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# An Empirical Investigation of Green Product Design and Development Strategies for Eco Industries Using Kano Model and Fuzzy AHP

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**Abstract:** Collaboration in green product design and development is becoming more significant to ensure a brighter future for eco industries, and research into such innovation has increased in recent years. So, it has been emphasized by practitioners that green thinking should be adopted from the design stage through the development stage and into the disposal stage of a product. However, it is challenging to identify the severity of strategies that mainly hampers the growth of green product design and development (GPDD). The current research aimed to identify and rank various strategies based on their significant impact on the development of green product design. The study contains three segments: (1) Multiple strategies were identified based on the published literature, project reports, and interactions with academics and industry experts. Then, 22 strategies were selected for GPDD that could be divided into five clusters: cooperation and commitment from top management commitment (TMC), design for environment (DFE), utilization of green technologies (UGT), green external supply chain management (GESCM), and green internal supply chain management (GISCM). (2) The Kano model was used to identify user requirements and satisfaction levels. (3) The priority weight and rank among selected strategies were determined using the fuzzy AHP approach. The results show that the "DFE" ranks highest among the main categories, and "design for disassembly" has been highlighted as a necessary sub-criteria in the emerging eco industries. Various recommendations are suggested to adopt these techniques, which augment the growth of green product design and development for eco industries.

**Keywords:** green product design and development; fuzzy AHP; Kano model; eco industries



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## 1. Introduction

Green product design and development (GPDD) has become a worldwide phenomenon. The primary goal of GPDD is to reduce the environmental impact of industrial growth around the world. In the face of severe economic and environmental difficulties, national and international measures used to stimulate green production growth as a new source of growth have escalated in recent years. Green production growth is a function of both economical and sustainable development policies. It combines two critical imperatives: continued inclusive economic growth, which developing countries require to eradicate poverty and promote wellbeing, and improved environmental management, which is needed to address resource scarcity and climate change. When green growth was first advocated as part of economic stimulus packages, some governments saw it enhance jobs and incomes in the short term by increasing investment in some green (particularly low-carbon) technology [1]. Developing countries are critical to attaining global green growth in two significant aspects. For starters, developing countries must consider environmental deterioration's potential economic and social consequences. They are the most vulnerable to climate change and are more reliant on exploiting natural resources for economic growth compared to industrialized economies.

Industries, particularly carbon- and energy-intensive manufacturing, will be critical in achieving global climate change mitigation goals. Energy-intensive sectors and power plants account for roughly half of the global greenhouse gas emissions, making them vital in attaining net-zero carbon emission targets. The continual conflict between industrial enterprises' economic development ambitions and climate pledges makes long-term sustainability particularly tough. Industry energy-efficiency methods are the most effective at lowering carbon emissions [2]. In fact, the COVID-19 pandemic holds critical insights into global climate change. Typically, even short-term shutdowns during the pandemic resulted in significant reductions in GHG emissions worldwide, demonstrating the need to lower fossil-fuel usage and industry emissions. However, as is the case in China and several other nations, this decrease is temporary. The desire to return to normal and stabilize the economy will result in a rapid spike in emissions. Short-term relaxation of environmental standards by avoiding obligations to use cleaner energy sources could damage previous efforts worldwide to transition to a cleaner, greener, and more sustainable environment. As a result, even with the most severe economic shock caused by a pandemic, there is still time to rethink critical policies in favor of a greener economy that minimizes the chances of climate-related crises in a short time [3].

The country's current growth patterns will assist in deciding on its transition to green, production-friendly economic growth and development patterns. Much-developing economies caught up with developed countries' per capita income growth rates to boost gross domestic product from 2000-10. As Figure 1 shows, the baseline projection shows global gross domestic product (GDP) is expected to nearly triple over the coming four decades. The most significant growth is observed in India and China, where considerable growth potential exists. The GDP of emerging countries is expected to increase faster than that of the OECD countries [4].

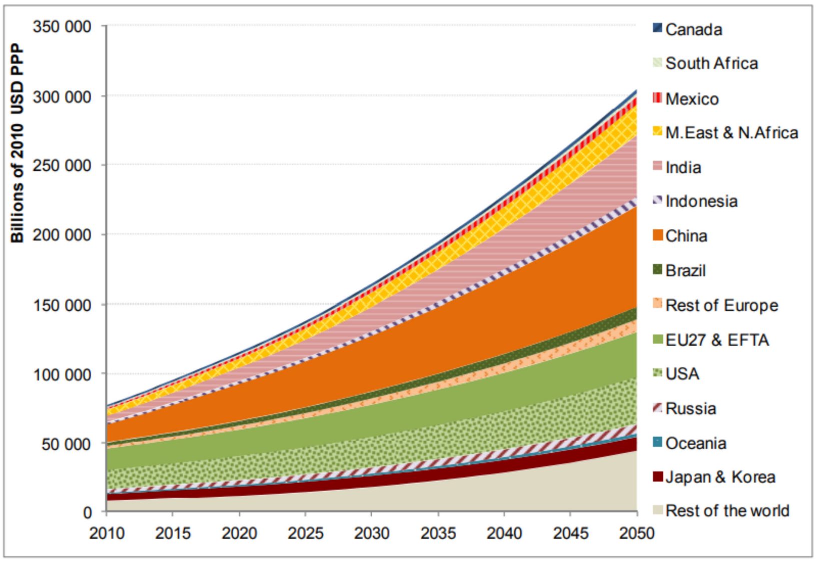


**Figure 1.** The trend in authentic gross domestic product (GDP) growth, 2010–2050. Purchasing power parity (PPP), constant 2010 prices, billion USD, (Chateau et al., 2011) [4].

The world's leading industrial product is steel. The greenhouse gases released from its conventional manufacturing techniques are also high in production. Almost 1.5 billion tons of steel are being produced per year worldwide. Each ton of steel production releases 2 tons of carbon dioxide into the atmosphere. It constitutes nearly 5% of the pollution and global warming [5]. Developing countries are not only vulnerable to climate change but they are also progressively contributing to it (Figure 2). Many emerging countries have already invested in energy sources that pollute the environment and produce high quantities of greenhouse gases. Energy-related $CO_2$ emissions from developing countries are expected to triple by 2050 unless new, low-emission energy sources are deployed on a scale comparable to the industrial revolution. The amount of $CO_2$ emitted that would generate the same time-integrated radiative forcing as a long-lived greenhouse gas, or a mixture of greenhouse gases over a particular horizon, is known as carbon dioxide equivalent [6]. The equivalent $CO_2$ emission is calculated by multiplying the greenhouse gas output by the global warming potential for the period in question (OECD Report, 2012) [7]. Recently, there has been a lot of focus on the world's transition to a low-carbon economy [8] and a multi-objective resource integration strategy is applied to an eco-industrial cluster that uses green technologies and renewable energy for optimal economic return and minimum $CO_2$ production (Ahmed et al., 2021) [9].

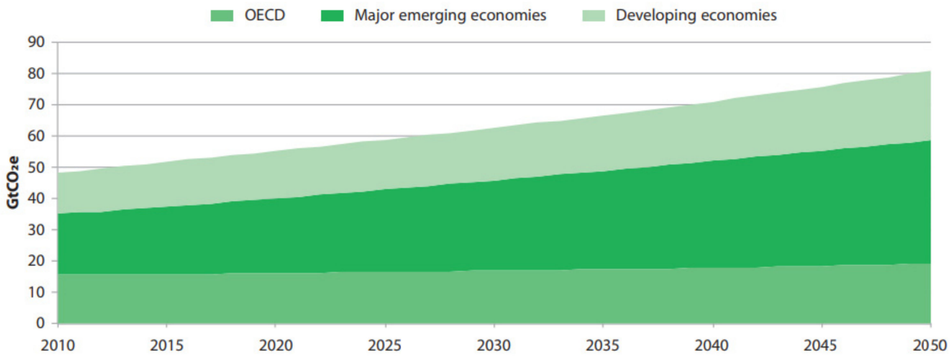


**Figure 2.** Trends of greenhouse gas emissions, 2010–2050 (OECD Report, 2012). GtCO2e = Giga tones of $CO_2$ equivalent. Note—Mexico and Chile are members of the Organization for Economic Co-operation and Development (OECD), despite receiving official development assistance (ODA). Brazil, China, India, and South Africa are emerging economies. Regardless of whether they receive ODA, all other nations are considered by developing and other economists.

### *1.1. Environmental and Economic Consequences*

Environmental concerns have been a top priority for most organizations regarding current product creation. Special measures must be followed to comply with the latest green requirements during product development. The structure of a product is acknowledged as a crucial aspect in reducing the environmental impact of a product's end of life. Due to a fixed product structure assumption, most of the previous research failed to take advantage of the considerable latitude at the design stage. We present a CAD-based methodology that allows for an automatic change in the 3D product structure by changing part combinations, assembly methods, and assembly sequences to address this shortcoming [10].

Design for the environment (DFE) was created to reduce a product's long-term environmental impact. Because of the growing severity of ecological concerns and its significant potential for environmental improvement, DFE has recently drawn more interest from the academic and practical sectors [11]. Because of government restrictions and consumers' increased environmental consciousness, businesses are under increasing pressure to create ecologically responsible products. Some countries, such as the United States, France, Switzerland, and China, allow authorized green products to bear "low-carbon" or "green" labels. Using green branding is a government law and a way for businesses to attract customers. Firms are urged to develop and design their products with environmental considerations. Green design is critical for companies to survive and thrive in the green market. Choosing the suitable material (based on product requirements) plays a significant role in an environmentally friendly design. Various lightweight construction concepts and the value chain provides information on specific correlations and interrelationships of relevant aspects throughout the PLC, ultimately leading to this, with the help of the decisive levers identified to improve future product development decisions [12]. The eco-design tools included two aspects of sustainability classified as partial sustainable product design tools (PSPD). According to a comprehensive investigation, most of the instruments studied were P-SPD equipment. Most of the P-SPD tools were helpful in the early design phases after considering the QFD concepts. Furthermore, the majority of P-SPD tools had a life cycle view [13].

(C. Chen, 2001) [14] represents a model that considers the interactions of these three fundamental factors crucial in today's marketplace. On the demand side, green users' purchasing habits. On the supply side, assess the firm's strategic decisions on the number of items introduced and their related prices and attributes, using optimal product design and market segmentation theories. Investigate the interplay between environmental standards, corporate strategy, and overall environmental quality on the policy front.

The design for environmental concerns is significant for eco industries; researchers and practitioners identify various barriers to green product development and plan for the environment [15]. Thus, effective policies and standards must be established. In Table 1, various barriers are represented in economic, technological, informational, and organizational categories.

**Table 1.** Barriers in green product design and development (GPDD).

| Barriers | Categories | Source |
| --- | --- | --- |
| Cost implication, Cost of disposal, hazardous materials, and cost Foreign direct investment (FDI) is in short supply. Expensive investments Cost of Design, supplier loss, Limited financial resources, Limited investment funds. | Economic | [16–18] |
| Lack of technical knowledge, Design complexity to reduce energy usage Due to a lack of sufficient environmental measures, Failure of fear, cybersecurity, Inadequate technological knowledge, Immaturity in terms of technology, Knowledge of advanced technology is limited. | Technological | [19] |
| Lack of training courses, a lack of sustainability certification, a lack of awareness about applying reverse logistics, a lack of understanding about green practices, a lack of awareness about green products, and a lack of accreditation, Inadequate communication, lack of norms, data privacy, and security | Informational | [20] |
| Inadequate organizational readiness or technical knowledge, green product adoption is hindered by corporate culture and a lack of recycling and reuse efforts. Competition in the marketplace social responsibility is lacking. Lack of a green disposal system, Structures for research and development are lacking. Internal knowledge deficits, limited human resources Supply chain complexity | Organizational | [20] |

The organization's management must take a proactive approach to buyer knowledge resources and allocate the necessary human and technological resources [21]. These materials would inspire managers to improve their knowledge, internal skills, and information transfer to customers to explain green product innovation in design and development [22]. The study looks at the link between green product innovation and competitive advantage and the mediating influence of green dynamic capability that competitors can easily imitate. Third, manufacturing companies should operate in good faith, take on social duties, and build a positive reputation [23].

### 1.2. Research Objective and Method

This study aimed to classify and categorize the various strategies for eco industries' applications to enhance green product production growth. First, we classified multiple processes using focus study qualitative research methods with industry experts. Second, we used the Kano model to categorize selection criteria identified via a questionnaire to evaluate user satisfaction and service requirements. The frequency of the quality attribute measures user satisfaction after using the fuzzy analytical hierarchy process to derive the criteria weights. We used the Kano model and F-AHP because the Kano model helps classify the service requirements in the growth of GPDD and the F-AHP helps rank the service requirement on a priority basis. It helps us implicate the essential aspects of using these two methods together.

### *1.3. Integration of Kano and Decision-Making Technique*

In green product design and development, the Kano model can be applied to identify the primary user's expectations. Other research approaches can be integrated with the Kano model. It is used for quality improvements in various industries, such as the tourism industry [24], the service industry [25], and the improvement of the quality of transportation services at mega-events [26]. The Kano model offers a better understanding of how users evaluate products and the classification of user requirements for product design [27], helping practitioners focus on the most critical quality attributes of corporate social responsibility domains that should be improved [28].

