Analysis of Rooftop Solar Power Development in Northwest Vietnam using the Analytic Hierarchy Process

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ABSTRACT

Traditional energy sources are gradually being exhausted, which causes many negative effects on the environment and contributes to the climate change. Countries around the world, including Vietnam, are focusing on developing renewable energy sources, such as solar power, to combat climate change and create a foundation for sustainable development. The development of solar power, particularly rooftop solar power, is being encouraged in various provinces and cities in Vietnam. The Northwest is a mountainous region in the Northern part of Vietnam with considerable solar energy potential. However, developing rooftop solar power projects requires balancing economic, technical, and environmental goals. Currently, there is no comprehensive research in Vietnam that fully evaluates the sustainable development goals for rooftop solar power in the Northwest region. This paper focuses on identifying the factors that influence the decision to install and use rooftop solar power in the Northwest region of Vietnam with the support of the Analytic Hierarchy Process (AHP) method and Expert Choice software. This impact ranges

to varying degrees. The most significant influencing factor is the solar energy development policy, with a priority of 36.1%, while the social factor has the lowest priority value of 7.7%. The primary factor affecting people's decisions is the future solar power development policy, with a weight value of 24.2.

Keywords-rooftop solar power; policy factor; AHP; expert choice

I. INTRODUCTION

Currently, solar power capacity is increasing in power systems [1, 2] with the reduction of investment costs [3] in countries around the world. Rooftop solar power [4, 5] is also expected to grow faster due to higher retail electricity prices and increasing policy support to help consumers save money on energy bills. The transition to solar energy systems has a huge social impact globally [6, 7]. Factors for evaluating the possibility of solar power development have been researched. For example, authors in [8] used Geographic Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) solutions to assess the potential of solar power in China. Authors in [9] evaluated the factors that affect the use of solar power in Turkey deploying the analytical hierarchy process (AHP) and F-VIKOR methods. In [10], GIS was utilized along with Fuzzy Logic and AHP techniques to assess the location priority of solar power plants in Khuzestan province in Iran. Authors in [11] evaluated obstacles in the process of developing commercial and industrial rooftop solar power in India adopting the fuzzy AHP method. Therefore, quantitative analysis methods, such as the AHP, were employed to analyze and select options. The advantage of this method is that the experts' interviews can replace the need for large amounts of data, without requiring extensive numerical data. This makes AHP quite suitable for choosing the means of implementing investment projects, which is considered a complex task due to the difficulty in quantifying the aspects that need to be evaluated, especially when related to risk before deciding to invest.

The economy of Vietnam is developing rapidly, and the energy demand is increasing [12]. Solar power can meet part of the energy demand in a sustainable and environmentally friendly way [13]. In 2021, Vietnam installed a total solar power capacity of about 16.4 GW and a wind power capacity of 11.8 GW. Consequently, Vietnam has been listed among the top 10 countries with solar power installation capacity in the world [14]. Until now, Vietnam has mainly installed grid-tied rooftop solar power stations [15, 16]. However, the old support policy for solar power was stopped [17, 18], whereas the new support policy has not been issued yet. So electricity supplied from rooftop solar power stations cannot be accepted into the power grid. Therefore, the rooftop solar power market in Vietnam is facing many difficulties, even though areas with high energy demand need more clean power sources. Vietnam has also conducted several studies on factors that affect the development of rooftop solar power. In [19], the factors that positively impact the investment in rooftop solar power systems in the Hanoi city area were studied. Authors in [20] identified weaknesses in existing solar power support policies and proposed possible solutions to maximize the economic benefits of solar energy development. Authors in [21] determined the factors affecting the customers' decisions to install rooftop solar power in Binh Thuan province, Vietnam. The Northwest is a mountainous region in Northern Vietnam with considerable solar energy potential. However, the obstacles and factors preventing the development of solar power in this area have not been determined. Developing rooftop solar power projects can only be sustainable if they simultaneously ensure economic, technical, and environmental goals. Currently, Vietnam lacks comprehensive research to fully evaluate these sustainable goals for the development of rooftop solar power in the Northwest region. Therefore, the criteria and analysis of both qualitative and quantitative factors can be considered using the AHP method. This method will help select the best sustainable development plan that satisfies these criteria.

