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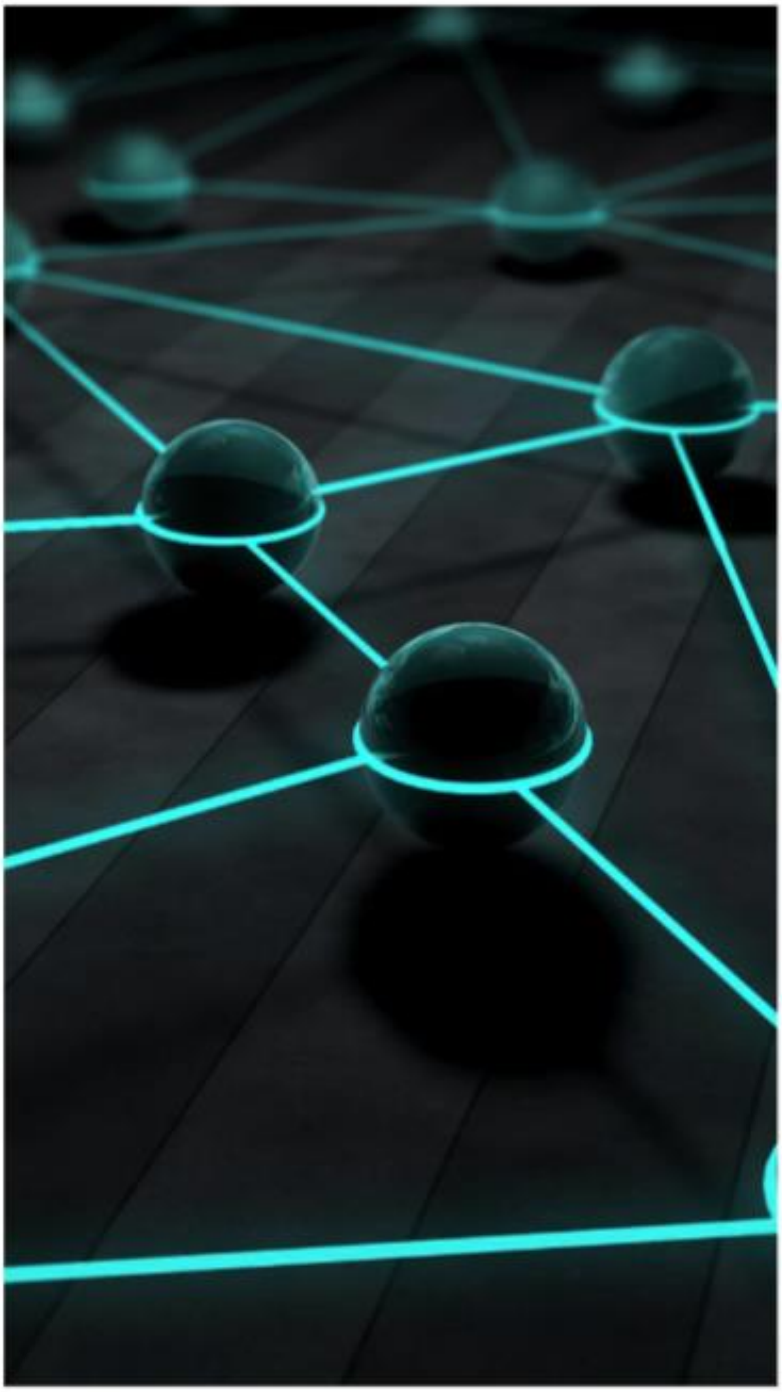

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Research Articles

Review Article

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Research Article

TECHNO-ECONOMIC FEASIBILITY ANALYSIS OF A LARGE-SCALE PARABOLIC TROUGH THERMAL POWER PLANT IN EFFURUN-WARRI, NIGERIA

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Abstract *In the modern world, solar energy is one of the most mature renewable energy resources for electricity generation. Because of the growing interest in green energy and* CO_2 *reduction, concentrated power technologies have gained prominence all over the world. Several parabolic trough power plants are currently operational in various parts of the world. However, despite the region's favorable weather conditions, Nigeria and Sub-Saharan Africa have yet to adopt this technology. To galvanize the integration of solar energy into the energy infrastructure in Nigeria, technical and economic feasibility studies are required. This paper presents a techno-economic viability assessment of a 25 MW Parabolic Trough solar thermal power plant for electricity generation in Effurun-Warri, Nigeria. The System Advisor Model (SAM) software was used for the analysis, based on the validated technical and financial models inbuilt into the software. Results showed that the plant is technically feasible in Effurun-Warri with a capacity factor of over 35%, which compares favorably with other similar plants across the globe. However, the levelized cost of electricity (LCOE) of 11.87 ₵/kWh obtained is significantly higher than the subsidized cost of electricity in the country, by 99%, leading to a negative net present value of the project. To improve cost, optimized design parameters of the plant should be adopted for performance simulation in the SAM software.*

Keywords - *Solar Energy; System Advisor Model (SAM); Concentrated Solar Power (CSP); Parabolic Trough Collectors (PTC); Techno-economic Assessment.*

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1. Introduction

There has been an explosion in population in recent times, particularly in developing regions such as Africa [1]. Several consequences of this population explosion now live with humans globally today; including energy poverty, food insecurity, spontaneous increase in greenhouse gases emissions, global warming, etc. Reducing the impacts of these adverse effects on the human race is a global concern today, and several scientists have been working hard in this regard. Specifically, a lot of efforts are ongoing to improvise energy and transportation systems that would emit little or no hazardous gases into the environment, fuelled principally by renewable energy resources [2]. However, although such solar, wind, biomass, and other renewable energy and transportation systems are rapidly gaining traction in the developed world in terms of development and commercialization, little is yet to be desired of these systems in many developing countries. Among the causes of low application of renewable energy systems in these developing regions is the lack of technical and economic viabilities of such projects, due to low research funding and technical know-how. Thus, a lot of research funding and technical efforts are still required to massively develop renewable energy infrastructure in developing countries; and this justifies the need for this study.

Solar is among the most widely studied renewable energy sources worldwide, perhaps due to its universal availability at no cost [3,4]. It can be harnessed using two main types of technologies; concentrated solar power (CSP) and photovoltaic (PV) systems. CSP systems employ tracking mechanisms to position a set of mirrors (collectors) in the direction of the sun, for the production of thermal energy in the receiver and subsequent conversion to electricity. In PV systems, however, panels track the photonic energy of the sun for direct conversion to electricity. Although the PV technology has advanced significantly in terms of scalability and cost, it generally has lower efficiency than the CSP technology [5]. Besides, CSP projects are easily amenable for the generation of thermal energy for industrial applications, and that has made them very attractive for off-grid energy applications [6]. Many researchers have applied different computer simulation methods to study the feasibilities and applications of CSP systems for off-grid energy generation in different countries; a summary of these studies is reported hereunder.

Martin-Pomares et al. [7] applied eleven-year hourly satellite-derived solar data to analyze the long-term feasibility of solar energy generation in Qatar and obtained that a parabolic trough CSP plant with a large thermal energy storage system had a huge potential in the country. Polo et al. [8] demonstrated the long-term feasibility of CSP plants based on a multi-year statistical analysis and System Advisor Model (SAM) simulation of four power plants in the Mediterranean North African region. Sequel to the aggressive plan of the Saudi Arabian Government to integrate about 25 GW of energy from CSP plants into the national grid, Kassem et al. [9] reported from their analysis of the strength, weakness, opportunity, and threat (SWOT) of different CSP technologies that the parabolic trough is the most mature and the most commercially deployed CSP technology. Serradj et al. [10] assessed the viability of a 100 MW parabolic trough thermal power plant for the city of Tamanrasset, Algeria, and reported that such a plant could satisfy about 78% of the city's total electricity demand in winter, and about 60% in summer. Similarly, Alotaibi et al. [11] employed the SAM software to design and analyze a 100 MW parabolic trough power plant for the city of Riyadh, Saudi Arabia, and reported that about 45% capacity factor was achievable by the plant at an acceptable levelized cost of electricity (LCOE). Sharma et al. [12] equally employed the SAM software to study the effects of the direct normal irradiation (DNI), solar multiple, and capacity of storage on the levelized unit cost of electricity (LUEC) of parabolic trough and linear Fresnel collectors. They reported the range of each parameter where the LUEC is lowest for each of the CSP technologies considered. Bishoyi and Sudhakar [13] reported, based on the design and performance simulation of a 100 MW parabolic trough power plant in India, that the thermal efficiency and electricity cost obtained from the hypothetical plant is such that should encourage further studies and innovations toward the implementation of CSP plants in the country. Also, Aseri et al. [14] reported the importance of integrating high-capacity thermal energy storage systems with CSP plants with low nominal capacities, over increasing the nominal capacities of such systems without energy storage. Praveen et al. [15] reported the feasibility of CSP plants to contribute to the development of sustainable energy in the Middle East, based on the SAM-based design and performance simulation of a parabolic trough power plant in the cities of Abu Dhabi and Aswan. In another study, Praveen et al. [16] proposed a fuzzy non-linear programming model to optimize the design of parabolic trough power plants, and when applied to a 100 MW plant in India, the approach was reported to improve significantly the capacity factor and cost. Ullah et al. [17] designed and constructed a small-scale parabolic trough solar power plant based on the results of modeling and simulation where different heat transfer fluids were compared for the CSP plant. Kherbiche et al. [18] assessed the viability of solar plants for electricity generation in M’Sila, Algeria, and recommended that the parabolic trough CSP plants should be adopted for the city. Furthermore, mohammadi et al. [19] investigated the feasibility of parabolic trough solar plants for industrial heat generation and reported that a 5 Mwt plant in Utah is competitive with plants fuelled with natural gas. Hirbodi et al. [20] assessed the techno-economic and environmental performance of CSP plants in the Southern region of Iran, and reported that a 100 MW plant with an average of 14 hours of thermal energy storage and a solar multiple of 3.0 would be competitive for electricity generation in the region. Tahir et al. [21] went beyond the usual techno-economic viability assessment of CSP plants in Pakistan, to also discuss robustly the financial, technical, infrastructural, political, and other barriers that might affect the implementation of such plants, and the possible way out of such barriers. Trabelsi et al. [22] assessed the techno-economic feasibility of deploying a 50 MW parabolic trough power plant in the southern region of Tunisia. They reported that adopting the dry cooling scheme for the power plant would lead to a technically viable system for this desert region, with LCOE of about 18 ₵$/kWh.