(Zoghi et al., 2021) [29] developed a decision system by incorporating Kano and fuzzy AHP techniques in which the preference of material selection is design for deconstruction. The integration of fuzzy AHP and Kano is used in various applications, such as the selection of sustainable suppliers in industries [30], the development of product-service systems by focusing on the analysis of user requirements [31], and analysis of the business requirements and business change factors for meeting the needs of its stakeholders [32]. Table 2 represents the various case studies based on the integration of Kano and decision-making technique.

**Table 2.** Integration of Kano and decision-making technique.

| MCDM Method | Year | Description of Study | Source |
|---|---|---|---|
| **F-AHP and TOPSIS** | 2021 | Material selection in design for deconstruction | [29] |
| **F-AHP** | 2021 | For the selection of sustainable suppliers in Palm Oil Industries Indonesia | [30] |
| **AHP** | 2021 | Text mining, intuitionistic fuzzy sets, and user satisfaction are used to design products. | [33] |
| **Fuzzy Analytical Hierarchy Process** | 2020 | To analyze the attractive factors of new products | [34] |
| **F-AHP** | 2020 | To prioritize intentions behind investment in cryptocurrency | [35] |
| **F-AHP** | 2018 | Product-Service Systems (PSSs) are developed by focusing on understanding client requirements. | [31] |
| **F-AHP** | 2018 | Aesthetic Product Design: Case Study of an Electric Scooter | [36] |
| **AHP** | 2016 | To prioritizing the bank's substructions | [37] |
| **AHP and M-TOPSIS** | 2014 | To disassembly line balancing under fuzzy environment | [38] |
| **AHP** | 2011 | To meet the expectations of its stakeholders, business requirements and business change factors should be analyzed appropriately to identify adequate needs. | [32] |

Thus, this current study adopted the Kano model method with fuzzy AHP to classify the various strategies for eco industries.

## 2. Research Approach and Methodology

In this study, we propose an improved technique to measure GPDD requirements in eco industry applications based on Kano's framework. There are three main steps conducted in this research. According to Figure 3, in the first stage, we identified the GPDD requirements in eco industry applications. In the second stage, we measured user satisfaction using Kano and established five groups: Must Be, Attractive, Performance, Indifferent, and Reverse. In the third stage, we ranked user service requirements in order of importance using fuzzy AHP to prioritize the most critical GPDD requirement based on expert opinions.

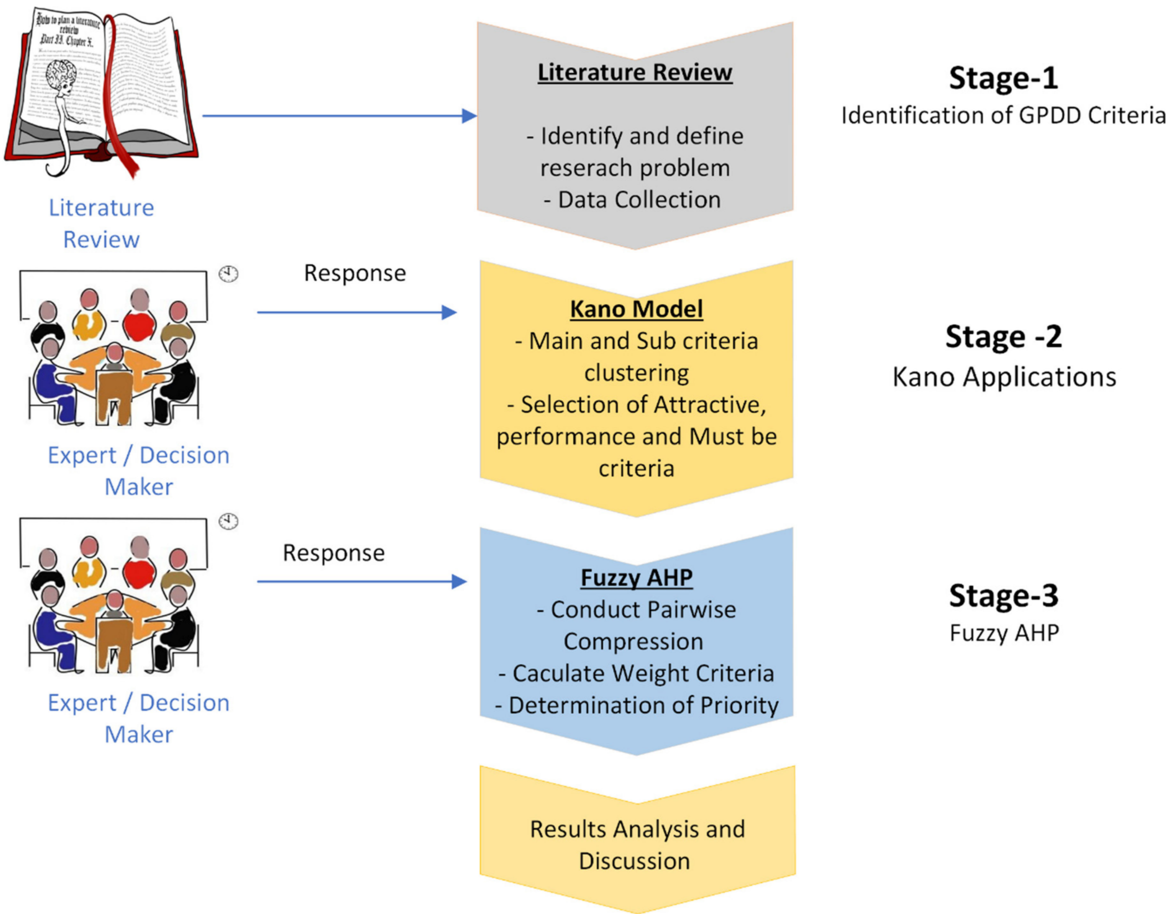


**Figure 3.** Framework of research methodology.

To achieve the research purpose, we looked at the importance of service quality using the Kano model and AHP. First, we identified 22 GPDD requirements for eco industries and categorized them into five main criteria of service requirements. We conducted the Kano questionnaire using the service requirements specified by the users through a focus group study. We classified each need using the Kano model and divided them into five groups based on their impact on user satisfaction (Must Be, One-Dimensional, Attractive, Indifferent, and Reverse). Second, we conducted a fuzzy AHP questionnaire on the experts based on the results we got from Kano. Then, we calculated the comparative importance of all the requirements in the same category using the fuzzy AHP method. We conducted a survey both online and offline. We visited the industry area by Jaipur to complete the survey specifically on machining experienced in using green concepts. Finally, we used 96 respondent's survey results as valid questionnaires to perform the further research.

## 3. Literature Survey

### 3.1. Identification and Finalization of Factors

According to the literature, there are various factors, such as "Top management commitment", "environmental support policies", [39] "green manufacturing", "DFE", "green marketing", "strategic management", "environmental management systems", "green SCM", life cycle assessment" [40,41], "green logistics", and "reverse logistic" [42] tools for green product development, falling under the categories of economic, social, and environmental [43]. Cross-functional collaboration, competencies, and internal procedures are the primary intra-organizational elements. Policy and practitioner implications have been discussed [44]. From a disciplinary and incentive standpoint, it is impossible to achieve rapid development through market forces; government intervention, environmental law, and R&D tax incentives are required to increase green product creation [45]. Stakeholder engagement, consumer behavior, and the relationship between green marketing and consumer purchasing behavior [46] is a virtual drive for green product development success. We discovered that design thinking could help stakeholders get more involved in the GPDD [47], and when the majority of individuals buy green toys, their willingness to buy green toys grows. It indicates that users are ecologically conscious of and concerned about environmental protection or that purchasing green toys is the outcome of a new economic trend and childhood education [48].

The topic of sustainable development can be approached in four ways: in terms of ecology, sustainable development entails safeguarding and strengthening the environmental system's production and renewal capacity; in terms of science and technology application, sustainable development entails a shift to cleaner and more effective technologies, aiming as closely as possible at "zero-emission" or "closed" process methods [49]. Process for green development as proposed by organizational strategic planning for sustainability, portfolio strategic planning, and project strategic planning is followed by development phases (product operational planning, production preparation, and product launch plan), as well as a post-development phase (market follow-up of the product) [50].

The philosophy of sustainable development is inextricably linked to the peculiarities of manufacturing firms, strengthening the theory of green product development from strategic enterprise operation, opportunities and risks, environmental competitiveness evaluation, green value chain innovation, and green performance evaluation [49]. Consumers are driving the present trend of efficient sustainable product creation, which is fueled by government laws, the integrated product development process (IPDP), and green supply chain management (GSCM) [51]. (Dekoninck et al., 2016) [52] outlined the most typical issues that the industry encounters while implementing eco-design, and (P.K. Singh & Sarkar, 2019) [53] provided solutions to overcome the barriers in the implementation of eco-design practices in small and medium enterprises.

We conducted five focus group interviews (five people) and ten unstructured interviews with industry users and experts after the literature review and before delivering the questionnaires to the industry experts. The participants were familiar with GPDD applications. We identified 22 expected qualities based on the responses and the debate, which were then divided into five critical criteria, as shown in Table 3: cooperation and commitment from top management (TMC), design for environment (DFE), utilization of green technologies (UGT), green external supply chain management (GESCM), and green internal supply chain management (GISCM).

**Table 3.** GPDD demands a library for eco industries.

| Objective: Green Product Design and Development (GPDD) | | | |
|---|---|---|---|
| **Main Factors and Sub-Factors** | **Code** | **Content Overview** | **Source** |
| **Top management commitment** | **F-1** | Top management commitment is essential for management. It facilitates employee empowerment. TQM (total quality management) focuses on leadership commitment, production, satisfaction, and user happiness. Top managers have more technical skills than conceptual. They must understand marketing strategy, social and political effects, economics, and competition.<br>Top management is a team that focuses on user requirements and organizational objectives. It controls the organization at the highest level to ensure effective and efficient management to decide on quality-based factors for evolvement and everyone's fulfillment. | [39,54] |
| **Training of employees of green product design and development** | F-11 | The "green business" concept focuses mainly on environmental and industrial growth. According to this, we train the employees for green and productive thinking. We choose measures that take proper care of the environment along with industrialization. We focus on healthy products and on recycling non-biodegradable products. Thus, formal training is given and detailed factors are taught to employees to shift towards the environment more than focus on greedy growth. | [55] |
| **Commitment on capital investment for green orientation of the organization** | F-12 | Green investing alludes to investing exercises lined up with a pledge to advance the earth, inviting strategic policies, and preserving regular assets. Green investments are speculation exercises that focus on organizations or ventures focused on protecting characteristic assets, creating and revealing elective fuel sources, executing of clean air and water ventures, or other naturally cognizant strategic approaches. | [56] |
| **Promoting R&D for green product development by top-level management** | F-13 | Exploration recommends that greening can assist organizations with increasing significant experiential information on new practices and expert new advancements. Creating ecological knowledge empowers firms to discover methods of augmenting efficiencies and investigating new market openings. Experiential information picked up from inclusion in eco-accommodating tasks streams starts with one division and then the next in the firm. This stream encourages a creative firm culture, conceivably expanding new product presentations. Along these lines, green practices are essential for upgrading and reviving a company's product development exercises. | [56] |
| **Design for Environment (DFE)** | **F-2** | It is an idea of design to reduce overall human health and how the product or service impacts the environment. Its impacts are considered across its life cycle. Many software tools have been developed to help designers find products and services useful to them. Initially, guidelines for DFE were written by a New York-based organization, East Meets West.<br>It slowly creates a global impact, influencing design initiatives and incorporating environmental motives. It aims to improve technology and designing techniques and increase eco-efficiency in the design techniques. It also aims to maintain user needs, balance social and ecological impacts, and improve interaction. | [11,14,15,57] |

**Table 3.** *Cont.*

| Objective: Green Product Design and Development (GPDD) | | | |
|---|---|---|---|
| **Main Factors and Sub-Factors** | **Code** | **Content Overview** | **Source** |
| **Design for Disassembly** | F-21 | To design for disassembly or deconstruction is to make items limit misfortune toward the finish of life. The significance of disassembly has developed throughout the years due to the monetary and ecological advantages that it brings. It principally targets rescuing significant materials and parts from the end of life (EOL) or disposed of items that, in any case, continue on to landfills and dirty the water bodies and air. It further aids in sparing the assets and lessens the requirement for new materials.<br>Design for disassembly is an idea in which structures and items are designed purposefully for material recovery, esteem maintenance, and practical next use. | [58,59] |
| **Design for disposability** | F-22 | An article, product, or service that is designed to be disposed of after use is called design for disposability. It is essential for the environment as non-disposable products provide maximum environmental damage. The used product should be converted into such a form to be disposed of quickly.<br>Design industries have become more ethical and sustainable these days. They very well know the importance of it. These companies are now creating products with such designs that can reduce non-disposable waste while maintaining the product's quality. Researchers have shown that plastic is the most famous refrain towards this step. Many other alternatives can be used, like natural products that are already quite popular in India and other countries in South Asia. | [59] |
| **Design for energy efficiency** | F-23 | It is designing products or services so that they are the most energy-efficient. Energy efficiency saving energy is the biggest help anyone can provide to the environment. There are many ways to design the most energy-efficient product, but to conserve the most energy, it is highly recommended to create energy-efficient manufacturing. The best way to do this is to make the building energy efficient. This means designing the buildings so there is proper lighting, energy-efficient appliances, energy conservation manufacturing line, etc. It helps a lot as the manufacturing sector is the largest sector in India after farming. These could benefit in significant energy savings, and many big companies have already been doing this, and the smaller ones are moving towards it. Researchers have shown people living in energy-efficient homes leave a negligible carbon footprint. People should turn towards renewable energy rather than oil and fossil energy sources. | [60] |
| **Design for recycling and reuse** | F-24 | It is an eco-friendly strategy in which products and services are designed to be reused or recycled after use. It is less harmful to the environment and has a lower impact. The difference between recyclable and reusable is that the former product is given some extra touches while the latter can be used again without any treatment. For the companies thinking of reducing their environmental impacts and minimizing carbon footprint, the first thing they need to do is review all their processes involved in product design and mold them so that they become either reusable or recyclable. Researchers have found many materials that can be used to create recyclable products, but companies often tend not to follow them as they fear it might reduce product quality. However, these days, the best recyclable materials have been found to make up for the requirements of all these companies and laws also make them use these materials for environmental benefit. | [58] |