This work focuses on researching and identifying the factors that influence the decision to install and use rooftop solar power in the Northwest region of Vietnam, supported by the AHP method and Expert Choice software. Thus, the main factors that determine the feasibility of installing rooftop solar power systems are determined and solutions are provided for improving solar energy sources in the Northwest region.

II. METHODOLOGY

AHP is considered one of the most widely utilized MCDM methods and is the preferred approach for researchers in complex decision making [22]. The purpose of AHP is to analyze complex situations and support professionals in their efforts to make the best decisions based on their established priorities. AHP helps to manage data consistency and identify inconsistencies. Inconsistent data lead to erroneous and invalid conclusions. Applications of AHP can be found in many decision-making studies in many different fields [23], including the energy sector [24, 25].

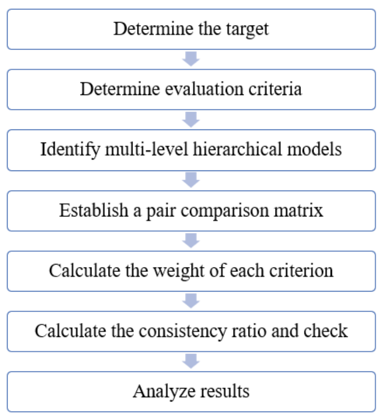

Fig. 1. Methodology process.

The research methodology followed in this work is presented in Figure 1. This study aims to identify specific sub-indicators for each main natural, technical, economic, social, and policy indicator. Comparisons, including quantitative calculations, are then conducted to choose options using the AHP method and Expert Choice software.

A. The AHP Method

The hierarchical structure diagram of the AHP method is described in Figure 2. The AHP is implemented based on the following principles [26]:

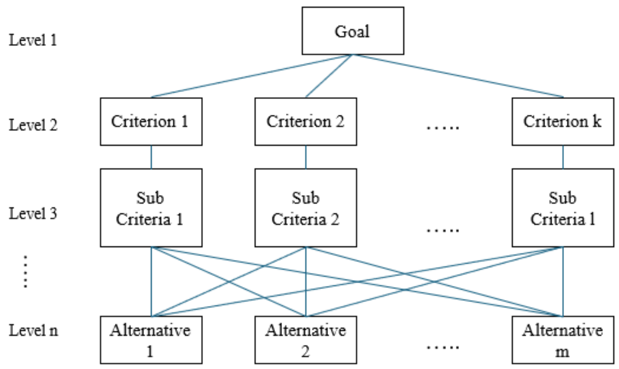

Fig. 2. Hierarchical structure diagram.

- Analytical principles: Identify goals, criteria, options, and other components related to the problem of making decisions. After that, arrange them in a hierarchical structure.
- Comparison principle: Determine the relative importance of the main criteria, sub-criteria, and options by pairwise comparison. The level of importance in pairwise comparisons is expressed by a single number between 1 and 9. The meaning of each number is depicted in Table I. Assess the level of importance in pairwise comparisons according to the AHP method.
- Synthesis principle: is the process of calculating priority from pairwise comparison matrices, specifically: Based on the pairwise comparison matrix, calculate the priority vector for the main criteria, sub-criteria, and options. Summarize the priorities of each option to obtain the result as the weight of the options.
- Principles for measuring inconsistency: When determining each priority vector of criteria and options, it is necessary to determine the consistency ratio. For example, option A may be better than option B, and B may be better than C, but A is not always better than C. This phenomenon is called inconsistency. The level of inconsistency of the statements is expressed by the Consistency Ratio (CR) with the following hypotheses:

  If CR < 10%, then weight calculation results are acceptable.

  If CR > 10%, then the results need to be reevaluated from previous steps.

  The CR is calculated according to:

$$CR = CI/RI \quad (1)$$

where CI is the consistency index which measures the degree of consistency deviation, calculated by the formula:

$$CI = \frac{\lambda max - n}{n-1} \quad (2)$$

in which: λmax is the average value of the consistency vector and n is the criterion. RI is the random index, which is the average value of CI. The RI value varies according to the number of criteria.

TABLE I. PRIORITY ASSESSMENT SCOREBOARD.

