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# A Hybrid Approach to On-Grid and Off-Grid Solar Energy with Optimum Investment: A Case Study in Vietnam

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## Abstract

In Vietnam, the demand for energy has grown significantly due to the country's fast economic development over the last ten years. The majority of energy in the future will have to come from renewable sources to avoid greenhouse gas emissions, which will force a significant transition away from fossil fuels as the primary energy source. In the Power Development Plan VIII with a vision to 2050, Vietnam's power sector is committed to developing new resources such as solar and wind energies in an effort to build and enhance the nation's power system. A technical and financial model for the construction of a hybrid grid-connected photovoltaic plant with a battery energy storage system under practical optimization problems is presented in this work. Certain business models link the analysis to hourly irradiation by taking into account the hourly energy demand profile for planned working activities. The suggested hybrid system's investment, needed power, and capacity are evaluated and optimized in several scenarios. These findings demonstrate the system's economic viability and technological viability in our suggested approaches.

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## 1. Introduction

To ensure Vietnam's national energy security, the Power Development Plan VIII (PDP VIII) aims at steady power at affordable costs for quick and sustained socio-economic growth [1–3]. Vietnam Electricity (EVN), an integrated state-owned utility, has a monopoly on the transmission, distribution, and operation of the power system, making it the primary producer of electricity in Vietnam [1]. The evolution and reform of Vietnam's power industry from the 1990s to 2020 was examined in [2]. Vietnam's overall power consumption has been rising quickly over the years to meet the requirements of the nation's economic growth. For the expected years 2030 and 2050, an appropriate power planning model by mixing simulation model of national energies is necessary in order to carry out an energy expansion that is compatible with the CO2 reduction objectives [3].

From a business perspective, investors primarily look to the project's net present value (NPV) to assess and contrast the viability of the project assessment when making an investment in a rooftop solar energy storage system [4–7]. Vietnam is seen to have enormous potential for producing sustainable energy. In fact, clean energy is crucial to the economy, society and energy security. The utilization of clean power sources has made significant progress in guaranteeing national energy security, conserving energy resources, and reducing adverse environmental effects associated with the generation of electricity [5, 7]. Renewable energy is becoming more competitive with traditional energy sources since its costs are declining more quickly than previously anticipated, particularly for wind and solar energy. Rising capacity factors, high levels of

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investment, and quick technical developments are pushing the replacement of fossil fuels with renewable energy in the world's energy output in the future [4, 6].

The solar power system's capacity must, first and foremost, completely satisfy the consumption needs of the manufacturing business [8]. The lack of capacity investment necessitates supplemental energy from other sources, such as conventional energy sources (hydropower, thermal power, etc.), which are now being steadily depleted. Hybrid renewable energy systems (HRES), which integrate several renewable energy resources in an ideal mix, may be able to help with the aforementioned problems. Secondly, battery energy storage systems (BESS) should be investigated to ensure that solar power production can support business operations both during the day and at night, in the presence and absence of radiation [9–11]. BESS has a broad range of applications, including transmission upgrade deferral, continuous power supply, reliability improvement, and long-term energy management [10]. The use of energy storage systems enables the growing adoption of renewable energy sources by storing and releasing energy over varying time periods. Because of its non-self-discharge feature, battery technology is also showing promise for applications requiring long-term storage. One significant disadvantage of the battery system is the higher initial investment and ongoing expenses related to the operation of a chemical plant, which includes pump systems and flow control with external storage [9]. Future research on grid-connected energy production systems with storage is required. This includes a power management mechanism for grid systems, performance evaluation, and the proposal of an energy dispatch schedule optimization technique and a cost-benefit analysis [11].

The rest of this paper is organized as follows. In Section I, we present the benefits and growth possibilities of employing renewable energy to the global and Vietnamese development. The system model of hybrid solar integrated with BESS and the motivation of practical optimization problem under-investment aspect are proposed in Section II. In the most important part of this work, three business models based on hybrid solar-BESS schemes are discussed in Section III. In Section IV, we provide numerical results to evaluate the proposed approach in three scenarios as described in Section III. Finally, the conclusion of this tutorial will be shown in Section V.