The literature review in the foregoing clearly shows that solar projects based on the parabolic trough CSP technology are ubiquitous, albeit with economic limitations. Also, it is explicitly revealed in the review that SAM is a very vital and popular tool being used for the design and simulation of CSP systems, perhaps because it is open-source software and it is able to account for the dynamic nature of climatic parameters up to minute-by-minute variation in the simulation. While feasibility studies have been carried out for different countries of the world, information is non-existent on the techno-economic feasibility of large-scale CSP systems for electricity generation in Nigeria, despite the favorable climatic conditions in the country. To bridge this gap, this study aims to apply the SAM software to assess the viability of a 25 MW parabolic trough CSP plant for the climatic condition of Effurun-Warri, Southern Nigeria. The specific objectives of the study are:

- To design a 25 MW solar parabolic trough system using the SAM software;
- To analyze the yearly energy production profile of the 25 MW parabolic trough system based on the ambient conditions of the twin city of Effurun-Warri in Southern Nigeria; and
- To assess the techno-economic feasibility of the 25 MW CSP plant based on the current market realities in Nigeria.

Section 2 summarizes the method employed in this study; the results obtained are presented and discussed in section 3, and the main conclusions are summarized in section 4.

2. Methodology

2.1. Plant scheme and site description

Figure 1 depicts a schematic illustration of the proposed CSP plant. It is made up of a network of intertwined pipelines and an array of parabola-shaped mirrors. The pipelines are known as solar receivers, and they carry heat transfer fluid (HTF) from the collectors to the power block for conversion into electricity. The plant includes two-tank thermal energy storage (TES) system that uses molten salt as the storage medium. When solar energy is abundant, the HTF heats the storage medium in the TES for later use in electricity generation during the hours when solar irradiation is low or non-existent. In this study, the power plant is an air-cooled steam power plant that operates on the Rankine cycle.

The climatic parameters of Delta State's Uvwie Local Government Area, where Effurun-Warri is located, were obtained from the National Solar Radiation Database (NSRDB), as shown in Table 1. They validate the SAM software's built-in data for this location.

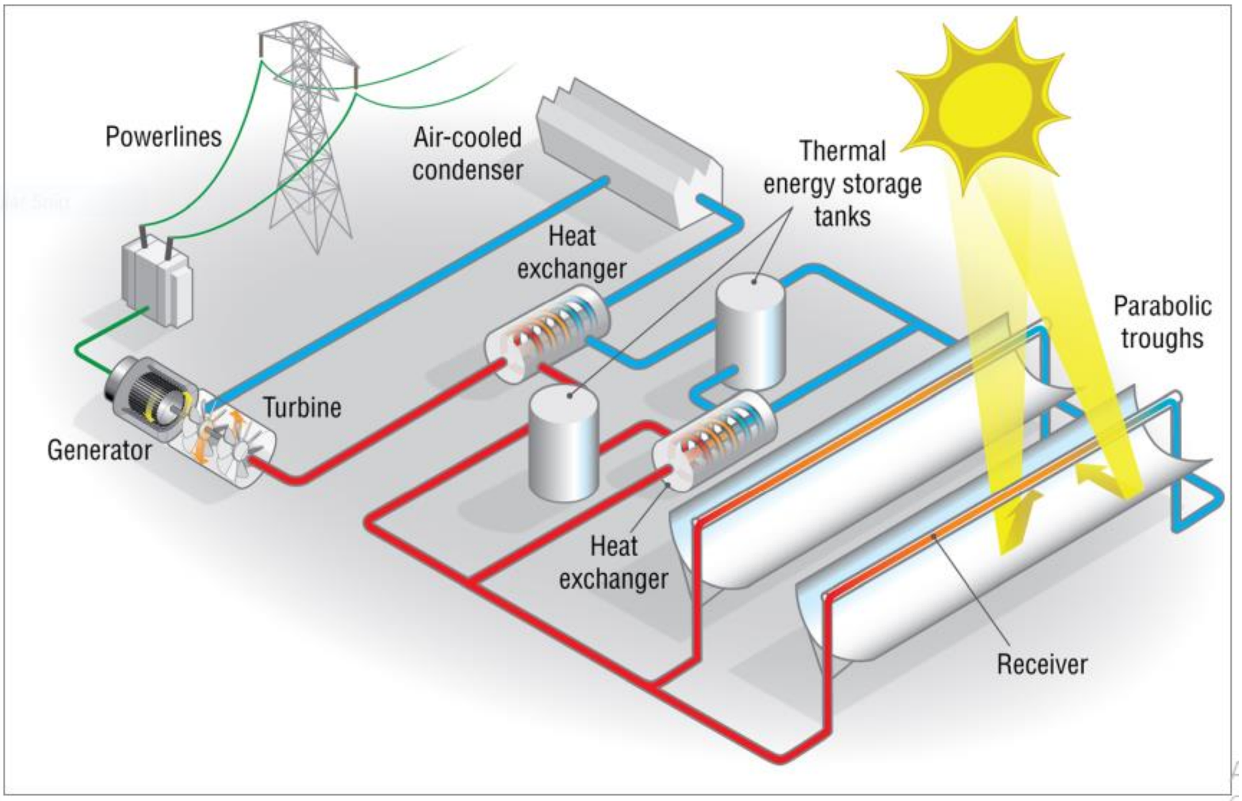


Fig. 1. Parabolic trough power plant scheme

Table 1. Climatic Parameters of Effurun-Warri, Nigeria

Parameter	**Value**
Latitude (^{0})	5.57
Longitude (^{0})	5.78
Tilt angle (^{0})	20
Azimuth angle (^{0})	180
Average temperature (^{0}C)	25.9
Global Horizontal Irradiation (GHI) (kWh/m^2/day)	3.39
Average wind speed (m/s)	0.4

2.2. System Advisor Model design parameters of the CSP plant

As previously stated, the SAM software [23] was used to simulate the CSP plant's techno-economic feasibility. It was originally developed by the National Renewable Energy Laboratory (NREL) in America; its source physical and financial models have been validated, making it a veritable tool in the open literature for simulation of renewable energy systems today. The power plant's design in SAM was based on a nominal direct normal irradiation (DNI) of 950 W/m2 and a solar multiple (SM) of 2. Because of its widespread use in practical systems, therminol VP-1 was chosen as the HTF. Again, molten salt is used as the storage medium in the TES system, and 6 hours of thermal energy storage was chosen for the design in the SAM software. Table 2 highlights all of the other input details for the power plant's performance simulation.

Table 2. Parabolic trough CSP plant parameters

Parameter	**Values**	**Units**
Solar multiple	2	
Field aperture	877, 000, 000	m^2
Design point DNI	950	W/m^2
Field thermal power	157	W/m^2
Loop inlet HTF temperature	293	^{o} C
Loop outlet HTF temperature	391	^{o} C
Number of loops	46	
HTF pump efficiency	0.85	
Power Cycle		
Design turbine gross output	28	MWe
Estimated gross-to-net conversion factor	0.9	
Estimated output at design	25	MWe
Cycle thermal eff.	0.356	
Cycle thermal power	76	MWt
Thermal Energy Storage		
Hours of storage at the design point	6	Hr
Tank height	12	M
Heat Transfer Field		
HTF	Therminol VP – 1	
Inflation rate	18	%/yr
Solar Field Area	149	Acres

3. Results And Discussion

3.1. Solar energy profile

The field absorbs only a fraction of the thermal power incident on the solar collectors. This is due to optical losses caused by mutual shading of collectors, row end losses, and solar field geometrical inaccuracies. Figure 2 depicts the cumulative solar thermal energy at the plant's location over the course of a typical year. The months in horizontal axis against solar radiation incident measured in megawatt (MW) in the vertical axis In Figure 2, $\mathfrak{e} + 06$ as generated by the System Advisor Model (SAM) software signifies mega unit (M). Hence, $4\mathfrak{e} + 06 = 4 * 10^6 = 4$MW, $5\mathfrak{e} + 06 = 5 * 10^6 = 5$MW, $6\mathfrak{e} + 06 = 6 * 10^6 = 6$MW, $7\mathfrak{e} + 06 = 7 * 10^6 = 7$MW, etc,. August had the most solar radiation incident on the solar field (10 MW), followed by September and July. February has the lowest incident thermal power on the solar field (3.98 MW).

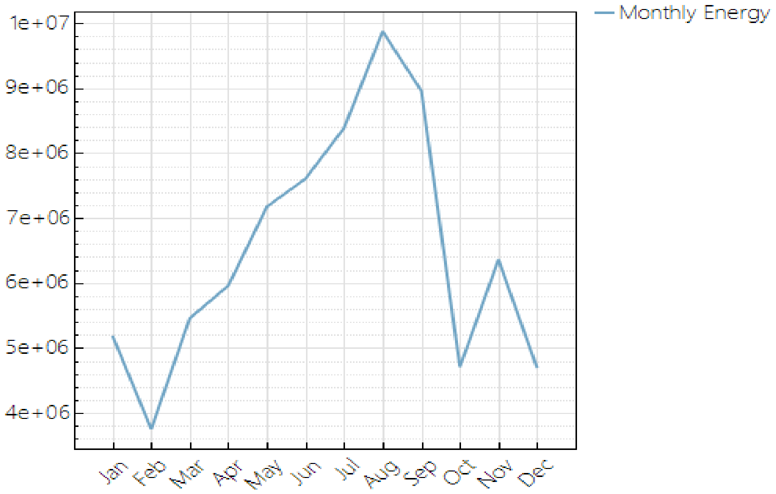


Fig. 2. Monthly solar energy profile of the CSP plant

3.2. Annual electrical energy production and techno-economic performance

The power cycle gross electrical output of the hypothetical power plant is 88.3GWh, with an annual net electrical energy production of around 78GWh. Figure 3 depicts the profile of the power plant's net electrical power output on typical Hour of Day (24hrs) in the horizontal axis in each month. The plant was designed to begin producing electrical energy when the solar field produced 25% of the nominal thermal energy required. The coldest months in Effurun are January, February, October, and December. They are also the times when the days are shorter. During these months, the power plant generates power for a total of 13 hours, with 6 hours at maximum capacity for the day (about 18.6 MW). In June, July, and August, the plant usually starts earlier and runs at full capacity for 9 hours. The months of August, June, and July have the highest annual power output.

