**IDENTIFYING OLD AND NEW FASION CLOTHING IN TEXTILE INDUSTRY USING MACHINE LEARNING.**

**Project Id: 24-25J-173**

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June 2025

**REDICT SUSTAINABLE FASHION DESIGN TRENDS USING INTEGRATED ENVIRONMENTAL METRICS.**

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## **DECLARATION**

I declare that this is my own work and this thesis document does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any other university or Institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgment is made in the text.

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The above candidate is carrying out research for the undergraduate dissertation under my supervision.

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## **ABSTRACT**

The fashion industry is increasingly called upon to address its environmental impact, driving the need for sustainable fashion practices. This research aims to analyze and integrate critical sustainability metrics such as carbon footprint, water usage, and material recyclability into the fashion design process. By leveraging an extensive dataset, this study seeks to understand the environmental implications of current fashion trends and develop methods for reducing their ecological impact. These metrics are central to evaluating how design choices influence the sustainability of fashion, guiding the industry toward more environmentally responsible practices.

The research focuses on the development of machine learning models that utilize this comprehensive dataset to predict the environmental impact of various fashion designs. By analyzing existing data, the study will identify patterns and relationships between design elements and sustainability outcomes. The results will be visualized through interactive dashboard, offering a clear and accessible way for designers and industry stakeholders to explore the impact of their choices. This approach allows for the identification of key factors that contribute to a reduced environmental footprint, fostering the development of innovative and sustainable fashion.

The goal of this research is to provide fashion designers with actionable insights through a centralized system, empowering them to make informed decisions that align with sustainability goals. By integrating these insights into the design process, the study aims to support the fashion industry in adopting more sustainable practices, thereby reducing its overall environmental impact and contributing to a more sustainable future.

**Keywords: sustainable fashion, sustainability metrics, carbon footprint, water usage, material recyclability, machine learning, environmental impact, innovative design.**

## **AKNOWLEDGEMENT**

I would like to extend my heartfelt appreciation to all the individuals who supported me in carrying out my 4th year research project. First, I sincerely thank our research project supervisor, Mr. Nelum Amarasena, who provided guidance and encouragement to continue this project successfully. I am also grateful for the guidance given by the CDAP panel through their advice on our project work. Also, I would like to thank our co-supervisor, Ms. Sandeepa Gamage, for her valuable advice on fulfilling our work more efficiently.

I am also grateful to my fellow project group members for their cooperation and support. Lastly, I owe a huge debt of gratitude to my parents and friends, whose support was crucial in making this project successful.

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## **LIST OF ABBREVIATIONS**

|  |  |
| --- | --- |
| **Abbreviation** | **Description** |
| CNN | Convolutional Neural Network |
| EIS | Environmental Impact Score |
| MAS | MAS Holdings |
| MT | Metric Tonnes |
| KG | Kilograms |
| UI | User Interface |
| CSV | Comma-Separated Values |
| TC | Test Case |
| ID | Identifier |
| MAE | Mean Absolute Error |
| RMSE | Root Mean Squared Error |
| ROC | Receiver Operating Characteristic |
| DB | Database |
| KPI | Key Performance Indicator |
| UX | User Experience |

## **INTRODUCTION**

Due to its large carbon emissions, heavy water use, and trash production, the fashion sector is one of the leading causes of environmental deterioration. The garment sector is under mounting pressure to embrace more sustainable methods as public knowledge and concern for environmental protection expand. Beyond simple resource management, fashion design must embrace comprehensive sustainability indicators as part of this movement toward sustainability. Our study aims to fill this gap by assessing and applying three important sustainability metrics to fashion design: carbon footprint, water usage, and material recyclability. The objective is to create fresh looks that are ecologically conscious in addition to being fashionable.

The body of research now available emphasizes how seriously fashion affects the environment, especially when it comes to carbon emissions, which make up about 10% of all emissions worldwide. The whole lifecycle of clothing, from production to disposal, is included in the carbon footprint of fashion. More advanced instruments are still desperately needed to monitor and control these effects, even in the face of numerous initiatives to reduce these emissions through the use of eco-friendly materials and renewable energy sources. In a similar vein, the use of water in the fashion industry, which is essential for the production of fibers and clothing, poses serious difficulties. Although strategies like recycling wastewater and using alternative materials are being investigated, there are still few practical implementations. Furthermore, although crucial for cutting waste, a material's potential to be recycled encounters obstacles because of material deterioration and energy usage.

In collaboration with MAS Holdings, a leading apparel manufacturing company known for its sustainability initiatives, a sample dataset was obtained during a field visit. With their consent, limited but vital data related to carbon usage, water usage, and material recyclability was accessed under strict confidentiality. This data provides an authentic basis for applying machine learning methods to predict sustainability outcomes in fashion design.

In order to solve these problems, a comprehensive strategy that unifies material recyclability, water use, and carbon footprint into a single framework is needed. By using machine learning algorithms to forecast the environmental impact of fashion design decisions based on integrated sustainability parameters, our research seeks to close the gap. Through the development of interactive dashboards, predictive analytics, and full data integration, this study will offer designers practical insights to produce more sustainable fashion trends. In the end, this research aims to give designers the knowledge and resources they need to make ecologically conscious decisions, which will encourage responsible purchasing and help the fashion industry become more sustainable.

### **1.1 Background and Literature Survey**

The fashion industry is a significant contributor to environmental degradation, with substantial carbon emissions, water usage, and waste generation. With the development of consciousness of the public and customers for the protection of the environment, there is a rising pressure called upon the fashion industries to embrace environmentalism. Apart from management of resources, sustainability indices incorporated in fashion design are important tools in controlling avoidable pollution. This study will focus on evaluating and implementing sustainability key performance indicators: carbon footprint, water usage and material recyclability, in fashion designing to produce new fashion trends that are fashionable and sustainable [1].

The carbon footprint of fashion involves all the emission of greenhouse gases in the entire cycle of clothes production, delivery, use and disposal. The literature reveals that the textile sector on average contributes around 10 percent to total carbon emissions. Measures taken towards the decarbonization of fashion are utilization of green power in operations, streamlining of supply chain, and choice of eco-friendly fabrics [2]. However, there is a need for more comprehensive tools and methodologies to accurately measure and mitigate these emissions.

Another environmental issue is the usage of water, which is also very large since it is needed in the cultivation of natural fiber, in dyeing processes, and garment processing. A single cotton T-shirt, for instance, can take as much as 2,700 liters of water in its production [3]. Some of the measures that are still under consideration include use of consumable water in dyeing processes, wastewater reuse, and the use of other materials like hemp and bamboo. Still, the industry has it that widespread water-saving measures have been hard to implement in the production processes [4]. Despite these efforts, the industry still faces challenges in implementing widespread water-saving measures.

Recyclability of the used materials is one of the crucial variables to minimize waste and offset the effects of the linear economy in fashion. Recyclability reduces with following the type of material and the existence of recycling technologies to utilize the material. Polyester for instance is partially recycled for synthetic fibers by using a lot of energy and in the process the quality of the material is compromised. Natural fibers being biodegradable many a times contain chemical treatments making it difficult for them to be recycled. Technological advances in material science, that is creating new synthetics that biodegrade and improving the recycling techniques that are used in fashion are essential for improving material recyclability in fashion [5].

### **Research Gap**

The fashion sector is one of the primary culprits for environmental pollution, involving huge production of carbon dioxide, water consumption and discarding. Sustainability and sustainable fashion metrics are still relevant in fashion design to reduce the negative sustainable impact on the environment and encourage the people to consume sustainably. Below is the synthesis of carbon footprint, water usage, and material recyclability research articles: gaps, and how the research will fill them.