## 2. System Model and Problem Formulation

### 2.1. System Model

We focus on the investment of solar energy systems to assess and optimize the viability of the project under the power development plan in each country (e.g., PDP VIII in Vietnam). Self-production and self-consumption

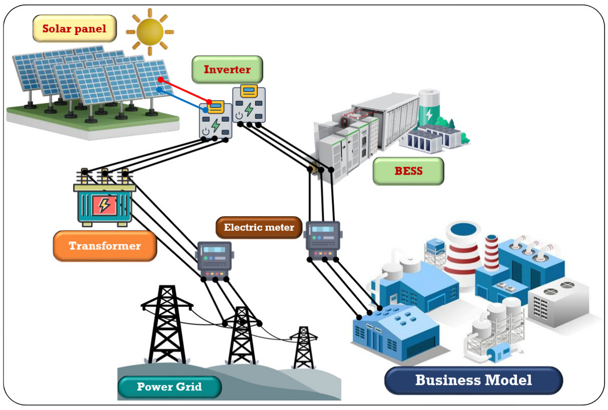


**Figure 1.** A system model of hybrid Solar-BESS.

will be a possible trend in the sustainable development of renewable energy sources, given the new strategy for developing solar power in the future [17, 20, 21]. Currently, we are dealing with two issues: including the grid transportation sector in future initiatives and integrating the significant portion of intermittent power from RE systems. In order to develop sustainable energy policies, it is not enough to focus only on cost reduction, efficiency gains, and renewable energy sources. Developing integrated energy system solutions and developing and incorporating flexible energy technologies also become important such as BESS.

Solar technology policies, investments, and assistance from a range of governmental and organizations have contributed to the establishment of a comprehensive framework for the use of this renewable energy source. However, significant reductions in solar power subsidies have already occurred in a number of nations, which might impede the industry's expansion. Policies are shifting to encourage the installation of solar power systems for large-scale electricity production, with Vietnam serving as an example, in an effort to reverse this possible decrease. The hybrid on-grid/off-grid (grid connection/energy storage) paradigm [13] is an efficient platform for satisfying the demands of consumers and power providers as shown in Fig. 1. Here, the key issue is how to get the most out of the investment in a solar power system.

One of the most important aspects of system construction in the solar energy industry is to supply the right capacity. In order to do this, our system model designs optimization problems to combine solar power with grid connection and storage, to maximize energy efficiency and economic efficiency. This allows us to optimize the size and manner in which solar power is operated in accordance with business models [10, 14, 17, 26].

In this part, we present a system model that includes solar, power grid, and energy storage system components to express the aforementioned views. Then, we analyze investment strategic planning models. General system parameters are provided and described in Table 1.

Firstly, based on the energy generated (by solar system) and energy consumed (by business), the difference between energy produced and energy consumed each day can be provided as

$$F_{obj}(P_{sys}, E_{bess}) = \left|E_{generate}(P_{sys}, E_{bess}) - E_{comsume}\right|. \quad (1)$$

Therein,

$$E_{generate}(P_{sys}, E_{bess}) = E_{solar}(P_{sys}) + E_{bess}, \quad (2)$$

where

$$E_{solar}(P_{sys}) = (t_{sun} + (12 - t_{sun})\alpha_{solar}) \times P_{sys}, \quad (3)$$

with the model of daily operational solar for generating energy as provided in Fig. 2.

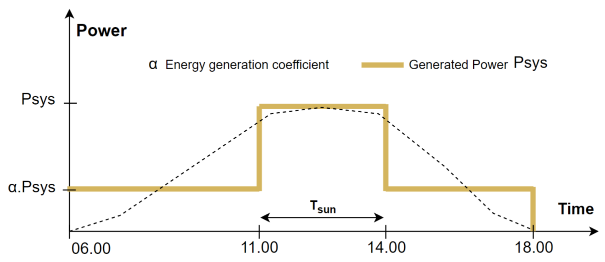


**Figure 2.** A model of operational solar system per day. The solar system harnesses energy during the whole of daylight (12 hours from 6 a.m.). The period of full solar radiation (100%) is from 11 to 2 (3 hours); meanwhile, the solar system still generates energy in the remaining time with a low level of radiation ($\alpha \leq 100$ percent).

$$E_{bess} = t_{charge/discharge} \times P_{bess}, \quad (4)$$

with $t_{charge/discharge}$ and $P_{bess}$ are the time and power of charging/discharging energy to the BESS system. In this work, we do not deeply mention these parameters, but the total capacity of BESS is considered a crucial variable for the optimization problem.

