

Material-Based Product Carbon Footprint Assessment and Sustainability Analysis System

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ABSTRACT - When we buy things, we usually don't stop to think about how they might affect the environment. The carbon footprint of a product depends on factors such as the materials, the way the product is made and the packaging of the product but this information is rarely shared in a way that it is useful for everyday shoppers. This paper introduces a user- online platform that helps people see the carbon emissions of a product based on what the product is made of and how the product is produced. Of using a complicated technical process the system uses a clear rule-based model: it takes the amount of each material in the product and multiplies it by standard carbon emission numbers from trusted public sources. This keeps the calculations of the carbon footprint simple, transparent and easy to check. The platform then shows the result for each product a sustainability score shows which materials contribute most to the carbon footprint of the product and suggests more eco-friendly alternatives for the product. Shoppers can compare products side, by side and even track how the carbon footprint of their choices adds up over time. All the results are shown using bar and pie charts making the carbon footprint data easy to understand even without a technical background. By bringing carbon footprint estimates, detailed breakdowns, product comparisons and clear visualizations this system aims to make sustainability a normal part of everyday shopping decisions.

Key Words: Carbon Footprint, Sustainability Analysis, Product Comparison, Emission Factors, Life Cycle Assessment, Rule-Based System, Eco-Friendly Alternatives, Data Visualization.

1. INTRODUCTION

Climate change is affecting our environment, and the products we use every day also play a part in it. Each product has a price that starts with getting materials and goes on through making, packaging, shipping using and finally throwing away. Most consumers however have no way of life contributes most to it.

This project fills that gap by offering a web-based platform that estimates the carbon footprint of a product, from the materials it is made of and the manufacturing process used to produce it. Of needing a full technical Life Cycle Assessment the system uses standard, publicly

documented emission factors and a clear rule-based calculation so that the result can be explained to a non-technical user in one sentence.

1.1 Background

Environmental labelling schemes and carbon calculators have existed for some time, but most are aimed at organisations reporting emissions at a company or supply-chain level rather than at individual consumers comparing two products on a shelf. Material choice is one of the largest and most easily quantified contributors to a product's footprint, since standard emission factors (kg CO₂-equivalent per kilogram of material) are widely published for common materials such as plastics, metals, glass, paper and textiles. This makes material-level estimation a practical starting point for a consumer-facing tool.

1.2 Need for a Material-Based Carbon Footprint System

I find that checking each step of a products life by hand takes a lot of time. The information needed is not always easy to find or available to everyone. A lighter-weight, material-based approach that still gives a reasonably accurate and, more importantly, explainable estimate is more practical for a consumer application. The proposed system is built around this idea: it collects the materials and manufacturing information for a product, applies known emission factors, and produces an estimate, a sustainability rating and a breakdown that a shopper can act on immediately.

2. LITERATURE REVIEW

The research on environmental impact assessment of products covers a key areas. One is the Life Cycle Assessment methodology. Another is structured footprint frameworks. There is also work on how carbon information affects consumer behavior. Each of these areas helps us understand the effects of products, in different ways.

2.1 Life Cycle Assessment and Environmental Impact Studies

Life Cycle Assessment (LCA) is the established method for evaluating the environmental impact of a product across its entire life, from raw-material extraction to end-of-life disposal [1]. Surveys of this literature show that material extraction and manufacturing typically account for a large share of a product's total emissions, which supports focusing an initial, simplified model on these two stages rather than the full life cycle [1].

2.2 Product Environmental Footprint Approaches

In my view the Product Environmental Footprint or PEF was created to make it easier to measure and compare the impacts of different products. The Product Environmental Footprint gives a method to add up the impacts from all parts of a product's life into one score. However the Product Environmental Footprint needs a lot of data and a complex calculation, which makes it hard for a normal consumer app to use. The new system takes the idea of a stage-by-stage breakdown, from the Product Environmental Footprint but makes the calculation simpler so that the process stays clear.

