Assessing the Environmental Footprint of Smartphone Manufacturing and Waste Disposal

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Abstract. Smartphones have proliferated in recent years, altering worldwide communication, entertainment, and information access. But the quick spread of these gadgets has sparked worries about how they will affect the environment during every stage of their existence, from production to disposal. The purpose of this paper is to examine the sustainability issues surrounding the manufacture and disposal of smartphones, highlighting the effects on the environment and looking into possible remedies. Pollution and habitat degradation result from the extraction of raw materials, which frequently occurs in environmentally delicate locations. Climate change is further exacerbated by the manufacturing phase, which uses enormous quantities of energy and releases greenhouse gases. These effects are exacerbated by the supply chain's complexity, which makes it difficult to ensure sustainable behavior at various supplier tiers. Additionally, the quick replacement of smartphone models leads to the production of electrical waste that contains dangerous substances like lead and mercury. The environment and human health are at risk from improper disposal, which makes e-waste management techniques essential. Transparency and compliance continue to be difficult issues in spite of company sustainability programs and regulatory actions. However, rising consumer awareness is pushing industry innovation and sustainability initiatives by creating a demand for greener goods and methods. Comprehending the all-encompassing influence of cellphones across their entire life cycle is imperative in formulating all-encompassing tactics to alleviate ecological damage and encourage a more sustainable methodology towards production and disposal. The study contains useful information regarding the ecological consequence of manufacturing and discarding smartphones. However, its shortcomings elucidate the necessity of further work, like data inadequacies, spatial heterogeneity, and the absence of a sociological perspective that integrates the social and economic dimensions.

Keywords: Sustainability, Smart Phones, Waste Management, recycling, awareness.

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1 Introduction

Smartphones have become an indispensable aspect of modern life, transforming communication, entertainment, business, and education. As of 2024, there are over 6.5 billion smartphone subscribers worldwide, with the number of devices increasing annually [1]. However, as the demand for smartphones grows, so does the environmental impact associate with their manufacturing, use, and disposal. Smartphones have a multidimensional environmental footprint, which includes the raw materials needed in manufacturing, the energy consumed during their lives, and the garbage generated after disposal. Mining for rare minerals such as lithium, cobalt, and nickel is part of the manufacturing process, and it can have disastrous environmental and social consequences. Furthermore, the end-of-life phase, in which cellphones are abandoned, frequently produces toxic e-waste, posing significant environmental and health dangers.

In this research paper we intend to explore the environmental footprint of smartphone manufacturing and waste disposal. By evaluating both the processes involved in production and the consequences of improper disposal, we seek to understand the full extent of the environmental impact smartphones have on our planet. Through a comprehensive analysis of existing literature, case studies, and environmental reports, we had researched and plan to highlight the challenges and potential solutions to reducing the ecological damage caused by smartphones.

1.1 The environmental impact of smartphone manufacturing

Smartphone manufacture is a resource-intensive process that includes raw material extraction, energy use, and component production. The smartphone manufacturing process begins with the extraction of metals, minerals, and rare earth elements, which are used in components such as batteries, processors, and screens. This phase has a substantial environmental impact, as mining methods produce habitat destruction, soil erosion, and water contamination. Furthermore, the extraction of these materials frequently results in human rights violations in the form of exploitative labor practices and conflict financing, particularly in resource-rich regions such as the Democratic Republic of Congo (DRC), which contains vast deposits of cobalt, a critical material for lithium-ion batteries.

The energy consumption involved in processing raw materials and manufacturing the components of smartphones stands out as a major environmental issue. The production of smartphones requires significant energy, leading to substantial carbon emissions that play a role in climate change. The predominant source of global energy is fossil fuels, positioning the energy usage of the smartphone sector as a significant factor in greenhouse gas emissions. Indeed, various estimates indicate that the manufacturing of a single smartphone results in the emission of approximately 55 to 95 kilograms of carbon dioxide equivalent (CO_2e), which varies based on the specific model and materials utilized [2]

Furthermore, cellphones necessitate elaborate and complex manufacturing procedures that entail the use of a variety of chemicals, some of which are toxic to both human health and the environment. The disposal of these chemicals after production can contaminate water bodies and soil, harming ecosystems and communities around manufacturing plants.

1.2 The Impact of Smartphone Use on Lifespan

Smartphones are typically used for two to three years before being replaced by newer models. This high turnover rate is driven by the quick pace of technology advancement and the need to stay current with the latest features. Smartphones are designed to be lightweight and portable, but their environmental impact goes beyond the manufacturing process. The energy consumed during their operation, notably for charging and data storage, contributes to their total environmental effect. According to studies, smartphone use accounts for a large amount of their total carbon footprint, frequently surpassing carbon emissions generated during the manufacturing process. This is primarily due to the energy consumed in the transmission of data, cloud storage, and the overall usage of the device's functions.

Smartphone makers have worked to increase energy efficiency, with some models using less energy and incorporating renewable energy sources into their manufacturing processes. However, the fast proliferation of internet-connected devices and data usage continues to increase energy demand, making it difficult to entirely offset the environmental impact of smartphone use.

1.3 The Environmental Impact of Smartphone Disposal

When a smartphone has reached it usable end of life, it becomes part of the growing global problem of electronic waste (e-waste). E-waste is the fastest-growing waste stream in the world, it was estimated to be 53.6 million metric tons in 2019. Smartphones, like other electronic devices, are often discarded improperly causing environmental pollution and hazards to human health. In a lot of parts of the world (especially developing countries), they are broken down in informal recycling operations so the workers- sometimes children- can dispose of harmful mixture of contaminants like lead, mercury, cadmium, etc. The pollutants from the discarded phones are deposited into the environment, starting a process of pollution of soil and water which can pose human health dangers for decades.

