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Department of AIML

Sustainable electronic goods Recommendation based on Carbon Footprint Insights

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Introduction

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Introduction

- Carbon footprint refers to the total amount of carbon dioxide(CO_2) gas emitted directly or indirectly over the life cycle of a product.
- Carbon footprint is the measure of whether an organization is environment-friendly.
- Various approaches have been proposed to measure the carbon footprint of products. Most of these approaches prescribe using an LCA-based framework to assess the carbon footprint.
- LCA refers to Life Cycle Assessment and involves calculating the emissions due to processes of the product over its entire lifecycle.
- Electronic products contribute significantly to global carbon emissions. The contribution to the carbon emissions is about 4% which is comparable to that of the airline industry having a contribution of 2-4%.

Problem Statement

Develop a system that optimises the recommendations based on both cost and carbon footprint, and recommends sustainable electronic goods, based on the carbon footprint values.

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Literature Survey

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Sl No	Author and Paper title	Details of Publication	Summary of the Paper
1	Digital Twin-Driven Product Sustainable Design for Low Carbon Footprint Authors: Zhu, Yue, Jie Zhang, et al.	Journal of Computing and Engineering 23.6(2023): 060805.	The paper outlines methodologies for integrating digital wins into lifecycle assessments to achieve a lower carbon footprint, specifically in manufacturing and product lifecycle management
2.	Comparative Study of Carbon Footprint and Assessment Standards Authors: Xiao, Feng, et al.	International Journal of Low-Carbon Technologies 9.3 (2024): 237.	The paper compares various standards for carbon footprint assessments, analyzing quantification methods and emission treatment approaches
3.	Carbon Footprint: Current Methods of Estimation Authors: Liang, Wei, et al	Springer Climate (2023)	This paper reviews existing carbon footprint estimation methods, focusing on the lifecycle approach. It identifies gaps in current methodologies and suggests improvements for greater precision.
4.	Research Trends and Hotspots in Global Carbon Footprint Tracking Authors: Zhang, Tianwei, et al.	Scientific Reports 14.1 (2024): 29183.	This paper explores global research trends in carbon footprint tracking. Emphasizes using technology like AI and blockchain for tracking carbon footprint in complex supply chains.
5.	ECO-CHIP: Estimation of Carbon Footprint of Chiplet-Based Architectures for Sustainable VLSI. Authors: Wu, Chen, et al.	arXiv preprint arXiv:2306.09434 (2024).	This paper analyzes the environmental impacts of integrated circuit (IC) production, emphasizing carbon footprint and energy demand, and advocates for standardized methodologies to reduce the ecological footprint.

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Literature Survey

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Sl No	Author and Paper title	Details of Publication	Summary of the Paper
6	Life cycle assessment(LCA) of circular consumer electronics based on IC recycling and emerging PCB assembly materials Authors: Zhang, Tianwei, et al.,	Scientific Reports 14.1 (2024): 29183	This paper contains the LCA of 2 electronic devices- smart watch and a TV remote, and this paper contains the different electronic componenets these devices have.
7.	A Methodology for Simplified LCAs of Electronic Products Authors: J. Malmodin and N. Lövehagen	2024 Electronics Goes Green 2024+ (EGG), Berlin, Germany, 2024, pp. 1-12, doi: 10.23919/EGG62010.2024.1063 1258.	This paper contains the methodology of LCA of a smartphone, also the data of individual components are given.
8.	Reinforcement Learning Model,Algorithms and Its Application Authors: Wang Qiang ,Zhan Zhongli	2011 International Conference on Mechatronic Science, Electric Engineering and Computer August 19-22, 2011	This paper conducts a Life Cycle Assessment (LCA) comparing a smartwatch and a TV remote by examining their electronic components and evaluating their environmental impacts throughout their lifecycle.
9.	Carbon Footprint meter prototype due to power consumption: case of study Colombia Authors: W. F. Álvarez-Castañeda, L. A. Martínez-Tejada and D. Y. Riscanevo-Espitia	2016 IEEE ANDESCON, Arequipa, Peru, 2016, pp. 1-4, doi: 10.1109/ANDESCON.2016.783622 0.	This paper presents the life cycle assessment (LCA) methodology for smartphones, detailing the environmental impact of individual components. It aims to inform consumers about the ecological footprint of their devices.
10.	The Environmental Footprint of IC Production: Meta-Analysis and Historical Trends Authors: T. Pirson, T. Delhaye, A. Pip, G. Le Brun, J. -P. Raskin and D. Bol	ESSDERC 2022 - IEEE 52nd European Solid-State Device Research Conference (ESSDERC), Milan, Italy, 2022, pp. 352-355, doi: 10.1109/ESSDERC55479.2022.994 7198.	This paper analyzes the environmental impacts of integrated circuit (IC) production, emphasizing carbon footprint and energy demand, and advocates for standardized methodologies to reduce the ecological footprint.

