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Finding The Best Method For Solar Panel Recycling Based On The Analytical Hierarchy Process (AHP) In Vietnam

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ABSTRACT

Along with the development of the world economy, renewable energy has become a n indispensable part. Currently in Vietnam there are many companies producing renewable energy, especially solar energy, showing the dynamism of the solar panel manufacturing market. But there is a problem: if the panels expire after their useful life, if not recycled, they will cause waste and seriously affect the environment. Recycling technologies will help take advantage of important components in solar panels, even using them entirely. Precious metals such as Silver and Lead are separated and reused to help save resources and capital costs. There are 4 ways to recycle solar panels: Mechanical, Thermal, Chemical, High Temperature Density Seperation. Research applying the Analytical Hierarchy Process method to select the best option to recycle solar panels for companies in Vietnam, which is High Temperature Density Seperation.

Key words: Solar Energy, Solar panel recycling, Analytical Hierarchy Process (AHP)

I. Introduction

Nowaday, in Vietnam, renewable energy sources are strongly promoted such as solar energy and wind energy. Solar energy is one of the fastest growing and cleanest energy technologies due to significant reductions in capital costs and technological advances. Asia has been the leader in installing new solar PV since 2013. Following that trend, growth in 2022 was driven by continued new capacity additions in the region, when Asia contributed about 59% of all new installations. The share of new installations in Asia was 53% during 2021 and 60% in 2020. In 2022, China drove growth in the region, accounting for around 77% of all new Asian (and about a 45% of all global) installations. Total expansion in Asia was 112 GW in 2022 (compared to 75 GW in 2021), and major capacity increases occurred in China (86 GW) and India (13.5 GW). Japan also added 4.6 GW, slightly more than in 2021. Historical markets outside Asia also continued to gain scale. The United States added 17.6 GW of solar capacity in 2022, Brazil added 9.9 GW and the Netherlands and Germany added 7.7 GW and 7.2 GW, respectively [1].

The amount of e-waste is increasing exponentially, this is a big problem in this decade and e-waste solutions also need to be put in place. Burning electronic waste causes not only negative impacts on the environment but also affects human life. Exposure to harmful amounts of waste from burning electronic waste or consuming food grown on it contaminated with metals such as arsenic or lead will disrupt human DNA function. Causes diseases related to the skin, respiratory, intestinal, immune, endocrine and nervous systems including cancer. These diseases can be prevented by proper management and disposal of e-waste. It has been proven through research results that the development of e-waste management systems depends both on public awareness and the participation of manufacturers. At the same time, governments also monitor the allocation of funds and environmental laws are accepted around the world [2].

These countries will all be the largest producers of solar panel waste by 2050. IRENA has provided scenarios for the loss of damaged solar panels, before the end of their lifespan to be included in the calculation. Wasted energy and damaged solar panels will be considered. IRENA also proposed a scenario where early losses will be larger than conventional scenarios, estimated at 20.10, 7.5, 7.5 and 4.3 million tons of waste for China, the US, and the US, respectively. Japan, India and Germany [3]. For several decades, solar power waste treatment has been considered the main method, however the main disadvantages of this method are soil damage, pollution and dangers from e-waste seeps into soil and water sources and causes hazards to human health. At the same time, there is an increasing scarcity of semiconductor materials for production. Environmentally friendly methods for recycling photovoltaics are being researched and tested [4]. In 2020, solar panels made from silicon accounted for about 73.3% of the solar panel market share worldwide. Therefore, PV recycling companies or strategies are focused on Si (Silicon) based solar panels. Differences in panel manufacturing, transportation and installation processes. Differences in recycling due to differences in battery manufacturing processes [5].

The average lifespan of each solar panel is 20-30 years. We don't need to worry about recycling, but with the first installed solar panels being decommissioned, this is a very important environmental issue. It is expected that by 2050, Vietnam is expected to have 12 million tons of waste due to expired solar panels. According to the report, 1MWP solar power capacity generates 70 tons of waste [6].

