

# Eco-Guard AI: An Intelligent Multi-Agent Framework for Campus Sustainability Management

Prof. Pallavi Parma<sup>1</sup>, Prof. Nitin Kumar Chaudhary<sup>2</sup>, Piyush Mahant<sup>3</sup>,  
Kaushal Shahare<sup>4</sup> and Mohammad Mubashshir<sup>5</sup>

<sup>1</sup>Assistant Professor, Department of Data Science, CSE (IoT) and CSE (Cyber Security)

<sup>2</sup>Professor, Department of Data Science, CSE (IoT) and CSE (Cyber Security)

<sup>3,4,5</sup>Students, Department of Data Science, CSE (IoT) and CSE (Cyber Security)

G H Rasoni College of Engineering, Nagpur, India

**Abstract:** *In today's world where there is a growing need for more responsible use of resources, and an ever-increasing amount of environmental impact to deal with, it is no wonder that environmental sustainability has emerged as a top priority for institutions of higher learning. As a result of this, campuses today rely on a great deal of electricity, water and other types of natural resources; therefore managing sustainability has become a crucial component for institutions to reach their smart-campus goals. However, many existing, traditional campus sustainability systems do not take advantage of modern technologies and extensively use manual monitoring techniques and multiple software applications that do not have intelligent analytics or real-time decision-making capabilities.*

*This article introduces "Eco-Guard AI," a "smart" system of several autonomous, cooperating groups (agents) that use "Artificial Intelligence (AI)," "Natural Language Processing (NLP)," and "Retrieval-Augmented Generation (RAG)" to manage the sustainability of college campuses through intelligent conversation and action.*

*The system contains several different types of agents, including an "Orchestrator agent," which is responsible for coordinating the activities of all other agents; a "Parameter extraction agent," which extracts parameters or information from each query; a "Clarification agent," which clarifies parameters from users as new parameters or assist by adding information to existing parameters; a "RAG Agent," which uses RAG to retrieve contextual knowledge from external sources and provide additional guidance; and an "Analysis agent," which analyzes resource consumption to make recommendations based on the previous agents.*

*This modular, scalable, maintainable and extensible architecture provides an innovative approach to managing our environment and optimizing our campus operations through intelligent environmental management and sustainable campus operations.*

**Keywords:** Artificial Intelligence, Multi-Agent Systems, Campus Sustainability, Retrieval Augmented Generation, Smart Campus, Resource Management, Natural Language Processing and Sustainability Analytics.

## I. INTRODUCTION

Due to the increasing use of energy, depletion of resources, and the rising level of environmental pollution, environmental sustainability has become a global issue. A large number of electricity and water usage, along with other resources are consumed by educational institutions, most often on University and College campuses, every day. As these institutions expand their infrastructure and student population, it can be increasingly difficult to



manage the complexity of sustainability-related activities. Therefore, campuses are searching for intelligent technology solutions to help them monitor, analyze, and optimize sustainability operations.

Innovations in Artificial Intelligence (AI), Natural Language Processing (NLP), and Multi-Agent Systems (MAS) have created new potential for intelligent solutions to manage the environment. Multi-Agent Systems provide a form of distributed intelligence, allowing specialized, autonomous, and cooperating agents to work together to solve complex problems. Their scalability, flexibility, and adaptability support the use of multi-agent systems in applications that require sustainability management.

Eco-Guard AI is an advanced multiagent system providing intelligent support for sustainability management on university campuses. By combining AI analytics, retrieval-augmented generation (RAG) contextual retrieval, and the coordination of multiple agents, Eco-Guard AI can generate actionable sustainability recommendations.

Eco-Guard AI uses natural language interaction, so administrators and other stakeholders can easily and intuitively interact with the tool to gain insights into the sustainability of their institutions.

The primary goal of this research is to develop a modular and scalable system capable of analyzing sustainability related data sets to produce evidence-based recommendations for the conservation of electricity, the management of water, and the reduction of waste. The research also demonstrates how the integration of multiple agent systems with retrieval-augmented generation (RAG) can support creation and dissemination of environmentally sustainable solutions.

## **II. LITERATURE REVIEW**

### **Multi-Agent Systems**

Agents operate independently of each other in a multi-agent system but work together towards a common goal through communication and coordination with one another.

