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Green Transformation Evaluation of Industrial Economies in Resource-Based Regions under the SuperHyperSoft Set Model

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Abstract: The green transformation of industrial economies in resource-based regions is a critical aspect of sustainable development. As these regions often depend heavily on extractive industries, they face distinct environmental and structural challenges when transitioning to greener economic models. This study aims to evaluate the effectiveness, challenges, and pathways of green transformation in such areas by establishing a multidimensional evaluation framework. Through the integration of environmental, economic, technological, and policy-related criteria, the research offers insights into the drivers and barriers of green transition. The analysis contributes to policymaking and industrial planning by providing a strategic perspective on regional development under ecological constraints. We use the SuperHyperSoft set to deal with values of criteria and cub criteria. This study uses eight criteria and seven alternatives. We divide the values of criteria into six clusters.

Keywords: SuperHyperSoft Set; Industrial Economies; Resource-Based Regions; Green Transformation.

1. Introduction

Resource-based regions have long been the backbone of industrial growth due to their rich reserves of minerals, fossil fuels, and forest products. However, the intensive exploitation of these resources has led to significant environmental degradation and economic vulnerability, especially as global markets shift toward low-carbon models[1], [2].

The concept of green transformation refers to the strategic reorientation of these industrial economies toward sustainable practices, renewable energy adoption, and ecological balance. It requires substantial shifts not only in infrastructure and technology but also in governance and labor force dynamics[3], [4].

In recent years, governments and international organizations have launched various policies to encourage greener industrial practices. These include subsidies for clean energy, stricter emission regulations, and incentives for innovation in green technologies. The effectiveness of these interventions, however, varies significantly across regions[5], [6].

One of the main challenges lies in the structural rigidity of traditional resource economies. Their dependence on a limited set of industries makes it difficult to diversify economically without substantial investments and long-term planning. Moreover, environmental remediation often competes with short-term economic goals.

Technological innovation plays a pivotal role in facilitating green transformation. Advanced waste recycling methods, carbon capture technologies, and cleaner production systems can reduce the ecological impact of existing industries while opening avenues for new economic sectors[7], [8].

Social dimensions also affect the green transition. The availability of green jobs, local education systems' capacity to retrain the workforce, and public awareness of sustainability issues all influence the speed and depth of transformation. Evaluation frameworks are essential for monitoring and guiding green transformation efforts. By assessing criteria such as emission reductions, policy effectiveness, and innovation adoption, stakeholders can identify strengths and areas needing intervention within each region[9], [10].

This study proposes a comprehensive, criteria-based evaluation model that reflects the complexity of green transformation in resource-based regions. It leverages expert input and regional data to measure progress and inform policy directions, ensuring that sustainability becomes a viable path for even the most resource-dependent economies.

Many research groups are still investigating the application of multiple criteria decision-making (MCDM) techniques for resolving different decision-making issues. Many popular MCDM techniques have been proposed because of earlier studies.

To calculate an alternative's total utility, the Simple Weighted Sum Product (WISP) technique combines four correlations between advantageous and non-beneficial characteristics. Using this approach to rank and choose the best option for an issue with m possibilities and n useful and non-beneficial factors[11], [12].

2. Simple Weighted Sum Product (WISP)

Smarandache introduced six new types of soft sets: HyperSoft Set, IndetermSoft Set, IndetermHyperSoft Set, SuperHyperSoft Set, TreeSoft Set, ForestSoft Set between 2018-2024 [13], [14], [15]. This study uses the SuperHyperSoft set model to deal with different criteria values in the decision-making process. SuperHyperSoft, a method that Smarandache developed, is seen as an extension of HyperSoft and is made up of many HyperSoft Sets [15], [16], [17]. The approach used in this study is to depict the identified qualities and sub-attributes for choosing the best alternative based on a set of criteria values.

The cartesian product of the criteria and sub criteria can be defined as:

$$P(Y_1) \times P(Y_2) \times P(Y_3) = \left\{ \begin{Bmatrix} \{Y_{11}\}, \{Y_{12}\}, \{Y_{11}, Y_{12}\} \times \\ \{Y_{21}\}, \{Y_{22}\}, \{Y_{21}, Y_{22}\} \times \\ \{Y_{31}\}, \{Y_{32}\}, \{Y_{33}\}, \{Y_{31}, Y_{32}\}, \{Y_{31}, Y_{33}\}, \{Y_{32}, Y_{33}\}, \{Y_{31}, Y_{32}, Y_{33}\} \end{Bmatrix} \right\} \tag{1}$$

Where Y refers to the criteria values, $P(Y_1)$ is the power set of Y_1.

We show the steps of the WISP method to rank the alternatives. Experts create the decision matrix based on their opinions. Combine the decision matrix into a single matrix using the average method.

Compute the criteria weights using the average method.

Normalize the decision matrix

$$H_{ij} = \frac{r_{ij}}{\max r_{ij}} \tag{2}$$

Determine the 4 distinct benefits values.

$$X_i = \sum_{g \in g^+} H_{ij} W_j - \sum_{g \in g^-} H_{ij} W_j \tag{3}$$

$$Y_i = \prod_{g \in g^+} H_{ij} W_j - \prod_{g \in g^-} H_{ij} W_j \tag{4}$$

$$Z_i = \frac{\sum_{d \in g^+} H_{ij} W_j}{\sum_{d \in g^-} H_{ij} W_j} \tag{5}$$

$$ZZ_i = \frac{\prod_{g \in g^+} H_{ij} W_j}{\prod_{g \in g^-} H_{ij} W_j} \tag{6}$$

Determine the normalized benefits values

$$X_i^- = \frac{1 + X_i}{1 + \max X_i} \tag{7}$$

$$Y_i^- = \frac{1 + Y_i}{1 + \max Y_i} \tag{8}$$

$$Z_i^- = \frac{1 + Z_i}{1 + \max Z_i} \tag{9}$$

$$ZZ_i^- = \frac{1+ZZ_i}{1+\max ZZ_i} \tag{10}$$

Determine the overall values.

$$U_i = \frac{X_i^- + Y_i^- + Z_i^- + ZZ_i^-}{4} \tag{11}$$

Rank the alternatives

3. Results and Discussion

This section shows the results of the proposed methodology. We use eight criteria and six alternatives to be evaluated.