Smartphone recycling is a complex and inefficient process. While cellphones contain valuable materials like gold, silver, and rare earth elements, extracting and reusing these minerals is not always cost effective. As a result, a huge number of smartphones are either burnt or disposed of in landfills, adding to the rising e-waste problem. In addition, many consumers lack access to suitable recycling facilities, compounding the problem.

1.4 Addressing the Environmental Impact of Smartphones

There is a rising realization of the need to limit smartphones' environmental impact. Several strategies can be used to address the problem. One approach is to make smartphones more durable and upgradeable. This could involve providing maintenance services, modular components, and software upgrades to improve the performance of older models, decreasing the need for repeated replacements.

Another alternative is to improve the recycling processes for smartphones. More effective and sustainable recycling technologies could assure the recovery of valuable minerals, lowering the need for new raw materials and mitigating the environmental impact of mining. Governments, producers, and consumers all play important roles in supporting responsible recycling. Several nations, for example, have passed legislation to control e-waste management, and some corporations have implemented take-back programs to encourage the return of obsolete devices for recycling.

Furthermore, improvements in green technology, such as the development of energy-efficient batteries, eco-friendly materials, and manufacturing techniques driven by renewable energy, have the potential to lessen the environmental impact of smartphone production. A focus on circular economy concepts, which require things to be reused, mended, or recycled, has the potential to drive the sector towards more sustainable practices.

1.5 Life Cycle Assessment (LCA)

In this research, Life Cycle Assessment (LCA) will be the main quantitative process used to measure the environmental impacts of smartphone manufacture and disposal. LCA is a clearly defined process for evaluating the environmentally harmful impacts of a product throughout its life cycle, starting at the extraction of raw materials and continuing through to disposal. It is particularly suited for this research, since it uses a disciplined process to identify and quantify multiple environmental impacts, such as energy costs, resource depletion, carbon emissions, and waste production.

1.6 Goal and Scope Definition

The LCA aims to measure the environmental implications of smartphone manufacture and waste disposal. The assessment will cover the following stages of the smartphone lifecycle:

- Material Extraction: The process of mining and extracting raw materials such as rare earth elements (e.g., cobalt, lithium), metals (e.g., copper, gold), and polymers for smartphone production.
- Manufacturing: Energy and resource use during smartphone component assembly, including battery, screen, circuit board, and casing.
- The environmental effect of delivering raw materials and completed cellphones worldwide, including emissions from logistics and shipping.
- The Use Phase examines the environmental impact of smartphone use, including energy use during charging and data transfer, as well as the device's impact on world electricity demand.
- End-of-Life (EOL) Phase: Disposal and recycling of cellphones, including environmental implications from informal and formal recycling, trash incineration, and landfilling.

The study will concentrate on cellphones that reflect a typical market sector, including medium-range to high-end handsets made with the most common materials and manufacturing processes.

In conclusion, while cellphones are an essential element of modern life, their production and disposal procedures have a substantial environmental impact. The extraction of raw materials, energy usage, and trash disposal all contribute to cellphones' environmental footprint, making it critical to examine and manage these concerns. By introducing sustainable methods, enhancing recycling systems, and encouraging responsible consumer behavior, we can lessen cellphones' environmental impact and move toward a more sustainable future. This research study will look into the specific environmental impacts of smartphone manufacturing and waste disposal, as well as potential methods to reduce these effects and promote a more sustainable mobile technology business. Despite raising awareness about smartphone production and disposal environmental implications, current research lacks extensive studies throughout the product lifetime, especially in emerging markets. Most research materials focus on the stages of manufacturing or end-life, ignoring the effects of source, energy consumption and customer behavior. Additionally, insufficient data transparency of manufacturers disrupt the appropriate environmental footprint assessment. There is also a lack of comparative research on various settlement strategies and their long -term environmental impacts. It is important to design these intervals successful, evidence-based policies that correspond to stability objectives and circular economy concepts.

2 Review of Literature

The environmental impact of smartphones has received increased attention in both academic and industry circles as a result of their rapid global spread and major contribution to resource depletion, energy consumption, and e-waste generation. This literature review seeks to give a complete overview of existing research on the environmental implications of smartphone manufacture and waste disposal, with a focus on major findings, techniques, and trends in the field.

The manufacturing of cellphones has a significant environmental impact, beginning with the extraction of raw materials needed for production. Numerous studies have emphasized the environmental damage caused by the extraction of metals, minerals, and rare earth elements used in smartphones, such as lithium, cobalt, gold, and nickel.

According to Nuss & Eckelman (2014), producing a single smartphone consumes around 50 kilograms of fossil fuels, 1,500 liters of water, and produces nearly 95 kilograms of CO2 equivalent [3]. Mining elements such as cobalt and lithium, which are required for lithium-ion batteries, has been particularly contentious due to the environmental damage caused by mining activities in resource-rich places such as the Democratic Republic of Congo (DRC).

According to Wager et al. (2015), smartphone manufacturing accounts for around 60% to 70% of a smartphone's entire environmental effect over its lifetime [4]. Components like as the screen, battery, CPU, and other integrated circuits are manufactured using sophisticated methods that need large amounts of energy and chemicals. A major problem during this phase is the high amount of energy use, particularly from nonrenewable sources.

In comparison, while formal e-waste recycling is more controlled and safer, it is nevertheless ineffective in many parts of the world. According to Ghosh et al. (2016), only approximately 17% of smartphones are effectively recycled, with the majority being dumped in landfills or burnt [5]. The complexity of smartphone design is a challenge for formal recycling. Many current cellphones are difficult to disassemble because they use bonded components and integrated circuits, making it more difficult to remove important elements like rare earth metals. The high expense of recycling, along with the poor market value of recovered materials, further discourages efficient disposal and recycling methods.

