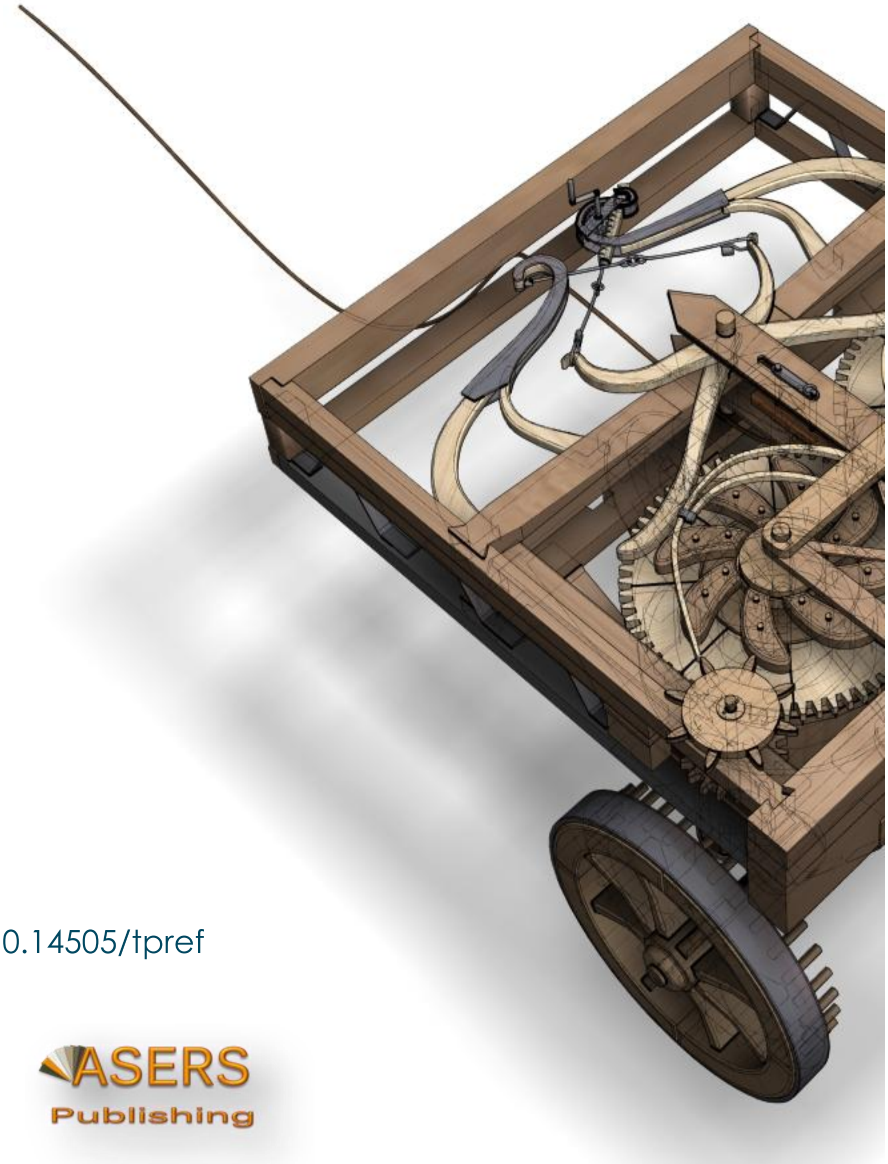
Theoretical and Practical Research in Economic Fields



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Environmental Policy Selection Based on Linear-Times-Exponential One-Switch Utility Function and ELECTRE I Method

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Abstract: This paper examines how utility functions perform in tackling the multicriteria decision-making problem, especially one-switch utility function. Linear-times-exponential one-switch, exponential, and linear utility functions are implemented, which transforms corresponding criteria into utilities with ELECTRE I method. The detailed formulation of the decision model is presented. A numerical example about environmental policy selection is introduced to illustrate the use of the new decision model. With different wealth levels and utility functions for a policymaker, the inconsistent outranking policies illustrate the special characteristic of linear-times-exponential one-switch utility function whose initial wealth level has a significant impact on the outranking environmental policy. This study is also the first study applying one-switch utility function in address/ing multicriteria decision-making problem.

Keywords: multicriteria decision making; one-switch utility function; linear-times-exponential utility function; ELECTRE I method; environmental policy selection.

JEL Classification: D81; Q50.

Introduction

Decision-making problems involving a single criterion allow for relatively straightforward ranking or selection among a list of alternatives. This is not the case, however, in the context of facing several criteria when a decision maker (DM) evaluates alternatives according to multiple criteria. In such cases, the interference and limitation of different units of criteria, different quantitative or qualitative information, etc. can complicate direct comparisons, making it challenging for DMs to accurately and efficiently select the best alternative. So, a DM has to face multicriteria decision-making (MCDM) problems and MCDM methods which contribute to help DMs select the best alternative when they evaluate more than one criterion in a MCDM problem.

In this study, the ELECTRE I (ÉLimination Et Choix Traduisant la REalité) method (Roy, 1968) is applied to construct a new decision model. Almeida (2002, 2005, 2007) applied utility functions in ELECTRE I method but the gap is that solely the power utility function and exponential utility functions are applied. In practical situations, a utility function of wealth, the one-switch utility function (Bell, 1988), is applied in this study. The new decision model with the combination of ELECTRE I method and the one-switch utility function is introduced and a numerical problem associated with the environmental policy selection is used to prove this new model is applicable and creates a foundation for further resolving practical environmental problem.

There are four contributions of this study. First, we further explore how the utility functions perform in ELECTRE I method by using linear-times-exponential one-switch utility function instead of solely linear or exponential utility function. Second, with different initial wealth levels of a policymaker, the one-switch utility function makes the outranking alternatives different, which is illustrated by a numerical example. Third, the numerical example also proves that this new decision model which consists of linear-times-exponential one-switch utility function and ELECTRE I method is able to address the problem of selection of outranking environmental policy. Lastly, this is also the pioneered study applying linear-times-exponential one-switch utility function in ELECTRE I to resolve a MCDM problem, which extends the study of one-switch utility function in a practical direction rather than theoretical one.

1. Literature Review

MCDM methods have been applied to solve practical problems across various domains, including transportation (Liu *et al.* 2023; Maserrat *et al.* 2024; Tian *et al.* 2023), renewable energy (Wu *et al.* 2018; Akpahou *et al.* 2024; Li *et al.* 2024), supplier selection (Aal, 2024; Abdulla and Baryannis, 2024; Chakraborty *et al.* 2024), location selection (Nafi'Shehab *et al.* 2024; Topaloğlu, 2024; Karbassi *et al.* 2025), environmental studies (Akram *et al.* 2021), and personnel selection (Gottwald *et al.* 2024; Pinto-DelaCadena *et al.* 2024; Ait Bahom *et al.* 2025). In addition, the emission of greenhouse gases (GHGs) is one of the most severe environmental issues currently. There are also studies addressing MCDM problems associated with GHGs. For example, Lee *et al.* (2008) evaluated the greenhouse gas technologies based on the hybrid model in MCDM problem; Marzouk and Mohammed Abdelkader (2019) compared different MCDM methods by evaluating sustainable construction alternatives which can minimize the emissions of GHGs; Narayanamoorthy *et al.* (2021) used two MCDM methods to select the best alternative fuel based on several criteria including CO2 emission levels.

The ELECTRE (ÉLimination Et Choix Traduisant la REalité) family of methods is a notable approach in MCDM. The ELECTRE I method was first formally introduced in detail by Roy (1968). Over time, several variations including have emerged, including ELECTRE II (Roy and Bertier, 1971), ELECTRE III (Roy, 1978), ELECTRE IV (Roy and Hugonnard, 1982), ELECTRE TRI (Yu, 1992), and ELECTRE IS (Roy and Bouyssou, 1993), each differing in their specific methodologies. For instance, ELECTRE IS method which is similar to ELECTRE I method uses the pseudo-criteria rather than true criteria and ELECTRE II method introduces two outranking relations (strong and weak) instead of just one outranking relation in ELECTRE I method. Additionally, ELCTRE III method combines features of ELECTRE II and ELECTRE IS method while ELECTRE IV method is similar to ELECTRE III method without requiring a set of weights from DMs.