1. C1: Environmental Policy Implementation
   - Values: Strong, Moderate, Weak
2. C2: Industrial Emission Reduction
   - Values: High, Medium, Low
3. C3: Clean Energy Adoption Rate
   - Values: Extensive, Partial, Minimal
4. C4: Resource Recycling Efficiency
   - Values: Efficient, Average, Inefficient
5. C5: Technological Innovation in Green Industries
   - Values: Advanced, Developing, Nascent
6. C6: Green Employment Growth
   - Values: Rapid, Steady, Slow
7. C7: Ecological Restoration Investment
   - Values: High, Moderate, Low
8. C8: Industrial Structure Diversification
   - Values: Highly Diversified, Moderately Diversified, Monolithic

- Coal-restructuring industrial zone
- Oil-dependent economy with green transition strategy
- Forestry-based economy with eco-tourism integration

- Mining-intensive area exploring renewable energy
- Agriculture-supported region moving toward bioeconomy
- Traditional manufacturing hub investing in clean tech.

Three experts evaluate the eight criteria and six alternatives. We combine the decision matrix into a single matrix. We compute the criteria weights using the average method such as C1=0.104641864, C2=0.122943967, C3=0.14266371, C4=0.123389251, C5=0.131159012, C6=0.127487687, C7=0.130577416, C8=0.117137093.

We use the SuperHyperSoft set to deal with the criteria values. We have indeterminacy with two criteria, so we divide the criteria values into six clusters

Cluster 1, C1: Strong, C2: High, C3: Extensive, C4: Efficient, C5: Advanced, C6: Rapid, C7: High, C8: Highly Diversified.

Cluster 2, C1: Strong, C2: Medium, C3: Extensive, C4: Efficient, C5: Advanced, C6: Rapid, C7: High, C8: Highly Diversified.

Cluster 3, C1: Strong, C2: Low, C3: Extensive, C4: Efficient, C5: Advanced, C6: Rapid, C7: High, C8: Highly Diversified.

Cluster 4, C1: Weak, C2: High, C3: Extensive, C4: Efficient, C5: Advanced, C6: Rapid, C7: High, C8: Highly Diversified.

Cluster 5, C1: Weak, C2: Medium, C3: Extensive, C4: Efficient, C5: Advanced, C6: Rapid, C7: High, C8: Highly Diversified.

Cluster 6, C1: Weak, C2: Low, C3: Extensive, C4: Efficient, C5: Advanced, C6: Rapid, C7: High, C8: Highly Diversified.

In cluster 1:

Eq. (2) is used to normalize the decision matrix as shown in Fig 1. Fig 2 is used to determine the weighted decision matrix.

Eqs. (3-6) are used to determine the 4 distinct benefits values as shown in Fig 3.

Eqs. (7-10) are used to determine the normalized benefits values

Eq. (11) is used to determine the overall values as shown in Fig 4.

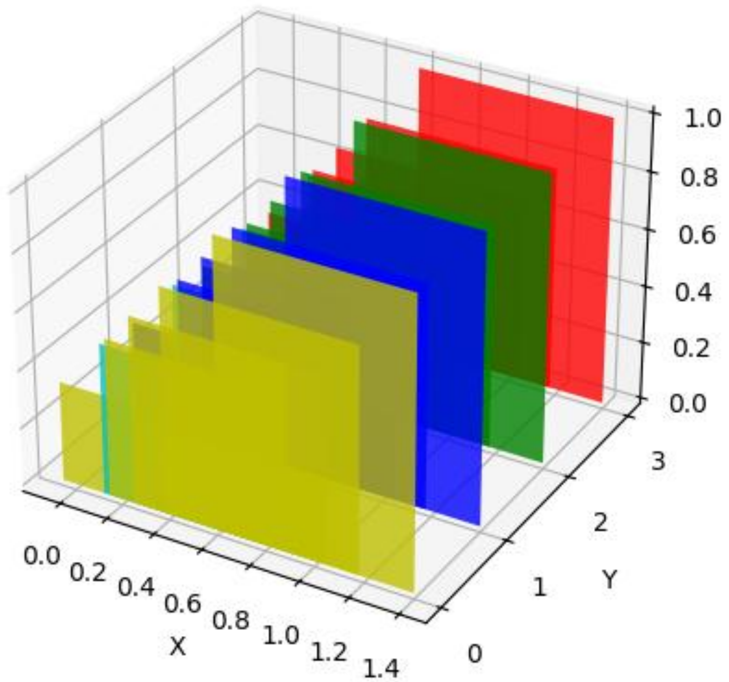

Fig 1. The normalized decision matrix.

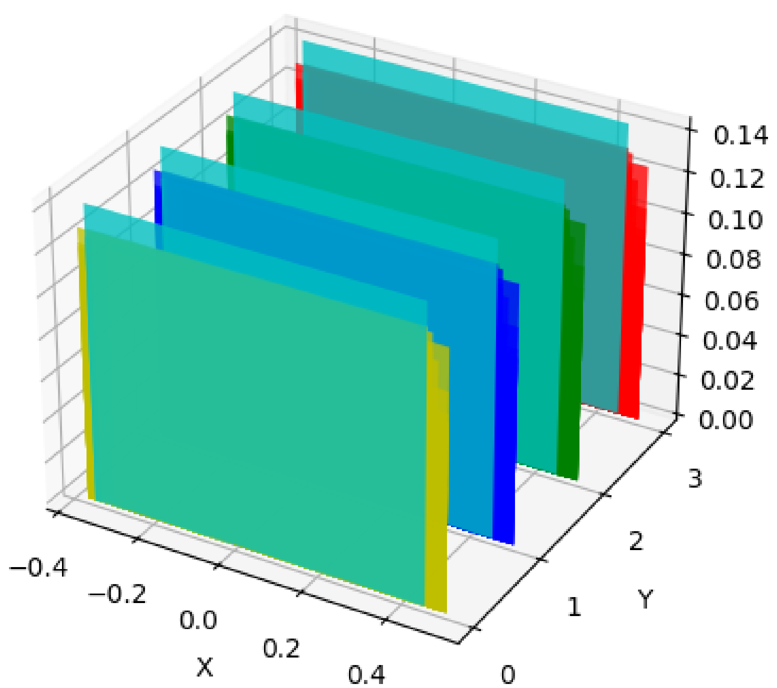

Fig 2. The weighted decision matrix.

