# ENERGY AND ENERGY MODELS FOR TROPICAL ISLANDS IN VIETNAM

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**ABSTRACT**

When delving into energy research, addressing the energy needs of islands becomes a noteworthy challenge due to their geographical isolation, making energy supply a formidable task. Constructing an energy model for islands can be regarded as building a scaled-down version of a national energy system. Vietnam, being a tropical country with an extensive coastline and over 3,000 islands, poses a significant issue for researching on-site energy potential for these islands and developing efficient energy usage models, reducing Carbon dioxide emissions-contributing substantially to the sustainable development of the islands. In this article, analytical, synthesis, and comparative methods are employed to evaluate and provide valuable insights, leading to the proposal of an energy-efficient model and Carbon dioxide emission reduction for Vietnam's tropical islands. The research results reveal a considerable energy potential in Vietnam's tropical islands, and the application of technical solutions to optimize energy usage for these islands is rational. The proposed energy model can not only be applied to Vietnam's tropical islands but can also contribute to promoting sustainable energy development for island communities worldwide with similar characteristics.

# NĂNG LƯỢNG VÀ MÔ HÌNH NĂNG LƯỢNG CHO CÁC ĐẢO NHIỆT ĐỚI Ở VIỆT NAM

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**TỪ KHÓA**

Mô hình năng lượng
Đảo nhiệt đới
Giải pháp
Sử dụng hiệu quả
Năng lượng tái tạo

**TÓM TẮT**

Khi nghiên cứu về năng lượng, vấn đề năng lượng cho các đảo là một thách thức đáng chú ý do sự cách biệt địa lý của chúng, dẫn đến việc cung cấp năng lượng trở nên khó khăn. Việc xây dựng mô hình năng lượng cho các đảo có thể được xem xét như việc xây dựng một mô hình thu nhỏ của hệ thống năng lượng quốc gia. Việt Nam là một quốc gia nhiệt đới, với bờ biển dài và hơn 3.000 hòn đảo, đặt ra vấn đề quan trọng là nghiên cứu tiềm năng năng lượng tại chỗ cho các đảo và phát triển mô hình sử dụng năng lượng hiệu quả, giảm phát thải $CO_2$ góp phần quan trọng vào sự phát triển bền vững của các đảo. Trong bài báo này phương pháp phân tích, tổng hợp và so sánh được sử dụng để đánh giá và đưa ra nhận xét có giá trị, từ đó đề xuất mô hình sử dụng năng lượng hiệu quả, giảm phát thải $CO_2$ cho các đảo nhiệt đới của Việt Nam. Kết quả nghiên cứu cho thấy tiềm năng năng lượng tại các đảo nhiệt đới của Việt Nam là rất đáng kể, việc áp dụng các giải pháp kỹ thuật nhằm tối ưu hóa việc sử dụng năng lượng cho các đảo này là hợp lý. Mô hình năng lượng được đề xuất không chỉ có thể áp dụng cho các đảo nhiệt đới của Việt Nam mà còn có thể góp phần thúc đẩy phát triển năng lượng bền vững cho cộng đồng đảo trên thế giới có các đặc điểm tương đồng.

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## 1. Introduction

Small offshore islands face energy scarcity and isolation due to their remote locations, requiring independent power systems. Currently, they rely heavily on fossil fuels, especially during high-demand months. Seasonal variations, fuel price fluctuations, and the pressure from tourism growth necessitate a sustainable energy supply. Meanwhile, due to the tropical island characteristics, on-site energy sources such as solar energy are abundant; islands often experience strong and consistent winds, and biomass sources like solid waste and agricultural residues are plentiful, albeit contributing to environmental pollution. The consideration of technical solutions for energy efficiency has also been neglected in application. Additionally, the islands' undeveloped or underutilized on-site energy sources result in heavy reliance on fossil fuels for electricity generation, transportation, and energy production, leading to significant $CO_2$ emissions into the environment. Developing energy models is imperative to reduce costs. This demonstrates the urgency of building energy models to mitigate costs and safeguard the environment.

Alexis Ioannidis and Konstantinos J. Chalvatzis [1] conducted research on the needs and strategies for addressing energy independence, sustainable development, and energy security on islands worldwide. They found that the growth of indigenous renewable energy sources directly contributes to energy independence, enhances sustainable development, and improves energy security. Specifically, firstly, we are examining the energy situation in the Indian Ocean Region.

(1) Mauritius: In 2015, the majority of electricity in Mauritius was generated from coal (40.0%) and diesel fuel (37.0%), with renewable energy playing a minor role. This indicates that Mauritius has not made significant progress towards its energy strategy. At the current pace, it is expected that Mauritius will not be able to achieve its energy targets for 2020 and 2025 [2].

(2) Reunion Island - France: Reunion Island boasts significant solar potential (6.5 kWh/m$^2$), contributing to 130 MW of installed solar photovoltaic capacity by 2016. Wind farms, with a combined capacity of 14.7 MW, show promise for further development. While hydropower has reduced to 1/4 of total output, biomass remains a diverse and essential energy source. To combat reliance on fossil fuels (44.5% of energy consumption), the government aims for 100% renewable energy by 2025, offering incentives like tax exemptions and subsidies [3], [4].