There are four main methods for recycling solar panels:

Mechanical recycling: is to use mechanical separation of solar panel components, then crushed to separate aluminum, glass, silicon for reuse, they become raw materials to produce panels new solar batteries, or repair old solar panels by replacing broken parts to create new products, this process does not recover valuable materials

Thermal: A method that involves using high temperatures to heat solar panels to break them down into basic components, using the ash produced into other products

Chemical: This is a method that uses chemicals to separate materials in solar panels, solar panels will be mechanically processed into small pieces then used chemicals to process and separate materials to reuse to produce solar panels or other products

High temperature density separation : is a method based on the material properties of each component such as melting point, boiling point, miscibility and density of each material to separate materials.

Recycling solar energy is a global trend towards a sustainable industry and brings great benefits to human life. In Vietnam today, there are also many economic and technical solutions for recycling solar energy. The author has mentioned four main methods, all of which are popular nowadays, but determining which method is the most optimal and effective is the goal that the research is aiming for.

II. Literature Review

The AHP method has been widely used in all fields of natural sciences, engineering and economics. Proper use of the AHP method brings research value to scientists and administrators**.**

Abdullah et al [7] showed that in the AHP method, the factors affecting the selection of suitable locations for placing solar panels are classified into groups of criteria and weights are determined. Through this method, efforts to improve the efficiency of solar energy systems often involve selecting the optimal location for a solar power (PV) plant. AHP [8] has been widely applied in selecting locations for solar power farms. This method offers the advantage of a hierarchical structure, which streamlines and reduces the number of comparisons. However, one drawback to note is the variation in factors depending on how the hierarchy is set up. In the process of finding ideal locations for solar panels, experts must identify and evaluate various criteria. After prioritizing each criterion based on expert opinion, AHP is used to calculate the final weight for each criterion. However, because the priority among criteria changes according to the opinions of experts or reference materials, the final weights may not be as initially expected. To achieve the proposed final weights and enhance the objectivity of the AHP, methodological adjustments are necessary. AHP is also applied in other energy industries. Rana Pratap Singh et. al [10] incorporated the AHP method to select strategies for Hydropower plants in Nepal. Because when making decisions, criteria need to be given related to high investment, low operating costs, long usage time and potential risks and challenges. At the same time, for resource use, hydropower is combined with irrigation, water supply, transportation, tourism, etc. Therefore, the model combines multi-criteria to optimize decisions.

Rishabh Rathore et.al, Identifying and assessing supply chain risks using the AHP methodology helps ensure the safety and reliability of food products as they move from manufacturer to consumer. The AHP method provides a systematic and structured approach to prioritizing and quantifying risk by dividing complex decisions into hierarchical criteria, sub-criteria, and alternatives. . This allows stakeholders to compare and evaluate different factors based on their relative importance. By applying AHP to the food distribution sector, organizations can effectively identify weaknesses, measure the likelihood and impact of potential risks, and develop specific strategies to mitigate them. and manage these risks. Through a combination of expert knowledge, data analytics and input from stakeholders, AHP helps decision makers make informed choices, improving the resilience and efficiency of food supply chains. products, protecting public health and maintaining consumer confidence [9]. Tc Lirn et.al [11] applied the AHP method to determine priority criteria in selecting transshipment ports. Shipping companies need to operate globally if they want to significantly meet demand from international shippers. Furthermore, every part of their network must be able to maximize revenue and minimize costs. Therefore, this study has a global scope, and also looks at the restructuring of the world container shipping network, emphasizing the geographical importance of Asian hubs in today's transshipment industry, and include these alternatives in the survey. AHP is also widely applied in the field of construction management. Skibniewski et.al have demonstrated the feasibility of applying AHP to evaluate the construction technology of two types of tower cranes [12]. Zhang et.al [13] established the G-AHP group multi-criteria model based on the AHP model. The model was applied to seven selected highway construction projects in Guangdong province showing numerical effectiveness. Sugihara et.al [14] proposed the fuzzy AHP model by changing the values in the basic matrix into fuzzy numbers to resolve the uncertainty in judgment when information is incomplete. This helps to compare the improved AHP model and the standard method.