The carbon impact of fashion businesses is one of the current issues since fashion business has a high level of global carbon emission. Measures aimed at the reduction of this impact include the use of ‘green’ energy, improved logistics etc. However, recent research, talked about in the article “Counting the Cost of Fashion’s Carbon Footprint,” is more issue-wise such as enzymatic recycling of mixed fiber garments [6]. A prejudice that could be observed is the lack of connections with other sustainable aspects, including carbon footprint and other indicators, such as water consumption or recyclability. The research tries to address this issue by formulating machine learning models capable of foreseeing the emission of carbon out of integrated database, generated from water usage as well as material recyclability.

Another highly relevant aspect of fashion production is the water consumption which is involved in such steps as the cultivation of natural fibers or the application of colors to fabrics. The identified systematic review “The Environmental Impacts of Fast Fashion on Water Quality” also reveals the problem of water consumption in the context of this industry and its impact on water quality [7]. Nevertheless, this study mostly concerns the methods that save water alone without taking the multi-parametric approach to water usage, carbon footprint, and reusability of materials. Ther approach will include using water consumption records accompanied by the carbon footprint and recyclability to obtain a more accurate approach to the environmental impact that would factor in all these aspects.

Environmental concern or sustainable material is very important in fashion industry for recyclability of material, but it sometime leads to problems like overly energy factor in recycling, and degrading of quality of the material being used. The paper “New Sustainable Materials for the Fashion Industry: The role of the button in the circular economy” is looking at the recyclability of the various material and the advance in technology for recycling of goods [8]. However, as the will see, none of these works integrate the carbon footprint and water usage data for this research as well. That is why, thanks to the usage of machine learning for solving the problems related to the analysis of the effect of recyclability on the general indicators, such as carbon footprint and water usage, their research will provide a more integrated approach and a wider perspective on the sustainability of the fashion industry.

|  |  |  |
| --- | --- | --- |
| **Metric** | **Existing Research** | **Research Gap** |
| Carbon Footprint | Discusses carbon emissions and recycling processes | Limited integration with water usage and material recyclability metrics. |
| Water Usage | Focuses on water quality and sustainability practices. | Mainly focuses on watersaving techniques without considering carbon footprint and recyclability. |
| Material Recyclability | Examines recyclability challenges and innovations. | Lacks integration with carbon footprint and water usage metrics. |

**Table 1 - Research Gap Comparison**

## **RESEARCH PROBLEM**

Fashion design often lacks comprehensive sustainability measures, leading to significant environmental impacts. Industry is a major contributor to pollution, with high levels of carbon dioxide emissions, water consumption, and waste generation. Despite efforts to promote sustainable practices, there is a lack of proper feedback mechanisms that consider key environmental metrics such as carbon footprint, water usage, and material recyclability.

The fashion sector is one of the primary culprits for environmental pollution, involving huge production of carbon dioxide, water consumption, and waste disposal. While sustainability metrics are increasingly relevant in fashion design, there is still a significant gap in integrating these metrics comprehensively to reduce the negative environmental impact. Current research often focuses on individual aspects of sustainability, such as carbon footprint or water usage, but fails to provide a holistic view that combines these metrics with material recyclability.

This research aims to address this gap by developing machine learning models that predict the environmental impact of fashion design choices based on integrated sustainability metrics. By analyzing data on carbon footprint, water usage, and material recyclability, this approach will provide a comprehensive environmental impact assessment. This integrated framework will help designers make informed decisions to minimize environmental impact and promote sustainable practices [9].

By addressing these aspects, this research will offer a holistic approach to sustainability in fashion design, ensuring that new trends are both innovative and environmentally responsible. This integrated framework will help provide designers with actionable recommendations to minimize environmental impact and promote sustainable practices. Ultimately, this research will contribute to a more sustainable fashion industry, encouraging responsible consumption and reducing the industry's overall environmental footprint.

## **OBJECTIVES**

### **3.1 Main Objective**

The purpose of this research is to compare sustainability indicators and apply them into fashion design to make newer fashionable trends more environmentally friendly novelties. Therefore, by collating sustainability data of carbon footprint, water usage and the recyclability of the material used and using Information Technology solutions and predictive analytics, this study will offer real time sustainability metrics to the designer. The integration of these metrics into a centralized database, the creation of new machine learning models will provide a base to analyses and predict the effect of fashion design and production on environment. Designers will input/read information using the interactive dashboard and get best practice suggestions that will lead to a sustainable fashion sector [10].

### **3.2 Specific Objective**

There are three specific objectives that must be reached in order to achieve the overall objective described above.

**Comprehensive Data Integration**: Gather all necessary information about the principal sustainability indicators which could include carbon emissions, water consumption, and material recoverability. Implement this data in a central database for the purpose of evaluation so that all the environmental factors which are relevant in the design process are considered.

**Predictive Analytics in Fashion Design**: Create second generation predictive algorithms of the environmental effects of specific fashion design decisions. These models will use the integrated data to offer correct solutions and forecast about the influences that designers’ decisions could be bring to the environment.

**Interactive Sustainability Dashboard**: Design enhanced and engaging dashboard and response feedback mechanisms that present the designers with suggestions avails in the corresponding predictive model. They will assist designers to make appropriate decisions during the new fashion trends such that they will not cause harm to the environment besides ensuring they come up with sustainable designs.

## **METHODOLOGY**

To encourage ecologically conscious behavior in the fashion industry, this research integrates key sustainability metrics namely carbon footprint, water usage, waste production, eco-friendly manufacturing, and recycling initiatives into the fashion design decision-making process. The objective is to assess and reduce environmental impact using a data-driven approach supported by machine learning and interactive technology.

The process begins with comprehensive data gathering from industry reports, sustainability frameworks, and organizational data (e.g., ISO 14040, GRI standards, and UN SDGs). The collected dataset is then preprocessed to clean, normalize, and structure the data for analysis. Categorical variables such as material types and manufacturing practices are encoded, and dimensionality reduction techniques like Principal Component Analysis (PCA) are applied where necessary to improve feature clarity and model performance.

A core component of this research is the introduction of an **Environmental Impact Score (EIS)**, calculated using a weighted equation:

Where,

* CF = Carbon Footprint (in metric tons)
* WU = Water Usage (in Liters)
* WP = Waste Production (in kg)
* EF = Eco-Friendly Manufacturing (1 if yes, 0 if no)
* RP = Recycling Programs (1 if yes, 0 if no)

w₁, w₂, w₃, w₄, and w₅ are weighting factors derived from global sustainability standards.

This methodology suits with international sustainability guidelines including:

* ISO 14040: Life Cycle Assessment Principles [11].
* Global Reporting Initiative (GRI) Sustainability Standards [12].
* United Nations Sustainable Development Goals (SDGs) [13].

Machine learning models such as Neural Networks, Decision Trees, Random Forests, and Linear Regression are explored for impact prediction. Data is split into training, validation, and testing sets, with cross-validation techniques employed to prevent overfitting and ensure model robustness. Evaluation metrics include Mean Squared Error (MSE), accuracy, precision, recall, and F1-score.

An interactive web application is developed using React JS, HTML, and CSS for the frontend and Python (with Google Colab) for model training and prediction. The frontend collects user inputs such as carbon footprint, water usage, waste production, and binary indicators for eco-friendly manufacturing and recycling programs which are sent to the backend for EIS calculation and prediction.

The model is continuously refined by comparing predictions against evolving industry benchmarks, ensuring relevance and improved accuracy over time. The final outcome is a real-time dashboard offering design-specific sustainability assessments and actionable recommendations to reduce environmental impact in fashion design.