2.3 Carbon Footprint Labelling and Consumer Behaviour

Studies of carbon footprint labelling show that presenting environmental information in a simple, comparable format can influence purchasing decisions, but that consumers often find raw emissions figures difficult to interpret without context such as a rating or a comparison against similar products [4]. This finding directly motivates two design choices in the proposed system: converting the raw emissions estimate into an easy-to-read sustainability rating, and building product comparison into the core workflow rather than treating it as an add-on.

2.4 Research Gap

Current carbon calculators for consumers usually give one overall number. They do not explain which materials or processes cause that number. They also rarely let users compare products side by side or keep a record of the user's choices over time. In addition there is link between estimating a footprint explaining materials at a detailed level suggesting alternative products and showing consumption history in a single interface. The new system aims to fix these problems by bringing those four parts into one simple platform, for everyday people not for corporate sustainability reporting.

3. PROBLEM STATEMENT

When people decide which products to buy they usually think about price, quality, brand and features. They rarely have easy-to-compare information about how a product affects the environment. A shopper finds it hard to know which materials in a product add most to its impact or how one product stacks up against another from a different brand. The data needed is either missing or written in a style meant for experts. As a result making friendly purchasing choices becomes more difficult than it ought to be. There should be a method through which the carbon footprint of any product can be estimated on the basis of the material and manufacturing process involved compared side by side.

4. OBJECTIVES

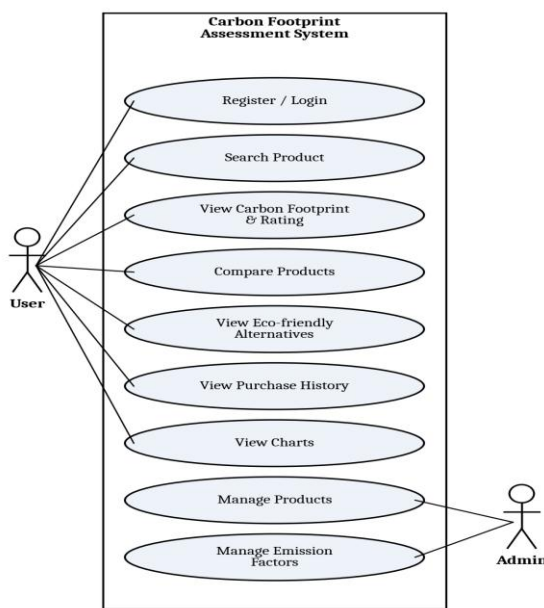
1. To estimate the carbon footprint of a product based on the materials used and its manufacturing process.
2. To provide a clear, material-level breakdown of a product's carbon emissions so users can see which factors contribute the most.
3. To assign an easy-to-read sustainability rating derived from the estimated carbon footprint.
4. To allow users to compare multiple products on their estimated environmental impact.
5. To recommend eco-friendly alternatives with a comparatively lower carbon footprint.
6. To maintain a user's purchase history and summarise their cumulative environmental impact over time.
7. To present all of this information through a simple, web-based interface with charts and visualisations rather than raw numbers.

5. REQUIREMENT ANALYSIS

Requirement analysis helps in understanding what the system should do and what is needed to develop it. For this project, the requirements are mainly based on the information entered by the user, carbon footprint calculation, product comparison, and displaying the results in an easy-to-understand way.

The system should be simple for users to enter product details such as materials, quantity, manufacturing, packaging, and transportation. Based on this information, it calculates the estimated carbon footprint.

The results should be easy to understand. Users can see the total emissions, view the contribution of different factors, and compare products using simple charts. The system also needs a database to store emission factors and should work smoothly on different devices.



5.1 Functional Requirements

The system must allow a user to search for a product and view its material composition. It must calculate the estimated carbon footprint from the material quantities and emission factors, assign a sustainability rating, and display the contribution of each material. It must let users select two or more products for side-by-side comparison, suggest lower-impact alternatives in the same category, and store a purchase history for registered users. It must also present the results as charts.

5.2 Non-Functional Requirements

Usability: a first-time user should be able to view a product's footprint without training. **Transparency:** every calculated value must be traceable to the emission factor used. **Performance:** a footprint calculation and comparison should be returned to the user within a few seconds. **Security:** user credentials must be stored securely and purchase history must be visible only to its owner. **Maintainability:** emission factors must be stored in the database rather than hard-coded, so they can be updated without changing the application code.