**Table 3.** *Cont.*

| Objective: Green Product Design and Development (GPDD) | | | |
|---|---|---|---|
| **Main Factors and Sub-Factors** | **Code** | **Content Overview** | **Source** |
| **Design for conservation and optimal utilization of resources** | F-25 | It means optimal use of materials and resources in manufacturing the product. The designing process needs to checked to see where the help or materials can be conserved, or it needs to go through a complete change and create a product that uses the resources in the best and most conserving manner. In this way, help can last longer and generate less harm for the environment. Resource conservation and management are areas that every company has been looking into as natural resources are soon exhausted. It leads large manufacturers like China, India, and the USA to look into their manufacturing process for optimal utilization of resources. Research papers have shown that if these big manufacturing countries ultimately adopt this design, it may majorly reduce their carbon footprint. | [61] |
| **Product life cycle environmental impact assessment** | F-26 | Product life cycle environmental impact assessment is a time-tested assessment technique that checks on the environmental impact throughout the life cycle of a product or service. It includes a life cycle from extraction of resources, manufacturing the development, and use of creation until the aging of the product. It checks on the consumption of resources, fumes released into the air, impact on water and soil, and many other things that might impact the environment<br>It has played a vital role in developing the life cycle midpoint damage framework, which has information on how much the product has environmental intervention and the ultimate health that it may cause to humans, which has significant importance for decision makers. Research papers have shown that the complete manner of assessment has been divided into five stages, which cover all the points and help companies follow standard procedures to check on their product life cycle environmental impact assessment. | [41,62,63] |
| **Utilization of Green Technologies** | **F-3** | Green technology utilizes non-dirtying practices to deliver things and materials that are non-poisonous. The creative methods used in this technology can positively change our everyday lives. The training includes satisfying the necessities of the general public without causing exhaustion of the accessible characteristic assets, saving them for some time later. Along these lines, green technology offers significance to continue simultaneously permitting the satisfaction of current requirements.<br>The primary territories where green technology can be utilized incorporate energy creation, green science, development of earth cordial structures, sewage treatment, and so forth; green technology in these zones can lessen the weight on the common assets, economy and climate. This will assume a significant function in keeping up the environmental equilibrium.<br>Decreasing contamination can forestall an Earth-wide temperature boost and greenhouse gas impact. There will not be many events of characteristic disasters and the climate will turn out to be more unsurprising. Sewage treatment by utilizing green technology makes the water assets less contaminated. It permits the utilization of reused water for different purposes.<br>Green science guarantees synthetic items that are alright for the climate. Medical issues caused by contamination would diminish. The world would become a prime spot to cherish for all living creatures.<br>It is expected that the utilization of green technology will stretch out into more zones in the coming years. The future financial exercises will rely on making items that are more secure and more gainful to the climate. The legislatures of different nations perceive the requirement for green technology and advance the utilization and acquisition of things delivered using green technology, which is naturally agreeable. There will be new professions opening up, which are fixated on green technology. Making mindfulness among individuals about the utilization of green energy and cordial earth items improves the extent of this technology. | [17,43,64] |

**Table 3.** *Cont.*

| Objective: Green Product Design and Development (GPDD) | | | |
|---|---|---|---|
| **Main Factors and Sub-Factors** | **Code** | **Content Overview** | **Source** |
| **Computer-aided management** | F-31 | CAFM (computer-aided facility management) is a rapidly emerging field of information technology that enables business owners and their organizations to bring critical logistical chores into the digital realm via business continuity and facility management software. | [65] |
| **Computer-aided Design** | F-32 | Computer-aided design (CAD) uses computers (or workstations) to assist in creating, modifying, examining, or enhancing a plan. CAD programming is used to increase the designer's profitability, improve the nature of innovation, improve correspondences through documentation, and create a manufacturing database. CAD output is commonly utilized as an electronic record for printing, machining, and other assembly operations.<br>Computer-aided design is a type of mechanical artistry that is widely used in various fields, including automobiles, shipbuilding, aviation, contemporary and engineering design, prosthetics, and more. DCC-automated content creation, sometimes known as computer-aided design, is widely utilized to give computers liveliness for embellishments in motion films, advertising, and technical manuals. Because of computers' cutting-edge universality and intensity, even perfume containers and cleanser allocators are developed using techniques that would have been unthinkable to architects in the 1960s. Due to its enormous monetary relevance, CAD has been a critical impetus for research in computational calculation, computer design (both equipment and programming), and discrete differential arithmetic. | [10] |
| **Computer-aided manufacturing** | F-33 | Computer-aided manufacturing includes computers that control the current natural cycles that create models and completed merchandise. For example, one standard method, known as computer mathematical control, or CMC, includes the utilization of an apparatus that manages a device head, such as a turning switch or machine cycle, over a crude workpiece. | [10] |
| **Computer-integrated manufacturing** | F-34 | Computer-integrated manufacturing (CIM) can be considered a severe business theory that combines an organization, designing, and manufacturing. The data innovation assumes a focal part for arranging and controlling the manufacturing cycle. It utilizes computers and correspondence organizations to change robotized manufacturing frameworks into interconnected frameworks that participate in every single authoritative capacity.<br>Numerous organizations over many ventures, for example, cars, bite-the-dust form, part manufacturing, position shops, aviation, protection, shipbuilding, electric and electronic, medical care, shopper durables, plastic, carpentry, food handling, mechanical technology, and glass working, have embraced them. | [66] |

**Table 3.** *Cont.*

| Objective: Green Product Design and Development (GPDD) | | | |
|---|---|---|---|
| **Main Factors and Sub-Factors** | **Code** | **Content Overview** | **Source** |
| **Computer-aided testing** | F-35 | Computer-aided testing (CAT) uses computers to control either simple or advanced test methods to assess the nature of parts and items. Computer-aided testing is utilized to watch the segment parts, subassemblies, and complete frameworks inside indicated resilience and perform up to determination. Researchers have shown that through computer-aided testing, the following advantages can be achieved:<br>1. Decreased estimation mistake; 2. the chance to see the in situ adjustments in the help loads and the separation, where the focal point of gravity has voyaged, and in the viable terms, to see how far the machine is from spilling; 3. the time decrease of the estimation cycle.<br>Computer-sided testing systems as computer programming bundles should be evaluated and analyzed. As benchmark programs seem to be, composed to assess computers, computerized circuits should be chosen to determine testing frameworks. Like computer frameworks, CATS require a few sorts of benchmarks since no single model can do the trick to quantify all ascribes of a framework | [10,66] |
| **4. Green External Supply Chain Management** | **F-4** | Marketers need to characterize and plan the 4 Ps of promoting blend from nature conservation. The green marketing blend components suitably and successfully address the vital ecological issues.<br>Component # 1. Green Products:<br>Consider items that devour more energy, utilize poisonous synthetic, can't be reused, and use general bundling. Such items are a danger to the climate due to ecological corruption and contamination. Then again, items that help in sparing energy, utilizing common fixings, reusing, or utilizing decreased bundling make commitments to the climate. Accordingly, those items delivered in amicability with the environment are known as 'green items.'<br>Component # 2. Green Price:<br>Creating green items requires an adjustment in the creation cycles, which requires consumption. Cost increment brings about expanded value purpose of green things that makes worthiness of the item in the market troublesome. The exorbitant cost may go about as an obstruction as users might be either reluctant or incapable of paying this green premium.<br>Component # 3. Green Place<br>Green place identifies with the dispersion of green items without damaging the climate. This is accomplished through the proficient usage of fuel and energy and organizing coordination with the least discharges.<br>Component # 4. Green Promotion<br>Buyers should be made mindful of green items and be propelled to buy them. Accordingly, an immense measure of money and assets are spent by organizations these days on advertising and the advancement of green things. Green promotion involves expanding the affectability of buyers towards green items just as advancing the items in a climate-friendly, well-disposed way, such as utilizing long-range interpersonal communication destinations to present profiles related to green showcasing. | [51,67] |

**Table 3.** *Cont.*

| Objective: Green Product Design and Development (GPDD) | | | |
|---|---|---|---|
| **Main Factors and Sub-Factors** | **Code** | **Content Overview** | **Source** |
| **Green procurement** | F-41 | Green procurement refers to goods and services with minor negative environmental consequences. It combines human health and ecological concerns with the pursuit of excellent goods and services at low prices. The great danger the executives and practical procurement go connected at the hip. For business, questioning procurement needs and practices can decrease working expenses, improve worker wellbeing and efficiency, lower natural effects and help consistence with ecological enactment. Improving the supportability of your items (both utilized and dispersed) considers your organization's picture reasonably. A solid procurement structure can likewise decrease hardware running expenses, improve end-of-life removal practice, and limit bundling and transport costs. Regarding purchasing energy-effective gear, it can have a slightly higher forthright capital use yet will convey critical lifetime costs and emanations investment funds. Expenses can be additionally diminished by purchasing in bulk, buying more extended life materials, or setting up re-use for materials bought. In the constructed climate, green assembled structures whose upkeep and procurement rehearses are not supportable can negatively affect the exhibition of the system in general. Different multilateral financing associations, worldwide associations, and nations have joined the global exertion to advance green procurement. This key center, through procurement, tries to build products with the most un-conceivable natural impression while delivering energy and even budgetary investment funds. The fusion of ecological models and prerequisites for the procurement of products, works, administrations, and consultancies doesn't mean more extraordinary expenses, but instead an adjustment in context, wherein speculation might be more proficient in the medium-term, making shared benefit circumstances for nations. When characterizing green procurement, it is basic to guarantee that there are sufficient providers to give the necessary works, products, administrations or consultancies with the ideal qualities and that these streamline an incentive for cash to accomplish the standards of economy, productivity, equivalent chance and straightforwardness that administer IDB procurement. | [64] |
| **Green marketing** | F-42 | Promoting ecologically friendly goods and services is referred to as green marketing. As more individuals become concerned about environmental issues and appreciate the importance of spending responsibly, it becomes increasingly widespread. Green marketing includes making an environmentally friendly product, employing environmentally friendly packaging, receiving sustainable strategic approaches, and focusing marketing efforts on messages that reflect an item's green benefits. This might be a more expensive promotion. However, due to the increased demand, it might also be beneficial. Items created locally in North America, for example, will be more expensive than those made abroad with minimal labor; yet, they will have a far lower carbon footprint because they will not have to travel across the globe to arrive. Buyers and enterprises, without a doubt, will benefit from the new legislation. Certainly, for buyers and entrepreneurs, the ecological advantage exceeds the value contrast. Nowadays, the natural issues concern every dynamic resident, endeavor, and foundation everywhere globally, significantly more than it completed 30 years prior. Worldwide investigations show that shoppers stress over the climate and change their conduct step by step. Consequently, another market for suitable or reasonable items arises, which is additionally reinforced by dynamic buyers since it is an approach to add to the assurance of the climate. | [5,14,46,68] |

**Table 3.** *Cont.*

| Objective: Green Product Design and Development (GPDD) | | | |
|---|---|---|---|
| **Main Factors and Sub-Factors** | **Code** | **Content Overview** | **Source** |
| **Reverse logistics** | F-43 | The region of graceful chains that cycle anything inwards through the flexible chain or voyaging 'in reverse' through the exquisite chain is reverse logistics. As a result, the names are backward in terms of logistics. Return merchandise, internal removal/reuse of packaging materials, the reusing/reliable removal of materials from previously sold items, and so on, are all examples of this. According to The Council of Logistics Management, the entire concept of reverse logistics is the means of executing, controlling, and organizing the practical advancement of completed items, crude materials, and in-measure stock. The stream runs from the point of use (for example, the client) to the end of recovery (for example, the producer) to properly discard or recover esteem. With the rapid development of outer weights in the conveyance market, it is well worth thinking about reverse logistics bound to resemble later on.<br>The nature of reverse logistics cycles will predictably affect the intensity and manageability of both flexible chains and ventures in general, and reverse logistics will most likely play a major role in the reasonability of business structures. Of the apparent multitude of development techniques, robotization will probably drive the absolute most noteworthy paces of advancement inside reverse logistics because of its broad and progressive advantages.<br>The Five R's of reverse logistics are returns, reviews, fixes, repackaging, and reusing. The audit finds that examination and practice in RL are centered around all parts of RL From an assortment of utilized items and their handling, to the yields of preparing, in particular, reused materials, saving details, remanufactured items, and waste material removal. The survey likewise shows that numerical displaying in RL research is mainly centered on deterministic techniques. There are restricted exploration papers considering stochastic interest for the remanufactured items and gracefully utilized items by the client. Likewise, it is discovered that the evaluating models for getting used items are as yet creating. | [5,42] |
| **Supplier's and Users involvement in green manufacturing** | F-44 | SCM (supply chain management) is a system that allows businesses to move, store, change over, and transport goods efficiently and effectively. It is an old concept that dates back to 1975. Another idea, known as green supply chain management (GSCM), was developed in the 1990s and included the buying capacity in exercises that included material reduction, reuse, and substitution. It is a closed-loop supply chain with minimal asset use and is environmentally friendly. GSCM is viewed as a significant piece of the hierarchical procedure for organizations that need to turn out to be earth agreeable and socially dependable to fulfill the clients' needs and fit the lawful necessities of governments. They additionally call attention to the fact that 14 components have a critical effect on the usage of GSCM in associations: pressure from clients and rivalry, administrative guidelines, provider affirmation of natural management framework, provider ecological cooperation, client-coordinated effort, social duty and morals, business benefits, pressure from representatives, fares and deals to unfamiliar clients, rivalry, the supportability of assets, decreased costs, rate of profitability and authoritative variables, which include responsibility, mindfulness, and experience. These are components that help associations that need to manage budgetary emergencies, absence of assets, environmental change, ecological effect of tasks, and client mindfulness for green items. Moreover, by receiving GSCM practices, associations can convey more viably to the public authority that they are focused on improving their ecological presentation. | [48,67] |