As the foundation of ELECTRE method, ELECTRE I (Roy, 1968) has three main concepts including the threshold value, concordance index and discordance index, which is designed for addressing selection problems instead of ranking in ELECTRE II, ELECTRE III, and ELECTRE IV or sorting in ELECTRE TRI (Almedia, 2005; Taherdoost and Madanchian, 2023). It aims to search for the outranking relations in the list of alternatives by pairwise comparisons. The values of alternatives are used directly in the procedures of ELECTRE I method but are the utility values obtained by subjecting true values of alternatives into utility functions applicable in the ELECTRE I method? Almeida (2002, 2005, 2007) applied utility functions in ELECTRE I method, which tackles the repair contract problem and outsourcing contracts selection problem in order to verify the effectiveness and validity of the new model. Brito *et al.* (2010) also applied utility function in ELECTRE TRI method to sort natural gas pipelines. However, the further exploration and extension of ELECTRE I method by using utility function remains limited. This study extends the ELECTRE I method by incorporating the linear-times-exponential utility function, a type of one-switch utility functions, and then applies it to a numerical example involving environmental policy selection to show the use of the proposed new model.

In addition, Bell (1988) introduced one-switch rule and one-switch utility functions based on expected utility theory initially developed by von Neumann and Morgenstern (vNM) in 1944. In accordance with the axioms of vNM expected utility theory, one-switch utility functions not only aim to identify the alternative with higher utility but also account for the at-most-once switch in preference dependent on the increase of wealth level. Bell (1988) noted that for a DM with one-switch utility functions, the preference to an alternative depends on the wealth level and with the increase of wealth level so the preference to one alternative will change to another one at most once. There are only four one-switch utility functions including quadratics, linear-plus-exponential, linear-times-exponential, and sumex utility functions.

There has been theoretical research about one-switch utility functions (Bell and Fishburn, 2001; Denuit *et al.* 2013; Abbas and Bell, 2015) and also about Markov decision problem (Liu and Koenig, 2005; Zeng *et al.* 2014). In addition, evaluating the measures of value of information, Bakır and Klutke (2011) discussed the conditions under which the methods of expected utility increase, the selling price method and the buying price method make an agreement in decision-making situations with linear-plus-exponential one-switch utility function, which is the only function which a decision maker keeps risk consistent as he or she gets wealthier. In addition, the demand of information before making decisions is relatively significant to the utility functions depending on the initial wealth levels. The case of quadratics one-switch utility function was considered by Abbas *et al.* (2013), who state that the value of information is monotonic to the risk aversion only in quadratic utility function. Their research applied buying price of information and also the information was also divided into perfect information and partition information. Bakır (2017) further investigated the relationship between risk aversion and the value of information with sumex and linear-times-exponential one-switch utility function. In mathematical economics, Denuit *et al.*

(2013) found that the linear-plus-exponential one-switch utility function satisfies the conditions of Ross DARA and DAP. Also, the linear-plus-exponential one-switch utility function is used to investigate a decision maker's risk-taking behaviors in response to changes in background risks in decreasing Ross risk aversion. However, the application of one-switch utility function in solving MCDM problem has not been explored before. So, this study demonstrates how one-switch utility function can be employed to resolve a MCDM problem.

2. Methodology

2.1 ELECTRE I

ELECTRE methods can be seen as outranking approaches. Specifically, ELECTRE I method contributes to help a DM choose one most preferable alternative when considering various criteria and make each criterion acceptable to the DM with satisfaction (Subramanian and Gershon, 1991). The explicit steps of ELECTRE I are explained as follows (Pohekar and Ramachandran, 2004; Milani *et al.* 2006; Alper and Başdar, 2017; Silvia *et al.* 2018; Tiwari, 2020; Ozsahin *et al.* 2021):

Step 1: Constructing the Decision Matrix (A_{mn}).

The alternatives and criteria are combined in a matrix. In the row, the alternatives are presented whereas the criterion is presented in the column. For example, with m-alternatives and n-criteria, then a decision matrix A_{mn} can be represented as follows:

$$A_{mn} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix},$$

where a_{mn} is the evaluation score for the alternative m with the criterion n, where $m \geq 1$, and $n \geq 1$.

Step 2: Calculating the Normalized Decision Matrix

After constructing the initial matrix above, the elements in normalized decision matrix X can be created by using the formula below with the elements in the decision matrix A_{mn}. The criteria can be classified into two types: benefit criteria and cost criteria. More specifically, benefit criteria represent gains or positive criteria while cost criteria represent losses or negative criteria. The better the performance of an alternative on a benefit criterion has, the higher desire a DM has on this alternative. The lesser the performance of an alternative on a cost criterion has, the higher desire a DM has on this alternative. If there are n criteria totally and the first t criteria are benefit criteria and the rests are cost criteria. The formula used for benefit criterion is: $x_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^{t} a_{kj}^2}}$, where $i = 1,2,\dots,m,\ \ j = 1,2,t,\dots,n$. The formula used for cost criterion is: $x_{ij} = \frac{{}^{1}/{}_{a_{ij}}}{\sqrt{\sum_{k=t+1}^{n}\left(\frac{1}{a_{kj}}\right)^2}}$, where $i = 1,2,\dots,m,\ \ j = 1,2,t,\dots,n$. So, the normalized decision matrix X is in the following form: $X_{mn} = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix}$.

Step 3: Weighting the Normalized Decision Matrix

The difference in significance of the assessment factors depends on each individual DM. The DM should determine the weights of the assessment factors with $\sum_{j=1}^{n} w_j = 1$.

Then, the weighted normalized decision matrix Y can be calculated by multiplying the elements in X_{mn} with the corresponding w_j values. The weighted normalized decision matrix Y with elements is expressed as:

$$Y = \begin{bmatrix} w_1x_{11} & w_2x_{12} & \cdots & w_nx_{1n} \\ w_1x_{21} & w_2x_{22} & \cdots & w_nx_{2n} \\ \vdots & \cdots & \ddots & \vdots \\ w_1x_{m1} & w_2x_{m2} & \cdots & w_nx_{mn} \end{bmatrix} = \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{22} & \cdots & y_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ y_{m1} & y_{m2} & \cdots & y_{mn} \end{bmatrix},$$

where w_j is the weight of *j*th criterion and the sum of w_j is 1.

Step 4: Determination of Concordance Sets Discordance Sets

The sets of concordance and discordance can be determined by the matrix Y. Each criterion is considered to make paired comparisons for each alternative. For example, with alternative A_p and A_q, where $p, q \in (1,\dots,m)$ and $p \neq q$, if alternative A_p is preferred to or equivalent to alternative A_q, then, a concordance set is $C_{pq} = \{j | y_{pj} \geq y_{qj}\}$, where j is the criterion. If alternative A_p is worse than alternative A_q, then a discordance set is $D_{pq} = \{j | y_{pj} \leq y_{qj}\}$, where j is the criterion. In ELECTRE method, each concordance set has a corresponding discordance set as a supplement set.