And

$$E_{comsume} = t_{operate} \times P_{model} \quad (5)$$

To build a hybrid Solar-BESS system, we have to invest in two main components such as the solar system (e.g., solar panel, inverters) and the BESS system (e.g., charging controllers, battery). Thus, the total investment cost of a hybrid Solar-BESS system is given by

$$TC = C_{solar} \times P_{sys} + C_{bess} \times E_{bess} \quad (6)$$

## 2.2. Problem Formulation

The primary objective of the challenge is to reduce the disparity in power between the produced energy from hybrid Solar-BESS and the necessary energy in the business model. The aforementioned may be formulated as a minimization problem below

$$\underset{P_{sys}, E_{bess} \geq 0}{\text{minimize}} \quad F_{obj}(P_{sys}, E_{bess}) \quad (7a)$$

$$\text{subject to} \quad 0 \leq P_{sys} \leq P_{sys}^{\max}, \quad (7b)$$

$$TC \leq TC^{\max}, \quad (7c)$$

$$E_{bess} \leq E_{consume}, E_{solar} \leq E_{consume}, \quad (7d)$$

where (7b) is a limited power scale (e.g., policy planning, area of land use), (7c) is a constraint of fund capacity for investment and (7c) are constrained solar or BESS energies which must be less than consumed energy. The aforementioned optimization problem model makes it evident that this is a linear multivariable constrained optimization problem, which can be simply solved by using well-known optimization problem-solving tools like CVX (using Matlab) and CVXPY (using Python). Our major goal is to leverage our attention on many scenarios with various business models to develop an intelligent investment plan with the hybrid Solar-BESS system.

The economic value of a hybrid Solar-BESS system is represented in two cases. The first benefit comes from solar energy produced by a solar system as an alternative to purchasing electricity from an electrical provider. Secondly, the BESS system (off-grid scheme) is utilized when the period of time is without solar radiation (in night). Secondly, the BESS system (off-grid scheme) is used to provide energy for ongoing operations during periods of no solar radiation, such as at night.

Following the above situation, the revenue of a hybrid Solar-BESS system is expressed as

$$NPV = Price_{grid} \times (E^*_{generate}) = Price_{grid} \times (E^*_{solar} + E^*_{bess}) \quad (8)$$

where $E^*_{solar}$ and $E^*_{bess}$ are the whole quantity of green energy by solar and BESS systems for only business purposes (useful energy). This amount of energy should be just sufficient for running the business since the selling price ($Price_{solar}$) of energy (hybrid Solar-BESS system) is much less than the buying price ($Price_{grid}$) (electrical grid) even the selling price of renewable energy may reach 0 in some countries.

**Table 1.** Parameters.

| Notations | Describes |
|---|---|
| $P_{sys}$ $(KWp)$ | Power of the solar system (system capacity) |
| $P_{model}$ $(KW)$ | Power of the load (business model) |
| $E_{solar}$ $(KWh)$ | Generated energy from solar system per day |
| $E_{comsume}$ $(KWh)$ | Consumed energy by business model per day |
| $E_{bess}$ $(KWh)$ | Capacity of BESS system |
| $C_{solar}$ $(\$/KWp)$ | Cost for building 1 unit of solar power (1 power unit = 1 KW) |
| $C_{bess}$ $(\$/KWh)$ | Cost for building 1 unit of battery energy storage (1 energy unit = 1 KWh) |
| $Price_{solar}$ $(\$/KWh)$ | Selling price of 1 unit of solar energy generated |
| $Price_{grid}$ $(\$/KWh)$ | Buying price of 1 unit of energy on grid |
| $t_h \in \{h = 1, ..., 24\}$ | The $h$th hour in a day |
| $t_{sun}, (t_{sun} \leq 24h)$ | The number of hours of sunshine with full radiation each day (calculated as the mean) |
| $\alpha_{solar}$ (%) | Energy generation coefficient of solar power in the hours without full radiation, (24 - $t_{sun}$) hours |
| $t_{operate}$ | The duration of operational hours required for energy consumption per day in a business model |

## 3. Hybrid Solar-BESS Energy Systems based on Business models

This section proposes three common business models to make use of the capabilities of the proposed Solar-BESS system. Any kind of company activity will need a flexible approach to system installation.

### 3.1. Model 1: A 24/7 service

We consider the business models that run around the clock, such as industrial livestock facilities, data centers, or supermarkets with cold storage warehouses. These models need substantial energy to sustain their production activities as shown in Fig. 3.