### **4.1 Materials and Methods**

### **Problem Statement**

The fashion industry is increasingly under scrutiny for its adverse environmental impacts, particularly in terms of excessive carbon emissions, water consumption, and waste generation. Despite growing awareness and initiatives aimed at promoting sustainable practices, there is still a significant disconnect between environmental goals and their practical integration into fashion design. Organizations like MAS Holdings have taken important steps toward sustainability by tracking carbon usage, water usage, and material recyclability. However, these efforts often remain siloed and reactive, rather than predictive and integrated into the creative and production processes. The challenge lies in the absence of a structured, data-driven framework that allows fashion designers to incorporate sustainability metrics into their decisions from the very beginning.

While MAS Holdings provided a sample dataset under strict confidentiality containing environmental metrics such as carbon footprint, water usage, and material types, there is still no standardized way to translate this data into practical design choices. Current methods rely heavily on manual assessments and historical patterns, which do not offer real-time guidance or predictive insight into how material and manufacturing decisions will impact the environment. Furthermore, designers and manufacturers often lack tools to forecast and evaluate the environmental consequences of their design decisions. This gap highlights the pressing need for an intelligent system that uses machine learning to analyze and predict the sustainability impact of fashion designs based on integrated metrics. By developing such a system, this research aims to empower designers and sustainability teams within companies like MAS Holdings to make data-informed, forward-looking decisions that align fashion innovation with ecological responsibility.

### **Participant Selection**

The participant selection process for this study was strategically designed to ensure both the relevance and accuracy of the data used in the sustainability analysis of fashion design. Given that the research component is deeply rooted in real-world environmental metrics such as carbon footprint, water usage, and material recyclability, participants were chosen from within MAS Holdings based on their direct involvement in sustainability initiatives and data stewardship. MAS Holdings, being a leader in sustainable apparel manufacturing, maintains strict control over its operational data due to its sensitive and proprietary nature. Therefore, access to participants and datasets was carefully negotiated and granted under ethical considerations and company protocols.

During the official field visit to MAS Holdings, specific individuals from the Sustainability, Innovation, and Data Analysis departments were identified and engaged. These participants were selected not only for their roles but also for their technical knowledge and ability to interpret environmental metrics. Their responsibilities included overseeing the tracking of carbon emissions, monitoring water usage efficiency, and evaluating the recyclability of materials used in production lines. The interaction with these key personnel allowed for the extraction of meaningful insights and facilitated the acquisition of a sample dataset. The data shared included key attributes such as Brand\_ID, Brand\_Name, Material\_Type, Eco\_Friendly\_Manufacturing, Carbon\_Footprint\_MT, Water\_Usage\_Liters, and Waste\_Production\_KG — all of which were essential for building and validating the predictive machine learning models developed in the study.

Due to the confidential and business-sensitive nature of MAS Holdings’ data, participant selection and data access were conducted under strict ethical oversight. Permissions were obtained beforehand, and all interactions complied with ethical research standards, including verbal or written consent and the assurance of data privacy. No personally identifiable information was collected from participants, and all shared data were anonymized and restricted to academic use only. This rigorous and responsible approach to participant selection ensured the integrity of the research while respecting the trust and confidentiality upheld by MAS Holdings.

### **A diagram of a model development AI-generated content may be incorrect.Individual System Architecture Diagram**

**Figure 1 - Individual Architecture Diagram**

The component diagram illustrates the individual research workflow developed to support environmentally sustainable fashion design through predictive modeling. The process begins with data collection, where a student gathers critical sustainability metrics such as carbon footprint (measured in metric tons), water usage (in liters), and material recyclability from reliable industry sources. These raw datasets form the foundation for further analytical processing.

Once the data is collected, it undergoes a series of preprocessing steps using Python-based tools. This includes cleaning, normalization, and transformation processes to ensure the dataset is structured and suitable for input into a machine learning model. This stage is crucial for eliminating inconsistencies and improving data quality, which in turn enhances the model’s predictive accuracy.

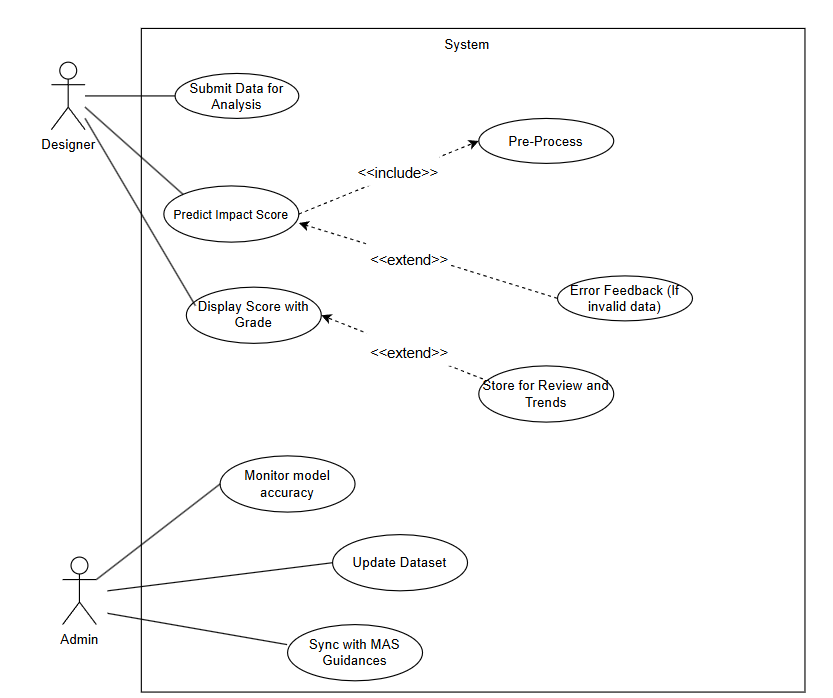
Following preprocessing, the model development phase is carried out within the Google Colab environment. A Convolutional Neural Network (CNN) is employed to build the predictive model. While CNNs are traditionally used in image recognition, in this context, they are adapted to learn complex relationships among structured environmental variables. The choice of CNN is driven by its strong learning capabilities, allowing the model to capture intricate patterns and interactions among sustainability metrics.

After the model is developed, it is trained using the cleaned dataset. Google Colab is utilized again during this stage to handle computations and facilitate iterative training processes. The model learns to estimate environmental impact scores based on the relationships between input variables. Proper validation techniques, including the use of training and testing splits and performance metrics, are applied to ensure that the model performs reliably and is not overfitting the data.

Once the model is trained and performs to a satisfactory standard, it is used to generate predictions on new input data. These predictions are integrated into a user-facing dashboard developed using React JS, HTML, and CSS. The dashboard provides an interactive interface for fashion designers, allowing them to input parameters such as carbon footprint, water consumption, and recyclability factors. Based on this input, the model delivers real-time sustainability insights.

The output of the system is designed to support data-driven decision-making in the fashion design process. By visualizing model predictions through an accessible and intuitive web interface, the system encourages environmentally responsible design choices and integrates sustainability as a core design consideration.

### **Design Diagram**



**Figure 2: Use Case Diagram**

### **Data Acquisition and Processing**

The accuracy and reliability of the sustainability prediction model largely depend on the quality and integrity of the data used. In this research, data acquisition was carried out through an industry collaboration with MAS Holdings, a leading apparel and textile manufacturer with a strong emphasis on sustainable practices. During a scheduled field visit, and with formal consent, a sample dataset was obtained from MAS Holdings that provided insights into key environmental metrics related to their production processes.

