Abstract. Renewable energy technology selection, which has a strategic importance for many countries and companies, is one of the most challenging decisions due to the complex features and large number of alternatives. Of all renewable energy sources, solar photovoltaic (PV) energy has attracted more attention as the greatest promising option for industrial application. This paper proposes an extension of fuzzy multi-criteria decision making (MCDM) approach for selecting solar PV energy technologies. In the proposed approach, several PV technologies are used as the alternatives. The ratings of alternatives - PV technologies under various criteria and the weights of criteria are assessed in linguistic terms represented by fuzzy numbers. These values are further averaged and normalized into a comparable scale. Then, the normalized weighted rating can be derived by interval arithmetic of fuzzy numbers. To avoid complicated aggregation of fuzzy numbers, these normalized weighted ratings are defuzzified into crisp values using the left and right indices ranking approach. Finally, this study applies the proposed fuzzy MCDM approach to solve a PV technologies selection problem, demonstrating its applicability and computational process.

Keywords: Fuzzy MCDM, Renewable energy technology, ranking method.

Introduction

Most of the world’s commercial energy derives from fossil fuel and hydropower energy. The demand evolves from human activities which exploit the natural resources and destroy the environment with pollution [21]. The pollutants containing toxic and hazardous chemicals contaminate water, land, and air. Moreover, the emission of greenhouse gases (CO2) worsens global environmental problems. This condition has decreased human living quality and health [23]. Furthermore, these global issues have challenge the government to explore other energy sources that environmentally friendly, available abundantly, and widely distributed.

In recent year, solar photovoltaic (PV) power generation has become one of clean, potential, and economics improved energy technology [2]. Solar PV efficiency,
flexibility, and quality improvement offer great benefit especially for the developing countries that have been optimally exposed by sunlight [7]. Another advantage of solar PV to be considered is that the demand of PV energy increases in global market that motivates solar PV industry development [16]. Solar PV modules convert sunlight into direct-current electricity. The modules are solid-state semiconductor [15]. There are many types of solar PV modules offered by the suppliers. They can be categorized into crystalline silicon, thin film, and multijunction, organic film, and emerged PV (see table 1). Two types of PV modules grown exponentially and recently available in the market are crystalline silicon and thin film [19].

The buyers of PV technology should select carefully a number of different technology alternatives that appropriate with their requirement although the selection of appropriate technology is increasingly difficult because of technology complexity and acceleration. Nevertheless, technology selection plays an important role in decision making regarding of PV technology selection. Technology selection has a big impact in enterprise competition and enacts it as a multi-criteria decision making problem [13,17,20].

Table 1. Efficiency and cost of PV technologies [11,13,18,24]

<table>
<thead>
<tr>
<th>Technology</th>
<th>Efficiency</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multijunction</td>
<td>&gt; 40%</td>
<td>Most expensive</td>
</tr>
<tr>
<td>Single-junction</td>
<td>26-29%</td>
<td></td>
</tr>
<tr>
<td>Hybrid</td>
<td>&gt;18%</td>
<td></td>
</tr>
<tr>
<td>Crystalline silicon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mono-crystalline silicon</td>
<td>12.5-15%</td>
<td></td>
</tr>
<tr>
<td>Poly-crystalline silicon</td>
<td>11-14%</td>
<td></td>
</tr>
<tr>
<td>Thin film</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tandem a-Si</td>
<td>10-12%</td>
<td></td>
</tr>
<tr>
<td>Copper Indium Gallium Selenide (CIGS)</td>
<td>10-13%</td>
<td></td>
</tr>
<tr>
<td>Cadmium Telluride (CdTe)</td>
<td>9-12%</td>
<td></td>
</tr>
<tr>
<td>Amorphous Si (a-Si)</td>
<td>5-7%</td>
<td></td>
</tr>
<tr>
<td>Organic film</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dye-sensitized solar cells (DSSCs)</td>
<td>&gt;7%</td>
<td></td>
</tr>
<tr>
<td>Polymer solar cells</td>
<td>5.80%</td>
<td></td>
</tr>
</tbody>
</table>

