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APPLICATION OF QUALITY FUNCTION DEPLOYMENT IN SUSTAINABLE PRODUCT IMPROVEMENT: A CASE STUDY OF MOBILE PHONES

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Purpose: This study integrates sustainability into smartphone product improvement using the Quality Function Deployment (QFD) method. The goal is to identify customer needs and translate them into technical specifications that align with customer expectations and environmental sustainability.

Design/Methodology/Approach: A survey was conducted with 31 participants to gather feedback on key smartphone features, including battery life, network performance, and energy efficiency. The QFD process, specifically the House of Quality (HoQ) matrix, was used to systematically prioritize these customer requirements alongside technical aspects like energy-saving capabilities, material reduction, and ease of maintenance.

Findings: The analysis revealed that Battery Life, Network Performance, and Touch Screen Sensitivity were the most valued customer requirements, while Energy Saving, Easy Maintenance, and Material Reduction emerged as critical technical attributes for sustainable smartphone design.

Originality/Value: This research offers a novel application of QFD in sustainable smartphone design, providing a framework for manufacturers to enhance customer satisfaction while addressing environmental concerns.

Keywords: Sustainability, Quality Function Deployment (QFD), Smartphone Design, Customer Requirements, Environmental Responsibility.

Category of the paper: Research Paper, Case Study.

1. Introduction

The integration of sustainability into product design, especially in industries with rapid technological advancements like electronics, has become a crucial aspect of contemporary engineering practices. In the smartphone sector, balancing consumer demands with environmental responsibility is challenging due to the high resource usage, carbon emissions, and waste associated with production and disposal processes. Smartphones contribute substantially to environmental issues, with studies emphasizing the necessity for sustainable practices across their lifecycle—from energy consumption and resource extraction to the generation of e-waste (Towler, 2024; Matinmikko-Blue, Arslan, 2023). This context underscores the importance of incorporating sustainable design principles into product development frameworks to align with global sustainability goals like the UN Sustainable Development Goals (SDGs).

Quality Function Deployment (QFD) has emerged as a versatile tool for integrating customer requirements into the design of sustainable products, bridging the gap between technical solutions and customer needs. QFD's application in various industries demonstrates its adaptability; for instance, it has been employed in sustainable nursing bed design (Geng et al., 2024), sustainable mobile applications (Alloghani, 2023), and even aviation seat optimization (Çetin, Üçler, 2023). Through techniques like Life Cycle Assessment (LCA) and integration with methodologies such as Six Sigma, QFD enables sustainable product design that minimizes environmental impacts while enhancing customer satisfaction (Kar, Rai, 2024). The use of QFD in sustainable smartphone design, as highlighted in recent research, offers a structured way to prioritize environmental considerations like energy efficiency, recyclability, and material reduction, thereby addressing both functional and sustainability aspects (Vilochani et al., 2024; Camañes et al., 2024).

This study applies QFD within the context of smartphone design, aiming to translate customer requirements into technical specifications that prioritize sustainability. By utilizing the House of Quality (HoQ) matrix, this research provides a framework for manufacturers to systematically integrate environmental and consumer-oriented design elements, supporting the development of smartphones that align with both market demand and ecological standards.