Summary of Literature Review

From the research papers, we have obtained the following things:

- The methodology of LCA of electronic goods.
- The emission data of individual components from the LCA done for electronic products.
- Usage of Reinforced Learning for recommendation and optimization system.

Research gaps

- The research papers only give the methods of LCA of electronic products, and do not specify a framework for storing the information, and using them further.
- The papers do not give us any sort of optimisation of cost and carbon footprint for recommendation.

Objectives

1. Analyse the data from suppliers, logistics, disposal etc. to extract the carbon footprint of electronic products across their lifecycles
2. Optimise cost and carbon footprint of electronic products.
3. Develop a system the recommends sustainable electronic goods

Requirement Analysis

Hardware Requirements

Development System

- Processor: Intel Core i5 or AMD Ryzen 5 (or higher)
- RAM: Minimum 8 GB (16 GB recommended for smooth ML model training and testing)
- Storage: 256 GB SSD (512 GB recommended for storing datasets and project files)
- Graphics: NVIDIA GPU (e.g., GTX 1650 or higher) for faster ML model training (optional)

Server/Hosting

- Processor: Multi-core CPU (e.g., Xeon or equivalent)
- RAM: 16 GB or higher for simultaneous user queries and ML computations
- Storage: 500 GB SSD or higher for databases and logs
- Network: High-speed internet connection (minimum 100 Mbps)

Additional Hardware

- Display: Monitor/PC for development
- Peripherals: Mouse, keyboard, and other standard development accessories

Requirement Analysis

Software Requirements

Development Tools

- Operating System: Windows 10/11, macOS, or Ubuntu (Linux preferred for servers)
- Programming Languages: Python (for ML), JavaScript (for frontend and backend)
- Libraries and Frameworks:
  - Python: Pandas, NumPy, Scikit-learn, TensorFlow,OpenAI's API (for Llama-2 chatbot integration and RL model)
  - JavaScript: React.js or Vue.js,Node.js (for interactive frontend and backend development)

Database

- SQL: PostgreSQL/MySQL for structured data

Frontend Development

- Languages: HTML, CSS, JavaScript
- Libraries: React.js
- Tools: Visual Studio Code

Requirement Analysis

Backend Development

- Frameworks: Express.js (Node.js)
- APIs: RESTful APIs for communication between frontend and backend

Model Development and Training

- Libraries:
  - TensorFlow for training the neural network
  - OpenLCA or equivalent tools for lifecycle assessment data preprocessing
- Environment: Jupyter Notebook or PyCharm for coding and testing

Hosting and Deployment

- Cloud Platforms:
  - AWS EC2 or Google Cloud Compute Engine for backend hosting
  - AWS S3 or Cloud Storage for dataset storage
- Web Hosting: Netlify or Vercel for frontend deployment

Chatbot Integration

- Tools: Hugging Face Transformers, OpenAI API (for Llama-2 integration)

System Architecture

Llama is an open-source language model developed by Meta. It is a transformer-based language model designed to understand and generate human-like text.It excels at tasks like question-answering, conversation making it ideal to develop a chatbot.