(3) Maldives Islands: Tourism constitutes 25% of the Maldives' GDP, with imported diesel powering the islands, including 290 MW in total diesel power generators. Despite solar panel installations, the country remains entirely reliant on oil imports for electricity [5].

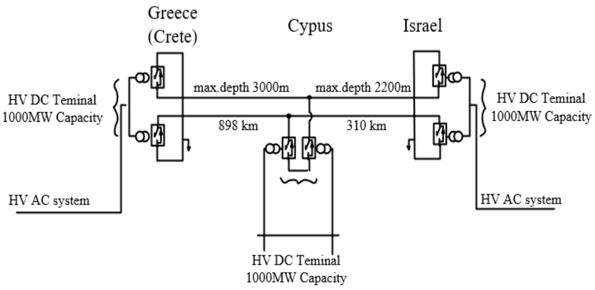


**Figure 1**. *Electrical Grid Connection Diagram between Greece, Cyprus, and Israel*

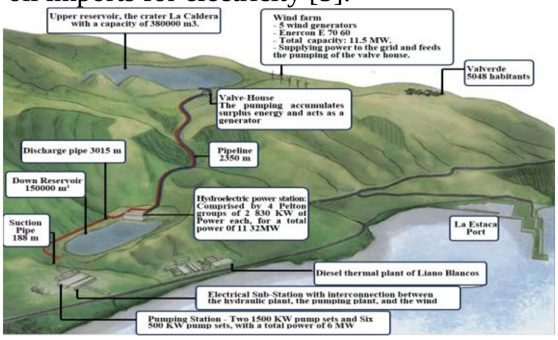


**Figure 2**. *Hydro-Wind Power System* [4]

Energy Models of Mediterranean Islands: Mediterranean islands, like Cyprus, face energy challenges, relying on the EuroAsia Interconnector, an underground DC power cable network connecting Greece, Cyprus, and Israel, with a 2,000 MW capacity, to address energy isolation and meet demand, as depicted in Figure 1 [1].

Next, the Energy Models of Atlantic Islands involve reducing reliance on fossil fuels through local renewable sources. To tackle intermittent energy challenges, smart grids are employed to monitor and manage energy supply and demand efficiently [6].

On Gran Canaria, the energy model is shifting from fossil fuels to prioritize electricity demand and renewable sources. The island aims for 100% renewable energy usage, implementing strategies across sectors like energy, heating, cooling, desalination, transportation, gas, and electricity production. Surplus energy will be used for advanced solutions like carbon capture for hydro production after meeting all electricity needs [7], [8].

El Hierro Island in Spain has transitioned from fossil fuels to renewable energy by combining hydroelectric and wind power systems (Figure 2). This system meets approximately 77% of the island's annual energy needs [4].

Vietnam has more than 3,000 islands of various sizes. Similar to many islands around the world, Vietnamese islands face a common issue of energy scarcity. Specific energy models have not been developed for Vietnam's islands. In particular, some tropical islands with relatively larger land areas, such as Phu Quoc, Phu Quy, and Con Dao, are of significant interest.

Phu Quoc, the largest island in the Gulf of Thailand, relies on the national grid and diesel backup for electricity. With plans to develop into a special economic zone, eco-tourism hub, and more by 2030, the island's population is growing rapidly, reaching an expected 177,540 people by 2023. However, the rising electricity demand poses a challenge for adequate supply (Table 1) [9].

Phu Quy Island, operating independently from the mainland, has been supplying continuous electricity since 2014. Despite the installation of wind turbines in 2012, the island's energy demand is projected to increase by 21% annually until 2030 [10]. The electricity output of Phu Quy for the period 2013-2028 is illustrated in Figure 3. The island heavily relies on diesel power generation, constituting 70% of the electricity output [11]. The current efficiency of the power system is not fully optimized.

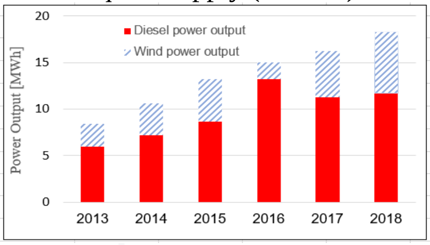


**Figure 3.** *Electricity production of Phu Quy island 2013-2018* [10]

Con Dao Island presently depends on diesel power. With an average electricity growth rate of 16% to 22% from 2015-2019, the demand is expected to peak at 27.3% in 2025.

The islands of Nam Du, An Son, and Tho Chu in Kien Giang province also rely on on-site diesel power generation. It is not feasible to extend the grid to these islands due to the long distances involved and their relatively low electricity consumption. Moreover, these islands do not currently have a specific energy model for future development.

