Green Technology Assessment with an Integrated AHP – Quality Function Deployment Approach

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Abstract: This study presents an integrated methodology for assessing green technologies by combining the Analytical Hierarchy Process (AHP) with Quality Function Deployment (QFD). As the global demand for sustainability intensifies due to climate change and resource challenges, merging quality with eco-friendly practices becomes paramount. We explore how green technologies—encompassing renewable energy, electric vehicles, and sustainable materials—can be effectively evaluated to meet quality and sustainability standards. The AHP framework aids in prioritizing decision criteria, while QFD translates these criteria into actionable technical specifications. The findings indicate that this combined approach enhances product quality and aligns with consumer expectations for sustainability. This structured framework encourages a collaborative process and provides practical insights for industries striving towards responsible production and consumption. By emphasizing the collaborative nature of the approach, the study aims to make the audience feel included and part of a more significant movement. The results underscore the critical interplay between quality and sustainability, reinforcing their role in shaping a sustainable future.

Key-Words: - AHP, Green Technology, Sustainability, Multi-Criteria Decision Making, Quality Function Deployment.

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1 Introduction

The future will likely see an even stronger integration of sustainability concepts as the world faces growing challenges related to climate change, resource depletion, and social inequality. Innovations in circular economy practices, renewable energy, and bio-based materials are expected to redefine standards for what is considered high-quality and sustainable. Consumers and businesses must adapt to a landscape where quality and sustainability are desirable and essential.

Electric vehicles (EVs) are a prime example of a product where sustainability meets quality. Companies like Tesla and Volkswagen are developing cars that use sustainable energy and materials while providing high safety, reliability, and comfort standards. In the technology sector, companies such as Apple focus on creating high-quality and increasingly sustainable devices, incorporating recycled materials and focusing on energy-efficient production methods.

Green technology refers to innovative methods, products, or processes that responsibly harness natural resources and reduce environmental harm. These technologies aim to minimize waste, reduce carbon emissions, and use energy more efficiently. Examples include renewable energy sources like solar and wind power, electric vehicles, energy-efficient appliances, smart grids, and sustainable construction practices. However, there are several technique requirements while designing green technologies. This study aims to present a research methodology for assessing green technologies by using the Analytical Hierarchy Process (AHP) and Quality Function Deployment (QFD) approach. AHP helps prioritize decision criteria for evaluating green technologies by weighing cost and environmental impact. At the same time, QFD translates these criteria into specific technical requirements and features, ensuring technologies meet sustainability and quality goals through a structured, collaborative approach.

The remainder of the study is as follows: The next section details the green technology concept. Section 3 summarizes related works. Section 4 provides the methodology. Section 5 provides an application, and Section 6 provides the conclusions.

2 Green Technology

Quality and sustainability are deeply interconnected concepts, particularly in the context of products, services, and business practices. Understanding their relationship can illuminate why they are essential for long-term success and positive societal impact [1, 2].

Modern consumers are more aware of sustainability issues and demand higher-quality, eco-friendly, and ethically produced products. Sustainable practices can lead to long-term cost savings. Energy efficiency, waste reduction, and longer-lasting products can lower manufacturing and operational expenses. Governments are increasingly enforcing environmental standards and regulations. Companies prioritizing quality and sustainability are better prepared to adapt to changing laws and avoid penalties. Therefore, quality and sustainability are fundamental elements of a responsible and forward-thinking approach to production and consumption [3].

Green technology significantly enhances quality and sustainability by providing innovative solutions that reduce environmental impact while maintaining or even improving product standards. This type of technology, also known as clean technology or eco-friendly technology, encompasses many tools, methods, and products that aim to create more sustainable systems. In this regard, household adoption of green technologies and the facilitation of the shift to sustainable future green technology are significantly influenced by energy access, cost, and the caliber of institutions [4].

3 Related Works About Green Technology

Dahmani [1] examined the impact of environmental fiscal policies, environmental technologies, and research and development expenditures on achieving ecological sustainability in the G7 countries. Jinping et al. [5] determined whether there are any differences in the relationship between three variables, green finance, environmental management innovation, and ecological performance, regarding the underlying causes of each variable.