Core Components of Llama

- **Input Embeddings layer :** It converts the words into numerical vectors. Involves both token embeddings and positional encodings.
- **Self-Attention mechanism :** Helps analyze connection and relationship between all words in a conversation and understand the context better.
- **Feed Forward Neural Network :** Uses fully connected neural network layers to refine the output of the attention mechanism.
- **Decoder Architecture :** Generates text by predicting the next word in a sequence(autoregression).
- **Output Layer :** Translates internal representations(vectors) back into human readable form by assigning probabilities to all possible next words.

System Architecture

Integration Architecture

- **Frontend :** User ask their query through web app or mobile interface.
- **Middle-ware :** It converts user queries into tokens for processing by Llama. It also converts Llama responses back into human readable form.
- **Llama-core :** Handles language-processing using pre-trained knowledge. Fine-tuned for sustainability-related queries.
- **Backend(Database) :** Stores product details, carbon footprint data, and previous converstions with users.

System Architecture

Proximal Policy Optimization (PPO) is a reinforcement learning algorithm designed to optimize policies in environments by balancing exploration and exploitation.It is known for its stability and efficiency in training agents for continuous and discrete action spaces.

Core Components of PPO

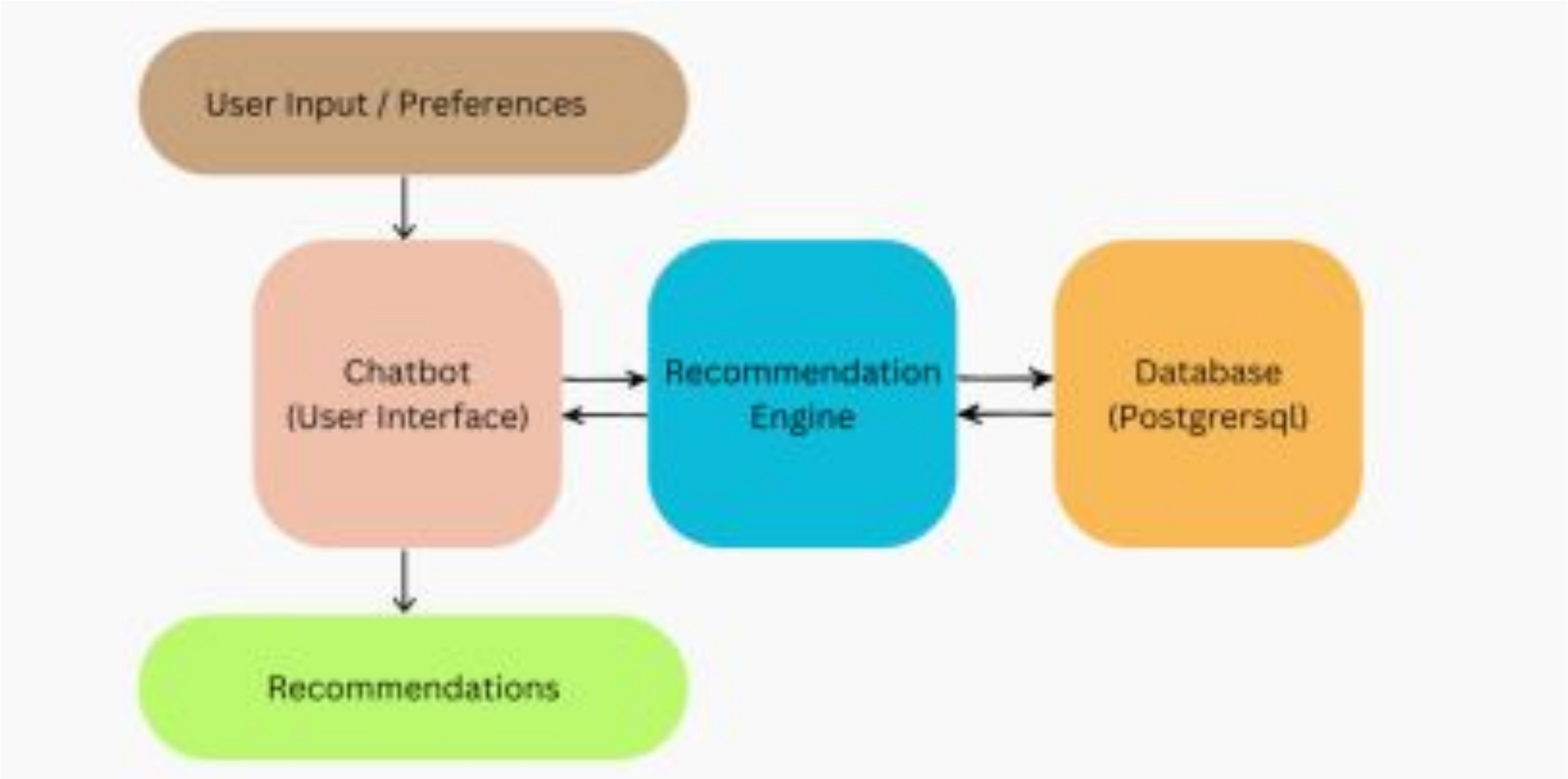
- **Input Layer :** Processes observations from the environment and converts them into feature representations.
- **Policy Network :** Generates a probability distribution over possible actions based on the current state.
- **Value Network:** Predicts the value of a given state, which estimates the expected cumulative reward starting from that state.
- **Advantage Estimation :** Calculates the advantage of an action to indicate how much better it is compared to the average action at the given state.
- **Output Layer :** Converts internal representations into action probabilities for decision-making in the policy network or a scalar value estimating expected returns in the value network.

