# FUZZY ANALYTICAL HIERARCHY PROCESS (FAHP) APPROACH TO ASSESS THE EFFECTIVENESS OF SOLAR-POWERED AND WIND-POWERED AQUAPONIC SYSTEMS

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## ABSTRAK

*This study proposes a decision model to determine the most efficient aquaponic system; between the solar-powered aquaponic system and wind-powered aquaponic system. Effectiveness is a measurement used to determine how efficiently a machine is running. It is also used as a tool to know the current condition of the machine. The criteria for evaluating the aquaponic systems effectiveness are availability, performance and quality. The application of Fuzzy Analytical Hierarchy Process (FAHP) will be the method of the decision model. The developed model will help users in determining the best energy to power aquaponic system with respect to selected criteria.*

**KEYWORD:** *Solar-powered Aquaponic system, Wind-powered Aquaponic system, Effectiveness, Fuzzy Analytical Hierarchy Process (FAHP)*

## 1. INTRODUCTION

Aquaponic system is a combination of aquaculture (fish farming) and hydroponic (soil-less growing of plants). Aquaponic can simultaneously produce two types of food (fish and vegetable).The fish are nurtured in tanks. Their wastewater provides food for growing plants and the plants act as a natural filter for the water which the fish live in (Graber & Junge, 2009). Thus, the plant and fish raise together in one integrated system.

Most aquaponic system uses electricity from the building to turn on the water pump. The water pump is used for water cycling; namely the flow of water from the fish tank to the medium of gardening and the water will be recycled back into the tank (Somerville et al., 2014). In the event of power failure, the water pump will stop working and the water cycle may be affected. Hence, the solar and wind powers have been identified as an alternative and potential sources of energy which can be helpful in providing the energy for water cycling (Tyson, Treadwel, & Simonne, 2011).

Wind energy is primarily used for electricity generation and to produce a usable mechanical power. It flows from high pressure locations to lower pressure locations. The speed of wind at the low pressure regions is slower compared to high pressure regions. Two different monsoons in Malaysia are the Southwest monsoon and the Northeast monsoon. The Southwest monsoon begins from May/June until September, while the Northeast monsoon flows from November until the end of March (Malaysian Meteorology Department). Therefore, Malaysia has a modest average wind speed.

Meanwhile, Ong, Mahlia and Masjuki (2011) stated that, worldwide, the land receives about 1700 TW worth of solar radiation and so has a huge photovoltaic (PV) energy potential. Since Malaysia is a country close to the Equator, makes the temperature is uniform throughout the year, with the average sunshine hours are 6 hours a day. As a result, the annual average daily solar radiation is in the range from 4.21 kWh /m² to 5.56 kWh /m² (Ong, Mahlia & Masjuki, 2011).

Both wind and solar energies are natural renewable energy sources that allow less or zero amount of greenhouse gases. However, there is a significant difference in how wind energy and solar energy is extracted. Wind energy is extracted mechanically via turning turbines that produce electricity. When the turbine blades in a wind-electric turbine capture the kinetic energy from the wind and rotates, the generator turns the rotational energy into electricity.

In contrast, the solar energy is extracted via solar panels, which directly convert sunlight into electricity. Energy is essentially captured and converted through photovoltaic cells. These cells are made from semiconductor materials such as silicon, to absorb solar energy. Once absorbed, the AC current is directed via magnetic fields and is extracted for power utilization.

**Figure 1: Sample of solar-powered aquaponic system**

The scope of this study is to assess or evaluate the effectiveness of the wind and solar aquaponic systems. **Figure 1** shows the solar-powered aquaponic system. Effectiveness is a measurement used to determine how efficiently a machine is running. It is also used as a tool to know the current condition of the machine. McKone, Schroeder and Cua (2001) and Nakajima (1989) stated that the effective operation of the individual machine is dependent on the three factors, which is availability, performance rate and quality rate of the machine. Therefore, the criteria for evaluating the aquaponic systems effectiveness are availability, performance rate and quality rate. In order to perform this evaluation, Fuzzy Analytical Hierarchy Process (FAHP) is one of multi-criteria decision-making method suitable to be used.