2. Literature Review

Quality Function Deployment (QFD) has been extensively applied in sustainable product development across various industries, demonstrating its effectiveness in addressing customer requirements and integrating sustainability into product design. The application of QFD in sustainable design is evident in the nursing bed product-service system (PSS), where a scenario-driven dual-layer requirement network and a modified QFD model are used to mine latent requirement attributes (RAs) and prioritize engineering characteristics (ECs) to maximize customer satisfaction while considering cost constraints (Geng et al., 2024). In the remanufacturing industry, an entropy-based fuzzy QFD model has been proposed to transform customer requirements into technical characteristics, emphasizing the importance of restorability and reliability in remanufactured products (Shi et al., 2024). The integration of QFD with eco-design methodologies, such as Life Cycle Assessment (LCA), allows for the optimization of environmental impacts during the design phase, as seen in the development of software tools for sustainable product design (Camañes et al., 2024). Furthermore, the ICT sector has explored sustainable software design through systematic literature reviews, identifying guidelines and techniques for reducing energy consumption and carbon footprint, which can be enhanced by QFD applications (Danushi et al., 2024). In the context of Industry 4.0, a hybrid neutrosophic MCDM approach combined with Six Sigma evaluation and QFD has been introduced to facilitate sustainable product design, providing a computationally inexpensive method for evaluating design alternatives based on ECs (Kar, Rai, 2024). The integration of value engineering with QFD and Design for Assembly (DFA) techniques has been shown to deliver necessary functionalities at the lowest life cycle cost, enhancing client satisfaction and reducing development times without compromising quality (Sistem et al., 2024). The concept of Design for Sustainability (DfS) in product engineering highlights the importance of integrating sustainability principles into product design, where QFD can play a crucial role in addressing environmental, social, and economic impacts (Reddy et al., 2023). The consolidation of management practices for Sustainable Product Development (SPD) further emphasizes the need for systematic incorporation of sustainability considerations, where QFD can aid in navigating the complexities of SPD and selecting relevant practices (Vilochani et al., 2024). The role of QFD in sustainable design is also supported by the increasing focus on product sustainability, time-to-market, and profit, where innovations in product design and development are crucial for addressing sustainable development concerns (Relich, 2023). Finally, the Sustainable Design Evaluation method, which incorporates QFD principles, enables product developers to assess the impact of their decisions across ecological, economic, and social criteria, providing a holistic sustainability assessment that is easy to interpret and apply (Reichard, Martin, 2023). Overall, the literature demonstrates that QFD is a versatile tool in sustainable product development, effectively bridging customer requirements with technical solutions while integrating sustainability across various industries.

Quality Function Deployment (QFD) is a powerful tool for integrating customer requirements into sustainable design practices, offering numerous benefits as highlighted by various studies. QFD facilitates the transformation of customer needs into engineering characteristics, ensuring that products are designed with a customer-centric approach. This is particularly beneficial in sustainable product design (SPD), where balancing customer satisfaction with environmental considerations is crucial. For instance, the integration of QFD with Six Sigma and multi-criteria decision-making (MCDM) techniques in Industry 4.0 contexts has been shown to enhance SPD by providing a structured, effective, and computationally inexpensive method for evaluating design alternatives, thus maintaining a competitive market position while enhancing customer satisfaction (Kar, Rai, 2024). Similarly, the use of QFD in the design of nursing beds demonstrates its ability to capture latent requirements and prioritize engineering characteristics by considering psychological preferences, ultimately maximizing customer satisfaction under cost constraints (Geng et al., 2024). In the context of sustainable manufacturing, QFD has been used to analyze customer participation, revealing that cost implications and government regulations are significant factors influencing sustainable practices (Song et al., 2024). Moreover, the integration of QFD with value engineering and design for assembly (DFA) techniques has been shown to lower expenses, shorten development times, and reduce the need for rework, all while maintaining product quality and performance (Sistem et al., 2024). The application of QFD in the redesign of toothpaste tubes using Green QFD II methodology highlights its role in addressing both usability and sustainability, demonstrating that sustainable products can be developed without compromising functionality (Angtuaco et al., 2023). Furthermore, the QFD-CE method incorporates sustainable development and circular economy principles, setting design goals based on both customer expectations and environmental impact, as demonstrated in the photovoltaic panel industry (Pacana, 2023). In the aviation industry, QFD combined with the analytic hierarchy process (AHP) has been used to optimize aircraft seat design by consolidating product quality characteristics and isolating dependable design variables, emphasizing safety, weight, and durability (Çetin, Üçler, 2023). The use of QFD in the design of an aquatic autonomous observatory for water quality monitoring illustrates its effectiveness in systematically constructing products that fulfill user needs while considering environmental conditions (Shukla, Bhattacharya, 2023). Additionally, the integration of text mining with spherical fuzzy QFD for smartwatches showcases how QFD can leverage online reviews to extract customer requirements and rank technical requirements, thus enhancing product design in a competitive environment (Ayber et al., 2023). Lastly, the use of QFD in the development of Sativa mouthwash demonstrates its ability to prioritize technical interests such as raw material management and halal labeling, which are crucial for green innovation and customer satisfaction (Zafriana, Setiawatie, 2023). Overall, these studies collectively underscore the value of QFD in integrating customer requirements into sustainable design practices, ensuring that products not only meet customer expectations but also contribute to environmental sustainability.