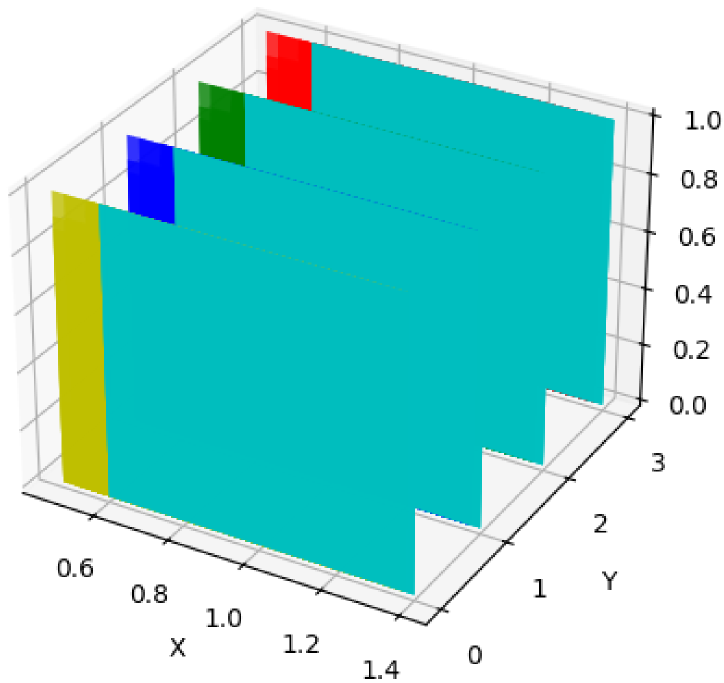

Fig 3. The 4 distinct benefits values.

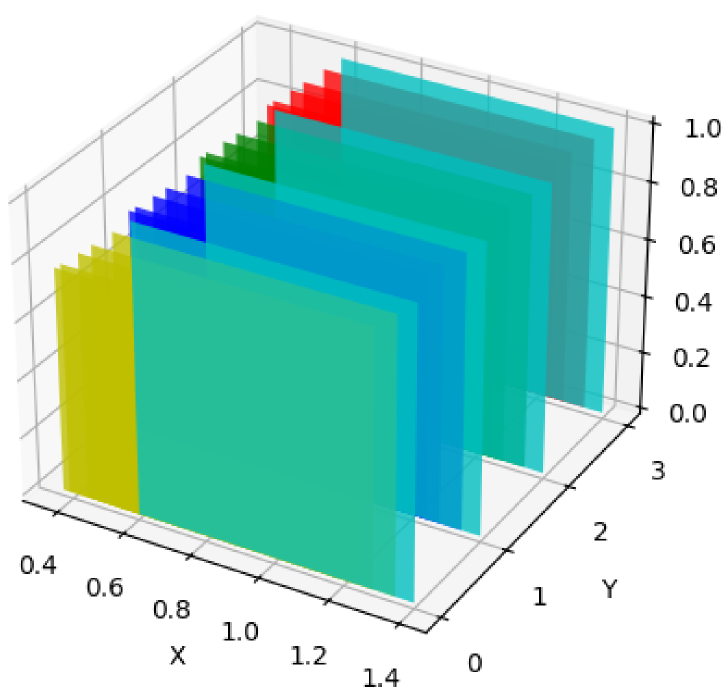

Fig 4. The overall values.

In cluster 2:

Eq. (2) is used to normalize the decision matrix as shown in Fig 5. Fig 6 is used to determine the weighted decision matrix.

Eqs. (3-6) are used to determine the 4 distinct benefits values as shown in Fig 7.

Eqs. (7-10) are used to determine the normalized benefits values

Eq. (11) is used to determine the overall values as shown in Fig 8.

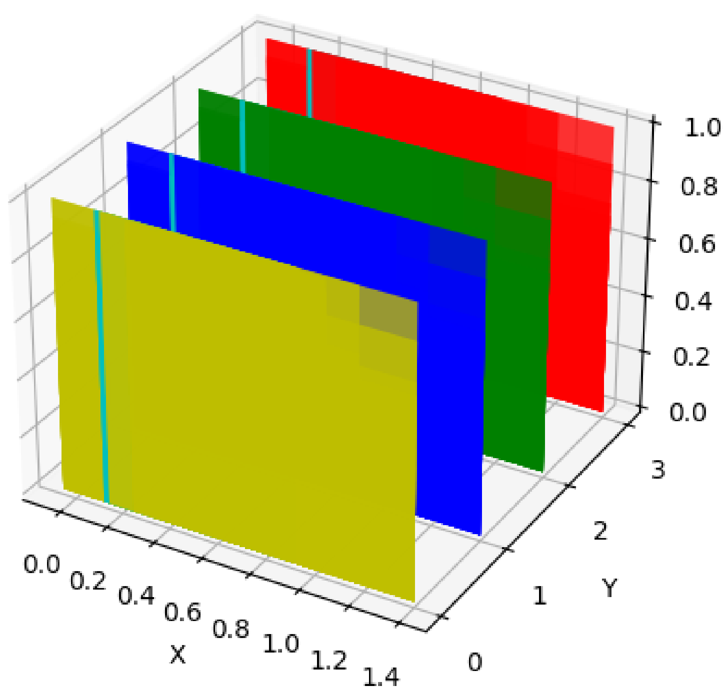

Fig 5. The normalized decision matrix.

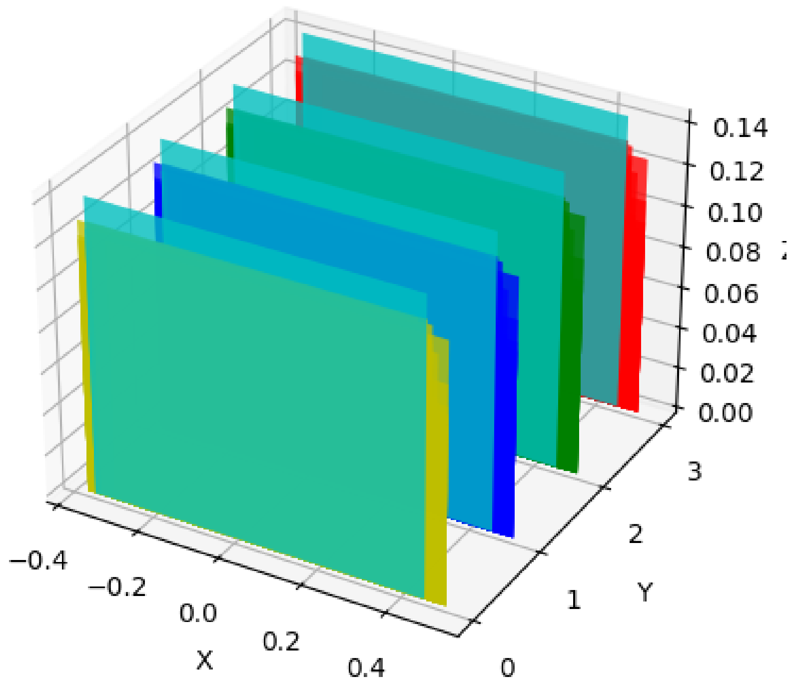

Fig 6. The weighted decision matrix.