Based on the above considerations, this study proposes a decision model to determine the most effective aquaponic system; between the solar-powered aquaponic system and wind-powered aquaponic system. The application of Fuzzy Analytical Hierarchy Process (FAHP) will be the method of the decision model. The developed model will help users in determining the best energy to power aquaponic system with respect to selected criteria.

The remainder of this paper is organized as follows. Next section presents the literature reviews on the current application of FAHP. It follows the section that describes the development of the FAHP decision model. This particular section provides a systematic guideline how the problem under study is formulated and analyzed. In the following section, the validation of the proposed FAHP decision model is presented and discussion on the results obtained. Last but not least, the final section concludes the findings of this research.

## 2. LITERATURE REVIEW ON FUZZY ANALYTICAL HIERARCHY PROCESS (FAHP) METHOD

As highlighted in the previous section, the FAHP method is applied in decision making towards selection the most effective aquaponic system. In common application, FAHP method is appropriate for the multi-criteria decision-making problems (Saaty, 1980, and Badiru et al., 1993).

FAHP method utilizes the hierarchical structure analysis and the concepts of fuzzy set theory to solve the above-mentioned problems systematically. The fundamental of FAHP is that it represents the expansion of a classical AHP method into fuzzy environments where the weights of criteria and ratings of alternatives are evaluated by fuzzy linguistic values (Petkovic et al., 2012). Also, FAHP has been proved to be one of the best methods if the consistency test is included. Although there are several techniques embedded in FAHP, the Buckley's method is applied within the scope of this study. Buckley proposed a geometric mean to determine the relative importance weights for both the criteria and the alternatives.

In literature, the applications of FAHP in selection problems/decisions have been reported in several number of publications. For example, Ayag and Özdemir (2006) used FAHP method for machine tool selection problem. The motivation of their study is because that improperly selected machine tool can negatively affect the overall performance of a manufacturing system. Chen et al., (2006) presented the application of FAHP approach towards supply chain management problem. The authors claimed that the proposed model is very well suited as a decision-making tool for supplier selection decisions. Wang et al., (2007) evaluated different maintenance strategies for different equipment using FAHP method. The authors claimed that the method proposed in their article was a simple and effective tool for tackling the uncertainty judgment of decision making which beneficial for plant maintenance managers to define the optimum maintenance strategy for each piece of equipment. Most recent, Deghanian et al., (2012) reported the application of FAHP approach towards critical component identification of power distribution system. Based on their FAHP methodology presented, the most critical component with respect to selected criteria has been identified, so that to be prioritized in maintenance scheduling. In the following section, the detail description of FAHP application is presented.

## 3. FUZZY ANALYTICAL HIERARCHY PROCESS (FAHP)

The structure of proposed decision model is illustrated in **Figure 2**. The research method starts with data gathering process. The sources of data for this study are gathered from interviews and by having several meetings with the experts. From the interviews and meetings, a set of criteria or alternatives is formulated. Next, FAHP is used as a method of the decision model. The FAHP contains four steps of analyses:

i. Hierarchy structuring of problem,
ii. Criteria weighting,
iii. Alternative weighting,
iv. Final score of alternatives

The final decision making or the output of the decision model is to determine the most effective aquaponic system; between solar-powered aquaponic system and wind-powered aquaponic system.

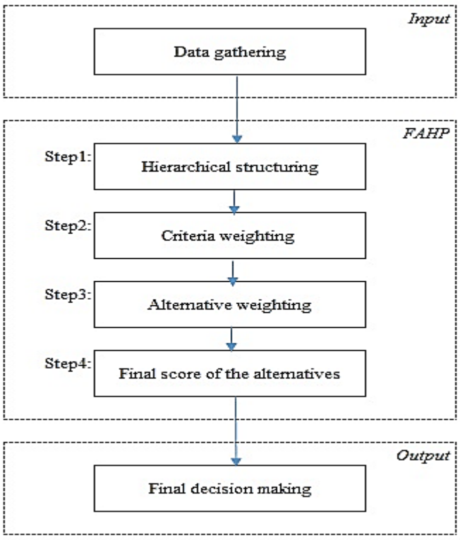


**Figure 2: FAHP decision model**

3.1 Hierarchy structuring of the problem

Developing the hierarchical structure includes the breakdown of complex decision problem into smaller manageable elements at different hierarchical levels. This assists the evaluator to have a full understanding about the decision making problem and to have it totally covered. In a general FAHP hierarchy structuring, the first level consists of the goal or objective, then the criteria and the alternatives are found in the second level and third level respectively (Kilincci and Onal, 2011). Then, a hierarchy structure of the problem can be framed.