Hassan et al. [2] investigated the influence of governance quality and environmental expenditure on environmental quality (CO_2 emissions) from 1996 to 2020 using the FMOLS model and the marginal effects. Xu et al. [3] employed a polynomial quadratic regression model to analyze the potential, specifically the nonlinear relationship between the digital economy and the ecological footprint across selected OECD countries. Khurshid et al. [4] evaluated the individual and interactive effects of green technology adoption-innovation, institutional quality, and energy access on household clean fuels technologies adoption and GHG emissions.

4 Method

This study employs the AHP method to compute the criteria weights and the QFD method to rank the technique requirements in green technology. Fig. 1 illustrates the study's flowchart, highlighting the central role of AHP and QFD in the methodology.

In the first stage, the goal of the assessment (e.g., selecting the most sustainable green technology) is identified. Then, the criteria and sub-criteria are determined. AHP method is used to structure and prioritize decision-making criteria related to green technology (e.g., environmental impact, cost, efficiency, etc.). The weights of the criteria are determined at the end of AHP. Then, the QFD Matrix is constructed by creating the QFD matrix to map customer requirements (e.g., sustainability goals) against the technical characteristics of green technologies. The weights are assigned to criteria based on AHP results. In the end, how well each technology meets customer requirements is determined. The AHP weights are used to weigh the scores for a comprehensive assessment. The scores from QFD analysis with AHP weights are aggregated. The technologies are ranked according to their scores to determine the best option. The green technology with the highest score is determined, and recommendations based on the integrated AHP-QFD analysis are provided.

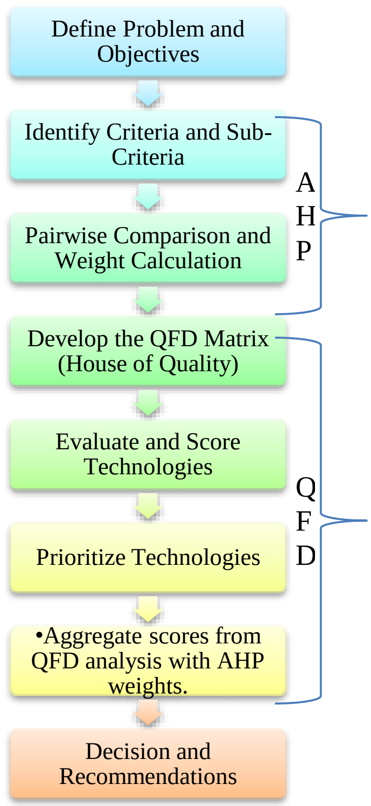

Fig. 1. The flowchart of the study

4.1 AHP Method

Step 1. The problem and the type of information searched are determined.

Step 2. The hierarchy of decisions from the top with the aim of the decision, then the criteria and sub-criteria to the lowest level, are constructed.

Step 3. A pair of comparison matrix sets is constructed. Each item at the top level is used to compare items at the level just below it.

Comparison matrix *A* is constructed. Every input a_{jk} of the matrix *A* represents the significance of the j^{th} criterion relative to the k^{th} criterion. The inputs a_{jk} and a_{kj} satisfy the constraint:

$$a_{jk}.a_{kj} = 1 \quad (1)$$

Table 1. Table of relative scores [6]

Value of a_{jk}	Interpretation
1	*j* and *k* are equally important
3	*j* is slightly more critical than *k*
5	*j* is more critical than *k*
7	*j* is enormously more important than *k*
9	*j* is absolutely more important than *k*

After the construction of matrix *A*, the normalized pairwise comparison matrix A_{norm} is built by making the sum of the inputs on each column equal to 1; each input of the matrix A_{norm} is calculated as:

$$\bar{a}_{jk} = \frac{a_{jk}}{\sum_{i=1}^{m} a_{jk}} \quad (2)$$

The vector of criterion weight(w) is constructed by taking the average of the entries on each row of A_{norm} as:

$$w_j = \frac{\sum_{l=1}^{m} \bar{a}_{jl}}{m} \quad (3)$$

The vector of criterion weight(w) is constructed by taking the average of the entries on each row of A_{norm} as:

Step 4. Each item uses the preferences from the comparison to weigh the preferences at the level just below. Then, the weighing values for each item at the level below are added, and global or global priority is taken.