Sustainability in mobile phone production and design is a multifaceted challenge that encompasses various aspects, from energy efficiency to ethical considerations. The global push towards mitigating climate change, as highlighted by the Paris Agreement, necessitates a shift towards carbon neutrality, which impacts the energy and resource use in mobile phone production (Towler, 2024). The integration of sustainability in mobile app development is crucial, as mobile platforms are increasingly complex, with challenges in requirement engineering due to limitations in device capabilities such as processors and batteries (Tanveer et al., 2023). The development of green mobile apps, guided by frameworks like PRISMA, emphasizes the role of digitalization in promoting environmentally conscious behaviors, although developers face challenges in balancing innovation with environmental obligations

(Alloghani, 2023). The transition to 6G mobile communications is also pivotal, as it offers opportunities to align with the UN Sustainable Development Goals (SDGs) by addressing the environmental footprint and energy consumption of communication networks (Matinmikko-Blue, Arslan, 2023) ("Design for sustainability - an imperative for future mobile networks", 2023). The Internet of Production (IoP) can be transformed into an Internet of Sustainable Production (IoSP), optimizing manufacturing processes to be more sustainable, which is crucial for mobile phone production (Bernhard et al., 2023). Additionally, the design of smartphone apps that evaluate product use sustainability, such as those collecting data on battery usage and emissions, can influence sustainable product use and inform future designs (Russell et al., 2024). The Exspiro app exemplifies how mobile applications can contribute to sustainability by reducing food waste, showcasing the potential for apps to address broader sustainability challenges (Pajpach et al., 2023). The pressure to improve energy efficiency in communication networks is compounded by the demand for faster data rates and higher capacities, necessitating a focus on reducing the environmental impact and ensuring inclusivity and fairness in technology use (Remedios et al., 2023). Educational initiatives, such as virtual project-based learning courses, are also essential in equipping future engineers with the knowledge to tackle sustainability challenges in mobile phone design and production, emphasizing the importance of green methodologies (Virtual Studies…, 2023). Overall, the studies underscore the need for a holistic approach to sustainability in mobile phone production and design, integrating technological advancements with environmental and ethical considerations to create a sustainable future.

3. Methodology

The study aims to integrate sustainability considerations into the smartphone product improvement process through a structured approach. The methodology involves customer input collection, the application of the House of Quality (HoQ) framework, and the integration of sustainability metrics into product design. The research procedure was conducted according to the stages presented in Figure 1.

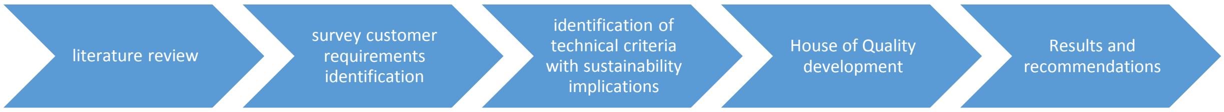


Figure 1. Research process diagram.

Source: Own elaboration.

The study began by identifying user requirements for smartphones. A survey questionnaire was designed to capture the needs and preferences of smartphone users. The target population consisted of 31 students aged 18 to 34 from the Silesian University of Technology in Poland. The questionnaire contained 20 multiple-choice questions, focusing on key factors such as smartphone features, functionality, and sustainability concerns. To maximize accessibility and response rate, the survey was distributed via email, Facebook, and WhatsApp. Participants rated their requirements on a Likert scale from 1 to 5, with 1 representing the least important and 5 representing the most important features. After the survey data was collected, it was analyzed to prioritize customer requirements. The ranking process focused on identifying critical smartphone attributes such as battery life, network performance, and ease of maintenance. The results of the analysis were used to determine the importance of each customer need, forming the basis for the subsequent technical specifications.