**Table 1.** *Power demand of Phu Quoc (2018-2025) (kW)* [9]

| 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 |
|---|---|---|---|---|---|---|---|
| 64.5 | 87.0 | 117.4 | 128.6 | 140.9 | 154.5 | 169.3 | 185.5 |

**Table 2.** *Energy supply solutions for some tropical islands*

| Region | Island | Energy supply solution |
|---|---|---|
| Indian Ocean | Mauritius | There are renewable energy development policies in place, but there is no comprehensive scientific strategy. |
| | Reunion | |
| | Maldives | |
| Southeast Asia | Bali | |
| | Phuket | Using the Kommod model to determine the optimal power generation structure |
| Mediterranean | Crete | Connecting electricity using a DC electrical system. |
| | Cyprus | |
| Atlantic Ocean | Madeira | Tailoring scenarios for each energy consumption sector. |
| | Gran Canaria | |
| | El Hierro | Hydropower-wind model. |
| Vietnam's tropical islands | Phu Quoc | Supplying electricity from the mainland using an underground cable system and backup diesel generators. |
| | Con Dao | Generating electricity from diesel and solar power. |
| | Phu Quy | Generating electricity from diesel and wind power. |
| | Ly Son | Supplying electricity from the mainland using an underground cable system and diesel power generation. |

Table 2 introduces the energy supply solutions for several tropical islands. In Europe, island groups have established specific energy models to meet future development needs due to limitations in enhancing renewable energy usage. In Southeast Asia, where renewable energy potential is abundant but specific energy policies and models are lacking.

In general, global research has convincingly shown that offshore islands have implemented various innovative energy models to meet their energy needs. However, in Vietnam, especially on tropical islands, an effective energy model is still absent. This poses numerous challenges in providing reliable energy and sustainable development. Extending the electricity grid to the islands may temporarily address political security issues but requires significant investments and faces difficulties in politically unstable situations. Therefore, proposing an efficient energy model based on renewable energy, waste management, and implementing optimized technical solutions for Vietnam's tropical islands is not only necessary but also urgent.

## 2. Materials and Methods

Synthesis approach: This method is employed to gather data and disseminate information about the energy models currently being implemented on tropical islands worldwide. This method aids in addressing the energy needs of these islands based on their natural conditions. These models are synthesized from studies published in reputable scientific journals globally. The synthesis includes results from the team's previous research, disclosed at international conferences and published in reputable scientific journals during the period from 2017 to 2023. Additionally, it incorporates findings from recent research by esteemed scientists published in reputable journals.

Analysis Technique: This study analyzes previously published documents on emerging energy forms, as well as the technical solutions proposed in the author's and other reputable scientists' prior research. This helps assess the current state of the study, enabling more precise and accurate recommendations for reasonable solutions.

Data Processing methods: Employing a comparative technique and creating statistical tables for summarizing and comparing research results related to the potential of various energy forms. This includes advanced technical solutions applicable to tropical islands, contributing to the efficient utilization of energy needs for tropical islands in both the current and future periods.

## 3. Findings and discussion

The diagram illustrating the construction of the energy model for tropical islands in Vietnam is presented in Figure 4.

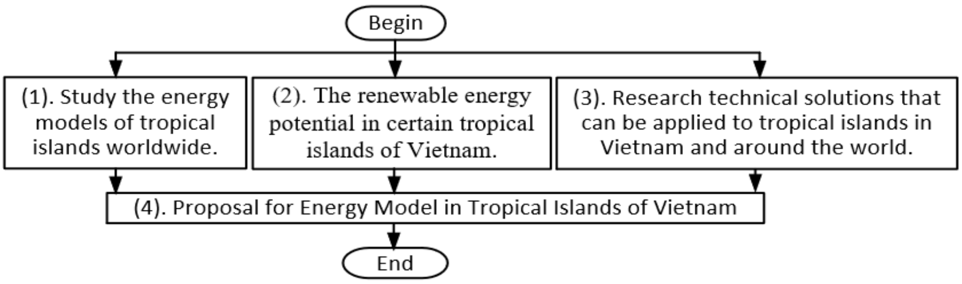


**Figure 4.** *Flowchart of the energy model research for tropical islands in Vietnam*

### *3.1. The renewable energy potential in certain tropical islands of Vietnam*

#### *3.1.1. Researching the potential for generating electricity from solid waste on islands*

To assess the possibility of generating electricity from solid waste on islands, the research team chose Phu Quoc for its accessible data infrastructure. Despite hosting diverse businesses, such as manufacturing and tourism services, Phu Quoc currently lacks a standardized waste management system, leading to environmental pollution. The prospect of generating electricity from solid waste on Phu Quoc Island is outlined in Figure 5 [12].

Harnessing energy from waste materials, specifically generating electricity from solid waste, involves tapping into the stored energy in organic matter. The research findings reveal that the potential for electricity generation from urban solid waste in Phu Quoc could reach a capacity ranging from 4.7 to 7.0 MW between 2020 and 2030. The associated electricity costs fluctuate from 6.4 to 5.4 cents/kWh between 2020 and 2030, as depicted in Figure 6 [12].