3.2 Criteria weighting

After forming the hierarchy structure for the problem under study, the normalized weights $N_i$, of each criteria are calculated according to the fuzzy arithmetic rules. A group of evaluators from decision making team would compare the criteria or alternatives using the scale provided in **Table 1**. The evaluators would be the experts who have direct experience dealing with the operation and maintenance of aquaponic systems. In this case study, it could be engineers or technicians.

**Table 1: Linguistic terms and the triangular fuzzy numbers (Ahyan, 2013)**

| Saaty scale | Definition | Fuzzy Triangular Scale |
|---|---|---|
| 1 | Equally important | (1,1,1) |
| 3 | Weakly important | (2,3,4) |
| 5 | Fairly important | (4,5,6) |
| 7 | Strongly important | (6,7,8) |
| 9 | Absolutely important | (9,9,9) |
| 2 | The intermittent values between two adjacent scales | (1,2,3) |
| 4 | | (3,4,5) |
| 6 | | (5,6,7) |
| 8 | | (7,8,9) |

The pairwise comparison matrix is shown in **Equation 1**, where $\widetilde{d_{ij}^{k}}$ indicates the *kth* evaluator's preference of *ith* criteria over *jth* criteria, via fuzzy triangular numbers. Example, $\widetilde{d_{12}^{1}}$ = (2, 3, 4). If there is more than one evaluator, preferences of each evaluator $\widetilde{d_{ij}^{k}}$ are averaged.

*Eq 1:*

$$\widetilde{A^k} = \begin{bmatrix} \widetilde{d_{11}^k} & \widetilde{d_{12}^k} & \dots \\ \widetilde{d_{21}^k} & \dots & \dots \\ \dots & \dots & \widetilde{d_{nn}^k} \end{bmatrix}$$

The consistency ratio (CR) in **Equation 2**, may be calculated to measure how consistent the evaluator has been (Saaty, 1980). The CR depends upon the consistency index (CI) and the random consistency index (RI).

*Eq 2:*

$$CR = \frac{CI}{RI} \quad Where \quad CI = \frac{\lambda max - n}{n-1}$$

As long as the CR is below 0.1, the comparison matrix is said to be consistent (Saaty, 1980). Larger values require the evaluator to reduce the inconsistencies by revising judgments.

According to Buckley (1985), the geometric mean $\widetilde{r_i}$ of fuzzy comparison values of each criteria, is calculated as shown in **Equation 3**. Here, $\widetilde{r_i}$ still represents triangular values.

*Eq 3:*

$$\widetilde{r_i} = \left( \prod_{j=1}^{n} \widetilde{d_{ij}} \right)^{1/n} \qquad i = 1, 2, \dots, n$$

Then find the vector summation of each $\widetilde{r_i}$. Find the reverse vector (power $^{-1}$ of summation). Replace the reverse vector, to make it in an increasing order. To find the fuzzy weight of criteria $\widetilde{w_i}$, multiply each $\widetilde{r_i}$ with this reverse vector. Since $\widetilde{w_i}$ are still fuzzy triangular numbers, they need to de-fuzzified by using centre of area method proposed by Chou and Chang (2008). The de-fuzzified weight $M_i$ is a non-fuzzy number and needs to be normalized by following **Equation 4**.

*Eq 4:*

$$Ni = \frac{Mi}{\sum_{i=1}^{n} Mi}$$

At each level of the hierarchy, sum of the normalized weightings, $N_i$ should be equal to 1. Otherwise, there is either a rounding error or an incorrect calculation of the normalized weights.

3.3 Alternative weighting

After achieving the normalized weights $N_i$ for each criteria, the same principles are applied to find the respective values for alternatives. But now, the alternatives should be compared in pairwise manner with respect to each criteria particularly. That means, the analysis should be repeated for several times depending on the number of criteria.

3.4 Final score of the alternatives

Having found the normalized weights of both criteria and the alternatives, then by multiplying each alternative weight with related criteria weight, the scores for each alternative is calculated. The results obtained are the final score of the alternatives. The final scores are then added for each of the alternatives to obtain the final ranking of all the alternatives. After that, the alternative with the highest score is selected and suggested to the user.