Multitasking and flexible operation are the reasons multi-agent architecture has been developed and is often used for distributed computer systems. Many studies have been conducted on the use of MAS in many areas including:

- Intelligent Cities
- Health Care
- Transportation
- Industrial Automation

MAS facilitates environmental sustainability by providing better integration between the various analytic components that are responsible for managing and optimizing the consumption of environmental resources.

Artificial Intelligence in Sustainability Management Sustainability and Environmental Management Deliver Early Solutions with Artificial Intelligence (AI)

The use of Artificial Intelligence (AI) Technology for Sustainability and Environmental Management applications has been growing rapidly, and there are numerous examples where AI applications have provided solutions. The use of Machine Learning (ML) Algorithms / Predictive Analytic Techniques as part of AI has allowed organisations to identify consumption patterns, identify anomalies and optimise Resource Usage. Examples of successful applications of AI include the use of AI-based Systems in Smart Energy Grids, Water Conservation, Waste Management and Carbon Footprint Analysis.

AI-Based Sustainability Systems will also improve Operational Efficiency through automating many of the Analysis Procedures, and by facilitating a Data-Driven Decision-Making Process. However, most of these existing solutions are limited to Single-Application or Domain Specific Uses, and do not possess Contextual Reasoning Capability.

### **Retrieval-Augmented Generation (RAG)**

Retrieval-Augmented Generation (RAG) is an advanced method of AI that combines the use of large-scale language models and mechanisms for searching for external information to form a coherent response rather than generating responses based solely on prior knowledge.



By using this method, AI-generated responses become more factually accurate, better able to understand context, and more reliably produced than through the use of only pre-trained language models.

This provides value to applications where expertise in a specific field is needed, such as sustainability management, where suggested actions must be based on authoritative guidelines or institutional policies.

Smart Campus Technologies. The use of intelligent and connected digital technologies is being integrated into Smart Campus Initiatives to enhance campus operations and sustainability through the use of IoT, AI, Cloud Computing and Data Analytics). By automating monitoring of resource consumption, environmental conditions and infrastructure performance, smart campus systems can assist in monitoring these metrics.

There are numerous areas of implementation for smart campus initiatives, including but not limited to: smart energy systems, intelligent waste management, water quality monitoring & renewable energy integration. Although there have been many technological advancements within the smart campus space; many still do not have Conversational AI capabilities or an Intelligent Recommendation Framework.

### **Research Gap**

The literature review shows that current sustainability management systems normally do not exhibit multi-agent systems (MAS). Furthermore, very few studies exist which engage the use of natural language for generating recommendations or analysis related to sustainability. EcoGuard AI is a framework for closing these gaps including the integration of MAS, RAG and AI powered analysis in an inclusive sustainability management system.

## **III. PROPOSED SYSTEM**

### **Overview of Eco-Guard AI**

Eco-Guard AI incorporates smart campus sustainability management abilities that utilize Artificial Intelligence (AI), Multi-Agent Systems (MAS), and Retrieval-Augmented Generation (RAG) techniques in order to support environmentally responsible decision making. This framework analyzes sustainability metrics associated with energy consumption, water consumption, and waste management.

The proposed architecture consists of coordinated groups of specialized agents governed by a central Orchestrator Agent. Each of these agents executes their own specialized tasks such as extracting parameters, retrieving contextual data, conducting sustainability analysis, processing clarification requests, and generating recommendations.

Users can interact with the system by entering natural language queries. The natural language interface enhances accessibility for campus administrators and staff as well as for non-technical stakeholders.

## **III. METHODOLOGY**

AI technologies and vector database systems based on the Python programming language were used to create the suggested solution. The process for developing the proposed application is divided into five main activities;

### **1. Data & Dataset Creation**

Simulated datasets reflecting energy use, water usage, and waste management on campus were created and structured.

### **2. Data Cleanup/Processing**

Pandas and NumPy libraries were utilized for data cleaning and processing of these datasets. Missing values were dealt with, and standardization techniques were applied to the data being processed.



### 3. Multi Agent Coordination

User requests of the application will be sent to the orchestrator agent, which will identify and call the appropriate agents needed for the successful execution of your request.