Therefore, it can be concluded that the potential for electricity generation from urban solid waste in Phu Quoc is highly feasible, and in other similar tropical islands with comparable economic conditions and population, the exploitation of electricity generation potential from solid waste is also viable.

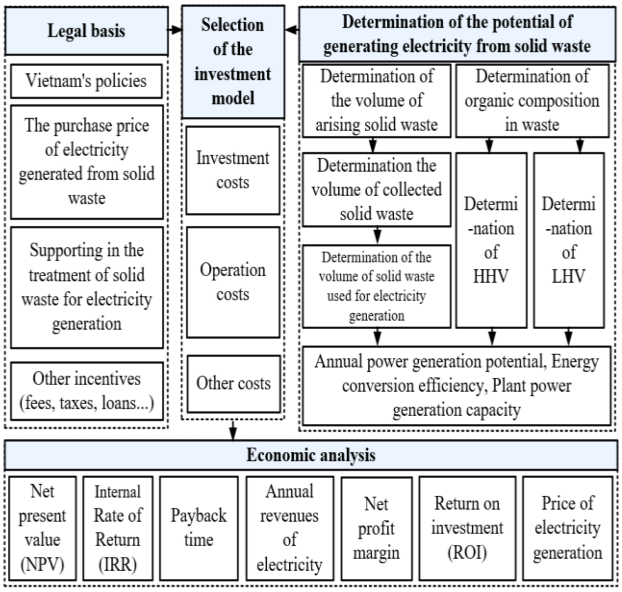


**Figure 5**. *Schematic of feasibility of producing electricity from urban waste*

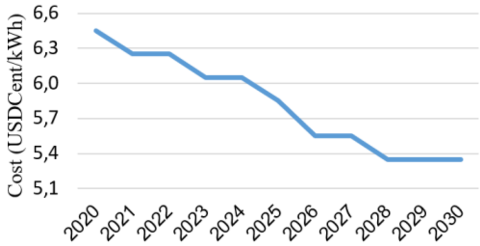


**Figure 6**. *Cost of electricity generation from solid waste [12]*

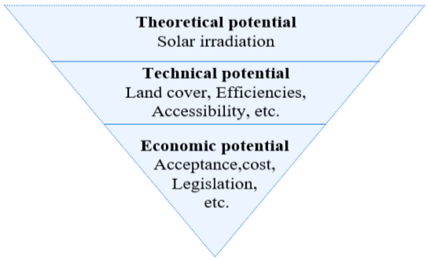


**Figure 7**. *Potential of solar energy using the top-down approach [13]*

*3.1.2. Researching the solar power potential on islands*

Similarly, for researching the solar power potential on islands, the authors selected Phu Quoc due to the advantages of available data infrastructure. The potential for solar power generation was investigated based on considerations of geographic location, solar radiation levels, land area, building structures, and more, which could be used for solar panel installation. To systematically calculate the photovoltaic potential, the research team employed a top-down approach, as illustrated in Figure 7 [13]. The theoretical solar potential was computed using mathematical function (1). The process for studying the solar power potential on the island is outlined in Figure 8, enabling the determination of total solar radiation energy and theoretical solar power generation potential within the surveyed area.

In the scope of the research, the research team utilized commonly available photovoltaic technologies in Vietnam with an efficiency of 16.30%. Subsequently, they assessed the economic and technical feasibility of solar power generation for different scales, including 5 kWp, 10 kWp, 30 kWp, 100 kWp, and 300 kWp in Phu Quoc [14]. The research team also proposed three solar power development scenarios, namely Scenario (1) - Low-level solar power development, Scenario (2) - Moderate-level solar power development, and Scenario (3) - High-level solar power development for Phu Quoc. These scenarios were aligned with the government's Phu Quoc development plan until 2030, and the results are presented in Table 3.

**Table 3.** *Scenarios - PV development at three levels* [14]

| Types of land use | Percentage of PV installation (%) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 kWp | | | 10 kWp | | | 30 kWp | | | 100 kWp | | | 300 kWp | | |
| | *(1)* | *(2)* | *(3)* | *(1)* | *(2)* | *(3)* | *(1)* | *(2)* | *(3)* | *(1)* | *(2)* | *(3)* | *(1)* | *(2)* | *(3)* |
| Urban construction | 15 | 10 | 20 | 5 | 10 | 20 | 5 | 10 | 20 | - | - | - | - | - | 20 |
| Eco-tourism | 5 | 15 | 25 | 5 | 15 | 25 | - | - | - | - | - | - | - | - | - |
| Mixed tourist | - | - | - | 5 | 15 | 20 | 5 | 15 | 20 | 5 | 10 | 20 | 5 | 10 | - |
| Tourist complexes | 5 | 10 | 10 | 5 | 5 | 10 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 15 |
| Cottage industries | - | - | - | 5 | 15 | 30 | 10 | 15 | 25 | 5 | 10 | 20 | - | - | - |
| Historical culture | - | - | - | 5 | 15 | 30 | 5 | 5 | 25 | 5 | 5 | 15 | 5 | 5 | - |
| Trees landscape | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 50 |
| Theme park | 5 | 10 | 25 | 5 | 10 | 25 | - | - | - | - | - | - | - | - | 25 |
| Airport land, seaport | - | - | - | - | - | - | 20 | 20 | 25 | 20 | 20 | 25 | 20 | 20 | - |
| Wastewater, waste treatment | - | - | - | - | - | - | 10 | 10 | 25 | 10 | 10 | 25 | 10 | 10 | - |
| Power plant, water plant | - | - | - | - | - | - | 10 | 10 | 25 | 10 | 10 | 25 | 10 | 10 | - |
| Rural villages | 5 | 10 | 10 | 5 | 10 | 10 | - | - | - | - | - | - | - | - | 10 |