The HoQ matrix was employed to translate customer needs into technical specifications. The use of HoQ allowed for a structured evaluation of how well product designs meet customer expectations and enables prioritization of design elements that require improvement. This tool helps ensure that the product's design aligns with customer desires while optimizing quality.

Sustainability metrics such as energy efficiency, material reduction, and the use of recycled materials were embedded into the QFD process. The HoQ correlation matrix was used to examine how each technical requirement related to sustainable design features, ensuring that these concerns were effectively addressed in the product improvement process. This step ensured that sustainability was not only integrated into the design but also prioritized alongside other technical considerations.

The results of the analysis were used to draw conclusions regarding the technical specifications that best align with both customer preferences and sustainability goals. Recommendations were formulated to improve the design and quality of smartphones while enhancing their sustainability profile.

4. Results

The smartphone market is characterized by rapid technological advancement and frequent product upgrades, leading to significant environmental concerns such as high energy consumption, resource depletion, and electronic waste. With an estimated 86% of the global population using smartphones, the industry contributes substantially to climate change, primarily through manufacturing and disposal processes. Addressing these sustainability challenges is crucial for minimizing the environmental footprint of mobile phones. The growth of the global population and smartphone users from 2016 to 2022 is presented in Figure 2.

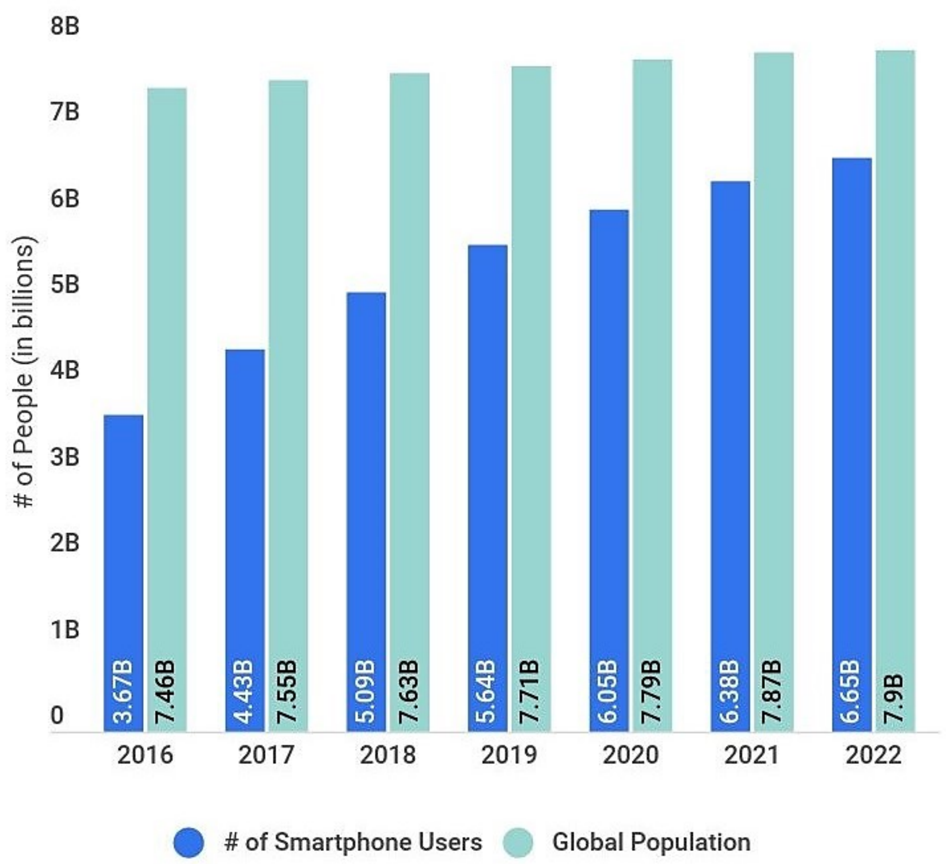


Figure 2. Growth of smartphone users.

Source: Flynn, 2022.

