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# Assessment of Environmental Sustainability Practices in Healthcare Facilities by Employing Fuzzy-AHP

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**ABSTRACT**

**Background/Purpose:** This study primarily aims to identify and rank the criteria employed in assessing practices that promote environmental sustainability in healthcare facilities, grounded in their relative significance and weighted contributions.

**Methods:** The criteria determined within the scope of evaluation of environmental sustainability practices were analyzed with Fuzzy-AHP (Analytical Hierarchy Process), which is one of the Multi-Criteria Decision-Making Techniques. In this context, the opinions of 5 participants who were experts in the fields of health management, environment and air conditioning, public health and real estate evaluation were received.

**Results:** The most important criterion used to evaluate applications to increase environmental sustainability in healthcare facilities is "Energy Efficiency" with a normalized weight score of 37.3%. It is followed by "Waste Reduction and Environmental Impact" (22.8%) and "Cost Effectiveness" (12.2%), respectively. In this direction, the first 3 criteria represent an important part with a weight score of 72.3%. "Technological Compliance" was determined as the least important criterion with a weight of 3.8%.

**Conclusion:** As a result, the complementary structure of these criteria increases the effectiveness of environmental sustainability strategies in healthcare facilities and makes significant contributions to sustainable healthcare service delivery. Therefore, healthcare facility managers' prioritization of these criteria in their selection processes regarding environmental sustainability practices will strengthen the environmental performance of the facilities while also supporting their financial sustainability.

**Keywords:** AHP, Fuzzy logic, Environmental sustainability, Healthcare facilities

**ÖZET**

**Amaç:** Bu çalışmanın amacı, sağlık tesislerinde çevresel sürdürülebilirliğin artırılmasına yönelik uygulamaların değerlendirilmesinde kullanılan kriterleri görece önemleri temeleninde önceliklendirmektir.

**Yöntemler:** Çevresel sürdürülebilirlik uygulamalarının değerlendirilmesi kapsamında belirlenen kriterler Çok Kriterli Karar Verme Tekniklerinden biri olan Bulanık-AHS (Analitik Hiyerarşi Süreci) ile analiz edilmiştir. Bu kapsamda sağlık yönetimi, çevre ve iklimlendirme, halk sağlığı ve gayrimenkul değerlendirme alanında uzman 5 katılımcının görüşleri alınmıştır.

**Bulgular:** Sağlık tesislerinde çevresel sürdürülebilirliği artırmaya yönelik uygulamaların değerlendirilmesi için kullanılan en önemli kriter %37,3 normalize ağırlık puanı ile "Enerji Verimliliği" dir. Sonrasında, sırasıyla, "Atık Azaltma ve Çevresel Etki" (%22,8) ve "Maliyet Etkinlik" (%12,2) yer almaktadır. Bu doğrultuda ilk 3 kriter %72,3 ağırlık puanı ile önemli bir parçayı ifade etmektedir. "Teknolojik Uygunluk" ise %3,8 ağırlık ile en az önemli kriter olarak tespit edilmiştir.

**Sonuç:** Kriterlerin birbirini tamamlayıcı yapısı, sağlık tesislerinde çevresel sürdürülebilirlik stratejilerinin etkinliğini artırmakta ve sürdürülebilir sağlık hizmet sunumuna da önemli katkılar sağlamaktadır. Dolayısıyla, sağlık tesisleri yöneticilerinin çevresel sürdürülebilirlik uygulamalarıyla ilgili seçim süreçlerinde öncelikli olarak bu kriterleri dikkate alması, tesislerin çevresel performansını güçlendirirken, finansal sürdürülebilirliklerini de destekleyecektir.

**Anahtar Kelimeler:** AHS, Bulanık mantık, Çevresel sürdürülebilirlik, Sağlık tesisleri

Environmental sustainability has an increasing importance in the health sector today. Health facilities create significant environmental impacts through activities such as energy consumption, water use and waste management (1). Diminishing these impacts not only contributes to the protection of the environment but also to reducing operating costs and increasing the awareness of social responsibility (2). In the healthcare sector, which provides uninterrupted service 7/24 with its labour and technology intensity, implementing sustainability principles and carrying out prioritization studies to determine sustainability strategies that will provide competitive advantage make an important contribution (3). Integrating energy efficiency to hospital design have positive results in the long term (4); processes that require energy consumption such as heating, ventilation, air conditioning and lighting (5); consumption of large amounts of water with the use of equipment and devices (6); ambulance transportation, which contribute to carbon emissions, and hospital transfers of workers and users within public and private transportation (7).

