Web Application Development of Secondary Education Carbon Footprint Monitoring System

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***Abstract*—This research presents a comprehensive solution to the significant challenge of environmental impact caused by the widespread integration of technology in secondary education. It proposes a web-based application that optimizes procurement decisions, aligning them with environmental sustainability goals. The system uses a data-driven approach, leveraging existing school data to monitor and reduce carbon emissions effectively. The application not only aids in making informed purchasing decisions but also in managing inventory and usage patterns, thus allowing a significant reduction in carbon footprint. This framework serves as a model for schools worldwide to integrate environmental considerations into their operational strategies, promoting a more sustainable future in education.**

***Keywords*—carbon footprint, emission, monitoring, optimization, secondary education**

I. Introduction

In recent decades, the integration of technology in education has surged remarkably, transforming the accessibility, efficiency, and efficacy of educational processes globally. Technologies have not only provided a more diverse and contemporary access to learning materials but have also enhanced interactions among students and teachers across different regions [1]. The widespread adoption of digital tools, software, and platforms seeks to enhance the quality of education and meet the varied needs of students.. Furthermore, the Indonesian government's commitment to digitalization in education is proven by the allocation of a 3 billion IDR budget for the procurement of ICT learning tools, benefitting 1,753,445 students across 36,281 schools in 2019 [2]. These tools include servers, tablets, laptops, LCDs, routers, and external hard disks.

However, the environmental impact of increasing technology use in schools often remains an overlooked concern [3]. Continuous technological upgrades and implementations in schools, particularly in Indonesia, could significantly contribute to carbon emissions if not managed with environmental considerations. This scenario poses serious issues related to high energy consumption, electronic waste, and an increased carbon footprint.

Tackling these challenges requires careful control and restriction of educational technology use, guided by detailed monitoring of its environmental effects. Understanding the natural resources and energy consumed by educational technologies is crucial. Such insights will aid in identifying areas where technology usage can be optimized without compromising educational quality.

While previous research has explored the significance of reducing carbon footprints within the context of sustainable development and climate protection, particularly in educational settings, there has been a notable gap in developing specific monitoring applications tailored for secondary education institutions. For instance, the study on 2021 [4] emphasized the importance of calculating carbon footprints to raise awareness among students about greenhouse gas emissions and to develop actionable steps for climate protection. Their work introduced Schools4Future tool, which enabled students to actively calculate and reduce their school's carbon emissions through an Excel-based assessment tool. Similarly, a detailed analysis of carbon emissions was conducted at a high school in Bulancak, Giresun, Turkey [5], which includes emissions from various activities by students and teachers as well as institutional emissions. However, both studies primarily focused on assessment and awareness rather than creating a dedicated application designed for secondary education institutions to continuously monitor and manage their carbon footprint systematically. This gap underscores the need for developing such applications to facilitate ongoing environmental management and education at the secondary education level.

This study explores the necessity of restricting technology use in schools by monitoring its environmental consequences. The goal is to provide foundational solutions that guide policymakers, educators, and stakeholders in integrating sustainability principles into the development and usage of technology in secondary education. This study aims to contribute significantly towards creating a more sustainable and environmentally friendly educational system for future generations.

II. Literature Review

A. Carbon Footprint

Greenhouse gases (GHGs) are composed of various gases that trap solar radiation and heat, thereby contributing to an increase in Earth's temperature and causing global warming. The major GHGs include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorocarbons such as CF4, C_2F_6, SF_6, and NF_3, which have been identified as significant contributors to global emissions trends over the years [6]. Global warming, a phenomenon where the average surface temperature of the Earth rises significantly over a prolonged period, is associated with the increased concentrations of GHGs in the atmosphere, intensifying the natural greenhouse effect. This temperature rise has severe implications on global climate change, potentially leading to extreme weather events like floods, droughts, and rising sea levels. A carbon footprint, quantitatively, is the total emissions of GHGs produced by an individual, organization, or specific activity [7]. Measuring the carbon footprint is the initial step towards recognizing the impact of daily activities on climate change and initiating actions to reduce GHG emissions.