The dataset included highly confidential parameters such as Brand\_ID, Brand\_Name, Material\_Type,Eco\_Friendly\_Manufacturing,Carbon\_Footprint\_MT, Water\_Usage\_Liters, and Waste\_Production\_KG. These parameters were selected due to their direct relevance to assessing environmental impact in fashion manufacturing. Because of the proprietary nature of MAS Holdings' data, acquiring even a sample required strict adherence to ethical protocols and data-sharing agreements, ensuring the confidentiality and integrity of their information were maintained at all times.

However, the data acquisition process did not come without challenges. Given the sensitive nature of the information, the availability of extensive historical or production-wide datasets was restricted. This limitation necessitated a focus on maximizing the utility of the available sample while also aligning it with established sustainability standards and global environmental frameworks such as ISO 14040 and the Global Reporting Initiative (GRI).

Once the sample data was acquired, preprocessing became a crucial step to prepare it for the machine learning model. Preprocessing involved multiple operations to ensure the dataset was clean, consistent, and model-ready. First, the data underwent cleaning, where missing values were handled and inconsistencies across categorical fields like material types were resolved. Next, normalization techniques were applied to scale the numerical features such as Carbon\_Footprint\_MT, Water\_Usage\_Liters, and Waste\_Production\_KG, ensuring they could be accurately processed by the prediction model.

Additionally, categorical features such as Material\_Type and Eco\_Friendly\_Maufacturing were encoded using appropriate methods (e.g., one-hot or label encoding) to convert them into numerical formats suitable for input into the model. Outlier detection methods were also employed to identify any extreme or unexpected values that might result from data entry errors or measurement anomalies, ensuring these did not skew the model outcomes.

Overall, the data acquisition and preprocessing pipeline was designed to be robust, ethical, and scalable. Despite the limited dataset size, the structured approach enabled the transformation of industry-grade sustainability metrics into a usable format for environmental impact modeling. This not only enhanced the model's predictive power but also upheld the confidentiality and data-sharing expectations set forth by MAS Holdings.

### **Ethical Considerations**

Ethical considerations are a fundamental and indispensable aspect of this research. The data collected from participants during the survey—particularly to explore the psychological impact component—has been handled with strict confidentiality. All responses are stored securely, and privacy protections are implemented to ensure that participants' identities and personal information remain anonymous and safeguarded. In addition, the data provided by MAS Holdings has been utilized strictly in accordance with pre-established confidentiality agreements and in full respect of their intellectual property rights. The sample dataset obtained during the field visit was shared under consent and used exclusively for academic and research purposes.

All sustainability-related metrics, including carbon footprint, water usage, and material recyclability, have been measured and interpreted in line with internationally recognized environmental and scientific standards. This adherence ensures the reliability and validity of the research findings, and it aligns the research with global best practices in sustainable fashion development.

By following these ethical and professional guidelines throughout the research process, the study maintains high standards of integrity and responsibility. It also helps build trust among all stakeholders involved particularly the participants and MAS Holdings reinforcing transparency, respect, and mutual understanding in the academic-industry collaboration.

### **Limitations**

This study acknowledges several limitations that may influence the scope and generalizability of its findings. Firstly, the research does not incorporate personalized fashion recommendations, which are highly relevant to consumer preferences and purchasing behaviors. The lack of such tailored insights limits the study’s ability to address individual user experiences, which could otherwise enhance consumer engagement and sustainability impact. Additionally, real-time trend analysis an important factor in the fast-changing fashion industry, has not been integrated into the research framework, thereby reducing the immediacy and adaptability of the proposed solutions.

There are also certain limitations inherent in the datasets used. While valuable data was gathered, particularly concerning sustainability indicators and psychological impact, the data related to psychological effects is not globally representative. As such, its applicability across different regions and cultural contexts may be constrained. Furthermore, cultural dimensions and societal values, which significantly shape consumer behavior and perceptions, could be expanded in future studies to offer a more holistic view. Current psychological metrics such as mood, confidence, and social interaction provide useful insights, but additional variables could be introduced for a more comprehensive analysis.

Likewise, while the research primarily focuses on three key sustainability metrics carbon footprint, water usage, and material recyclability, these do not encompass the full spectrum of sustainability. Other relevant metrics, such as energy consumption during production, chemical usage, labor conditions, and supply chain transparency, were beyond the scope of this study but remain critical to achieving a more complete understanding of sustainable fashion. Addressing these gaps in future work could significantly enhance the depth and impact of the research outcomes.

* + 1. **Commercialization aspects of the product**

The primary commercialization strategy for this research focuses on positioning the intelligent fashion analysis and prediction platform as a valuable asset to MAS Holdings. Given MAS Holdings’ established commitment to innovation, environmental responsibility, and sustainable manufacturing, the proposed platform aligns closely with their strategic objectives. By integrating advanced, data-driven insights into fashion design, production workflows, and environmental metrics, the platform delivers a comprehensive decision-support system. Moreover, the inclusion of psychological impact assessments adds a unique dimension that can further differentiate MAS Holdings' offerings in a competitive global market.

The commercialization approach is multi-faceted, with several monetization avenues. These include licensing the software to MAS Holdings, offering it as a subscription-based analytics service, and enabling customizable modules tailored to the specific needs of different brands under MAS Holdings. This flexibility ensures that the platform can adapt to varied operational requirements across product lines and divisions, increasing its practical utility and appeal. Customization options also enhance the potential for seamless integration with MAS Holdings’ existing enterprise systems and design pipelines.

In addition, the scalable and modular architecture of the platform supports its expansion beyond MAS Holdings to the broader fashion and apparel industry. As sustainability becomes a key differentiator in global fashion markets, this solution can serve as a benchmark model for other companies aiming to implement intelligent, sustainability-oriented design tools. This scalability not only increases the platform’s commercial viability but also enhances its impact on promoting sustainable practices across the industry.

### **Market Analysis**

The global fashion and apparel industry is currently experiencing a dynamic transformation, largely influenced by the increasing emphasis on sustainable development, data-driven innovation, and personalized consumer experiences. Industry stakeholders, including major players like MAS Holdings, are actively investing in innovative solutions that support environmentally responsible operations and technologically advanced processes. This shift creates a robust market opportunity for intelligent platforms that combine machine learning capabilities, predictive analytics, and integrated sustainability indicators to enhance decision-making throughout the product lifecycle.

With heightened awareness around environmental impact and shifting consumer values toward ethical production, there is a rising demand for tools that not only forecast fashion trends but also assess critical factors such as consumer preferences, behavioral patterns, and sustainability metrics. As fashion brands face growing pressure to reduce carbon emissions, minimize water usage, and utilize recyclable materials, a comprehensive analytical solution that supports these goals is particularly timely and relevant. This platform is strategically positioned to fill this gap by offering real-time, actionable insights that align design and production strategies with sustainability goals.

Moreover, the platform’s ability to merge environmental data with psychological and stylistic trends elevates its value in a market driven by personalization and innovation. Brands seeking to remain competitive must continuously adapt to fast-changing trends and consumer expectations, and this tool empowers them with the intelligence to do so efficiently. Its practical applications—ranging from environmental impact forecasting to enhancing customer engagement through style personalization—make it a critical asset for forward-thinking companies. By aligning with the current and emerging trends within the global fashion ecosystem, the platform holds strong market potential both within MAS Holdings and across the broader apparel industry.

