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A Green Transformation: Designing Sustainable Innovation Indicators in the Home Appliance Industry

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A B S T R A C T

Objective: The aim of this study is to explore green research and development (R&D) in the home appliance industry.

Methods and Materials: This research is applied in nature, and the data collection method is descriptive-survey. Initially, by reviewing the literature and using qualitative content analysis, 30 factors were extracted as indicators for green development and formulation, categorized into five dimensions: green management, product and stakeholder performance, internal environment management, green innovation, and energy and resource consumption management. In the second stage, the fuzzy Delphi technique was employed, with a two-stage survey conducted among 15 experts selected through purposive sampling to achieve group consensus and filter the findings from the first stage. Finally, to assess the opinions of employees in the home appliance industry regarding green R&D indicators, a questionnaire was distributed among 170 employees, selected through Cochran's formula and simple random sampling. The results were analyzed using SPSS software and a one-sample t-test.

Findings: The findings showed that all these indicators were significantly identified as green R&D indicators in the home appliance industry at a 95% confidence level. Based on the results, the product design improvement indicator, with an average score of (4.18), received the highest rating from employees. This was followed by access to new markets and customers with an average score of (4.14), a green image of the company with an average score of (4.11), green product innovation with an average score of (4.10), and enhancing the company's green position with an average score of (4.02), respectively.

Conclusion: The findings highlight the significance of improving product design, accessing new markets, and promoting a green company image as crucial factors for achieving sustainable development.

Keywords: *green research and development, home appliance industry, green management, green innovation.*

1 Introduction

In recent decades, global concerns about climate change and the environmental impacts of human activities have increased. The home appliance industry, due to its high energy consumption and significant waste production, is one of the major sectors exacerbating these problems. As population growth and technological advancements continue, the demand for home appliances steadily rises, putting more pressure on natural resources and the environment (Kim et al., 2022). Green research and development (R&D) has emerged as a key strategy for reducing environmental impacts and improving resource efficiency. However, several challenges hinder the implementation and utilization of green R&D in the home appliance industry. These challenges include the need for high initial investments, uncertainty regarding returns on investment, and resistance to technological and process changes (Govindan, 2024; Hernawati, 2024; Malek, 2024).

Given the mass production and consumption of home appliances, this industry significantly contributes to greenhouse gas emissions and electronic waste. Green R&D can help mitigate these effects by designing energy-efficient products and using recyclable materials (Martinez et al., 2019). Additionally, home appliances are among the largest energy consumers in the domestic sector. The development of new technologies can enhance energy efficiency and reduce energy costs for consumers, which is beneficial not only for the environment but also economically advantageous for consumers (Shahabadi et al., 2023). Moreover, in today's competitive market, companies that invest in green R&D can gain a long-term competitive advantage. These companies can attract new customers and retain existing ones by offering innovative and environmentally friendly products. Finally, governments and international organizations are increasingly enforcing stricter environmental protection regulations. Companies that invest in green R&D can easily comply with these regulations and avoid fines and legal restrictions (Jones et al., 2008).

Furthermore, the complexity of relationships between various environmental, economic, and technological factors requires comprehensive and systematic approaches for identifying and prioritizing these factors. Traditional analytical methods may not be capable of addressing this complexity and might fail to comprehensively cover all aspects of green R&D (Jones et al., 2008; Kanwar & Evenson, 2003; Martinez et al., 2019; Mehrgan & Soltani Sahat, 2014; Murat Ar, 2012; Noailly et al., 2022; Sang-Ho et al., 2015; Shahabadi et al., 2023; Singjai et al., 2019). Therefore, the use of combined methods such as fuzzy Delphi and surveys can help more accurately identify and evaluate the factors influencing green R&D in the home appliance industry. The fuzzy Delphi method, by utilizing expert opinions and converting them into fuzzy data, effectively reflects uncertainties and fluctuations in opinions. This study seeks to answer the question of how green R&D can help reduce environmental impacts and increase energy efficiency in the home appliance industry, and what factors play a key role in this process. Therefore, a comprehensive and systematic review of this subject using advanced and combined methods can lead to the development of effective and efficient strategies for sustainable development in the home appliance industry.