The plant's capacity factor is 35.4%, implying that the parabolic trough power plant could contribute significantly to meeting Effurun-electricity Warri's demands. The plant would require a total land area of 1,140 m^2, which should not be a problem given the city's abundance of inhabited land. The plant consumes 19.2 MWe of parasitic power per year. The plant's solar field energy absorption efficiency is 56.2%. Furthermore, a levelized cost of electricity of 11.87 ₵/kWh was obtained for the power plant, which is 99% higher than the cost of electricity available in this part of Nigeria (0.10 ₵/kWh), however, this depreciates as plant’s aged without optimizing plant’s design parameters. Furthermore, a negative NPV of $-13.2 M was obtained for the proposed project, implying that the investment cost would not be completely offset over the lifetime of the system, resulting in losses to investors. Figure 4 depicts the CSP plant's detailed techno-economic performance metrics. Furthermore, the plant's annual production has been observed to depreciate as it ages, and the trends of energy production and project cash flow for the 25-year plant life assumed in this study are depicted in Fig. 5.

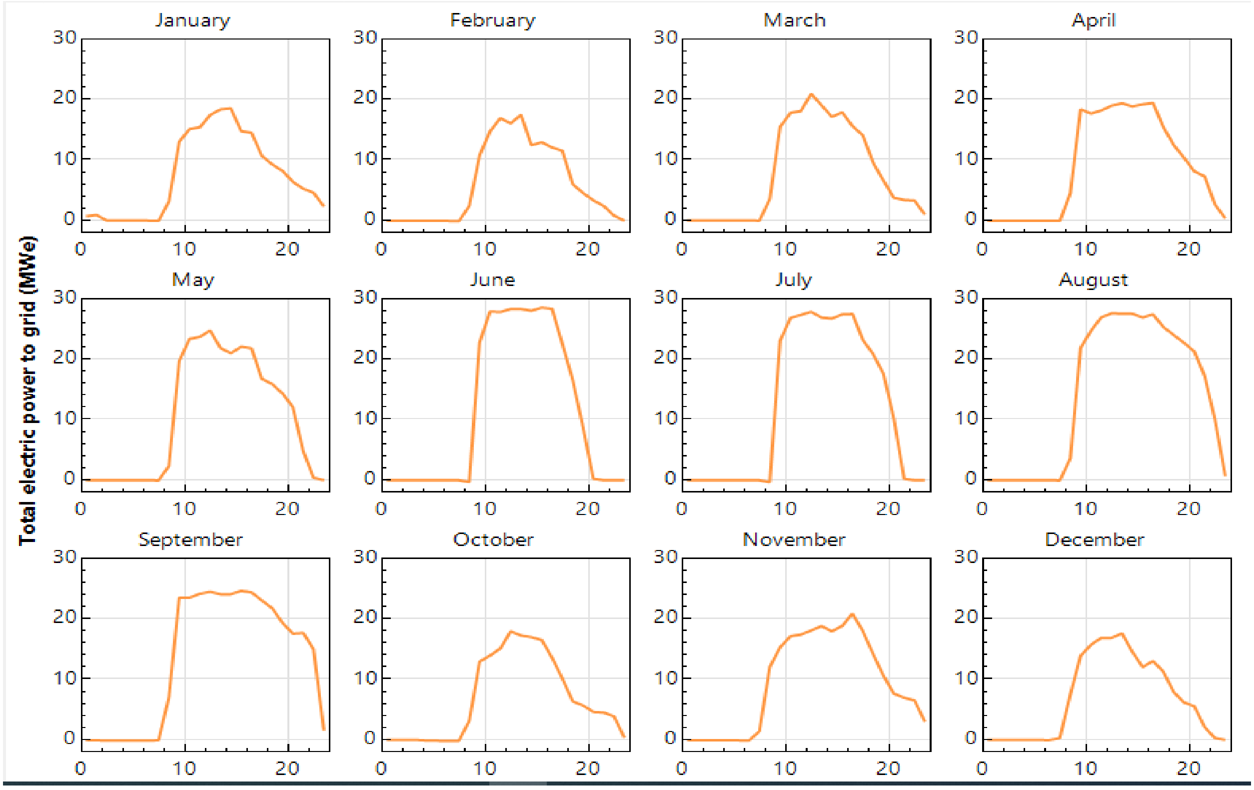
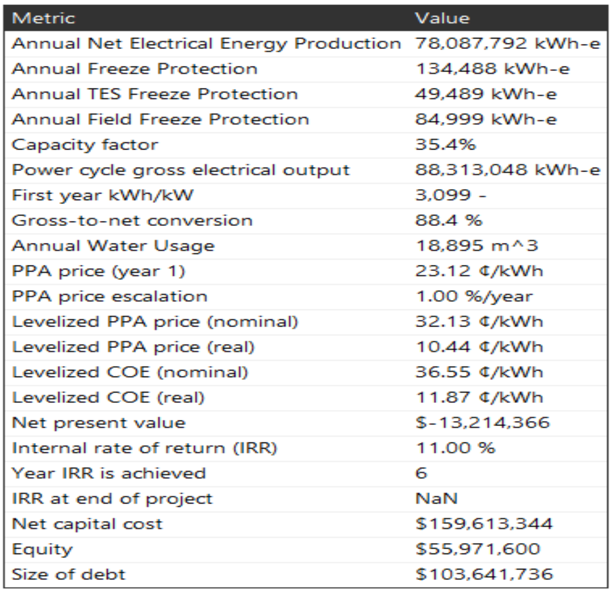


Fig. 3. Monthly electrical energy produced by the power plant



Metric	Value
Annual Net Electrical Energy Production	78,087,792 kWh-e
Annual Freeze Protection	134,488 kWh-e
Annual TES Freeze Protection	49,489 kWh-e
Annual Field Freeze Protection	84,999 kWh-e
Capacity factor	35.4%
Power cycle gross electrical output	88,313,048 kWh-e
First year kWh/kW	3,099 -
Gross-to-net conversion	88.4 %
Annual Water Usage	18,895 m^3
PPA price (year 1)	23.12 ¢/kWh
PPA price escalation	1.00 %/year
Levelized PPA price (nominal)	32.13 ¢/kWh
Levelized PPA price (real)	10.44 ¢/kWh
Levelized COE (nominal)	36.55 ¢/kWh
Levelized COE (real)	11.87 ¢/kWh
Net present value	$-13,214,366
Internal rate of return (IRR)	11.00 %
Year IRR is achieved	6
IRR at end of project	NaN
Net capital cost	$159,613,344
Equity	$55,971,600
Size of debt	$103,641,736

Fig. 4. Techno-economic performance metrics of the parabolic trough CSP plant

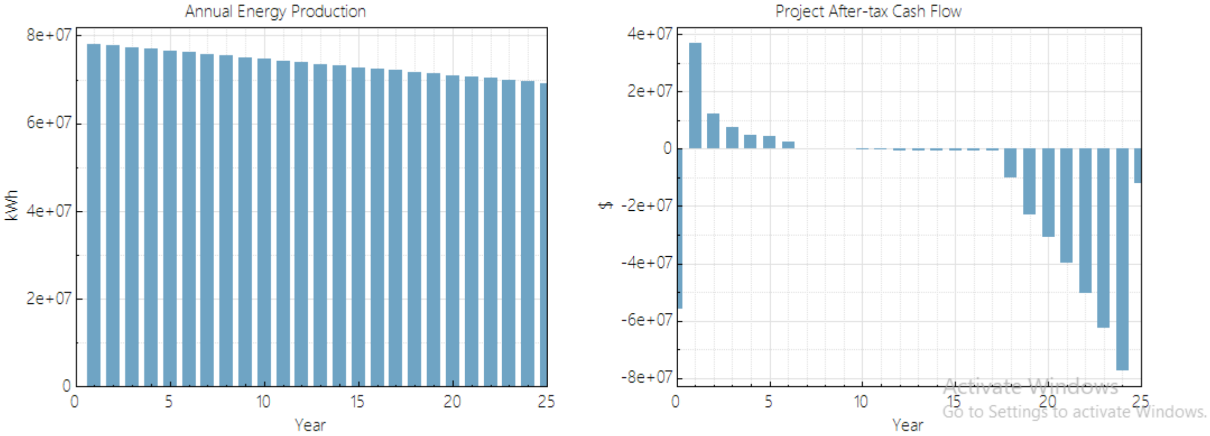


Fig. 5. Annual energy production and project cash flow over the plant life

Figure 5 show cased yearly Annual Energy Production in kWh and Project After - Cash Flow in dollar. It can be deduced from the above figure that energy production decreases as year increases and that Tax Cash Flow turns negative immediately after tenth year. This is because the plant's design parameters (Concentrated Solar Power CSP, Parabolic Trough Collectors PTC, Regional Climate Change, etc.) were not altered or optimized over these years which possibly have the capacity to retard energy production rate. The designed model competes favorably with other major parabolic trough power plants around the world. The SEGS solar plants in California's Mojave deserts, which cover a total land area of 1600 acres, have a combined rated power of 361 MW and a capacity factor of 21%. The Khata solar spark in South Africa covers an area of 1977 acres and has a rated net capacity of 100 MW with a capacity factor of 44.5 %. The Andasol solar power plant has a rated output of 150 MW, a capacity factor of 37.7 %, and a land area of 1500 acres.

Table 3. Comparative techno-economic performance results with some reviewed literatures

Author (s)	**Year**	**Work**	**Method(s)**	**Material(s)**	**Results**
Praveen et al	2022	Optimization of a 100 MW PTC plant	Fuzzy non-linear model	Parabolic Trough Collectors (PTC)	Significant improve in Capacity Factor and Cost
Polo et al	2016	Feasibility of a Long-Term operation of a CSP power plant in Saudi Arabia	System Advisor Model (SAM) software	Concentrated Solar Power (CSP)	25 GW
Serradj et al	2021	Viability of a 100MW PTC power plant in Tamanrasset, Algeria	HOMER and System Advisor Model (SAM) software	Parabolic Trough Collectors (PTC)	78 % in winter and 60 % in summer energy required
Alotaibi et al	2021	Design and analysis of a 100 MW PTC power plant in Riyadh, Saudi A rabia	System Advisor Model (SAM) software	Parabolic Trough Collectors (PTC)	45% capacity factor achievable

Table 3 Continued

Author (s)	Year	Work	Method(s)	Material(s)	Results
Sharma et al	2016	Effect of a direct normal irradiation (DNI), solar multiple and capacity storage on LUEC	System Advisor Model (SAM) software	Parabolic Trough Collectors (PTC) and Linear Fresnel Collector (LFC)	Range of lower compared to CSP
Trabelsi et al	2016	Feasibility of a 50 MW PTC plant in southern region, Tunisia	System Advisor Model (SAM) software	Parabolic Trough Collectors (PTC)	Dry cooling scheme determines viable system in Tunisia of LCOE of about 18₵$ /kWh
Pareen et al	2018	Feasibility of CSP power plant in Middle East	System Advisor Model (SAM) software	Concentrated Solar Power (CSP)	Feasibility of CSP power plant in Middle East
John Akpaduado, Joseph Oyekale	**2021**	**Feasibility Of A Large-Scale Ptc Thermal Power Plant In Effurun-Warri, Nigeria**	**System Advisor Model (Sam) Software**	**Ptc Power Plant, Hours Per Day Consideration**	**78 Gwh Net Electricity Energy, 35.4 % Capacity Factor, 11.87₵ /Kwh, And 0.10 ₵ /Kwh**

4. Conclusions

This study evaluated the techno-economic viability of a 25 MW parabolic trough solar thermal power plant for electricity generation in Effurun-Warri, Nigeria. For the evaluation, the technical and financial models built into the System Advisor Model (SAM) software were used. The city's meteorological data were also generated by SAM and confirmed by the National Solar Radiation Database (NSRDB). The following are the main study highlights:

- The plant's annual net electrical energy production was estimated to be around 78 GWh;
- The parabolic trough solar power plant can operate for more than 12 hours per day, resulting in a capacity factor of 35.4 %;
- The power plant's LCOE was 11.87 ₵/kWh, compared to the current cost of energy in Nigeria is 0.10 ₵/kWh, with a negative NPV, indicating an unprofitable investment.