*Remarks: (1) low level (Scenario 1), (2) medium level (Scenario 2) and (3) high level (Scenario 3)*

**Table 4.** *Results of PV potential feasibility for Phu Quoc regarding to 2030* [14]

| | **Scenario 1** | **Scenario 2** | **Scenario 3** |
|---|---|---|---|
| The total capacity of PV generating of Phu Quoc (MWp) | 606 | 920 | 1,550 |
| The potential of capacity solar power generation at Phu Quoc (MWh/y) | 229,174 | 347,716 | 585,719 |
| The feasibility of reducing $CO_2$ emission (ton $CO_2$/year) | 107,826 | 163,600 | 275,581 |

The results of the assessment of the feasible solar power potential for Phu Quoc until 2030 are illustrated in Table 4, indicating that Scenario (2) with a moderate-level solar power development is the most feasible. Phu Quoc could potentially develop 920 MWp, generating 347,716 MWh per year.

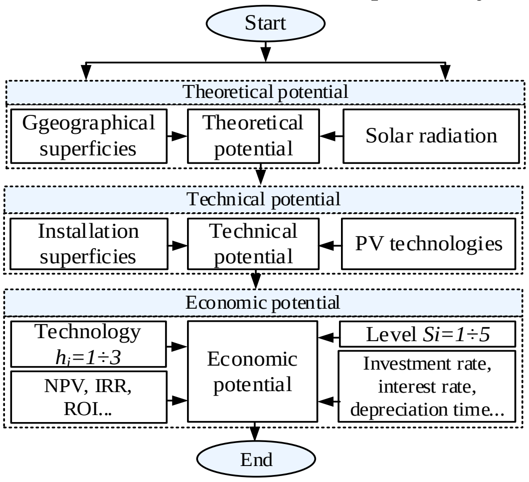


**Figure 8**. *Feasibility flowchart dedicated to calculating PV potential* [14]

**Table 5.** *Wind speed and average monthly power generation of Phu Quy wind power plant* [10]

| | **6/2018** | **8/2018** | **9/2018** |
|---|---|---|---|
| $V_{win}$ [m/s] | 9,6 - 11,5 | 11,4 - 12,3 | 8,6 - 10,1 |
| $P_{win}$ [kW] | 370 - 664 | 668 - 787 | 395 - 452 |

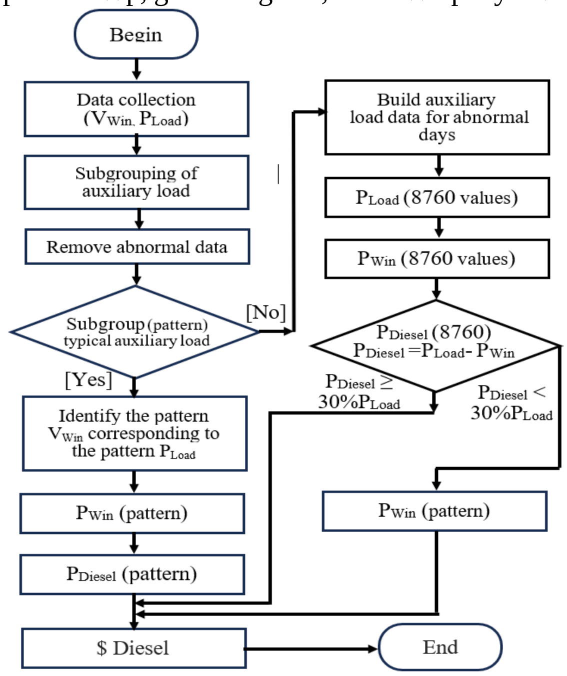


**Figure 9**. *Algorithm flowchart for diesel-wind power system operation* [10]

*3.1.3. Wind power on the islands*

To study wind power on the islands, the research group selected Phu Quy Island, which enjoys a relatively mild monsoon climate year-round, with an average wind speed exceeding 9 m/s. Notably, during the months of July, August, October, and December, wind speeds can reach over 11 m/s [10]. In addition to its temperate climate, Phu Quy Island also boasts abundant wind and solar resources. Since 2015, the island has been equipped with a 5 MW diesel power source and three wind turbines, providing a total capacity of 6 MW [10]. In 2018, the island's electricity demand fluctuated between $P_{min}$ = 1,450 kW and $P_{max}$ = 3,445 kW. The maximum power demand for Phu Quy Island in 2018 was $P_{max}$ = 3,445 kW, and the minimum was $P_{min}$ = 1,450 kW. The island's electricity production from 2013 to 2018 is depicted in Figure 3, showing an annual growth rate of approximately 17%. Among these, electricity was generated from two sources: diesel and wind, with shares of 70% and 30%, respectively [11]. It is projected that electricity demand will increase by about 21% annually until 2030 [10].