GHG emissions can be classified into three groups based on their source and the impact of the activities that produce these emissions [8].

- Scope 1 refers to direct emissions from sources owned or controlled by the organization, such as fuel combustion.
- Scope 2 covers indirect emissions from the generation of purchased energy consumed by the organization, such as electricity bought from external power plants.
- Scope 3 includes other indirect emissions that occur from activities related to the organization but are not under its direct control, including supply chain operations, business travel, and customer product usage. Typically, Scope 3 emissions are the largest source for most organizations.

The calculation of greenhouse gas emissions varies with each source and organization. This study focuses on Scope 2 emissions, particularly from technology use in secondary schools. The calculation that will be used in this research is as follows, where $E_{electricity}$ represents the emissions produced by the use of electricity, $Ef_{electricity}$ represents the electricity grid emission factor in Indonesia which was 0.7848 kg CO_2e / kWh in 2022 [9], P represents the power of an electronic device (Watt), and t represents the usage time (hours).

$$E_{electricity} = Ef_{electricity} \times \frac{P \times t}{1000} \quad (1)$$

B. Optimization Modeling

An optimization modeling is a tool used to find the best possible solution to a given problem by maximizing or minimizing a particular objective with specific constraints [10]. Optimization modellings are crucial for decision-making processes. These models are typically constructed to reflect the goals of the system—whether reducing costs, enhancing performance, increasing efficiency, or minimizing environmental impact.

The optimization problem designed for minimizing the environmental impact and costs associated with purchasing school supplies includes both variables and constraints tailored to the specific needs and resources of educational institutions. The objective function combines the costs and emissions associated with each item, adjusted by their priorities, ensuring that the most critical items with the least environmental impact are prioritized. Constraints are formulated to ensure that each rooms' needs are met without exceeding the budget or emissions caps. This structured approach enables schools to make more informed and sustainable purchasing decisions by evaluating the trade-offs between cost, necessity, and environmental impact within a mathematical framework. This methodology underscores the potential of optimization in enhancing resource allocation in educational settings.

III. Problem and Solution Definition

A. Research Problem

The widespread integration of technology in secondary schools worldwide has led to significant benefits in education but has not been accompanied by sufficient awareness of its environmental impacts. Schools often deploy these technologies without fully considering the resultant carbon emissions from energy consumption and electronic device production. This lack of awareness prevents effective environmental management in educational settings.

Currently, there are no specific system that monitors the carbon emissions from educational technologies specifically used in secondary education. This gap makes it challenging for schools to objectively evaluate the environmental impact of their technology usage or to make sustainable technology choices. Therefore, there is an urgent need for a system that not only tracks and predicts emissions but also guides schools in implementing strategies to reduce their carbon footprint, thereby promoting more sustainable educational practices.

B. Proposed Solution

Schools need a system to manage the purchase of goods based on emission data collected from users, a crucial step toward implementing emission reduction strategies. This system would include an optimization function to prioritize purchases that align with the school's carbon footprint goals. The function will be integrated into a user-friendly web-based application, accessible on various devices. The primary users of this web-based application include school administrators and procurement officers who are responsible for managing the school's resources. The application is designed to meet their needs by providing tools for tracking emissions, monitoring resource use, and optimizing procurement decisions based on environmental sustainability goals. The system's features, such as the inventory management and purchase optimization, are tailored to support the decision-making process of these users. The proposed solution can be seen on Figure 1.

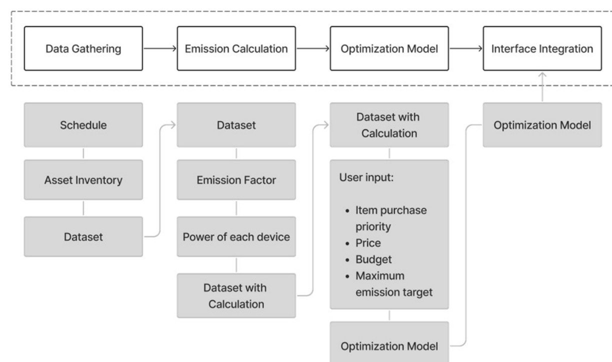

Fig. 1. Proposed Solution Workflow

This application will use existing data, such as school schedules, inventory, and the energy data of devices, to optimize purchasing decisions. Inputs like purchase priorities, item prices, budget, and emission targets will guide the optimization to ensure purchases do not exceed the carbon limits or financial constraints. This setup aims to equip schools with the tools to make informed decisions that contribute to sustainability, reducing future carbon emissions and enhancing environmental awareness.