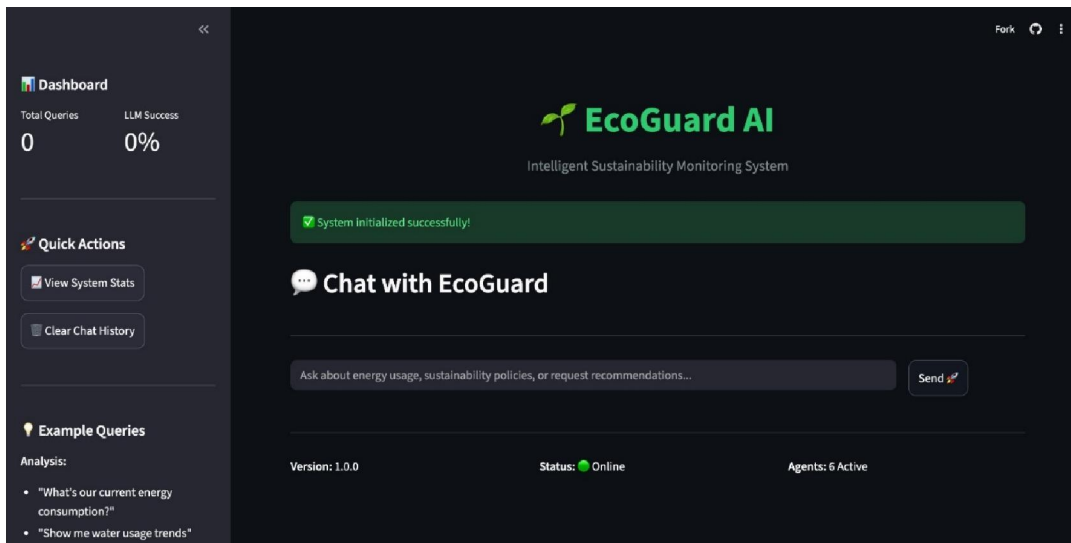
### 4. Retrieval-Augmented Generation

The RAG module retrieves contextual evidence and factual evidence from the vector databases containing sustainability-related information to enhance factual accuracy and improve your understanding of context.

### 5. Recommendations Generation

The Recommendations agent uses the information retrieved (domain-specific to sustainability) based upon analysis of the processed dataset, as well as aggregated data retrieved through RAG's data retrieval methods to develop strategies for improving sustainability.

An application was created using the following programming languages/technologies: Python, LangChain, OpenAI API, FAISS/Chroma vector databases, and Streamlit/FastAPI user interface.



## IV. RESULT AND DISCUSSION

The Eco-Guard AI framework has been tested on sustainability-related data sets that reflect the use of campus resources.

The Eco-Guard AI framework could effectively respond to user requests and provide context-based recommendations. The parameter extraction agent effectively identified such data as building names, time periods, and resource types. The use of RAG improved the reliability of the generated results by supplementing them with information obtained from sustainability policies and institutional knowledge.

Some examples included:

The analysis of energy consumption patterns in campus buildings.

Tracking the patterns of wasteful water use.

Recommendations on how to manage waste based on recycling practices.



The use of multi-agents increased processing efficiency in the development of the Eco-Guard AI Framework by sharing the workload among the individual agents that were created for specific tasks. The use of a modular design structure simplified

Scaling and maintaining the overall system.

The findings indicate that the Eco-Guard AI framework has the potential to help educational institutions monitor their sustainability performance and make well-informed environmental decisions.

## **V. CONCLUSION**

The development of Eco-Guard AI was presented in this paper, an intelligent multi-agent framework that will help in managing sustainability across campus. This proposed eco-management system uses a blend of artificial intelligence (AI), multi-agent systems (MAS), and retrieval-augmented generation (RAG) results to support delivering data-driven sustainability analysis and recommendations.

The framework architecture supports efficient resource monitoring, context-relevant knowledge retrieval, and intelligent decision support (via natural language-based interactions) among other purposes. Testing of the framework indicates that it supports improvements to the quality of the sustainability assessment and the likelihood of providing actionable recommendations.

Potential areas for future development include: integrating IoT devices for real-time resource monitoring; using machine learning to implement predictive analytics; using a cloud service to support scalability of the solution; and creating advanced visualisation dashboards to support the sustainability reporting process.

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