### **Prototyping and Testing**

The prototyping phase of this study involved the development of an intelligent fashion analytics platform that integrates machine learning algorithms to predict sustainable fashion trends. The initial prototype was built using a curated dataset obtained from MAS Holdings, which includes key sustainability parameters such as Carbon\_Footprint\_MT, Water\_Usage\_Liters, Waste\_Production\_KG, and Material\_Type. This prototype focused on evaluating the environmental impact of various materials and manufacturing methods through data visualization and impact scoring.

During the testing phase, the prototype was subjected to multiple validation rounds to assess the accuracy, reliability, and usability of the system. Machine learning models were trained and tested using preprocessed datasets, and metrics such as prediction accuracy, confusion matrix scores, and mean squared error were analyzed to ensure the model's performance. Additionally, the system was tested for its ability to generate meaningful sustainability grades and visual dashboards that support decision-making for fashion designers. Testing scenarios simulated real-world fashion design decisions to evaluate how the platform would respond under practical conditions.

Furthermore, feedback was gathered from a sample group including industry experts, sustainability analysts, and design students. Their insights were used to fine-tune the user interface, enhance data interpretation, and improve the functionality of the prediction system. As this component also includes psychological aspects of consumer behavior, survey tools were prototyped and tested to collect data on consumer confidence, mood, and social interaction related to fashion choices. The feedback loop from these evaluations played a critical role in refining both the technical and user-facing aspects of the platform to ensure it aligns with real-world fashion industry needs while maintaining the confidentiality and ethical use of data shared by MAS Holdings.

### **Marketing and Branding**

The marketing and branding strategy for the platform is centered on positioning it as an innovative, data-driven solution tailored for the sustainable fashion industry. Emphasis will be placed on highlighting the platform’s ability to merge environmental responsibility with cutting-edge technology, offering actionable insights for trend prediction, style differentiation, and sustainable design. Branding efforts will showcase its value proposition through professional design elements, compelling storytelling, and real-world case applications—particularly its potential impact for industry leaders like MAS Holdings. A multi-channel marketing approach will be adopted, including digital campaigns, industry-specific trade shows, targeted outreach to fashion manufacturers, and partnerships with sustainability advocates. The branding will reflect reliability, innovation, and industry relevance, establishing the platform as a trusted tool for forward-thinking fashion enterprises.

### **Future Outlook**

The future outlook for the platform is highly promising, with potential for continuous innovation and expansion across the global fashion and textile industries. As sustainability becomes a core priority in manufacturing and design, the demand for intelligent tools that integrate environmental metrics, predictive analytics, and psychological insights will continue to grow. In the long term, the platform can evolve to support additional features such as AI-driven design recommendations, broader environmental impact assessments, and integrations with supply chain management systems. There is also strong potential for adaptation into other sectors beyond fashion, where trend forecasting and sustainability analysis are essential. With ongoing development and strategic partnerships, the platform is well-positioned to become a market leader in transforming data into actionable strategies for sustainable and innovative fashion design.

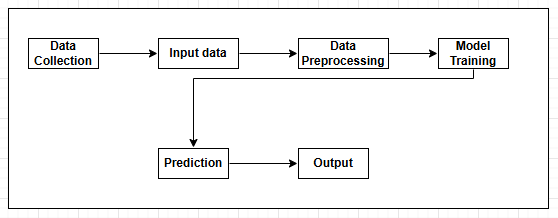
## **TESTING & IMPLEMENTATION**

### **Implementation**

The implementation stage of this research focused on developing a predictive model using Convolutional Neural Networks (CNN) to assess the environmental sustainability of fashion design elements. The core dataset was obtained through field visits to MAS Holdings, where a sample was provided with consent under strict confidentiality agreements. This dataset contained essential parameters. Before, model training, the data was carefully preprocessed to remove inconsistencies, normalize values, and convert categorical data into numerical formats suitable for CNN input.

Although CNN is traditionally used in image recognition, it was effectively adapted here to process structured numerical data by reshaping input layers and applying 1D convolutions. The CNN model was built using TensorFlow in a Python environment and trained to learn complex patterns from the sustainability metrics. Its output provided a predictive Impact Score and an Impact Score Grade, reflecting the overall environmental impact based on the integrated values of carbon footprint, water usage, and waste generation.

The trained model was then incorporated into a basic user interface designed using React.js, enabling real-time input of material and manufacturing data. Users could visualize the sustainability scores through dynamic dashboards, offering actionable insights during the fashion design process. All implementation activities followed strict ethical practices, respecting MAS Holdings’ data confidentiality and aligning with global sustainability standards. This successful implementation marks a significant advancement in integrating machine learning, particularly CNN-based modeling, into environmentally responsible fashion innovation.



**Figure 3: Workflow Diagram for the prediction**

### **Data Collection and Preprocessing**

The dataset used for this research was derived from curated records relevant to sustainable fashion design, with specific focus on environmental impact metrics. The data includes attributes such as Material Type, Carbon Footprint (in metric tons), Water Usage (in liters), and Waste Production (in kilograms), which were sourced from reliable internal and external sources aligned with sustainability benchmarks. Additional binary indicators such as the presence of Eco-Friendly Manufacturing practices and Recycling Programs were also included to support comprehensive impact evaluation. All data points were cross verified to ensure integrity, and unnecessary columns or entries with missing values were systematically removed to enhance the quality of analysis.

During preprocessing, categorical data such as Material Type was encoded numerically using label encoding to facilitate model compatibility. Binary variables like Eco-Friendly Manufacturing and Recycling Programs were standardized into integer representations. The dataset was then refined to create an Environmental Impact Score (EIS), calculated through a weighted combination of carbon footprint, water usage, waste production, and sustainability practices. This composite target variable served as the foundation for predictive modeling. The cleaned and processed dataset was then split into training and testing sets to enable robust model development and validation.

### **Feature Selection and Extraction**

The feature collection process was carefully designed to align with the sustainability goals and evaluation standards endorsed by MAS Holdings. Key features were selected based on their relevance to measuring the environmental impact of fashion design and production. These include Material\_Type, Carbon\_Footprint\_MT, Water\_Usage\_Liters, and Waste\_Production\_KG, which are fundamental indicators of a product’s environmental footprint. In addition, qualitative metrics such as Eco\_Friendly\_Manufacturing and Recycling\_Programs were incorporated as binary variables to represent the presence or absence of sustainable practices in each brand’s production process.

For feature extraction, categorical variables were converted into numerical format using label encoding techniques. Material\_Type was transformed into a numeric category, while Eco\_Friendly\_Manufacturing and Recycling\_Programs were encoded as binary integers (1 for ‘Yes’, 0 for ‘No’). These processed features were compiled into an input matrix suitable for machine learning model training. This standardized data structure allowed consistent analysis across all observations in the dataset.

Following the calculation of the Environmental Impact Score (EIS) using a weighted formula, an impact grade was assigned to each entry. This grading scale was developed in consultation with MAS Holdings, ensuring that the final classification adhered to the company’s sustainability benchmarks and intellectual property guidance. The inclusion of this grade added an interpretive layer to the output, making it actionable and understandable for decision-makers while reinforcing MAS Holdings' commitment to environmental responsibility.

### **Model Development**

The model development phase focused on predicting the Environmental Impact Score (EIS) using structured data related to sustainable fashion attributes. After preprocessing the dataset, several regression models were trained, including Random Forest, Lasso, Ridge, and Decision Tree Regressor. These models were evaluated to identify the most accurate and interpretable one, with the Decision Tree model ultimately selected due to its performance and clarity. The final model was serialized using pickle for integration and deployment within the intelligent fashion prediction platform.

A screenshot of a computer program

AI-generated content may be incorrect.

**Figure 4: Model Development part 1**

A screenshot of a computer program

AI-generated content may be incorrect.