**Table 3.** *Cont.*

| **Objective: Green Product Design and Development (GPDD)** | | | |
|---|---|---|---|
| **Main Factors and Sub-Factors** | **Code** | **Content Overview** | **Source** |
| **Green Internal Supply Chain Management** | **F-5** | Green internal supply chain management is merging environmental thinking with supply chain management. It also includes designing the product or finding appropriate material for the manufacturing process and other supply chain stages. Green supply chain management has more advantages than its name suggests, as managers profit from increased productivity and lower costs. Green policy implementation does not have to be complicated.<br>This concept was introduced in the 1990s, but companies only started implementing it in 2000 and later. Industries use it to check the suppliers for their measures in environment-friendly manufacturing without degrading product quality and overall management of suppliers. Information technology (IT) is used to sort out the companies' and suppliers' green supply chain issues. It includes fetching all the information like material systems, information management systems, etc., combining all the information, and creating procedures to achieve green and clean manufacturing. The supply chain also needs to ensure green internal supply chain management levels through management systems, production processes, and analysis of product components. | |
| **Green/sustainable manufacturing** | F-51 | Green manufacturing or sustainable manufacturing is manufacturing such that it reduces damage to the environment and creates minimal waste. This can be achieved by adopting different product and process design and operational principles. Sustainable manufacturing also improves employee, community, and product safety.<br>Many companies have now started treating it as an essential objective in manufacturing to increase growth and global competitiveness. One of the best ways companies can turn green is by using renewable energy sources. Companies involved in mass production require loads of energy, and if they can obtain power from renewable energy, it will be a huge breakthrough. Many leading Indian companies have also been awarded for adopting green manufacturing practices and deploying sustainability. | [43,69,70] |
| **Waste management** | F-52 | Waste is unwanted or unused materials. In every company, waste is generated, especially the manufacturing companies involved in developing a large amount of waste. Many types of waste are generated: solid waste, hazardous waste, wastewater, radioactive waste, etc.<br>What one sees as waste can be a resource for another person. Thus, it is not just physical processes that create waste but also psychological. There are four terms associated with waste: dry trash; wet garbage; refuse, which is both; and rubbish, which is refuse plus construction. The companies either reuse the waste like ashes produced in coal-powered plants; the waste can be used to create bricks, or the companies may dispose of the waste properly after treating it. This is known as resource recovery. It is processing recyclables, recovering materials, and resources, or converting them to energy. | [71] |

**Table 3.** *Cont.*

| Objective: Green Product Design and Development (GPDD) | | | |
|---|---|---|---|
| **Main Factors and Sub-Factors** | **Code** | **Content Overview** | **Source** |
| **Environment management system** | F-53 | An environmental management system (EMS) is a collection of procedures that enables a business to reduce its environmental footprint while increasing its operational efficiency. The most widely used International Organization for Standardization (ISO) 14001 is the basis for EMS. Instead of defining environmental performance requirements, it gives a framework that a corporation can follow.<br>The main reason for using EMS is to increase compliance. Compliance is maintaining minimal legal standards. If a company does not follow it, it may face legal consequences. Another big reason is it helps in waste reduction. Waste reduction is initiated in the design phase through water pollution. Waste is also reduced by recycling. Environmental management systems can handle high-frequency data, have performance indicators, have powerful calculating machines, and have multiple integration capabilities. They also hold data and have potent processors and process that data. It also must have flexible reporting of conclusions. According to these factors, selecting an environmental management system has to be made.<br>Research and surveys have shown that the environmental management system has been a critical mechanism for improving the economic growth of any company. It has also been found that using an environmental management system has helped evaluate environmental performance and enhance business performance. It is a valuable system that helps companies gain competitive advantages and increase economic performance. | [39,72] |
| **Green packaging** | F-54 | Green packaging is also called sustainable packaging. It can be defined as using materials and procedures for packaging products so that it does not adversely affect the environment and keeps check on energy consumption. It can be done most easily by using biodegradable materials or recycling the supplies. We also need to simultaneously keep energy efficiency in mind.<br>The main benefit of using green packaging is to save the environment from earlier or older packaging techniques that were causing harm to the environment. There are many wide varieties of methods to assist in protecting the environment using green packing that can be applied in daily lives: for example, using complete paper back and forth with proper justified space-saving alignment when printing or using recycled papers.<br>There are many other methods for green packaging, such as using thin plastic for packaging, increasing recycled materials in packaging, and redesigning the box for space-saving measures, etc. These can be used very effectively in our daily lives. We also need to keep in mind the part involving energy consumption. This can be done by using renewable power, appliances with efficient power consumption, and planned and efficient transportation and delivery services to help us save valuable energy.<br>Researchers have shown and proven that green packaging techniques enable the packaging of goods more efficiently by using light weight, recyclable/reusable materials and more biodegradable materials. Government laws can help companies adopt these environmental-friendly techniques. Furthermore, if companies invest in creating new and better eco-friendly materials, that would be the most significant aid to the environment. | [5,73] |

### *3.2. Discussion on Critical Factors for GPDD*

The factors necessary for implementing GPDD were studied by examining the extant literature and receiving validation by experts.

## **4. Research Analysis**

### *4.1. Kano Model Analysis*

#### 4.1.1. Data Collection for Kano Model

The Kano model can recognize the user's green product design and development expectations. After the literature review process of identifying the criteria and sub-criteria for GPDD, a questionnaire was prepared. Later, we determined which elements to categorize under Must Be, Performance, Attractive, and Indifferent through the Kano questionnaire. The questionnaire consisted of 22 criteria for GPDD divided into five clusters: cooperation and commitment from top management, collaboration, and commitment from top management (TMC), design for environment (DFE), utilization of green technologies (UGT), green external supply chain management (GESCM), and green internal supply chain management (GISCM). We processed 96 questionnaires to a sample of GPDD visiting nearby industries that use green manufacturing concepts. Sample demographics of the survey are shown in Table A1 in Appendix A.

Each surveyed user's responses were sorted and analyzed following the Kano evaluation form to determine the Kano category for each requirement. Then, using the relative majority principle, all the Kano categories for each required item for all users were summed up to determine the final Kano category for each demand item.

#### 4.1.2. Kano Methodology

The Kano model gives practitioners a better understanding of how users evaluate products, focusing on the essential quality traits that need improvement. Kano's approach was first developed for product development and it provided a unique, in-depth way of understanding users' requirements by assigning distinct categories to different scenarios. While assessing the user's requirements, it considers the user's description of the problem to be solved, including functional and dysfunctional components.

Step 1: First, the needs are determined through personal interviews with decision makers. Then, based on the associated needs, requirements are established. Following that, a list of criteria is determined to meet the requirements. The functional and dysfunctional questions on these traits are then incorporated into a questionnaire. Figure 4 depicts an example of a question utilized in the current study.

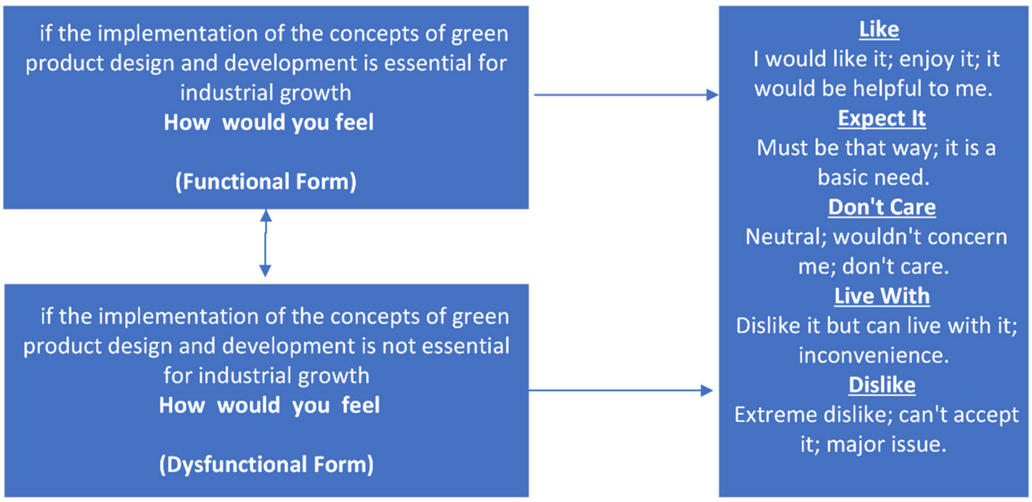


**Figure 4.** A modified Kano questionnaire.

Step 2: (Madzík, 2018) [74] proposed assessing the questionnaire and determining a conclusion based on a combination of functional and dysfunctional responses. Tables 4 and 5 illustrate a modified Kano assessment matrix.

**Table 4.** Kano assessment matrix.

| | | **Dysfunctional Form** | | | | |
|---|---|---|---|---|---|---|
| | | Like | Expect It | Don't Care | Live With | Dislike |
| **Functional Form** | Like | Q | A | A | A | P |
| | Expect It | R | I | I | I | M |
| | Don't Care | R | I | I | I | M |
| | Live With | R | I | I | I | M |
| | Dislike | R | R | R | R | Q |

**Table 5.** Kano assessment category.

| | | |
|---|---|---|
| **M** | Must Be | These Requirements Are Not Fulfilled; the User will Be Depressed. |
| **P** | Performance | With a higher level of fulfillment, the user is high satisfaction and vice versa. |
| **A** | Attractive | Attractive requirements are neither explicitly, neither expressed nor expected by the user. There are no sentiments of disappointment because these conditions are not reached. |
| **I** | Indifferent | Whether the product, service, or process is dysfunctional or completely functional, the user is neither satisfied nor unhappy. |
| **Q** | Questionable (invalid) | There is a contradiction in the user's answer to the question. |
| **R** | Reversal (invalid) | The user does not want this requirement, but they expect the reverse. |

Step 3: The U.S. value (user satisfaction coefficient) and the U.S. value (user dissatisfaction coefficient) were calculated for each requirement item after the assessment table and the impact of each demand item was determined on the level of user satisfaction. The user satisfaction coefficient is between 0 and 1 (1 values are close to high satisfaction while those of 0 indicate low satisfaction). The user dissatisfaction coefficient has a value between $-1$ and 0 (values relative to $-1$ represent great dissatisfaction while values close to 0 indicate quiet discontent). The following are the calculated equations:

$$US = Ai + Pi / Ai + Pi + Mi + Ii$$
$$DS = Mi + Pi / Pi / Ai + Pi + Mi + Ii * (-1)$$

where Ai, Pi, Mi, and Ii represent the number of Attractive, Performance, Must Be, and Indifferent attributes of demand item 'i', respectively [75]. Table 6 summarizes the Kano category distribution of each user demand item in GPDD and the derived C.S. value and D.S. value for each demand item.