6. TECHNOLOGY STACK

The proposed system is developed as a web-based application using standard, widely supported web technologies. The frontend is built with HTML5, CSS3 and JavaScript, which provide the page structure, styling and interactive behaviour for the product search, comparison and dashboard pages. It runs in any modern browser, such as Google Chrome, Microsoft Edge or Mozilla Firefox, so users do not need to install anything. The backend uses a server-side programming environment to receive requests

from the frontend, run the emission calculation and rating logic, and manage user accounts. Product, material, emission factor, user and purchase data are stored in a MySQL relational database, which suits the system because these entities are linked by well-defined relationships (Fig -3). MySQL Workbench is used to design the database schema and manage the data. Graphical visualization tools present the results as bar charts, pie charts and trend graphs. The system is developed in Visual Studio Code, and internet access is needed to obtain environmental datasets and other web-based resources.

7. PROPOSED METHODOLOGY

The proposed system follows a straightforward pipeline: product data is collected, emission factors are applied to compute a footprint, the result is broken down and rated, and the output is delivered to the user through comparison and visualisation features.

Enter Product Details → Check Emission Factors → Calculate Emissions → Give Rating → Compare Results

7.1 System Architecture

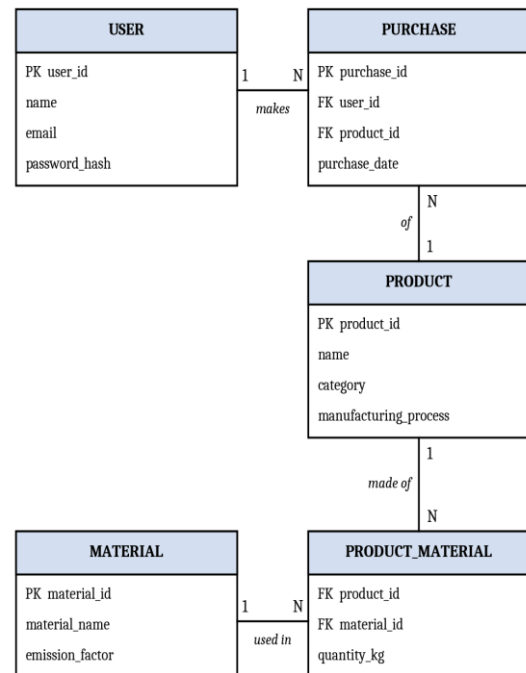
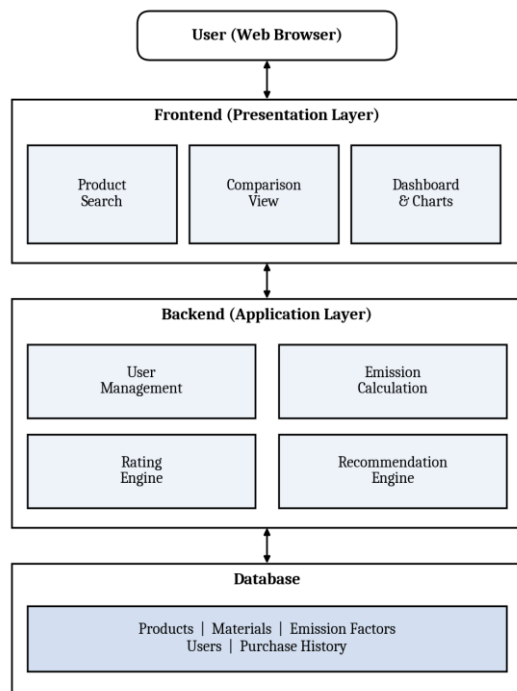
The system is built as a web application with three main layers: the frontend, backend, and database. These layers work together to collect product information, calculate the carbon footprint, and display the results to the user.

The **frontend** is the part that users interact with. It allows users to search for products and enter the required product details. Users can view the estimated carbon footprint, understand the contribution of different materials and processes, and compare the results of different products. The frontend also provides access to purchase history and displays the results using simple charts and graphs.