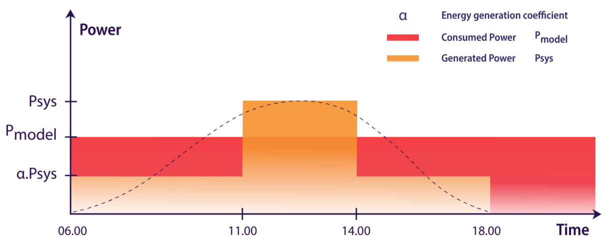


**Figure 3.** A case study of the first business model.

The model's energy usage will be evenly distributed over a 24-hour day ($t^{(1)}_{operate} = 24h$). Therefore, the hybrid Solar-BESS system will be designed to provide uninterrupted energy for the whole duration of company operations based on two schemes. Firstly, $P_{sys}$ of the solar system at the full radiation level ($t_{sun}$) must be larger than $P_{model}$. The excess energy of the solar system in this period of time will be charged to the BESS system for supplying energy to the business in periods of less solar radiation $(24 - t_{sun})$.

In this case, an expression of the energy stored in the BESS is given by

$$E^{(1)}_{bess}(P_{sys}) = \max\left\{0, (12 - t_{sun})(P^{(1)}_{model} - \alpha_{solar}P_{sys})\right\} + 12P^{(1)}_{model}. \quad (9)$$

The problem (7) can be rewritten as

$$\underset{P_{sys}\geq 0}{\text{minimize}} \quad F_{obj}(P_{sys}, E^{(1)}_{bess}(P_{sys})) \quad (10a)$$

$$\text{subject to} \quad (7b), (7c), (7d). \quad (10b)$$

### 3.2. Model 2: 8 working hours per day

Businesses often have established operating models that include the use of standardized equipment and a workforce that works for a certain number of hours. There is a prescribed energy consumption threshold that must be met within a certain time period each day, e.g., $t^{(2)}_{operate} = 8$ hours as shown in Fig. 4.

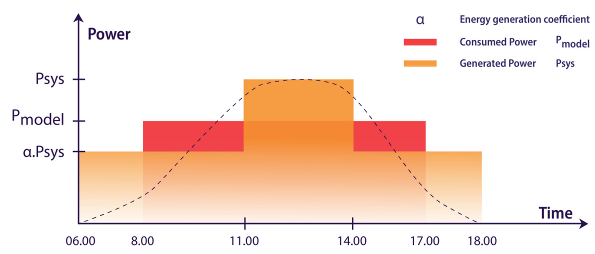


**Figure 4.** A case study of the second business model.

The hybrid Solar-BESS system is designed as the same as in the first case study. The business operates for only 8 hours per day. Based on the operational scheme in this business, the model's energy usage will be evenly distributed over $t_{operate}$ of 8 hours. Thus, the energy stored in the BESS can be expressed as

$$E^{(2)}_{bess}(P_{sys}) = \max\left\{0, (t^{(2)}_{operate} - t_{sun})(P^{(2)}_{model} - \alpha_{solar}P_{sys})\right\}. \quad (11)$$

Based on the modified $E_{bess}(P_{sys})$ in equation (11), the problem (7) can be rewritten as

$$\underset{P_{sys}\geq 0}{\text{minimize}} \quad F_{obj}(P_{sys}, E^{(2)}_{bess}(P_{sys})) \quad (12a)$$

$$\text{subject to} \quad (7b), (7c), (7d). \quad (12b)$$

### 3.3. Model 3: A weekly model

Businesses often have established operating models that include standardized equipment and a workforce that operates five days a week, namely from Monday to Friday. The company is operational for 8 hours per working day. Over the course of Saturday and Sunday, the hybrid Solar-BESS model continues to function and store energy in the BESS for supplying energy in the next week, as shown in Fig. 5.