Step 5. The decision maker's decisions should be consistent during the evaluation phase. To provide this condition, a consistency ratio is computed. The inconsistency index (consistency ratio) is calculated with the equation:

$$CI = \frac{\lambda_{max} - N}{N-1} \quad (4)$$

4.2 QFD Method

QFD is a vital planning, development, communication, and design technique that transforms customers' needs into product or service characteristics in all functional components. This approach aims to translate customer needs into appropriate technical or technological requirements [7].

House of Quality (HOQ) is the most frequently used matrix in the QFD process, as illustrated in Fig. 2. A team of multidisciplinary experts conducts this matrix to translate customer needs gathered from market research and benchmark data into technical requirements that are sought when designing a new product or service.

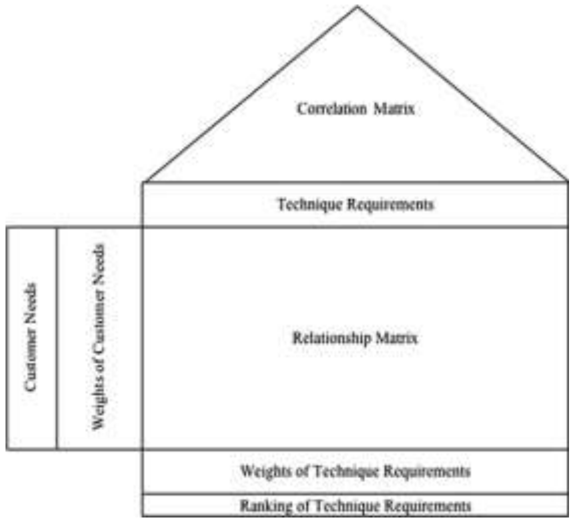

Fig. 2. House of Quality

Step 1. Customer needs are determined.

Step 2. Technique requirements are determined.

Step 3. The HOQ contains the customer needs, technique requirements, weights, and the matrix relating customer needs to technical requirements.

Step 4. The degrees of importance of technique requirements are determined.

4.3 Green Technology Assessment Model

The factors are determined based on literature [8, 9]. The green technology criteria (i.e., customer needs) are illustrated in Fig.3.

Customer Needs (What): These are the key requirements or expectations from the customer's perspective, listed in Table 2.

Technique Requirements (How): These are the specific technical specifications or characteristics that can be used to meet customer needs. They are listed in Table 3.

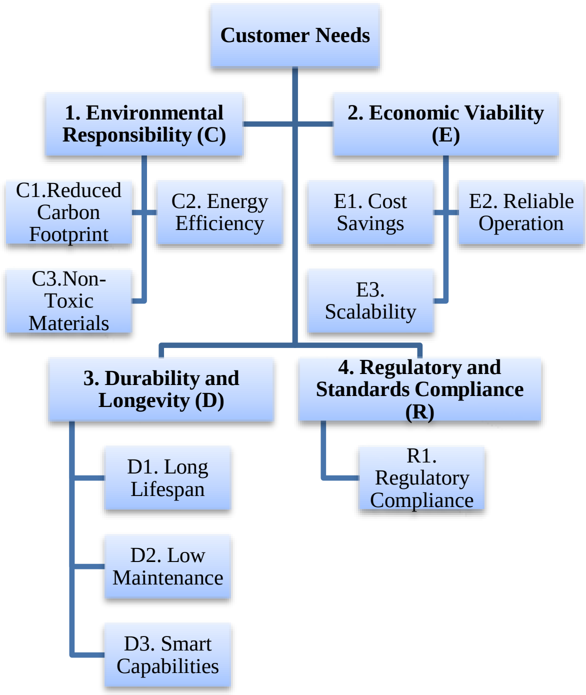

Fig. 3. The hierarchical model of customer needs

Table 2. The customer needs

Customer Needs	Description
Reduced Carbon Footprint	Lower CO2 emissions and overall environmental impact.
Cost Savings	Reduction in energy and operational costs over time.
Energy Efficiency	High energy output with minimal energy consumption.
Reliable Operation	Dependable performance with minimal failures.
Non-Toxic Materials	Use of safe, non-toxic materials that don't harm health.
Long Lifespan	Durability and longevity of the technology.
Low Maintenance	Minimal maintenance required for optimal performance.
Regulatory Compliance	Adherence to industry and environmental standards.
Scalability	Ability to scale up or down as needed.
Smart Capabilities	Integration with IoT for performance monitoring and control.