Customer Needs Identification

Customer requirements were identified through the survey, where participants rated features like battery life, network performance, and ease of maintenance. The survey results showed that Battery Life, Network Performance, and Touch Screen Sensitivity were the top priorities for customers. This input guided the initial phase of the QFD process, where customer needs (WHATs) were mapped out. The average value of importance based on customer feedback is presented in Figure 3. The features are ranked on a scale of 1 to 5.

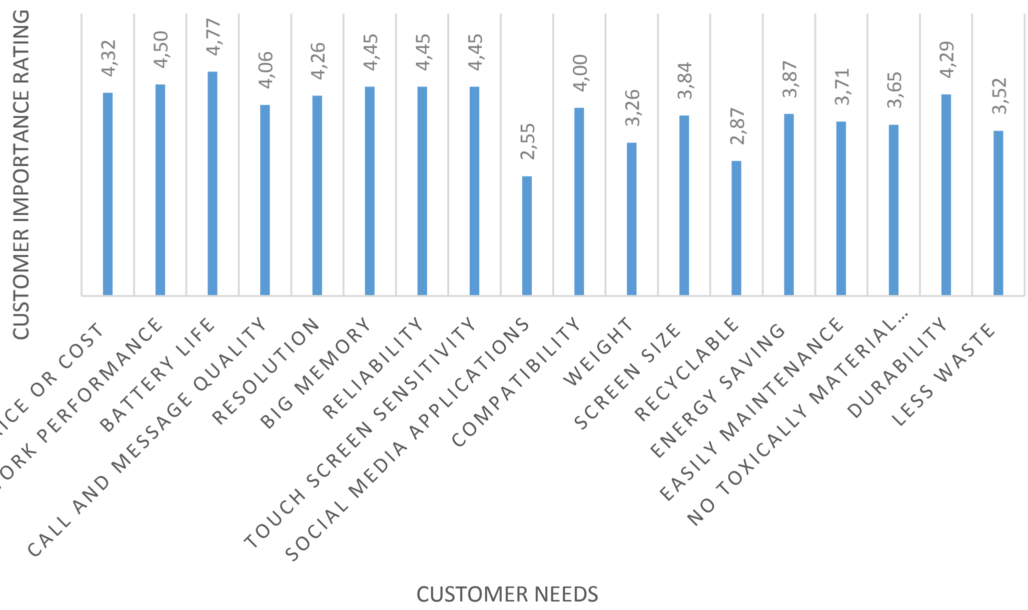


Figure 3. Customer importance rating.

Source: Own elaboration.

Design Requirements

The HoQ matrix was used to translate customer needs into technical specifications (HOWs). For example, the need for longer battery life was linked to technical requirements such as energy-saving capabilities and battery longevity. The relationship matrix classified the strength of connections between customer needs and technical features, using a 9-3-1 scale to indicate strong, moderate, or weak correlations. Table 1 provides technical characteristics for smartphones that could be tailored to meet the customer's needs.

Table 1.
Technical Characteristics for Smartphones

No.	Technical characteristics	Description
1	Rate of Recycled Material	What is the proportion of recycled materials used in the production of the smartphone?
2	Energy Saving	The smartphone's capacity to conserve energy through efficient power management and minimal power consumption.
3	Easily Maintenance	The ease of maintenance and repair of smartphones results in a reduced frequency of replacement and consequently, a decrease in waste generation.
4	Toxically Material Released	The quantity of hazardous substances employed in the production of the smartphone and the temporal context of its utilization.
5	Durability	The durability of a smartphone, as measured by its ability to withstand wear and tear, is positively correlated with its longevity and reduced frequency of replacement.
6	Reused Material	The quantity of reused material in the production of the smartphone.
7	Less Waste	The quantity of waste generated during the production and utilization of the smartphone.
8	Material Reduction	Reducing the quantity of resources utilized in the production of a smartphone.

Cont. table 1.

9	Battery Life	The duration of the smartphone's battery life is a crucial factor to consider in order to minimize the frequency of replacement.
10	Pollution Control	the measures used to minimize and regulate pollution both during the manufacturing of the smartphone and during usage.