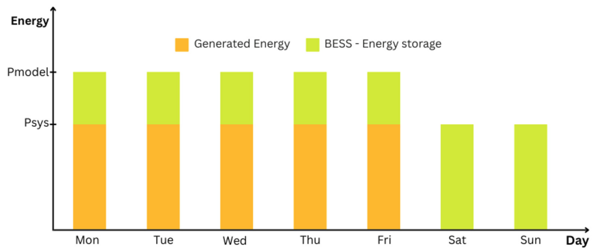


**Figure 5.** A case study of the third business model.

Our objective is to maximize the efficiency of the renewable energy system in order to achieve a balanced energy generation and consumption for the company throughout the week while adhering to technical limitations and financial considerations. Following the equation (3) and (5), the energy stored in the BESS can be expressed as

$$E^{(3)}_{bess}(P_{sys}) = 5\max\left\{(E_{consume} - E_{solar}(P_{sys}))\right\} + 2E_{solar}(P_{sys}). \quad (13)$$

The problem (7) can be rewritten as

$$\underset{P_{sys}\geq 0}{\text{minimize}} \quad F_{obj}(P_{sys}, E^{(3)}_{bess}(P_{sys})) \quad (14a)$$

$$\text{subject to} \quad (7b), (7c), (7d). \quad (14b)$$

## 4. Some testbed: Case studies in Vietnam

In this section, we provide numerical results with the practical values of system parameters as shown in Table 1 for three business models. To demonstrate the benefit of the proposed approach, we consider four schemes related to solar and BESS systems based on On-grid and Off-grid including On-grid without solar and BESS, On-grid with solar but without BESS, Off-grid with solar but without BESS and Off-grid with solar and BESS. The widely-used tool CVXPY is used in our simulations to resolve the optimization issue and validate the outcomes attained via the hybrid Solar-BESS model's implementation.

Table 2 provides references and practical values for the system's general parameters.

**Table 2.** The value of general system parameters.

| Parameters | Values |
|---|---|
| $C_{solar}$ | \$480/KWp |
| $C_{bess}$ | \$240/KW |
| $Price_{solar}$ | \$0.08/KWh |
| $Price_{grid}$ | \$0.1/KWh |
| $t_h \in \{h = 1, ..., 24\}$ | The $h$th hour in a day |
| $t_{sun}, (t_{sun} \leq 24h)$ | 3 hours |
| $\alpha_{solar}$ | 20% |

### 4.1. A testbed of model 1

In order to illustrate the production activities in the first business model, we will test with an industrial livestock model e.g., a pig farm. The farm has a capacity of $10,000$ animal units. The energy consumption of the model is around 4MWh per day. In addition, other system parameters in this scenario are as below.

**Table 3.** The value of system parameters in the model 1.

| Parameters | Values |
|---|---|
| $t^{(1)}_{operation}$ | 24h/day |
| $P^{(1)}_{model}$ | 0.166MW |
| $P^{\max}_{sys}$ | 1MWp |

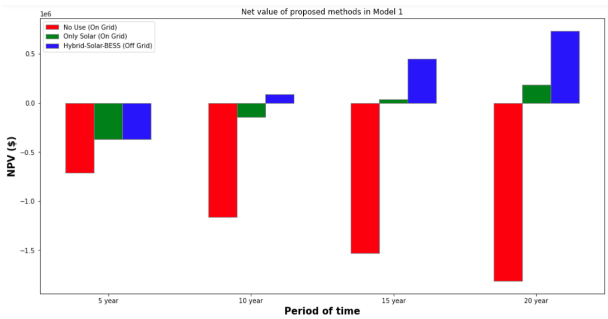


**Figure 6.** The net value of model 1 under different schemes ($ unit).

**Table 4.** The net value of model 1 under different schemes ($ unit).

| Period | On-grid without Solar | On-grid with Solar | Off-grid (Hybrid system) |
|---|---|---|---|
| 5 years | $ -708, 324 | $ -370, 202 | $ -370, 350 |
| 10 years | $ -1, 164, 888 | $ -141, 919 | $ 86, 213 |
| 15 years | $ -1, 526, 702 | $ 38, 987 | $ 448, 026 |
| 20 years | $ -1, 813, 429 | $ 182, 351 | $ 734, 753 |

Fig. 6 and Table 4 provide the net value of proposed schemes for model 1 after subtracting the investment cost of the single solar system or the hybrid Solar-BESS. As expected, the hybrid Solar-BESS system achieves the best net value among three schemes. After 10 years, the investment in hybrid solar-BESS system will break even and it starts to generate profits. A crucial aspect to consider is that the decreasing prices of technology and system deployment will enhance the effectiveness of the payback time and advantages associated with solar and hybrid solar systems.

### 4.2. A testbed of model 2

In the second business model, we implement a testbed with a factory operated power of 2MW with 8 hours working per day.