III. Research Method

3.1 Data collection

In this study, the author utilized the opinions of 15 experts, who are specialists in the field of solar energy research and managers from companies. The expert opinions were collected from February to April 2023, including both direct and indirect interviews. These opinions were then applied to the AHP model, which is one of the highly effective models widely used in various fields of Science and Economics.

3.2 Analytical Hierachy Process

AHP is one of the multi-criteria decision making (MCDM) methods that aims to simplify problems with complex and unclear structures by using a pairwise comparison matrix to arrange criteria. The main advantage of the method is to rank the options in order of effectiveness [15]. In the AHP model, measures are compared pairwise and are based on nine levels of a standardized comparison scale. The AHP method is applied to select priority levels at all levels in the pairwise comparison matrix from a scale of 1-9 at all levels in the hierarchy [15].

Figure 1 gives us an example Hierarchical Tree, which helps us build an AHP model for this research.

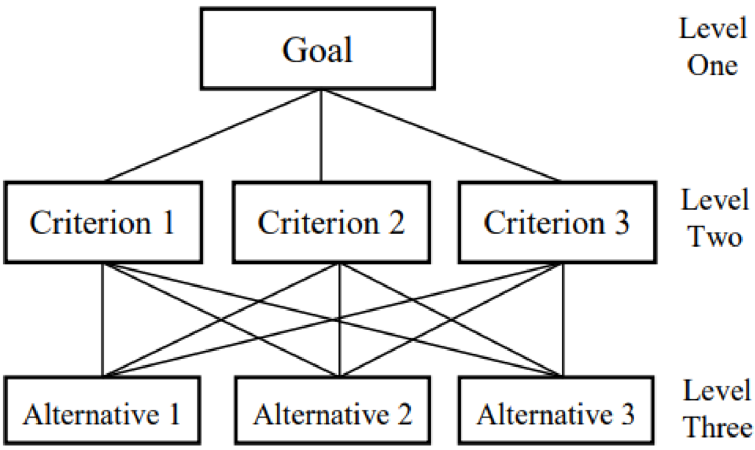

Figure 1: Sample Hierarchical Tree

To conduct pairwise comparisons, the researcher needs to design a questionnaire and distribute it to respondents (can be managers, experts, users,…) to collect their opinions. The individual judgments are then converted into group judgments using the geometric mean. The scale ranges from one to nine, which has an implication that the two factors are the same or equally important. The converted pairwise scales for each indicator are illustrated in Table 1 and 2.

Table 1: Ratings for the significance of the variable

Importance Scale	Definition of Importance Scale
1	Equally Important Preferred
2	Equally to Moderately Important Preferred
3	Moderately Important Preferred
4	Moderately to Strongly Important Preferred
5	Strongly Important Preferred
6	Strongly to Very Strongly Important Preferred
7	Very Strongly Important Preferred
8	Very Strongly to Extremely Important Preferred
9	Extremely Important Preferred

Table 2 gives us a scoring method, showing how important security criteria are in pairwise comparisons.

Table 2: Sample questionaire

Factor	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Factor
Privacy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Reliability
Privacy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Validation
Privacy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Verification
Privacy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Integrity
Privacy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Confidentiality
Privacy	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Availability

The data analysis process included a pairwise comparison matrix called the A matrix, which was extracted from the data collected from the interviews. The right eigenvector of the matrix is calculated as 'w'.

In the case of incomplete consistency and incompatible matrices, the pairwise comparison matrix cannot be used as a normalized column to obtain Wi.

For a positive and reversed matrix, Eigenvector technique can be used which in it:

$$e^T = (1,1,\dots,1) \quad (1)$$

$$W = \lim_{k\to\infty} \frac{A^k \cdot e}{e^T \cdot A^k \cdot e} \qquad (2)$$

To be able to achieve convergence between sets in the answer of successive iterations, the calculation must be repeated many times to make a decision when an incompatible matrix is encountered. The following formula is applied to convert raw data into meaningful absolute values and normalized weights w = (w1, w2, w3… wn).

$$A_w = \lambda\, max\, w\,, \lambda \text{max} \geq n \quad (3)$$

$$\lambda_{max} = \frac{\sum ajwj - n}{w1} \qquad (4)$$

$$A = \{a_{ij}\}\, with\, a_{ij} = \frac{1}{a_{ij}} \cdot \qquad (5)$$

A: pair wise comparison

w: normalized weight vector

λmax : maximum eigen value of matrix A

aij: numerical comparison between the values i and j.