Table 3. The technique requirements

Technique Requirements	Description
Energy Consumption	Measures the energy used by the technology.
Carbon Emissions	Emissions produced during operation.
Materials Used	Type of materials, focusing on recyclability and safety.
Production Process	Methods of production and their environmental impact.
Maintenance Frequency	Frequency of service or maintenance required.
Compliance Certifications	Standards met, such as ISO 14001 and ENERGY STAR.
Integration Features	Ability to connect and communicate with existing systems.
Cost of Technology	Total cost of ownership, including initial and ongoing costs.
Product Lifespan	Expected operational duration before significant degradation.
Smart Sensors	Built-in sensors for real-time

and Controls	data collection and automation.

5 Application

Several factors can be considered when choosing green technologies. Numerous studies emphasize how crucial the creation of criteria is to the decision-making process. They recommend thoroughly gathering the requirements to assess technical, social, environmental, and economic performance [9].

An application is provided to illustrate the potential use of the AHP-QFD approach. Experts evaluated the green technology assessment criteria. Table 4 illustrates the evaluation of the main criteria.

Table 4. Evaluation of the main criteria

	C	**E**	**D**	**R**
C	1.00	5.00	7.00	1.00
E	0.20	1.00	3.00	0.500
D	0.14	0.33	1.00	0.250
R	1.00	2.00	4.00	1.00

The steps of the AHP method are applied, and the criteria weights are determined. The results are illustrated in Table 5.

Table 5. Criteria weights

	Customer Needs' Weights	**Rank**
1. Environmental Responsibility		
C1.Reduced Carbon Footprint	0.304	2
C2. Energy Efficiency	0.073	5
C3.Non-Toxic Materials	0.087	3
2. Economic Viability		
E1. Cost Savings	0.045	6
E2. Reliable Operation	0.016	8
E3. Scalability	0.085	4
3. Durability and Longevity		
D1. Long Lifespan	0.012	9
D2. Low Maintenance	0.010	10
D3. Smart Capabilities	0.042	7
4. Regulatory and Standards Compliance		
R1. Regulatory Compliance	0.324	1

The consistency ratios are CR_{main}: 0.045, CR_C: 0.025, CR_E: 0.03, and CR_D: 0.024.

Experts assessed the technique requirements of green technology. The steps of the QFD method are applied, and the ranking of the technique requirements is determined. The assessments are provided in Table 6. The results are illustrated in Table 7.

Table 7. Ranking of technique requirements

	Scores	**Norm. Scores**	**Rank**
T1. Energy Consumption	1.146	0.112	3
T2. Carbon Emissions	1.727	0.169	2
T3. Materials Used	0.668	0.065	9
T4. Production Process	0.572	0.056	10
T5. Maintenance Frequency	0.676	0.066	8
T6. Compliance Certifications	2.040	0.199	1
T7. Integration Features	0.919	0.090	4
T8. Cost of Technology	0.773	0.076	7
T9. Product Lifespan	0.851	0.083	6
T10. Smart Sensors and Controls	0.852	0.083	5
Sum:	**10.225**	**1.000**	

At the end of the application, the most critical customer needs are ranked as regulatory compliance (R1), reduced carbon footprint (C1), and non-toxic materials (C3). The most essential requirements of technique for green technologies are ranked as “T6. Compliance Certifications”; “T2. Carbon Emissions”; and “T1. Energy Consumption”.