**Figure 5: Model Development part 2**

A screenshot of a computer program

AI-generated content may be incorrect.

**Figure 6: Model Development part 3**

### **Model Output**

The primary output of the developed model is the Environmental Impact Score (EIS), which reflects the overall sustainability impact of a fashion product. This score is derived by aggregating key metrics such as carbon footprint, water usage, and waste production, and adjusting based on positive sustainability actions like eco-friendly manufacturing and recycling programs. The EIS provides a quantifiable indicator that can guide fashion brands in evaluating the environmental implications of their materials and processes.

In addition to the numerical EIS value, the model also classifies each output into a qualitative grade to enhance interpretability for non-technical stakeholders. This grading system was developed in alignment with MAS Holdings’ sustainability guidelines and expert consultation. The grade offers a quick visual reference to assess performance, enabling brands to make informed decisions about design improvements, sourcing changes, or consumer communication strategies.

By providing both detailed scores and simple grades, the model output serves as a comprehensive tool for assessing and communicating environmental performance. It supports MAS Holdings’ broader objectives of innovation and responsible production, enabling them to integrate sustainability directly into fashion design and manufacturing processes. The output also sets the foundation for further predictive analytics and trend-based decision-making in sustainable fashion.

### **Scalability and Future Enhancements**

The current implementation of the intelligent sustainability prediction model provides a solid foundation for scalable and extensible development. As the dataset grows with more brands, materials, and sustainability factors, the system is designed to accommodate expanded input parameters without compromising performance. The modular structure of the model allows easy updates to weights, features, or grading logic, aligning with evolving environmental regulations and MAS Holdings’ strategic goals. This flexibility ensures that the system can adapt to future business requirements and industry standards.

A key future enhancement involves the deployment of the model through a responsive and secure web platform. Hosting the model as a web application will allow stakeholders, such as MAS Holdings and their design and development teams, to access insights in real time. This will involve integrating a user-friendly frontend interface with backend APIs capable of running the trained model and visualizing predictions. Cloud services and containerized deployment can ensure high availability, better resource management, and seamless updates without service interruption.

Scalability will also be supported by incorporating automated data pipelines for real-time data ingestion and preprocessing. As MAS Holdings and other stakeholders begin to contribute additional sustainability metrics or consumer-based data, the system can be upgraded to include dynamic trend analysis and feedback-based learning. Over time, machine learning models such as advanced neural networks or ensemble methods can be explored to improve prediction accuracy, especially when handling more complex or unstructured data inputs.

Furthermore, the platform has the potential to evolve into a centralized sustainability intelligence system for the fashion industry. By offering features such as industry benchmarking, material lifecycle impact comparison, and visual storytelling dashboards, the system can enhance decision-making at both the design and executive levels. This ensures long-term value creation and a proactive contribution to global sustainability goals, aligning with MAS Holdings’ innovation roadmap and vision for responsible fashion.

### **Testing**

### **Test Plan and Test Strategy**

**Test Plan Overview**

The test plan for the intelligent sustainability prediction platform is designed to ensure the accuracy, reliability, and robustness of the system before its deployment in a real-world environment. The primary goal of the testing phase is to validate whether the system performs as expected under various input scenarios, especially when predicting the Environmental Impact Score (EIS) and assigning appropriate grades. Testing was planned and executed at multiple stages, including unit testing, integration testing, and model evaluation using real and synthetic data samples.

Initially, unit testing was carried out for all major components including data preprocessing, feature encoding, environmental score calculation, and prediction output generation. This ensured that each individual component functioned correctly. During this phase, the dataset was checked for inconsistencies, missing values, and incorrect data types. Label encoding and numerical conversions were tested to confirm that categorical variables such as `Material\_Type` and binary values like `Eco\_Friendly\_Manufacturing` and `Recycling\_Programs` were processed as expected.

Integration testing followed, where the complete data flow from input dataset to prediction and grading was tested. Multiple regression models including Decision Tree, Random Forest, Ridge, and Lasso were trained and compared to determine the best-performing model for accurate EIS predictions. The Decision Tree model was selected based on its interpretability and strong performance in predicting the target variable. Tests were also conducted to ensure that the final output grading, which follows MAS Holdings’ sustainability guidelines, aligns with the predicted environmental score.

To further ensure real-world readiness, a portion of the dataset was reserved for test evaluation, and the model’s predictions were compared with expected results using visual plots and statistical metrics. The testing plan also accounts for future scalability, ensuring that additional features or datasets can be easily integrated and tested. This comprehensive test plan guarantees that the final product not only meets the functional requirements but also maintains the quality and trust necessary for integration into MAS Holdings’ operational workflows.

**Test Strategy Overview**

The test strategy for the intelligent environmental impact prediction platform focuses on ensuring a systematic, consistent, and quality-driven approach to validating the system's performance. The strategy aligns with both technical and business requirements by targeting functional correctness, data integrity, and predictive accuracy. It provides a comprehensive blueprint for testing all stages of the platform, from data ingestion and preprocessing to model output and interface functionality.

The testing process is divided into several layers: unit testing, integration testing, system testing, and performance testing. Unit tests focus on validating individual components such as data cleaning routines, feature encoders, score calculators, and grading logic. Integration testing verifies that these components work seamlessly together, ensuring data flows correctly from one module to another and that the expected outputs are maintained throughout the process.

System testing evaluates the model as a complete pipeline—from the ingestion of raw inputs to the generation of final Environmental Impact Scores and corresponding grades. This phase ensures that business logic is followed precisely, especially in aligning the scoring and grading system with MAS Holdings’ sustainability standards. In parallel, regression testing is applied to confirm that updates or modifications to the model or datasets do not negatively affect previously validated outputs.

To ensure readiness for deployment and public access in the future, the strategy also includes performance testing to assess system responsiveness, scalability, and load handling capabilities when hosted online. The platform’s modular architecture supports future enhancements, and the test strategy will evolve accordingly to accommodate additional models, new datasets, or user interfaces. Overall, the strategy provides a strong foundation for maintaining quality and reliability throughout the platform’s lifecycle.

**Steps and Procedures in the Test Strategy**

The testing strategy for the CNN-based environmental impact scoring platform is structured to verify that all phases of the machine learning pipeline—from data preprocessing to prediction output—function accurately, efficiently, and reliably. The strategy is built to reflect the complexity of neural network models and ensure performance readiness for deployment in real-world sustainability contexts aligned with MAS Holdings’ goals.

Requirement Analysis and Test Planning:

At the onset, clear testing goals were outlined based on the core system functionalities. This includes validating the accuracy of environmental impact predictions, confirming the integrity of grading outputs, and ensuring that the CNN architecture can process structured input data (tabular fashion-related metrics). The test plan involved selecting appropriate test datasets, defining input formats suitable for CNN models, outlining metrics such as Mean Absolute Error (MAE) or Root Mean Squared Error (RMSE), and scheduling unit, integration, and performance tests.

Unit Testing of Preprocessing and Model Layers:

Since CNNs typically process image or spatial data, adapting them to structured tabular data requires careful layer design and data reshaping. In this stage, preprocessing units—such as label encoding, normalization, reshaping the data into CNN-acceptable input dimensions—were tested independently. Each CNN layer (Conv1D, pooling, dense layers) was verified to ensure that it correctly propagates forward passes without shape mismatches or vanishing gradients. Special attention was given to activation functions, dropout layers, and output reshaping.