The consistency ratio (CR) is calculated using the formula, CR = CI/RI in which the consistency index (CI) is:

$$CI = \frac{\lambda max - n}{n-1} \quad (6)$$

IV. Results

In Vietnam today, the rapid development of solar panel production is evident. From 2008 to 2018, the average growth rate of solar power development exceeded 40% per year. This impressive growth can be attributed to several key factors. Firstly, the economics of solar power have significantly improved, making it increasingly competitive with traditional fossil fuels. Secondly, the technology behind solar panels has become simpler and more optimized, reducing costs and enhancing efficiency. Additionally, solar energy is abundant and evenly distributed across the Earth's surface, allowing nearly any country or region to harness its potential.

Currently, solar power ranks third globally in terms of total installed capacity, trailing only hydropower and wind power. In light of the growing importance of solar energy, the challenge of recycling solar panels has become a critical issue. To address this, the Analytic Hierarchy Process (AHP) model has been employed. This model is renowned for its ability to synthesize expert opinions and develop methods for selecting the best options. By using the AHP model, researchers can optimize the selection process for the most effective recycling methods for solar panels.

The AHP model's efficacy has led to its widespread application in scientific studies worldwide. This powerful tool has been utilized across various disciplines, ranging from environmental science to engineering, due to its robust methodology for decision-making and problem-solving. Given its proven effectiveness in aggregating expert opinions and systematically evaluating complex options, we have chosen to utilize this model to identify the optimal recycling method for solar panels. This decision was driven by the need for a reliable and comprehensive approach to address the environmental challenges posed by the increasing number of decommissioned solar panels.

The findings of our research are detailed in the table below, offering a clear and concise representation of the optimal recycling methods as determined through our rigorous analysis. These results were derived from the insights of 15 industry experts, whose opinions were meticulously analyzed and processed using the AHP model by our research team. The selection of these experts was based on their extensive experience and knowledge in the field of solar energy and recycling technologies, ensuring that the data collected was both relevant and high-quality.

Our research team employed a systematic approach to gather, assess, and synthesize the expert opinions. This involved several stages, including initial consultations, detailed surveys, and iterative reviews, to refine the data and enhance the accuracy of our findings. The AHP model facilitated the comparison of various recycling methods based on multiple criteria, such as cost-effectiveness, environmental impact, and technological feasibility.

This rigorous approach ensures that the selected recycling method is both efficient and sustainable, contributing to the ongoing development of the solar power industry. By identifying the best practices for recycling, we aim to mitigate the environmental footprint of solar panel disposal and promote a circular economy within the renewable energy sector. This not only helps in conserving resources but also supports the broader goal of transitioning to a more sustainable and resilient energy system.

Moreover, the implementation of these optimized recycling methods has the potential to set new standards in the industry, encouraging other countries and regions to adopt similar practices. The knowledge gained from this study can be shared and applied globally, driving advancements in solar panel recycling technologies and policies. As the solar power industry continues to grow, the importance of effective recycling methods will become increasingly critical, making our research a valuable contribution to the field.