System Architecture

Integration Architecture

- **Frontend :** User or agent interacts with the environment by taking actions and receiving state observations and rewards.
- **Middle-ware :** Processes observations for the PPO model and converts policy outputs into actions for execution.
- **PPO-core :** Handles policy optimization and value prediction, using collected experience to refine decision-making.
- **Backend :** Stores trajectories (states, actions, rewards) for training and optimization.

Project Architecture Diagram



Block diagram

Methodology

1) Requirement Analysis :

- Involves identifying pain points and user needs related to sustainability tracking.
- Identification of functional and non-functional requirements for the product. For example, functional requirements may involve querying carbon footprint data by product, category and providing recommendations. Non-functional requirements may include scalability, security of the system.
- Finalizing the tech stack for the system.

2) Data Collection and Database design :

- Collection of data from public repositories, manufacturers and lifecycle assessments(ISO-compliant).
- Categorizing data into different phases : manufacturing emissions, transport, usage and disposal
- Design and Implementation of Database : Developing ER diagram with entities and their attributes. Set up a database with partitioning and indexing for large-scale data handling.

Methodology

3) Deep Learning(Reinforcement Learning) for Predictions and Optimization :

- Develop a model to predict carbon footprints for new products.
- Optimizing both the cost and carbon footprint.
- Input : Product specs, supply chain details, historical data. Output: Predicted carbon footprint values.
- Use supervised learning with lifecycle analysis data.

4) Chatbot Development :

- Creating a set of FAQs and sustainability to fine-tune Llama.
- Using APIs to connect the chatbot to DBMS and handling unsupported queries.
- Having a query-handling workflow : Tokenize user queries, Execute SQL queries for specific data, and generate a response.

5) Testing :

- Chatbot accuracy, prediction relevance.
- Testing individual components like DBMS queries, prediction models.
- Validating integration, ensuring seamless data flow between chatbot, DBMS and prediction models.

Methodology

6) Deployment and Maintanence :

- Hosting the DBMS and chatbot on a secure cloud platform.
- Using Conatainerization.
- Monitoring the errors and logging errors.
- Periodically retrain the chatbot and prediction model with updated data.

Module Specifications

Module 1: Carbon Footprint Calculator

- **Input**: Product details (e.g., materials, energy consumption).
- **Function:**
  - Perform LCA-based carbon footprint calculations.
  - Use a regression model to estimate missing parameters.
- **Output:** Carbon footprint values for each product.