Source: Own elaboration.

The relationship matrix between customer requirements and technical features is presented in Figure 4.

House Of Quality

Relationships: Strong= 9, Medium= 3, Weak= 1

			Technical Requirements (How)									
			Rate of Recycled Material	Energy Saving	Easily Maintenance	Toxically Material Released	Durability	Reused Material	Less Waste	Material Reduction	Battery Life	Pollution Control
Row		Customer Requirements (What)	Importance	1	2	3	4	5	6	7	8	9	10
1	Easy to use	Touch Screen Sensitivity	4.45	0	1	3	0	1	3	1	1	1	0
2		Social Media Applications	2.55	0	3	3	0	1	0	1	0	1	0
3		compatibility	4.00	0	1	0	0	3	0	3	0	0	0
4	Structure	Weight	3.26	1	9	3	0	1	3	1	3	0	0
5		Screen size	3.84	1	3	3	0	1	3	1	3	0	0
6	Performance	Network Performance	4.50	0	9	1	3	1	1	1	0	0	0
7		Battery Life	4.77	1	0	3	9	3	0	1	3	9	9
8		Calls and Messages quality	4.06	0	0	3	0	1	0	1	3	1	0
9		Resolution	4.26	0	3	3	0	1	0	1	0	0	0
10		Big memory	4.45	0	9	0	0	1	0	1	0	0	0
11		Reliability	4.45	0	9	3	0	9	0	1	3	3	0
12	Cost	Price or Cost	4.32	3	9	3	0	0	9	3	9	3	0

Figure 4. Customer-technical requirement matrix.

Source: Own elaboration.

Sustainability Considerations

Sustainability metrics, including energy efficiency, use of recycled materials, and waste reduction, were integrated into the QFD framework. Technical requirements such as the rate of recycled material, ease of maintenance, and pollution control were prioritized based on their potential to meet customer needs while minimizing environmental impact. For instance, the technical requirement "Energy Saving" was identified as a crucial factor, showing a strong correlation with customer demands for long battery life and reduced environmental impact.

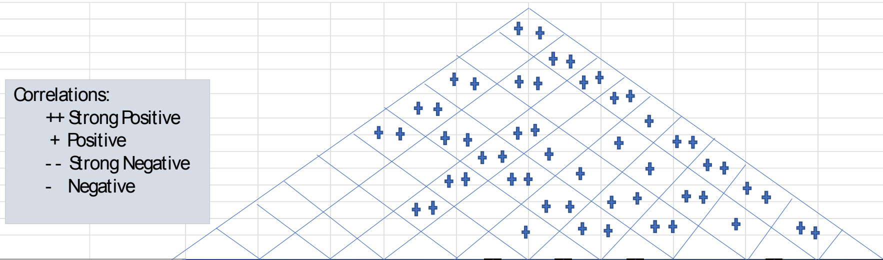
Analysis of Findings

The findings of this study align with and expand upon previous applications of Quality Function Deployment (QFD) in sustainable product design across various industries. The identification of Battery Life, Network Performance, and Touch Screen Sensitivity as top customer priorities is consistent with consumer expectations reported in prior research, emphasizing usability and efficiency as paramount features in sustainable mobile applications and product design (Alloghani, 2023; Russell et al., 2024). These results reaffirm the importance of aligning technical specifications with user needs in achieving both functional excellence and market appeal.

Notably, this study highlights the prioritization of energy-saving attributes, material reduction, and ease of maintenance—elements that reflect the growing emphasis on sustainability in the ICT sector. Similar findings have been observed in industries such as aviation and healthcare, where QFD has been used to maximize durability, simplify maintenance, and enhance lifecycle sustainability (Geng et al., 2024; Çetin, Üçler, 2023). However, this study distinguishes itself by integrating these attributes into the rapidly evolving smartphone sector, addressing challenges unique to high-turnover products, such as electronic waste and short product lifespans.