Step 5: Calculation of Concordance and Discordance Indices and Matrices

The concordance sets are used to create concordance matrix C. Matrix C is $m \times m$ in size and does not take a value where $p = q$. The elements in matrix C are calculated by $c_{pj} = \sum_j w_j$, where j is the factor (s) in the concordance set C_{pq}. Matrix C is expressed as follows:

$$C = \begin{bmatrix} - & c_{12} & c_{13} & \cdots & c_{1m} \\ c_{21} & - & c_{23} & \cdots & c_{2m} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ c_{m1} & c_{m2} & c_{m3} & \cdots & - \end{bmatrix}.$$

The discordance matrix D consists of set of discordances. It is $m \times m$ in measure and does not take a value where $p = q$. The elements in matrix D are calculated by:

$$d_{pq} = \frac{\max\left|y_{pj^0} - y_{qj^0}\right|}{\max\left|y_{pj} - y_{qj}\right|_{\forall j}},$$

where j^0 is the factor in the discordance set D_{pq} and $\forall j$ are all criteria.

Matrix D is expressed as follows:

$$D = \begin{bmatrix} - & d_{12} & d_{13} & \cdots & d_{1m} \\ d_{21} & - & d_{23} & \cdots & d_{2m} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ d_{m1} & d_{m2} & d_{m3} & \cdots & - \end{bmatrix}.$$

Step 6: Creation of Concordance Superiority (F) and Discordance Superiority (G) matrix

The concordance superiority matrix F is $m \times m$ in size. We evaluate the concordance limit $(\underline{c})$ with elements c_{pq} in concordance matrix.

$$\underline{c} = \frac{1}{m(m-1)} \sum_{p=1}^{m} \sum_{q=1}^{m} c_{pq}.$$

The elements f_{pq} compose matrix F out of 1 or 0 with no value in its diagonal.

$$f_{pq} = \begin{cases} 1, \text{if } c_{pq} \geq \underline{c} \\ 0, \text{if } c_{pq} < \underline{c} \end{cases}.$$

The discordance superiority matrix (G) is $m \times m$ in size. We evaluate the concordance limit $(\underline{d})$ with elements c_{pq} in discordance matrix.

$$\underline{d} = \frac{1}{m(m-1)} \sum_{p=1}^{m} \sum_{q=1}^{m} d_{pq}.$$

The elements g_{pq} compose matrix G out of 1 or 0 with no value in its diagonal.

$$g_{pq} = \begin{cases} 1, \text{if } d_{pq} \geq \underline{d} \\ 0, \text{if } d_{pq} < \underline{d} \end{cases}.$$

Step 7: Creation of Aggregate Dominance Matrix (E)

The aggregate dominance matrix, which is $m \times m$ in size, consists of the element-wise product of f_{pq} and g_{pq} in matrix F and G above. The component e_{pq} is 1 or 0.

$$E = \begin{bmatrix} - & e_{12} & e_{13} & \cdots & e_{1m} \\ e_{21} & - & e_{23} & \cdots & e_{2m} \\ e_{31} & e_{32} & - & \cdots & e_{3m} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ e_{m1} & e_{m2} & e_{m3} & \cdots & - \end{bmatrix}.$$

Step 8: Determination of the Orders of Policies

The matrix E above shows the decision points. The component $e_{pq} = 1$ is considered that the action p outranks the action q. Following the eight steps above, a DM can find out which alternative outranks the others with several criteria.

2.2 One-Switch Utility Function

There are four types of one-switch utility functions including quadratic, linear-plus-exponential, linear-times-exponential, and sumex utility functions (Bell, 1988). Among these four types of one-switch utility functions, a DM with the linear-plus-exponential utility function is decreasingly risk-averse and with the sumex utility function is increasingly and decreasingly risk-averse. It is seemingly natural, reasonable, and appropriate to assume that a

DM is decreasingly risk-averse in research because a DM may accept more risky alternatives when he or she becomes wealthier (Sheng, 1984) but we assume that a policymaker tends to avoid risky alternatives in policy selection in this study because with the long-lasting impact of an environmental policy, a policymaker is likely to keep hating or avoiding risks against the long-term potential negative impacts of that policy even though the policymaker has a higher wealth level. So, this implies that a DM continues to hate or try to avoid risks even though he or she becomes wealthier. The quadratic utility function has been applied in many MCDM research such as Malakooti (1993), Farahani and Asgari (2007), Wu and Tiao (2018), Alizadeh and Yousefi (2019), and so on. As Li (2022) reviewed about the applications of one-switch utility functions, however, studies associated with the linear-times-exponential utility function are still a few including only Anchugina (2017) which introduced one-switch discount utility function and Bakır (2017) which explored the relationship between the value of information and risk aversion. This study pioneers the integration of the linear-times-exponential one-switch utility function with ELECTRE I method to address a MCDM problem.

The linear-times-exponential utility function satisfies the one-switch rule for any choice of parameter b, h, s and l with w for wealth level which is the sum of a DM's initial wealth level, x, and the return of an alternative selected, r.

$$\mathrm{u(w)} = (\mathrm{bw} + \mathrm{h}) \cdot \mathrm{e}^{\mathrm{sw}} + \mathrm{l}.$$

3. Problem Description

Selecting the most effective or the best policy is a pivotal objective for a policymaker, especially facing with a variety of criteria. While facing environmental policies which can reduce the emission of greenhouse gases (GHGs), a policymaker needs to consider several criteria to find the outranking policy. Three relatively important criteria in this case are considered, including financial returns, costs, and the reduced amount of GHGs by the policy. More specifically, the financial returns which can be generated by applying one policy and obtained by the policy-making authorities include the tax revenues, investments, and so on, which have been used in resolving previous MCDM problems such as Ren *et al.* (2009), Džiugaitė-Tumėnienė *et al.* (2017), Ferrer-Martí *et al.* (2018), Yang *et al.* (2018), and Vasić (2018); the costs of an environmental policy include the direct costs of applying one policy such as the purchase of tools, building of infrastructures and so forth, and the indirect costs such as costs of developing new technologies or equipment, which have been applied in the MCDM research such as Yang *et al.* (2018), Babatunde *et al.* (2019), Seddiki and Bennadji (2019), and Parvaneh and Hammad (2024); Lastly, the reduced amount of GHGs of one policy is about how much amount of GHGs can be reduced by implementing one environmental policy in metric tons. This criterion has been considered as one of the environmental criteria in MCDM research such as Ekholm *et al.* (2014), Väisänen *et al.* (2016), Džiugaitė-Tumėnienė *et al.* (2017), Yang *et al.* (2018), Babatunde *et al.* (2019), and so forth. In this study, only these three criteria are considered based on utility functions and ELECTRE I method. In real cases, it is possible to have more criteria in the selection process but the main goal of this study is to consider these three criteria in a numerical example below to prove the applicability of the new model so three comparatively critical criteria in the selection of environmental policy which can reduce the GHGs including the reduced amount of GHGs, financial return of a policy, and costs of a policy, are solely considered in this study.

The action space corresponding to a set of environmental policies available to an environmental policymaker. A policy as an element in the set is represented by $\mathrm{a_i}$, where $\mathrm{i} = 1,2, \dots, \mathrm{m}$. The discrete policies in the set with m elements are represented by $\{\mathrm{a_1}, \mathrm{a_2}, \dots, \mathrm{a_m}\}$. Each element in this set is corresponding to one environmental policy faced by a policymaker. Five policies are considered in this study so $\mathrm{m} = 5$.

There are three criteria considered in this case, including financial returns, costs, and reduced amount of GHGs so $\mathrm{n} = 3$. Therefore, one policy $\mathrm{p_i}$ is associated with corresponding financial return $\mathrm{r_j}$, cost $\mathrm{c_j}$, and reduced amount of GHGs $\mathrm{k_j}$, where $\mathrm{j} = 1, \dots, \mathrm{n}$. Thus, the decision matrix $\mathrm{A_{mn}}$ is:

$$\mathrm{A_{53}} = \begin{bmatrix} \mathrm{a_{11}} & \mathrm{a_{12}} & \mathrm{a_{13}} \\ \mathrm{a_{21}} & \mathrm{a_{22}} & \mathrm{a_{23}} \\ \mathrm{a_{31}} & \mathrm{a_{32}} & \mathrm{a_{33}} \\ \mathrm{a_{41}} & \mathrm{a_{42}} & \mathrm{a_{43}} \\ \mathrm{a_{51}} & \mathrm{a_{52}} & \mathrm{a_{53}} \end{bmatrix}.$$

The main objective of this study is to figure out which policy outranks the others by a policymaker while considering three different criteria.