IV. Research and Analysis

A. Business Understanding

Carbon emissions are a critical global issue affecting the quality of life across all living beings, with educational sectors worldwide contributing significantly through their expansive use of technology. While education is prioritized highly by both governments and communities, leading to well-funded and technology-rich environments, these improvements often overlook the environmental impacts, such as increased carbon emissions from electronic devices and other school facilities.

Currently, while there are government regulations detailing the necessary infrastructure for schools [11], these do not include guidelines on managing carbon emissions or promoting environmentally friendly practices. Interviews with several schools revealed a lack of regulated measures in the purchase and use of new electronic equipment, often driven by immediate needs or special vendor offers. There's an absence of environmental considerations in these procurement processes, suggesting a critical area for intervention. Implementing carbon emission evaluations during the procurement phase could serve as an effective measure to ensure environmental sustainability is considered in school operations.

B. Data Understanding and Preparation

The modeling process for this study uses data from X school, a junior high school located in Central Jakarta, chosen for its extensive use of electronic equipment in teaching and a detailed inventory of each classroom. This selection is based on the school's diverse electronic equipment usage patterns and comprehensive classroom inventories, providing a solid baseline for developing a system that other schools could potentially adopt. There are three data that X school provided.

- Room Usage Schedule: Available in PDF format, detailing which classes use each room and for how long, accommodating the school's moving class system where one room hosts multiple classes and subjects.
- Class Data: Provided in a spreadsheet, this includes the number of students per class.
- Inventory of Items: A PDF document listing all items in each classroom, including quantity and brand, crucial for calculating carbon emissions based on the power usage of each electronic device.

The data preparation process for analyzing carbon emissions in schools involves several key steps.

- Data Preprocessing: The existing data is reformatted into a tabular form using spreadsheet software to make it workable. This involves structuring data around three main entities: Rooms, Classes, and Devices.
- Data Integration: These entities are combined to create a comprehensive view of energy consumption for each room. This involves relationships such as 'Room Usage' by specific classes and 'Devices in Rooms', identifying which devices are in which rooms. This integrated data is then imported into a Jupyter Notebook using the pandas library to handle it as a DataFrame.
- Emission Calculation: A single table is formed from the integrated data, and carbon emissions are calculated using a specific formula, resulting in a final DataFrame that includes emission details.

The preparation process results in a dataset with the specification listed on Table I. Each entity represents a new .csv file created from the data preparation process.

TABLE I. FINAL ENTITIES

Entity	Attribute	Description
Room	room_name (string)	Data about rooms in the school that can be used for educational activities.
Class	class_name (string) number_of_students (string)	Data about the classes in the current academic year. The term 'classes' refers to groups of students.
Device	device_name (string) device_brand (string) price (float) watt (float)	Data about the electronic devices in the school.
Room_ Class	room_name (string) day (string) start_time (string) end_time (string) class_name (string)	Data about the rooms used by classes, along with their usage schedules.
Room_ Device	room_name (string) device_name (string) device_brand (string) device_quantity (string)	Data about the devices present in each classroom.

C. Modeling

The optimization model is implemented using the SciPy optimize function in Python. The goal of this function is to optimize the allocation of school equipment procurement based on priorities, costs, and the carbon emissions generated. Key parameters such as room needs, existing inventory, carbon emissions, and the costs of each piece of equipment are defined and organized into appropriate data structures.