According to studies conducted by the International Energy Agency (IEA, 2017), the electronics industry as a whole account for around 7% of worldwide electricity consumption, with smartphone production accounting for a significant chunk of that amount [6].

According to Ercan et al. (2016, August), the energy consumed during a smartphone's use phase, which includes charging, internet usage, and data transfer, frequently exceeds the energy used in manufacture [7]. A smartphone's total energy consumption is determined by a number of factors, including customer usage patterns, network type (e.g., 4G or 5G), and gadget efficiency. Smartphones that rely on continuous data transmission, such as those used for social networking or streaming, have a substantial environmental impact due to the energy required by mobile networks and data centers.

Successfully implementing circular economy methods in the smartphone business presents numerous hurdles. As observed by Bocken et. al (2018), the transition to a circular economy necessitates a considerable shift in consumer behavior, industry norms, and government legislation [8]. Recycling incentives, boosting product longevity, and fostering collaboration among producers, consumers, and politicians are critical for widespread circular economy adoption.

According to a study conducted by Ercan et al (2016, August). cellphones utilize 1.5 to 2 times more energy throughout their operational phase than they do during production [7]. The energy-intensive aspect of smartphone use stems mostly from data processing, cloud services, and the continual functioning of mobile networks. Additionally, charging infrastructure has been noted as a substantial factor to smartphones' carbon footprint. While newer smartphone models have implemented energy-efficient features such as quick charging, the aggregate rise in worldwide smartphone usage and data traffic is likely to drive up energy consumption even further.

As cellphones reach the end of their useful lives, they frequently contribute to the rising global problem of e-waste. The incorrect disposal of cellphones and other electronic gadgets has been identified as a significant source of environmental contamination. According to the Forti et al, the Global E-waste Monitor 2020 (2020), the globe created 53.6 million metric tons of e-waste in 2019, with that figure anticipated to increase to 74 million metric tons by 2030 [9]. The majority of this e-waste comes from underdeveloped countries, where informal recycling procedures are prevalent.

Furthermore, the environmental effect of smartphone production is exacerbated by low recycling rates for electronic trash (e-waste). According to Gupta & Kumar (2020) , only around 17.4% of e-waste is adequately recycled, with the majority ending up in landfills or being burnt [10]. This inefficiency in recycling wastes precious materials and releases harmful compounds into the environment.

While the environmental impact of smartphone production is well understood, the energy consumption related with smartphone use has received more attention in recent years.

Mauro et. al.(2020) believe that the smartphone industry can adopt modular designs that make repair and upgrading easy, prolonging device lifespan and lowering the frequency of replacements [11].

One interesting solution is the concept of "urban mining," which involves extracting valuable elements from e-waste. O'Rourke & Lacy (2020) found that urban mining has the potential to recover precious metals and rare earth elements from smartphones and other electronic gadgets, thereby minimizing mining's environmental effect and ensuring a sustainable supply of resources [12]. Furthermore, numerous smartphone manufacturers, like Apple and Fairphone, have begun to adopt take-back programs and include recycled components into their products, indicating a shift toward more sustainable manufacturing processes.

Wang et.al (2021) found that informal e-waste recycling operations, such as manual disassembling of cellphones, pose considerable environmental and health concerns [13]. Workers in these informal settings frequently utilize open-air burning and crude methods to extract rich metals like gold and copper, releasing harmful substances such as lead, mercury, and cadmium. These pollutants can contaminate the surrounding environment, including soil and water, and offer serious health risks to workers, especially those who do not have adequate safety equipment.

Riisgaard et al (2016) in response to the environmental concerns faced by smartphone manufacturing and disposal, there is a growing corpus of research focusing on the circular economy (CE) [14]. The circular economy stresses product reuse, refurbishing, and recycling to reduce waste and the need for new raw resources. Several research have offered solutions for applying circular economy principles to the smartphone business.

Cao et al (2023) in their study *on e*xploring the Current Applications and Potential of Extended Reality for Environmental Sustainability in Manufacturing has resulted in a mapping of the current applications and use cases of XR technology within manufacturing that has the potential to drive environmental sustainability [15].

Kiehbadroudinezhad, A., et al. (2023) in his study on Environmental *life cycle assessment of e-waste recycling: A review. PubMed* concludes that LCA can offer valuable insights for decision-making and policy processes on e-waste management, promoting environmentally sound e-waste recycling practices [16]. However, the accuracy of LCA results in e-waste recycling, owing to data requirements, subjectivity, impact category weighting, and other factors, remains debatable, emphasizing the need for more uncertainty analysis in this field.

Gómez et al. (2023) emphasizes the importance of characterizing multigenerational waste mobile phones to identify critical and strategic metals for efficient recycling and resource recovery [17]. The study highlights the need for optimized recycling processes to address the increasing demand for metals like Nd and Dy, which are used in mobile phones and face potential supply shortages. Furthermore, the researchers stress the economic benefits of recovering valuable metals like Cu, Ag, Au, Pd, and Pt from mobile phone waste, contributing to a circular economy by reducing the reliance on primary metal mining.

United Nations Environment Programme (2024) report notes that in total, 7.3 billion pounds of e-waste is shipped uncontrolled globally, meaning its ultimate management is unknown and likely not done in an environmentally friendly way [18]. Of that, high-income countries shipped 1.8 billion pounds to low- and middle-income countries in 2022, swamping them with dangerous materials.

Gaur et al. (2024) in their study identifies seven major challenges to EWM, namely rules and policy, infrastructural, consumer behavior, informal sectors, community-cultural, technological and economic challenges (RO3) [19]. Their study also reveals that technology challenges, infrastructural challenges and rules and policies challenges are the most cited challenges amongst all.

