling stations. Four solar energy-integrated green hydrogen supply options have been presented. The findings show that solar energy-integrated hydrogen supply channels reduce CO2 emissions significantly. When compared to the standard coal gasification for hydrogen production coupled with gas H2 transportation to a local filling station pathway. Takatsu and Farzaneh (2020) used techno-economic analysis of a novel Hydrogen-based hybrid renewable energy system for grid-tied and Off-grid power supply in Japan, the case of Fukushima Prefecture. That presented a revolutionary hydrogen-based hybrid renewable energy system (HRES), in which hydrogen fuel can be produced, utilizing solar electrolysis and biomass feedstock (SCWG). In all scenarios, the proposed HRES can generate roughly 47.3 MWh of energy, which is required to meet the external load need in the research region.

Nasiraghdam and Safari (2020) discussed a techno-economic assessment of combined power to hydrogen technology and hydrogen storage in optimal bidding strategy of high renewable units penetrated microgrids. Their goal was to develop a novel method for finding the best bidding strategies for magnesium (MG) modified by renewable resources in the day-ahead energy and spinning reserve markets, taking advantage of the capabilities of power to hydrogen (P2H) and hydrogen storage (HS) technology. It used the power to hydrogen (P2H) and hydrogen storage (HS) technologies' capabilities. In addition, the unscented transformation has been employed to efficiently simulate the uncertainty in the entity's renewable resources, load consumption, and electricity. The cost of operating the system without energy storage is 779 dollars but utilizing an energy storage system (ESS) reduces the cost to 741 dollars, a savings of 4%. Furthermore, by employing (ESS) as both energy and reserve suppliers, the operational cost drops to 640$, a savings of 18%. On the other hand, using the HS system cuts operating costs by as much as 26% and 40% for energy suppliers and energy and reserve suppliers, resulting in 577$ and 487$, respectively.

3. Methods

The literature review assisted in gathering the necessary data and information for the techno-economic assessment of adding hydrogen storage to a PV plant in NEOM City. The capacity of the PV facility is 30 MW per year on the grid. The authors aim to calculate the payback period (PP) and the intern rate of return (IRR), and other economic parameters with and without adding the hydrogen storage, located in NOEM city, Saudi Arabia. The authors used the System Advisor system (SAM).

3.1 The PV plant without hydrogen storage

Figure 2 shows a PV plant without hydrogen storage. Table 2 presents header data from weather file from system advisor model (SAM), and the system design variables that are used to size a solar system are listed in table 3. The AC Sizing inputs determine the system's AC rating. The sizing summary variables values SAM calculates based on the inputs you specify.

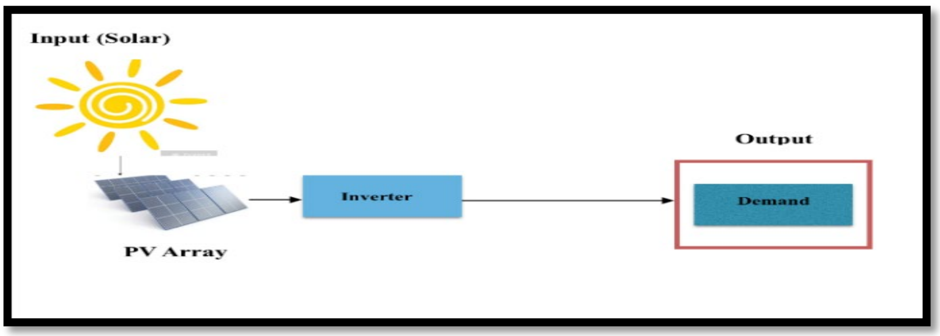

Figure 2. PV system.

Table 2. Header data from weather file.

Latitude	24.65
Longitude	46.7
Time zone	GMT 3

Table 3. Sizing Summary.

Nameplate DC capacity	29,997.513 KWdc
Total AC capacity	24,640.000 kWac
Total inverter DC capacity	25,334.606 KWdc
Number of modules	75,872
Number of strings	4,742
The number of inverters	32 units
Total module area	145,674.240 m^2
Desired array size	30000 KWdc
Desired DC to AC ratio	1.2

Based on the design parameters and incident solar radiation (plane-of-array irradiance) supplied from data in the weather file, the module model calculates the DC electrical output of a single module for each simulation time step. The selected module type is Jinko Solar Co. Ltd JKMS395M-72L-V-MX3. The reference conditions from model characteristics at reference condonations from the system advisor model are shown in (Figure 3). The number of modules is 75,872 units. Also, the inverter was chosen according to the performance model and an inverter from a list. SMA America is the inverter type, SC750CP-US with ABB EcoDry Ultra transformer. The reference conditions from efficiency curve and characteristics from the system advisor model are shown in (Figure 4).

