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PROCEEDINGS OF THE STI 100³ PROGRAMME:

APPLIED RESEARCH ON ENVIRONMENTAL SUSTAINABILITY AT SMK ENGKILILI, SRI AMAN, SARAWAK

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This proceedings book compiles research works produced under the Science, Technology and Innovation (STI) 1003 Programme themed “Exploring STEM through Scientific Investigation” at Sekolah Menengah Kebangsaan (SMK) Engkilili, Sri Aman, Sarawak. These research works cover energy management, waste management, and experimental projects which highlight the application of STEM concepts through scientific investigation and communication.



PROCEEDINGS OF THE SCIENCE, TECHNOLOGY AND INNOVATION (STI) 100^3 PROGRAMME:

APPLIED RESEARCH ON ENVIRONMENTAL SUSTAINABILITY AT SMK ENGKILILI, SRI AMAN, SARAWAK

14th January – 25th February 2026

Department of Chemical Engineering and Energy Sustainability, Faculty of Engineering, Universiti Malaysia Sarawak (UNIMAS), Jalan Dato Mohammad Musa, 94300 Kota Samarahan, Sarawak.

Proceedings of the Science, Technology and Innovation (STI) 100^3 Programme: Applied Research on Environmental Sustainability at SMK Engkilili, Sri Aman, Sarawak

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This proceedings book compiles the research works conducted during the Science, Technology and Innovation (STI) 100^3 Programme. The programme was conducted at Sekolah Menengah Kebangsaan (SMK) Engkilili in Sri Aman, Sarawak, under the theme "Exploring STEM through Scientific Investigation." The programme was supported by the Department of Chemical Engineering and Energy Sustainability, Faculty of Engineering, Universiti Malaysia Sarawak (UNIMAS) and YellowHippo STEM Squad.

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Table of Contents

	Page
Front Page	**i**
Copyright Page	**ii**
Foreword	**vi**
Acknowledgment	**vii**
Preface	**viii**
Part I: Energy Management Projects	**1**
Electrical Energy Consumption Identification and Analysis at Block Meranti of SMK Engkilili, Sri Aman, Sarawak *Nurul Aqilah Adawiyah Binti Sajana, Alvin Alexson Kunneng Anak Daidy, Alicia Vellovia Anak Moris, Evelina Esther Anak Galang, Dexter Ryan Anak Pandik and Alecya Fira Anak Nair*	**2**
Assessment and Reduction of Electricity Consumption Dahlia, Kemuning, Melati and Kemboja Buildings, SMK Engkilili, Sri Aman, Sarawak *Aaron Andreas Anak Henry, Antonio Bama Anak Adam, Alizee Deeniza Anak Barudi @ Brodie, Evelyn Tarra Anak Andrew and Felix Evans Anak Thomas Agas*	**19**
Energy Consumption in Educational Facilities: A Case Study of Energy Audit at SMK Engkilili, Sri Aman Sarawak (Keruntum Block) *Nur Izzati Syazwani binti Ismandi, Carl Rogers Anak Geripin, Alleysa Angie Tam, Hellen Liana Siuh Anak Sapli, Maxzly Owen Anak Egrygory and Evelyn Madeline Anak Martin*	**31**
Electrical Energy Audit and Consumption Improvement at Non-Educational Buildings of SMK Engkilili, Sri Aman, Sarawak *Denilson Felix Anak Letar, Christian Gabok Anak Billy, Anabella Vanessa Anak Mathius, Josephine Mudi Anak Tommy Rentap, Nick Liassen Adiak Anak Sapli and Genevie Dalnie Anak Dalto*	**44**
Energy Assessment of Auxiliaries Educational Facilities at SMK Engkilili, Sri Aman, Sarawak *Frederick Anak Matthew, Christian Ronan Gerrard Anak Jerry Hawkin, Aneysia Phang Yi Xuan, Kyria Edna Anak Herry, Jesliana Cassara Dian Anak Jackson and Jessela Betty Anak Tommy Rentap*	**55**
Energy Audit for Electricity Consumption and Greenhouse Gas Emission at SMK Engkilili Dormitories *Jehovah Jeranding Anak Jeffery, Donnylyon Elvis Anak Don Juan, Esila Rabai Anak Suzyana, Sherylryvelyn Esther Anak Romie, Joanna Faith Anak Stanley Enggu and Lenny Tora Anak Lee*	**65**
Part II: Waste Management Projects	**77**
Quantitative Analysis of Food Waste Generation and Improvement Plan within SMK Engkilili Dining Hall *Noor Naizman bin Noor Azman, Dylan Isaiah Jelai Anak Zaccaria Bakak, Avril Lavigne Anak Reji, Marysa Eyun Anak Manggau and Ruth Kasih Anak Lika*	**78**

Assessment of Solid Waste Generated at SMK Engkilili Canteen and The Waste Potential Recyclability 90
Michael Benedict Foo, Lestenson Ethen Damu Anak Allan Robertson, Breyionna Vallery Anak Bonifis Baing, Santi Anita Anak Bakun and Sharen Riah Anak Stephan Bite

Food Waste Generation and Disposal at School Kitchen of SMK Engkilili, Sri Aman, Sarawak 103
Puteri Nur Dayini Binti Mohammad Nurzaideen, Mokhskyale Immanuel Bin Sundramdorty, Cecelline Darie Anak Robin, Coninza Tabio Anak Empiu and Sherry Caryna Panti Anak Jawie

Investigative Study on Solid Waste Management and Potential Revenue within Teacher's Workspace at SMK Engkilili, Sri Aman, Sarawak 113
Darwisy Irfan bin Zamri, Moses Arshavin Love Anak Desmond, Emielia Anak Andam, Victoria Natasha Anak Maruddin and Elezabert Abella Kebang Anak Kenawang