Table 6. The HOQ matrix

		Technical Requirements									
Customer Needs	**W_i**	**T1. Energy Consumption**	**T2. Carbon Emissions**	**T3. Materials Used**	**T4. Production Process**	**T5. Maintenance Frequency**	**T6. Compliance Certifications**	**T7. Integration Features**	**T8. Cost of Technology**	**T9. Product Lifespan**	**T10. Smart Sensors and Controls**
C1. Reduced Carbon Footprint	0.304	X	XXX				XX				
C2. Energy Efficiency	0.073	XXX	XX		X	X	X	XX	XX	XXX	XX
C3. Non-Toxic Materials	0.087	X	X	XXX			XX				
E1. Cost Savings	0.045	X	XX	X	X	XX	X	XX	XXX	XX	X
E2. Reliable Operation	0.016	X	X	X	XX	XXX	X	X	X	XX	X
E3. Scalability	0.085	X	X		X	X	X	XXX	X	X	XX
D1. Long Lifespan	0.012	X	X	X	X	XX	X		X	XXX	X
D2. Low Maintenance	0.010	X	X	X		XXX	X		X	XX	X
D3. Smart Capabilities	0.042	X	X				X	XX	X	X	XXX
R1. Regulatory Compliance	0.324	X	X	X	X	X	XXX	X	X	X	X
Scores:		1.146	1.727	0.668	0.572	0.676	2.040	0.919	0.773	0.851	0.852
Normalized Scores:		0.112	0.169	0.065	0.056	0.066	0.199	0.090	0.076	0.083	0.083
Ranking:		3	2	9	10	8	1	4	7	6	5

6 Conclusion

In conclusion, quality and sustainability are not just trends but fundamental elements of a responsible and forward-thinking approach to production and consumption. When aligned, they create more enduring and impactful products that benefit people and the planet. Implementing them effectively, balancing initial costs with long-term gains, and fostering an industry culture that prioritizes these ideals is challenging.

Green technology is essential for fostering quality and sustainability across different industries. By prioritizing eco-friendly innovations and integrating them with high-quality manufacturing and design practices, businesses and consumers can contribute to a more sustainable and resilient future. The ongoing development of green technology will continue to reshape how products are created and consumed, paving the way for more responsible and durable solutions that benefit both the planet and the people who live on it.

At the end of the application, green technologies' most critical customer needs are regulatory compliance, reduced carbon footprint, and non-toxic materials. The most essential technical features for green technologies are compliance certifications, carbon emissions, and energy consumption.

The findings suggest that integrating sustainability with quality considerations improves overall product standards. Companies can create competitive advantages in the market by focusing on reducing environmental impact while maintaining high-quality standards.

References:

[1] Alnoor, A., Chew, X., Khaw, K. W., Muhsen, Y. R., & Sadaa, A. M. (2024). Benchmarking of circular economy behaviors for Iraqi energy companies based on engagement modes with green technology and environmental, social, and governance rating. Environmental Science and Pollution Research, 31(4), 5762-5783.

[2] Dahmani, M. (2024). Environmental quality and sustainability: Exploring the role of environmental taxes, environment-related technologies, and R&D expenditure. Environmental Economics and Policy Studies, 26(2), 449-477.

[3] Dursun, M., & Karsak, E. E. (2013). A QFD-based fuzzy MCDM approach for supplier selection. Applied Mathematical Modelling, 37(8), 5864-5875.

[4] Hassan, S. U., Basumatary, J., & Goyari, P. (2024). Impact of governance and expenditure effectiveness on CO2 emission (air pollution): lessons from four BRIC countries. Management of Environmental Quality: An International Journal, 35(8), 1721-1743.

[5] Jinping, L., Zeeshan, M., Rehman, A., & Uktamov, K. (2024). A green revolution in the making: integrating environmental performance and green finance for China's sustainable development. Frontiers in Environmental Science, 12, 1388314.

[6] Khurshid, A., Huang, Y., Khan, K., & Cifuentes-Faura, J. (2024). Innovation, institutions, and sustainability: Evaluating drivers of household green technology adoption and environmental sustainability of Africa. Gondwana Research, 132, 88-102.

[7] Saaty, T. L. (2008). Decision-making with the analytic hierarchy process. International journal of services sciences, 1(1), 83-98.

[8] Si, J., Marjanovic-Halburd, L., Nasiri, F., & Bell, S. (2016). Assessment of building-integrated green technologies: A review and case study on applications of Multi-Criteria Decision Making (MCDM) method. Sustainable cities and society, 27, 106-115.

[9] Xu, L., Dabuo, F. T., Madzikanda, B., & Appiah-Twum, F. (2024). Beyond Bits and Bytes: Examining the Dynamic Influence of Digital Economy on Ecological Footprint in OECD Economies. Journal of Cleaner Production, 144141.