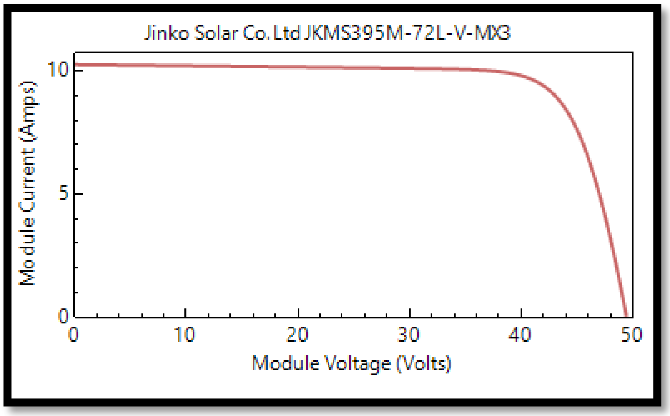

Figure 3. PV power.

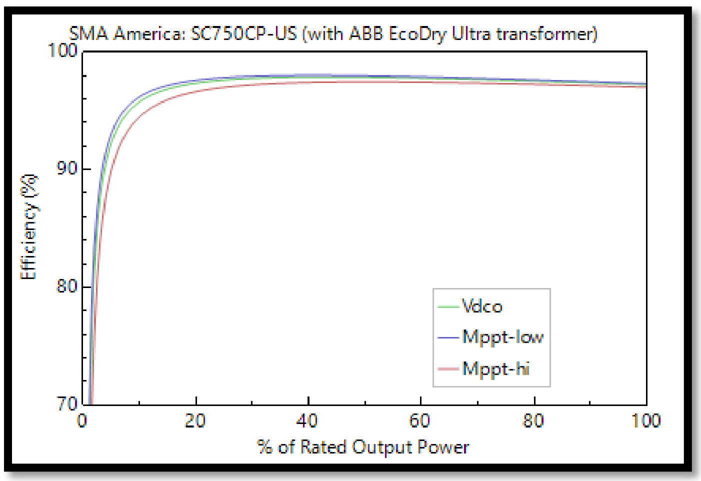

Figure 4. Efficiency Curve.

3.2 The PV plant with hydrogen storage

The PV system with hydrogen storage is shown in Figure 5. Table 4 specifies the desired values for DC units, the nominal bank capacity, and power for SAM to calculate the number of cells and strings. The type of fuel cell is solid oxide fuel cell (SOFC), which operates at a temperature between 650 and 1,000 and can convert a wide range of fossil fuels.

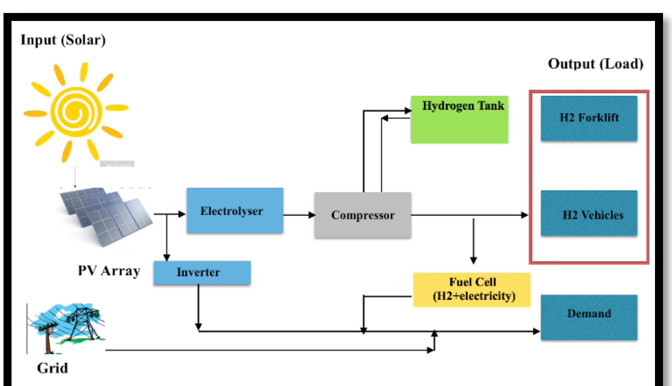

Figure 5. PV system with hydrogen storage.

Table 4. Battery Bank Sizing data.

The desired bank power	15000 KW
The desired bank capacity	17 hours

4. Results and Discussion

All simulation results obtained by the System Advisor Model. The proposed design produces 30MW per year on grid. The summary of the development for the project with and without adding the hydrogen storage. The summary result from the system advisor model (SAM) indicates the payback period (PP) and intern rate of return (IRR),), and other economic parameters for the projects.