The **backend** handles the main processing of the system. It manages product, material, and emission-factor information. When a user provides product details, the backend uses the relevant emission factors to calculate the estimated carbon footprint. It also handles the comparison, rating, and other system functions before sending the results back to the frontend.

The **database** stores the information required by the application. It contains details about products, materials, emission factors, users, and purchase records. The database helps the system store and retrieve information whenever it is needed.

Overall, these three layers work together to make the carbon footprint assessment process simple and easy for users.



7.2 Data Collection

Data collection is an important part of the system because the carbon footprint calculation depends on the information provided about each product. The system collects details such as the product name, materials used, quantity, manufacturing process, packaging, and transportation.

Product records contain information about the materials used and the manufacturing process involved in making the product. This information is used as the main input for calculating the product's carbon footprint.

The system also uses emission factors for commonly used materials such as plastics, metals, glass, paper, and textiles. These values are taken from publicly available sustainability and environmental datasets and stored in the database as a lookup table.

When a calculation is performed, the system selects the appropriate emission factor based on the material and other available details. Keeping these values in a separate table makes them easier to update and helps track which emission factor was used for each calculation.

The collected data is then used by the backend to calculate the estimated carbon footprint and provide the results to the user.

7.3 Carbon Footprint Calculation

For each material in a product, the estimated emissions are computed by multiplying the quantity of the material by its emission factor. A manufacturing-process adjustment factor is then applied to account for the emissions produced during production and the manufacturing-process adjustment factor also corrects the total emission figure. The total estimated footprint of a product is the sum of these material-level contributions plus the manufacturing contribution:

$$\text{Carbon Footprint} = \Sigma (\text{Material Quantity} \times \text{Emission Factor}) + \text{Manufacturing Emission Contribution}$$

Keeping the calculation additive and rule-based, rather than a black-box model, means that the material-level breakdown needed for objective 2 falls directly out of the calculation instead of requiring a separate explanation step.

7.4 Sustainability Rating

Once the total footprint is calculated, the product is placed into a rating band (for example Low, Moderate or High impact) using threshold values defined for its product category. The rating gives users an immediate sense of a product's impact without needing to interpret a raw emissions figure, addressing the interpretability concern raised in the literature on carbon labelling.

7.5 Product Comparison

Users can select two or more products and view their estimated footprints, ratings and material breakdowns side by side. The comparison view also highlights which specific materials account for the difference between products, and surfaces alternative products in the same category with a lower estimated footprint.

7.6 Purchase History and Visualisation

Registered users can maintain a record of products they have viewed or purchased. The system aggregates this history to show cumulative estimated emissions over time, using bar charts, pie charts and trend graphs so that patterns in consumption become visible without requiring the user to read tables of numbers.

Table -1: Data Used for Carbon Footprint Assessment

Field	Description
Material Type	Raw material category (plastic, metal, glass, paper, textile)
Material Quantity	Amount of each material used, by weight
Emission Factor	CO2-equivalent value per unit of material
Manufacturing Process	Process type used, affecting emissions
Packaging Type	Material and quantity of packaging used
Est. Carbon Footprint	Total emissions, in kg CO2-equivalent
Sustainability Rating	Rating band based on the footprint

8. MODULE DESCRIPTION

8.1 User Module. Handles registration, login and profile management. Registered users can access their purchase history and cumulative footprint summary.

8.2 Product Module. Stores product records with their category, materials, quantities and manufacturing process, and supports search and filtering.

8.3 Emission Calculation Module. Retrieves the emission factor for each material, applies the calculation formula, adds the manufacturing contribution and returns the total footprint together with a per-material breakdown.

8.4 Rating Module. Compares the calculated footprint against the threshold values for the product's category and assigns a rating band.