**Table 6.** User requirements by frequency.

| Main Factors | Sub-Factors Code | M | P | A | I | R | Q | Total | Category | U.S. Value | D.S. Value |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Top management commitment (F-1)** | F-11 | 30 | 35 | 15 | 12 | 4 | 0 | 96 | P | 0.5434783 | −0.70652174 |
| | F-12 | 28 | 35 | 10 | 12 | 10 | 1 | 96 | P | 0.5294118 | −0.74117647 |
| | F-13 | 52 | 30 | 10 | 2 | 2 | 0 | 96 | M | 0.4255319 | −0.87234043 |
| **Design for Environment (DFE) (F-2)** | F-21 | 24 | 22 | 48 | 1 | 1 | 0 | 96 | A | 0.7368421 | −0.48421053 |
| | F-22 | 18 | 34 | 30 | 12 | 2 | 0 | 96 | P | 0.6808511 | −0.55319149 |
| | F-23 | 30 | 35 | 19 | 10 | 1 | 1 | 96 | P | 0.5744681 | −0.69148936 |
| | F-24 | 49 | 30 | 16 | 1 | 0 | 0 | 96 | M | 0.4791667 | −0.82291667 |
| | F-25 | 29 | 37 | 25 | 5 | 0 | 0 | 96 | P | 0.6458333 | −0.6875 |
| | F-26 | 24 | 30 | 32 | 6 | 3 | 1 | 96 | A | 0.673913 | −0.58695652 |
| **Utilization of Green Technologies (F-3)** | F-31 | 26 | 27 | 14 | 29 | 0 | 0 | 96 | I | 0.4270833 | −0.55208333 |
| | F-32 | 34 | 41 | 13 | 6 | 2 | 0 | 96 | P | 0.5744681 | −0.79787234 |
| | F-33 | 45 | 32 | 15 | 3 | 1 | 0 | 96 | M | 0.4947368 | −0.81052632 |
| | F-34 | 34 | 39 | 16 | 5 | 2 | 0 | 96 | P | 0.5851064 | −0.77659574 |
| | F-35 | 36 | 41 | 10 | 7 | 2 | 0 | 96 | P | 0.5425532 | −0.81914894 |
| **Green External Supply Chain Management (F-4)** | F-41 | 34 | 35 | 25 | 2 | 0 | 0 | 96 | P | 0.625 | −0.71875 |
| | F-42 | 33 | 38 | 20 | 4 | 0 | 1 | 96 | P | 0.6105263 | −0.74736842 |
| | F-43 | 26 | 28 | 22 | 12 | 5 | 3 | 96 | P | 0.5681818 | −0.61363636 |
| | F-44 | 34 | 38 | 15 | 5 | 4 | 0 | 96 | P | 0.576087 | −0.7826087 |
| **Green internal supply chain management (F-5)** | F-51 | 35 | 39 | 18 | 4 | 0 | 0 | 96 | P | 0.59375 | −0.77083333 |
| | F-52 | 59 | 30 | 5 | 2 | 0 | 0 | 96 | M | 0.3645833 | −0.92708333 |
| | F-53 | 30 | 29 | 35 | 2 | 0 | 0 | 96 | A | 0.6666667 | −0.61458333 |
| | F-54 | 30 | 31 | 30 | 5 | 0 | 0 | 96 | P | 0.6354167 | −0.63541667 |

#### 4.1.3. Results of Kano

Following the data gathering, we proceeded to classify each GPDD criteria. The output of this classification might prove to be particularly relevant for GPDD developers because it allows them to establish a difference between each requirement. It may then be possible to build green products based on the requirements and wishes of users, resulting in improved levels of consumer satisfaction and an environmentally sustainable approach. We applied the frequency approach to the total number of responses using the Kano assessment matrix for each criterion. This helped in investigating green product design and development strategies to categorize under Kano categories.

We evaluated the results by using the frequency method. We determined the different categories of the requirements based on the highest frequency obtained, as shown in Table 6. The frequency of the questionable results was shallow. As a result, the questionnaire could have had a high level of authenticity. Some practical indications emerge by considering the frequencies of the results and applying the categorized A > P >M > I rule. Suppose industries wish to develop green production to improve user satisfaction. The consideration of Must Be, Attractive, and Performance attributes are key for the success of achieving high user satisfaction [28].

The Kano categories of GPDD demands are summarized in Table 7. Figure 5 represents the mean of user satisfaction for each requirement, resulting in the order F2 > F5 > F4 > F1 > F3. Three industry demand items belonged to the Kano category of Attractive criteria, which were F-21, F-26, and F-53. "Design for Disassembly" and "Product life cycle environmental impact assessment" belong to the primary category "Design for Environment." The absolute value of the U.S. value (the influence of the GPDD item on improving user satisfaction) and the total value of the U.S. value (the power of the demand item on reducing user satisfaction) were found to be significantly different. Although the absolute value of U.S. was more significant than 0.5, the total value of D.S. was low, indicating that when this factor has a high level of satisfaction, it can significantly improve user satisfaction. It will not cause users to be dissatisfied to a high degree. It is widely known that 'Design for Environment' is the basic unit for eco industries because it decreases a product's lifetime environmental impact. Studies have shown that 80% to 90% of green product design and development growth depends on DFE. As a result, increasing Attractive demand (F-2, design for environment) can increase the total service level of eco industries.

**Table 7.** Summary of Kano category for GPDD.

| Kano Category | GPDD Demand Item in Eco Industries |
|---|---|
| **Attractive demand (A)** | Design for disassembly, product life cycle environmental impact assessment, environment management system |
| **Performance (P)** | Training of employees of green product design and development, commitment on capital investment for green orientation of the organization, design for disposability, design for energy efficiency, design for conservation and optimal utilization of resources, computer-aided design, computer integrated manufacturing, computer-aided testing, green procurement, green marketing, reverse logistics supplier's involvement in green manufacturing, green/sustainable manufacturing, green packaging |
| **Must-Be demand (M)** | Promoting R&D for green product development by top-level management, design for recycling and reuse, computer-aided manufacturing, waste management |
| **Indifferent (I)** | computer-aided management |

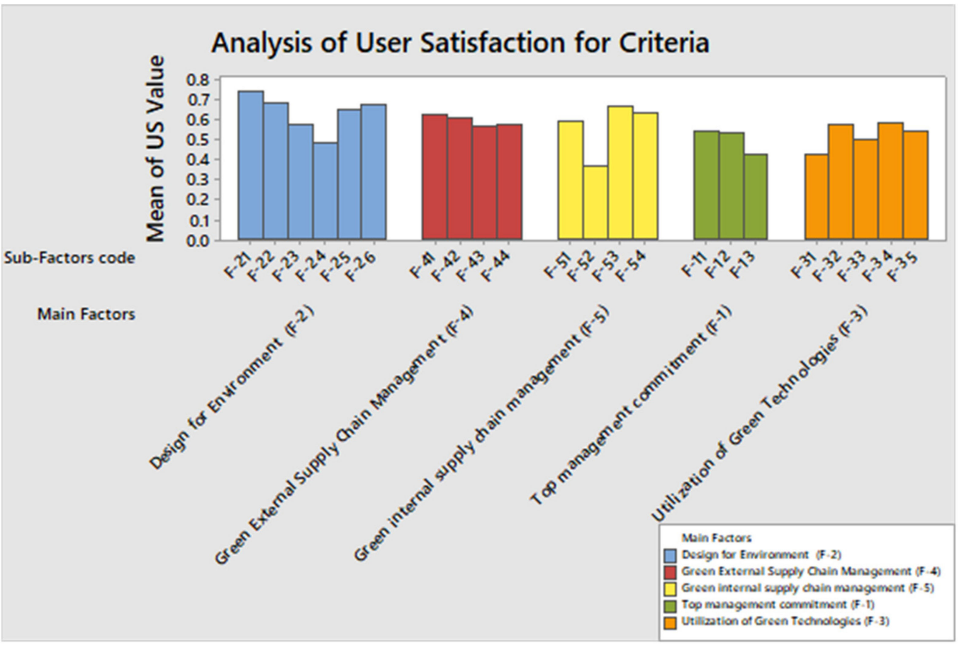


**Figure 5.** Analysis of user satisfaction for criteria.

Four GPDD demand items belonged to the Kano category of Must-Be demand, with the serial numbers F-13, F-24, F-33, and F-52. The absolute value of D.S. was comparatively high among the four demand items, whereas the total value of the U.S. was deficient. When such criteria are not available or are in low availability, user satisfaction suffers dramatically. As a result, continuously improving the service facilities in the daily production processes of eco industries must ensure that users' Must-Be demand is met, such as by promoting R&D for green product development by top-level management, design for recycling and reuse, computer-aided manufacturing, and waste management.

The Kano category of Performance demand contains fourteen user demand elements. Significant demand categories include green product design and development training for employees, commitment to capital investment for green orientation of the organization, design for disposability, design for energy efficiency, and so on, as shown in Table 7. For the 14 demand items, the absolute C.S. and U.S. values were above 0.5. The difference between U.S. and D.S. was negligible, but it considerably impacted user satisfaction and discontent, directly related to satisfaction. Eco industries must pay attention to Performance demand items as critical functional criteria. As a result, for the growth of eco-production, they must pay close attention to the maintenance and enhancement of such demand items and do their best to meet such needs to maximize the use of resources.

### *4.2. Fuzzy Analytic Hierarchical Process (F-AHP)*

One of the most significant drawbacks of the M > A > O > I rule is that it does not define a hierarchical order within the same classification. As a result, after grouping the requirements into Kano's five clusters, we employed AHP to investigate the hierarchical order of criteria in the same type (Must Be, One-Dimensional, Attractive). Due to its flexibility, ease of calculation, and integration with other techniques, it is the most effective and preferred method for multi-criteria decision supports. We did not evaluate Indifferent and Reverse requirements because Kano does not advocate this approach. The significance value and pair-wise comparison of the selected requirements found in the problem statement were determined. We asked five experts to rate the importance of each need on a scale of 1 (not important) to 9 (very important) in the AHP questionnaire. Then, a pair-wise comparison of all requirements in the same category was performed. The main differences between the Kano and the AHP questionnaires are summarized in Table 8.

**Table 8.** Kano and AHP questionnaire.

| Approach | Questionnaire | Scales | Respondents |
|---|---|---|---|
| **Kano Model** | If X is fulfilled, how do you feel about it? If X isn't fulfilled, how do you feel about it? | Linguistic (Must Be, Performance, Attractive, and Indifferent) | Users |
| **Fuzzy AHP** | To what extent is X1 preferred to X2? | Numeric (Saaty's 1 to 9 point scale) | Decision maker/Experts |

The analytical hierarchy process (AHP) is the most extensively utilized multi-scale decision making procedure in risk assessment. It is the most successful and popular method for multi-criteria decision aids due to its flexibility, ease of calculation, and connection with other techniques. The AHP technique is a statistical method for assessing difficult decisions based on the decision maker's experience utilizing quantitative and qualitative data. This method enables hierarchical modeling, which depicts the link between the problem's aim and primary and secondary criteria of the problem. AHP was designed to make paired comparison matrices and calculate each parameter's weightage factors [76]. AHP has chosen the most fabulous waste management model in recent years. Most of this research has concentrated on selecting a municipal and industrial waste model, and not all model selection criteria have been considered [77].

AHP is a modern strategy for dealing with MCDM that also assists the decision maker in setting the preference to make the best selection possible. AHP is a set of methodologies and philosophies for ranking criteria and sub-criteria. It is a mathematical method for calculating the weighting value. Decision making in a risk environment by ambiguity and uncertainty is exceptionally challenging. The emergence of fuzzy set theory has aided decision makers in dealing with this ambiguity and uncertainty. Expert preference is frequently articulated in words and measured using the Likert scale [78]. However, because each linguistic phrase is assigned a single value, the Likert scale cannot handle ambiguity or vagueness in decision making. The fuzzy set theory allows words to be quantified using fuzzy numbers, effectively capturing the ambiguity in choice. The fuzzy set is commonly utilized with triangular and trapezoidal fuzzy numbers. Still, a recently developed three-dimensional spherical fuzzy set is an addition to the fuzzy set that effectively addresses uncertainty and quantifies expert judgments [79]. Standard fuzzy sets (type-1 fuzzy sets) successfully capture the vagueness but cannot handle uncertainty. So, researchers have developed different additions to fuzzy set theory, such as interval type-2 fuzzy sets [80] to successfully cope with data uncertainties.

The applications of fuzzy AHP (F-AHP) in different areas of decision making have been an important milestone in evaluating the weights for decision criteria in some applications due to the calculation process of fuzzified synthetic extent analysis. The selection of the design concept does not mean that no attention has been paid to the design concept. In essence, the application of F-AHP decision models in the design concept selection process needs to be examined to achieve an environmentally friendly product development design [81]. Fuzzy AHP depends on several steps [82].

Step 1: Build a hierarchical structure around classifications and specific criteria for green product design and development for eco industries (Figure 6). In this study, this was the process of decomposing the problem into a hierarchical tree. Twenty-two measures for GPDD were identified. These criteria have been divided into five categories. The figure displays the hierarchical structure.