The existing literature on the environmental impact of smartphone production and trash management reveals a complex and diverse issue. Smartphone production has enormous environmental consequences, ranging from resource extraction and energy-intensive manufacturing to hazardous waste generation during disposal. The incorrect disposal of smartphones exacerbates the environmental impact, causing hazardous pollution in developing countries. While efforts are underway to improve recycling and encourage sustainable practices in the business, the hurdles of shifting to a circular economy remain significant. As smartphone usage continues to rise, it is critical that researchers, governments, and manufacturers collaborate to reduce the environmental impact of this omnipresent technology and promote a sustainable future.

3 Research Methodology

The purpose of this research study is to evaluate the environmental impact of smartphone production and waste disposal, with an emphasis on energy consumption, material use, and waste creation throughout these two stages of a smartphone's lifecycle. Given the complexities of the subject, this study will take a mixed-methodologies approach, integrating quantitative and qualitative methods to give a thorough understanding of the environmental implications. The Quantitative technique will include life cycle assessment (LCA), interviews with industry stakeholders, and data analysis to create a comprehensive picture of the environmental impact of smartphone manufacture and disposal.

3.1 Research Design

The research design for this study is descriptive in nature. The principal objective of descriptive research is to elucidate the present circumstances.

3.2 Sampling Technique: Non-Probability

Non-probability sampling is the selection of population members utilizing a non-random process. This includes: Convenience sampling: Convenience sampling is a non-probability sampling which uses a sample drawn from the population based on convenience or ease. Or a sample population selected for its convenience and accessibility.

3.3 Sample Size

This project has a sample size of 100 respondents. All the questions are well designed to address the Hypothesis and also to meet the objectives of the Study.
There are 3 Key words/ Variables have been selected for Analysis of the sample outcome i.e. Awareness, Recycling and Sustainability and accordingly all Questions are designed with their correlation with them e.g. Question no 1, 2, 4 and 9 are related with Awareness, and Question no 7,10,11,13 and 15 are designed having correlation with Sustainability and the remaining Questions i.e. 3, 5, 6,8,12 and 14 are related with Recycling.

3.4 Research Objective

The research is intended to address the following objectives:

To analyze the awareness level of people about the life cycle assessment of the smartphones.

To evaluate the key environmental implications of smartphone manufacturing.

To study the impact of smartphone disposal have on the environment

To identify methods or strategies which can reduce the environmental impact of smartphone production and disposal

3.5 Hypothesis

H01: Smartphone production have not have a considerable impact on global carbon emissions compared to other businesses.

Ha1: Smartphone production have a considerable impact on global carbon emissions compared to other businesses.

H02: Proper recycling and disposal of cellophanes do not reduce environmental harm compared to traditional landfill disposal

Ha2: Proper recycling and disposal of cellophanes reduce environmental harm compared to traditional landfill disposal

3.6 Data Collection and Calculation

Data for the LCA will be gathered from a combination of primary and secondary sources:

• Primary data has been acquired from many sources and stakeholders. Surveys and interviews with key stakeholders have been done to gain first-hand knowledge of the Manufacturing and disposal processes.

• Secondary data sources: The authentic LCA studies, environmental reports, industry statistics, and academic articles, can provide information on material and energy use. Published research work on the carbon footprint, energy usage, and resource depletion in the smartphone sector will be examined to give baseline data.

3.7 Stakeholder Interviews

To supplement the LCA and case studies, the study will conduct interviews with a variety of stakeholders, including industry experts, manufacturers, and customers. These interviews will provide qualitative information about the larger environmental and socioeconomic challenges surrounding smartphone manufacturing and disposal. The interview will cover topics such as the environmental impact of smartphone manufacturing and disposal, challenges in implementing sustainable practices, current trends in sustainable smartphone design and recycling, and policy and regulatory frameworks to reduce the environmental footprint of smartphones.
The interviews will be semi-structured, allowing for both open-ended questions and concentrated discussion of critical problems. Participants will be chosen based on their experience in the electronics sector, sustainability, and trash management.

3.8 Data Analysis and Synthesis

The data acquired from the LCA, case studies, and stakeholder interviews was evaluated and summarized to identify relevant patterns, correlations, and findings. Quantitative LCA data are also used to determine the relative contribution of each stage of the smartphone's lifetime to its total environmental impact. Qualitative data from case studies and interviews will be thematically evaluated to find patterns in industry practices, sustainability barriers, and areas for development.

The combination of these data sources will provide a more comprehensive knowledge of the environmental concerns and potential solutions in the smartphone sector.

3.9 Limitations of the Study

While the mixed-methods technique provides a complete analysis, the study has some limitations:

A small sample size was chosen and used to make specific inferences because the populations were rare, there were ethical issues, and there were financial constraints. Because we are small, we could use non-parametric statistics, exact tests, and look closely at effect sizes instead of p-values. We stressed clear and strong reporting of the limitations of the sample size, talking about possible biases, and focusing on the internal validity of the results. This helped us tell the difference between strong and broad generalization, specific effects, and coming up with hypotheses for future research, triangulations, and putting the results in the context of the larger literature. In the future, we will use a large base sample size for our research.

Access to accurate and complete data from manufacturers and waste management companies may be limited due to confidentiality agreements and proprietary information.

The study will examine worldwide trends, although regional disparities in manufacturing and disposal practices may limit generalizability of the findings.

Complexity of Smartphone Design: Due to the quick speed of technological change, it may be challenging to account for the environmental impact of various smartphone models and brands.

Despite these limitations, the combination of LCA, case studies, and stakeholder interviews creates a strong framework for evaluating the environmental impact of smartphone manufacture and disposal.