This data forms the basis of a binary optimization problem where binary decision variables $x_i \in \{0,1\}$ represent whether each item i is purchased ($x_i = 1$) or not ($x_i = 0$). The objective function below is designed to effectively maximize priority, represented mathematically as the negative logarithm of one plus the priority value of each item. This translates to minimizing the negative of this expression, ensuring high-priority items are favored, subject to budgetary and emissions constraints.

$$\text{Minimize } -\sum_{i=1}^{n} x_i \log(1 + \text{priority}_i) \quad (2)$$

Constraints are put in place to ensure that the total spending does not exceed the maximum budget and the total emissions do not surpass the allocated emission limits. The optimization process, executed using the SLSQP method, seeks to find the optimal combination of items that meet these criteria. If the optimization succeeds, the result provides a clear decision on the quantity of each item to be purchased, facilitating strategic procurement aligned with financial constraints and sustainability goals.

- Budget Constraints

$$\sum_{i=1}^{n} price_i \cdot x_i \leq \text{Max Budget} \quad (4)$$

- Emission Constraints

$$\sum_{i=1}^{n} (power_i \cdot emission\ factor \cdot x_i) + \text{Total Emissions} \leq \text{Max Emissions} \quad (5)$$

The optimization model developed is a key feature within the web-based application, allowing users to make data-driven decisions regarding procurement. By embedding the model into the application, users can input relevant data (such as budget, emission targets, and item priorities) and receive optimized recommendations for procurement. This integration ensures that the application not only serves as a monitoring tool but also actively aids in reducing carbon emissions by guiding sustainable purchasing decisions.

D. Result and Evaluation

After the model is executed, the results are evaluated to determine the success of the optimization. Each variable in the solution is interpreted to assess the number of items to be purchased and their impact on the budget and total emissions. The status of the solution, which can be feasible or infeasible, provides insight into the viability of the proposed solution based on the established criteria.

The model shows which items that should be bought, along with which room that will have it and its quantity. The example of the function result is shown on Figure 2.

```
Status: Infeasible
Purchase_('Class103',_'Komputer') = 1.0
Purchase_('Class103',_'Smartboard') = 3.0
```

Fig. 2. Optimization Function Example

E. Web Application Development

Based on the main feature of the system, which is monitoring and optimizing the purchase decisions of new items, functionality requirements can be defined. The features are also accompanied by several other additional features that could help further the schools to monitor their electricity usage and emissions. During the development of the application, the assumed needs of school administrators and procurement officers were considered based on the availability of data that was provided by X school. However, formal user requirement gathering and testing were not conducted in this study. The functional requirements are as follows.

- Users can register to access the web-based application.
- Users can log in to the website.
- Users can view the existing inventory data in the database.
- Users can upload and edit room data, equipment data, class data, room and class data, and room and equipment data.
- Users can view the amount of emissions generated during a specific period at the school level.
- Users can view the number of rooms used during a specific period at the school level.
- Users can view the number of devices used during a specific period at the school level.
- Users can view the amount of emissions generated during a specific period at the room level.
- Users can view the number of devices used during a specific period at the room level.
- Users can view predicted carbon emissions at the school level for a user-specified period.
- Users can input purchase priorities, new item prices, purchase budget, and maximum emission targets to get purchase decision results.

Based on the functional requirements of the application, an architecture for software development can be defined, as seen on Figure 3. User-entered data will be stored in a database and retrieved by the interface system. The software development is divided into three parts: frontend, backend, and database. Calculations and predictions will be conducted in the backend, which fetches data from the database, while the frontend manages the interactive display for users.

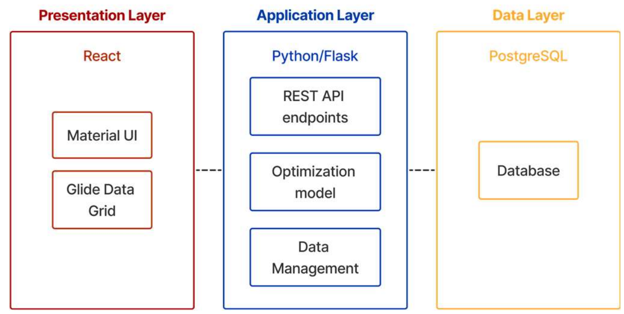

Fig. 3. Application Architecture

The development of the web-based application adheres to the requirements and the software interface is developed using React with TypeScript, incorporating user interaction components from Material UI such as buttons, text fields, dropdown menus, etc. Data tables queried from the backend are displayed using Glide Data Grid, an open-source library from Glide that enables attractive table views for easy data management. The development uses Indonesian language for its main language to adhere to Indonesian schools. Figure 4 shows the user flow diagram of the planned application.