Numeric value	Priority
1	Equal priority
2	Equal to moderate priority
3	Moderate priority
4	Moderate to Moderate priority
5	Slightly more priority
6	Slight priority to high priority
7	High priority
8	High priority to extremely prioritiorized
9	Extremely prioritized

B. The Main Factors Affecting the Decision to Install Rooftop Solar Power in the Northwest Region

In this paper, the main factors affecting the decision to install rooftop solar power in the Northwest region are:

Natural factors:

- Geography, land, weather.

Theoretical potential of solar power.

Economic factors:

- Economic characteristics and income of people.
- Power consumption demand.

Technical factors:

- Efficiency of electricity saving due to solar power usage.
- Quality of solar panels.

Social factors:

- People's awareness of renewable energy.
- Energy saving behavior combined with rooftop solar power.

Policy factors:

- The solar power development policy of the government from past to present.
- Future solar power development policy.

C. Structure of the AHP Method Model

The AHP multilevel factor system evaluation method was used to conduct calculations and evaluate factors affecting the decision to install and use rooftop solar power in the Northwest region. The structure of the AHP method model and the included levels are shown in Figure 3.

D. Data Analysis

Questionnaires were developed to interview experts for comparing factors following the AHP method. Data were collected from the questionnaires, with a total of 18 questionnaires distributed. Data analysis was conducted implementing the specialized Expert Choice software. This software facilitates the construction of an evaluation factor system, and the data analysis process to determine weights representing the importance of factors, and also enables the determination of an index to assess consistency in evaluations provided by experts. The software's outcome will prioritize the main influencing factors for selection.

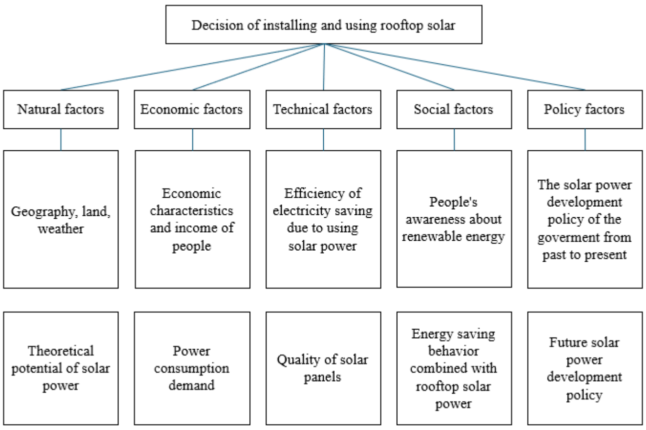

Fig. 3. Structure of the AHP method model.

III. THE SOLAR POWER POTENTIAL OF THE NORTHWEST REGION OF VIETNAM

The area of study was the western mountainous region of Northern Vietnam, which shares borders with Laos and China. Currently, there are six provinces in the Northwest region which are: Hoa Binh, Lao Cai, Son La, Dien Bien, Lai Chau, and Yen Bai [27]. The solar power potential of the Northwest region was assessed using the online solar radiation data source "Global Solar Atlas" [28], as illustrated in Table II. Table II demonstrates that the Dien Bien province has the best solar power potential of 2.95 kWh/kWp/day to 3.59 kWh/kWp/day, whereas the solar power potential in Lao Cai province is the lowest with values from 2.5 kWh/kWp/day to 3.13 kWh/kWp/day.

TABLE II. THE SOLAR POWER POTENTIAL OF THE NORTHWEST REGION TAKEN FROM [28]

Province	Parameter		
	PV_{OUT} (kWh/kWp)	DNI (kWh/m^2)	GHI (kWh/m^2)
Lao Cai	2.50 – 3.13	1.28 – 2.05	3.06 – 3.74
Yen Bai	2.48 – 3.35	1.20 – 2.32	3.04 – 3.91
Dien Bien	2.95 – 3.59	1.90 – 2.72	3.59 – 4.26
Lai Chau	2.66 – 3.49	1.50 – 2.58	3.14 – 4.11
Son La	2.82 – 3.48	1.68 -2.49	3.40 – 4.17
Hoa Binh	2.82 – 3.20	1.70 – 2.11	3.49 – 3.84