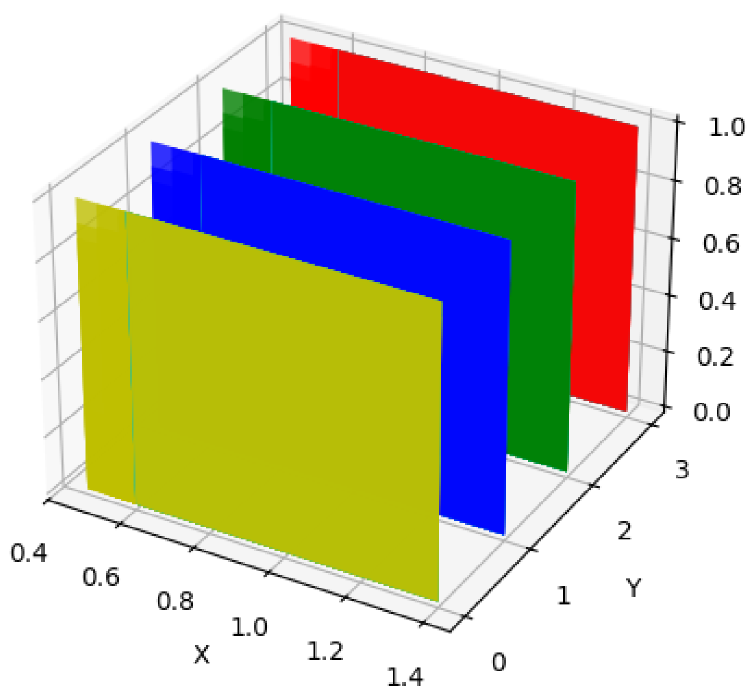

Fig 7. The 4 distinct benefits values.

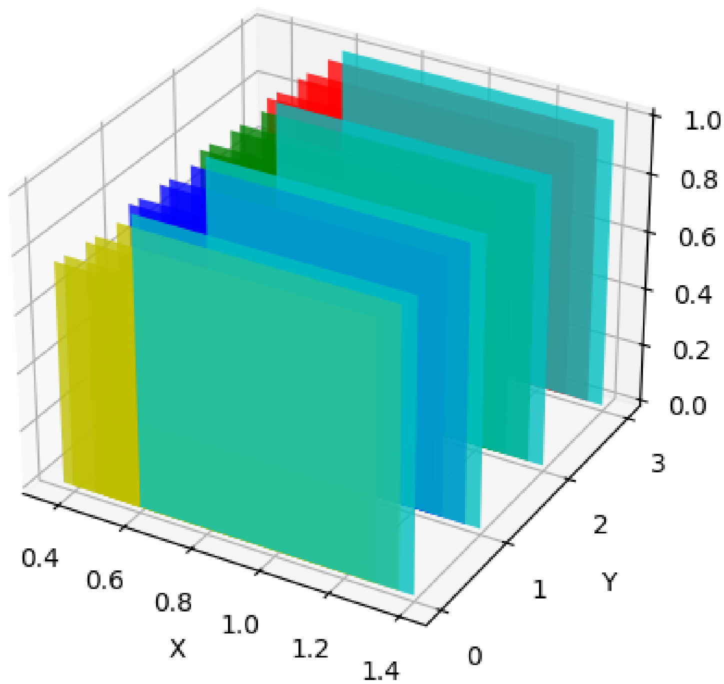

Fig 8. The overall values.

In cluster 3:

Eq. (2) is used to normalize the decision matrix as shown in Fig 9. Fig 10 is used to determine the weighted decision matrix.

Eqs. (3-6) are used to determine the 4 distinct benefits values as shown in Fig 11.

Eqs. (7-10) are used to determine the normalized benefits values

Eq. (11) is used to determine the overall values as shown in Fig 12.

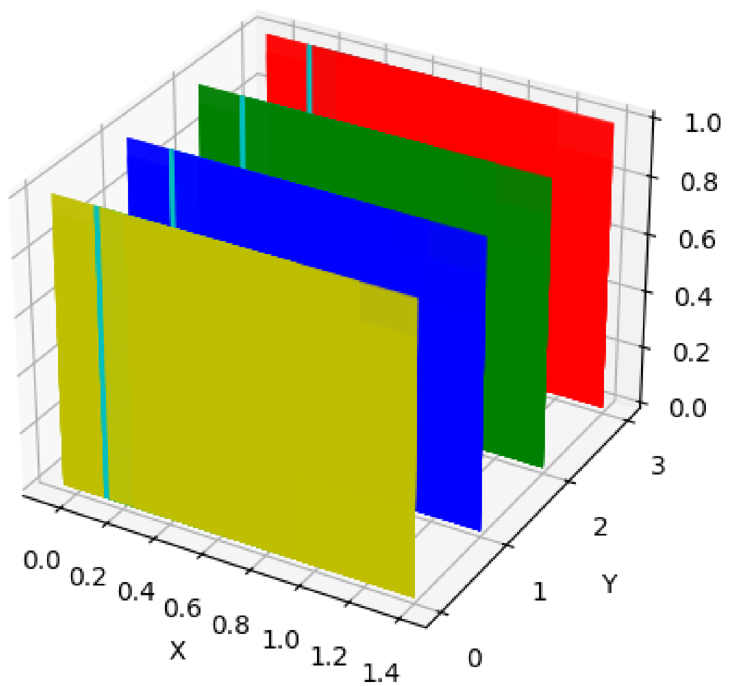

Fig 9. The normalized decision matrix.

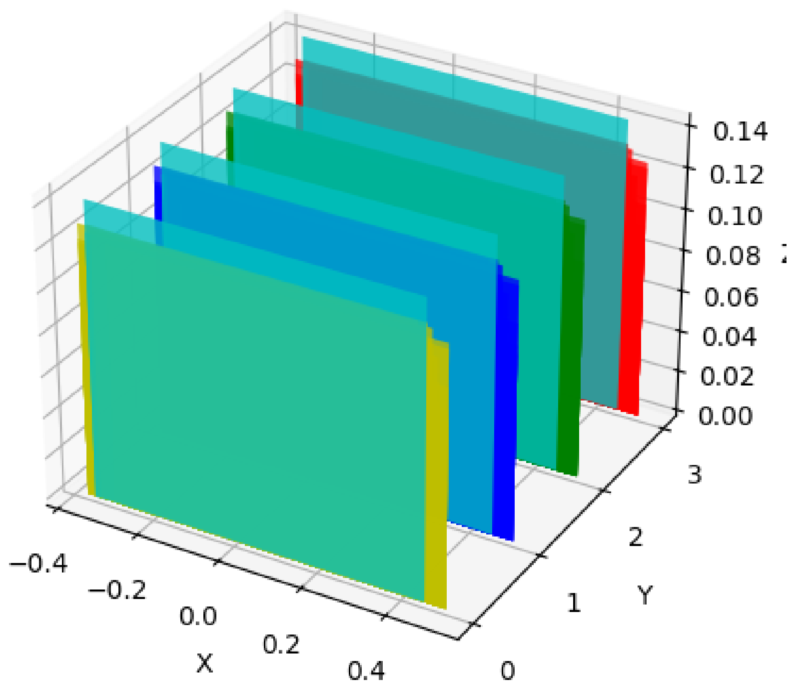

Fig 10. The weighted decision matrix.