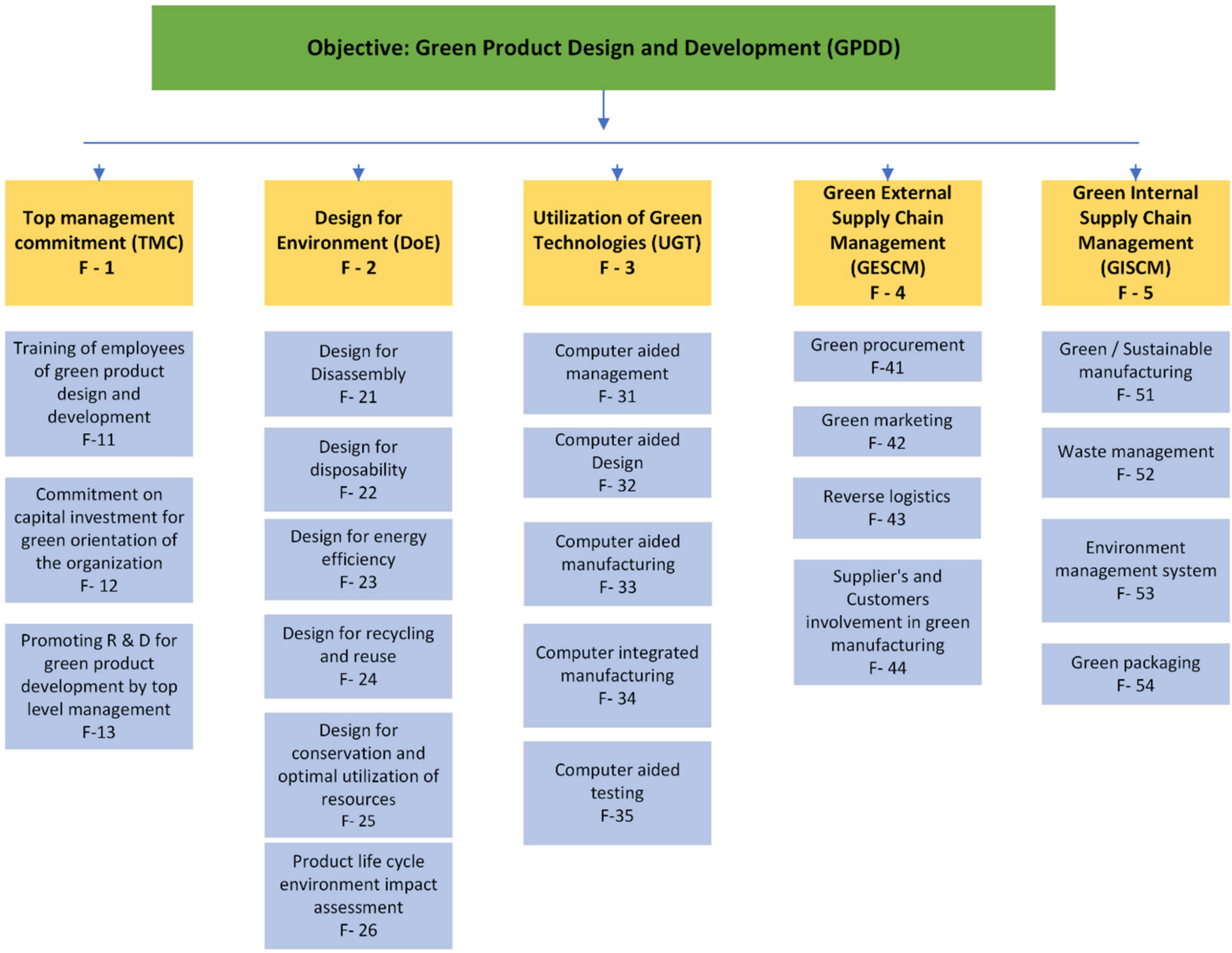


**Figure 6.** Hierarchical structure of primary and sub-factors used in the selection of GPDD.

Step 2: Construct a pair-wise comparison matrix based on the survey's nine-point Saaty scale of importance (see Table 9). The survey population includes experts and masters in that field of study. According to Saaty (1989), experts must be between 5 to 10 people; therefore, we conducted an AHP questionnaire with five experts by email and used Excel to evaluate the collected survey data. Two experts had an academic background and three were industry experts. The list of experts participating in the survey is shown in Appendix A in Table A1. The model of a fuzzy pair-wise contribution comparison matrix, with Õ representing the fuzzy relative importance of each pair element, is provided by (Buckley, 1985) [83].

$$\tilde{O} = \begin{bmatrix} \mathbf{1} & \tilde{o}_{21} & \cdots & \tilde{o}_{1n} \\ \tilde{o}_{12} & \mathbf{1} & \cdots & \tilde{o}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{o}_{m1} & \tilde{o}_{m2} & \cdots & \mathbf{1} \end{bmatrix} \quad (1)$$

**Table 9.** Saaty's scale of importance for pair-wise comparison matrices of fuzzy AHP.

| Fuzzy Crisp Number | Linguistic Variable | Trapezoidal Fuzzy Number (a, b, c, d) | Triangular Fuzzy Number (l, m, u) |
|---|---|---|---|
| **1˜** | Equal importance | (1, 1, 1, 1) | (1, 1, 1) |
| **3˜** | Moderate importance | (2, 2.5, 3.5, 4) | (2, 3, 4) |
| **5˜** | Essential or high importance | (4, 4.5, 5.5, 6) | (4, 5, 6) |
| **7˜** | Very high importance | (6, 6.5, 7.5, 8) | (6, 7, 8) |
| **9˜** | Extreme importance | (8, 8.5, 9, 9) | (9, 9, 9) |
| **2˜, 4˜, 6˜, 8˜** | Intermediate values between the two adjacent judgments | $x-1, x-\frac{1}{2}, x+\frac{1}{2}, x+1$ | (1, 2, 3), (3, 4, 5), (5, 6, 7), (7, 8, 9) |
| **Reciprocals of above $\tilde{O}^{-1}$ = 1/u; 1/m; 1/l (Triangular fuzzy number) $\tilde{O}^{-1}$ = 1/d; 1/c; 1/b;1/a (Triangular fuzzy number)** | | | |

Here, use the trapezoidal and triangular fuzzy membership function for fuzzy AHP analysis. A trapezoidal fuzzy number can be expressed as $\tilde{O}$ = (a, b, c, d); $\mu_{\tilde{O}}$ is the membership function õ.

$$\mu\, \tilde{o}\, (x) = \begin{cases} x - a/b - a,\ a \le x \le b \\ 1,\ b \le x \le c \\ d - x/d - c,\ c \le x \le d \end{cases} \quad (2)$$

A mean interval is defined as [b, c], while the lower and higher limits of õ are defined as a and b, respectively. When b = c, then õ is called a triangular fuzzy number, denoted by õ = (l, m, u), where m = b = c. As a result, a triangular fuzzy number is a particular fuzzy trapezoid number, or to put it another way, a triangular fuzzy number.

$$\mu\, \tilde{o}\, (x) = \begin{cases} x - l/m - l,\ l \le x \le m \\ u - x/u - m\ ,m \le x \le u \end{cases} \quad (3)$$

It is easy to see that the trapezoid fuzzy number õ is reduced to an actual number 'a', if a = b = c = d. Conversely, a natural number m can be created as a trapezoid fuzzy number õ = (m, m, m, m) [84].

Step 3: Develop a pair-wise comparison matrix. In this study, it was developed concerning the goals and criteria in each category based on the survey data collected. While studying the views of the experts, comparative judgments were combined by applying the geometric mean to the opinions to form the matrix of the relative assessment. We used Expert Choice and Excel to evaluate the collected survey data. According to Buckley (1985) [83], the geometric mean approach is used to compute the geometric mean of the fuzzy pair-wise judgment matrices as indicated in Equations (4) and (5), as well as to calculate fuzzy weights for each criterion and sub-criteria.

$$\widetilde{r}_i = (\tilde{o}_{i1} * \tilde{o}_{i2} * \tilde{o}_{i3} * \ldots\ldots.. * \tilde{o}_{in})^{1/n} \tag{4}$$

$$\widetilde{w}_i = (\widetilde{r}_1 * \widetilde{r}_2 * \widetilde{r}_3 * \ldots\ldots.. * \widetilde{r}_n)^{-1} \tag{5}$$

Step 4: De-fuzzify the fuzzy weights: As shown in Equation (6), the center of the area procedure is utilized to determine the optimum nonfuzzy performance. We consider both trapezoid and fuzzy triangular numbers throughout this research for the sake of simplicity and generality and calculate the de-fuzzified crisp value as following $P_i$ [85].

$$P_i = \begin{cases} a + 2b + 2c + d/6, & \text{trapezoid fuzzy number } \tilde{o} = (a,\ b,\ c,\ d) \\ l + m + u/3, & \text{triangular fuzzy number } \tilde{o} = (l,\ m,\ u) \end{cases} \tag{6}$$

Step 5. Normalize the nonfuzzy number $P_i$ using the following Equation (7):

$$N_i = \frac{P_i}{\sum_{i=1}^{n} P_i} \tag{7}$$

Step 6: Calculate the consistency. Determine the absolute or relative weights of the greatest Eigenvector. Then, using Equation (8), determine the consistency index (CI) value for each n-dimensional matrix. The consistency ratio (CR) can be determined using Equation (9) and the random consistency index (RI). The equations are given below:

$$CI = \frac{(\lambda_{max} - n)}{n - 1} \tag{8}$$

$$CR = \frac{CI}{RI} \tag{9}$$

Table 10 illustrates the value of R.I. for matrices ordered (N) 1-10, derived by approximating random indices using a sample size of 500, where the variance of R.I. values is dependent on the order of the matrix. If the consistency ratio (C.R.) value was less than 0.10, the calculation was accepted as the AHP model output; otherwise, due to the inconsistent AHP output, the subjective scores were readjusted [86].

**Table 10.** Random consistency index values.

| **n** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
|---|---|---|---|---|---|---|---|---|---|---|
| **RI** | 0 | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

The allowable consistency ratio (C.R.) range changes depending on the matrix size, e.g., 0.05 for a 3 × 3 matrix, 0.08 for a 4 × 4 matrix, and 0.1 for all larger matrices, $n \geq 5$. If the C.R. value is less than or equal to 5, it means that the matrix evaluation is appropriate or has a high level of consistency. However, if CR exceeds the allowable amount, the matrix has become inconsistent and the evaluation process should be evaluated, reconsidered, and improved.

#### 4.2.1. Results for Fuzzy AHP

In the prioritization of the factors, a comparative matrix of Table 11 was obtained by solving the AHP technique. The target matrix and the consistency ratio for the parameters were derived. The same procedure was presented for the sub-criteria factors to obtain the other priorities.

**Table 11.** Pair-wise comparison matrix for main factors in the selection of GPDD.

| Main Barriers | F-1 | F-2 | F-3 | F-4 | F-5 | Local Priority Weight | Rank |
|---|---|---|---|---|---|---|---|
| **F-1** | (1, 1, 1)<br>(1, 1, 1, 1) | (0.25, 0.33, 0.5)<br>0.25, 0.285, 0.4, 0.5) | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | (0.33, 0.5, 1)<br>(0.333, 0.4, 0.66, 1) | (0.25, 0.33, 0.5)<br>0.25, 0.285, 0.4, 0.5) | 0.117082208 | 5 |
| **F-2** | (2, 3, 4)<br>(2, 2.5, 3.5, 4) | (1, 1, 1)<br>(1, 1, 1, 1) | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | (3, 4, 5)<br>(3, 3.5, 4.5, 5) | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | 0.390125933 | 1 |
| **F-3** | (0.33, 0.5, 1)<br>(0.333, 0.4, 0.66, 1) | (0.33, 0.5, 1)<br>(0.333, 0.4, 0.66, 1) | (1, 1, 1)<br>(1, 1, 1, 1) | (1, 1, 1)<br>(1, 1, 1, 1) | (1, 1, 1)<br>(1, 1, 1, 1) | 0.142329624 | 4 |
| **F-4** | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | (0.2, 0.25, 0.33)<br>(0.2, 0.22, 0.28 0.33) | (1, 1, 1)<br>(1, 1, 1, 1) | (1, 1, 1)<br>(1, 1, 1, 1) | (1, 1, 1)<br>(1, 1, 1, 1) | 0.153694086 | 3 |
| **F-5** | (2, 3, 4)<br>(2, 2.5, 3.5, 4) | (0.33, 0.5, 1)<br>(0.333, 0.4, 0.66, 1) | (1, 1, 1)<br>(1, 1, 1, 1) | (1, 1, 1)<br>(1, 1, 1, 1) | (1, 1, 1)<br>(1, 1, 1, 1) | 0.19676815 | 2 |

Maximum Eigenvalue = 5.334567. Consistency Index (CI) = 0.08364.

It can be seen that the design for environment (F-2) main factor contribution is the highest, with a criteria weight of 0.3901 in the selection of green product design. According to the findings (see Figure 7), design for environment (F-2) has a significant impact on the growth of eco industries because it is a design approach for reducing the overall human health and environmental effects of a product, process, or service, with consequences considered throughout its life cycle [15]. Green internal supply chain management (F-5) ranked second highest and obtained a weight of 0.1967, followed by green external supply chain management (0.1536), utilization of green technologies (0.1423), and top management commitment (0.1170).

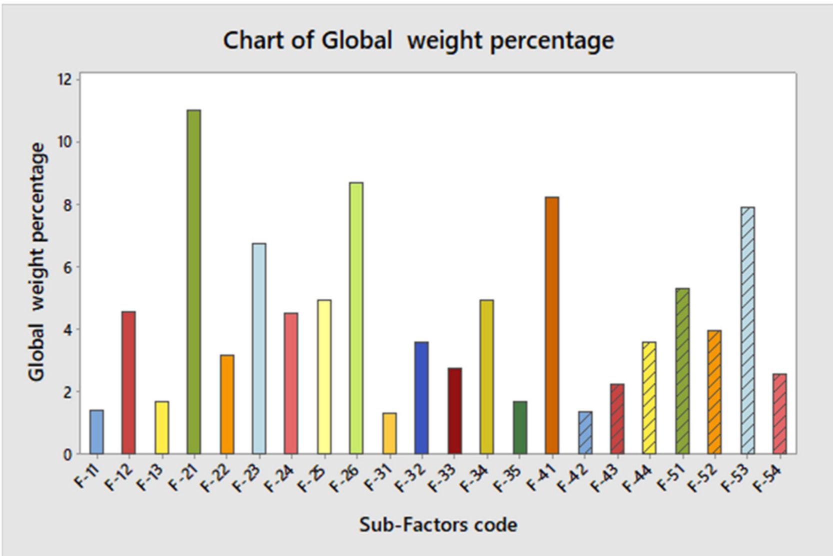


**Figure 7.** The final overall ranking and global weight criteria of sub-factors for selection of GPDD.

The final weights of the sub-factors were calculated by multiplying the local weight of each sub-factor by the main factor weight of its category. Table 12 shows the final global weights of the sub-barriers. Figure 7 shows the final overall ranking of these sub-barriers, which is obtained with the help of global weight. Tables A2–A6 of Appendix A show the pair-wise comparative matrices for sub-criteria factors. Such pair-wise matrices were eventually resolved to obtain the results described and discussed in the following section. The maximum Eigenvalue and consistency index of each matrix after the calculation is mentioned in the table. The ranking of sub-factors in the selection of GPDD is: (F-21) > (F-26) > (F-41) > (F-53) > (F-23) > > (F-51) > (F-34) > (F-25) > (F-12)> (F-24) > (F-52) > > (F-44) > (F-32) > (F-22) > (F-33) > (F-54) > (F-43) > (F-13) > (F-35) > (F-11) > (F-42) > (F-31). Design for disassembly got the highest ranking, with a weight percentage of 11.07% and a product life cycle environment impact assessment of 8.67%, placing second and followed by the remaining sub-factors.