## 4. MODEL VALIDATION AND DISCUSSION

This section presents the way to collect data, the construction of a hierarchical structure to be analyzed and the steps of generating the fuzzy pair-wise comparison matrix. The next step deals with computation of the final scores for prioritizing. To ensure a smooth process of data analysis, the steps of FAHP decision model are followed appropriately.

### 4.1 Hierarchy structuring of the problem

To achieve the goal of the study, three criteria have been chosen to evaluate the effectiveness of the aquaponic systems. These criteria are availability, performance rate and quality rate. The multiplication of three criteria is equivalent to Overall Equipment Effectiveness (OEE). The OEE was originated from the Total Productive Maintenance (TPM) practices, developed by S. Nakajima. OEE is a potential measurement tool for assessing the effectiveness of a single machine and also a continuous equipment system. Nonetheless, the OEE calculation is quite general and can be applied to any manufacturing organization (Philip, 2002). The literature reveals that no standard exists for calculation of OEE. **Table 2** shows the criteria types.

**Table 2: Criteria types**

| Criteria types | Relating losses | Description of losses |
|---|---|---|
| Availability | Equipment failure/breakdown losses | Downtime loss: machine is not functioning |
| Performance rate | Idling and minor stoppage losses | Speed loss: stoppage due to weather change |
| Quality rate | Defect losses | Defects in the output: reverse current, voltage drop |

The two products (called as alternatives) are considered for further study. These alternatives are solar-powered aquaponic system and wind-powered aquaponic system. Then, the hierarchy structure of the problem can be framed in **Figure 3**.

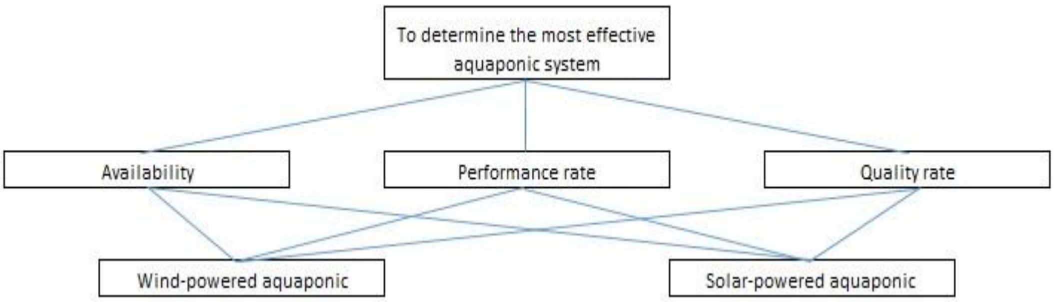


**Figure 3: Hierarchy structure of the problem**

### 4.2 Criteria weighting

The pairwise comparison matrix of the criteria is completed as presented in **Table 3**. Then, the geometric mean $\widetilde{r_i}$ of fuzzy comparison values of each criteria is obtained by using Equation 3. Accordingly, the fuzzy weight $\widetilde{w_i}$ of each criteria can be obtained by multiplying each $\widetilde{r_i}$ with the reverse vector. The next step, the de-fuzzified weight, $M_i$ is calculated by taking the average of fuzzy weight $\widetilde{w_i}$. After that, the normalized weights, $N_i$ for each criterion is calculated by using Equation 4.

**Table 3: Pairwise comparison of criteria**

| Criteria | Availability | Performance | Quality | Geometric mean $\tilde{r}_i$ | | | Fuzzy weight $\tilde{w}_i$ | | | Non-fuzzy weight $M_i$ | Normalized weight $N_i$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Availab-ility | 1,1,1 | 1/5,1/4,1/3 | 1/7,1/6,1/5 | 0.31 | 0.35 | 0.41 | 0.06 | 0.09 | 0.14 | 0.10 | **0.09** |
| Perfor-mance | 3,4,5 | 1,1,1 | 1/3,1/2,1/1 | 1.00 | 1.26 | 1.71 | 0.20 | 0.33 | 0.56 | 0.36 | **0.34** |
| Quality | 5,6,7 | 1,2,3 | 1,1,1 | 1.71 | 2.29 | 2.76 | 0.34 | 0.60 | 0.91 | 0.62 | **0.57** |

## 4.3 Alternative weighting

The next step deals with normalized weights of all the alternatives. The same principles are applied to find the respective values for alternatives. But now, the alternatives pairwise comparison should be repeated for 3 times for each criteria particularly. Hence, the matrix shown in **Tables 4, 5** and **6** are gained and framed.