There are some researches of technology selection. Van der Valk et al. [22] evaluated emerging technology in uncertainty demand. Meanwhile, Adner and Snow [1] examined update of existing technologies and development of new technologies. Yu and Lee [25] selected optimal emerging technology by applying a hybrid approach of two levels SOM and combination of AHP/DEA-AR and analytic hierarchy process (AHP) rating method. Huang et al. [9] proposed crisp judgment matrix in a fuzzy analytic hierarchy process method to examine subjective expert judgments. The judgments issued by the technical committee of the Industrial Technology Development Program in Taiwan. Different with previous research, Ma et al. [13] applied integrating the fuzzy AHP and Delphi method to yield two-way linkage model for technology selection criteria and industrial main technology fields. Peterseim et al. [14] used Multi-criteria decision making (MCDM) to assess most appropriate concentrated solar power (CSP) technologies with Rankine cycle power plants. Although several studies have used fuzzy MCDM approach for technology selection, however, most of the aforementioned approaches cannot develop defuzzification formulae from the membership functions of the final evaluation values, limiting the applicability of the existing fuzzy MCDM approach.

In this study, an extension of fuzzy MCDM approach for selecting solar PV energy technologies is proposed, where the ratings of PV technologies under various criteria and the weights of criteria are assessed in linguistic terms represented by triangular fuzzy numbers. Then, these values are averaged and normalized into a comparable
scale. Next, the normalized weighted ratings are derived by interval arithmetic of fuzzy numbers. To avoid complicated aggregation of fuzzy numbers, these normalized weighted ratings are defuzzified into crisp values using the left and right indices ranking approach. Finally, this study applies the proposed fuzzy MCDM approach to solve a PV technologies selection problem, illustrating its applicability and computational process.

The rest of the paper is organized as follows. Section 1 reviews the basic concepts of fuzzy sets theory. Section 2 proposes a fuzzy MCDM approach using left and right indices ranking approach. The proposed fuzzy MCDM approach is applied to solve the PV technology selection problem in Section 3. Finally, conclusions are drawn in Section 4.

1. Fuzzy sets theory

This section reviews some basic notions and definitions of fuzzy sets and fuzzy numbers as follows [8,10]:

**Definition 1.** A real fuzzy number \( A \) is described as any fuzzy subset of the real line \( R \) with membership function \( f_A \) that can be generally be defined as:

- (a) \( f_A \) is a continuous mapping from \( R \) to the closed interval \([0,1]\), \( 0 \leq \sigma \leq 1 \);
- (b) \( f_A(x) = 0 \), for all \( x \in (-\infty,a] \);
- (c) \( f_A \) is strictly increasing on \([a,b]\);
- (d) \( f_A(x) = \sigma \), for all \( x \in [b,c] \);
- (e) \( f_A \) is strictly decreasing on \([c,d]\);
- (f) \( f_A(x) = 0 \), for all \( x \in (d,\infty] \),

where \( a, b, c \) and \( d \) are real numbers. Unless elsewhere specified, it is assumed that \( A \) is convex and bounded (i.e. \(-\infty < a,d < \infty \)).

**Definition 2.** The fuzzy number \( A=[a,b,c,d;\sigma] \) is a trapezoidal fuzzy number if its membership function is given by:

\[
f_A(x) = \begin{cases} 
  f_A^L(x), & a \leq x \leq b, \\
  \sigma, & b \leq x \leq c, \\
  f_A^R(x), & c \leq x \leq d, \\
  0, & \text{otherwise,}
\end{cases}
\]