The fossil fuel dependency significantly increases healthcare energy demand and $CO_2$ emissions. Healthcare facilities are among the largest consumers of energy. Mainly, hospitals, due to their building design and operational needs, are particularly responsible for environmental pollution. Hospitals located in warmer climates generally consume more electricity, while hospitals located in colder climates consume more fuel (8). Managing energy means reducing the energy consumed and the costs incurred, while maintaining quality and minimising environmental impact. Effective energy management is crucial not only for economic sustainability but also for environmental goals, as continuous operation of systems such as heating and ventilation further increases energy consumption (9).

Hospitals are known to consume large amounts of energy and water, in addition hazardous and non-hazardous waste, and use many different materials. However, the "green" approach to healthcare has emerged due to limited resources, inadequate waste management facilities, lack of staff training in the handling of hazardous materials, and insufficient incentives for the use of renewable energy. The green hospital concept aims at promoting efficient use of energy, water and materials, avoiding waste and implementing green building design. however, obstacles such as high investment costs, lack of information and awareness, cultural and administrative resistance and technological infrastructure problems are encountered in the transition process to this concept (10).

It is shown that studies on sustainable healthcare services mainly focus on five main topics: energy efficiency and building design (10,11), renewable energy systems costs (8,12), minimizing environmental impacts (13,14), determining sustainability criteria (15, 16) and increasing awareness levels of managers (17-19). Studies have also focused on issues such as reducing energy costs of green hospital applications, the impact of innovation and learning perspective on sustainability, and the integration of social, economic and environmental dimensions. Sustainable healthcare services stand out as an important area in terms of environmental and economic sustainability in the healthcare sector.

The objective of this study is to ascertain the relative weight and importance levels of the criteria employed for the assessment of practices aimed at enhancing environmental sustainability in healthcare facilities. Therefore, the objective is to make environmentally focused decisions in an appropriate and objective manner, considering a range of criteria.

## Material and Method

### *2.1. Participants*

The criteria were evaluated by 5 experts in the fields of health management, environment and air conditioning, public health and real estate evaluation (Table 1).

**Table 1:** Participants (decision makers) characteristics

| Decision Makers | Specialization | Education | Position | Experience |
|---|---|---|---|---|
| **DM1** | Health Management | PhD | Prof. | 15 years |
| **DM2** | Health Management | PhD | Assoc. Prof. | 10 years |
| **DM3** | Environment and Climate | Master | Engineer | 8 years |
| **DM4** | Public Health | PhD | Assoc. Prof. | 11 years |
| **DM5** | Real Estate Assessment | PhD | Prof. | 13 years |

### 2.2. Identifying to criteria

In the study, data were analyzed using Fuzzy Analytical Hierarchy Process (Fuzzy-AHP) one of the multicriteria decision making techniques. AHP expresses the intuitions of decision makers in the form of crisp data based on the two-way comparisons of the criteria. It is a powerful tool for solving complex decision problems. It solves problems by transforming into hierarchical structures through pairwise comparisons. In fact, this study aimed to make a weight and importance ranking based on 8 criteria determined in line with expert opinions and included in the literature for the evaluation of environmental sustainability practices. In this direction, the criteria and their explanations are expressed in Table 2.

**Table 2:** Criteria and Explanations to be Used in the Study

| # | Abbreviation | Criteria | Explanation |
|---|---|---|---|
| 1 | **CR** | Corporate Reputation | Meeting ecological responsibility and increasing its reliability and prestige in the eyes of society |
| 2 | **CE** | Cost Effectiveness | The total cost of the application and the financial savings it provides over time. |
| 3 | **EE** | Energy Efficiency | The scope to which the application reduces energy usage. |
| 4 | **LC** | Legal Compliance | The application's adherence to local, national, and international environmental protection laws. |
| 5 | **PSS** | Patient and Staff Safety | The impact of the application on patient and employee safety. |
| 6 | **SI** | Societal Impact | The impact of the practice on society, i.e. its contribution to local communities and public health. |
| 7 | **TC** | Technological Compliance | Compliance with regulatory standards by adopting advanced environmentally friendly solutions |
| 8 | **WRE** | Waste Reduction and Environmental Impact | Contribution to reducing waste, increasing the recycling rate and safely disposing of hazardous waste. |

*Reference: 10-19*

The weights and importance levels of the criteria were determined by making the relevant calculations of the Fuzzy-AHP method via Microsoft 365 Excel.