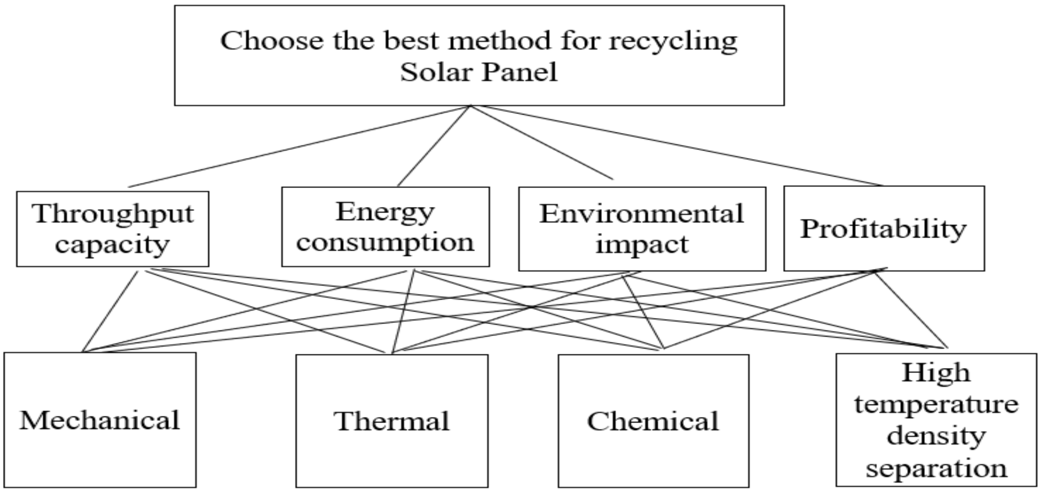

Figure 2: Framework of Analytical Hierachy Process

In this model, there are four main factors that influence experts' choices about solar panel recycling methods.

- Throughput capacity: The maximum speed for any given system under ideal conditions. For a system consisting of multiple components (such as a device or machine). Throughput capacity applies to the entire system and not to individual components. Categories of throughput capacity such as "small", "medium" or "large"[16].

- Energy consumption: Energy consumption not only depends on the device but also has a time aspect. Therefore, failures over different time periods are a relevant factor in measuring energy consumption. Energy consumption follows external influences and creates a cycle at certain points in different time dimensions [17].

- Environmental Impact: Depending on the technology, the environmental impact of solar energy is very different, divided into two basic types: concentrated solar power plants and PV solar power plants. Energy environmental impacts include land use, GHG emissions, hazardous materials, noise, water consumption [18].

- Profitability: Profitability: Determining such a value necessitates environmental analyses to quantify the exact value of emission reductions, but it is also contextually linked to the economic value associated with CO2. Therefore, economic analyses aim to support policymakers by highlighting how the profitability of a recycling plant varies under this scenario. This involves examining the potential cost savings from reduced emissions, evaluating market trends in carbon pricing, and assessing the overall impact on operational costs. Additionally, understanding these dynamics can guide investment decisions and help to forecast long-term financial viability, ultimately aiding in the formulation of sustainable economic policies [19].

Table 3: Results of quantitative evaluation of AHP method

	Name	Ideals	Normals	Raw
1	Mechanical	0.87	0.36	0.18
2	Thermal	0.27	0.11	0.056
3	Chemical	0.26	0.10	0.05
4	High temperature density seperation	1	0.42	0.21

From the table above we can see that all 3 main results are Ideals, Normals and Raw with results of 1, 0.42, 0.21 respectively for the 4th method: Hige temperature density seperation. Thus, through the AHP method, it shows that all 4 methods to recycle solar panels above bring results, but the 4th method is the most optimal and meets all criteria: Throughput capacity, Energy consumption, Environmental Impact, Profitability.

V. Summary and Prospect

The development of solar power plants has spanned two decades, installed capacity also increases to meet the needs of economic development and the needs of the environment and social security. Vietnam is a developing country and solar panel factories are also increasing. Recycling solar panels is very necessary and brings significant benefits to the economy and society.

Currently, there are companies in the world that recycle solar panels. Although the profit is not much, the environmental, economic and social values are undeniable. The above research shows that there are 4 main methods currently used to recycle solar panels in Vietnam, and choosing the most optimal method to serve companies or administrators is important. bring great benefits to the company. Four criteria help administrators make decisions: throughput capacity, energy consumption, environmental impact, profitablity. The AHP method has helped us decide on one of four methods: Mechanical, Thermal, Chemical, High temperature density separation. The fourth method High temperature density separation is the most effective method and at the same time brings economic and environmental values through this method.

This study, through the AHP model, has provided administrators and researchers with values and suggestions in the process of choosing methods and making decisions.

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