A key contribution of this research is its explicit focus on balancing customer satisfaction with sustainability goals. For instance, technical requirements like Energy Saving and Pollution Control were identified as critical not only for meeting customer expectations but also for minimizing environmental impact. This dual focus underscores the adaptability of QFD in addressing sustainability concerns in industries characterized by fast-paced innovation.

Compared to previous studies, this research provides a unique framework for applying QFD to consumer electronics. It demonstrates that sustainability metrics, such as the use of recycled materials and reduced waste, can be effectively embedded into the design process without compromising functionality. By bridging consumer needs with ecological priorities, this study offers a roadmap for manufacturers to innovate responsibly, setting a precedent for integrating QFD into other high-demand sectors. Figure 5 presents the final HoQ for smartphones.



				1	2	3	4	5	6	7	8	9	10
Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)				▲	▲	▲	▼	▲	▲	▲	▲	▲	▲
House Of Quality		Relationships: Strong= 9, Medium= 3, Weak= 1		Technical Requirements (How)									
				Rate of Recycled Material	Energy Saving	Easily Maintenance	Toxically Material Released	Durability	Reused Material	Less Waste	Material Reduction	Battery Life	Pollution Control
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2		Social Media Applications	2.55	0	3	3	0	1	0	1	0	1	0
3		compatibility	4.00	0	1	0	0	3	0	3	0	0	0
4	Structure	Weight	3.26	1	9	3	0	1	3	1	3	0	0
5		Screen size	3.84	1	3	3	0	1	3	1	3	0	0
6	Performance	Network Performance	4.50	0	9	1	3	1	1	1	0	0	0
7		Battery Life	4.77	1	0	3	9	3	0	1	3	9	9
8		Calls and Messages quality	4.06	0	0	3	0	1	0	1	3	1	0
9		Resolution	4.26	0	3	3	0	1	0	1	0	0	0
10		Big memory	4.45	0	9	0	0	1	0	1	0	0	0
11		Reliability	4.45	0	9	3	0	9	0	1	3	3	0
12	Cost	Price or Cost	4.32	3	9	3	0	0	9	3	9	3	0
		Absolute Importnce		24.83	229.22	112.38	56.43	97.73	78.03	65.55	104.47	80.30	42.93
		Relative Importance (%)		2.78	25.70	12.60	6.33	10.96	8.75	7.35	11.71	9.00	4.81
		Rank		10th	1th	2th	8th	4th	6th	7th	3th	5th	9th

Figure 5. The House of Quality (HoQ) for smartphones.

Source: Own elaboration.

Discussion

This study makes a unique contribution to the field of sustainable smartphone design by applying Quality Function Deployment (QFD) to directly integrate environmental attributes into customer-driven needs. By doing so, it establishes a structured framework that aligns consumer expectations with sustainability goals, a critical challenge in high-turnover consumer products like smartphones. Unlike previous studies that have primarily used QFD for durability and cost-effectiveness (Geng et al., 2024; Çetin, Üçler, 2023), this research focuses on incorporating sustainability metrics—such as energy efficiency, material reduction, and ease of maintenance—into the QFD process. This approach offers valuable insights for industries seeking to balance ecological responsibility with high consumer demand.

Prior research on QFD has highlighted its role in enhancing product durability and cost efficiency (Geng et al., 2024; Çetin, Üçler, 2023), primarily in industries like aviation and healthcare. Our research builds on these findings by tailoring QFD to address the unique challenges of smartphone design, where frequent product upgrades and high consumer expectations create sustainability dilemmas. In particular, while previous studies emphasize energy efficiency and material reduction, we introduce the concept of ease of maintenance as a critical technical attribute, which is often overlooked in the ICT sector. This new focus aligns with the growing importance of repairability and longevity in sustainable product design.

Our findings on energy-saving technical attributes are consistent with existing research that emphasizes carbon reduction and energy efficiency in sustainable design (Danushi et al., 2024; Remedios et al., 2023). However, the prioritization of ease of maintenance diverges from traditional priorities in the smartphone industry, which usually focus on performance and aesthetics. This shift in focus reflects a growing alignment with circular economy principles, as consumers increasingly demand repairable, long-lasting products. This divergence represents a new opportunity for the industry to adopt sustainability in a more holistic way.