It is recommended that the plant's design parameters be optimized using comparative analysis, and that further feasibility studies of CSP projects in Nigeria be conducted taking into account the country's various climatic regions.

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Research Article

POWER BILL OPTIMIZATION FOR GRID-TIE SOLAR PV-BATTERY HOUSE

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Abstract: *This study focuses on the optimization of power bills for a house equipped with a grid-tie solar PV-battery system. Rather than adhering to conventional load scheduling practices or minimizing grid power usage at each time interval, a novel approach is adopted wherein the optimization is performed for the entire 24-hour period simultaneously. By directly incorporating time-of-use rates into the cost function, an absolute optimal solution is attained. The findings indicate that compared to single time step optimization, the proposed method results in a reduction of the power bill ranging from 6% to 10%, depending on load-generation variations. Furthermore, if the utility or government enforces the summer tariff consistently throughout the year, the savings escalate to a range of 15% to 22%. Introducing a more intelligent tariff structure can thus serve as an effective means to expedite the transition towards renewable energy by incentivizing individual investments in solar PV, battery systems, and smart home energy management.*

***Keywords**: smart house; renewable energy integration; solar PV; energy storage; Home battery*

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1. Introduction

Problem overview: Electricity grids worldwide face technical, socio-economic, and environmental challenges, including aging infrastructure [1]. In Europe, for instance, 36% of power capacity is set to shut down by 2030 [2]. This aging system lacks smart grid features, resulting in increased power outages, particularly in impoverished nations [3]. The growing penetration of intermittent solar and wind energy, which rose by 15% in 2019, further adds uncertainty to generation [4], endangering grid stability. Without decarbonization efforts, CO2 emissions and associated climate change issues will worsen.

Current solution: Smart grids and energy storage serve as tools to facilitate the energy transition [5]. While there is no universally agreed-upon definition of a "smart grid," research papers often consider any grid system enabling load control, automated power recording, tariff acquisition, and bill optimization as smart [3]. Presently, in standard smart grid control system, excess green energy is prioritized over grid power and stored in batteries, minimizing grid consumption.

Proposed direction: From a customer perspective, incorporating time-of-use rates (ToU) into optimization equations and solving the problem for multiple time steps simultaneously (e.g., 24 steps instead of 1 step) may reduce the overall energy bill, possibly at the expense of grid power. Essentially, storing excess green energy and utilizing grid energy during cheaper tariff periods can contribute to bill reduction. The proliferation of electric cars with their substantial batteries makes load-generation-tariff-based bill optimization more appealing to households compared to traditional grid power minimization. Study Scope: This paper addresses the optimization of the overall energy bill for a smart grid-connected solar PV-battery house, considering unpredictable load-generation variations.

2. Literature Review

Since the 1973 oil crisis, optimizing energy consumption has been a concern for power industry stakeholders, including consumers, utilities, and governments [6]. Consumers aim to reduce bills and lower CO2 emissions, while utilities seek to avoid investing in low-capacity factor power plants and transmission systems to meet peak demand. For instance, a study optimizing a microgrid with solar PV, wind turbines, and batteries found that utility operation costs can be reduced by up to 28% through demand response programs [7]. Governments prioritize enhancing energy supply chain performance and reliability to strengthen the economy and social welfare.

The residential sector accounts for around 25% of global electricity consumption [8]. Energy bill optimization has been addressed through energy efficiency measures, smart demand control, time-of-use (ToU) tariff design, solar PV, and battery solutions [9]. Retrofitting old air conditioners with variable-speed AC units and replacing old lamps with efficient LED lamps can achieve up to 40% savings [10-12]. Research on smart houses focuses on load scheduling algorithm development, demand response optimization, and integration of renewable energy (RE) and electric energy storage (EES) systems. Load scheduling separates the house load into deferrable (e.g., washing machine, air conditioner) and non-deferrable loads (e.g., lights, TV), optimizing peak-to-average ratio (PAR) and energy bills [13-15]. Model predictive control (MPC) combined with ToU rates and feed-in tariffs can reduce costs by 13% for PV-battery houses' AC consumption [16]. Linear programming, genetic algorithms, quadratic programming, and neural networks have been used for cost function optimization [17,18]. For instance, studies optimizing thermostatically controlled AC consumption in PV-battery houses achieved cost reductions of 20% to 30% [19,20]. While load scheduling achieves lower PAR and energy bills, its implementation poses convenience issues due to deferrable load timings. However, IoT-based solutions can automate scheduling by adjusting AC power based on weather forecasts or ToU rates [21]. Financial incentive-based demand response schemes have improved power factor by 17% for 300 houses [22]. Punishment-based optimization temporarily disconnects customers from the grid if they fail to comply with load reduction orders to prevent blackouts [23].

EES is increasingly adopted by residential houses and utilities for grid frequency stabilization. Although battery costs are high, their size is minimized in studies. However, controlling a group of residential users' EES as a single battery yields the benefits of large-scale EES, reducing power shortage by 23% for a group of users [24]. The concept extends to vehicle-to-grid (V2G) systems where electric car batteries integrate with the grid. Optimizing solar PV and V2G systems using linear programming resulted in payback periods ranging from 4 to 8 years based on battery charge profiles [25]. This study optimizes the energy bill of a smart grid-connected solar PV-battery house without imposing load scheduling on users. Furthermore, instead of standard time step optimization, simultaneous 24-hour consumption is considered for optimization.

3. System Modeling

The study examines four smart house system cases, as shown in Figure 1, incorporating PV panels, battery, and loads [26,27]. Feed-in tariff restrictions prevent residential users from feeding solar power into the grid, given the opposition and scalability challenges of subsidies [26,27]. Sun radiation data for a typical meteorological year (TMY) in California is obtained from PVGIS and soda pro, while system efficiency is adjusted to match the annual generation from the prediction of global solar atlas [26-28]. A PV cost of \$1.5/Watt from TESLA is assumed [29]. The load consists of household appliances, HVAC, and lighting, utilizing a California residential base load profile [30]. Load scheduling is not considered for optimization. The battery capacity and state of charge serve as

simulation variables, with charge-discharge limits set at 0.5C for commercially available cells. A base battery capacity of 30 kWh (100% of daily mean energy production) is used, subject to revision for convergence [30,31]. The battery system cost is set at $150/kWh, considering projected cell costs of $100/kWh by 2025 [31]. ToU rates vary by country, with California's actual tariff applied [32]. The grid energy is assumed to be unlimited, while the house's subscribed power is limited to 150% of peak load for realistic modeling. The simulation scenarios are as follows:
Case 1: Minimize hourly grid power withdrawal [33]. Multiply the obtained grid power profile by ToU rates to calculate the energy bill.
Case 2: Express the cost function as the hourly energy bill. Simultaneously minimize the sum of 24-hour bill functions to obtain the daily energy bill, as hourly optimization may yield local minima.
Case 3: Use the battery charge-discharge profile from case 2 as a reference. Introduce an uncertain load to analyze its impact, adding a normally distributed random load between ±50% of peak demand.
Case 4: Conduct a sensitivity analysis to assess the effect of PV generation variations on case 2. Utilize data for a specific year, such as 2015, instead of adding random solar radiation values to the TMY PV output.

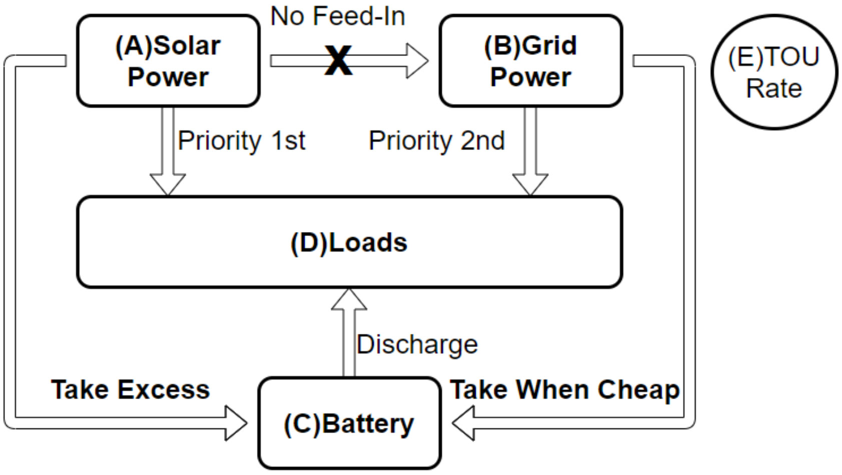

Figure 1. System Illustration

4. Mathematical Modeling

The simulation utilizes key inputs, including solar power (A), load power (D), and Time-of-Use (ToU) rates (E). These inputs generate outputs: the battery charge-discharge profile (C) and grid power (B). Post-simulation processing yields various key performance indicators (KPIs) such as the bill, Peak-to-Average Ratio (PAR), simple payback period (SPB), grid power standard deviation, and more. The system settings can be found in Table 1.