According to Table 5 and table 6, Project one without hydrogen storage produces 54,815,952 kWh of annual energy in year one, with an energy yield of 1,827 kWh/Kw, whereas project two with hydrogen storage produces 60,697,240 kWh of annual energy in year one, with an energy yield of 1,971 kWh/Kw. As a result, when we compare production costs, project two comes out on top.

Furthermore, as shown in Tables 5 and 6, project one without Hydrogen Storage will sell energy at 5.00 Euro/kWh for a capital cost of $ 33,402,842, but Project Two with Hydrogen Storage will sell energy at 10.54 Euro/kWh for a capital cost of $ 62,140,600. As a result, when we evaluate the project from the perspective of the clients and the cost of insulation, the project becomes more appealing.

Similarly, as indicated in Tables 5 and 6, project one without hydrogen storage has a net present value of $2,014,911. However, project two with hydrogen storage has a net present value of $6,887,662. As a result, project 2 incorporates the time value of money from the supplied value.

Also, as shown in Tables 5 and 6, the Project One without Hydrogen storage estimates the profitability of prospective investments at 8.01 percent, with a year of completion at the end of year 10. where Project 2 with Hydrogen storage estimates possible investment return at 10% and the year of completion at the end of year 8. As a result, from the perspective of the investor, project two will generate more money.

Table 5. The system without hydrogen storage.

Annual energy (year1)	54,815,952KWh
DC capacity factor (year1)	20.9%
Energy yield	1,827 KWh/KW
Performance ratio (year1)	0.79
PPA price (year1)	5.00 Euro/kWh
PPA price escalation	1.00 %/year
Levelized PPA price (nominal)	5.40 Euro/kWh
Levelized PPA price (real)	4.31 Euro/kWh
Levelized COE (nominal)	5.01 Euro/kWh
Levelized COE (real)	4.00Euro/kWh
Net present value	$2,014,911
Internal rate of return (IRR)	8.01%
Year IRR is archived	10
IRR at end of the project	13.12%
Net Capital cost	$33,402,842
Equity	$13,409,554
Size of debt	$19,993,288
Debt percent	59,86%

Table 6. The system with hydrogen storage.

Annual energy (year1)	60,697,240KWh
DC capacity factor (year1)	22.9%
Energy yield	1,971 KWh/KW
Performance ratio (year1)	0.79
Battery roundtrip efficiency	100.00%
Thermal bill without system (year1)	$-0
Thermal bill with system (year1)	$-0
Net thermal savings with system (year1)	$0
PPA price (year1)	10.54 Euro/kWh
PPA price escalation	1.00%/year
Levelized PPA price (nominal)	11.27 Euro/kWh
Levelized PPA price (real)	9.27 Euro/kWh
Levelized COE (nominal)	9.95 Euro/kWh
Levelized COE (real)	8.18 Euro/kWh
Net present value	$6,887,662
Internal rate of return (IRR)	10.00%
Year IRR is archived	8
IRR at end of the project	19.21%
Net Capital cost	$62,140,600
Equity	$6,935,462
Size of debt	$55,205,140
Debt percent	88.84%

4.1 Cash Flow

Besides, as shown in figure 6 and figure 7, the cash flow of project One without Hydrogen storage balanced at the end of year 10, whereas the cash flow of Project 2 balanced at the end of year 8. As a result, the cash flow of project two is more attractive even when we see a double capital cost.

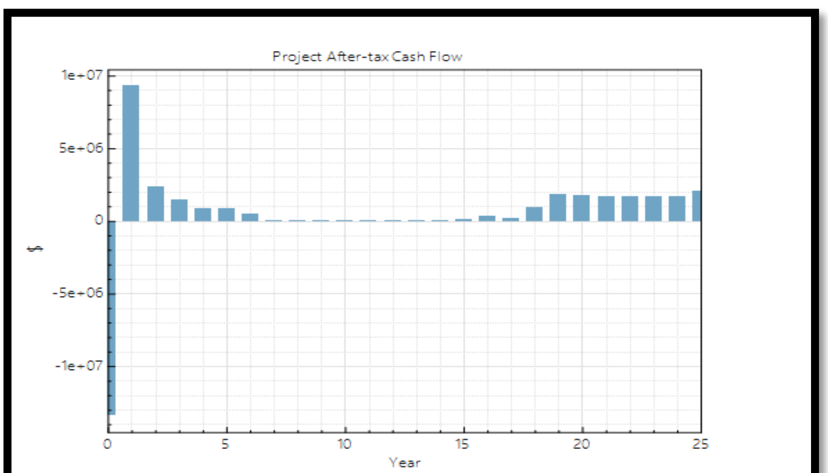

Figure 6. The cash flow for system without Hydrogen Storage.