**Table 12.** Final weights for main and sub-criteria factors for selection of green product design and development (GPDD).

| Main Factors | Sub-Factors | Sub-Factors Code | Main Criteria Weight | Local Criteria Weight | Global Criteria Weight | Final Weight Percentage | Rank |
|---|---|---|---|---|---|---|---|
| **Top management commitment (F-1)** | Training of employees of green product design and development | F-11 | 0.117082208 | 0.117082208 | 0.013708243 | 1.370824338 | **20** |
| | Commitment on capital investment for green orientation of the organization | F-12 | | 0.390125933 | 0.045676805 | 4.567680546 | **9** |
| | Promoting R&D for green product development by top-level management | F-13 | | 0.142329624 | 0.016664267 | 1.666426658 | **18** |
| **Design for Environment (F-2)** | Design for disassembly | F-21 | 0.390125933 | 0.282400175 | 0.110171632 | 11.01716318 | **1** |
| | Design for disposability | F-22 | | 0.080969928 | 0.031588469 | 3.158846871 | **14** |
| | Design for energy efficiency | F-23 | | 0.172381962 | 0.067250674 | 6.725067376 | **5** |
| | Design for recycling and reuse | F-24 | | 0.115360486 | 0.045005117 | 4.500511724 | **10** |
| | Design for conservation and optimal utilization of resources | F-25 | | 0.126559993 | 0.049374335 | 4.937433535 | **8** |
| | Product life cycle environmental impact assessment | F-26 | | 0.222327455 | 0.086735706 | 8.673570582 | **2** |
| **Utilization of Green Technologies (F-3)** | Computer aided management | F-31 | 0.142329624 | 0.091529591 | 0.013027372 | 1.302737225 | **22** |
| | Computer-aided Design | F-32 | | 0.252557568 | 0.035946424 | 3.594642363 | **13** |
| | Computer-aided manufacturing | F-33 | | 0.192285855 | 0.027367973 | 2.73679734 | **15** |
| | Computer integrated manufacturing | F-34 | | 0.347130078 | 0.049406893 | 4.94068934 | **7** |
| | Computer-aided testing | F-35 | | 0.116496909 | 0.016580961 | 1.658096123 | **19** |
| **Green External Supply Chain Management (F-4)** | Green procurement | F-41 | 0.153694086 | 0.534012424 | 0.082074551 | 8.207455149 | **3** |
| | Green marketing | F-42 | | 0.087883637 | 0.013507195 | 1.350719527 | **21** |
| | Reverse logistics | F-43 | | 0.144059242 | 0.022141054 | 2.214105355 | **17** |
| | Supplier's involvement in green manufacturing | F-44 | | 0.234044698 | 0.035971286 | 3.597128597 | **12** |
| **Green internal supply chain management (F-5)** | Green/sustainable manufacturing | F-51 | 0.19676815 | 0.269955573 | 0.053118659 | 5.311865856 | **6** |
| | Waste management | F-52 | | 0.199693424 | 0.039293306 | 3.929330552 | **11** |
| | Environment management system | F-53 | | 0.401349126 | 0.078972725 | 7.897272484 | **4** |
| | Green packaging | F-54 | | 0.129001877 | 0.025383461 | 2.538346062 | **16** |

#### 4.2.2. Sensitivity Analysis

The produced data vary in "multi-criteria decision-making" approaches and are typically erroneous. Hence, sensitivity analysis is involved in model testing. By changing the model variable, sensitivity analysis aids in determining the extent of a variable's influence on the overall model output [87]. Sensitivity analysis is typically carried out when there is a risk that one or more parameters may be unclear. It aids in figuring out how little a change in the current weights of the criteria can affect where the alternatives are currently positioned. This strategy involves changing one variable at a time, but it can be expanded to include many variables [88].

Since the weights of the variables were based on the expert's subjective evaluation during this analysis, the fuzzy AHP method's results demand sensitivity analysis. The "Design for Environment (F-2)" factor indicates tremendous significance, exhibits the most significant dimension weight, and is ranked first. The local and global priority weights of the GPDD sub-factors are displayed in Table 12. As a result, "Design for Environment (F-2)" changes the overall weight for other levels and ranges from 0.1 to 0.6 in steps of 0.1 (see Table 13). Table 14 demonstrates the ranking of all sub-factors changing the "Design for Environment (F-2)" values from 0.1 to 0.6.

**Table 13.** Priority values of sub-factors after varying the "Design for Environment (F-2)" dimension.

| Sub-Factors Code | Priority Values in a Sensitivity Analysis by Changing "Design for Environment (F-2)" Dimension Values from 0.1 to 0.6 | | | | | | |
|---|---|---|---|---|---|---|---|
| | Normal (0.3901) | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 |
| F-11 | **0.01370824** | 0.02022945 | 0.01798174 | 0.01573402 | 0.01348639 | 0.01123868 | 0.01123868 |
| F-12 | **0.04567681** | 0.06740593 | 0.05991638 | 0.05242683 | 0.04493759 | 0.03744804 | 0.03744804 |
| F-13 | **0.01666427** | 0.02459170 | 0.02185929 | 0.01912688 | 0.01639458 | 0.01366217 | 0.01366217 |
| F-21 | **0.11017163** | 0.02824002 | 0.05648004 | 0.08472005 | 0.11296007 | 0.14120009 | 0.16944011 |
| F-22 | **0.03158847** | 0.00809699 | 0.01619399 | 0.02429098 | 0.03238797 | 0.04048496 | 0.04858196 |
| F-23 | **0.06725067** | 0.01723820 | 0.03447639 | 0.05171459 | 0.06895278 | 0.08619098 | 0.10342918 |
| F-24 | **0.04500512** | 0.01153605 | 0.02307210 | 0.03460815 | 0.04614419 | 0.05768024 | 0.06921629 |
| F-25 | **0.04937434** | 0.01265600 | 0.02531200 | 0.03796800 | 0.05062400 | 0.06328000 | 0.07593600 |
| F-26 | **0.08673571** | 0.02223275 | 0.04446549 | 0.06669824 | 0.08893098 | 0.11116373 | 0.13339647 |
| F-31 | **0.01302737** | 0.01922468 | 0.01708861 | 0.01495253 | 0.01281654 | 0.01068047 | 0.01068047 |
| F-32 | **0.03594642** | 0.05304666 | 0.04715259 | 0.04125852 | 0.03536468 | 0.02947061 | 0.02947061 |
| F-33 | **0.02736797** | 0.04038732 | 0.03589984 | 0.03141236 | 0.02692506 | 0.02243758 | 0.02243758 |
| F-34 | **0.04940689** | 0.07291047 | 0.06480931 | 0.05670815 | 0.04860731 | 0.04050615 | 0.04050615 |
| F-35 | **0.01658096** | 0.02446877 | 0.02175001 | 0.01903126 | 0.01631262 | 0.01359387 | 0.01359387 |
| F-41 | **0.08207455** | 0.12111861 | 0.10766099 | 0.09420337 | 0.08074628 | 0.06728866 | 0.06728866 |
| F-42 | **0.01350720** | 0.01993277 | 0.01771801 | 0.01550326 | 0.01328860 | 0.01107385 | 0.01107385 |
| F-43 | **0.02214105** | 0.03267388 | 0.02904345 | 0.02541302 | 0.02178273 | 0.01815230 | 0.01815230 |
| F-44 | **0.03597129** | 0.05308335 | 0.04718520 | 0.04128705 | 0.03538914 | 0.02949099 | 0.02949099 |
| F-51 | **0.05311866** | 0.07838798 | 0.06967821 | 0.06096843 | 0.05225900 | 0.04354923 | 0.04354923 |
| F-52 | **0.03929331** | 0.05798570 | 0.05154285 | 0.04509999 | 0.03865740 | 0.03221454 | 0.03221454 |
| F-53 | **0.07897273** | 0.11654120 | 0.10359218 | 0.09064316 | 0.07769466 | 0.06474564 | 0.06474564 |
| F-54 | **0.02538346** | 0.03745874 | 0.03329666 | 0.02913458 | 0.02497266 | 0.02081058 | 0.02081058 |

**Table 14.** Ranking of sub-factors after varying "Design for Environment (F-2)" values.

| Sub-Factors Code | Ranking of Sub-Factors Changing the "Design for Environment (F-2)" Values from 0.1 to 0.6 in the Sensitivity Analysis | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Normal (0.3901)** | **0.1** | **0.2** | **0.3** | **0.4** | **0.5** | **0.6** |
| **F-11** | **20** | 16 | 19 | 20 | 20 | 20 | 20 |
| **F-12** | **9** | 5 | 5 | 7 | 10 | 11 | 11 |
| **F-13** | **18** | 13 | 17 | 18 | 18 | 18 | 18 |
| **F-21** | **1** | 12 | 6 | 3 | 1 | 1 | 1 |
| **F-22** | **14** | 22 | 22 | 17 | 14 | 10 | 8 |
| **F-23** | **5** | 19 | 12 | 8 | 5 | 3 | 3 |
| **F-24** | **10** | 21 | 16 | 13 | 9 | 7 | 5 |
| **F-25** | **8** | 20 | 15 | 12 | 7 | 6 | 4 |
| **F-26** | **2** | 15 | 10 | 4 | 2 | 2 | 2 |
| **F-31** | **22** | 18 | 21 | 22 | 22 | 22 | 22 |
| **F-32** | **13** | 8 | 9 | 11 | 13 | 14 | 14 |
| **F-33** | **15** | 9 | 11 | 14 | 15 | 15 | 15 |
| **F-34** | **7** | 4 | 4 | 6 | 8 | 9 | 10 |
| **F-35** | **19** | 14 | 18 | 19 | 19 | 19 | 19 |
| **F-41** | **3** | 1 | 1 | 1 | 3 | 4 | 6 |
| **F-42** | **21** | 17 | 20 | 21 | 21 | 21 | 21 |
| **F-43** | **17** | 11 | 14 | 16 | 17 | 17 | 17 |
| **F-44** | **12** | 7 | 8 | 10 | 12 | 13 | 13 |
| **F-51** | **6** | 3 | 3 | 5 | 6 | 8 | 9 |
| **F-52** | **11** | 6 | 7 | 9 | 11 | 12 | 12 |
| **F-53** | **4** | 2 | 2 | 2 | 4 | 5 | 7 |
| **F-54** | **16** | 10 | 13 | 15 | 16 | 16 | 16 |

It is well-known that the local weights of each sub-barrier were multiplied by the local weight of the main barrier in each group to determine the global weights of the sub-factors. Global priority changes when "Design for Environment (F-2)" is changed during sensitivity analysis from 0.1 to 0.6. Table 13 displays the overall priority of all sub-factors changing as a result. The typical values of "Design for Environment (F-2)," which fall between 0.3 and 0.4, show the original priority values. Effects of the sensitivity analysis aid in validating how each sub-factor is ranked (See Table 14). The outcomes of the sensitivity analysis are shown in Figure 8. According to analysis, "Green marketing" tops the list and achieves the top rank after changing the value of the design for environment (F-2) factor from 0.3901 to 0.1. This invites modifications to the priority and weighting of other parameters, attaining a minimal priority weight of 0.2 and 0.3 for "design for disassembly". The factor "Design for disassembly" therefore receives the highest priority weight and is given the top rank, ranging from 0.4 to 0.6. As a result, sensitivity analysis aids in validating the outcomes of the AHP technique of analysis. The ranking of the enablers that advance the development of GPDD is dominated by "Design for Environment (F-2)," according to both AHP and sensitivity analysis.

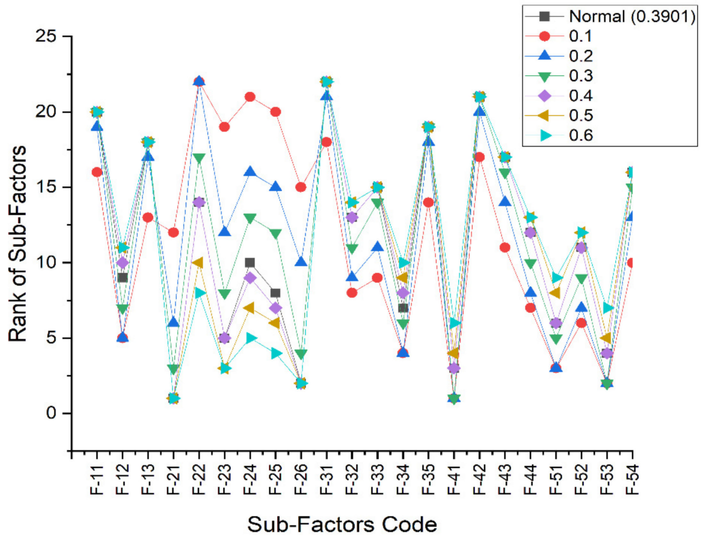


**Figure 8.** Sensitivity analysis.

## 5. Conclusions

The evolution of industry trend is changing from time to time, and now a day, advance in eco-production is at a rapid speed. Green product design and development (GPDD) is quickly gaining traction as a viable manufacturing solution to the world's most pressing issues. However, to meet this goal, various strategies for eco industries would have to be addressed to improve green production. The study focuses on enhancing user satisfaction for green production applications by classifying the multiple processes and categorizing them in hierarchical order based on their importance. According to the findings, "DFE(F-2)" received the most weight, followed by "GESCM," "GISCM, "UGT," and finally, "TMC." According to the ranking of sub-factors, design for disassembly has been identified as one of the essential sub-criteria and Attractive requirements in the rising green sectors. The F-AHP model is most suited to this unique goal, given the multiple scenarios and factors of sustainability. Based on the findings of AHP, it is recommended that a significant authority be established to control and promote GPDD by making it easier to obtain approvals and develop new policies or update existing ones.