### 2.3. Fuzzy-AHP

Fuzzy-AHP is an extension of AHP that incorporates fuzzy logic to address the uncertainties and ambiguities inherent in decision-making processes. Conventional AHP often struggles with the uncertainty of human judgment, especially when decision makers are asked to provide precise numerical values for their preferences. Fuzzy-AHP alleviates this problem by allowing decision makers to express their preferences using linguistic terms, which are then converted into fuzzy numbers, typically triangular or trapezoidal, to represent the uncertainty in their judgments (19-21).

Fuzzy-AHP usually involves several stages. The first stage is the creation of a hierarchical structure that decomposes the decision problem into a set of criteria and sub-criteria. This hierarchical model is important because it organizes the decision-making process into manageable components and facilitates a clearer analysis of the relationships between different criteria (19, 22).

The second stage involves collecting pairwise comparison data from decision makers, where decision makers evaluate the relative importance of each criterion over others. These terms are then converted into fuzzy numbers to form a fuzzy pairwise comparison matrix (20, 23).

The third stage is the synthesis of the fuzzy pairwise comparison matrix to derive fuzzy priority weights for each criterion. It involves applying fuzzy arithmetic operations to collect a set of fuzzy comparisons that reflect the preferences of decision makers (22).

The fourth stage is the fuzzification process, in which fuzzy priority weights are converted into crisp data to facilitate the ranking of alternatives. Common methods for fuzzification include the centroid method or the average of maximums (21). In this study, Chang's method was used for fuzzy pairwise comparisons of criteria. The analysis developed by Chang (24) provides a more meaningful and flexible comparison opportunity by using pairwise comparison matrices and triangular fuzzy numbers.

The final stage involves analysis of the results, where clear priority weights are used to rank the alternatives according to defined criteria. This ranking helps decision makers to determine the most appropriate option among the alternatives considered.

In Fuzzy-AHP, decision makers receive linguistic terms and pairwise comparisons on a scale of 1-9. Then, the pairwise comparisons of the decision makers are converted into triangular fuzzy numbers as shown in Table 3.

**Table 3:** Triangular fuzzy scales

| Linguistic term | Abbreviation | Relative Importance | Fuzzy scales | Inverse fuzzy scales |
|---|---|---|---|---|
| Equal | E | 1 | 1,1,1 | (1/1, 1/1, 1/1) |
| Moderate | MS | 3 | 2,3,4 | (1/4, 1/3, 1/2) |
| Strong | S | 5 | 4,5,6 | (1/6, 1/5, 1/4) |
| Very Strong | VS | 7 | 6,7,8 | (1/8, 1/7, 1/6) |
| Extremely Strong | ES | 9 | 9,9,9 | (1/9, 1/9, 1/9) |
| Intermediate Values | IV | 2;4;6;8 | 1,2,3;3,4,5;5,6,7;7,8,9 | (1/3, 1/2, 1; 1/5, 1/4, 1/3; 1/7, 1/6, 1/5; 1/9, 1/8, 1/7) |

## Results

The determined criteria were evaluated by experts and comparison matrices containing the opinions of decision makers were obtained. For instance, the decision matrix illustrates the perception of DM1, is shown in Table 4.

**Table 4:** Pairwise comparison matrix of determinants (DM1)

| | EE | WRE | CE | PSS | LC | SI | CR | TC |
|---|---|---|---|---|---|---|---|---|
| **EE** | E | MS | S | VS | MS | S | VS | ES |
| **WRE** | | E | MS | S | MS | S | VS | S |
| **CE** | | | E | MS | E | MS | S | S |
| **PSS** | | | | E | MS | S | VS | MS |
| **LC** | | | | | E | MS | S | MS |
| **SI** | | | | | | E | MS | E |
| **CR** | | | | | | | E | MS |
| **TC** | | | | | | | | E |

The degrees of importance for each criterion comparison in the decision matrices were combined with the opinions of the other 4 decision makers and expressed as fuzzy numbers in Table 3, and an integrated fuzzy decision matrix containing the common opinions of 5 experts was created. In the integrated fuzzy decision matrix, triangular fuzzy numbers were calculated for each criterion comparison. Finally, the fuzzy weights, averages and normalized relative weights of the criteria were calculated. In Table 5, the final importance weights are presented.