The findings of this research validate our hypothesis that QFD can effectively integrate sustainability considerations into smartphone design without compromising functionality. Specifically, the study confirms that manufacturers can use QFD to systematically prioritize technical specifications that align with both market expectations and environmental responsibility. Our approach demonstrates that sustainability does not have to be an afterthought but can be embedded in the very foundation of product development, offering a model for manufacturers to follow.

Future research should explore the integration of artificial intelligence (AI) into the QFD process to enhance real-time analysis of customer feedback. This would enable more dynamic and adaptive prioritization of technical attributes, allowing manufacturers to respond more rapidly to consumer demands. Furthermore, we plan to expand the demographic scope of survey participants to include a more diverse sample, ensuring that our findings are more generalizable. Additionally, incorporating emerging sustainability metrics, such as carbon footprint and material lifecycle assessments, would further refine the QFD framework, making it more robust and applicable across different industries.

5. Conclusions

This research underscores the potential of Quality Function Deployment (QFD) as a strategic tool for integrating sustainability into smartphone design. By prioritizing attributes like energy efficiency, ease of maintenance, and material reduction, we provide a practical framework that can help manufacturers align their product development processes with both consumer demands and environmental goals. Our findings suggest that QFD can be used to address the challenges posed by high turnover rates and environmental impact in consumer electronics, offering a significant advantage in sustainable product design.

While this study contributes valuable insights, it also has limitations that must be acknowledged. The sample size of 31 student participants restricts the generalizability of our findings, particularly to a broader demographic. Moreover, while our application of QFD offers a promising approach to sustainable smartphone design, the model requires further refinement to fully address the complex and multidimensional aspects of sustainability. Future research should focus on expanding the sample size and exploring more diverse product categories to better understand the applicability of QFD in different contexts.

This study provides a foundation for future work on sustainable product design, offering insights that can be applied not only to smartphones but also to other industries facing similar sustainability challenges. For instance, industries like electronics, automotive, and consumer goods could benefit from the same QFD approach to integrate environmental responsibility into their product development processes. Our research also suggests that sustainability can be effectively incorporated into high-turnover products without sacrificing functionality, providing a pathway for industries to meet both consumer expectations and sustainability targets.

The broader impact of this research lies in its ability to offer a scalable framework for sustainable innovation in product design. By demonstrating how QFD can incorporate both ecological and functional perspectives, this study provides a valuable tool for manufacturers seeking to align their products with the principles of circular economy and sustainable development. Future practitioners and researchers can use these insights to refine QFD and develop more sustainable products, contributing to the broader objective of reducing environmental impact while meeting the needs of consumers.

The recommendations from this study on applying Quality Function Deployment (QFD) to sustainable product improvement in mobile phones underscore several strategic directions for manufacturers. Prioritizing energy efficiency is essential; smartphone manufacturers should focus on developing energy-saving features, such as advanced battery management systems and optimized power usage, to better align products with environmental objectives and meet consumer demand for sustainability. Enhancing material sustainability through the integration of recycled and biodegradable materials in smartphone production can reduce environmental waste and promote circular economy practices. This approach addresses ecological concerns and aligns with the growing demand for environmentally responsible products. Increasing customer awareness about sustainable smartphone usage and disposal practices is another key area. By educating consumers and launching awareness campaigns that emphasize eco-friendly features and end-of-life recycling options, manufacturers can foster a culture of environmental responsibility and promote a more sustainable lifecycle for their products. Adopting modular design for ease of maintenance is also recommended. A modular approach, which enables simple replacement of individual components, can extend device longevity and reduce the frequency of disposal, contributing significantly to sustainable lifecycle management. Finally, the consistent application of QFD in product development is recommended to integrate evolving customer needs and sustainability considerations effectively. By doing so, manufacturers can create products that better align with consumer expectations and environmental goals, enhancing both product appeal and ecological responsibility.

These recommendations provide a pathway for manufacturers to balance innovation with environmental stewardship, demonstrating the value of QFD in promoting sustainable development within the smartphone industry.

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