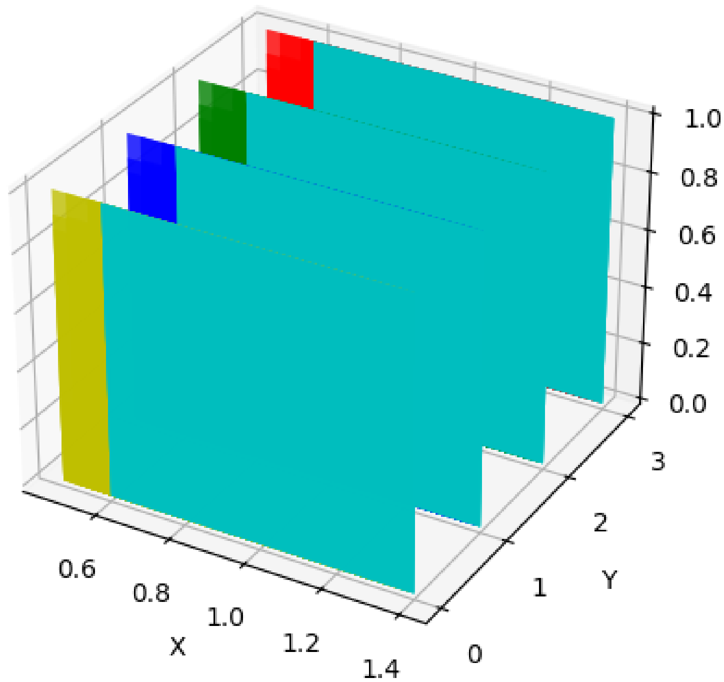

Fig 11. The 4 distinct benefits values.

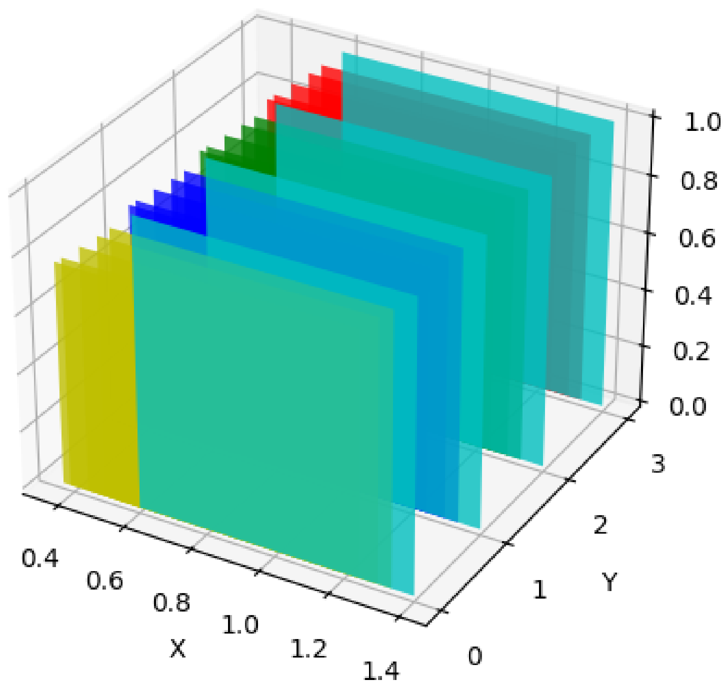

Fig 12. The overall values.

In cluster 4:

Eq. (2) is used to normalize the decision matrix as shown in Fig 13. Fig 14 is used to determine the weighted decision matrix.

Eqs. (3-6) are used to determine the 4 distinct benefits values as shown in Fig 15.

Eqs. (7-10) are used to determine the normalized benefits values

Eq. (11) is used to determine the overall values as shown in Fig 16.

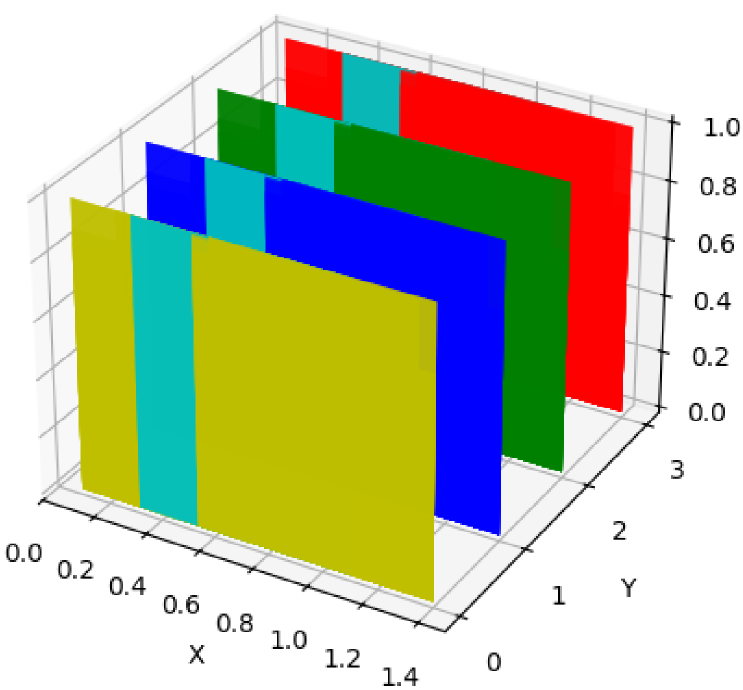

Fig 13. The normalized decision matrix.