IV. RESULTS AND DISCUSSION

A. Results

The Expert Choice software has indicated a consistency ratio of CR = 0.01 (<10%), which is deemed suitable to proceed with calculating weights and evaluating influencing factors. This ratio also reflects the consistency in assessing the data provided by experts who completed the survey. According to the research findings presented in Table III, social factors exhibit the least influence on the decision to install and use rooftop solar power, accounting for only 7.7% (with a weight value of 0.077) compared to the other factors. Natural factors rank second in priority level, representing 27% (corresponding to a weight value of 0.270), while economic factors and technical factors hold almost equal priority levels at 14.8% and 14.4%, respectively (weighted values of 0.148 and 0.144). Lastly, the factor exerting the greatest influence on the decision is the policy factor, with a priority of up to 36.1% (weight value of 0.361). The study results in the prioritization of factors, as evidenced in Figure 4. It is highlighted that the primary factor influencing people's decisions is the policy factor, particularly addressing to the future solar power development policy, with a weight value of 24.2. Establishing policies that align with the economic and social conditions of the population in the Northwest region will undoubtedly enhance the efficiency of utilizing rooftop solar power.

TABLE III. RESULTS OF PRIORITY ORDER OF FACTORS

Priority order	Factor	Priority level (%)
1	Policy	36.1
2	Natural	27
3	Economic	14.8
4	Technology	14.4
5	Social	7.7

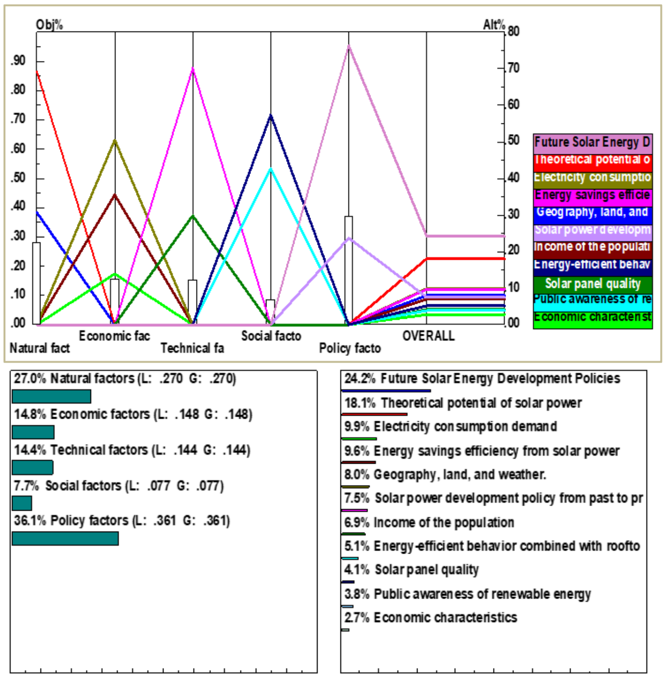

Fig. 4. Results of prioritization of factors.

B. Discussion

Firstly, social factors encompass people's awareness of renewable energy with a weighted value of 0.426, and the behavior of using energy-saving methods combined with rooftop solar power is 0.574. Improving people's awareness of renewable energy will likely lead to increased adoption of energy-saving behaviors, thereby influencing their decision to install and use solar power. However, other factors may not have as significant an impact on the decision, as there may be instances where households are aware of energy-saving practices but lack the financial resources to install solar power systems.

Secondly, technical factors encompass electricity-saving efficiency due to using solar power with a weight value of 0.702, and solar panel quality with a weight value of 0.298. The factor of electricity-saving efficiency due to utilizing solar power is rated higher than the remaining ones. This suggests that higher efficiency in electricity savings can increase households' willingness to invest in rooftop solar power. Additionally, the quality of solar panels plays a crucial role due to environmental concerns associated with expired panels. Therefore, local authorities, along with cultural, educational, and media institutions, should initiate awareness and educational campaigns within schools and communities to enhance understanding and awareness of environmental issues. Furthermore, manufacturers and suppliers of solar power systems should focus on developing products that are user-friendly and emphasize the benefits of contributing to environmental preservation.