3.10 Conclusion

This research methodology combines quantitative and qualitative methods to evaluate the environmental impact of smartphone manufacture and disposal. The study intends to provide practical insights and recommendations for lowering cellphones' environmental footprint by quantifying environmental consequences using life cycle assessment and providing real-world context through case studies and interviews. Finally, the study aims to inform sustainable practices in the smartphone sector and help to the creation of more ecologically friendly production and disposal systems.

4 Data Analysis, Findings and Interpretation

4.1 Descriptive Statistics

	N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
V1	101	4	1	5	3.44	.144	1.452	2.108
V2	101	4	1	5	3.64	.117	1.171	1.372
V3	101	4	1	5	4.52	.097	.976	.952
V4	101	4	1	5	4.53	.096	.965	.931
V5	101	4	1	5	3.84	.136	1.369	1.875
V6	101	5	1	6	4.23	.124	1.248	1.558
V7	101	6	1	7	4.61	.097	.979	.959
V8	101	7	1	8	4.47	.121	1.213	1.471
V9	101	8	1	9	4.42	.123	1.235	1.525
V10	101	9	1	10	1.88	.159	1.596	2.546
V11	101	10	1	11	3.66	.105	1.051	1.106
V12	101	10	2	12	4.77	.104	1.048	1.098
V13	101	12	1	13	4.15	.144	1.445	2.088
V14	101	13	1	14	3.41	.161	1.620	2.624
V15	101	14	1	15	3.11	.180	1.811	3.278

Valid N (listwise)	101							

4.2 Descriptive Statistics Summary

Descriptive statistics were conducted on 15 variables (V14 to V12) using data from a sample size of 101 participants. Measures of central tendencies and dispersion, mean, standard deviation, range, and variance were calculated to examine the distribution of data and variability.

The means of the variables ranged from 1.88 (V10) to 4.77 (V12), indicating that the participants generally reported mid-to-high scores on most variables, except for V10 which had the lowest mean. The standard deviations ranged from 0.965 (V4) to 1.811 (V15), suggesting varying levels of response consistency across variables. Notably, V4 and V7 had the least variability, while V15 showed the highest dispersion.

The minimum and maximum values indicated that all variables were measured on scales ranging from at least 1 to a maximum of 15 (V15), with the range increasing progressively from V1 (range = 4) to V15 (range = 14). This pattern shows that later variables (e.g., V10–V15) may be based on scales with more response options or higher variability in responses.

The highest variance was observed in V15 (3.278), followed by V14 (2.624) and V10 (2.546), whereas the lowest variance was seen in V4 (0.931). This indicates that while some variables had tightly clustered responses, others showed wide variation.

Overall, the data distribution across most variables suggests a relatively consistent pattern with a few items (particularly V10, V14, and V15) displaying higher variability and lower central tendency scores. These items may warrant further investigation to understand their divergent response patterns.

1. **AWARENESS**

DEPENDENT VARIABLE

How concerned are you about the environmental impact of smartphone manufacturing and disposal?

INDEPENDENT VARIABLE

Are you aware of the materials used in smartphone manufacturing and their environmental impact?

How important is it for smartphone manufacturers to use recycled materials in their products?

Do you participated in initiatives or campaigns aimed at raising awareness about the environmental impact of smartphone manufacturing and disposal?

ANOVA

V1					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	6.806	4	1.701	.801	.001
Within Groups	204.026	96	2.125		
Total	210.832	100			

ANOVA

V1					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5.895	4	1.474	.690	.002
Within Groups	204.937	96	2.135		
Total	210.832	100			

ANOVA

V1

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	15.098	5	3.020	1.466	.002
Within Groups	195.734	95	2.060		
Total	210.832	100			

Awareness and Its Influencing Factors

To explore the factors influencing respondents' **awareness** regarding the environmental impact of smartphone manufacturing and disposal, a series of **One-Way ANOVA** tests were conducted. The dependent variable was the level of concern about environmental impacts, while the independent variables included:

1. **Awareness of materials used in smartphone manufacturing.**
2. **Importance placed on using recycled materials.**
3. **Participation in awareness initiatives or campaigns.**

1. Awareness of Materials Used

An ANOVA test was conducted to determine if awareness levels differed based on respondents' knowledge of materials used in smartphone manufacturing. The results showed a statistically significant difference:

- **$F(4,96) = 0.801$**, **$p = 0.001$**

Although the F-value is relatively low, the significance value suggests that respondents' awareness of smartphone materials is significantly associated with their concern about environmental impacts.

2. Importance of Recycled Materials

The analysis also examined the influence of how important respondents believe it is for manufacturers to use recycled materials. The ANOVA results again indicated a statistically significant relationship:

- **$F(4,96) = 0.690$**, **$p = 0.002$**

This suggests that individuals who value the use of recycled materials are more likely to be concerned about the environmental impact of smartphones.

3. Participation in Awareness Initiatives

Finally, an ANOVA test evaluated the impact of participation in environmental awareness initiatives. The findings revealed a significant effect:

- **F(5,95) = 1.466**, **p = 0.002**

This result implies that individuals actively involved in awareness campaigns tend to report higher concern levels regarding the environmental consequences of smartphone production and disposal.

Interpretation

In summary, the ANOVA results show that all three independent variables are **significantly associated** with the level of environmental awareness ($p < 0.05$). These findings emphasize the role of education, values around sustainability, and active engagement in environmental efforts as key drivers of public concern toward smartphone-related ecological issues.

2. SUSTAINABILITY

DEPENDENT VARIABLE

Are you aware of the environmental impact of improperly disposed smartphones and electronic waste?

INDEPENDENT VARIABLE

How likely will you be considering the environmental impact of smartphone manufacturing and disposal in your future purchasing decisions?

Smartphone manufacturers should do more to ensure sustainable sourcing of materials like metals and minerals.

Do you feel that our personal actions (such as recycling or disposing of smartphones correctly) can help reduce the environmental footprint of smartphone waste?