where \( f_A^L: [a,b] \rightarrow [0,\sigma] \) and \( f_A^R: [c,d] \rightarrow [0,\sigma] \) are two continuous mappings from the real line \( R \) to the closed interval \([0,\sigma]\). If \( \sigma = 1 \), then \( A \) is a normal fuzzy number; otherwise, it is said to be a non-normal fuzzy number. If \( f_A^L(x) \) and \( f_A^R(x) \) are both linear, then \( A \) is referred to as a trapezoidal fuzzy number and is usually denoted by \( A = (a,b,c,d;\sigma) \) or simply \( A = (a,b,c,d) \) if \( \sigma = 1 \). Figure 1 is an illustration of the trapezoidal fuzzy number \( A = (a,b,c,d;\sigma) \). In particular, when
The trapezoidal fuzzy number is reduced to a triangular fuzzy number, and can be denoted by \( A = (a, b, d; \sigma) \) or \( A = (a, b, d) \) if \( \sigma = 1 \). So, triangular fuzzy numbers are special cases of trapezoidal fuzzy numbers.

\[
A = [a, b, c, d]
\]

**Figure 1.** Trapezoidal fuzzy number.

**Definition 3.** \( \alpha \)-cuts of fuzzy numbers

The \( \alpha \)-cuts of fuzzy number \( A \) can be defined as 
\[
A^\alpha = \{ x \mid f_A(x) \geq \alpha \}, \quad \alpha \in [0, 1]
\]
where \( A^\alpha \) is a non-empty bounded closed interval contained in \( R \) and can be denoted by \( A^\alpha = [A^\alpha_L, A^\alpha_U] \), where \( A^\alpha_L \) and \( A^\alpha_U \) are its lower and upper bounds, respectively.

For example, if a triangular fuzzy number \( A = (a, b, d) \), then the \( \alpha \)-cuts of \( A \) can be expressed as:

\[
A^\alpha = [a^\alpha_L, a^\alpha_U] = [(b - a)\alpha + a, (b - d)\alpha + d]
\]

**Definition 4.** Arithmetic operations on fuzzy numbers

Given fuzzy numbers \( A \) and \( B \), where \( A, B \in R^+ \), the \( \alpha \)-cuts of \( A \) and \( B \) are \( A^\alpha = [A^\alpha_L, A^\alpha_U] \) and \( B^\alpha = [B^\alpha_L, B^\alpha_U] \), respectively. By the interval arithmetic, some main operations of \( A \) and \( B \) can be expressed as follows:

\[
(A \oplus B)^\alpha = [A^\alpha_L + B^\alpha_L, A^\alpha_U + B^\alpha_U]
\]

\[
(A \ominus B)^\alpha = [A^\alpha_L - B^\alpha_L, A^\alpha_U - B^\alpha_U]
\]

\[
(A \odot B)^\alpha = [A^\alpha_L \cdot B^\alpha_L, A^\alpha_U \cdot B^\alpha_U]
\]

\[
(A \oslash B)^\alpha = [A^\alpha_L / B^\alpha_L, A^\alpha_U / B^\alpha_U]
\]

\[
(A \odot r)^\alpha = [A^\alpha_L \cdot r, A^\alpha_U \cdot r], \ r \in R^+
\]
2. Proposed fuzzy MCDM approach

In this section, an extension of fuzzy MCDM approach is developed for supporting the PV technology selection and evaluation selection process by the following procedure:

2.1. Aggregate ratings of alternative versus criteria

Assume that a committee of \( l \) decision makers \((M_t, t = 1, \ldots, l)\) is responsible for evaluating \( m \) alternatives \((A_i, i = 1, \ldots, m)\) under \( n \) selection criteria \((C_j, j = 1, \ldots, n)\). A MCDM problem can be concisely expressed in matrix format as:

\[
A = \begin{bmatrix}
A_1 & \cdots & A_m
\end{bmatrix}
\]

where

\[
M_t = \begin{bmatrix}
x_{11} & \cdots & x_{1n} \\
x_{21} & \cdots & x_{2n} \\
\vdots & \cdots & \vdots \\
x_{m1} & \cdots & x_{mn}
\end{bmatrix}
\]