After investigating the wind power output on Phu Quy Island, it was observed that the actual electricity generated from wind power was significantly lower than the expected values based on wind speed data. This is specifically presented in Table 5. This suggests that the wind power generation system is currently operating inefficiently from an economic perspective.

In a study on a novel operational method to enhance the economic efficiency of the diesel-wind power system on Phu Quy Island while adhering to operational and grid stability constraints, the focus was on reducing diesel costs by maximizing wind power utilization. The research addressed the optimization problem of an independent power system using both diesel and wind sources, building upon prior research [15] - [19]. However, domestic studies had yet to tackle the issue of load demand over 8760 hours and inconsistent power generation data.

The paper proposed an algorithmic flowchart (Figure 9) to optimize the operation of this system. The operational scheme was constructed based on load demand categorization and wind speed through the Kmax - Kmin algorithm, utilizing Lindo software [20]. In cases of data deficiency or noise, the algorithm approximated calculations based on simulated load data and power generation characteristics from wind turbines and diesel sources.

The research results revealed that when operated under the new approach, wind power generation increased by 81.69% compared to actual figures, constituting 59.97% of the total power output of the electrical system on Phu Quy Island. Correspondingly, the monthly diesel power generation, when operated using the new method, decreased by 31.23% compared to actual values, accounting for 40.03% of the total power output of the electrical system on Phu Quy Island.

Based on the results above, it is evident that wind power on islands holds significant potential. However, at present, it is either underutilized or, when in operation, not yet efficient. Continuing research and proposing energy models to meet the energy development needs of islands are essential.

***3.2. Technical solutions for optimizing energy usage on islands***

*3.2.1. Energy-efficient lighting design for buildings*

In the study titled "A new approach in daylighting design for buildings," the research team proposes a novel integrated simulation-design process based on the requirements of current regulations and standards, making use of building design and simulation software [21]. The feasibility of this new design process is demonstrated through exemplary application studies. The content of each element within the proposed process is presented concisely and comprehensively, with the most crucial details provided along with specific instructions, as the research has indicated:

(1) Concerning daylighting design for areas adjacent to the building envelope: Utilize design techniques to harness natural light effectively; Employ low-emissivity glass to reduce radiant heat; Implement mobile shading systems and solutions to direct light into the building; Avoid using dark colors on wall, ceiling, and floor surfaces [21].

(2) Regarding daylighting design for core areas inside the building: Utilize skylights and sloped windows to maximize natural light; Incorporate reflective roofs to minimize direct heat gain; Select suitable window placements to optimize natural light; Utilize shading solutions to adjust light intensity [21].

(3) Concerning material selection: Choose light-transmitting materials and appropriate glass to make the most of natural light; Consider material properties such as overall heat transfer coefficient, visible light transmittance, and solar heat gain coefficient [21].

(4) For shading and exterior view design: Implement shading solutions to protect the building from direct sunlight and regulate light direction; Evaluate the intended use of shading solutions and ensure suitable exterior views [21].

(5) In terms of assessing compliance with design standards: Select materials and windows that adhere to energy-saving standards and conduct checks to confirm compliance.

Simulation results have demonstrated that the proposed method can accurately quantify the effectiveness of reducing energy consumption for lighting systems within buildings by up to 34%, equivalent to savings of over 4,000 tons of $CO_2$ emissions annually. With daylighting design, the initial investment increases by approximately 7% of the total initial capital, but it yields substantial returns in the long run [21].

*3.2.2. Introducing a study on electric vehicles as alternatives to diesel cars in island settings*

The research focuses on the potential for reducing $CO_2$ emissions by integrating electric vehicles as replacements for conventional fuel vehicles, contributing to the achievement of sustainable development goals in Phu Quoc. The author proposes multiple electric vehicle penetration scenarios and identifies the potential for $CO_2$ emissions reduction by 2030. Additionally, the study suggests policy frameworks and recommendations to facilitate the prompt implementation of research outcomes in Phu Quoc. The research diagram on the $CO_2$ reduction potential of electric vehicles is depicted in Figure 10. [22].

