Selection for Technology Acquisition using AHP: A Case Study of Tulip VAWT Effectiveness

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ABSTRACT

The increasing energy demand in Indonesia, particularly from the industrial sector, has heightened the need to reduce reliance on fossil fuels by integrating new and renewable energy (NRE) sources into the energy mix. For the industrial sector, adopting NRE technologies presents options such as purchasing, manufacturing, or acquiring technology. This study focuses on selecting the most effective option for a small Vertical Axis Wind Turbine (VAWT), specifically the Tulip VAWT, by evaluating its hardware performance. The selection process utilizes subjective judgment and the Analytical Hierarchy Process (AHP), considering five key factors: installability, usability, affordability, availability, and maintainability. Results indicate that Technology Acquisition (TA) is the optimal choice, with an AHP score of 0.65, outperforming the purchasing options (0.322) and manufacturing options (0.296). These findings suggest that evaluating these five factors significantly impacts the decision-making process regarding adopting the Tulip VAWT. However, the study does not assess the effectiveness of the associated knowledge (software) or organizational factors, as no established methodology exists for this evaluation yet.

1. Introduction

The demand for energy in Indonesia is projected to rise significantly due to economic growth and population expansion. Under the business-as-usual (BAU) scenario, energy demand is estimated to increase from 159 million tonnes of oil equivalent (MTOE) in 2015 to 1050 MTOE by 2050, with an annual growth rate of 3.3%. By 2025, the final energy demand is predicted to reach 248.4 MTOE, with the industrial sector accounting for the largest share at 47.6%, followed by transportation (30.3%), household (15.0%), and commercial sectors (4.9%), with the remaining 2.2% from other sectors. The current energy mix heavily relies on fossil fuels, comprising 69% in 2015, with projections of a decline to 47.5% by 2025 and further to 44% by 2050. The

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Indonesian government has initiated a transition towards a cleaner energy mix, with a target of 23% new and renewable energy (NRE) by 2025 and 31.2% by 2050. This shift aligns closely with the National Energy Policy and global commitments to Sustainable Development Goal 7 (SDG7), which focuses on providing affordable and clean energy [1-4].

NRE sources, such as geothermal, hydropower, bioenergy, solar, and wind, offer significant advantages over fossil fuels, including renewability and zero carbon emissions [1-3]. To meet the ambitious NRE targets, substantial investments and the development of renewable technologies are required. The Indonesian government has emphasized the need to boost domestic industrial competitiveness through policies that increase the use of Local Content Requirements (LCR), or Domestic Component Level (TKDN), particularly in the development of electricity infrastructure. LCR policies, as outlined in Minister of Energy and Mineral Resources Regulation No. 50 of 2017 and Government Regulation No. 29 of 2018, mandate a significant contribution from domestic components in NRE projects [5]. Consequently, strategies aimed at fulfilling TKDN, including technology acquisition and localization efforts, are crucial for Indonesia's energy transition.

According to the National Energy General Plan (RUEN), the industrial sector is the largest consumer of energy in Indonesia, with projected final energy consumption reaching 118.4 MTOE (47.7% of the total energy mix) by 2025 and 293.2 MTOE by 2050 [2, 3]. As a result, industries are seeking ways to reduce energy consumption and increase energy efficiency by adopting a new and renewable energy (NRE)-based energy mix. Among various NRE sources, wind energy stands out as one of the fastest-growing options worldwide [6]. Wind energy can be harnessed through two main types of turbines: Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT) [6]. While HAWT is widely used due to its superior ability to extract wind energy and higher efficiency compared to VAWT, it has several limitations. HAWTs require significant space, generate noise, and are less effective in locations with low wind speeds or confined urban environments [7].

In contrast, VAWT presents several advantages that make it an attractive option for industrial applications, particularly in urban settings. VAWTs can capture wind energy from any direction, are smaller, have simpler designs, produce less noise, and require less space, making them more suitable for city locations and industrial environments with space constraints [6, 7]. Given these benefits, small-scale VAWTs offer a promising alternative for industries adopting NRE technologies. Among VAWTs, the Savonius type features a simple design but is less efficient than the Darrieus type [8]. This study addresses the growing need for efficient NRE solutions by evaluating the suitability of small-scale VAWTs for industrial use, focusing on their effectiveness and applicability in supporting Indonesia's NRE-based energy transition.