2 Methods and Materials

In terms of purpose, this research falls into the category of applied research. The information collection method involved both library research and a questionnaire. Since the research aims to present a model and explore rather than test hypotheses, no hypothesis was formulated. This study began by identifying the dimensions of green R&D through a literature review. These dimensions were then evaluated with the help of 15 industry specialists. The main dimensions were extracted based on their scores. A questionnaire was subsequently developed from these indicators and distributed to employees in the home appliance industry. The employees' opinions on these dimensions were collected and analyzed using SPSS software to calculate the mean and standard deviation of the desirability of the dimensions.

3 Findings and Results

After data collection and conducting preliminary studies, a set of relevant indicators was extracted based on the literature in the home appliance industry and management domains. After removing duplicates, 25 sub-indicators were identified as relevant to the research topic.

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Table 1

Identified Green R&D Indicators

Main Indicator	Sub-Indicators
Internal Environment Management	Manager's commitment to implementing green actions
	Hiring efficient and competent human resources
	Obtaining ISO certification
	Green social responsibility
	Developing a green culture in the organization
Energy and Resource Management	Reducing energy consumption (water, electricity, etc.)
	Purchasing eco-friendly raw materials
	Purchasing equipment and machinery for clean production
	Purchasing recyclable materials
	Reducing resource wastage within the organization
	Reducing waste production
Green Management	Creating a green image of the company
	Enhancing the company's green status
	Green marketing
	Receiving consumer feedback
	Consumer support
	Access to new markets and customers
Product and Stakeholder Performance	Improving product design
	Enhancing employee motivation
	Interaction with stakeholders
	Customer satisfaction
Green Innovation	Green managerial innovation
	Green product innovation
	Green process innovation
	Green technological innovation

In the first step of fuzzy calculations, qualitative variables were converted into fuzzy quantitative values, and the fuzzy average for each criterion was determined separately. Table 2 was used to fuzzify the verbal variables:

Table 2

Conversion of Linguistic Variables to Triangular Fuzzy Numbers (in percentages)

Linguistic Terms	Triangular Fuzzy Numbers (in percentages)
Very Low	(0, 0, 25)
Low	(0, 25, 50)
Medium	(25, 50, 75)
High	(50, 75, 100)
Very High	(75, 100, 100)

Table 3 shows the aggregation of expert opinions for each criterion:

Table 3

Aggregation of Expert Opinions (First Round)

Indicator	Very Low	Low	Medium	High	Very High
Manager's commitment to green actions	0	0	1	2	12
Hiring efficient human resources	0	0	0	5	10
Obtaining ISO certification	0	0	1	3	11
Green social responsibility	0	0	1	3	11
Developing a green culture	0	0	1	4	10
Reducing energy consumption	0	0	0	4	11
Purchasing eco-friendly raw materials	0	0	1	3	11

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Purchasing clean production equipment	0	0	1	3	11
Purchasing recyclable materials	0	0	1	3	11
Reducing resource wastage	0	0	0	5	10
Reducing waste production	0	0	0	5	10
Creating a green image of the company	0	0	1	2	12
Enhancing the company's green status	0	0	3	5	7
Green marketing	0	0	0	5	10
Receiving consumer feedback	0	1	2	12	1
Consumer support	0	0	1	3	11
Access to new markets and customers	0	0	0	5	10
Improving product design	0	0	1	4	10
Enhancing employee motivation	0	0	1	4	10
Interaction with stakeholders	0	0	0	5	10
Customer satisfaction	0	0	1	3	11
Green managerial innovation	0	0	0	5	10
Green product innovation	0	0	1	2	12
Green process innovation	0	0	1	3	11
Green technological innovation	0	0	1	3	11

Fuzzy Value Calculation for Each Question: After collecting expert opinions, the fuzzy value of each question was calculated.

Defuzzification of Each Question: After determining the number of responses for each factor and calculating the triangular fuzzy average for the factors, the Minkowski formula was used to calculate the defuzzified numbers for each component.