4. Decision Model

Almeida (2002, 2005, 2007) introduced a new decision model, which considers utility functions and probability density functions in ELECTRE I method to address MCDM selection problems. However, Almeida's implementation was limited to linear and exponential utility functions, which Bell (1988) classified as zero-switch utility functions. The values of utility are analysed in the procedure of ELECTRE I to find the outranking relations. So, in order to innovate our decision model, not only is the ELECTRE I method integrated with utility functions which transform values in three criteria into utility but also the one-switch utility function is applied. One-switch utility functions are the utility functions of wealth, which implies that the wealth level has an impact on the preference of alternatives. So, we propose that while a policymaker is facing a list of environmental policies with three criteria above, the initial wealth level owned by a policymaker is a contributing factor in the utility function of financial returns and then impacts the preference of policy and outranking policy. The linear-times-exponential one-switch utility function is applied in the financial returns of an environmental policy to describe a policymaker's decision-making behaviour in this study, which is $u(w) = (bw + h) \cdot e^{sw} + l$, where w is the sum of a policymaker's initial wealth level x, and the return of an environmental policy, r. Almeida (2002, 2005, 2007) give values of utility functions in the numerical example in order to check if the model is feasible or not. Therefore, for the numerical example in this study below, more specifically, here is the specific settings of the parameters: $b = 5$, $h = 10$, $s = -0.01$, and $l = 10$. So, the linear-times-exponential one-switch utility function is as follows:

$$u(w) = (5w + 10) \cdot e^{-0.01w} + 10.$$

Exploring how the initial wealth level of a policymaker can impact the rankings of policies is a new research direction compared with previous research. In the numerical application section below, two initial wealth levels ($x = 0$ and $x = 100$) are considered to make a comparison to show how the outranking environmental policy differs by applying the one-switch utility function. Moreover, a linear utility function is also applied in the criterion of financial returns with two wealth levels ($x = 0$ and $x = 100$) so as to show the divergent results obtained by two different utility functions and the special characteristic of the linear-times-exponential one-switch utility function. The linear function is as follows:

$$u(w) = 0.8w.$$

In addition, while a policymaker selects an environmental policy, the cost of one policy, c, is considered with the zero-switch utility function. The exponential utility function belonging to zero-switch utility functions is as follows:

$$u(c) = e^{-0.01c}.$$

The exponential utility function shows the undesirable attitude of an environmental policy makers towards the costs because the higher the cost of implementing a policy is, the lower utility value the exponential utility function has, which implies that an environmental policy with higher cost is not preferred.

Lastly, the other zero-switch utility function, linear utility function, is subjected to the reduced amount of GHGs generated by the introduction of one policy, k. After transforming it to utility values, the reduced amount of GHGs can be compared with the other two criteria. So, the linear utility function is as follows:

$$u(k) = 0.5k.$$

Based on the settings in three different utility functions above, a numerical example is considered to check the difference between the application of one-switch utility function and zero-switch utility function, which shows the unique characteristic of one-switch utility function. In addition, if different outranking results could be obtained, it also implies that this new model is applicable in the further cases of environmental policy selection.

5. Numerical Applications of Proposed Model

To show the application of one-switch utility function with ELECTRE I method in MCDM problem, one numerical example is considered in this section. Moreover, different wealth levels are also set to show the special characteristic of one-switch utility function. The case regarding the selection of environmental policy is applied here. There are 5 elements in the set of policies, $\{a_1, a_2, a_3, a_4, a_5\}$; three criteria including financial returns of policy, costs of policy, and reduced amount of GHGs of policy are used to search for the outranking policy. The details of five policies with corresponding criteria are shown in Table 1. The decision models of a policymaker are modelled on the corresponding utility functions mentioned in Section 4. Because the one-switch utility function is the utility function of wealth, different initial wealth levels are set in this study in order to show how the ranking of a policy is affected by the initial wealth level of a DM.

Table 1. Policies with Corresponding Criteria

	Return (r)	Cost (c)	GHGs (k)
Policy 1	90	60	35
Policy 2	45	50	90
Policy 3	15	20	40
Policy 4	80	55	70
Policy 5	65	10	10

Source: compiled by the author

The values in Table 1 are subjected to the corresponding decision-making utility functions including linear-times-exponential one-switch utility function, exponential utility function, and linear utility function, respectively, mentioned in Section 4. The situations in two different wealth levels are also considered. So, the values of utilities for policies are as follows in Table 2:

Table 2. Utilities Values for Policies with Different Wealth Levels

	$\mathrm{x}=0$	$\mathrm{x}=100$		
	$\mathrm{u}(\mathrm{x}+\mathrm{r})$	$\mathrm{u}(\mathrm{x}+\mathrm{r})$	$\mathrm{u}(\mathrm{c})$	$\mathrm{u}(\mathrm{k})$
Policy 1	197.022	153.586	0.549	17.5
Policy 2	159.843	182.409	0.607	45
Policy 3	83.160	195.233	0.819	20
Policy 4	194.225	160.422	0.577	35
Policy 5	184.885	170.362	0.905	5

Source: calculated by the author

Then, following the Step 2 in Section 2.1, the formula for benefit criterion is used for the utility of the wealth level, $\mathrm{u}(\mathrm{x}+\mathrm{r})$, and on the utility of reduced amount of GHGs, $\mathrm{u}(\mathrm{k})$ while the formula for cost criterion is used for the utility of costs of policy, $\mathrm{u}(\mathrm{c})$. So, the normalized values of utilities are shown in Table 3:

Table 3. Normalized Utilities for Policies

	$\mathrm{x}=0$	$\mathrm{x}=100$		
	$\mathrm{u}(\mathrm{x}+\mathrm{r})$	$\mathrm{u}(\mathrm{x}+\mathrm{r})$	$\mathrm{u}(\mathrm{c})$	$\mathrm{u}(\mathrm{k})$
Policy 1	0.521	0.397	0.531	0.277
Policy 2	0.422	0.471	0.481	0.713
Policy 3	0.220	0.505	0.356	0.317
Policy 4	0.513	0.415	0.506	0.555
Policy 5	0.489	0.440	0.322	0.079

Source: calculated by the author

The weights for three criteria are 0.4, 0.25, and 0.35, respectively. Then, the weighted normalized utilities for policies are shown in Table 4 as follows:

Table 4. Weighted Normalized Utilities for Policies

	$\mathrm{x}=0$	$\mathrm{x}=100$		
	$\mathrm{u}(\mathrm{x}+\mathrm{r})$	$\mathrm{u}(\mathrm{x}+\mathrm{r})$	$\mathrm{u}(\mathrm{c})$	$\mathrm{u}(\mathrm{k})$
Policy 1	0.208	0.159	0.133	0.097
Policy 2	0.169	0.189	0.120	0.250
Policy 3	0.088	0.202	0.089	0.111
Policy 4	0.205	0.166	0.126	0.194
Policy 5	0.195	0.176	0.081	0.028

Source: calculated by the author

Following Step 5 and Step 6, when the initial wealth level is 0 $(\mathrm{x}=0)$, the concordance matrix and the discordance matrix are:

$$\mathrm{C}=\begin{bmatrix} - & 0.65 & 0.65 & 0.65 & 1 \\ 0.35 & - & 1 & 0.35 & 0.6 \\ 0.35 & 0 & - & 0 & 0.6 \\ 0.35 & 0.65 & 1 & - & 1 \\ 0 & 0.4 & 0.4 & 0 & - \end{bmatrix}, \text{ and } \mathrm{D}=\begin{bmatrix} - & 0.6875 & 0.0625 & 0.4375 & 0 \\ 0.3265 & - & 0 & 0.302 & 0.2199 \\ 1 & 0.6735 & - & 0.9754 & 0.8934 \\ 0.124 & 0.25 & 0 & - & 0 \\ 1 & 1 & 0.375 & 0.88 & - \end{bmatrix}.$$

The concordance limit ($\underline{c}$) is 0.50 and the discordance limit ($\underline{d}$) is 0.46.