Let \( x_{ij} = (a_{ij}, b_{ij}, c_{ij}) \), \( i = 1, \ldots, m, j = 1, \ldots, n, t = 1, \ldots, l \), be the suitability rating assigned to alternative \( A_i \) by decision maker \( M_t \) for subjective \( C_j \). The averaged suitability rating, \( x_{ij} = (a_{ij}, b_{ij}, c_{ij}) \), can be evaluated as:

\[
x_{ij} = \frac{1}{l} \sum_{t=1}^{l} x_{ij}
\]

where \( a_{ij} = \frac{1}{l} \sum_{t=1}^{l} a_{ij}, b_{ij} = \frac{1}{l} \sum_{t=1}^{l} b_{ij}, \) and \( c_{ij} = \frac{1}{l} \sum_{t=1}^{l} c_{ij} \).

2.2. Aggregate the importance weights

Let \( w_{ij} = (o_{ij}, p_{ij}, q_{ij}) \), \( w_{ij} \in \mathbb{R}, j = 1, \ldots, n, t = 1, \ldots, l \) be the weight assigned by decision maker \( M_t \) to criterion \( C_j \). The averaged weight, \( w_j = (o_j, p_j, q_j) \), of criterion \( C_j \) assessed by the committee of \( l \) decision makers can be evaluated as:

\[
w_j = \frac{1}{l} \sum_{t=1}^{l} w_{ij}
\]

where \( o_j = \frac{1}{l} \sum_{t=1}^{l} o_{ij}, p_j = \frac{1}{l} \sum_{t=1}^{l} p_{ij}, q_j = \frac{1}{l} \sum_{t=1}^{l} q_{ij} \).

2.3. Normalize performance of alternatives versus criteria

In this paper, criteria are classified into benefit (B) and cost (C) criteria. A benefit criterion has the characteristic of “the larger the better”. The cost criterion has the characteristic of “the smaller the better”. To ensure compatibility between average
ratings and average weights, the average ratings are normalized into comparable scales. Suppose \( r_i = (e_i, f_i, g_i) \) is the performance of alternative \( i \) on criteria \( j \). The normalized value \( x_{ij} \) can then be denoted as [4]:

\[
x_{ij} = \left( \frac{e_i}{g_j}, \frac{f_i}{g_j}, \frac{g_i}{g_j} \right), j \in B; \quad x_{ij} = \left( \frac{e_i^r \cdot e_j^r}{g_n}, \frac{f_i^r}{f_j^r}, \frac{g_i^r}{g_j^r} \right), j \in C
\]

(10)

where \( e_i^r = \min e_{ij} \), \( g_i^r = \max g_{ij}, i = 1, \ldots, m, j = 1, \ldots, n \).

2.4. Develop a membership function of each normalized weighted rating

The membership function of each final fuzzy evaluation value, i.e. \( G_i = \left( \frac{1}{n} \sum_{j=1}^{n} r_i \otimes w_j \right), \ i = 1, \ldots, m, j = 1, \ldots, n \) can be derived by the interval arithmetic of fuzzy numbers. By Equations (2), (3), and (5), the \( \alpha \)-cuts of \( G_i \) can be expressed as follows:

\[
G_i^\alpha = \left( \frac{1}{n} \sum_{j=1}^{n} \left( r_i \otimes w_j \right)^\alpha \right)
\]

\[
= \left[ \left( \frac{1}{n} \sum_{j=1}^{n} \left( f_i - e_i \right) \left( p_i - o_j \right) \right) \alpha^2 + \left( \frac{1}{n} \sum_{j=1}^{n} \left( e_i \left( p_i - o_j \right) + o_j \left( f_i - e_i \right) \right) \right) \alpha + \left( \frac{1}{n} \sum_{j=1}^{n} \right) \right],
\]

(11)

Two equations to solve, namely:

\[
A_1 \alpha^2 + B_1 \alpha + Q_1 + x = 0
\]

(12)

\[
A_2 \alpha^2 + B_2 \alpha + Z_2 - x = 0
\]