Several studies have explored small-scale Vertical Axis Wind Turbines (VAWTs), primarily focusing on their feasibility, design optimization, and performance enhancement [9-12]. These studies have evaluated various aspects, such as aerodynamic efficiency, rotor configurations, and the potential for small-scale VAWTs to contribute to renewable energy solutions. However, most existing research emphasizes technical improvements without addressing the strategic decision-making involved in technology acquisition, particularly within industrial applications. This gap highlights the need for a more comprehensive analysis that considers the technical feasibility and the decision-making processes behind acquiring or developing small-scale VAWT technology for practical use in industry.

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In contrast to previous studies, this paper presents a case study focused on the Technology Acquisition (TA) of a small-scale VAWT, specifically the Savonius VAWT with a Tulip blade design. Unlike standard approaches of buying or manufacturing, TA is chosen for its effectiveness in bridging the technology gap while considering internal capabilities, costs, and resources. TA strategies vary, with closed external acquisition, typically conducted by a company's R&D division, being one of the most effective methods. The novelty of this research lies in its objectives: (1) to assess the feasibility of wind energy as an alternative energy source for enhancing the energy mix at industrial facilities, (2) to evaluate the effectiveness of TA through subjective decision-making techniques combined with the Analytical Hierarchy Process (AHP) [13], (3) to facilitate knowledge transfer to engineers, thereby building internal capacity for renewable energy technologies, and (4) to align with the Government of Indonesia's (GoI) directives on green economy, energy security, and sustainable energy policies, including the Local Content Requirement (TKDN). This research not only fills the gap in the literature regarding the decision-making process for TA in small-scale VAWTs but also contributes to academic knowledge by offering insights into how small wind turbines can serve as viable non-fossil energy solutions for industry. The outcomes are expected to support practical implementation in industrial sectors and further research on renewable energy technologies.

2. Literature Review

The term "technology" can hold various meanings depending on the context. Technology encompasses more than machines, processes, and inventions, extending to a broader set of elements contributing to innovation. Technology includes products, knowledge, processes, tools, methods, and systems used to create and provide goods or services. For this paper, we define technology as "tools, techniques, practical knowledge, or skills necessary to perform specific activities."

When discussing the components of technology, the Economic and Social Commission for Asia and the Pacific (ESCAP) and Smith and Sharif [14] identify four critical elements of technology, summarized as the THIO framework: Technoware, Humanware, Infoware, and Orgaware. Technoware refers to object-embodied technologies such as tools, machines, and physical infrastructure. Humanware encompasses person-embodied elements, including knowledge, skills, and experience. Infoware covers document-embodied technologies, which include processes, methods, designs, and manuals. Finally, Orgaware pertains to institution-embodied aspects such as organizational practices and management structures that support technological advancements. Technology in terms of hardware and software offers a simplified categorization of these elements.

Technology acquisition is defined as "acquiring and adapting new technology through know-how, hardware, software, design, and manufacturing capabilities to enhance performance and ensure long-term competitiveness." This paper defines technology acquisition as acquiring and adapting technological knowledge through tangible products and intangible expertise.

3. Methods

This study employed action-based research, an approach integrated into a project to solve a company's problem. The results are intended to benefit the company directly. The primary objective of this research project is to acquire wind energy technology, focusing on limited hardware elements (products) and software (know-how). The specific

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objectives of the research include (1) Assessing and testing small wind turbines suitable for the company's conditions, (2) Conducting trials under specific weather conditions, and (3) Measuring the energy output of the turbines.