Table 1. System Settings

No	Items	Value	Unit
1	PV rated AC power	4.77	kW
2	PV location lat.	34.271	deg
3	PV location long.	-118.517	deg
4	PV energy output	1813	kWh/kWp/Yr
5	PV daily energy output	23.7	kWh/day
6	PV cost	1.5	$/W
7	Battery base capacity	30	kWh
8	Battery limits	0.5	C
9	Battery cost	150	$/kWh
10	Peak load	4.77	kW
11	Minimum load	0.76	kW
12	Mean load	1.9	kW
13	Grid power limit	7.2	kW

In terms of data, a preliminary simulation using 8760 hours of data revealed extended computation times exceeding 10 minutes on a laptop featuring an Intel Core i3 4005U 1.7GHz processor and 4GB RAM running MATLAB 2018. To expedite the simulation process, the annual solar and load data points were reduced by calculating a representative Typical Day (TD) dataset, akin to the Typical Meteorological Year (TMY) approach. The TMY approach considers the most representative monthly data spanning a period of at least 10 years. To obtain Typical Day (TD) data, the average value of a specific hour is calculated for each month. For example, the average PV output at 10 am in January represents the TD data for that hour in January. This approach significantly reduces the data from 8760 hours to 288 hours (24 hours multiplied by 12 months), resulting in a 96% reduction. Consequently, the entire year is now represented by only 12 data points. A random load is generated using the formula provided in equation (1). As for the PV output, the Typical Meteorological Year (TMY) output serves as the base, and data from the year 2015 is utilized for sensitivity analysis.

$$P_{loadTDrand} = P_{loadTDbase}(1 - 0.5 + rand\ [0,1]) \tag{1}$$

$P_{loadTDrand}$ $[kW]$: Random generated load power
$P_{loadTDbase}$ $[kW]$: Base load power

The actual Time-of-Use (ToU) rates, specific to California residential users with photovoltaic (PV) panels and energy storage systems (EES), are used. These rates are applied during both summer (June to October) and winter (November to May) seasons to ensure practicality and real-world relevance. Additionally, a semi-synthetic ToU rate, which extends the summer tariff into the winter period, is employed as a test tariff to assess the potential improvement of the proposed optimization method and its efficiency.

CVX Optimization is a MATLAB toolbox utilized for convex function optimization. In the first case (Case 1), at each hourly time step k, the objective function being minimized is the grid power as defined in eq (2), where the only unknown variable is the battery power. The linearity of Pgrid allows for it to be assumed as a convex function.

$$Pgrid1(k) = -PVout(k) + Pload(k) + Pbatt(k) \tag{2}$$

k $[-]$: Hour time index
$Pgrid1$ $[kW]$: Power consumption from the grid
$PVout$ $[kW]$: Solar PV system power output
$Pload$ $[kW]$: House power consumption
$Pbatt$ $[kW]$: Battery charge/discharge power

To incorporate losses caused by non-unity battery round trip efficiency, the term Pbatt (k) in eq (2) is adjusted by dividing it by the efficiency of the battery “Efficiencybatt” when the battery is in the charging mode. The calculation of the hourly bill for Case 1 is determined using eq (3). The total yearly bill is then calculated by integrating the typical daily bills over 12 months.

$$Bill1(k) = Pgrid1(k) * dh * ToUR(k) \tag{3}$$

$Bill1$ [\$]: Bill amount in USD
dh $[h]$: Time step in hour
$ToUR$ $[\$ / kWh]$: Electricity time of use rate in USD/kWh

The optimization problem is subject to several constraints, including the maximum (max), minimum (min) limits on grid power, the battery power as well as the energy state of charge as specified in eq (4)-(6).

$$Pgridmin \le Pgrid1(k) \le Pgridmax \tag{4}$$

$$Pbattmin \le Pbatt1(k) \le Pbattmax \tag{5}$$

$$SoCmin * Qbatt \le Ebatt(k+1)) \le SoCmax * Qbatt \tag{6}$$

SoC[%]: Battery state of charge
$Qbatt$$[kWh]$: Battery capacity
$Ebatt$ $[kWh]$: Battery energy at time k

The bill and grid energy are calculated by integrating the function Bill1(k) and Pgrid1(k) respectively. The Peak-to-Average Ratio (PAR) is defined according to equation (7).

$$PAR = max\,(Pgrid1)/mean(Pgrid1) \tag{7}$$

In order to determine the simple payback period (SPB), it is crucial to have knowledge of the bill before and after making the investment in the PV-Battery system. The bill when solely relying on the grid as the power source is considered as the baseline for comparison as in eq (8).

$$Bill0 = \int_{n=1}^{n=12} \int_{k=1}^{k=24} Pload(n+k) * dh * ToUR(n+k) \tag{8}$$

$n$$[-]$: Month index

The simple payback period (SPB) is calculated according to eq (9), where CAPEX represents the capital expenditure required for constructing the Renewable Energy System (RES) and Energy Storage System (EES). A comprehensive analysis would typically include additional factors such as operational expenditure (OPEX), cost of capital, inflation rate, materials depreciation, and other relevant considerations. However, for the purpose of showcasing the value trend of the proposed method, these factors have been omitted in this study to maintain simplicity.

$$SPB \;= (CAPEX_{PV} \;+ CAPEX_{batt})/(Bill0 - Bill1) \qquad (9)$$

In the second proposed case (Case 2), a different approach is taken where instead of optimizing the grid power and subsequently calculating the bill, the cost function is directly formulated as shown in eq (10). This means that the bill for a specific day, denoted as 'n', is determined by minimizing the sum of the bills for all 24 hours. In eq (10), each optimization involves 24 unknown variables: Pbatt1, Pbatt2, ..., Pbatt24, representing the battery power at each hour. Since this is a linear combination of linear functions, the cost function (Bill2) remains linear as well, allowing it to be assumed as convex for optimization purposes.

$$Bill2 = \int_{n=1}^{n=12}\int_{k=1}^{k=24}\big(PVout(n+k) + Pload(n+k) + Pbatt(n+k)\big) * dh * ToUR(n+k) \quad (10)$$

The optimization constraints for the cost function (Bill2) are similar to those of the grid power (Pgrid1). There are 24 constraints for the hourly limits of grid power and 24 constraints for the limits of battery charge and discharge power. However, since the hourly battery power profile is not available as in Case 1, it is not possible to directly calculate the battery energy level and ensure it stays within the desired state of charge. To address this issue, an additional constraint is introduced in eq (11) where the sum of the 24-hour battery power is set to nearly zero. This constraint ensures that the net energy transfer of the battery over the course of the day is zero.

At the end of the simulation, the cumulative battery power is computed to examine the range of charge and discharge levels. If this range falls within the battery's state of charge (SoC) requirements, the optimization results are considered valid. Otherwise, lower charge or discharge rates are set for a new optimization attempt. The bill, grid energy, and Peak-to-Average Ratio (PAR) are calculated using the established methodology as mentioned previously.

$$-0.01 \leq Pbatt1 + Pbatt2 + \ldots\ldots + Pbatt24 \leq 0.01 \qquad (11)$$

In both Case 1 and Case 2, a base load (PloadTDB) and a base PV generation (PVoutTDTMY) are utilized. In Case 3, the load is replaced by a randomly variable load (PloadTDRand), and in Case 4, the PV generation is replaced by PVoutTD2015. The optimized battery charge/discharge profile obtained in Case 2 serves as a model for charge/discharge in Case 3 and Case 4. This means that whenever the calculated state of charge and power of the battery for the next time step fall within the specified limits, the current battery power is used as the command for charge/discharge. If the limits are exceeded, the battery power is set to zero for that time step.

Case 3 and Case 4 examine how an offline optimized battery power profile can still be effective under varying load and generation conditions. In practice, historical load and PV generation data can be employed to calculate the optimal battery power profile. The key performance indicators (KPIs) of the system are calculated using the same methodology as in Case 1.

5. Simulation Results

The absolute key performance indicators (KPIs) for Case 1 are summarized in table 2, considering both the official Time-of-Use (ToU) rates and the synthetic rates. The synthetic ToU rates result in a 16% increase in the base bill. However, it is worth noting that the simple payback period (SPB) decreased by 16% as well. These seemingly contradictory figures can be explained by the fact that the synthetic ToU rates yield a base bill0 that is 17% higher than that of the real ToU rates. In reality, the savings achieved with the synthetic ToU rates are nearly 20% higher compared to the savings with the real ToU rates. The grid energy, grid mean power, and Peak-to-Average Ratio (PAR) remain consistent regardless of the ToU rates. This outcome confirms that Case 1 optimizes only for grid power and not the overall bill.

Table 2. Reference Case Absolute Results

KPI	Real ToUR	Synthetic ToUR
Bill_0 (No Investment) [$]	5048	5938
Bill_1 [$]	2202.9	2533.0
GridEnergy1 [kWh]	7185.0	7185.0
PAR_1 [-]	5.0	5.0
GridPmean_1 [kW]	0.8	0.8
SPB_1 [Month]	49.1	41.0

In Figures 2-3, the grid power profiles of Case 1 and the compared cases under real Time-of-Use (ToU) rates are analyzed. It can be observed that, relative to Case 1, the peak hours of Case 2 are shifted forward. Upon closer examination, a zoomed view reveals that the peak hours in Case 2 occur between midnight and 6 am, unlike Case 1 where they are between 10 pm and 2 am. Additionally, in the summer season, the peak hours in Case 2 last longer compared to the winter season. The extended duration of peak hours during the night indicates that the optimization method used in Case 2 prioritizes storing energy during low tariff periods for later utilization. This is further supported by the fact that the grid power in Case 2 drops to nearly zero between 8 am and 10 pm. Furthermore, in Figure 3, it can be observed that the grid power profiles of Case 3 and Case 4 closely resemble that of Case 2. This suggests that load or generation variations have minimal influence on the optimized battery power profile.