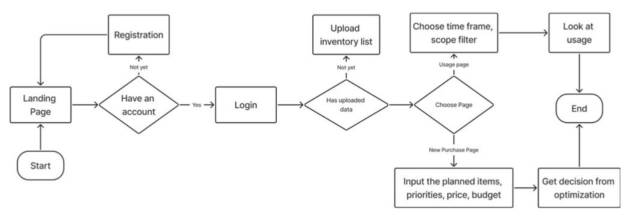

Fig. 4. Application User Flow Diagram

The backend development utilizes Python Flask to provide endpoints, perform calculations, predictions, and run optimization functions as previously determined. Results from database retrievals and other programming logic are output as JSON data through Flask-provided endpoints. The software's database is managed using the PostgreSQL database management system.

The development of a web-based application employs a structured database architecture comprising several tables, each serving a distinct purpose in managing school operations. The 'users' table manages user authentication details, while the 'inventory' and 'locations' tables store data about school equipment and physical locations, respectively. The 'classes' table captures class information, and relational tables like 'location_class' and 'inventory_location' link these entities to manage schedules and equipment allocation efficiently.

F. Web Application Results

As seen on Figure 5, the optimization model has succeeded in showing that the items should not be purchased. The status is not optimal because there is a constraint that was not fulfilled, and that is having all of them bought. The application shows the status to let the users know that their initial goals might not be reached but there is an alternative to what they can do, since the application can also show which device to buy.

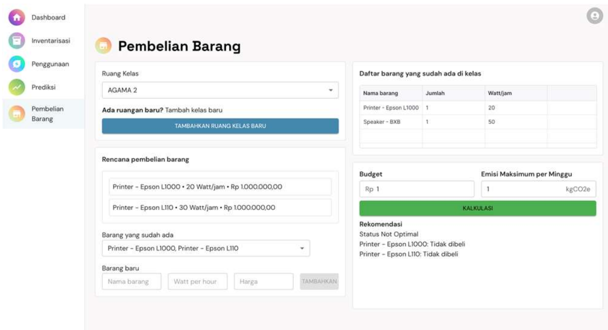

Fig. 5. Purchase Decision Page

Aside from the purchase decision page, there is also a page that shows the usage of electronic devices across rooms, which shows how many rooms are used, how many devices are used, and how much is the emission caused by the usage of the devices based on the calculation from the time frame selected on the filter section. The Usage page can be seen on Figure 6.

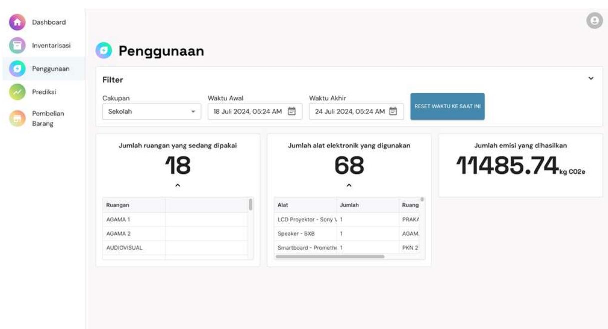

Fig. 6. Usage Page

While this application provides a foundation for reducing carbon emissions in schools, further development are suggested to be involved for the gathering user requirements and testing process. These steps will ensure the system meets the practical needs of school administrators and other stakeholders.

V. CONCLUSION

This research highlights the critical need for systems that monitor and manage carbon emissions in secondary education settings. The proposed web-based application addresses the gap in environmental awareness related to the use of educational technologies. Through its functionalities, such as monitoring emissions and optimizing resource procurement, the application supports schools in making informed decisions. By integrating such systems, schools can take significant strides towards sustainability, ensuring they contribute positively to both educational outcomes and environmental stewardship. This study lays the groundwork for further research into sustainable practices in educational environments and the development of more advanced systems to support these efforts.

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