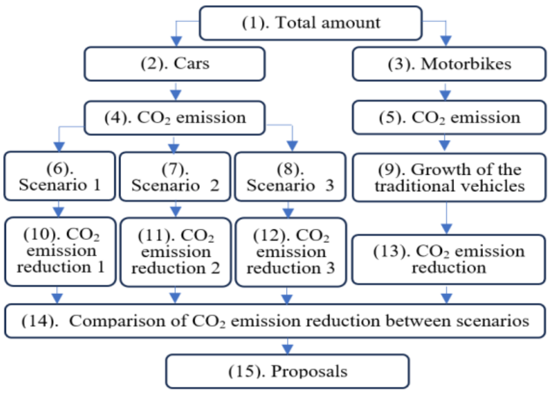


**Figure 10**. *Flowchart of research on the potential to reduce $CO_2$ of the electric vehicles* [22]

With a projection to 2030, the emissions from fossil fuel-powered vehicles are estimated at approximately 79,901 tons. By means of the proposed policy frameworks for electric vehicle development, the projected $CO_2$ emissions are expected to decrease by 17-20%. The research results also demonstrate that the adoption of electric vehicles to replace traditional fuel vehicles in Phu Quoc is not only necessary and feasible for reducing $CO_2$ emissions but also contributes to transforming the locality into a green international tourism destination [22].

### *3.3. Proposal for energy model in tropical islands of Vietnam and discussion*

*3.3.1. Proposal for energy model in tropical Islands of Vietnam*

The energy model for Vietnam's tropical islands is proposed as shown in Figure 11.

*3.3.2. Model explanation*

(1) To construct and foster a sustainable economic framework aimed at low carbon emissions for tropical islands, the pivotal aspect lies in the timely and judicious implementation of governmental policies. This policy package comprises two primary categories: (1) Impeding measures targeting sectors/entities utilizing inefficient/unclean energy sources; (2) Facilitating measures to support sectors/entities employing efficient/clean energy sources. Commonly employed instruments include policies pertaining to land use, taxes/fees, technical/environmental standards, advocacy campaigns, establishment of pilot models...

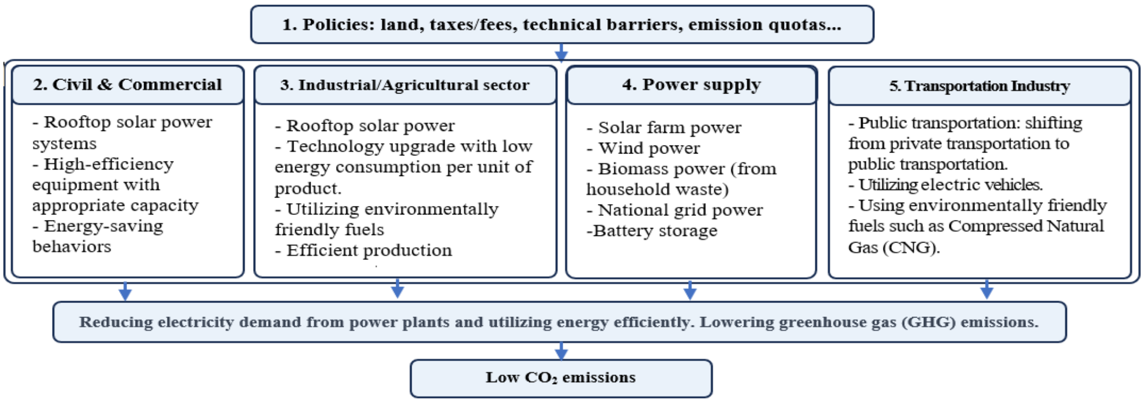


**Figure 11**. *Energy model for tropical islands in Vietnam*

(2) Solutions for Reducing $CO_2$ Emissions in the Commercial and Residential Sectors: (a) Solar Rooftop Power: The island's equatorial location offers ample potential for solar energy, particularly in residential and commercial areas, similar to islands like Reunion and Gran Canaria. Implementing solar power is both feasible and effective in reducing $CO_2$ emissions. (b) High-Efficiency Energy-Saving Equipment: Enhancing electricity usage efficiency requires plans for energy reduction in buildings, hotels, airports, and large facilities. Implementing energy-saving technologies contributes to energy security, reduced fuel consumption, and improved quality of life. Consideration should be given to adopting Energy-Efficient Lighting Design for Buildings. (c) Energy-Saving Behavior: Significant in achieving electricity usage efficiency goals, it involves community awareness, establishing rules, and providing training on energy-saving practices for household appliances like refrigerators, air conditioners, and lighting systems.

(3) Industrial and Agricultural Sectors: (a) Solar Roof Energy: Beyond residential and commercial use, solar roof energy can also cut $CO_2$ emissions in the industrial and agricultural sectors, following successful models in places like Reunion, Madeira, and Gran Canaria. (b) Product-Specific Energy Efficiency: In tourist and small islands, the industrial sector's energy consumption is limited, but outdated machinery leads to energy wastage. Urgent measures are needed to enhance energy efficiency in each product. (c) Environmentally Friendly Fuels: The agricultural sector can adopt eco-friendly fuels like biogas and biochar to reduce emissions and replace firewood, contributing to environmental cleanliness and groundwater protection. (d) Production Management Improvement: Enhancing production management is crucial for optimizing resources, reducing waste, and minimizing environmental impacts, including $CO_2$ emissions. This involves sustainable technologies, process improvement, and the promotion of renewable energy sources.