3.1. Data Collection Procedure

The data collection process involved several steps to acquire technology and evaluate its effectiveness. The steps for the technology acquisition process are as follows: (1) Determining the needs of the company; (2) Defining clear targets and objectives for technology acquisition; (3) Forming a cross-functional team to ensure diverse input and expertise; (4) Conducting a literature review to identify relevant technologies; (5) Identifying various wind energy equipment and their components from suppliers through e-commerce platforms; (6) Designing and simulating potential systems; (7) Installing and testing the wind turbines in the company's facilities; (8) Collecting data during testing, including environmental factors such as wind speed and turbine energy output; (9) Verifying the results obtained from the tests; (10) Analyzing the data and drawing conclusions regarding the effectiveness of the installed technology; and (12) Providing recommendations based on the analysis.

3.2 Data Analysis Procedure

To evaluate the effectiveness of the technology, specific criteria must be established. While Platts [15] and Baines [16] provide feasibility, usability, and utility criteria, this study adopts five factors to assess the technology: installability, usability, affordability, availability, and maintainability. These factors are then used in conjunction with the Analytical Hierarchy Process (AHP), a Multi-Criteria Decision Making (MCDM) method developed by Saaty [13, 17-20].

The Analytical Hierarchy Process (AHP) in this study was carried out in several structured steps to facilitate decision-making and prioritization of criteria. The first step involved defining the goals, where specific objectives and desired outcomes were identified. After establishing the goals, the system was broken down into simpler components by creating a hierarchy, which allowed complex decision criteria to be cascaded into lower-level elements. The next step was to define priorities by constructing a pairwise comparison matrix. This matrix compares criteria on a scale from 1 to 9, with values indicating the relative importance of each criterion [13, 21, 22]. Once the matrix was created, the criteria were ranked based on the comparative values. A crucial part of the AHP process is the consistency test, which ensures that the weightings assigned to the criteria are logical and reliable. The first step in this process was to define the matrix size (n) and the corresponding Random Index (RI), which is based on the number of criteria (as shown in Table 1).

Table 1. Random Index

n	1,2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0.58	1.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

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To calculate the maximum eigenvalue (λ_{max}), the following formula was used (Equation (1)):

$$\lambda_{max} = \frac{1}{n}\sum\frac{Eigen\ Value}{Weight} \quad (1)$$

The Consistency Index (CI) was then determined using the Equation (2):

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

Finally, the Consistency Ratio (CR) was computed using the formula Equation (3):

$$CR = CI/RI \quad (3)$$

The judgments were considered consistent and acceptable if the CR value was less than or equal to 0.1. However, if the CR value was more significant than 0.1, it indicated inconsistency in the pairwise comparisons, requiring a review of the criteria weighting. This consistency check ensured that the AHP process produced reliable and valid results.

3.3 Data sources

Data for the AHP analysis was gathered through group assessments and expert judgment. Experts from relevant fields participated in discussions and evaluations, providing subjective ratings for each criterion. Data was collected through focus group discussions, expert interviews, and structured questionnaires to ensure comprehensive and accurate input for the AHP calculations.

4. Results and Discussion

The small-size Tulip Vertical Axis Wind Turbine (VAWT) was tested to achieve several key objectives, including evaluating and testing a small wind turbine suitable for the company's operational conditions. The VAWT used for this testing was a 700W Tulip model purchased via international e-commerce platforms. It has a height of 1.1 meters and a diameter of 0.52 meters, with a rated voltage of DC 12V/24V (See Table 2).

A movable support structure with an adjustable height was designed and constructed to facilitate installation in a predetermined location for optimal performance. The chosen installation site and turbine height were selected based on wind speed data collected from various locations around the company. The goal was to ensure that the turbine could be positioned in an area where wind speeds were sufficiently high to generate maximum energy output. The wind speed data used for this selection was measured during the initial phase of the study across several points within the vicinity of the company [23].