**Table 5.** The value of system parameters in the model 2.

| Parameters | Values |
|---|---|
| $t^{(2)}_{operation}$ | 8h/day |
| $P^{(2)}_{model}$ | 2MW |
| $P^{\max}_{sys}$ | 10MWp |

Table 6 shows the advantages of solar and hybrid Solar-BESS systems. Both in On-grid and Off-grid platforms, the net values of two approaches significantly outperform other schemes. It is important to acknowledge that off-grid solar systems require upfront investment expenses and a significant amount of time to recoup the original expenditure. Nevertheless, this approach remains more advantageous than purchasing power directly from the grid. Overall, it is evident that using renewable energy systems offers more efficiency in comparison to the conventional practice of procuring power from fossil fuels.

### 4.3. A testbed of model 3

In this model, we also perform a testbed with a factory operated power of 2MW over 5 working days per week and 8 hours working per day. Other parameters are the same as in model 2.

The net values of the proposed systems are shown in Table 7. For model 3 (weekly model), the solar system connecting to On-grid solar power achieves the best profit. In the aforementioned business models, particularly in this third model, the benefits of solar and BESS systems increase when industrial activities become more continuous when energy consumption rises. On-grid and off-grid solar and hybrid Solar-BESS systems exhibit higher levels of efficiency compared to the conventional scheme. This aligns with the prevailing trajectory of energy use in Vietnam and globally.

## 5. Conclusion

Given the rising energy demand and the potential exhaustion of fossil fuel reserves, clean energy is emerging as the crucial factor for achieving sustainable development in the future. By using a hybrid system that combines grid-connected and off-grid solar electricity, we can maximize the return on investment in renewable energy in Vietnam. This study focuses on the use of optimization techniques to enhance the efficiency of investing in solar energy systems. It is based on the recognition of the importance of optimization models in many aspects of society. The optimization strategy described in the article is crucial for harnessing the full potential of solar energy, enhancing economic gains, and safeguarding the environment. The optimization of investment in three different company models showed the adaptability and practicality of implementing the suggested approach across a range of business types.

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**Table 6.** The net value of model 2 under different schemes ($ unit).

| Period | On-grid without Solar | On grid with Solar | Off-grid without BESS | Off-grid with BESS |
|---|---|---|---|---|
| 5 years | $ -128, 010 | $ -22, 824 | $ -221, 080 | $ -45, 222 |
| 10 years | $ -210, 521 | $ 18, 293 | $ -138, 568 | $ 37, 288 |
| 15 years | $ -275, 909 | $ 50, 878 | $ -73, 180 | $ 102, 676 |
| 20 years | $ -327, 728 | $ 76, 701 | $ -21, 362 | $ 154, 494 |

**Table 7.** The net value of model 3 under different schemes ($ unit).

| Period | On-grid without Solar | On grid with Solar | Off-grid without BESS | Off-grid with BESS |
|---|---|---|---|---|
| 5 years | $ -81, 053 | $ -25, 536 | $ -268, 037 | $ -193, 369 |
| 10 years | $ -133, 298 | $ -6, 548 | $ -215, 792 | $ -141, 124 |
| 15 years | $ -174, 700 | $ 8, 498 | $ -174, 389 | $ -99, 722 |
| 20 years | $ -207, 511 | $ 20, 422 | $ -141, 579 | $ -66, 911 |

## References


[1] Le TH, Han P, Le HC, Bui MT. *Electricity market development in Vietnam: Historical trends and future outlooks.* Utilities Policy. 2023 Apr 1;81:101510.

[2] Tuan NA. *A case study on power sector restructuring in Vietnam.* Pacific energy summit. 2012 Feb 13.

[3] Hoffmann C. *A power development planning for Vietnam under the CO2 emission reduction targets.* Energy Reports. 2020 Feb 1;6:19-24.

[4] Nguyen XP, Le ND, Pham VV, Huynh TT, Dong VH, Hoang AT. *Mission, challenges, and prospects of renewable energy development in Vietnam.* Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. 2021 Aug;17:1-3.

[5] Hoi HT. *Potential for solar energy development in Vietnam.* International Journal of Environmental Science and Development. 2020 Jul;11(7):358-64.

[6] Nguyen PA, Abbott M, Nguyen TL. *The development and cost of renewable energy resources in Vietnam.* Utilities Policy. 2019 Apr 1;57:59-66.