Module 2: Recommendation Engine

- **Input:** User preferences, carbon footprint data, and price.
- **Function:**
  - Generate product recommendations based on hybrid filtering (content and collaborative).
  - Optimize for low carbon footprint and price using ML algorithms.
- **Output:** A ranked list of recommended products.

Module 3: Optimization Engine

- **Input:** Product data (footprint, price) and user constraints.
- **Function:**

a. Employ reinforcement learning to optimize price and footprint trade-offs.
b. Suggest actionable alternatives (e.g., product substitutions).

- **Output:** Optimized configurations with recommendations.

Module 4: Chatbot Integration

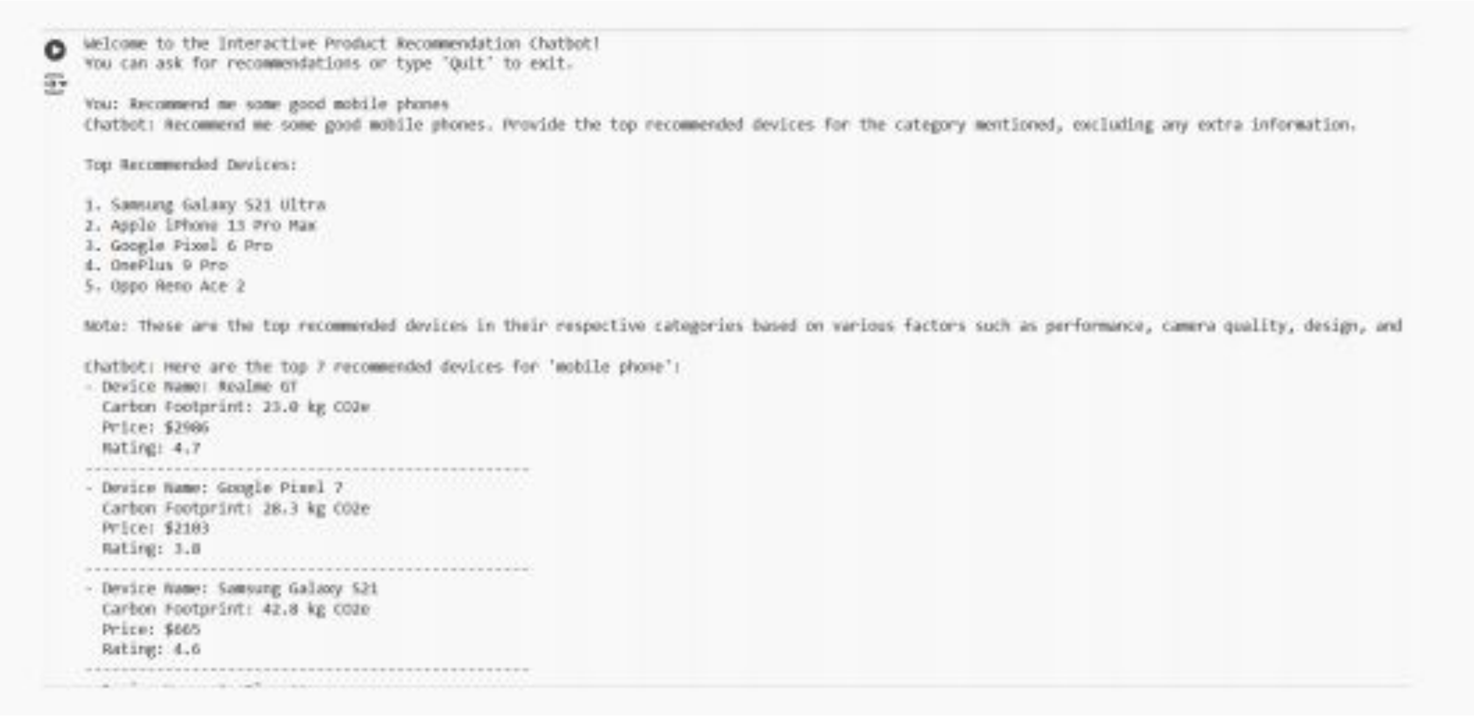
- **Input:** User queries.
- **Function:**
  - Interpret user inputs and respond using Llama-2's conversational abilities.
  - Provide insights into carbon footprint comparisons and sustainability tips.
- **Output:** Interactive responses tailored to user needs.