Table 2. Small-size Tulip Vertical Axis Wind Turbine (VAWT) specification

Specification of Axial Tulip Wind Turbine	
Rated Power	700W
Started wind speed	3.0m/s
Rated voltage	DC12V/24V
Overspeed protection	Electromagnet brake
Generator	3-phase permanent magnet

The Tulip Vertical Axis Wind Turbine (VAWT) trials were conducted under specific weather conditions to evaluate its performance. The primary goals of the trial were to measure the output voltage at various wind speeds, assess operational stability, and determine the turbine's durability during continuous operation. The Tulip VAWT has fixed pitch turbine blades, non-adjustable pitch blades, and a generator. The trials were conducted at several locations with wind speeds ranging from 0.5 m/s to 1.4 m/s at a height of 2 meters. According to the data, the highest recorded wind speeds were 1.4 m/s and 1.3 m/s, while the lowest was 0.5 m/s at the same height [23]. These wind speeds are slightly below the average value provided by the Global Wind Atlas, which reports an average wind speed of 1.43 m/s in the same area. Additionally, the wind speeds observed at different locations averaged 1.5 m/s, with maximum gusts reaching 8.7 m/s. This information is crucial for evaluating the effectiveness of the Tulip VAWT in generating energy.

Performance tests were also conducted to evaluate the turbine's output under varying wind conditions. The results indicate that the turbine generates a minimum output voltage of 0.6 volts at a wind speed of 1.8 m/s and a maximum of 14 volts at a wind speed of 5.9 m/s. As shown in Table 2, the results demonstrate a clear correlation between wind speed and output voltage. Specifically, the motor RPM and output voltage rise significantly as wind speed increases. This performance analysis highlights the potential of the Tulip VAWT in harnessing wind energy, albeit with limitations in low wind speed conditions.

Table 3. Performance test results

N	Wind Speed (m/s)	Motor RPM (r/min)	Output voltage (V)
1	1.8	88	0.6
2	2.1	434	7.9
3	5.1	617	11.7
4	5.9	773	14

The measurement of energy output from the small-size Tulip Vertical Axis Wind Turbine (VAWT) focused on calculating the electric power (W) and the resulting energy in kilowatt-hours (kWh) based on an average wind speed of 1.5 m/s. As summarized in Table 3, the turbine has a total blade sweep area of 0.6 m^2 and an overall system efficiency of 45%. Under these conditions, the Tulip VAWT produced an electric power of 0.52 W, which resulted in an energy generation of approximately 0.012 kWh per day or 4.55 kWh per year.

The results from Table 2 and Table 3 confirm that the energy generation objectives have been partially achieved. While the Tulip VAWT can produce a small amount of electric power at an average wind speed of 1.5 m/s, the output voltage remains below 0.6 V, as indicated in Table 2. This voltage is insufficient for practical applications such as battery charging. However, it is essential to note that the voltage and energy output will increase as wind speed, turbine efficiency, and blade sweep area improve.

Table 2 demonstrates that the small-size Tulip VAWT is more effective at wind speeds exceeding 5.1 m/s, generating proper voltage and energy. To enhance its practical utility at lower wind speeds like 1.5 m/s, significant improvements in turbine design and efficiency are necessary to achieve higher voltage and energy output.

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Table 4. Energy measurement results of Tulip VAWT

Parameter	Result
Average wind speed (m/s)	1.5
Total area blade sweep (m^2)	0.6
Total turbine system efficiency	0.45
Electric Power (W)	0.52
kWH generated per day	0.012
kWH generated per year	4.55

The process of evaluating the options to buy, make, or conduct technology acquisition (TA) for the Tulip Vertical Axis Wind Turbine (VAWT) was carried out using the Analytic Hierarchy Process (AHP). Five key factors were considered in the assessment: installability, usability, affordability, availability, and maintainability. A subjective assessment of these factors, summarized in Table 4, reveals that the Tulip VAWT is easy to install and maintain. However, it falls short in terms of usability, affordability, and availability. The average score across all factors is 2.1, categorized as "fairly good."

Table 5. Subjective assessment of five factors.