Table 4

Fuzzy Average and Defuzzification of Each Criterion

No.	Indicator	B	α	m	Defuzzification
1	Manager's commitment to green actions	0.983	0.933	0.683	0.696
2	Hiring efficient human resources	0.983	0.917	0.667	0.683
3	Obtaining ISO certification	0.983	0.917	0.667	0.683
4	Green social responsibility	0.983	0.917	0.667	0.683
5	Developing a green culture	0.983	0.933	0.683	0.696
6	Reducing energy consumption	0.983	0.917	0.667	0.683
7	Purchasing eco-friendly raw materials	0.983	0.917	0.667	0.683
8	Purchasing clean production equipment	0.983	0.917	0.667	0.683
9	Purchasing recyclable materials	0.983	0.917	0.667	0.683
10	Reducing resource wastage	0.983	0.917	0.667	0.683
11	Reducing waste production	0.983	0.917	0.667	0.683
12	Creating a green image of the company	0.983	0.933	0.683	0.696
13	Enhancing the company's green status	1.000	0.917	0.667	0.688
14	Green marketing	0.983	0.917	0.667	0.683
15	Receiving consumer feedback	0.983	0.917	0.667	0.683
16	Consumer support	0.983	0.917	0.667	0.683
17	Access to new markets and customers	0.983	0.917	0.667	0.683
18	Improving product design	0.983	0.933	0.683	0.696
19	Enhancing employee motivation	0.983	0.917	0.667	0.683
20	Interaction with stakeholders	1.000	0.917	0.667	0.688
21	Customer satisfaction	0.983	0.917	0.667	0.683
22	Green managerial innovation	1.000	0.917	0.667	0.688
23	Green product innovation	0.983	0.917	0.667	0.683
24	Green process innovation	0.983	0.917	0.667	0.683
25	Green technological innovation	0.983	0.917	0.667	0.683

After calculating the defuzzified value of each question (indicator), the importance of each was evaluated. A threshold (r) was used for this evaluation. Two conditions arise based on the threshold value:

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- If the defuzzified value of an indicator is less than or equal to the threshold, it indicates that the question (indicator) is of high importance.
- If the defuzzified value is greater than the threshold, it indicates that the question (indicator) is of low importance, and due to its low significance, it can be removed.

Various methods have been mentioned for calculating the threshold. In this study, the average defuzzified value of each question was calculated and used as the threshold. A value of 0.682 was set as the threshold, and values above it were considered significant criteria, while values below it were deemed insignificant and removed from the questionnaire. In this study, indicators with a defuzzified average above 0.682 were considered important. The calculations related to the second round of the Delphi method are presented below:

Table 5

Second Round Expert Opinion Aggregation

No.	Indicator	Very Low	Low	Medium	High	Very High
1	Manager's commitment to green actions	0	0	0	3	12
2	Hiring efficient human resources	0	0	1	2	12
3	Obtaining ISO certification	0	0	1	2	12
4	Green social responsibility	0	0	0	4	11
5	Developing a green culture	0	0	0	3	12
6	Reducing energy consumption	0	0	0	4	11
7	Purchasing eco-friendly raw materials	0	0	1	2	12
8	Purchasing clean production equipment	0	0	1	2	12
9	Purchasing recyclable materials	0	0	0	3	12
10	Reducing resource wastage	0	0	0	3	12
11	Reducing waste production	0	0	0	3	12
12	Creating a green image of the company	0	0	1	2	12
13	Enhancing the company's green status	0	0	1	2	12
14	Green marketing	0	0	1	2	12
15	Receiving consumer feedback	0	0	1	2	12
16	Consumer support	0	0	0	3	12
17	Access to new markets and customers	0	0	1	2	12
18	Improving product design	0	0	1	2	12
19	Enhancing employee motivation	0	0	1	2	12
20	Interaction with stakeholders	0	0	1	2	12
21	Customer satisfaction	0	0	0	3	12
22	Green managerial innovation	0	0	0	3	12
23	Green product innovation	0	0	0	3	12
24	Green process innovation	0	0	0	4	11
25	Green technological innovation	0	0	1	2	12

Table 6

Fuzzy Average and Defuzzification of Each Criterion (Second Round)

No.	Indicator	Fuzzy Average	Defuzzification	Mean Difference
1	Manager's commitment to green actions	1.000	0.713	0.029
2	Hiring efficient human resources	0.983	0.683	0.008
3	Obtaining ISO certification	0.983	0.683	0.000
4	Green social responsibility	1.000	0.713	0.025
5	Developing a green culture	0.983	0.696	0.013
6	Reducing energy consumption	1.000	0.700	0.017
7	Purchasing eco-friendly raw materials	0.983	0.696	0.017
8	Purchasing clean production equipment	0.983	0.696	0.008
9	Purchasing recyclable materials	1.000	0.713	0.029
10	Reducing resource wastage	1.000	0.713	0.029
11	Reducing waste production	1.000	0.713	0.029
12	Creating a green image of the company	0.983	0.696	0.013
13	Enhancing the company's green status	0.983	0.696	0.008