(13)

where

\[
A_1 = \left( \frac{1}{n} \sum_{j=1}^{n} \left( f_i - e_i \right) \left( p_i - o_j \right) \right), \quad B_1 = \left( \frac{1}{n} \sum_{j=1}^{n} \left( e_i \left( p_i - o_j \right) + o_j \left( f_i - e_i \right) \right) \right),
\]

\[
A_2 = \left( \frac{1}{n} \sum_{j=1}^{n} \left( f_i - g_i \right) \left( p_i - q_j \right) \right), \quad B_2 = \left( \frac{1}{n} \sum_{j=1}^{n} \left( g_i \left( p_i - q_j \right) + q_j \left( f_i - g_i \right) \right) \right),
\]

\[
Q_1 = \left( \frac{1}{n} \sum_{j=1}^{n} \right), \quad Y_i = \left( \frac{1}{n} \sum_{j=1}^{n} f_i p_j \right), \quad Z_2 = \left( \frac{1}{n} \sum_{j=1}^{n} g_i q_j \right).
Only the roots in [0,1] will be retained in (12) and (13). The left and right membership functions $f_G^L(x)$ and $f_G^R(x)$ of $G_i$ can be calculated as:

\begin{align*}
  f_G^L(x) &= \left\{ -B_0 + [B_0^2 + 4A_0(x-Q_i)]^{1/2} \right\} / 2A_0, \quad Q_i \leq x \leq Y_i, \\
  f_G^R(x) &= \left\{ -B_0 - [B_0^2 + 4A_0(x-Z_i)]^{1/2} \right\} / 2A_0, \quad Y_i \leq x \leq Z_i,
\end{align*}

(14)

(15)

For convenience, $G_i$ is expressed as:

\[ G_i = (Q_i, Y_i, Z_i; A_{i,r}, B_{i,r}; A_{i,l}, B_{i,l}), i = 1, \ldots, m, j = 1, \ldots, n \]

### 2.5. Obtain the Ranking Values

This paper applies Dat et al.’s [6] ranking method to defuzzify all the final fuzzy evaluation values $G_i$. Using Dat et al.’s [6] method, the left and right indices values of $G_i$ are given by:

\begin{align*}
  x_L &= \gamma^2 A_{i,r} + \gamma B_{i,r} + Q_i \\
  x_R &= \gamma^2 A_{i,l} + \gamma B_{i,l} + Z_i
\end{align*}

(16)

(17)

Then, the subtractions of left relative values from right relative values of $G_i$ with index of optimism $\alpha = 0.5$ and decision levels $\gamma = 0.5$, are defined as:

\[ D_{0.5}^{0.5}(G_i) = \frac{A_{i,l} + A_{i,r} + B_{i,l} + B_{i,r} + (\alpha Q_i + Z_i)}{4} - \frac{x_{\min} + x_{\min}}{2} \]

(18)

The greater the $D_{0.5}^{0.5}(G_i)$, the bigger the fuzzy number $A_i$ and the higher its ranking order.

### 3. Application for PV technologies selection and evaluation problem

In this section, the proposed fuzzy MCDM approach is applied to solve a PV technologies selection problem.

In order to achieve the desired output with minimum cost and specific application, PV technology selection has been an important issue for companies. Assume that a manufacturing company must select a suitable PV technology for a production process. After preliminary screening, five PV technologies, i.e. $A_1, A_2, A_3, A_4$, and $A_5$, (can be selected from Table 1) are identified for further evaluation. A committee of three decision makers, i.e. $M_1, M_2$, and $M_3$, is formed to conduct the selection of the five technologies. Further, suppose five criteria are considered including innovation of technology ($C_1$), technology supportability ($C_2$), existing market share ($C_3$), potential
market size ($C_4$), and environmental risk ($C_5$) [13]. The computational procedure is summarized as follows:

**Step 1. Aggregate ratings of alternatives versus criteria**

Assume that the decision makers use the linguistic rating set $S = \{VL, L, M, H, VH\}$, where $VL = \text{Very Low} = (0.0, 0.1, 0.3)$, $L = \text{Low} = (0.2, 0.4, 0.5)$, $M = \text{Medium} = (0.4, 0.5, 0.7)$, $H = \text{High} = (0.6, 0.8, 0.9)$, and $VH = \text{Very High} = (0.8, 0.9, 1.0)$, to evaluate the suitability of the PV technologies under each criteria. Table 2 presents the suitability ratings of alternatives versus five criteria. By using equation (8), the aggregated suitability ratings of five technologies versus five criteria from three decision makers, can be obtained as shown in Table 2.