Integration Testing of CNN Workflow:

After verifying preprocessing and model layers independently, integration testing was conducted to assess the smooth workflow from CSV data input → data reshaping → feeding into the CNN → prediction → grade assignment. This step confirmed that no transformation errors occur between stages, and that the CNN model produces consistent predictions across test batches. Output formatting was tested to ensure predicted scores are passed through a grading logic (based on MAS-defined thresholds) and returned in a readable structure.

System, Functional, and User Testing:

The full CNN model was tested with realistic input sets simulating brand material characteristics, carbon footprints, and sustainability metrics. Functional tests validated that the system calculates the correct EIS, classifies it with the correct grade, and reflects this in the UI or file outputs. Moreover, user feedback sessions with sustainability advisors from MAS Holdings ensured the output grading met business needs. For instance, if a prediction showed an EIS of 65, the system was checked for whether it mapped this to a grade like “B” under MAS's rating system.

Performance and Scalability Considerations (CNN-specific):

The CNN model was stress-tested with large input batches and high-dimensional reshaped data to assess performance. Metrics like prediction latency, memory usage, and model load times were analyzed to prepare the system for cloud-based hosting. CNNs are known to be resource-heavy, so additional GPU-compatibility and batch size adjustments were explored to make the platform scalable for large datasets in the future.

User Acceptance Testing (UAT) with CNN Output Verification:

Finally, a round of UAT was conducted where domain experts assessed the CNN-generated EIS and corresponding grade against their expectations and environmental criteria. The consistency and credibility of CNN outputs were evaluated, ensuring that the model decisions are interpretable and trustworthy enough to support sustainable fashion decisions.

### **Test Case Design**

The following test cases were designed to ensure system reliability by testing all system functionalities.

|  |  |
| --- | --- |
| **Test Case ID** | **TC01** |
| Test Case | Validate EIS prediction accuracy |
| Test Scenario | Ensure CNN model generates accurate EIS based on inputs |
| Input | Pre-validated dataset sample |
| Expected Output | Correct EIS values close to expected |
| Actual Result | Predicted values match expected EIS range |
| Status (Pass / Fail) | Pass |

**Table 2:est Case TC01 – Accuracy Validation of CNN-Based EIS Prediction Model**

|  |  |
| --- | --- |
| **Test Case ID** | **TC02** |
| Test Case | Test input validation for nulls |
| Test Scenario | Ensure the system handles empty input fields gracefully |
| Input | Missing value in "Water\_Usage\_Liters" |
| Expected Output | Validation error or warning message |
| Actual Result | Warning displayed |
| Status (Pass / Fail) | Pass |

**Table 3:Test Case TC02 – Input Field Validation for Missing Environmental Data**

|  |  |
| --- | --- |
| **Test Case ID** | **TC03** |
| Test Case | Model response to extreme values |
| Test Scenario | Evaluate if model handles unusually high carbon footprint inputs |
| Input | Carbon\_Footprint\_MT = 9999 |
| Expected Output | EIS calculated; Grade = “High Impact” |
| Actual Result | Output returned as expected |
| Status (Pass / Fail) | Pass |

**Table 4:Test Case TC03 – Handling of Extreme Input Values for Carbon Footprint**

|  |  |
| --- | --- |
| **Test Case ID** | **TC04** |
| Test Case | User feedback on submission |
| Test Scenario | Ensure users are notified upon model execution |
| Input | User submits form with complete data |
| Expected Output | Feedback: “Processing…” → Results displayed |
| Actual Result | Feedback and output displayed |
| Status (Pass / Fail) | Pass |

**Table 5: Test Case TC04 – User Feedback Mechanism on Submission of Data**

|  |  |
| --- | --- |
| **Test Case ID** | **TC05** |
| Test Case | UI feedback on data input |
| Test Scenario | Display feedback or results immediately after user inputs data |
| Input | New environmental data manually input |
| Expected Output | Immediate feedback on data input status |
| Actual Result | Feedback provided instantly |
| Status (Pass / Fail) | Pass |

**Table 6: Test Case TC05 – User Interface Feedback During Manual Data Entry**

|  |  |
| --- | --- |
| **Test Case ID** | **TC06** |
| Test Case | Data preprocessing pipeline check |
| Test Scenario | Ensure correct encoding/scaling before prediction |
| Input | Raw CSV data with mixed types |
| Expected Output | Data preprocessed (encoded + scaled) |
| Actual Result | Cleaned data ready for model |
| Status (Pass / Fail) | Pass |

**Table 7: Test Case TC06 – Validation of Preprocessing Pipeline (Encoding and Scaling)**

## **RESULTS AND DISCUSSIONS**

### **Results**

### **Data Collection and Processing**

The dataset was compiled to represent key sustainability metrics relevant to fashion design, including Material Type, Carbon Footprint, Water Usage, and Waste Production. Additional attributes like Eco-Friendly Manufacturing and Recycling Programs were included based on MAS Holdings' guidance to enhance relevance and alignment with real-world practices.

During preprocessing, unnecessary columns were removed, missing values were cleaned, and categorical values were encoded for machine learning compatibility. The dataset was then used to calculate an Environmental Impact Score (EIS), serving as the model’s output target.

This structured approach to data collection and processing ensured the input was clean, meaningful, and aligned with sustainability goals, allowing for accurate predictions and practical application in fashion decision-making.

### **Feature Selection and Engineering**

In this research, feature selection and engineering play a crucial role in improving model accuracy and relevance. Key features include Material\_Type, Carbon\_Footprint\_MT, Water\_Usage\_Liters, Waste\_Production\_KG, Eco\_Friendly\_Manufacturing, and Recycling\_Programs. These were chosen based on their direct contribution to assessing environmental sustainability within fashion production. Categorical values were label-encoded, and numerical features were scaled where necessary to standardize input and ensure optimal model performance.

Additionally, a new target feature called Environmental Impact Score (EIS) was engineered using a weighted formula. This composite score enabled the model to reflect a holistic environmental impact by aggregating multiple sustainability metrics. Feature engineering steps also included cleaning the data, encoding categorical variables, and balancing the dataset to prevent model bias, ensuring that the final model output aligned with MAS Holdings' sustainability evaluation standards.

### **Predictive Model Development**

The predictive model was developed using a Convolutional Neural Network (CNN) architecture tailored to process the structured environmental data. CNN layers were adapted to identify patterns across environmental indicators and derive insights that contribute to calculating the Environmental Impact Score. The model was trained using labeled data, where each sample was tagged with a calculated EIS and corresponding grade, guided by MAS Holdings' sustainability framework.

During training, techniques like dropout layers and learning rate tuning were applied to reduce overfitting and enhance generalization. The model demonstrated its capacity to analyze feature interactions and predict EIS with reasonable accuracy. Ultimately, the CNN model outputs both a numeric score and a grade providing actionable insights for designers and sustainability strategists.

### **Model Validation and Performance Metrics**

To ensure the reliability of the CNN model, rigorous validation procedures were followed. The dataset was split into training and test subsets, and the model’s predictions were evaluated using standard performance metrics such as Mean Squared Error (MSE), Root Mean Squared Error (RMSE), and R² score. These metrics helped quantify the accuracy and consistency of the predictions across unseen data.

Visualization tools, including real vs. predicted score plots, were also used to assess model behavior. The model consistently performed well within acceptable error margins, indicating good generalization. Moreover, performance benchmarking across alternative models (like Random Forest and Ridge Regression) showed that CNN provided comparable or superior results in handling the multidimensional sustainability data.

### **Real-Time Alert System**

Although currently in the prototype phase, the proposed system is designed to support real-time feedback mechanisms. Once the model is integrated into a web interface, users such as sustainability officers and designers can input real-time production or material data and instantly receive insights about its environmental impact. This alert system will enable fast decision-making to reduce harmful practices during production.