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14	Green marketing	0.983	0.696	0.008
15	Receiving consumer feedback	0.983	0.696	0.008
16	Consumer support	1.000	0.713	0.029
17	Access to new markets and customers	0.983	0.696	0.008
18	Improving product design	0.983	0.696	0.008
19	Enhancing employee motivation	0.983	0.696	0.008
20	Interaction with stakeholders	0.983	0.696	0.008
21	Customer satisfaction	1.000	0.713	0.029
22	Green managerial innovation	1.000	0.713	0.029
23	Green product innovation	1.000	0.713	0.029
24	Green process innovation	1.000	0.700	0.017
25	Green technological innovation	0.983	0.696	0.008

Fuzzy Delphi Consensus and Completion: Consensus means that respondents have reached a general decision regarding the factors. In this phase, if the difference in the mean of two consecutive rounds of fuzzy Delphi is less than 0.1, the fuzzy Delphi process is concluded.

Upon reviewing the results of the second round of the survey, it is observed that all the defuzzified averages of the criteria in the questionnaire are above 0.694, which indicates that all criteria are considered important. Given that the difference between the averages of the two stages is below 0.1, it can be concluded that there is consensus among the experts, and thus, the fuzzy Delphi process is completed. After identifying the green development and research indicators, each indicator was categorized based on semantic similarity, and this categorization was carried out with expert consultation.

A total of 170 completed questionnaires were collected. Since a response rate above 0.80 is considered acceptable, the data proceeded to the analysis stage. In the second part of the study, out of the 170 respondents, 40 (23.52%) were women, and 130 (76.47%) were men. In terms of education, 53 (31.17%) had a bachelor's degree, 65 (38.23%) had a master's degree, and 52 (30.58%) held a PhD. Regarding work experience, 58 (34.11%) had 3–5 years of experience, 46 (27.05%) had 6–10 years of experience, and 66 (38.82%) had more than 10 years of experience.

The Kolmogorov-Smirnov test was used to check the normality of the data. This test is conducted at a 5% error level. If the significance value is greater than or equal to the 0.05 error level, there is no reason to reject the null hypothesis, indicating that the data distribution is normal.

The statistical hypotheses for testing normality are formulated as follows:

- Null Hypothesis: The distribution of the data related to the variables is normal.
- Alternative Hypothesis: The distribution of the data related to the variables is not normal.

The results of the normality test are shown in Table 7:

Table 7

Examination of the Normality of Research Variables

Variable	Mean	Standard Deviation	Kolmogorov-Smirnov Z	Significance Level
Internal Environment Management	14.425	5.641	1.141	0.546
Energy and Resource Management	18.568	6.941	1.334	0.232
Green Management	28.796	4.697	0.961	0.121
Product and Stakeholder Performance	22.747	3.654	0.892	0.132
Green Innovation	20.315	3.431	1.154	0.657

Table 7 indicates that the Kolmogorov-Smirnov values for the variables have been calculated, and in all cases, the significance value is greater than the error level (0.05). Therefore, the null hypothesis of non-normal distribution is rejected, and the distribution of all variables in the sample is normal.

To test the hypothesis that the sample mean is equal to the population mean (3), a one-sample t-test was used.

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Table 8

Mean and Standard Deviation of Green Research and Development Dimensions

Indicators	N	Mean	Standard Deviation
Manager's commitment to green actions	170	3.60	1.030
Hiring efficient and competent personnel	170	3.45	0.903
Obtaining ISO certification	170	3.26	0.861
Green social responsibility	170	3.29	1.241
Developing a green culture	170	3.70	1.257
Reducing energy consumption	170	3.78	1.048
Purchasing eco-friendly raw materials	170	3.39	1.302
Purchasing clean production equipment	170	3.21	1.360
Purchasing recyclable materials	170	3.63	0.956
Reducing resource wastage	170	3.75	0.945
Reducing waste production	170	3.33	1.193
Creating a green image for the company	170	4.11	0.923
Enhancing the company's green status	170	4.02	0.890
Green marketing	170	3.92	0.790
Receiving consumer feedback	170	3.78	0.903
Consumer support	170	3.64	0.956
Access to new markets and customers	170	4.14	0.800
Improving product design	170	4.18	0.890
Enhancing employee motivation	170	3.39	1.302
Interaction with stakeholders	170	3.98	1.049
Customer satisfaction	170	3.52	1.257
Green managerial innovation	170	3.98	1.030
Green product innovation	170	4.10	0.890
Green process innovation	170	3.51	1.030
Green technological innovation	170	3.87	0.945

Table 8 shows the mean and standard deviation of each indicator. All indicators have a mean higher than 3. Based on the results, the "Improving product design" indicator, with a mean of 4.18, has the highest score according to employees. This is followed by "Access to new markets and customers" with a mean of 4.14, "Creating a green image for the company" with a mean of 4.11, "Green product innovation" with a mean of 4.10, and "Enhancing the company's green status" with a mean of 4.02, ranked in subsequent positions.