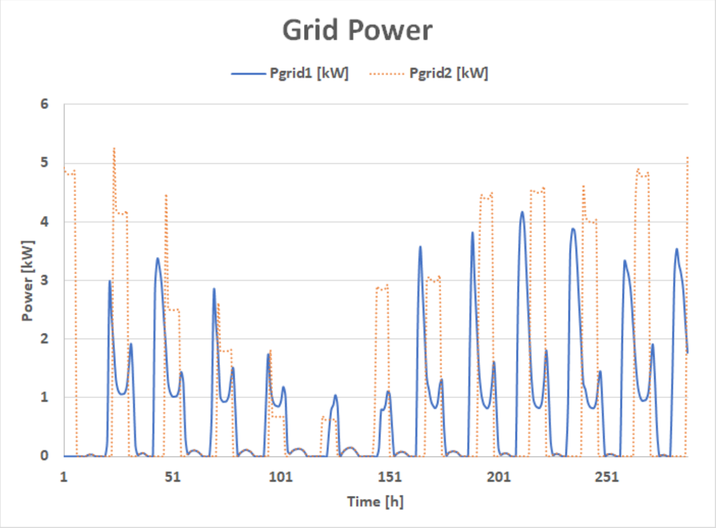

Figure 2. Grid Power Case 1-2

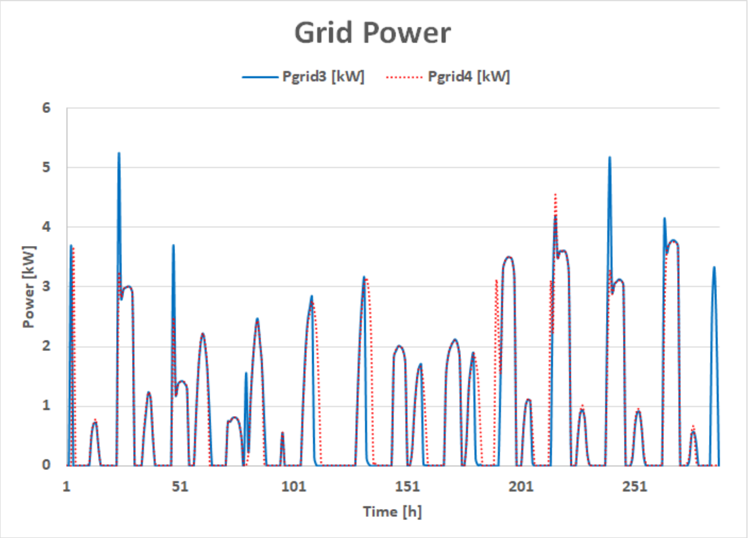

Figure 3. Grid Power Case 3-4

The bill profiles shown in Figure 4 illustrate that Case 2 has a lower bill during nighttime compared to Case 1. This outcome can only be achieved if the power tariff is low during that period, which is indeed the case. Despite the power profile of Case 2 being higher during the same time period, the optimized strategy allows for cost savings due to the lower tariff at night. Similarly, the bill profiles of Case 3 and Case 4 in Figure 5 closely resemble that of Case 2, indicating that the billing patterns align with the optimized power profiles.

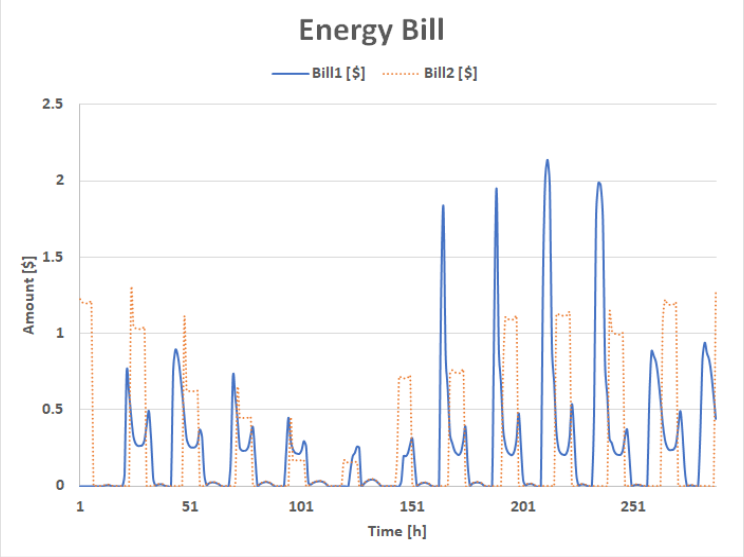

Figure 4. Energy Bill 1-2

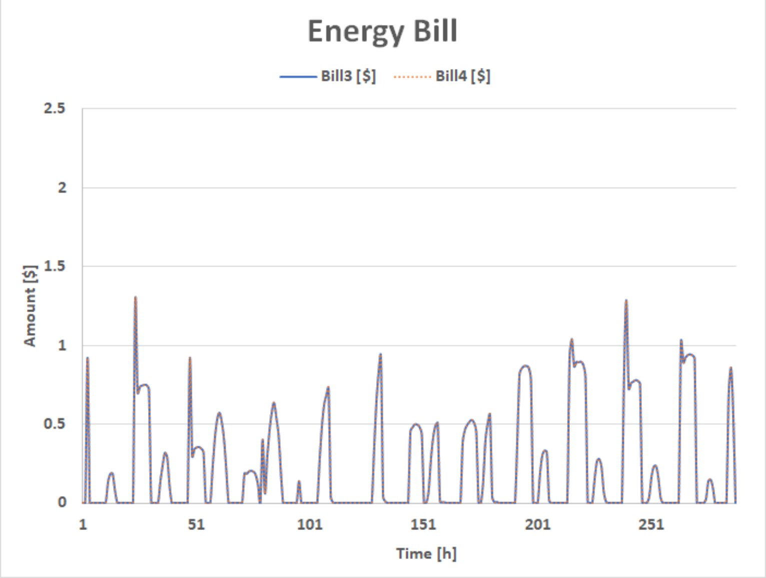

Figure 5. Energy Bill 3-4

The hourly grid power and bill profiles presented earlier are not easily understandable when comparing different optimization methods to Case 1. However, a more effective comparison can be made using the Key Performance Indicators (KPIs) shown in Figure 6. Analyzing the bill reductions, Case 2 and Case 4 exhibit approximately a 6% reduction, while Case 3 shows a higher reduction of 10%. This indicates that variations in the load have a greater impact on the system compared to variations in generation. The Simple Payback Periods (SPBs) are directly proportional to the bills, meaning they follow a similar trend. All the compared cases consume 6%-14% more grid energy than Case 1.

Regarding the Peak-to-Average Ratios (PARs), it is noteworthy that PAR 3 is exceptionally high at 16.6%. This occurs when the load changes, and the optimized battery peak charge power coincides with the new peak load, resulting in a high overall peak power from the grid. The slight reduction in PAR 4 can be explained if the peak PV power aligns with the peak load power or if the battery's peak discharge matches the peak load. In both cases, less power is required from the grid, resulting in a lower PAR value.

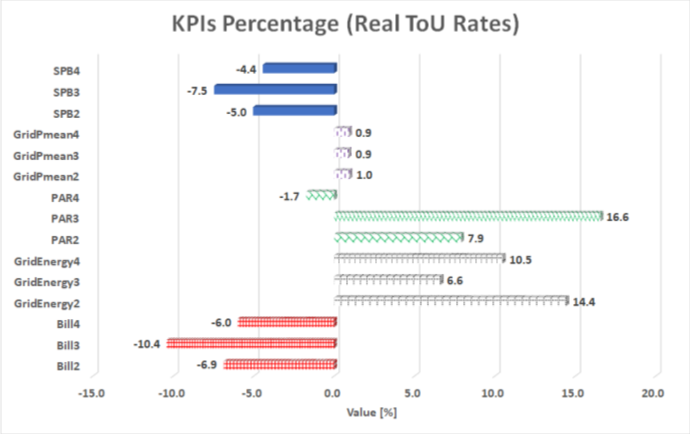

Figure 6. Real ToU Rates KPIs

The KPIs results for the synthetic Time-of-Use (ToU) rates are presented in Figure 7. The profiles of the KPIs are similar to those of the real ToU rates, but the magnitude of the bills differs significantly. In all three cases studied, the bill reduction with synthetic ToU rates is more than double (15%-22%). This highlights the crucial importance of the ToU rates for the effectiveness of the optimization process. In countries where the ToU rates are flat, storing energy for later use would not provide any benefit. From a customer perspective, the overall results of 24-hour simultaneous bill minimization are positive. However, from a utilities standpoint, the increased Peak-to-Average Ratio (PAR) and the higher consumption of grid energy may not be welcomed. Nevertheless, it is worth noting that the peak grid power occurs during off-peak times, which can still be considered a positive outcome by utilities since it increases the plant capacity factor.

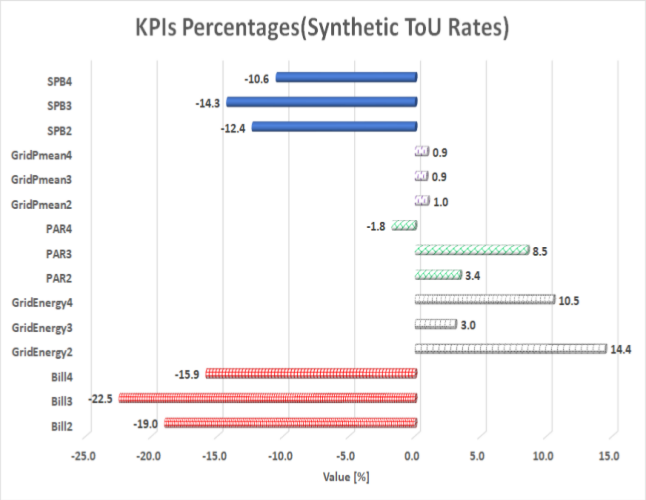

Figure 7. Synthetic ToU Rates KPIs

6. Conclusion

This study focuses on minimizing a household's energy bill by optimizing the 24-hour bill profile instead of individual time step power usage. The method efficiently utilizes Time-of-Use (ToU) rates to store energy during low tariff periods for use during peak tariff periods. By avoiding the need for load scheduling methods, bill reductions of 6% to 10% are achieved, depending on load or PV output variations. If the summer ToU rates are extended to the winter, savings can potentially reach 15%-22%, highlighting the potential of ToU rates to promote PV-battery system investments.

In comparison, load scheduling methods only provide 6%-10% savings according to a cited study, and they come with customer constraints. The proposed method achieves greater savings without imposing any constraints on customers. Although the Peak-to-Average Ratio (PAR) ratios increase up to 16%, a closer examination of the grid power profile reveals that the peak occurs during a low tariff off-peak period, which does not add extra stress to the grid. This indicates a better utilization of generation capacity, leading to improved return on investment for power plants.

From the customer's perspective, the Simple Payback (SPB) period is reduced by 4% to 14%, resulting in a time gain of up to 14 months. The next step in the study is to implement this optimization strategy in hardware using affordable electronics, making the solution accessible to a larger number of households.