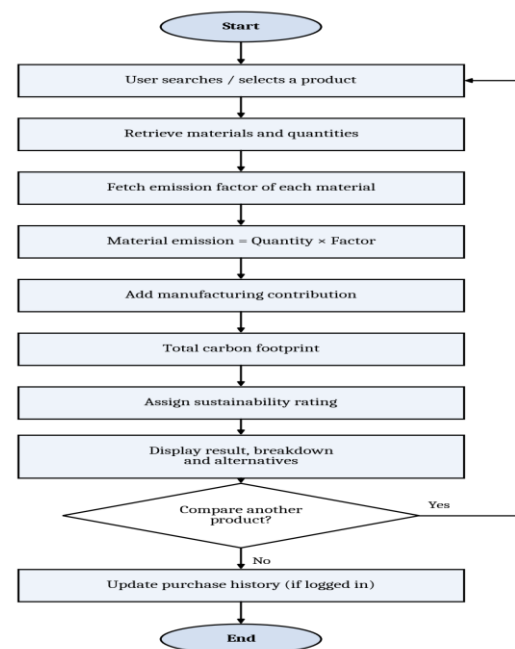
8.5 Comparison and Recommendation Module. Presents selected products side by side and identifies products in the same category with a lower estimated footprint.

8.6 Visualization Module. Converts the calculated values into bar charts, pie charts and trend graphs.

9. ALGORITHM

The calculation and rating procedure is summarized below.

- Step 1: Input the product and retrieve its material list and quantities.
- Step 2: For each material, retrieve its emission factor from the database.
- Step 3: Compute the material emission as quantity × emission factor.
- Step 4: Add the material emissions to obtain the material subtotal.
- Step 5: Apply the manufacturing adjustment factor to the subtotal to obtain the manufacturing contribution.
- Step 6: Compute the total footprint as the material subtotal plus the manufacturing contribution.
- Step 7: Compare the total with the category thresholds and assign the rating.
- Step 8: Return the total, the rating and the per-material breakdown for display.



10. ILLUSTRATIVE EXAMPLE

To explain the calculation, consider a hypothetical plastic water bottle. The values below are assumed for demonstration only and are not measured data. Replace them with factors from your chosen dataset (for example IPCC, DEFRA or another cited source) before publication.

Table -2: Illustrative Footprint Calculation

Material	Quantity (kg)	Emission Factor (kg CO ₂ e / kg)	Emission (kg CO ₂ e)
PET plastic (bottle)	0.050	2.50	0.1250
HDPE plastic (cap)	0.005	2.00	0.0100
Paper (label)	0.002	1.10	0.0022
Material subtotal			0.1372

Applying an assumed manufacturing adjustment of 15% adds 0.0206 kg CO₂e, giving a total estimated footprint of approximately 0.158 kg CO₂e. Under the illustrative thresholds in Table -3, this product falls in the Moderate band. The example also shows the transparency of the approach: the PET bottle body contributes about 79% of the total material emissions (0.1250 of 0.1372), so a user can see immediately which material to target when choosing an alternative.

11. RATING THRESHOLDS

Rating bands are defined per product category because a reasonable footprint for a beverage container differs from that of a garment or an appliance.

Table-3: Illustrative Rating Bands (Beverage Containers)

Rating	Footprint (kg CO ₂ e)
Low Impact	Below 0.10
Moderate Impact	0.10 to 0.25
High Impact	Above 0.25

These threshold values are illustrative. In the implemented system they should be derived from the distribution of footprints of products within each category in the dataset, and documented so the rating can be justified.

12. COMPARISON WITH EXISTING APPROACHES

Table -4: Comparison of the Proposed System with Existing Approaches

Feature	Generic Online Calculators	Full LCA Software	Proposed System
Aimed at consumers	Partly	No	Yes
Material-level breakdown	Rarely	Yes	Yes
Side-by-side product comparison	Rarely	Limited	Yes
Rating for easy interpretation	Rarely	No	Yes
Eco-friendly alternatives	No	No	Yes
Purchase history tracking	No	No	Yes
Data and expertise required	Low	High	Low to moderate

The table summarizes the general characteristics of each category of tool. Full LCA software is more complete but requires specialist data and expertise, while generic calculators are simple but seldom explain their results. The proposed system aims for a middle position. (Check this table against two or three specific tools you have actually tried, and adjust the entries so they are accurate.)