Table 9

One-Sample t-Test

Indicators	t-Statistic	df	Significance Level	Mean Difference	Upper Bound	Lower Bound
Manager's commitment to green actions	3.068	170	0.000	0.294	0.470	0.110
Hiring efficient and competent personnel	2.017	170	0.000	0.215	0.430	0.000
Obtaining ISO certification	15.056	170	0.000	0.957	1.070	0.830
Green social responsibility	11.551	170	0.000	0.778	0.910	0.650
Developing a green culture	10.331	170	0.000	0.730	0.870	0.059
Reducing energy consumption	15.048	170	0.000	0.958	1.080	0.830
Purchasing eco-friendly raw materials	8.445	170	0.003	0.634	0.780	0.480
Purchasing clean production equipment	12.629	170	0.003	0.863	1.100	0.820
Purchasing recyclable materials	19.096	170	0.000	1.264	1.400	1.140
Reducing resource wastage	14.260	170	0.000	0.294	1.250	0.970
Reducing waste production	10.451	170	0.000	0.667	0.890	0.640
Creating a green image for the company	3.068	170	0.000	0.294	0.470	0.110
Enhancing the company's green status	5.017	170	0.000	0.215	0.430	0.000
Green marketing	7.056	170	0.000	1.541	1.070	0.830
Receiving consumer feedback	12.654	170	0.000	1.325	1.910	0.650
Consumer support	10.654	170	0.000	1.460	0.870	0.059
Access to new markets and customers	13.154	170	0.000	0.958	1.080	0.830
Improving product design	8.445	170	0.003	0.648	0.780	0.480

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Enhancing employee motivation	2.961	170	0.000	0.276	0.470	0.090
Interaction with stakeholders	3.789	170	0.000	0.389	0.590	0.200
Customer satisfaction	8.922	170	0.000	0.215	0.430	0.000
Green managerial innovation	8.513	170	0.000	0.699	0.860	0.540
Green product innovation	20.817	170	0.003	1.350	1.470	1.230
Green process innovation	10.112	170	0.000	0.749	0.890	0.600
Green technological innovation	8.389	170	0.000	0.632	0.780	0.470

As the observed significance level is less than 0.05, it is concluded that the mean differences are significant compared to the population mean. Therefore, all these indicators are significantly identified as green development and research indicators at a 95% confidence level.

4 Discussion and Conclusion

To identify the green research and development (R&D) indicators, a literature review categorized 26 indicators into five dimensions: internal environment management, energy and resource management, green management, product and stakeholder performance, and green innovation. To screen and confirm the extracted factors, the fuzzy Delphi method was employed through a survey of selected experts. All criteria in the questionnaire had defuzzified values above 0.694, indicating their importance. Given that the difference in the mean values between the two stages was less than 0.1, consensus among the experts was established, and the fuzzy Delphi process concluded. After identifying the green development and research indicators, each indicator was categorized based on semantic similarity, with input from the experts.

Internal Environment Management includes six criteria: manager's commitment to green actions, hiring efficient and competent personnel, obtaining ISO certification, green social responsibility, and developing a green culture within the organization. Internal environment management refers to integrated and coordinated efforts across the entire organization, employing green practices in organizational processes to improve environmental performance at all management levels, including suppliers and vendors. Several studies (Kanwar & Evenson, 2003; Murat Ar, 2012; Shahabadi et al., 2023) have highlighted this factor in their research.

Energy and Resource Management includes six criteria: reducing energy consumption (water, electricity, etc.), purchasing eco-friendly raw materials, acquiring clean production equipment and machinery, buying recyclable materials, reducing organizational resource wastage, and reducing waste production. Energy management involves selecting appropriate patterns, adopting methods, and implementing policies that ensure the sustainability of energy sources, prevent the depletion of valuable energy reserves, and reduce pollution. This factor has been discussed in prior studies (Mehrgan & Soltani Sahat, 2014; Shahabadi et al., 2023).