**Table 2. Rating of alternatives versus criteria**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>PV Technologies</th>
<th>Decision makers</th>
<th>$r_{ij}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_1$</td>
<td>$A_1$</td>
<td>$M_1$</td>
<td>0.533, 0.700, 0.833</td>
</tr>
<tr>
<td></td>
<td>$A_2$</td>
<td>$M_2$</td>
<td>0.733, 0.867, 0.967</td>
</tr>
<tr>
<td></td>
<td>$A_3$</td>
<td>$M_3$</td>
<td>0.600, 0.800, 0.900</td>
</tr>
<tr>
<td></td>
<td>$A_4$</td>
<td>$M_4$</td>
<td>0.733, 0.867, 0.967</td>
</tr>
<tr>
<td></td>
<td>$A_5$</td>
<td>$M_5$</td>
<td>0.400, 0.500, 0.700</td>
</tr>
<tr>
<td></td>
<td>$A_6$</td>
<td>$M_6$</td>
<td>0.667, 0.833, 0.933</td>
</tr>
<tr>
<td></td>
<td>$A_7$</td>
<td>$M_7$</td>
<td>0.800, 0.900, 1.000</td>
</tr>
<tr>
<td>$C_2$</td>
<td>$A_1$</td>
<td>$M_1$</td>
<td>0.667, 0.833, 0.933</td>
</tr>
<tr>
<td></td>
<td>$A_2$</td>
<td>$M_2$</td>
<td>0.600, 0.800, 0.900</td>
</tr>
<tr>
<td></td>
<td>$A_3$</td>
<td>$M_3$</td>
<td>0.667, 0.833, 0.933</td>
</tr>
<tr>
<td></td>
<td>$A_4$</td>
<td>$M_4$</td>
<td>0.467, 0.600, 0.767</td>
</tr>
<tr>
<td></td>
<td>$A_5$</td>
<td>$M_5$</td>
<td>0.467, 0.600, 0.767</td>
</tr>
<tr>
<td>$C_3$</td>
<td>$A_1$</td>
<td>$M_1$</td>
<td>0.733, 0.867, 0.967</td>
</tr>
<tr>
<td></td>
<td>$A_2$</td>
<td>$M_2$</td>
<td>0.667, 0.833, 0.933</td>
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<tr>
<td></td>
<td>$A_3$</td>
<td>$M_3$</td>
<td>0.600, 0.800, 0.900</td>
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<tr>
<td></td>
<td>$A_4$</td>
<td>$M_4$</td>
<td>0.600, 0.800, 0.900</td>
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<tr>
<td></td>
<td>$A_5$</td>
<td>$M_5$</td>
<td>0.800, 0.900, 1.000</td>
</tr>
<tr>
<td>$C_4$</td>
<td>$A_1$</td>
<td>$M_1$</td>
<td>0.733, 0.867, 0.967</td>
</tr>
<tr>
<td></td>
<td>$A_2$</td>
<td>$M_2$</td>
<td>0.400, 0.500, 0.700</td>
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<td>$A_3$</td>
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<tr>
<td></td>
<td>$A_4$</td>
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</tr>
<tr>
<td></td>
<td>$A_5$</td>
<td>$M_5$</td>
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</tr>
<tr>
<td>$C_5$</td>
<td>$A_1$</td>
<td>$M_1$</td>
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</tr>
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<td></td>
<td>$A_2$</td>
<td>$M_2$</td>
<td>0.467, 0.600, 0.767</td>
</tr>
<tr>
<td></td>
<td>$A_3$</td>
<td>$M_3$</td>
<td>0.400, 0.500, 0.700</td>
</tr>
</tbody>
</table>