Concordance superiority matrix and discordance superiority matrix are:

$$F=\begin{bmatrix} - & 1 & 1 & 1 & 1 \\ 0 & - & 1 & 0 & 1 \\ 0 & 0 & - & 0 & 1 \\ 0 & 1 & 1 & - & 1 \\ 0 & 0 & 0 & 0 & - \end{bmatrix}, \text{ and } G=\begin{bmatrix} - & 0 & 1 & 1 & 1 \\ 1 & - & 1 & 1 & 1 \\ 0 & 0 & - & 0 & 0 \\ 1 & 1 & 1 & - & 1 \\ 0 & 0 & 1 & 0 & - \end{bmatrix}.$$

By element-wise product between these two matrices, the aggregate dominance matrix with 0 initial wealth level is:

$$E=\begin{bmatrix} - & 0 & 1 & 1 & 1 \\ 0 & - & 1 & 0 & 1 \\ 0 & 0 & - & 0 & 0 \\ 0 & 1 & 1 & - & 1 \\ 0 & 0 & 0 & 0 & - \end{bmatrix}.$$

By Step 8 in Section 2.1 shown, we can draw conclusions from the aggregate dominance matrix above: Policy 1 outranks Policy 3; Policy 1 outranks Policy 4; Policy 1 outranks Policy 5; Policy 2 outranks Policy 3; Policy 2 outranks Policy 5; Policy 4 outranks Policy 2; Policy 4 outranks Policy 3; Policy 4 outranks Policy 5. So, we can finally conclude that Policy 1 is the outranking policy with 0 initial wealth level.

On the other hand, when the initial wealth level is 100 ($x = 100$), the concordance matrix and the discordance matrix are:

$$C=\begin{bmatrix} - & 0.25 & 0.25 & 0.25 & 0.6 \\ 0.75 & - & 0.6 & 0.75 & 1 \\ 0.75 & 0.4 & - & 0.4 & 1 \\ 0.75 & 0.25 & 0.6 & - & 0.6 \\ 0.6 & 0 & 0 & 0.4 & - \end{bmatrix} \text{ and } D=\begin{bmatrix} - & 0.6921 & 1 & 0.4375 & 0.4028 \\ 0.2419 & - & 0.3079 & 0.1179 & 0 \\ 0.8379 & 0.625 & - & 0.7139 & 0 \\ 0.124 & 0.528 & 0.8359 & - & 0.75 \\ 1 & 1 & 0.5972 & 0.876 & - \end{bmatrix}.$$

The concordance limit ($\underline{c}$) is 0.51 and the discordance limit ($\underline{d}$) is 0.55.

Concordance superiority matrix and discordance superiority matrix are:

$$F=\begin{bmatrix} - & 0 & 0 & 0 & 1 \\ 1 & - & 1 & 1 & 1 \\ 1 & 0 & - & 0 & 1 \\ 1 & 0 & 1 & - & 1 \\ 1 & 0 & 0 & 0 & - \end{bmatrix}, \text{ and } G=\begin{bmatrix} - & 0 & 0 & 1 & 1 \\ 1 & - & 1 & 1 & 1 \\ 0 & 0 & - & 0 & 1 \\ 1 & 1 & 0 & - & 0 \\ 0 & 0 & 0 & 0 & - \end{bmatrix}.$$

So, the aggregate dominance matrix with 100 initial wealth level is:

$$E=\begin{bmatrix} - & 0 & 0 & 0 & 1 \\ 1 & - & 1 & 1 & 1 \\ 0 & 0 & - & 0 & 1 \\ 1 & 0 & 0 & - & 0 \\ 0 & 0 & 0 & 0 & - \end{bmatrix}.$$

Similarly, we can make conclusions based on the aggregate dominance matrix when the wealth level is 100: Policy 1 outranks Policy 5; Policy 2 outranks Policy 1; Policy 2 outranks Policy 3; Policy 2 outranks Policy 4; Policy 2 outranks Policy 5; Policy 3 outranks Policy 5; Policy 4 outranks Policy 1. So, we can finally conclude that Policy 2 is the outranking policy with 100 initial wealth level.

By applying linear-times-exponential one-switch utility function on financial return, exponential utility function on costs, and linear utility function on the reduced amount of GHGs, we can notice that the outranking results are different with initial wealth level 0 and initial wealth level 100. It is reasonable to state that the initial wealth level plays a critical role in a DM's preference on environmental policies with linear-times-exponential one-switch utility function.

In contrast, as mentioned in Section 4, the linear utility function, $u(w) = 0.8w$, is also applied on the criterion of financial returns of an environmental policy to compare with one-switch utility function. The utility functions for costs of policies and reduced amount of GHGs remain same, exponential and linear utility functions, respectively. The case with five policies under three criteria in Table 1 is still considered here. With the linear utility function on the financial return of an environmental policy, the utility values are different from Table 2. Two different initial wealth levels of a policymaker are still considered. The same procedure in Section 2.1 is applied to find the outranking policy with linear utility function on the financial return of an environmental policy with two different initial wealth levels ($x = 0$ and $x = 100$), whose aggregate dominance matrix with 0 and 100 initial wealth levels is:

$$\mathrm{E} = \begin{bmatrix} - & 0 & 1 & 1 & 1 \\ 0 & - & 1 & 0 & 1 \\ 0 & 0 & - & 0 & 0 \\ 0 & 1 & 1 & - & 1 \\ 0 & 0 & 0 & 0 & - \end{bmatrix}.$$

So, we can draw conclusions: Policy 1 outranks Policy 3; Policy 1 outranks Policy 4; Policy 1 outranks Policy 5; Policy 2 outranks Policy 3; Policy 2 outranks Policy 5; Policy 4 outranks Policy 2; Policy 4 outranks Policy 3 Policy 4 outranks Policy 5. So, we find that Policy 1 is the outranking policy with both 0 and 100 initial wealth levels.

6. Discussions

Comparing the results of the linear-times-exponential utility function with those of the linear utility function for the financial return criterion reveals an evident difference in policy preferences. Specifically, with the linear-times-exponential one-switch utility function, the outranking policy swaps from Policy 1 to Policy 2 as the initial wealth level increases from 0 to 100. Conversely, with the linear utility function, the outranking policy keeps the same as Policy 1 regardless of the initial wealth level increase from 0 to 100. These comparisons are summarized in Table 5. The utility functions for the other two criteria- costs and reduced amount of GHGs- remain the same in comparison. Moreover, the sensitivity test varying the weights on criteria by approximately 10% yields the same results, indicating that the outranking policies with different utility functions on the criterion of financial return with different wealth levels are sufficiently robust.

Table 5. Summary of Comparison Results

Criterion	Initial Wealth Level	Utility Function	Outranking Policy
Financial Return (r)	$\mathrm{x} = 0$	Linear-times-exponential One-switch Utility Function	Policy 1
		Linear Utility Function	Policy 1
	$\mathrm{x} = 100$	Linear-times-exponential One-switch Utility Function	Policy 2
		Linear Utility Function	Policy 1

Source: summarized by the author

These results illustrate the significant impact of wealth levels on the preferences or the selection on outranking policies. With the linear utility function for the criterion of financial returns of a policy, the policymaker's preference remains unchanged regardless of their initial wealth, a scenario that does not align well with realistic decision-making processes. In contrast, under the linear-times-exponential one-switch utility function, the policymaker's selections toward the financial returns of a policy vary with different initial wealth levels. This variation reflects a more realistic depiction of a policymaker's decision-making behaviour. As a result, the linear-times-exponential one-switch utility function can be applied to describe a policymaker's decision-making behaviours much more practically and accurately than the linear utility function. This is also the reason why one-switch utility function is employed in this research rather than linear or exponential utility functions used in previous studies. The results also show the linear-times-exponential one-switch utility function is able to be incorporated with ELECTRE I method in resolving the MCDM problem. In addition to the linear or exponential utility function, or probability density functions in Almeida (2002, 2005, 2007), this study further provides an option of utility function to describe a DM's behaviour with the linear-times-exponential utility function.