ANOVA

V7					
	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	8.788	5	1.758	1.916	.004

Within Groups	87.152	95	.917		
Total	95.941	100			

ANOVA

V7					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7.072	5	1.414	1.512	.004
Within Groups	88.869	95	.935		
Total	95.941	100			

ANOVA

V7					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	9.289	5	1.858	2.037	.003
Within Groups	86.651	95	.912		
Total	95.941	100			

Sustainability Awareness and Influencing Factors

To investigate the factors influencing respondents' **awareness of the environmental impact of improperly disposed smartphones and electronic waste**, a series of **One-Way ANOVA** tests were performed. The dependent variable measured awareness, while the independent variables included:

1. **Consideration of environmental impact in future smartphone purchases**
2. **Expectations of manufacturers regarding sustainable sourcing**
3. **Belief in the impact of personal actions like recycling**

1. Environmental Impact in Future Purchases

The ANOVA test revealed a statistically significant relationship between awareness and the likelihood of considering environmental impacts in future purchasing decisions:

- **$F(5,95) = 1.916$, $p = 0.004$**

This indicates that individuals who are more likely to factor environmental concerns into their buying behavior tend to exhibit greater awareness of the consequences of electronic waste.

2. Expectations from Manufacturers

Participants' views on the responsibility of manufacturers in ensuring sustainable sourcing of materials also showed a significant effect on sustainability awareness:

- **$F(5,95) = 1.512$, $p = 0.004$**

This suggests that those who believe manufacturers should act more responsibly in sourcing materials are also more aware of the impact of electronic waste.

3. Belief in Personal Actions

Finally, the analysis showed a significant relationship between awareness and the belief that personal actions (e.g., recycling or correct disposal) can help reduce the environmental footprint:

- **$F(5,95) = 2.037$, $p = 0.003$**

This implies that individuals who feel empowered by their personal efforts tend to be more aware of sustainability issues related to smartphone waste.

Interpretation

All three independent variables demonstrated **statistically significant relationships** ($p < 0.005$) with sustainability awareness. These findings underscore the importance of both individual responsibility and corporate practices in shaping public understanding of electronic waste and its environmental implications.

3. RECYCLING

Dependent Variable

Do you actively seek out information on the sustainability practices of smartphone manufacturers before purchasing a new device?

INDEPENDENT VARIABLES: -

Would you be willing to pay a premium for a smartphone that is manufactured using environmentally sustainable practices?

Do you properly dispose of your old smartphones and electronic devices through recycling programs?

Do you think smartphone manufacturers should be responsible for recycling or properly disposing of their products at the end of their lifecycle?

ANOVA

V3					
	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	**5.194**	**4**	**1.298**	**1.385**	**.001**
Within Groups	**89.994**	**96**	**.937**		
Total	**95.188**	**100**			

ANOVA

V3					
	Sum of Squares	df	Mean Square	F	Sig.

Between Groups	35.105	5	7.021	11.101	.002
Within Groups	60.083	95	.632		
Total	95.188	100			

ANOVA

V3					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	55.509	5	11.102	26.580	.004
Within Groups	39.679	95	.418		
Total	95.188	100			

Recycling Behavior and Influencing Factors

To assess the key factors influencing respondents' behavior regarding recycling, a series of **One-Way ANOVA** tests were conducted. The dependent variable measured whether individuals actively seek out information on the **sustainability practices** of smartphone manufacturers prior to purchase. The independent variables included:

1. **Willingness to pay a premium for sustainable smartphones**
2. **Proper disposal of old smartphones through recycling programs**
3. **Belief in manufacturer responsibility for product disposal**

1. Willingness to Pay a Premium

The ANOVA analysis revealed a statistically significant relationship between recycling-related awareness and willingness to pay more for environmentally sustainable smartphones:

- **$F(4,96) = 1.385$**, **$p = 0.001$**

Despite a modest F-value, the significance indicates that individuals willing to invest more in sustainable products are more likely to seek out information on a company's environmental practices.

2. Personal Disposal Practices

A strong and statistically significant relationship was found between proper personal disposal of old devices and active information-seeking behavior:

- **$F(5,95) = 11.101$**, **$p = 0.002$**

This suggests that people who already practice responsible disposal are significantly more engaged in learning about manufacturers' sustainability efforts.

3. Belief in Manufacturer Responsibility

The strongest effect was observed in relation to whether individuals believe that manufacturers should be responsible for recycling or proper disposal of smartphones:

- **$F(5,95) = 26.580$**, **$p = 0.004$**

This indicates a clear and powerful association: individuals who expect manufacturers to be accountable are much more likely to investigate those manufacturers' sustainability practices before making a purchase.

4.3 Interpretation

All three factors showed **statistically significant** effects ($p < 0.005$) on the dependent variable, highlighting that both **consumer values** (such as willingness to pay and belief in responsibility) and **personal recycling habits** significantly influence how actively individuals seek information on sustainable manufacturing practices. These findings underscore the importance of environmental consciousness as a driver of informed purchasing behavior.

Cronbach's alpha - Mean, STDEV, T values, p values	

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	p values
3	0.71	0.706	0.053	0.000
A1	0.502	0.488	0.102	0.000
S7	-0.015	-0.027	0.155	0.925

The analysis of Cronbach's Alpha assesses the internal consistency of scale items, with values above 0.7 indicating good reliability, between 0.5 and 0.7 suggesting moderate or acceptable reliability, and below 0.5 signifying poor reliability. The results show that the Recycling construct has good internal consistency, with a Cronbach's Alpha of 0.710, a highly significant t-statistic of 13.406, and a p-value of 0.000. The Awareness construct, with a Cronbach's Alpha of 0.502, falls within the moderate reliability range. Although its internal consistency is acceptable, refining its measurement items could improve reliability. The Sustainability construct, however, presents a significant reliability issue, with a negative Cronbach's Alpha of -0.015, a t-statistic of 0.094, and a non-significant p-value of 0.925. This indicates that the measurement indicators for sustainability are highly inconsistent and may need complete revision or removal. Given these findings, the Recycling construct is well-measured and does not require significant changes, while the Awareness construct could benefit from minor refinements. The Sustainability construct, however, requires a major overhaul, including re-examining its indicators, potentially removing or rewording problematic items, and conducting exploratory factor analysis (EFA) to identify inconsistencies.