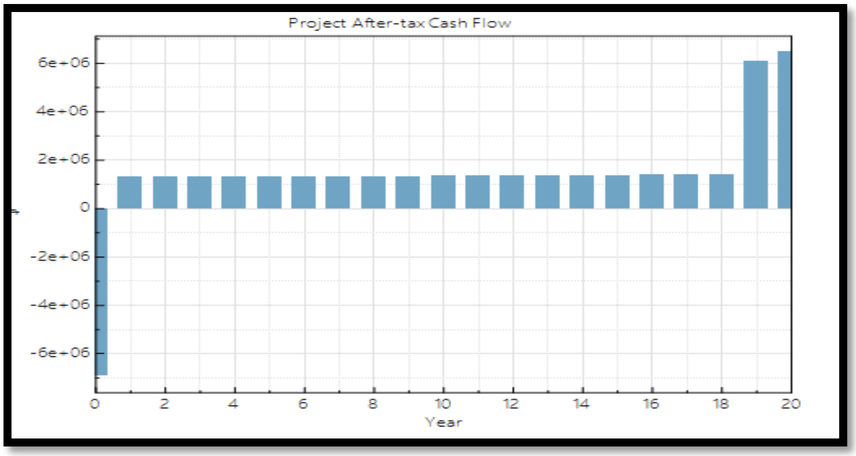

Figure7. The cash flow for system with Hydrogen Storage.

5. Conclusion

The research focuses on adding hydrogen storage in a photovoltaic (PV) plant in Neom city represents the vision "2030" to limit CO2 emission. Hydrogen storage could provide a fully renewable and clean power source for fixed and mobile applications. Must scaled-up hydrogen production and the legislative framework needed to define commercial deployment models explicitly. More technology advancements are expected to minimize the associated costs of extraction, storage, and transportation and more investment in the infrastructure supporting Neom city. The following conclusions are drawn from the study:

- The techno-economic of PV plant has been simulated successfully by using System Advisor Model.
- The estimates are possible of PV plant with hydrogen storage intern rate of return at 10% and the year of completion at the end of year 8, which is considered relatively good.
- The net present value of PV plant with hydrogen storage is considered $6,887,662, which means more time value of money from the supplied value.
- The techno-economic assessment of this study was limited to a PV plant with a total capacity of 30 MW on-grid. At the same time, there is a chance to extend the analysis to other plants for further exploration.

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Biography

Eng. Mashael A. Rajeh is a master of Energy Engineering student and Electrical and Computer Engineer. She received her bachelor's degree from Effat University with a second honor degree in 2019. she worked as a field professional reservoir evaluation engineer at Halliburton in 2019-2020. She finished her internships in two different companies at Saudi Aramco, Dahran, Eastern Province, as an Electrical Engineer, in 2018. At General Electrical, Dammam, Eastern Province as a Maintenance Engineer, in 2017. she did a capstone project about a (Hybrid wind and solar power system) at Effat University in 2019. She participated in Arab Remotely Operation vehicle computation. She is an active IEEE member. she participated with her colleagues in publishing a conference paper at the International Conference on Industrial Engineering and Operations Management (IEOM) in Singapore 2020 titled "Design and Simulation of a Standalone P.V. System for a Mosque in NEOM City." She Participated in Saudi Arabia smart grid Conference (SASG2018) with a poster about Hybrid wind and solar power systems. She participated in Saudi Arabia smart grid Conference (SASG2017) with a poster about Solar Roadways.

Prof. Dr. Mohamed F. El-Amin is a full professor of computational sciences at Effat University, Saudi Arabia. As a mathematician, he has over 25 years of research experience in the field of computational sciences, applied mathematics, heat and mass transfer, fluid dynamics, and petroleum engineering. After obtaining his PhD in 2001, he held research positions in several universities including South Valley University and Aswan University (Egypt), Stuttgart University (Germany), Kyushu University (Japan), and at King Abdullah University of Science and Technology (KAUST), Saudi Arabia. The research of Dr. El-Amin has resulted in over 180 publications including journal/conference papers and book chapters. He also edited three books and a number of journal special issues, and organized workshops and conferences.