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Review Article

ELECTRIFYING THE TRANSPORTATION SECTOR: IMPLICATIONS FOR THE OIL AND GAS INDUSTRY

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Abstract: *This review article explores the implications of electrifying the transportation sector for the oil and gas industry. The current state of the transportation sector and the role of oil and gas in it are discussed, followed by an introduction to the concept of electrification and its potential benefits and challenges. The article analyzes the potential impacts of electrification on the oil and gas industry, including changes in demand for oil and gas and opportunities for investing in renewable energy and developing new technologies. Several case studies of companies in the oil and gas industry that are adapting to the transition to electrification are presented, including those investing in renewable energy and developing electric vehicle charging infrastructure. The role of government policies and regulations in the transition to electrification is also discussed, including incentives for electric vehicles and renewable energy and their potential impact on the oil and gas industry. The article concludes with a summary of the potential implications of electrifying the transportation sector for the oil and gas industry, along with recommendations for how companies in the oil and gas industry can adapt to the transition to electrification. Overall, the article provides a comprehensive overview of the electrification of the transportation sector and its impact on the oil and gas industry, offering insights and recommendations for industry stakeholders.*

Keywords: *Electrification, Transportation sector, Oil and gas industry, Renewable energy*

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1. Introduction

Electrifying the transportation sector is seen as a potential solution to these challenges, as it can reduce emissions and improve air quality. Electrification refers to the shift from traditional fossil-fuel powered vehicles to electric vehicles (EVs), which are powered by electricity from the grid or renewable sources such as solar or wind. The potential implications of electrifying the transportation sector for the oil and gas industry are significant. As the demand for oil and gas decreases, the industry may face challenges in maintaining its profitability and may need to adapt to remain competitive. However, electrification also presents opportunities for the industry, such as investing in renewable energy and developing new technologies [1-4]. Several case studies have demonstrated how companies in the oil and gas industry are adapting to the transition to electrification. For example, British Petroleum (BP) has invested heavily in renewable energy, with plans to increase its renewable energy capacity to 50 gigawatts by 2030 [5]. Shell has also made significant investments in electric vehicle charging infrastructure, with plans to install 2.5 million EV charging points by 2030 [6].

Government policies and regulations are also playing a significant role in the transition to electrification. For example, Norway has set a target for all new passenger cars to be zero-emission vehicles by 2025, while China has set a target for new energy vehicles to account for 25% of all car sales by 2025 [8]. In this review article, we will explore the implications of electrifying the transportation sector for the oil and gas industry, providing insights and recommendations for industry stakeholders.

2. Electrifying the Transportation Sector

Electrifying the transportation sector refers to the process of replacing traditional internal combustion engine vehicles with electric vehicles (EVs) powered by electricity from the grid or renewable sources such as solar or wind [8]. This shift is seen as a critical component of efforts to reduce greenhouse gas emissions and improve air quality. The current state of electrification varies across different regions and countries. In 2020, China had the largest EV market, accounting for around 40% of global EV sales, followed by Europe and the United States [2]. There are also different types of EVs available, including battery electric vehicles (BEVs), which are entirely powered by electricity, and plug-in hybrid electric vehicles (PHEVs), which use both electricity and traditional fuels.

In addition to EVs, there are various types of charging infrastructure available, including slow chargers, fast chargers, and ultra-fast chargers. Slow chargers are typically used in homes and workplaces and take several hours to fully charge an EV, while fast chargers can charge an EV in under an hour. Ultra-fast chargers, also known as high-power chargers, can charge an EV in just a few minutes, but are currently less common [7]. Electrifying the transportation sector offers several benefits, including reduced greenhouse gas emissions and improved air quality, as well as lower operating costs for EV owners [8-9]. However, there are also several challenges associated with electrification, including high upfront costs for EVs and charging infrastructure, limited range and charging options for long-distance travel, and concerns about the environmental impact of battery production and disposal [4-10].

3. Implications for the Oil and Gas Industry

The electrification of the transportation sector has significant implications for the oil and gas industry, as transportation accounts for a significant portion of global oil demand. As the use of EVs increases, demand for gasoline and diesel fuel is expected to decline [11]. According to the International Energy Agency (IEA), the demand for oil in road transport is expected to decline by around 10% by 2040 [2]. While the decline in demand for oil and gas presents challenges for the industry, it also creates opportunities. Some companies in the oil and gas industry have already started investing in renewable energy sources such as wind and solar, recognizing the potential for growth in these areas [12]. Additionally, the development of new technologies, such as carbon capture and storage, could help to reduce the carbon footprint of the oil and gas industry and make it more compatible with a low-carbon future [13].

The shift towards electrification also presents opportunities for oil and gas companies to become involved in the development of charging infrastructure and energy storage systems. For example, BP has invested in charging infrastructure company Free Wire Technologies and is exploring opportunities in battery storage [14]. Shell has also invested in charging infrastructure and is developing a network of hydrogen fueling stations [15]. As a summary, while the electrification of the transportation sector is expected to have a significant impact on the demand for oil and gas, it also presents opportunities for the industry to diversify and invest in renewable energy sources and new technologies.

4. Case Studies

As the transportation sector shifts towards electrification, companies in the oil and gas industry are adapting to this transition by diversifying their operations and investing in renewable energy sources and EV charging infrastructure. The following case studies highlight some examples of companies that are taking action towards a low-carbon future:

1. BP: The British energy company operates in over 70 countries and has set a goal to become a net-zero emissions company by 2050. BP has invested in electric vehicle charging infrastructure in the UK and Europe, as well as in renewable energy projects such as wind and solar power. The company has pledged to increase its low-carbon investment to $5 billion per year by 2030. BP has invested in wind and solar projects and is also exploring opportunities in hydrogen and electric vehicle charging infrastructure [5].

2. Shell: Company is headquartered in the Netherlands and operates in over 70 countries worldwide. Shell has set a goal to become a net-zero emissions energy company by 2050 and has invested in electric vehicle charging infrastructure in the UK, Netherlands, and China. In addition, the company has invested in renewable energy projects such as wind and solar power. The company has pledged to invest up to $2 billion per year in renewable energy sources. Shell has invested in EV charging infrastructure, including a network of hydrogen fueling stations, and is also exploring opportunities in wind and solar projects [16].

3. TotalEnergies: The French energy company operates in over 130 countries and has invested in electric vehicle charging infrastructure and battery storage projects in France, Germany, and the UK. The company has set a target of reaching net-zero emissions by 2050 and has pledged to invest up to 20% of its capital expenditure in low-carbon electricity by 2030. TotalEnergies has invested in wind and solar projects and is also exploring opportunities in hydrogen and EV charging infrastructure [17].

4. Repsol: The Spanish energy company operates in over 30 countries and has set a goal to become a net-zero emissions company by 2050. Repsol has invested in electric vehicle charging infrastructure in Spain and Portugal, as well as in renewable energy projects such as wind and solar power. The company has pledged to invest €18.3 billion in low-carbon projects over the next five years [18].

5. Eni: The Italian oil and gas company operates in over 60 countries and has set a goal to become carbon neutral by 2050. Eni has invested in renewable energy projects such as solar and wind power in Italy and Africa, as well as in carbon capture and storage projects. The company has pledged to increase its investment in renewable energy sources to €8 billion by 2022. [19].

6. Equinor: The Norwegian energy company operates in over 30 countries and has invested in offshore wind projects and plans to develop floating wind farms to power oil and gas production facilities. The company has set a target of becoming a net-zero energy company by 2050 and has pledged to invest up to 15-20% of its capital expenditure in renewable energy sources by 2030. Equinor has invested in wind and solar projects and is also exploring opportunities in hydrogen and carbon capture and storage [20].

7. ExxonMobil: The American oil and gas company operates in over 50 countries and has invested in research and development of new technologies for low-carbon transportation, including electric and hydrogen fuel cell vehicles. The company has set a target of reducing its greenhouse gas emissions by 15-20% by 2025 and has pledged to invest $3 billion in low-emissions technologies by 2025. ExxonMobil is exploring opportunities in carbon capture and storage and biofuels [21].

8. Chevron: The Company has set a target of reducing its greenhouse gas emissions by 35% by 2028 and has pledged to invest $10 billion in low-carbon technologies by 2028. Chevron is exploring opportunities in hydrogen and carbon capture and storage [22].

9. Petronas: The Malaysian oil and gas company operates in over 50 countries and has invested in solar power projects in Malaysia. Petronas has set a goal to reduce its carbon emissions by 50% by 2050. The company has pledged to invest $3.6 billion in renewable energy sources by 2025. Petronas has invested in solar and wind projects and is also exploring opportunities in hydrogen and EV charging infrastructure [23].

10. Petrobras: The Brazilian oil and gas company operates in Brazil and has invested in biofuels, including ethanol and biodiesel, as well as developing offshore wind projects. Petrobras has also invested in carbon capture and storage projects to reduce emissions from its operations. The company has pledged to invest $1.1 billion in low-carbon projects by 2025 [24].

11. Sinopec: The Chinese state-owned oil and gas company operates in over 30 countries and has invested in electric vehicle charging infrastructure and plans to increase production of hydrogen fuel cells. Sinopec has also invested in renewable energy projects such as wind and solar power [25].

These companies are investing in wind and solar projects and exploring opportunities in hydrogen and electric vehicle charging infrastructure, as well as carbon capture and storage and biofuels. The transition to electrification is a global phenomenon, and these companies operate in various countries such as the United Kingdom, Norway, Malaysia, Brazil, Italy, and the United States. By taking these steps, these companies are positioning themselves for a future where the demand for oil and gas is likely to decline due to the increasing adoption of electric vehicles and renewable energy sources.

5. Government Policies and Regulations

The transition to electrification is heavily influenced by government policies and regulations. Incentives for electric vehicles (EVs) and renewable energy sources, as well as the imposition of carbon pricing and emissions regulations, have played a critical role in the adoption of electric vehicles and the shift towards renewable energy. One example of such policies is the Zero Emissions Vehicle (ZEV) program in California, which mandates automakers to sell a certain percentage of electric, hybrid, and fuel cell vehicles in the state. This policy has been credited with the rapid growth of the EV market in California [26]. In addition, various countries have introduced tax incentives and subsidies to encourage the adoption of electric vehicles, such as Norway's exemption from value-added tax for EVs and China's subsidies for EV purchases [27]. Renewable energy policies have also played a significant role in the transition to electrification. The Renewable Portfolio Standards (RPS) in the United States require utilities to produce a certain percentage of their electricity from renewable sources, which has led to a significant increase in renewable energy capacity [28]. The Feed-in Tariff (FIT) system, implemented in many countries, provides a guaranteed price for renewable energy, which has encouraged investment in renewable energy projects [29].