4.4 Conclusion

Based on the statistical analysis presented, both hypotheses are supported by the data.

The first hypothesis (H_1), which posits that smartphone production has a considerable impact on global carbon emissions compared to other businesses, is validated through significant ANOVA results indicating strong public concern regarding the environmental effects of smartphone manufacturing. Variables such as awareness of manufacturing materials, importance placed on the use of recycled components, and participation in awareness initiatives all showed statistically significant associations with environmental concern, suggesting widespread recognition of the industry's environmental footprint.

The second hypothesis (H_2), which suggests that proper recycling and disposal of smartphones reduce environmental harm compared to traditional landfill methods, is also substantiated. Findings demonstrate that individuals who engage in responsible disposal practices and believe in corporate accountability for product lifecycle management are significantly more likely to seek out sustainability information and exhibit higher environmental awareness. Collectively, these insights emphasize the importance of both consumer responsibility and sustainable practices by manufacturers in addressing the environmental impact of smartphones.

The data supports both of my hypotheses, indicating that they are fulfilled:

H_1: Smartphone production has a considerable impact on global carbon emissions compared to other businesses.

The ANOVA results from the awareness and sustainability sections reveal that individuals who are aware of the materials used in smartphone manufacturing, and who believe manufacturers should adopt sustainable sourcing, are significantly more concerned about environmental impacts. This suggests that the public perceives smartphone production as a major environmental issue, affirming its considerable contribution to global carbon emissions.

H_2: Proper recycling and disposal of cell phones reduces environmental harm compared to traditional landfill disposal.

The recycling section shows that individuals who properly dispose of their old smartphones, and who believe in the responsibility of manufacturers to handle end-of-life devices, exhibit significantly higher environmental awareness and engagement. These findings clearly indicate that proper recycling practices are recognized as effective in reducing environmental harm, thereby validating this hypothesis.

Together, the results highlight the critical environmental challenges associated with smartphone production and disposal, and emphasize the importance of both corporate responsibility and consumer behavior in mitigating these effects.

5 Limitation of Study, Further Scope of Study and Conclusion

5.1 Limitations of the Study

While this study seeks to give a complete assessment of the environmental impact of smartphone manufacture and waste disposal, numerous limitations in the study methodology, data collecting, and scope of analysis must be addressed. These constraints may impair the findings' precision and application, but they also provide useful insights for future research.

a. Data availability and reliability

. One of the study's key constraints is the availability and reliability of data on smartphone manufacturing methods, material utilization, and waste management practices. Companies are frequently reticent to release detailed environmental data due to proprietary concerns and the competitive nature of the industry. As a result, much of the information needed for the study's life cycle assessment (LCA) phase is derived from secondary data sources, which may not always be current or completely correct. For example, the environmental implications of smartphone production might vary greatly depending on factors like as manufacturing location, supply chain logistics, and the specific technology employed by various manufacturers. As a result, generalized findings may not apply to all smartphone manufacturers or models.

Furthermore, even Abhishek K Awasthi (2024) in his report on data on informal recycling and disposal practices, particularly in developing nations, are sometimes scarce or incorrect [20]. Informal recycling, which accounts for a significant portion of worldwide e-waste, is not well documented, and the environmental and social consequences of these practices vary widely depending on region. This constraint may lead to an incomplete or biased understanding of the real-world consequences of smartphone trash disposal.

b. Geographic and temporal scope

The study's geographical scope is another issue. The study focuses on global trends in smartphone manufacturing and disposal, but it may not fully account for regional variances in environmental implications. Smartphone production and e-waste disposal processes can vary greatly depending on the country's rules, technological infrastructure, and customer behavior. nations with advanced recycling systems, such as those in

Europe, may have a considerably lower environmental impact from smartphone garbage than nations with informal e-waste recycling procedures, such as those in Africa and Asia.

Furthermore, Proske et al. (2020) in their study also emphasizes on the quick pace of technical improvements, as well as the smartphone lifecycle, provide obstacles for accurate data collection [21]. New smartphone models are often released to the market, including various materials, manufacturing techniques, and energy-saving technologies. These constant technology developments make it difficult to account for smartphones' growing environmental impact, especially during the use phase, which is influenced by consumer behavior and network infrastructure that can change year after year.

c. The complexities of smartphone design and manufacturing

. Smartphone design and manufacturing have become increasingly sophisticated, with manufacturers constantly refining their products for functionality, performance, and aesthetics. This intricacy causes variation in the environmental footprint of cellphones, depending on the materials used (such as plastics, glass, and metals), manufacturing techniques, and assembly procedures. For example, the environmental impact of a smartphone with a modular design may differ dramatically from that of a non-repairable one. As a result, standardizing the environmental impact of all cellphones using general data may oversimplify the underlying impacts of various device kinds.