The numerical example also implies that the utility function can also give impact on the selection of the outranking alternative. So, it is necessary to choose an appropriate utility function to describe a DM's behavior and subject it in the procedure of ELECTRE I method rather than using the original values of alternatives directly in the decision matrix. As the pioneered research integrating linear-times-exponential one-switch utility function in ELECTRE I method, this research provides a further research direction about how the outranking results can be impacted by a DM with different utility functions in ELECTRE I method while facing MCDM problems.

Conclusions

This study further extends the research about how the utility functions work with ELECTRE I method in the MCDM problem based on Almeida's research (2002, 2005, 2007). In the procedures of ELECTRE I method, the true value of each alternative is not used but the utilities obtained from utility functions are considered. The exponential utility function is applied in the criterion of costs, and the linear utility function is applied in the criterion of reduced amount of GHGs. Compared with previous studies, the different point of this study is to apply linear-times-exponential one-switch utility function and linear utility function in the criterion of financial returns with two different initial wealth levels so as to show how the initial wealth levels of a DM with linear-times-exponential one-switch utility function can give impacts on the outranking policy than the results with linear utility function.

The numerical example shows the use of the linear-times-exponential one-switch utility function in the MCDM problem, which is the pioneered application of linear-times-exponential one-switch utility function in the MCDM research. Thus, the consideration of linear-times-exponential one-switch utility function makes a policymaker's preference on environmental policy more realistic and reasonable because it is reasonable to recognize that a DM's preference on alternatives may be influenced by the initial wealth he or she owns. Moreover, by different settings on wealth levels in the numerical example, the outranking environmental policies are different, which is Policy 1 and Policy 2, respectively. This shows the special characteristic of one-switch utility functions whose utility is dependent on the initial wealth levels rather than sole returns as applied in the linear utility function. This also implies that while an environmental policymaker considers the financial return one of the criteria in selecting a policy, the impact of initial wealth level cannot be overlooked because it indirectly impacts the outranking policies.

Finally, this study also contributes to the decision model in environmental economics about policy selection, albeit theoretical, when a policymaker tries to find the outranking policy among a list of policies with several criteria. Because the one-switch utility functions are the utility functions of wealth, the mechanism is to transform the wealth level or returns into utility function, which can be seen as one limitation of one-switch utility functions so future work may explore if one-switch utility function can be applied in other criteria instead of financial returns and check how the selection or ranking of alternative may be impacted.

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References

[1] Aal, S.I.A. (2024). A Multi-Criteria Decision-Making Model for Sustainable and Resilient Supplier Selection and Management. *Neutrosophic Systems with Applications*, 15: 33-45. DOI:https://doi.org/10.61356/j.nswa.2024.1513956

[2] Abbas, A.E., & Bell, D.E. (2015). Ordinal one-switch utility functions. *Operations Research*, 63(6): 1411-1419. DOI: https://doi.org/10.1287/opre.2015.1426

[3] Abbas, A.E., Bakır, N. O., Klutke, G.A., & Sun, Z. (2013). Effects of Risk Aversion on the Value of Information in Two-action Decision Problems. *Decision Analysis*, 10(3): 257-275. DOI:https://doi.org/10.1287/deca.2013.0275

[4] Abdulla, A., & Baryannis, G. (2024). A hybrid multi-criteria decision-making and machine learning approach for explainable supplier selection. *Supply Chain Analytics*, 7, 100074. DOI:https://doi.org/10.1016/j.sca.2024.100074

[5] Ait Bahom, S., Chraïbi, L., & Sefiani, N. (2025). A new personnel selection model for quality positions. *Journal of Applied Research on Industrial Engineering*, 12(1): 103-118. DOI:https://doi.org/10.22105/jarie.2024.420649.1567

[6] Akpahou, R., Mensah, L.D., Quansah, D. A., & Kemausuor, F. (2024). Long-term energy demand modeling and optimal evaluation of solutions to renewable energy deployment barriers in Benin: A LEAP-MCDM approach. *Energy Reports*, 12: 1888-1904. DOI: https://doi.org/10.1016/j.egyr.2024.07.055

[7] Akram, M., Ilyas, F., & Garg, H. (2021). ELECTRE-II method for group decision-making in Pythagorean fuzzy environment. *Applied Intelligence*, 1-19. DOI: https://doi.org/10.1007/s10489-021-02200-0

[8] Alizadeh, A., & Yousefi, S. (2019). An integrated Taguchi loss function–fuzzy cognitive map–MCGP with utility function approach for supplier selection problem. *Neural Computing and Applications*, 31(11): 7595-7614. DOI: https://doi.org/10.1007/s00521-018-3591-1

[9] Almeida, A.T. (2002). Multicriteria modelling for a repair contract problem based on utility and the ELECTRE I method. *IMA Journal of Management Mathematics*, 13(1): 29-37. DOI: 10.1093/imaman/13.1.29

[10] Almeida, A.T. (2005). Multicriteria modelling of repair contract based on utility and ELECTRE I method with dependability and service quality criteria. *Annals of Operations Research*, 138: 113-126. DOI:https://doi.org/10.1007/s10479-005-2448-z

[11] Almeida, A.T. (2007). Multicriteria decision model for outsourcing contracts selection based on utility function and ELECTRE method. *Computers & Operations Research*, 34(12): 3569-3574. DOI:https://doi.org/10.1016/j.cor.2006.01.003

[12] Alper, D., & Başdar, C. (2017). A comparison of TOPSIS and ELECTRE methods: an application on the factoring industry. *Business and Economics Research Journal*, 8(3): 627. DOI:https://doi.org/10.20409/berj.2017.70

[13] Anchugina, N. (2017). One-Switch Discount Functions. arXiv preprint arXiv:1702.02254. DOI:https://doi.org/10.48550/arXiv.1702.02254

[14] Babatunde, O.M., Munda, J.L., & Hamam, Y. (2019). Selection of a hybrid renewable energy systems for a low-income household. *Sustainability*, 11(16), 4282. DOI: https://doi.org/10.3390/su11164282

[15] Bakır, N.O. (2017). Value of information for decision makers with sumex and linear times exponential utility. Available at: https://hdl.handle.net/20.500.12939/1905

[16] Bakır, N.O., & Klutke, G. A. (2011). Information and Preference Reversals in Lotteries *European Journal of Operational Research*, 210(3): 752-756. DOI: https://doi.org/10.1016/j.ejor.2010.09.037

[17] Bell, D.E. (1988). One-switch utility functions and a measure of risk. *Management Science*, 34(12): 1416-1424. DOI: https://doi.org/10.1287/mnsc.34.12.1416

[18] Bell, D.E., & Fishburn, P. C. (2001). Strong one-switch utility. *Management Science*, 47(4): 601-604. DOI:https://doi.org/10.1287/mnsc.47.4.601.9825

[19] Brito, A.J., de Almeida, A. T., & Mota, C. M. (2010). A multicriteria model for risk sorting of natural gas pipelines based on ELECTRE TRI integrating Utility Theory. *European Journal of Operational Research*, 200(3): 812-821. DOI: https://doi.org/10.1016/j.ejor.2009.01.016

[20] Carpitella S., Certa A., & Mario E. (2018). The ELECTRE I method to support the FMECA, IFAC-PapersOnLine, Volume 51(11): 459-464. DOI: https://doi.org/10.1016/j.ifacol.2018.08.361