(4) Electricity Industry: The electricity industry will attempt to control electricity on the islands through four approaches: connecting to the national grid, on-site power generation, renewable energy production, and energy storage. Most islands in Vietnam use on-site diesel power generation, which has been in use for many years and is outdated. Connecting to the national grid is not widely used on islands worldwide because of the significant initial investment cost and the risk of damage in times of political instability. Nevertheless, renewable energy is prioritized for low-carbon economic development, and energy storage can improve the reliability of the electricity system. To develop a sustainable economy, enhancing renewable energy production while maintaining electricity grid connections is crucial. This approach ensures system stability and continuity on the islands.

*(a)* Solar Farms: We can learn from places like Reunion, Madeira, Gran Canaria, etc., in promoting the strong development of solar farm electricity, similar to Vietnam's solar development phase from 2017 to 2020. This contributes to the supply of green energy and reduces $CO_2$ emissions on the islands.

*(b)* Wind Energy: As assessed in the Wind Power on the Islands section and various studies in Reunion, El Hierro, Gran Canaria, etc., wind energy on islands is abundant and has significant potential for electricity generation, making a substantial contribution to island energy supply.

*(c)* Biogas from Domestic Waste: Biogas from domestic waste has considerable potential as a renewable energy source on islands, as indicated by the research on generating electricity from solid waste on islands. Biogas has untapped potential and plays a crucial role in environmental protection and energy development on islands.

*(d)* Grid Connection: Similar to the Electricity Industry section, grid connection is important if islands can secure reliable electricity power. Unless there are unusual political fluctuations, a dependable electricity grid connection ensures power reliability.

*(e)* Battery Storage: Battery storage is becoming increasingly necessary to ensure a stable power supply when combining various energy sources such as solar and wind energy. Battery storage contributes to stable power supplies, ensuring electricity during the night or adverse weather conditions, reducing intermittency, and improving reliability.

(5) Transportation industry: Various sectors emit $CO_2$ into the atmosphere, with the transportation sector accounting for 23% of the total global carbon emissions [23].

*(a)* Public Transportation: Shifting from personal vehicles to public transportation is a solution to reduce energy consumption and greenhouse gas emissions. Specifically, developing urban rail systems, expanding electric vehicle networks, introducing electric tramways, and improving bus routes will bring significant benefits such as increased transport capacity and reduced greenhouse gas emissions.

*(b)* Using Electric Vehicles to Reduce $CO_2$ Emissions and Fossil Fuel Dependency: Promoting electric vehicles (EVs) can reduce $CO_2$ emissions and dependence on fossil fuels. Factors such as population size, GDP growth rate, and vehicle growth rate need to be considered. Using IEA EV penetration scenarios and policy frameworks, tropical islands can predict their potential $CO_2$ reductions compared to conventional transportation methods.

*(c)* Using Environmentally Friendly Fuels: after applying the above measures, the remaining vehicles still using fossil fuels should be encouraged to switch to using bioethanol gasoline. Bioethanol gasoline is produced by blending bioethanol with regular gasoline in a certain ratio, for example, E5 gasoline contains 5% ethanol and 95% regular gasoline. This type of ethanol is produced from sugarcane, cassava, wheat, agricultural waste, etc., which are renewable resources. Substituting regular gasoline with biofuels will reduce the consumption of fossil fuels. Moreover, using agricultural waste to produce ethanol contributes to efficient use and reduces agricultural waste.

## 4. Conclusion

The research findings indicate that the potential for renewable energy sources such as solar, wind, and biomass can be feasibly tapped into in Vietnam's tropical islands. Vietnam's islands can integrate these renewable energy sources by implementing specific technical solutions, such as introducing electric vehicles on the islands and adopting energy-saving measures, notably energy-efficient lighting design for island buildings. Based on this information, the islands can operate the proposed energy model developed by the authors. The proposed low $CO_2$ emission energy usage model for tropical islands can be implemented across five key areas: (1) Policy: Implementing policies that support energy efficiency and emission reduction. (2) Energy-saving and Emission Reduction Solutions for Civil and Industrial Sectors: This includes research on solar applications for rooftops, the use of high-performance devices, and energy-saving initiatives. (3) Industry and Agriculture: Researching the application of solar panels, exploring changes in technology, and efficient production management. (4) Electricity Sector: Suggesting the consideration of solar power for farm applications, integrating wind power sensibly, and combining biomass power generation. The final factor is energy storage batteries, suitable for the increasing trend of storage capacity and decreasing costs. (5) Transportation: Proposing a model to maximize the benefits of public transportation, gradually transitioning from private to public transportation, and incorporating electric vehicles. Particularly, emphasizing the rapid adoption and application of smart vehicles and exploring the use of environmentally friendly fuels. In conclusion, on-site energy potential is viable, technical solutions are reasonable, and the proposed energy-efficient model with low $CO_2$ emissions can be effectively applied to Vietnam's tropical islands. Furthermore, this model may be applicable to other islands worldwide with similar conditions.

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