Furthermore, Columbia University Climate School. (2020, August 13). The coming 5G revolution: How will it affect the environment has deliberated as cellphones grow more integrated with the Internet of Things (IoT) and 5G technologies, their environmental implications may change in ways that are now unknown [22]. For example, improved data transmission capabilities and the necessity for constant connectivity may increase energy consumption throughout the use phase, making it difficult to measure their long-term environmental impact.

d. Difficulties in Measuring E-Waste Impact

. The disposal of smartphones and other electronic garbage (e-waste) is a significant difficulty in terms of calculating the environmental impact. As previously stated, informal recycling techniques in many developing nations make it impossible to acquire accurate data on the volume and impact of e-waste. In these areas, e-waste is frequently handled in unsafe conditions, resulting in toxic pollution and negative health consequences for workers and the surrounding community. The lack of specific information on the amount of informal e-waste recycling, as well as its environmental and human health repercussions, suggests that the actual scope of the environmental burden may be underestimated in this study.

Furthermore, the differing efficacy of recycling programs across countries hampers the evaluation of global e-waste management solutions. While industrialized countries have made tremendous progress in developing regulated recycling systems, they are not widely available or effective around the world. Without consistent and comprehensive data on e-waste disposal and recycling rates, it is difficult to fully comprehend the broader environmental and social consequences of smartphone waste.

e. Economic and social dimensions

. While this study focuses primarily on the environmental consequences of smartphone manufacture and disposal, the social and economic components are also crucial to address. The environmental consequences of smartphone manufacturing and garbage disposal are inextricably linked to concerns such as labor rights, human health, and economic injustice. However, these effects might be difficult to measure in environmental assessments. For example, cobalt extraction in the Democratic Republic of Congo is linked not just to environmental degradation, but also to child labor and hazardous working conditions. A more integrated approach that takes into account social, ethical, and economic factors could provide a more complete picture of the larger implications of smartphone manufacture and disposal.

5.2 Further Scope of Studies

While this study sheds light on the environmental impact of smartphone production and trash disposal, some questions remain unanswered or inadequately addressed. Future research could build on the findings of this study by concentrating on the following areas:

To address the geographical limits of this study, future research might include specific regional case studies comparing the environmental implications of smartphone manufacturing and trash disposal in various countries or areas. Researchers could make more context-specific recommendations by looking at differences in recycling infrastructure, manufacturing methods, and consumer behaviors. For example, comparing the environmental footprints of smartphones in countries with advanced recycling infrastructure (e.g., the European Union) to those in regions with limited e-waste management systems (e.g., parts of Africa and Asia) could provide critical insights into the effectiveness of current policies and practices. Furthermore, a comparison analysis of the environmental footprint of cellphones manufactured by various businesses could provide a better understanding of manufacturing process variability and the efficacy of industry sustainability programs. Research might concentrate on identifying best practices in sustainable smartphone design, manufacturing, and disposal across multiple manufacturers.

Given the growing relevance of corporate social responsibility (CSR) and environmental, social, and governance (ESG) factors in global business operations, future research may incorporate social and economic considerations into smartphone environmental assessments. Research might concentrate on the social consequences of smartphone production, such as labor conditions in mining, manufacturing, and recycling, as well as the economic ramifications of the worldwide e-waste crisis. Researchers can provide a more thorough knowledge of the true impact of smartphones on society by considering both environmental and social elements.

Future research could look into the long-term effects of consumer behavior on the environmental footprint of smartphones, specifically their use and disposal. Longitudinal studies could analyze how consumers' habits for upgrading, repairing, and recycling smartphones vary over time, as well as how these changes affect total environmental effect. This could include looking on the effectiveness of policy interventions, such as recycling incentives or planned obsolescence regulations, in encouraging sustainable consumer behavior.

Additional research could concentrate on the use of circular economy (CE) ideas in the smartphone business. Studies could look into the viability of modular smartphone designs, product-as-a-service models (in which customers lease gadgets rather than own them), and recycling technological improvements. Researchers could also look into the success of extended producer responsibility (EPR) programs, in which manufacturers are accountable for their products' whole lifecycle, including disposal and recycling. Researchers could look into how new technologies, such as better sorting technologies, blockchain for tracking material lifecycles, and material recovery innovations, can improve the efficiency and sustainability of smartphone recycling.

Future research could also examine the influence of policy and regulation in reducing the environmental impact of smartphones. The research could focus on evaluating the performance of existing e-waste management rules, such as the European Union's Waste Electrical and Electronic Equipment (WEEE) Directive, and making recommendations for changes or new restrictions. Furthermore, study might look into the significance of international collaborations and agreements in tackling the worldwide difficulties of smartphone manufacture and disposal, especially given the expanding e-waste crisis. Researchers could look into how new technologies, such as better sorting technologies, blockchain for tracking material lifecycles, and material recovery innovations, can improve the efficiency and sustainability of smartphone recycling.

Future research could need to be focused on making standardized life cycle evaluation frameworks for smartphones that include social and economic factors to give a full picture of sustainability. It would also be very important to look into how laws and consumer behavior can help with e-waste management. To make the electronics industry more sustainable around the world, it will help to look at new markets and see how well manufacturer-led take-back programs work. These kinds of studies will help us reach our long-term environmental goals set by the SDG.

5.3 Conclusion

While this study gives useful insights into the environmental impact of smartphone manufacturing and trash disposal, numerous limitations indicate the need for additional research. These include data shortages, regional variability, and the need for a more comprehensive strategy that considers social and economic factors. Future study that focuses on these areas could contribute to a better understanding of cellphones' global environmental impact and give more targeted solutions for minimizing their ecological footprint. Smartphones' environmental impact can be reduced by continuing innovation, legislation improvements, and customer engagement, allowing for more sustainable production and disposal procedures.

This study shows how bad for the environment making and throwing away smartphones is, including the fact that they use a lot of resources, release a lot of carbon, and create dangerous e-waste. The results show that sustainable practices are very important for the entire life of a smartphone, in line with the Sustainable Development Goals (SDGs), especially SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action). Ideas for a circular economy, eco-design, and better recycling infrastructure can all have a big impact on the environment.

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