13. EXPECTED OUTCOMES

The system is expected to give users a clear estimate of a product's carbon footprint along with a breakdown of which materials and processes drive that footprint, rather than a single opaque number. Presenting this alongside a sustainability rating and a direct comparison with similar products is expected to make it noticeably easier for a non-technical user to factor environmental impact into a purchasing decision, alongside price and quality. Tracking purchase history over time is expected to help users notice broad patterns in their own consumption, such as a tendency to buy heavily packaged or high-churn products, and adjust their choices accordingly.

Because the calculation is rule-based rather than a trained statistical model, the accuracy of the estimates will depend directly on the quality and coverage of the emission-factor dataset. As more materials, manufacturing processes and packaging types are added to the reference data, the accuracy and coverage of the system's estimates are expected to improve correspondingly.

14. TESTING AND VALIDATION PLAN

The system will be tested step by step at three levels. Unit testing will verify the calculation and rating functions using products whose expected footprint can be computed by hand. Integration testing will check that data flows correctly between the frontend, backend and database, including search, comparison and history features. Accuracy validation will compare the system's estimates for a set of sample products against footprints computed manually from the same emission factors, and against values reported in published sources where available. Usability testing will collect feedback from a small group of users on how easily they can find, understand and compare product footprints.

15. LIMITATIONS AND ASSUMPTIONS

The system estimates footprint from materials and manufacturing only, so transportation, use-phase and end-of-life emissions are not included. Accuracy depends on the quality and coverage of the emission factor data, and factors vary by region and production method. Material quantities may be approximate when manufacturers do not publish exact composition. The rating thresholds are category-specific and depend on the dataset used. The output should therefore be treated as a decision-support estimate, not a certified measurement.

16. ETHICAL AND DATA CONSIDERATIONS

Environmental claims can mislead if presented without context, so the system displays the emission factors and assumptions behind each estimate. Emission data are taken from publicly available sources, which are cited. User purchase history is personal data, so it is stored securely, used only to show the user's own summary, and not shared with third parties.

17. WORK PLAN

1. Requirement analysis and identification of the metrics needed for footprint estimation.
2. Literature survey of existing carbon footprint and LCA-based approaches.
3. System design, including database schema and overall workflow.
4. Collection of material, manufacturing and packaging emission-factor data.
5. Frontend development: product search, footprint display, comparison and alternatives.
6. Backend development: footprint calculation, rating logic and data management.
7. Database integration for products, materials, users and purchase history.
8. Integration of frontend, backend and database components.

9. Testing, validation and deployment of the complete system.

18. DISCUSSION

The proposed approach gives up a bit of precision to achieve transparency and simplicity. A full Life Cycle Assessment would include transportation, usage and disposal impacts well but it would also need data that is usually not available to a consumer application. By concentrating on materials and manufacturing factors that the literature shows are contributors to a product's environmental footprint the system tries to provide a reasonably accurate estimate while staying simple enough to explain to any user.

The comparison and rating features are designed to close the interpretability gap mentioned in the reviewed literature. A raw emissions number is hard to act on. A rating and a side-by-side comparison with other options make the information much more useful. This sets the system up as a decision-support tool than a tool, for exact measurements.

19. CONCLUSION

This paper presented the design of a Material-Based Product Carbon Footprint Assessment and Sustainability Analysis System intended to help consumers understand and compare the environmental impact of the products they buy. By estimating emissions from material and manufacturing data using a transparent, rule-based calculation, and presenting the results through a sustainability rating, material-level breakdown, product comparison and simple visualisations, the system aims to make environmental impact a practical part of everyday purchasing decisions rather than a specialist concern. The approach deliberately favours simplicity and explainability over the completeness of a full Life Cycle Assessment, which makes it suitable for a consumer-facing platform where the priority is decision support rather than precise measurement.

20. FUTURE SCOPE

The system has the potential to grow by adding transportation and packaging logistics into the footprint calculation. This would bring it closer to a Life Cycle Assessment. Including data sources and expanding the emission-factor database would help cover a wider range of product types. Machine Learning could be used to predict emission factors, for materials that are not yet listed. Natural Language Processing might help pull material details from product descriptions. In the run the platform could connect with retailer or e-commerce systems. That way users see footprint and rating information right when they are about to buy a product.

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