Module 5: Frontend Display

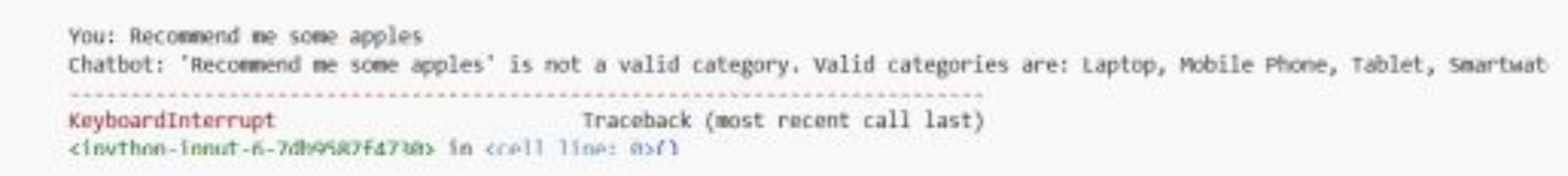
- **Input:** Data from the backend (API responses).
- **Function:**
  - Render lifecycle emissions data and recommendations interactively.
  - Integrate charts and filters for product exploration.
  - Include chatbot for navigation and support.
- **Output:** Engaging, user-friendly web interface.

Result

- The chatbot gives the recommendation of the products, if a valid product category is mentioned, as shown in Figure
- The chatbot tells the user that the category is not valid, if invalid category is entered,as shown in Figure



The result when a valid category is given



The result when an invalid category is entered

Result

- User give product details which is taken as input by PPO model and it recommends top 7 products accordingly.

- Recommendations are shown in the figures.

- Based on user behaviour and actions , it optimize itself which is a continuous process.

```
Enter the product category (select number or type the category name): Laptop

Enter product specifications:
RAM (e.g., 8GB): 16GB
Processor (e.g., Intel i7): AMD
Storage (e.g., 256GB SSD): 512GB

Recommended Products:

Device Name: Asus ZenBook
Category: Laptop
Specifications: Specifications for Asus ZenBook - RAM: 16GB, Processor: AMD, Storage: 512GB
Carbon Footprint: 70.1 kg CO2e
Price: $573
Rating: 3.1
```

```
Device Name: Acer Swift 3
Category: Laptop
Specifications: Specifications for Acer Swift 3 - RAM: 16GB, Processo
r: AMD, Storage: 512GB
Carbon Footprint: 42.9 kg CO2e
Price: $2573
Rating: 3.0


Device Name: HP Spectre x360
Category: Laptop
Specifications: Specifications for HP Spectre x360 - RAM: 16GB, Proces
sor: AMD, Storage: 512GB
Carbon Footprint: 63.2 kg CO2e
Price: $1217
Rating: 4.6
```

Product Recommendations Output

Conclusion

- The Sustainability Recommender System showcases how AI and reinforcement learning (PPO) can drive eco-friendly consumer behavior. By integrating an AI-powered recommendation engine, an LLama chatbot, and LCA-based carbon footprint analysis, the system personalizes product suggestions while ensuring efficient data handling through PostgreSQL and enhancing user accessibility with a Streamlit interface.

- Unlike conventional recommendation systems, this approach prioritizes sustainability, offering consumers real-time insights into the carbon footprint of their choices.

- This scalable system holds significant potential for integration with e-commerce platforms, corporate sustainability initiatives, and environmental policies. By leveraging AI-driven insights, it empowers users to make informed, eco-conscious decisions, contributing to a more sustainable future. Future enhancements, including expanded product categories and improved chatbot intelligence, will further strengthen its impact in promoting responsible consumption.

THANK YOU