Thirdly, economic factors include electricity consumption demand with a weight value of 0.505, people's income with a weight value of 0.355, and economic characteristics with a weight value of 0.139. The demand for electricity consumption significantly influences households' capacity to adopt solar power. In recent years, there has been a notable increase in people's demand for electricity consumption, largely attributed to enhancements in income levels. The government has consistently allocated substantial resources to invest in building and upgrading electricity systems in rural areas. This investment has facilitated changes in farming practices and scale, increased productivity, and contributed to poverty reduction and rural development initiatives.

Fourthly, the natural factor is the second priority, accounting for 27% (wherein geographical factors, land, and weather have a weight value of 0.307, while theoretical solar power potential is 0.693). The Northwest region has a significant theoretical solar power potential. However, its complex geological structure, characterized by massive high mountains and vast plateaus, poses challenges. It is the most rugged terrain in the country, strongly fragmented, with most areas having altitudes of less than 1000 m, while many mountain peaks exceed 2000 m. Consequently, installing and utilizing rooftop solar power in this region encounters several difficulties.

Another challenge influencing people's installation decisions in the area is the climatic conditions, characterized by a tropical monsoon climate in high mountains, similar to other provinces in the Northern mountainous region of Vietnam. The winters are relatively warm compared to the Northeast region, featuring two distinct seasons: a dry season from November to March of the following year and a rainy season from April to October. The most favorable period for solar energy exploitation in the Northwest region is from March to September, while solar energy efficiency is significantly lower during winter months. Generally, natural factors are immutable. However, technology advancements in solar panels can be tailored to suit the natural and climatic conditions in the area. Solar power stations in the Northwest region have largely utilized crystalline silicon solar panels due to their high performance and widespread availability on the market. Crystalline silicon technology, though, remains relatively expensive, and its effectiveness in real-world conditions in the area diminishes during unfavorable weather. Therefore, businesses operating in the solar panel industry should continue to develop technologies that are better suited to the natural conditions prevailing in the Northwest region.

Finally, policy factors are the ones occupying the top priority position, with the solar power development policy carrying a weight value of 0.237, and the future solar power development policy with a weight value of 0.763. It is evident that government support policies, including Feed-in Tariff (FIT) pricing in the past, have received significant attention and exerted a primary influence on decisions. However, a limitation of these policies is that the fixed FIT is insufficient to incentivize regions with lower solar potential, such as provinces in the North, which has led to imbalanced development across regions. While the South and Central regions have experienced excessive development, resulting in grid overloads, the North region has progressed more slowly and faced electricity shortages. The major policy barrier lies in the absence of national planning for solar energy. Moreover, economic conditions and per capita income in provinces and cities in the Northwest region still represent a small proportion. Thus, implementing policies to support electricity prices would encourage greater adoption of rooftop solar power. Consequently, households are keenly interested in the government's future solar power development policy, which is considered the primary influencing factor on household decisions.

In the future, the government aims to adopt the development of self-produced rooftop solar power, particularly in regions susceptible to electricity shortages, such as the Northern region of Vietnam. By 2030, priority will be given to implementing pioneering policies to promote solar energy development on household and commercial rooftops. To achieve this, future price policies must evolve towards harmonization, encompassing all facets of solar power production based on capacity. This entails adjusting the electricity purchase price mechanism to accommodate fluctuations in production input costs, amidst risks associated with sharp increases in raw material prices, inflation, and global commodity price hikes. Furthermore, pricing policies should encompass various capacity segments and solar power sources, thereby enhancing households' capacity to adopt solar power in the Northwest region.

V. CONCLUSION

This work investigated the factors affecting individuals' decisions to adopt rooftop solar power in the Northwest region of Vietnam, by using the Analytic Hierarchy Process (AHP) method and Expert Choice software. These factors exert varying degrees of influence on rooftop solar power development across Northwest provinces. Notably, solar energy development policy emerges as the predominant factor, commanding a priority value of 36.1%, while social factors carry the least weight at 7.7%. The future solar power development policy, with a weight value of 24.2%, stands out as the primary factor affecting the decision of installing rooftop solar panels.

Overcoming the constraints posed by outdated development policies and addressing other influencing factors can catalyze increased rooftop solar power installations in the region. Such advancements in rooftop solar power can usher in economic and social benefits while harnessing the Northwest region's renewable energy potential.

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