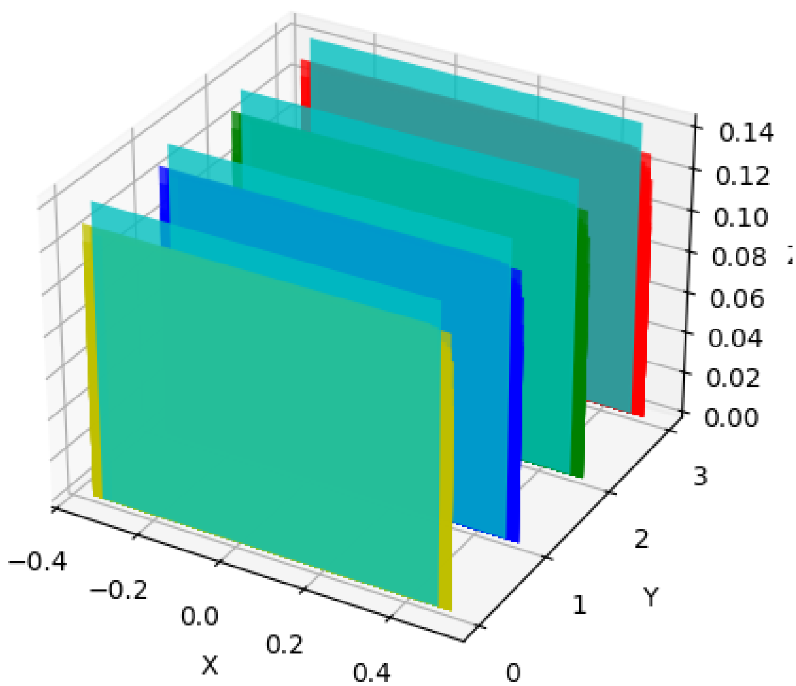

Fig 14. The weighted decision matrix.

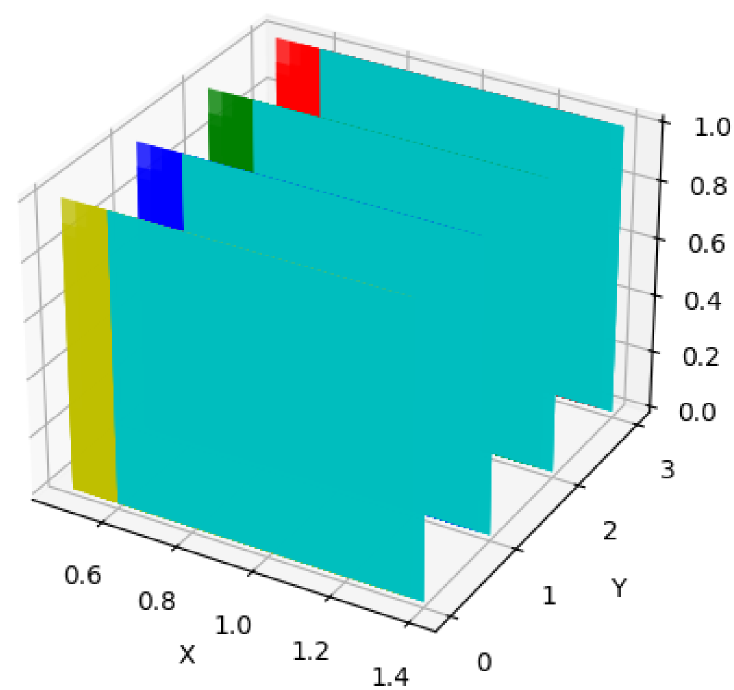

Fig 15. The 4 distinct benefits values.

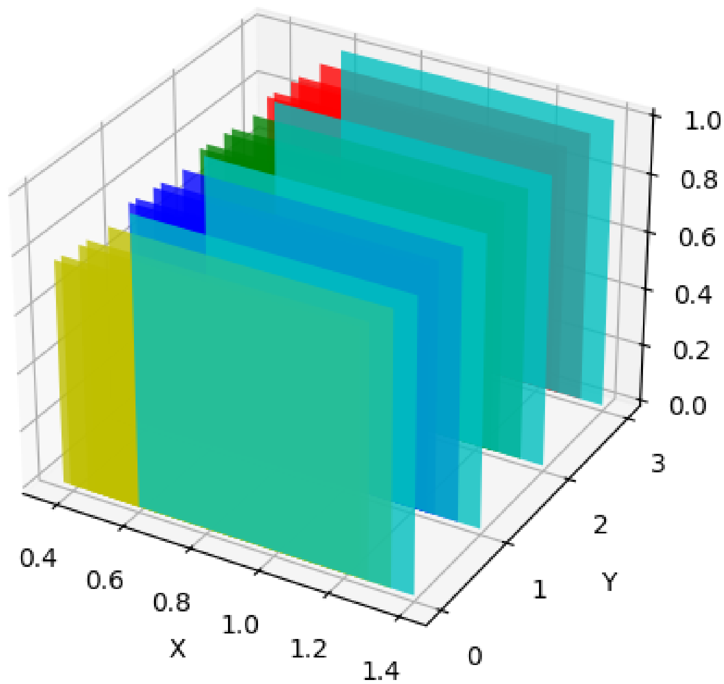

Fig 16. The overall values.

In cluster 5:

Eq. (2) is used to normalize the decision matrix as shown in Fig 17. Fig 18 is used to determine the weighted decision matrix.

Eqs. (3-6) are used to determine the 4 distinct benefits values as shown in Fig 19.

Eqs. (7-10) are used to determine the normalized benefits values

Eq. (11) is used to determine the overall values as shown in Fig 20.

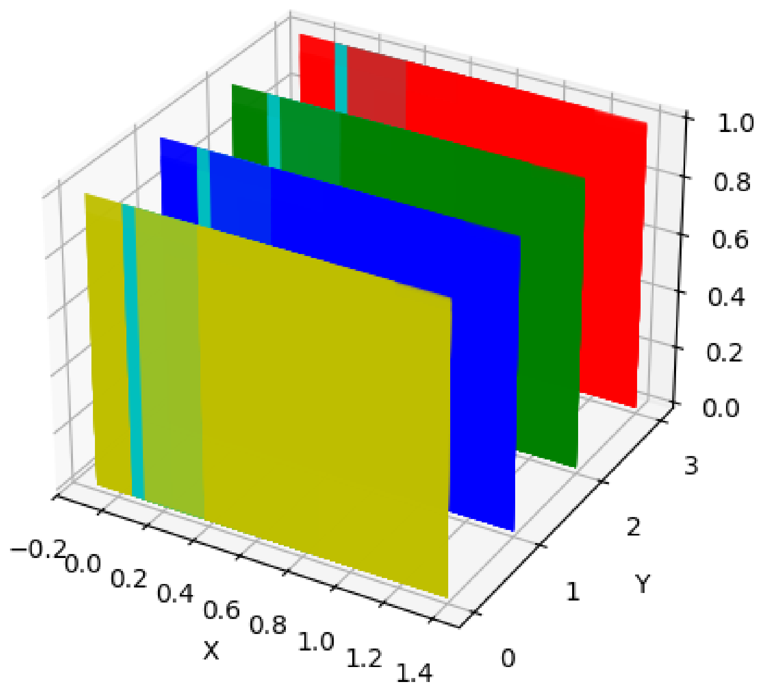

Fig 17. The normalized decision matrix.