The main managerial implication of this study is the suggestion of a practical and transparent approach for identifying and ordering the various strategies for GPDD. In addition, analysis results can provide some helpful hints on developing user and industrial person-oriented green production applications. To improve user satisfaction, GPDD application developers must first ensure the Performance requirements. Once the Performance requirements have been fulfilled, application developers should focus on providing Attractive needs. If additional resources are available, then it is advisable to consider the presence of Indifferent requirements. However, according to the Kano model, Indifference means these attributes refer to neither good nor bad aspects. They do not result in either user satisfaction or user dissatisfaction, like computer-aided management. It might be essential to manage the whole plant efficiently, but users are unaware of the distinction. We think the service requirements under Indifference could be either Performance or Attractive in the future study. However, the results show that "Promoting R&D for green product development by top-level management," "Design for recycling and reuse," "Computer-aided manufacturing," and "Waste management" were preferred as Must Be requirements. The above-mentioned practical implication could be helpful to the GPDD application developers in eco industries.

This paper provides an enormous research contribution to the field of GPDD. The main research implication of this study is the proposal of a simple research approach. Using the Kano model and fuzzy AHP as the methodology will provide beneficial literature and guidance for future studies. The participants in the focus group study revealed service requirements in the GPDD applications. This research offers meaningful managerial implications in classifying and evaluating service requirements in GPDD. We were able to organize and categorize 22 service requirements with the help of the Kano model. Finally, AHP helped us rank these classified service requirements in priority order. The special thing about AHP is that we conducted the test with experts in eco production. Therefore, this study brings uniqueness to make it an academic contribution. It provides numerous decision makers, politicians, and stakeholders with an analytical and theoretical framework to help them better comprehend the constraints to GPDD growth. The research and academic implications of this research can provide the literature and some of the directions for future research.

## 6. Limitations and Further Study

The Kano model has been critiqued for various reasons, even though it aids in exploring non-linear dimensions of service quality and user satisfaction. The Kano model's questionnaire structure is the first barrier researchers face when applying it. [89] stated that collecting the Kano questionnaire's functional and dysfunctional sets is time-consuming and inconvenient. Second, the Kano model has been chastised for its subjective evaluation of Kano's qualities. According to previous studies, it is unable to quantify consumer satisfaction levels. Different MCDM methods were integrated with Kano analysis to obtain and compare these results with other studies.

Although this research may provide benefits and new business opportunities for green production, it poses several challenges and constraints. For example, application developers should include a diverse range of services, which may be a barrier to implementation. The sample size is one of the study's significant weaknesses; if the sample size had been more extensive and diverse, the outcome might have been different. Nonetheless, the 22-criteria sample might be expanded to include and study the specificities of various market situations. As a result, other issues should be addressed in future studies.

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## Abbreviations

| | |
|---|---|
| GPDD | green product design and development |
| DFE | design for environment |
| TMC | top management commitment |
| UGT | utilization of green technologies |
| GESCM | green external supply chain management |
| GISCM | green internal supply chain management |
| F-AHP | fuzzy-analytical hierarchy process |

## Appendix A

**Table A1.** Sample demographics for survey.

| Category | Position of Expert | Age | Qualification | Frequency of Response for Kano Model |
|---|---|---|---|---|
| **Academic Expert** | Professor | 50–60 | Ph.D. | 6 |
| | Associate Professor | 42–48 | Ph.D. | 10 |
| | PhD student or researcher | 28–38 | Post-Graduate | 15 |
| **Industrial Expert** | Deputy and Executive Director | 40–45 | MBA | 3 |
| | R&D Officer | 35–45 | Ph.D. | 2 |
| | Quality Officer | 35–45 | Graduate | 10 |
| | Manufacturing technician | 25–40 | Diploma | 15 |
| | Supply chain analyst | 25–40 | Graduate | 9 |
| | Manufacturing production supervisor | 25–40 | Graduate | 20 |
| | Occupational health and safety manager | 35–45 | Graduate | 6 |

**Table A2.** Pair-wise comparison matrix for sub-factors of F-1 in the selection of GPDD.

| Sub Factors | F-11 | F-12 | F-13 | Local Criteria Weight | Rank |
|---|---|---|---|---|---|
| **F-11** | (1, 1, 1)<br>(1, 1, 1, 1) | (2, 3, 4)<br>(2, 2.5, 3.5, 4) | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | 0.117082208 | 1 |
| **F-12** | (0.25, 0.33, 0.5)<br>0.25, 0.285, 0.4, 0.5) | (1, 1, 1)<br>(1, 1, 1, 1) | (0.33, 0.5, 1)<br>(0.333, 0.4, 0.66, 1) | 0.390125933 | 3 |
| **F-13** | (0.33, 0.5, 1)<br>(0.333, 0.4, 0.66, 1) | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | (1, 1, 1)<br>(1, 1, 1, 1) | 0.142329624 | 2 |

Maximum Eigenvalue = 3.00920. Consistency Index (CI) = 0.00460.

**Table A3.** Pair-wise comparison matrix for sub-factors of F-2 in selection of GPDD.

| Sub-Factors | F-21 | F-22 | F-23 | F-24 | F-25 | F-26 | Local Criteria Weight | Rank |
|---|---|---|---|---|---|---|---|---|
| **F-21** | (1, 1, 1)<br>(1, 1, 1, 1) | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | (2, 3, 4)<br>(2, 2.5, 3.5, 4) | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | 0.282400175 | 1 |
| **F-22** | (0.33, 0.5, 1)<br>(0.333, 0.4, 0.66, 1) | (1, 1, 1)<br>(1, 1, 1, 1) | (0.33, 0.5, 1)<br>(0.333, 0.4, 0.66, 1) | (0.25, 0.33, 0.5)<br>0.25, 0.285, 0.4, 0.5) | (0.33, 0.5, 1)<br>(0.333, 0.4, 0.66, 1) | (0.25, 0.33, 0.5)<br>0.25, 0.285, 0.4, 0.5) | 0.080969928 | 6 |
| **F-23** | (0.25, 0.33, 0.5)<br>0.25, 0.285, 0.4, 0.5) | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | (1, 1, 1)<br>(1, 1, 1, 1) | (2, 3, 4)<br>(2, 2.5, 3.5, 4) | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | (0.33, 0.5, 1)<br>(0.333, 0.4, 0.66, 1) | 0.172381962 | 3 |
| **F-24** | (0.33, 0.5, 1)<br>(0.333, 0.4, 0.66, 1) | (2, 3, 4)<br>(2, 2.5, 3.5, 4) | (0.25, 0.33, 0.5)<br>0.25, 0.285, 0.4, 0.5) | (1, 1, 1)<br>(1, 1, 1, 1) | (0.33, 0.5, 1)<br>(0.333, 0.4, 0.66, 1) | (0.33, 0.5, 1)<br>(0.333, 0.4, 0.66, 1) | 0.115360486 | 5 |
| **F-25** | (0.33, 0.5, 1)<br>(0.333, 0.4, 0.66, 1) | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | (0.25, 0.33, 0.5)<br>0.25, 0.285, 0.4, 0.5) | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | (1, 1, 1)<br>(1, 1, 1, 1) | (0.25, 0.33, 0.5)<br>0.25, 0.285, 0.4, 0.5) | 0.126559993 | 4 |
| **F-26** | (0.33, 0.5, 1)<br>(0.333, 0.4, 0.66, 1) | (2, 3, 4)<br>(2, 2.5, 3.5, 4) | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | (2, 3, 4)<br>(2, 2.5, 3.5, 4) | (1, 1, 1)<br>(1, 1, 1, 1) | 0.222327455 | 2 |

Maximum Eigenvalue = 6.46826. Consistency Index (CI) = 0.09365.

**Table A4.** Pair-wise comparison matrix for sub-factors of F-3 in the selection of GPDD.

| Sub-Factors | F-31 | F-32 | F-33 | F-34 | F-35 | Local Criteria Weight | Rank |
|---|---|---|---|---|---|---|---|
| **F-31** | (1, 1, 1)<br>(1, 1, 1, 1) | (0.33, 0.5, 1)<br>(0.333, 0.4, 0.66, 1) | (0.25, 0.33, 0.5)<br>0.25, 0.285, 0.4, 0.5) | (0.25, 0.33, 0.5)<br>0.25, 0.285, 0.4, 0.5) | (0.33, 0.5, 1)<br>(0.333,0.4, 0.66, 1) | 0.091529591 | 5 |
| **F-32** | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | (1, 1, 1)<br>(1, 1, 1, 1) | (2, 3, 4)<br>(2, 2.5, 3.5, 4) | (0.33, 0.5, 1)<br>(0.333, 0.4, 0.66, 1) | (1,2,3)<br>(1, 1.5, 2.5, 3) | 0.252557568 | 2 |
| **F-33** | (2, 3, 4)<br>(2, 2.5, 3.5, 4) | (0.25, 0.33, 0.5)<br>0.25, 0.285, 0.4, 0.5) | (1, 1, 1)<br>(1, 1, 1, 1) | (0.33, 0.5, 1)<br>(0.333, 0.4, 0.66, 1) | (2,3, 4)<br>(2, 2.5, 3.5, 4) | 0.192285855 | 3 |
| **F-34** | (2, 3, 4)<br>(2, 2.5, 3.5, 4) | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | (1, 1, 1)<br>(1, 1, 1, 1) | (2,3, 4)<br>(2, 2.5, 3.5, 4) | 0.347130078 | 1 |
| **F-35** | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | (0.33, 0.5, 1)<br>(0.333, 0.4, 0.66, 1) | (0.25, 0.33, 0.5)<br>0.25, 0.285, 0.4, 0.5) | (0.25, 0.33, 0.5)<br>0.25, 0.285, 0.4, 0.5) | (1,1,1)<br>(1,1,1,1) | 0.116496909 | 4 |

Maximum Eigenvalue = 5.34913. Consistency Index (CI) = 008728.

**Table A5.** Pair-wise comparison matrix for sub-factors of F-4 in the selection of GPDD.

| Sub-Factors | F-41 | F-42 | F-43 | F-44 | Local Criteria Weight | Rank |
|---|---|---|---|---|---|---|
| **F-41** | (1, 1, 1)<br>(1, 1, 1, 1) | (4, 5, 6)<br>(4, 4.5, 5.5, 6) | (3, 4, 5)<br>(3, 3.5, 4.5, 5) | (2, 3, 4)<br>(2, 2.5, 3.5, 4) | 0.534012424 | 1 |
| **F-42** | (0.166, 0.2, 0.25)<br>0.166, 0.181, 0.22.0.25) | (1, 1, 1)<br>(1, 1, 1, 1) | (0.33, 0.5, 1)<br>(0.333, 0.4, 0.66, 1) | (0.25, 0.33, 0.5)<br>0.25, 0.285, 0.4, 0.5) | 0.087883637 | 4 |
| **F-43** | (0.2, 0.25, 0.33)<br>(0.2, 0.22, 0.28, 0.33) | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | (1, 1, 1)<br>(1, 1, 1, 1) | (0.33, 0.5, 1)<br>(0.333, 0.4, 0.66, 1) | 0.144059242 | 3 |
| **F-44** | (0.25, 0.33, 0.5)<br>0.25, 0.285, 0.4, 0.5) | (2, 3, 4)<br>(2, 2.5, 3.5, 4) | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | (1, 1, 1)<br>(1, 1, 1, 1) | 0.234044698 | 2 |

Maximum Eigenvalue = 4.05123. Consistency Index (CI) = 0.01707.

**Table A6.** Pair-wise comparison matrix for sub-factors of F-5 in the selection of GPDD.

| Sub-Factors | F-51 | F-52 | F-53 | F-54 | Local Criteria Weight | Rank |
|---|---|---|---|---|---|---|
| **F-51** | (1, 1, 1)<br>(1, 1, 1, 1) | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | (0.33, 0.5, 1)<br>(0.333, 0.4, 0.66, 1) | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | 0.269955573 | 2 |
| **F-52** | (0.33, 0.5, 1)<br>(0.333, 0.4, 0.66, 1) | (1, 1, 1)<br>(1, 1, 1, 1) | (0.33, 0.5, 1)<br>(0.333, 0.4, 0.66, 1) | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | 0.199693424 | 3 |
| **F-53** | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | (1, 2, 3)<br>(1, 1.5, 2.5, 3) | (1, 1, 1)<br>(1, 1, 1, 1) | (2, 3, 4)<br>(2, 2.5, 3.5, 4) | 0.401349126 | 1 |
| **F-54** | (0.33, 0.5, 1)<br>(0.333, 0.4, 0.66, 1) | (0.33, 0.5, 1)<br>(0.333, 0.4, 0.66, 1) | (0.25, 0.33, 0.5)<br>0.25, 0.285, 0.4, 0.5) | (1, 1, 1)<br>(1, 1, 1, 1) | 0.129001877 | 4 |

Maximum Eigenvalue = 4.07121. Consistency Index (CI) = 0.02373.

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