[21] Chakraborty, S., Raut, R.D., Rofin, T.M., & Chakraborty, S. (2024). On solving a healthcare supplier selection problem using MCDM methods in intuitionistic fuzzy environment. *Opsearch*, 1-29. DOI:https://doi.org/10.1007/s12597-023-00733-1

[22] Denuit, M.M., Eeckhoudt, L., & Schlesinger, H. (2013). When Ross meets Bell: the linex utility function. *Journal of Mathematical Economics*, 49(2): 177-182. DOI: https://doi.org/10.1016/j.jmateco.2013.01.006

[23] Džiugaitė-Tumėnienė, R., Motuzienė, V., Šiupšinskas, G., Čiuprinskas, K., & Rogoža, A. (2017). Integrated assessment of energy supply system of an energy-efficient house. *Energy and Buildings*, 138: 443-454. DOI:https://doi.org/10.1016/j.enbuild.2016.12.058

[24] Ekholm, T., *et al.* (2014). A multi-criteria analysis of climate, health and acidification impacts due to greenhouse gases and air pollution—The case of household-level heating technologies. *Energy Policy*, 74: 499-509. DOI: https://doi.org/10.1016/j.enpol.2014.07.002

[25] Farahani, R. Z., & Asgari, N. (2007). Combination of MCDM and covering techniques in a hierarchical model for facility location: A case study. *European Journal of Operational Research*, 176(3): 1839-1858. DOI:https://doi.org/10.1016/j.ejor.2005.10.039

[26] Ferrer-Martí, L., Ferrer, I., Sánchez, E., & Garfí, M. (2018). A multi-criteria decision support tool for the assessment of household biogas digester programmes in rural areas. A case study in Peru. *Renewable and Sustainable Energy Reviews*, 95: 74-83. DOI: https://doi.org/10.1016/j.rser.2018.06.064

[27] Gottwald, D., Chocholáč, J., Kayacı Çodur, M., Čubranić-Dobrodolac, M., & Yazir, K. (2024). Z-Numbers-Based MCDM approach for personnel selection at institutions of higher education for transportation. *Mathematics*, 12(4): 523. DOI: https://doi.org/10.3390/math12040523

[28] Karbassi Yazdi, A., Tan, Y., Birau, R., Frank, D., & Pamučar, D. (2025). Sustainable solutions: using MCDM to choose the best location for green energy projects. *International Journal of Energy Sector Management*, 19(1): 146-180. DOI: https://doi.org/10.1108/IJESM-01-2024-0005

[29] Lee, S. K., Mogi, G., & Kim, J. W. (2008). Multi-criteria decision making for measuring relative efficiency of greenhouse gas technologies: AHP/DEA hybrid model approach. *Engineering Letters*, 16(4): 493-7. Available at: https://www.engineeringletters.com/issues_v16/issue_4/index.html

[30] Li, T., Wang, H., & Lin, Y. (2024). Selection of renewable energy development path for sustainable development using a fuzzy MCDM based on cumulative prospect theory: the case of Malaysia. *Scientific Reports*, 14(1): 15082. DOI: https://doi.org/10.1038/s41598-024-65982-6

[31] Li, Y. (2022). One-switch Utility Functions and Applications: a Review Article. *The Keizai Ronkyu*, 173: 23-72. DOI: https://doi.org/10.15017/4796012

[32] Liu, A., Li, Z., Shang, W. L., & Ochieng, W. (2023). Performance evaluation model of transportation infrastructure: Perspective of COVID-19. *Transportation Research Part A: Policy and Practice*, 170, 103605. DOI: https://doi.org/10.1016/j.tra.2023.103605

[33] Liu, Y., & Koenig, S. (2005). Risk-sensitive planning with one-switch utility functions: Value iteration. In *Proceedings of the twentieth AAAI conference on artificial intelligence* (p. 993–999).

[34] Malakooti, B. B. (1993). A decision support system for discrete multiple-criteria problems: certainty, uncertainty, and hierarchical. *Applied Mathematics and Computation*, 54(2-3): 131-166. DOI:https://doi.org/10.1016/0096-3003(93)90056-K

[35] Marzouk, Mohamed & Mohammed Abdelkader, Eslam. (2019). On the use of multi-criteria decision-making methods for minimizing environmental emissions in construction projects. *Decision Science Letters*. 8. DOI:https://doi.org/10.5267/j.dsl.2019.6.003

[36] Maserrat, Z., *et al.* (2024). A Dempster–Shafer Enhanced Framework for Urban Road Planning Using a Model-Based Digital Twin and MCDM Techniques. *ISPRS International Journal of Geo-Information*, 13(9): 302. DOI: https://doi.org/10.3390/ijgi13090302

[37] Milani, A.S., Shanian, A., & El-Lahham, C. (2006). Using different ELECTRE methods in strategic planning in the presence of human behavioral resistance. *Journal of Applied Mathematics and Decision Sciences*, 2006. DOI: https://doi.org/10.1155/JAMDS/2006/10936

[38] Nafi'Shehab, Z., Faisal, R. M., & Ahmed, S. W. (2024). Multi-criteria decision making (MCDM) approach for identifying optimal solar farm locations: A multi-technique comparative analysis. *Renewable Energy*, 237: 121787. DOI: https://doi.org/10.1016/j.renene.2024.121787

[39] Narayanamoorthy, S., Ramya, L., Kalaiselvan, S., Kureethara, J. V., & Kang, D. (2021). Use of DEMATEL and COPRAS method to select best alternative fuel for control of impact of greenhouse gas emissions. *Socio-Economic Planning Sciences*, 76, 100996. DOI: https://doi.org/10.1016/j.seps.2020.100996

[40] Ozsahin, D.U., Gökcekus, H., Uzun, B., & LaMoreaux, J. W. (2021). *Application of multi-criteria decision analysis in environmental and civil engineering*, Springer International Publishing.

[41] Parvaneh, F., & Hammad, A. (2024). Application of Multi-Criteria Decision-Making (MCDM) to Select the Most Sustainable Power-Generating Technology. Sustainability, 16(8): 3287. DOI:https://doi.org/10.3390/su16083287

[42] Pinto-DelaCadena, P.A., Liern, V., & Vinueza-Cabezas, A. (2024). A Comparative Analysis of Multi-Criteria Decision Methods for Personnel Selection: A Practical Approach. *Mathematics*, 12(2): 324. DOI:https://doi.org/10.3390/math12020324

[43] Pohekar, S.D., & Ramachandran, M. (2004). Application of multi-criteria decision making to sustainable energy planning—A review. *Renewable and Sustainable Energy Reviews*, 8(4): 365-381. DOI:https://doi.org/10.1016/j.rser.2003.12.007

[44] Ren, H., Gao, W., Zhou, W., & Nakagami, K. I. (2009). Multi-criteria evaluation for the optimal adoption of distributed residential energy systems in Japan. *Energy Policy*, 37(12): 5484-5493. DOI:https://doi.org/10.1016/j.enpol.2009.08.014

[45] Roy, B. (1968). Classement et choix en présence de points de vue multiples (La methode ELECTRE). *Revue Française d'informatique et de recherche opérationnelle*, 2(8): 57-75.

[46] Roy, B. (1978). ELECTRE III: un algorithme de classements fondé sur une représentation floue des préférences en présence de critères multiples. *Cahiers du Centre d'études de recherche operationnelle*, 20: 3-24.

[47] Roy, B., & Bertier, P. (1971). La Methode ELECTRE II: une Methode de Classement en Presence de Criteres Multiples., Note de Travail No. 142, Direction Scientifique. Group Metra, Paris.

[48] Roy, B., & Bouyssou, D. (1993). Aide multicritère à la décision: méthodes et cas (p. 695). Paris: Economica.