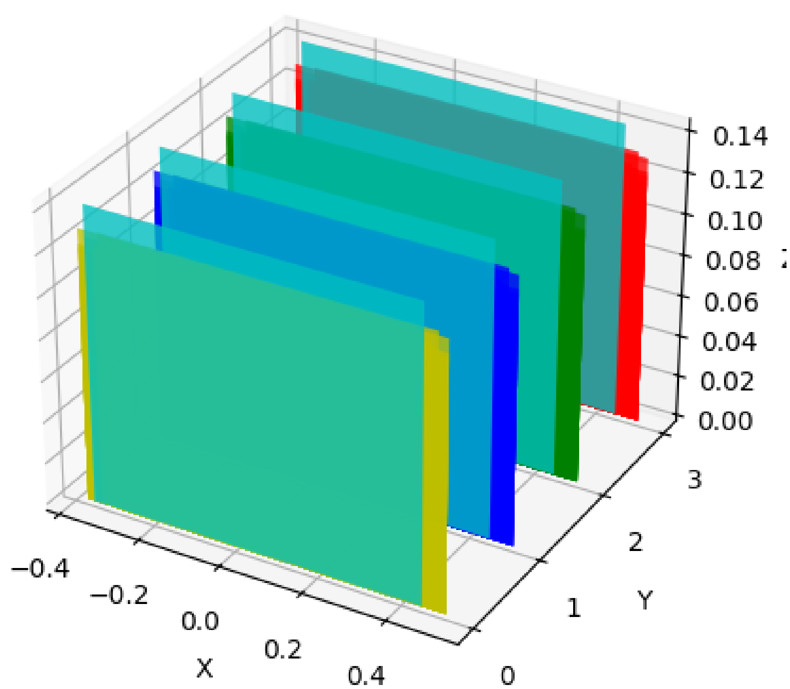

Fig 18. The weighted decision matrix.

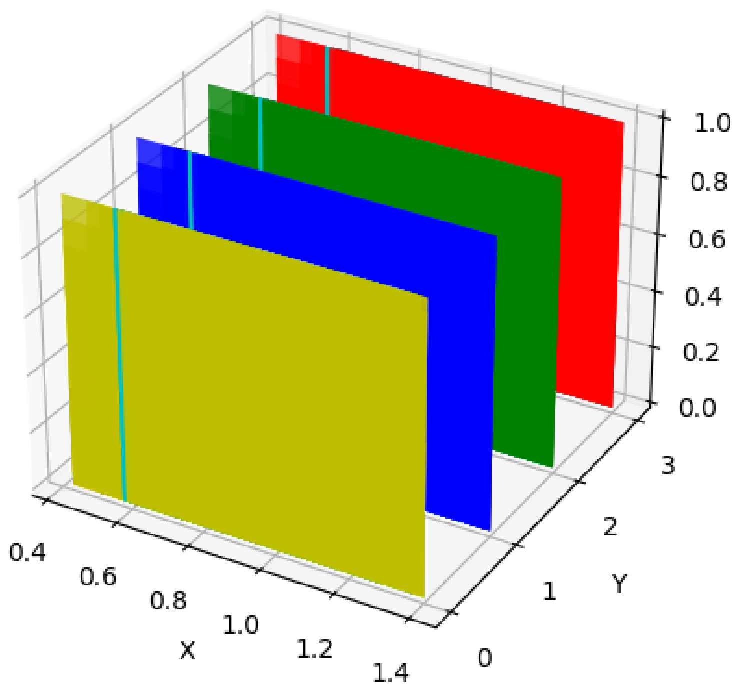

Fig 19. The 4 distinct benefits values.

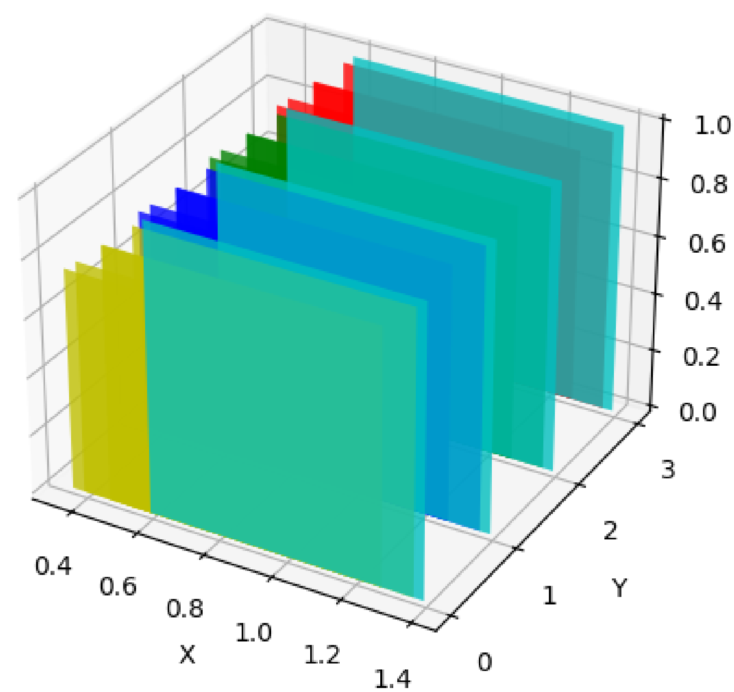

Fig 20. The overall values.

In cluster 6:

Eq. (2) is used to normalize the decision matrix as shown in Fig 21. Fig 22 is used to determine the weighted decision matrix.

Eqs. (3-6) are used to determine the 4 distinct benefits values as shown in Fig 23.

Eqs. (7-10) are used to determine the normalized benefits values

Eq. (11) is used to determine the overall values as shown in Fig 24.

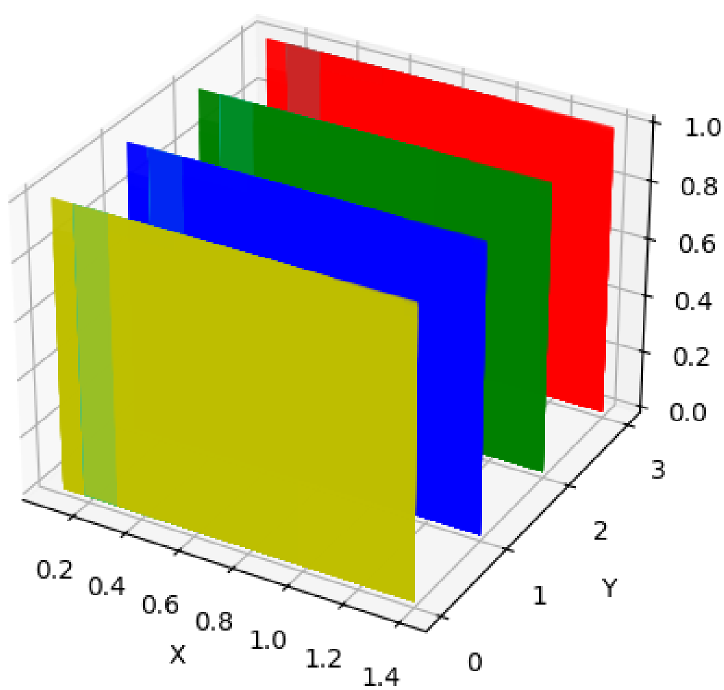

Fig 21. The normalized decision matrix.