[7] Riva Sanseverino E, Le Thi Thuy H, Pham MH, Di Silvestre ML, Nguyen Quang N, Favuzza S. *Review of potential and actual penetration of solar power in Vietnam.* Energies. 2020 May 16;13(10):2529.

[8] Wang CN, Viet VT, Ho TP, Nguyen VT, Husain ST. *Optimal site selection for a solar power plant in the Mekong delta region of Vietnam.* Energies. 2020 Aug 6;13(16):4066.

[9] Divya KC, Østergaard J. *Battery energy storage technology for power systems—An overview.* Electric power systems research. 2009 Apr 1;79(4):511-20.

[10] Yang Y, Bremner S, Menictas C, Kay M. *Battery energy storage system size determination in renewable energy systems: A review.* Renewable and Sustainable Energy Reviews. 2018 Aug 1;91:109-25.

[11] Bortolini M, Gamberi M, Graziani A. *Technical and economic design of photovoltaic and battery energy storage system.* Energy Conversion and Management. 2014 Oct 1;86:81-92.

[12] Nguyen VH, Vo CV, Nguyen LD, Phan BT. *Green Scenarios for Power Generation in Vietnam by 2030.* Engineering, Technology & Applied Science Research. 2020 Jul;2019 Apr 1;9(2).

[13] Vu TT, Teyssèdre G, Le Roy S, Anh TT, Tran TS, Nguyen XT, Nguyen QV. *The challenges and opportunities for the power transmission grid of Vietnam.* European Journal of Electrical Engineering. 2019 Dec 21;21(6):489-97.

[14] Nguyen KH, Vu NH, Nguyen XT. *The Status and Potential Assessment of Solar Power Energy Development in Vietnam.* International Journal of Energy and Power Engineering. 2020;9(5):69.

[15] Dincer I. *Renewable energy and sustainable development: a crucial review.* Renewable and sustainable energy reviews. 2000 Jun 1;4(2):157-75.

[16] Moriarty P, Honnery D. *What is the global potential for renewable energy?.* Renewable and Sustainable Energy Reviews. 2012 Jan 1;16(1):244-52.

[17] Lund H. *Renewable energy strategies for sustainable development.* Energy. 2007 Jun 1;32(6):912-9.

[18] Kannan N, Vakeesan D. *Solar energy for future world:-A review.* Renewable and sustainable energy reviews. 2016 Sep 1;62:1092-105.

[19] Mekhilef S, Saidur R, Safari A. *A review on solar energy use in industries.* Renewable and sustainable energy reviews. 2011 May 1;15(4):1777-90.

[20] Kabir E, Kumar P, Kumar S, Adelodun AA, Kim KH. *Solar energy: Potential and future prospects.* Renewable and Sustainable Energy Reviews. 2018 Feb 1;82:894-900.

[21] Okoro OI, Madueme TC. *Solar energy investments in a developing economy.* Renewable Energy. 2004 Jul 1;29(9):1599-610.

[22] Dupont E, Koppelaar R, Jeanmart H. *Global available solar energy under physical and energy return on investment constraints.* Applied Energy. 2020 Jan 1;257:113968.

[23] Okoro OI, Madueme TC. *Solar energy: a necessary investment in a developing economy.* International Journal of Sustainable Energy. 2006 Mar 1;25(01):23-31.

[24] Hannan MA, Wali SB, Ker PJ, Abd Rahman MS, Mansor M, Ramachandaramurthy VK, Muttaqi KM, Mahlia TM, Dong ZY. *Battery energy-storage system: A review of technologies, optimization objectives, constraints, approaches, and outstanding issues.* Journal of Energy Storage. 2021 Oct 1;42:103023.

[25] Padmanabhan N, Ahmed M, Bhattacharya K. *Battery energy storage systems in energy and reserve markets.* IEEE Transactions on Power Systems. 2019 Aug 19;35(1):215-26.

[26] Yang Y, Bremner S, Menictas C, Kay M. *Modelling and optimal energy management for battery energy storage systems in renewable energy systems: A review.* Renewable and Sustainable Energy Reviews. 2022 Oct 1;167:112671.

[27] Nair NK, Garimella N. *Battery energy storage systems: Assessment for small-scale renewable energy integration.* Energy and Buildings. 2010 Nov 1;42(11):2124-30.