No.	Factors	Score*	Results of Assessment
1	Installability	4	The small-size Tulip VAWT is easy to install.
2	Usability	1	The small-size Tulip VAWT is easy to use because there are not many components in the product. However, the voltage and energy generated are still too low.
3	Affordability	1.5	The small-size Tulip VAWT is quite expensive for personal investment. Therefore, affordability depends on the person.
4	Availability	1	As the small-size Tulip VAWT purchased via international e-commerce. Thus, currently, it is not easily available in the local market.
5	Maintainability	3	The small-size Tulip VAWT is designed to be installed at a low elevation, making it easy to disassemble for maintenance.
	Average	2.1	(fairly good)

*) Scale 1 to 5.
0: Poor — 2: Fairly good — 4: Very Good
1: Not good — 3: Good — 5: Excellence

The AHP method was then applied to compare these factors pairwise, as shown in Table 5. Values for pairwise comparisons are scored on a scale of 1-9 [13][21][22], (See Table 6). The analysis results indicate that availability (35%) is the most critical factor, followed by usability (28.83%) and affordability (17.41%). Installability (9.31%) and maintainability (9.46%) ranked lower, signifying their lesser importance in decision-making. These rankings suggest that the critical criteria for selecting an option are ensuring the availability and usability of the VAWT and considering the overall affordability.

Table 6. Pairwise comparison criteria and validation

Factor	Install-ability (1)	Usa-bility (2)	Afford-ability (3)	Avail-ability (4)	Maintain-ability (5)	Priority or Weight (6)	% (7)	Eigen value (8)	Eigen Value: Weight (9)=(8)/(6)
Install-ability	1.00	0.50	0.33	0.25	1.00	0.09	9.31	0.48	5.13
Usa-bility	2.00	1.00	3.00	1.00	2.00	0.29	28.83	1.54	5.33
Afford-ability	3.00	0.33	1.00	0.50	2.00	0.17	17.41	0.91	5.25
Avail-ability	4.00	1.00	2.00	1.00	5.00	0.35	35.00	1.83	5.23
Maintain-ability	1.00	0.50	0.50	0.20	1.00	0.09	9.46	0.49	5.17
TOTAL	**11.00**	**3.33**	**6.83**	**2.95**	**11.00**	**1.00**	**100**		**26.11**
	RI =	1.12	(matrix n = 5)						
	λmax =	5.22	(λmax = total of column (9) / n = 26.11/5)						
	CI =	0.06	(CI=λmax - n/n - 1)						
	CR =	0.05	(CR=CI/RI, if CR < 0.1 then it is **Consistent**)						

Note: RI=Random Index, CI=Consistency Index, CR=Consistency Ratio

Table 7. Pairwise comparison rating scale

Importance	Definition	Remark
1	Equal importance	Both elements have similar effects.
3	Weak importance of one over	Experience and judgment strongly favor one element compared to its pair.
5	Essential or strong importance	One element is more important than the other.
7	Demonstrated importance	One element is more important than the other elements.
9	Extreme importance	One element is more important than the other elements
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed. Values between two adjacent judgment values.
Reciprocal	Opposite	Reciprocals for inverse comparison.

In the next step, the AHP method was applied to assess the three options—buy, make, or conduct technology acquisition (TA)—based on the same five factors. The pairwise comparisons for each option are detailed in Table 8 based on rating scale in Table 7, and the final results are summarized in Table 9. Technology acquisition (TA) emerged as the best option, with the highest total weight (0.65), indicating that acquiring the technology is more favorable than buying or making the VAWT. The second-best alternative is to buy, with a total weight of 0.322, while the option to make scored the lowest, with a weight of 0.296.

Table 8. Pairwise comparison of Buy, Make, and TA factors.

Install-ability	Buy	Make	TA	Weight
Buy	1.00	0.20	0.25	0.098
Make	5.00	1.00	2.00	0.568
TA	4.00	0.50	1.00	0.334
Total	10.00	1.70	3.30	1.00

Usability	Buy	Make	TA	Weight
Buy	1.00	2.00	0.25	0.224
Make	0.50	1.00	0.33	0.156
TA	4.00	3.00	1.00	0.619
Total	5.50	6.00	1.58	1.00

Affordability	Buy	Make	TA	Weight
Buy	1.00	0.33	0.20	0.104
Make	0.50	1.00	0.33	0.231
TA	5.00	4.00	1.00	0.665
Total	9.00	5.33	1.45	1.00

Availability	Buy	Make	TA	Weight
Buy	1.00	3.00	4.00	0.633
Make	0.33	1.00	1.00	0.192
TA	0.25	1.00	1.00	0.175
Total	1.58	5.00	6.00	1.00