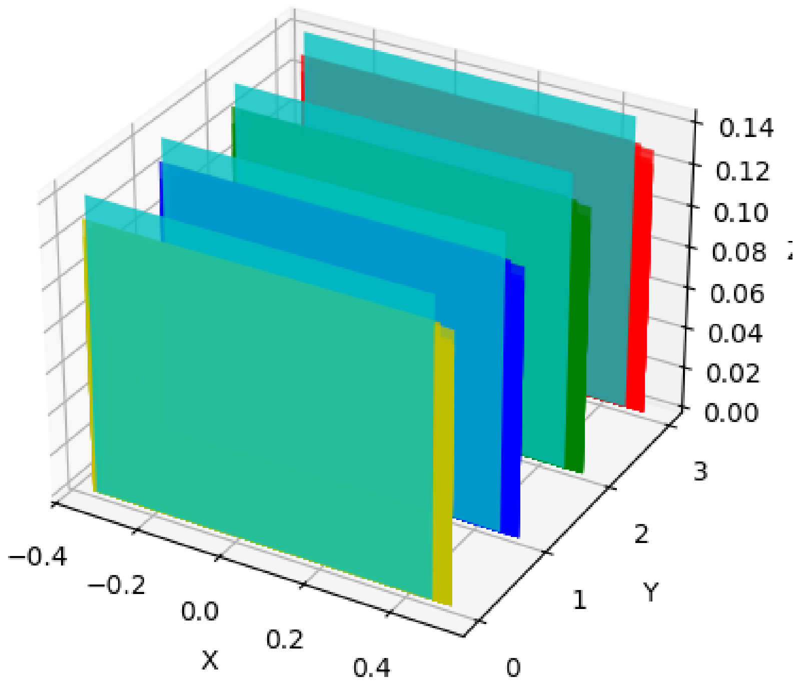

Fig 22. The weighted decision matrix.

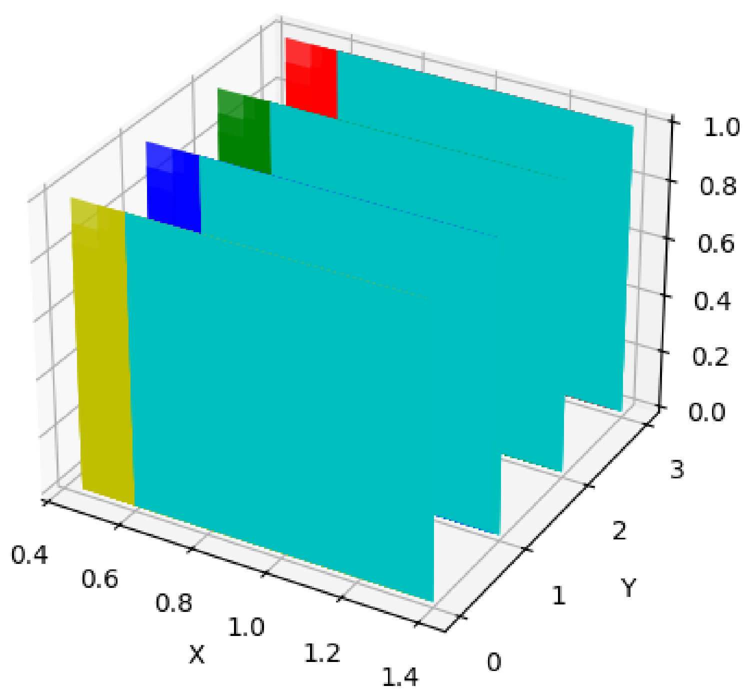

Fig 23. The 4 distinct benefits values.

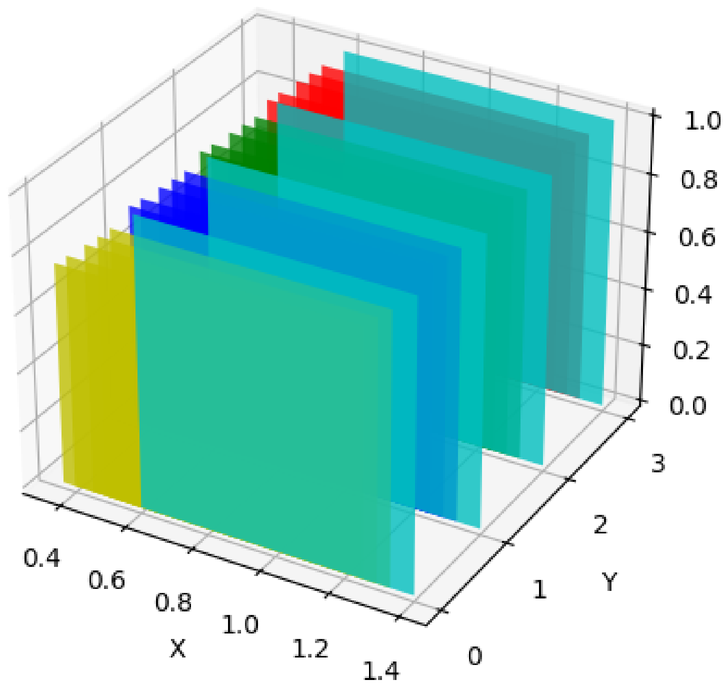

Fig 24. The overall values.

4. Conclusions

Green transformation in industrial, resource-based regions is both an environmental necessity and a developmental opportunity. While challenges such as economic dependency, social inertia, and technological gaps remain, the coordinated application of policy, innovation, and evaluation frameworks can guide regions toward a sustainable future. This study's multidimensional approach offers practical tools and strategic insight to facilitate this transition, contributing meaningfully to the global sustainability agenda. We use the WSIP method to rank alternatives. The average method is used to compute the criteria weights. We used the SuperHyperSoft set to deal with various criteria values. We use six clusters with different criteria values. The results show the stability of the ranks of the alternatives.

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