[49] Roy, B., & Hugonnard, J. C. (1982). Ranking of suburban line extension projects on the Paris metro system by a multicriteria method. *Transportation Research Part A: General*, 16(4): 301-312. DOI:https://doi.org/10.1016/0191-2607(82)90057-7

[50] Seddiki, M., & Bennadji, A. (2019). Multi-criteria evaluation of renewable energy alternatives for electricity generation in a residential building. *Renewable and Sustainable Energy Reviews*, 110: 101-117. DOI:https://doi.org/10.1016/j.rser.2019.04.046

[51] Sheng, C.L. (1984). A general utility function for decision-making. *Mathematical Modelling*, 5(4): 265-274. DOI: https://doi.org/10.1016/0270-0255(84)90005-8

[52] Subramanian, G. H., & Gershon, M. (1991). The Selection of Computer-Aided Software Engineering Tools: A Multi-Criteria Decision-Making Approach. *Decision Sciences*, 22(5): 1109-1123. DOI:https://doi/10.1111/j.1540-5915.1991.tb01909.x

[53] Taherdoost, H., & Madanchian, M. (2023). A Comprehensive Overview of the ELECTRE Method in Multi Criteria Decision-Making. *Journal of Management Science & Engineering Research*, 6(2): 5-16. DOI:https://doi.org/10.30564/jmser.v6i2.5637

[54] Tian, G., *et al.* (2023). A survey of multi-criteria decision-making techniques for green logistics and low-carbon transportation systems. E*nvironmental Science and Pollution Research*, 30(20): 57279-57301. DOI:https://doi.org/10.1007/s11356-023-26577-2

[55] Tiwari, R., Agrawal, S., & Kasdekar, D. K. (2020, February). Application of ELECTRE-I, II methods for EDM performance measures in manufacturing decision making. In *IOP Conference Series: Materials Science and Engineering* (Vol. 748, No. 1, p. 012015). IOP Publishing. DOI: 10.1088/1757-899X/748/1/012015

[56] Topaloğlu, F. (2024). Development of a new hybrid method for multi-criteria decision making (MCDM) approach: a case study for facility location selection. *Operational Research*, 24(4): 60. DOI:https://doi.org/10.1007/s12351-024-00871-4

[57] Väisänen, S., *et al.* (2016). Using a multi-method approach for decision-making about a sustainable local distributed energy system: A case study from Finland. *Journal of Cleaner Production*, 137: 1330-1338. DOI:https://doi.org/10.1016/j.jclepro.2016.07.173

[58] Vasić, G. (2018). Application of multi criteria analysis in the design of energy policy: Space and water heating in households–City Novi Sad, Serbia. *Energy Policy*, 113: 410-419. DOI: 10.1016/j.enpol.2017.11.025

[59] von Neumann, J., & Morgenstern, O. (1944). *Theory of Games and Economic Behaviour*. Princeton University Press, Princeton.

[60] Wu, J. Z., & Tiao, P. J. (2018). A validation scheme for intelligent and effective multiple criteria decision-making. *Applied Soft Computing*, 68: 866-872. DOI: https://doi.org/10.1016/j.asoc.2017.04.054

[61] Wu, Y., Xu, C., & Zhang, T. (2018). Evaluation of renewable power sources using a fuzzy MCDM based on cumulative prospect theory: A case in China. *Energy*, 147: 1227-1239. DOI:https://doi.org/10.1016/j.energy.2018.01.115

[62] Yang, Y., Ren, J., Solgaard, H. S., Xu, D., & Nguyen, T. T. (2018). Using multi-criteria analysis to prioritize renewable energy home heating technologies. *Sustainable Energy Technologies and Assessments*, 29: 36-43. DOI: https://doi.org/10.1016/j.seta.2018.06.005

[63] Yu, W. (1992). ELECTRE TRI (aspects méthodologiques et manuel d'utilisation). Document- Université de Paris-Dauphine, LAMSADE, No. 74, Université Paris-Dauphine.

[64] Zeng, W., Zhou, H., & You, M. (2014). Risk-sensitive multiagent decision-theoretic planning based on MDP and one-switch utility functions. *Mathematical Problems in Engineering*. DOI: 10.1155/2014/697895

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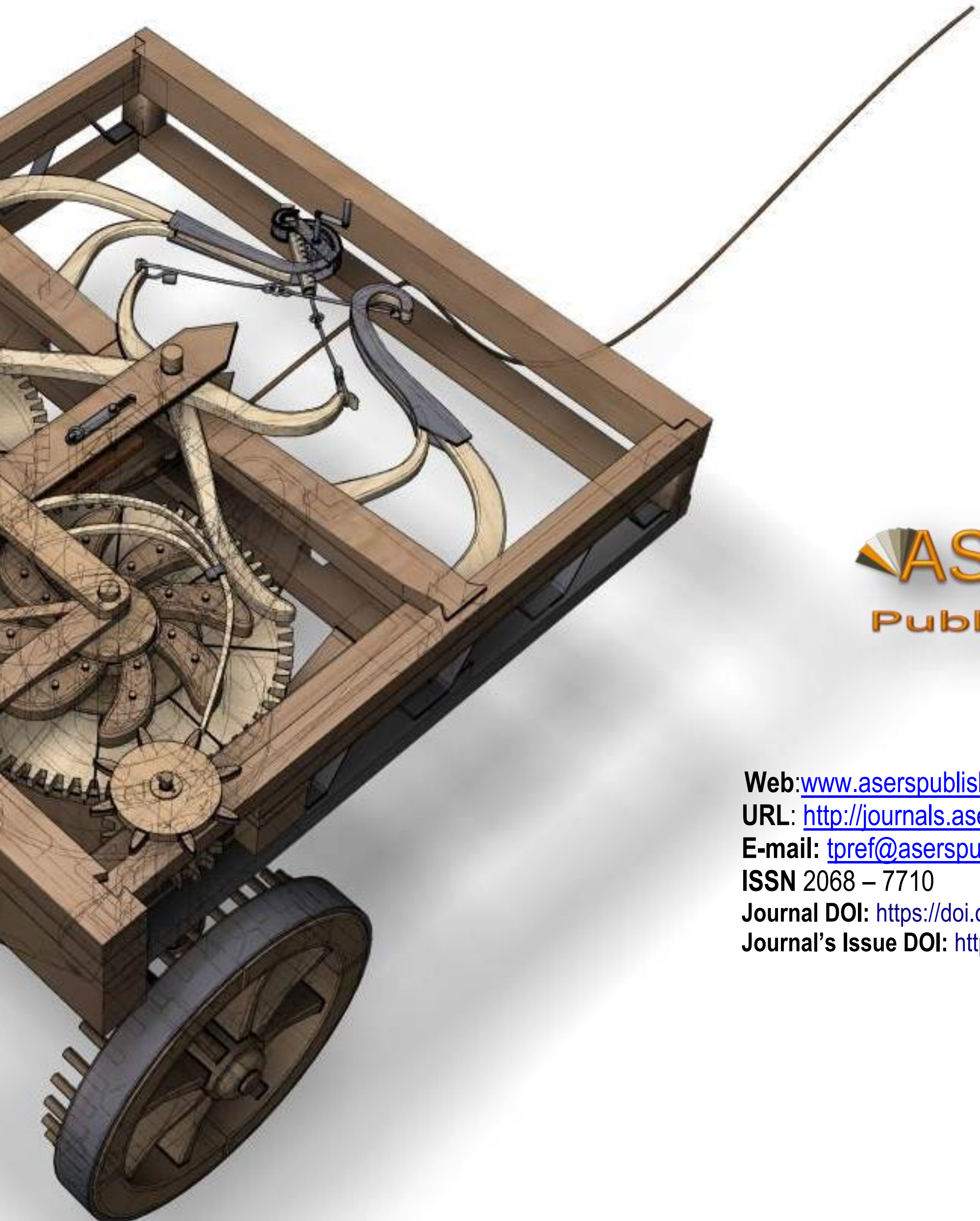

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