The potential impact of these policies and regulations on the oil and gas industry cannot be ignored. The increased adoption of electric vehicles and renewable energy sources could lead to a decline in demand for fossil fuels, which could impact the profitability of oil and gas companies. In response, some oil and gas companies, such as BP and Shell, have started investing in renewable energy projects to diversify their portfolios and remain competitive in a rapidly changing energy landscape [5-30]. In conclusion, government policies and regulations have played a critical role in the transition to electrification, incentivizing the adoption of electric vehicles and renewable energy sources, and imposing carbon pricing and emissions regulations. These policies have the potential to significantly impact the oil and gas industry, which has led to some companies diversifying their portfolios to include renewable energy projects.

Turkey has also implemented several government policies and regulations to encourage the transition to electrification and increase the use of renewable energy. In 2017, Turkey introduced a National Renewable Energy Action Plan (NREAP) with a target of reaching 30% renewable energy in the electricity mix by 2023. The plan aims to increase the share of wind and solar power in the energy mix and to reduce the share of fossil fuels, including coal and gas [31]. In addition, Turkey offers incentives for the purchase of electric vehicles to encourage the uptake of low-emission vehicles. The government has introduced a tax exemption for electric vehicles, reduced the value-added tax (VAT) rate for electric vehicle sales, and provided financial support for the installation of electric vehicle charging infrastructure [32]. Furthermore, Turkey has also implemented regulations to increase the share of renewable energy in electricity generation. In 2019, the government introduced a regulation that requires large industrial facilities to meet a certain share of their electricity consumption from renewable sources, with the share increasing over time [33]. These government policies and regulations are expected to have a significant impact on the oil and gas industry in Turkey, as the country seeks to reduce its dependence on fossil fuels and increase the use of renewable energy. However, the success of these policies will depend on effective implementation and monitoring, as well as the availability of renewable energy sources and supporting infrastructure.

6. Advancements in Battery Technology

As the electrification of the transportation sector continues to accelerate, advancements in battery technology have become critical in driving the growth of electric vehicles (EVs). The development of more efficient and affordable batteries with longer range and shorter charging times is essential for the widespread adoption of EVs. One of the major advancements in battery technology is the development of solid-state batteries, which use a solid electrolyte instead of a liquid electrolyte. Solid-state batteries offer higher energy density, longer cycle life, and increased safety compared to traditional lithium-ion batteries. Automakers such as Toyota and BMW have invested in solid-state battery research and plan to bring solid-state battery-powered EVs to market in the next few years [34]. Another emerging technology is the use of sodium-ion batteries, which have the potential to offer lower cost and improved safety compared to lithium-ion batteries. In 2021, a Chinese battery company, Envision AESC, announced plans to build a sodium-ion battery factory in Japan, with plans to expand globally [35].

In Turkey, there has been significant research and development in battery technology. In 2021, Turkish battery manufacturer, Atılım Enerji, announced a project to develop high-energy-density lithium-sulfur batteries with the support of the Turkish government. The project aims to develop advanced batteries with higher energy density and lower cost, which could be used in electric vehicles [36]. The advancements in battery technology are not limited to electric vehicles. The use of batteries for energy storage in renewable energy systems is also becoming increasingly important. Batteries can store excess energy generated by wind and solar power, making it available when demand is high. In 2022, the world's largest battery energy storage system, with a capacity of 1.2 GWh, was commissioned in the United Kingdom [37]. In conclusion, advancements in battery technology are critical for the widespread adoption of electric vehicles and the integration of renewable energy systems. The development of more efficient and affordable batteries is crucial in driving the growth of the electrification of the transportation sector.

7. Infrastructure Challenges for Electrification

The widespread adoption of electric vehicles requires the development of a robust charging infrastructure. This infrastructure should include public charging stations, private charging points, and charging stations at workplaces. However, the development of charging infrastructure has been slower than anticipated due to several challenges. One of the main challenges is the lack of standardization of charging infrastructure. There are several types of chargers available in the market, such as Level 1, Level 2, and DC fast charging, which differ in their charging speed and connector type. The lack of a universal charging standard has made it difficult for charging infrastructure providers to make significant investments. Standardization efforts such as the Combined Charging System (CCS) and the Open Charge Point Protocol (OCPP) are underway to address this challenge [39]. Another challenge is the high cost of charging infrastructure installation. This challenge is especially acute in developing countries where the cost of infrastructure development is relatively high. Governments can play a significant role in addressing this challenge by providing incentives for private companies to invest in charging infrastructure. For example, in China, the government offers subsidies to companies that invest in charging infrastructure [38].

Turkey has also taken steps to address the infrastructure challenge. In 2020, the Ministry of Environment and Urbanization announced plans to install 1,000 new charging stations across the country by the end of the year, with a goal of having 10,000 charging stations installed by 2023 [39]. The government has also introduced incentives for private companies to invest in charging infrastructure through the Green Energy Support Scheme (GESS), which provides financial support to renewable energy and energy efficiency projects, including EV charging stations [40]. In conclusion, the development of charging infrastructure is a critical component of the transition to electrification of transportation. Standardization efforts and government incentives can play a significant role in addressing the infrastructure challenges.

8. Economic Implications for the Energy Industry

The shift towards electrification has significant economic implications for the energy industry, particularly the oil and gas sector. As electric vehicles become more popular and renewable energy sources become more competitive, the demand for oil and gas is expected to decline. This shift can impact the profitability of traditional oil and gas companies and result in a restructuring of the industry. According to a report by BloombergNEF, electric vehicles could displace 7.3 million barrels of oil per day by 2040, which would represent a 7% decline in demand from the transportation sector [41]. This shift could lead to stranded assets and reduced revenue for oil and gas companies, which could also impact the financial stability of oil-producing countries. In response to these economic implications, some oil and gas companies have begun to diversify their portfolios by investing in renewable energy sources. For example, Shell has pledged to invest up to $2 billion per year in renewable energy sources, such as wind and solar power, and has also invested in electric vehicle charging infrastructure [42]. Similarly, TotalEnergies has pledged to invest up to 20% of its capital expenditure in low-carbon electricity by 2030 and has invested in renewable energy projects such as solar power and offshore wind [43].

In Turkey, the government has introduced policies to promote the use of electric vehicles and renewable energy sources. In 2017, the Turkish government announced a plan to increase the number of electric vehicles on the roads to 1 million by 2023 [44]. In addition, Turkey has set a target to generate 30% of its electricity from renewable sources by 2023 [45]. These policies have the potential to impact the demand for oil and gas in the country and drive investments towards renewable energy sources.

Overall, the shift towards electrification and renewable energy sources has significant economic implications for the energy industry, particularly the oil and gas sector. Companies and governments that are able to adapt to this shift and invest in renewable energy sources have the potential to thrive in the changing energy landscape.

9. Social and Environmental Impacts

The transition to electrification has various social and environmental impacts. The adoption of electric vehicles (EVs) can have positive impacts on air quality and public health by reducing emissions of greenhouse gases and harmful pollutants such as nitrogen oxides (NOx), sulfur oxides (SOx), and particulate matter (PM) [46]. Additionally, EVs can lead to energy security and a reduction in the dependence on foreign oil imports, which can have positive geopolitical implications [2]. On the other hand, the production of EV batteries and charging infrastructure can have negative environmental impacts, particularly in terms of carbon emissions and resource depletion [47]. The mining of materials such as lithium, cobalt, and nickel, which are used in EV batteries, can have negative environmental and social impacts, including deforestation, water pollution, and human rights abuses [48]. The disposal of EV batteries can also create environmental hazards and waste management challenges.

In terms of social impacts, the transition to electrification can create both winners and losers. The shift towards EVs and renewable energy sources can create new job opportunities in the manufacturing and installation of EV batteries, charging infrastructure, and renewable energy systems. However, this shift can also lead to job losses in the oil and gas industry, particularly in countries where the sector plays a significant role in the economy. Moreover, the adoption of EVs can also create equity issues, particularly in developing countries where access to EVs and charging infrastructure may be limited [2].

In Turkey, the government has set a target of having 1 million EVs on the road by 2023 and has implemented policies and incentives to promote the adoption of EVs, including tax exemptions, subsidies, and the development of charging infrastructure [45]. However, the lack of charging infrastructure remains a major barrier to the widespread adoption of EVs in the country [49].

10. Future Outlook and Recommendations

The electrification of the transportation sector is expected to continue to accelerate in the coming years, driven by advances in battery technology, government policies, and decreasing costs. According to a report by BloombergNEF, electric vehicles are projected to make up 31% of new car sales globally by 2040, with China leading the way in adoption [50]. This transition to electrification will have significant impacts on the oil and gas industry, as demand for traditional fossil fuels decreases. To adapt to this changing landscape, oil and gas companies are diversifying their portfolios and investing in renewable energy sources, as well as exploring opportunities in EV charging infrastructure and battery storage. Governments can also play a crucial role in promoting electrification by providing incentives and funding for renewable energy and EV infrastructure.

In Turkey, the government has set a target of increasing the share of electric vehicles in total car sales to 10% by 2030 [51]. To achieve this goal, the government has introduced various incentives, including tax breaks and subsidies for EV purchases, as well as investment in charging infrastructure [52]. However, the country still faces challenges in terms of infrastructure development and grid capacity to support the growing demand for EVs. Overall, the electrification of the transportation sector presents both challenges and opportunities for the energy industry. While the transition to renewable energy sources will have economic, social, and environmental implications, it also offers a path towards a more sustainable future.

11. Conclusion

In conclusion, the electrification of the transportation sector has the potential to bring significant changes to the oil and gas industry. With the adoption of electric vehicles, there is a potential decrease in demand for oil-based products and an increase in demand for renewable energy sources, such as wind and solar power. However, the pace of electrification depends on several factors, including government policies, advancements in battery technology, and infrastructure developments. For companies in the oil and gas industry to adapt to this transition, they should consider diversifying their portfolios and investing in renewable energy sources. This can include investing in carbon capture and storage projects, as well as developing renewable energy projects. Additionally, oil and gas companies can explore partnerships with electric vehicle manufacturers and infrastructure providers to adapt to the changing market.

In Turkey, the government has introduced several initiatives to promote the adoption of electric vehicles, such as offering tax incentives and providing funding for charging infrastructure. However, there are still challenges to be addressed, including the development of a robust charging infrastructure network and overcoming consumer hesitancy towards electric vehicles. Overall, while the transition to electrification presents challenges for the oil and gas industry, it also presents opportunities for companies to adapt and thrive in the evolving energy market.

Conflict of interest

This research has no conflict of interest involved with any individual as well as institution. All the contributions are well referred and acknowledged the sources where necessary.

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