Maintainability	Buy	Make	TA	Weight
Buy	1.00	0.20	0.25	0.964
Make	5.00	1.00	3.00	0.619
TA	4.00	0.33	1.00	0.284
Total	10.00	1.50	4.25	1.00

Table 9. Summary of selection results to buy, to make, or to do TA

Alternative	**Install-ability**	**Usability**	**Afford-ability**	**Avail-ability**	**Maintain-ability**	**Total Weight**
	Weight Priority					
	0.093	**0.288**	**0.174**	**0.350**	**0.095**	
Buy	0.098	0.224	0.104	0.633	0.096	0.322
Make	0.568	0.156	0.231	0.192	0.619	0.296
TA	0.334	0.620	0.665	0.175	0.284	**0.650**

In evaluating the availability of the Tulip Vertical Axis Wind Turbine (VAWT), the technology acquisition (TA) option yielded the lowest value at 0.175, compared to buying (0.633) or making (0.192). It suggests that the most favorable option for availability is to buy the Tulip VAWT. Additionally, regarding usability and affordability, TA is the best choice due to its high value. These findings imply that TA is a desirable strategy for organizations prioritizing availability, usability, and affordability when considering the Tulip VAWT. This option is particularly advantageous for companies unfamiliar with VAWT technology, as it allows them to effectively acquire and integrate small VAWT systems into their operations.

However, this assessment does not fully capture the technology absorption aspect, particularly concerning the know-how and knowledge (software), an essential competence gained from conducting this research. Subjective self-assessment indicates that engineers' know-how and knowledge competencies have increased as a result of this study. This increase falls within the broader competency framework encompassing cognitive, affective, and psychomotor domains [24]. Each domain's level reflects the corresponding know-how and knowledge. Logically, successful technology acquisition is expected to enhance competencies in these domains. Therefore, the effectiveness of technology acquisition can be gauged by measuring improvements in competency levels across these domains. Despite the significant advancement in engineers' know-how and knowledge, developing methodologies that quantitatively assess technology acquisition by measuring domain levels before and after the research remains crucial.

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5. Conclusion

This research provides insights into the technology assessment, focusing specifically on the product (hardware) aspect of the Tulip Vertical Axis Wind Turbine (VAWT). Five critical factors were identified for evaluating whether to buy, make, or conduct a technology assessment for the Tulip VAWT: installation capability, usability, affordability, availability, and maintainability. Among these, availability, usability, and affordability emerged as the key factors influencing the decision. The findings concluded that technology acquisition (TA) is the most favorable option for the Tulip VAWT, particularly when considering affordability and usability. However, it falls short in availability, installation, and maintainability.

The performance tests revealed that the Tulip VAWT has low voltage and energy output, indicating a need for significant improvements, mainly when operating in conditions of average wind speed at or below 1.5 m/s. In contrast, the turbine performs more effectively in locations with wind speeds exceeding 5.1 m/s, suggesting it may not be suitable for low-wind environments. While the assessment did not include the know-how/knowledge (software) and organizational elements, subjective evaluations indicated that the research team improved their understanding and analytical skills related to the Tulip VAWT throughout the study. Future research should address these elements to provide a more comprehensive assessment.

This study underscores the importance of conducting a thorough evaluation and real-world trials when adopting new technology or products to ensure performance meets expectations. If performance does not align with expectations, further investigation should be undertaken through internal company resources or in collaboration with academic institutions. Such partnerships can enhance performance and knowledge acquisition related to the technology. Additionally, when considering broader adoption of the product or technology, companies should weigh the options of making or buying while exploring the possibility of acquiring parts of the technology for local production.

Ultimately, this research highlights that TA is the best option when new product performance does not meet expectations in real-world conditions. However, further technology acquisition is necessary, as this study focused primarily on hardware, illustrating that acquiring new technology extends beyond hardware considerations. Moreover, it indicates that conducting TA in collaboration with academic institutions is often more cost-effective than relying solely on internal company resources, notably when relevant knowledge is lacking within the organization. Balancing cost, uncertainty, and outcomes is crucial for successful technology acquisition.

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