**Table 5.** Fuzzy AHP Average and Normalization Weights

| # | Criteria | Weight (Avarage) | Weight (Normalized) | Rank |
|---|---|---|---|---|
| **EE** | Energy Efficiency | 0,3927 | 0,3727 | 1 |
| **WRE** | Waste Reduction and Environmental Impact | 0,2398 | 0,2276 | 2 |
| **CE** | Cost Effectiveness | 0,1281 | 0,1216 | 3 |
| **PSS** | Patient and Staff Safety | 0,0736 | 0,0865 | 4 |
| **LC** | Legal Compliance | 0,0911 | 0,0699 | 5 |
| **SI** | Societal Impact | 0,0432 | 0,0421 | 6 |
| **CR** | Corporate Reputation | 0,0444 | 0,0410 | 7 |
| **TC** | Technological Compliance | 0,0404 | 0,0383 | 8 |

According to Table 7, the most important criterion used to evaluate practices to increase environmental sustainability in healthcare facilities is "Energy Efficiency" with a normalized weight score of 37.3%. Then, "Waste Reduction and Environmental Impact" (22.8%) and "Cost Effectiveness" (12.2%) come next. In this direction, the first 3 criteria represent a significant majority with a weight score of 72.3%. "Technological Compliance" was determined as the least important criterion with a weight of 3.8%.

## Discussion

This study revealed that the most crucial criteria used to evaluate practices to increase environmental sustainability in healthcare facilities are energy efficiency, waste reduction, environmental impact and cost effectiveness, respectively.

There are different studies indicating that the energy efficiency criterion has the highest importance (37.3%). Similarly, Çakmak Barsbay (8) emphasized that energy expenditures are an important expenditure item in the healthcare sector and significantly affect sustainability. Mcgain et al. (25), who discussed the impact of energy resources on the ecological footprint of healthcare services, emphasized that energy efficiency is vital for reducing environmental pollutants and promoting sustainability.

The second crucial criterion (22.8%) is waste reduction and environmental impact. In the literature, Mehra and Sharma (26) emphasized that strategies such as innovation and waste reduction will guide sustainability goals by using multi-criteria decision-making methods. Castro de Fátima et al. (27) developed 52 criteria under environmental, socio-cultural, economic, technical and regional opportunity dimensions in their study where they applied the AHP method and stated that environmental criteria were of the highest importance . In addition, the World Health Organization (28) estimates that 15% to 25% of healthcare waste is hazardous, which shows the importance of the process of evaluating the necessary practices to ensure environmental sustainability.

The third critical criterion (12.2%) is cost-effectiveness. Indeed, in the literature; Zadeh et al. (29) emphasize the need for cost-effective criteria to create sustainable healthcare environments by reducing costs on the one hand and supporting health and healing missions on the other. Zuhri (30) emphasized that the concept of environmental sustainability is closely linked to the efficient use of resources, which can lead to significant cost savings.

## Conclusion

The complementary structure of the criteria increases the effectiveness of environmental sustainability strategies in healthcare facilities and makes significant contributions to the provision of sustainable healthcare services. Therefore, healthcare facility managers should prioritize these criteria in their selection processes regarding environmental sustainability practices, which will strengthen the environmental performance of the facilities and support their financial sustainability. The detailed recommendations as below;

Energy-efficient applications such as the commissioning of building automation systems, LED lighting, smart HVAC systems, trigeneration systems and renewable energy sources (solar, wind) significantly reduce operating costs.

Reducing medical, chemical and plastic waste, establishing appropriate waste management procedures, programs that encourage recycling and reuse of materials, and supplying environmentally friendly products (e.g. biodegradable packaging, reusable tools) contribute to reducing environmental impact.

Cost effectiveness, on the other hand, provides significant savings in the long term thanks to the high return potential of investments made in sustainable practices, and also brings economic advantages by offering the opportunity to benefit from financial incentives and supports.

## Declarations

### *Conflict of Interest*

The authors have declared no conflict of interest.

### *Ethics Approval*

Istanbul Medipol University Non-Interventional Ethics Committee decided that this study was approved (Date: 16/10/2024, Decision No: 956, Number: E-10840098-202.3.02-6359). The study was conducted in accordance with the principles of the Declaration of Helsinki. Informed consent was obtained from all participants.

### *Availability of Data and Material*

All data have been presented here. Material may be available upon request.

### *Authors' Contributions*

EG performed the research, analysed the data, and wrote the paper also he conceived of and designed the overall study.

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