**Step 2. Aggregate the importance weights**

Also assumes that the decision makers apply a linguistic weighting set $W = \{UI, OI, I, VI, AI\}$, where $UI = \text{Unimportance} = UI = (0.0, 0.1, 0.3)$, Ordinary
Importance = OI = (0.2, 0.3, 0.5), I = Importance = (0.3, 0.5, 0.7), Very Importance = VI = (0.6, 0.8, 1.0), and Absolutely Importance = AI = (0.8, 0.9, 1.0), to assess the importance of all the criteria. Table 3 displays the importance weights of five criteria from the three decision-makers. By using equation (9), the aggregated weights of criteria from the decision making committee can be obtained as presented in Table 3.

Table 3. The importance weights of the criteria and the aggregated weights

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Decision makers</th>
<th>( w_j )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( M_1 )</td>
<td>( M_2 )</td>
</tr>
<tr>
<td>( C_1 )</td>
<td>AI</td>
<td>AI</td>
</tr>
<tr>
<td>( C_2 )</td>
<td>I</td>
<td>I</td>
</tr>
<tr>
<td>( C_3 )</td>
<td>I</td>
<td>I</td>
</tr>
<tr>
<td>( C_4 )</td>
<td>VI</td>
<td>AI</td>
</tr>
<tr>
<td>( C_5 )</td>
<td>I</td>
<td>VI</td>
</tr>
</tbody>
</table>

**Step 3.** Develop the membership function of each normalized weighted rating

The final fuzzy evaluation values can be developed via arithmetic operation of fuzzy numbers by using equations (11) - (15).

**Step 4.** Defuzzification

Using equations (16) - (18), the left, right indices, and the subtraction of left relative value from right relative value of each PV technology \( A_i \) with \( \alpha = 1/2 \) and \( \gamma = 1/2 \) can be obtained, as shown in Table 4.

According to Table 4, the ranking order of the five PV technologies is \( A_5 \succ A_2 \succ A_4 \succ A_3 \succ A_1 \). Thus, the best selection is \( A_5 \).

Table 4. The left indices, right indices, and subtraction value of each alternative

<table>
<thead>
<tr>
<th>PV technologies</th>
<th>( x_L (A_i) )</th>
<th>( x_R (A_i) )</th>
<th>( D^L_{R_0} (A_i) )</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A_1 )</td>
<td>0.398</td>
<td>0.598</td>
<td>-0.017</td>
<td>4</td>
</tr>
<tr>
<td>( A_2 )</td>
<td>0.451</td>
<td>0.640</td>
<td>0.031</td>
<td>2</td>
</tr>
<tr>
<td>( A_3 )</td>
<td>0.449</td>
<td>0.653</td>
<td>0.036</td>
<td>1</td>
</tr>
<tr>
<td>( A_4 )</td>
<td>0.401</td>
<td>0.601</td>
<td>-0.014</td>
<td>3</td>
</tr>
<tr>
<td>( A_5 )</td>
<td>0.348</td>
<td>0.587</td>
<td>-0.047</td>
<td>5</td>
</tr>
</tbody>
</table>

**4. Conclusion**

The selection and development of industrial technologies can affect a company's technological strategy portfolio and future competitiveness. In order to reflect the uncertainty of human thought, this study developed an extension of fuzzy MCDM for the PV technologies selection problem, where the importance weights of different criteria and the ratings of various technologies under different subject criteria are assessed by triangular fuzzy numbers. The membership function of each weighted rating of each technology versus each criterion was clearly developed. To make the procedure easier and more practical, the normalized weighted ratings were defuzzified into crisp values by using a novel ranking approach based on left and right indices. A numerical example was used illustrating the applicability and computational process of proposed method. The results indicated that the proposed fuzzy MCDM approach is practical and useful. The proposed approach can also be applied to other management problems.
References