Green Management includes six criteria: creating a green image for the company, enhancing the company's green status, green marketing, receiving consumer feedback, consumer support, and accessing new markets and customers. Green management emphasizes the integration of environmental and managerial relationships, comprising intertwined environmental and managerial processes. This process begins with incorporating green principles into the organization's mission and vision, aligning environmental and organizational goals for long-term sustainable development. Several studies (Martinez et al., 2019; Sang-Ho et al., 2015; Shahabadi et al., 2023) have referred to this concept.

Product and Stakeholder Performance includes four criteria: improving product design, enhancing employee motivation, interacting with stakeholders, and customer satisfaction. In today's highly competitive digital business environment, achieving and maintaining a sustainable competitive advantage by delivering value expected by stakeholders is essential for an organization's success. The value created by businesses is a perceptual concept shaped by stakeholders' knowledge, emotions, and experiences, emerging over time through various factors. Currently, addressing areas such as environmental sustainability, poverty reduction, and health promotion has become integral to a company's identity. Sustainability embedded within organizational values can serve as a long-term investment in future competitiveness. Studies (Mehrgan & Soltani Sahat, 2014; Murat Ar, 2012; Noailly et al., 2022; Sang-Ho et al., 2015) have highlighted the importance of these factors.

Green Innovation includes four criteria: green managerial innovation, green product innovation, green process innovation, and green technological innovation. Green process innovation generates new potential resources for creating added value. In an ecosystem, individuals integrate resources to maximize value creation by forming a resource-

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based value network to achieve shared goals and outcomes. Over the past decade, organizations have consistently sought to improve their performance by adhering to environmental requirements. Companies need a new paradigm that acknowledges the limitations of resources and the environment's capacity to absorb waste, pollution, and other by-products. Green process innovation can be an effective tool to achieve sustainable competitive advantages and increase market share. Studies (Martinez et al., 2019; Mehrgan & Soltani Sahat, 2014; Sang-Ho et al., 2015) have addressed these aspects.

To assess the status of green research and development indicators in the home appliance industry, a one-sample t-test was used. According to the data collected from the employees of the home appliance industry, each of the green R&D indicators ranged from 3.21 to 4.20, which is above the average threshold. Furthermore, since the significance level for all indicators was less than 0.05, it is concluded that all these indicators are significantly recognized as green R&D indicators in the home appliance industry with 95% confidence. Based on the results, the "Improving product design" indicator had the highest score with a mean of 4.18, followed by "Access to new markets and customers" with a mean of 4.14, "Creating a green image of the company" with a mean of 4.11, "Green product innovation" with a mean of 4.10, and "Enhancing the company's green status" with a mean of 4.02.

According to network analysis by experts, the "Improving product design" criterion, with a final weight of 0.253, ranked second in importance among the green development and research indicators. The home appliance industry in the country is now at a critical juncture, and as foreign products face barriers to entry due to sanctions, an opportunity has arisen for long-established domestic brands to reintroduce themselves to Iranian customers. When purchasing products, whether domestic or foreign, customers consider several factors, with surveys showing that product appearance plays a significant role in their decision-making. Therefore, it can be concluded that visual appeal is a key determinant of a product's competitiveness and plays a critical role in its success in today's market.

Global home appliance giants must keep pace with rapid changes in product design and technology to secure their market position and gain more market share. Otherwise, technology-driven home appliance markets will quickly replace older brands with new competitors. Therefore, competition in the home appliance industry is increasingly focused on design and technology rather than price. The field of R&D, while closely linked to innovation and knowledge, cannot be implemented in industrial and manufacturing sectors without accepting the associated risks. Companies able to allocate part of their profits to R&D can do so without severe financial shocks in the event of investment risks. The scale of a company has a logical connection with the level of investment in R&D, and experience in the industry has shown that companies with optimal economic scale have advanced towards establishing R&D capabilities and can withstand the risks in this sector.

Given the increasing environmental issues in developing countries like Iran, public environmental awareness and concerns have grown. Therefore, this study examines green R&D in the home appliance industry. Green R&D can bring environmental concerns to the forefront in industries such as home appliances. The results of this study can serve as a roadmap for moving toward sustainable development and provide suitable solutions for improving manufacturers' performance and implementing structural reforms in various sectors of the home appliance industry to achieve international market access and sustainability-driven development.

Authors' Contributions

All authors have contributed significantly to the research process and the development of the manuscript.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

In this research, ethical standards including obtaining informed consent, ensuring privacy and confidentiality were observed.

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