**Table 4: Pairwise comparison of alternative with respect to Availability**

| Alternative | Wind aquaponic system | Solar aquaponic system | Geometric mean $\tilde{r}_i$ | | | Fuzzy weight $\tilde{w}_i$ | | | Non-fuzzy weight $M_i$ | Normalized weight $N_i$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Wind aquaponic system | 1,1,1 | 2,3,4 | 1.41 | 1.73 | 2.00 | 0.52 | 0.74 | 1.04 | 0.77 | **0.74** |
| Solar aquaponic system | 1/4,1/3,1/2 | 1,1,1 | 0.50 | 0.58 | 0.71 | 0.19 | 0.25 | 0.37 | 0.27 | **0.26** |

**Table 5: Pairwise comparison of alternative with respect to Performance Rate**

| Alternative | Wind aquaponic system | Solar aquaponic system | Geometric mean $\tilde{r}_i$ | | | Fuzzy weight $\tilde{w}_i$ | | | Non-fuzzy weight $M_i$ | Normalized weight $N_i$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Wind aquaponic system | 1,1,1 | 1,2,3 | 1.00 | 1.41 | 1.73 | 0.37 | 0.66 | 1.09 | 0.71 | **0.64** |
| Solar aquaponic system | 1/3,1/2,1/1 | 1,1,1 | 0.58 | 0.71 | 1.00 | 0.21 | 0.33 | 0.63 | 0.39 | **0.36** |

**Table 6: Pairwise comparison of alternative with respect to Quality Rate**

| Alternative | Wind aquaponic system | Solar aquaponic system | Geometric mean $\tilde{r}_i$ | | | Fuzzy weight $\tilde{w}_i$ | | | Non-fuzzy weight $M_i$ | Normalized weight $N_i$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Wind aquaponic system | 1,1,1 | 1/4,1/3,1/2 | 0.50 | 0.58 | 0.71 | 0.19 | 0.25 | 0.37 | 0.27 | **0.26** |
| Solar aquaponic system | 2,3,4 | 1,1,1 | 1.41 | 1.73 | 2.00 | 0.52 | 0.74 | 1.04 | 0.77 | **0.74** |

It is noteworthy that in the presented study, the consistency ratio (CR) of the criteria and the alternative pairwise comparison matrixes seem to be in the desirable limit of 0.1 or lower. Using the Equation 2, the CR is achieved.

## 4.4 Final score of the alternatives

A final score of the alternative is shown in **Table 7** whose final score for each component can be found by multiplying each alternative normalized weight with related criteria normalized weight.

**Table 7: The final score of the alternatives**

| | Availability | Performance | Quality | TOTAL |
|---|---|---|---|---|
| Wind aquaponic system | 0.07 | 0.22 | 0.15 | 0.44 |
| Solar aquaponic system | 0.02 | 0.12 | 0.42 | 0.56 |

Depending on this result, **Solar-powered Aquaponic system** has the largest total score. Therefore, it is suggested as the most effective aquaponic system among two of them, with respect to three criteria and the fuzzy preferences of experts/evaluators.

## 5. CONCLUSION

This study used the FAHP to solve the problem of evaluating and selecting a product of aquaponic system. It is utilized due to its ability for taking into account both the quantitative and qualitative measures. Three decision criteria have been used for assessing two different products of the aquaponic system. In this study, the triangular fuzzy numbers are utilized in establishing the pair-wise comparisons of criteria and alternatives through linguistic scales. FAHP can deal substantially with the uncertain judgement of evaluators.

As the result of the study, it is seen that the solar-powered aquaponic system outperforms the other one. This finding result will help the buyer/user to select the best product of aquaponic systems. Meanwhile, the problems of voltage drop at the output of the wind-powered aquaponic system are the critical issues to be solved.

In further studies, other models such as Fuzzy ANP or ELECTRE can be applied for the same problem and the results can be compared. In addition, hybrid models combining different methodologies incorporating the strong sides of each can be performed to solve this problem.

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