The future version of the system could integrate thresholds for EIS values, triggering alerts when certain metrics exceed sustainable limits. For instance, if carbon emissions or water usage rise beyond the MAS-approved range, the system can prompt warnings, encouraging immediate mitigation actions. Such features will enhance the platform’s usefulness in day-to-day sustainable fashion planning.

### **Scenario Analysis and Stress Testing**

Scenario analysis was considered to evaluate the robustness of the CNN model under varying sustainability inputs. By modifying individual metrics—such as increasing water usage or reducing recycling efforts—the model’s responses to hypothetical worst-case or best-case situations were observed. This helped test how well the model generalizes across diverse data scenarios.

Stress testing further involved simulating extreme data points and outliers to ensure the model maintains reliable performance under pressure. These tests validated the system’s stability and confirmed that the grading logic remains consistent even when exposed to high or low environmental values. Such evaluations are crucial for industrial adoption, where unpredictability in supply chains and material sourcing is common.

### **Stakeholder Feedback and Iterative Refinement**

Stakeholder feedback, particularly from MAS Holdings, played a pivotal role throughout the model’s development. Their input helped shape the feature selection criteria, validation thresholds, and grading scale. By aligning the model outputs with MAS's internal sustainability benchmarks, the research ensured practical relevance and usability for real-world applications.

Iterative refinement was implemented after each feedback round. Model parameters, feature weights, and dataset preprocessing techniques were fine-tuned to reflect stakeholder expectations. This agile development approach ensured the system is not just academically sound but also industry-compliant, encouraging long-term adoption and scalability.

### **Research Findings**

The research revealed several key insights into the integration of environmental sustainability metrics within the fashion industry, specifically focusing on predictive modeling using CNN. One of the most significant findings was the effectiveness of combining multiple sustainability factors—such as carbon footprint, water usage, waste production, and recycling programs—into a single predictive model. The CNN model demonstrated a high capability to capture underlying patterns and dependencies among these features, producing accurate environmental impact scores and grade classifications. This grading system offers an intuitive summary of sustainability performance, which can assist designers and decision-makers in selecting materials and production processes that align with MAS Holdings' sustainability goals.

Another major finding was the importance of proper data preprocessing and feature engineering. The research showed that environmental metrics collected across different brands and product categories often varied in format and scale. By standardizing these inputs and deriving a composite environmental score, the research established a consistent and measurable framework for sustainability analysis. Feature engineering also helped enhance model accuracy, particularly when dealing with categorical data like Material\_Type or Eco\_Friendly\_Manufacturing, which were transformed into meaningful inputs using encoding techniques. This step was crucial in ensuring the CNN model could make nuanced predictions across diverse scenarios.

Furthermore, the model's validation phase revealed robust performance across multiple testing sets, confirming its generalizability and reliability. Metrics such as R², RMSE, and MSE indicated that the model was not only fitting the training data well but also capable of making accurate predictions on unseen data. Stress testing and scenario simulations further proved that the model maintained consistent output behavior even under extreme conditions, such as sudden spikes in carbon emissions or drastic reductions in recycling efforts. These findings validate the model's utility in real-world applications, supporting its integration into digital tools for sustainable fashion planning.

Lastly, stakeholder collaboration emerged as a pivotal aspect of the research. The inclusion of MAS Holdings' domain knowledge ensured that the grading system and output interpretations were aligned with actual business practices and sustainability targets. Their feedback throughout the project guided adjustments in model parameters, thresholds, and usability considerations. This participatory approach not only increased the model’s practical relevance but also emphasized the need for continuous iteration and refinement based on evolving industry standards. Overall, the research findings underscore the potential of AI-driven models to revolutionize sustainability analysis in the fashion domain, providing scalable, data-informed solutions for more responsible production practices.

### **Discussion**

This research primarily explored the integration of environmental sustainability metrics into a predictive framework using Convolutional Neural Networks (CNN), with the objective of supporting sustainable decision-making in fashion design. The discussion begins with how the data collected—centered on carbon footprint, water usage, waste production, and sustainability practices—was translated into meaningful features. These indicators were combined to calculate an Environmental Impact Score (EIS), which was further categorized into grades, reflecting the overall sustainability of various material types. This framework allowed for nuanced insights into the ecological impact of different production materials, enabling data-driven comparisons.

A central point of discussion is the efficiency and relevance of using a CNN model for this type of structured data. Although CNNs are traditionally used for image and spatial data, their layered architecture was leveraged here for feature pattern recognition and regression-based predictions. The decision to use CNN was based on its strength in learning feature hierarchies, even in non-image data when adapted accordingly. The model was trained on preprocessed and normalized data and showed promising results during both training and validation stages. The output—an EIS score and corresponding grade—was not only accurate but aligned with the domain-specific insights provided by MAS Holdings. Their involvement ensured that the model's predictions held practical relevance for the sustainable apparel sector.

The discussion also reflects on the technical and practical limitations encountered. One such limitation was the availability of consistent and high-resolution sustainability data across all brands, which required significant preprocessing. Additionally, while the current model focused on a few measurable metrics, real-world sustainability assessment often involves qualitative factors such as labor conditions or supply chain transparency, which are harder to quantify and predict using AI models alone. Despite this, the inclusion of industry expertise helped refine the scope and interpretability of the results.

Finally, the project opens the floor to numerous future enhancements. Discussions with stakeholders revealed potential extensions such as integrating the model into real-time fashion design platforms, offering instant feedback as new materials are selected. There is also scope to incorporate dynamic metrics like changing supply chain practices or localized water stress levels. Overall, the research presents a novel and effective way of utilizing AI to support sustainable choices, while highlighting the importance of continuous updates, interdisciplinary collaboration, and scalability for long-term impact.

## **CONCLUSION**

This research successfully demonstrates the development and application of a predictive model aimed at evaluating and supporting sustainable fashion design, focusing on quantifiable environmental metrics. By leveraging a Convolutional Neural Network (CNN), the study effectively predicted an Environmental Impact Score (EIS) based on core features such as material type, carbon footprint, water usage, and waste production. These scores were further translated into sustainability grades, offering an accessible and practical method to assess and compare fashion materials from an environmental standpoint. This data-driven approach aligns with the broader goals of MAS Holdings, ensuring industry relevance and operational feasibility.

The methodology encompassed careful data collection and preprocessing, feature selection and engineering based on real-world environmental concerns, and the development of a CNN model tailored to structured sustainability data. Each step was informed by domain expertise and iterative feedback, resulting in a system that balances technical robustness with interpretability. The involvement of MAS Holdings played a critical role in refining the outcome metrics and validating the grading criteria, ensuring that the results were not only technically sound but also meaningful to practitioners within the sustainable apparel ecosystem.

Moreover, the model was integrated into a prototype application, enabling real-time predictions and user interaction. This reinforces the tool’s practical utility in design-stage decision-making, empowering designers and manufacturers to prioritize low-impact materials early in the production process. While the model currently evaluates fixed environmental parameters, it establishes a scalable foundation for future development. Enhancements may include real-time data integration, scenario simulation, and expansion to cover broader lifecycle metrics.

In conclusion, the project bridges the gap between sustainability data and practical application in fashion design by introducing an intelligent, transparent, and customizable prediction tool. It underscores the value of integrating AI in sustainable innovation and paves the way for future research that can further refine the model, broaden its scope, and deepen its impact on sustainable product development. The predictive model not only serves as an analytical engine but also as a strategic compass guiding the fashion industry toward a more eco-conscious future.

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## **APPENDICES**

**Appendix - A: Plagiarism report**