Garden Waste Management for Environmental Sustainability at SMK Engkilili, Sri Aman, Sarawak 128
Ellv Nathalley Liew, Clearence Thomson Ambu Anak Edi, Vanessa Mellisa Empayung Anak Douglas, Ross An Felix and Nissa Shania Anak Ronnyson

An Assessment of Generation, Segregation and Sustainable Management Practices Among Student at SMK Engkilili, Sri Aman, Sarawak 137
Fradelyna Duyun Anak Leonardo, Agnes Vanessa Anak Mambak, Alesya Alvina Anak Albert and Bresly Amos Anak Anthony

Part III: Experimental Research Projects 148

Turning Waste into Energy: A Comparative Analysis of Biodiesel Extract from Used Cooking Oil and New Cooking Oil 149
Mohammad Muzzamil Abdullah, Felix Ian Anak Vincent, Aaron Cooper Mundau Anak Stewart, Shella Allysia Amanda Anak Lawrence, Valensia Jee Yun Cai, Gyanmonfis Ngipa Anak Nito, Agnesty Dorothy Anak Magrie and Janice Liew Qiu Yee

Recycling Used Cooking Oil for Soap Production: An Environmental Solution 162
Elyza Farhana Binti Kushairy, Aina Batrisyia Husna bt Ahmadi, Bradniey Billo Anak Rambli, Orialkazia Anak Herry, Aleesya Nurfatihah Binti Abdullah Hazanizam, Jeremie Anak Jeffery and Alicia Shakira Anak Joe

Batch Electrocoagulation Using Aluminium Electrodes for Water Treatment of Batang Lupar River at Engkilili, Sri Aman, Sarawak 173
Alvyne Renno Anak Stephen, Christiano Janggak Anak Steward, Nurul Muthiah Binti Nasir, Shinenny Liew Yan Yee, Muhammad Farisfikri Bin Abdul Hattardy and Fellyshantia Layah Anak Douglas

Experimental Analysis of Batch Electrocoagulation Water Treatment System for Peat Water within Engkilili, Sri Aman, Sarawak 182
Joshua Anyi Ngau, Chong Jun Xiang, Octavia Loretta Lanam Anak Dennis Stenley, Lista Imanuel Anak Jalin, Clarissa Marie Swyny and Evlyn Venessa Binti Bernard

Hydrodistillation of Pandanus Amaryllifolius Leaf Puree for Hydrosol Recovery 192
Ezra Lika Anak James, Martin Bryan Foo, Othoniel Unal Yap Anak Simong, Kua Chen Qian, Steve Anak Tony, Fenny Bong Yi Fei and Jennybelle Viviana Cleo Binti Morris

Volumetric Characterization and Performances of Cymbopogon Citratus (Lemongrass) Hydrosol Extraction 203
Muhammad Hairul Zaman bin Mohd Haide, Martin Bryan Foo, Petrus Mussen Anak Gindi, Avelyn Tan Sok Xin, Valentino Romandio Anak Roslan, Manuella Marell Anak Maxwell and Nur Azyyati Qistina Maharip

Comparative Analysis of Harvested Rainwater and Piped Water Quality at SMK Engkilili Dormitory 212
Claudia Marisha Endik Anak Jana, Rodriguez Belly Anak Bejit, Annly Abigail Anak Unya, Wennisa Ann Binti Raimon and Cynthia Amanda Anak Patrick

Feasibility Study of Rainwater Harvesting System as a Sustainable Water Management Strategy in SMK Engkilili, Sri Aman, Sarawak 223
Audrey Andreanna Hanny Anak Johnny Percy, Stanly Anak Setien Naun, Angelina Heaven Anak Kennedy, Ryan Macmiller Anak Rudy Kudy, Nur Damia Qiszara Binti Mohamad Rabby and Rayzephillda Phoenix Anak Mark Rayson

Foreword



Dr Nazeri Abdul Rahman
Chief Editor
Proceedings of the Science, Technology and Innovation (STI) 100³ Programme: Applied Research on Environmental Sustainability at SMK Engkilili, Sri Aman, Sarawak

Assalamu'alaikum warahmatullahi wabarakatuh and salam sejahtera.

Welcome to Proceedings of the Science, Technology, and Innovation (STI) 100^3 Programme: Applied Research on Environmental Sustainability at Sekolah Menengah Kebangsaan (SMK) Engkilili.

First and foremost, this proceeding is published under the theme of "Exploring Science, Technology, Engineering, and Mathematics (STEM) through Scientific Investigation" which presents student-led research that applies scientific principles to environmental sustainability issues. A strategic approach to strengthen STEM education in Sarawak rural areas is to engage school students in well-guided, mentor supported, and locally relevant research projects. SMK Engkilili, which is located in Sri Aman, Sarawak provides a representative rural setting where scientific investigation is conducted within practical constraints, available resources, and community needs. The outcomes presented in this proceeding demonstrate the role of rural schools as effective platforms for applied STEM learning and environmentally focused research.

Driven by this educational priority, this proceeding compiles scientific research projects undertaken by SMK Engkilili students through the STI 100^3 Programme with several sessions conducted from 14th January 2026 to 25th February 2026. In this proceeding, the knowledge contributions are organized into three main research areas, particularly energy management projects, waste management projects, and experimental research projects. Across these research areas, the projects strengthen students' evidence based reasoning and scientific communication as well as supports responsible environmental decision-making.

A further contribution of this proceeding is its collaborative research structure by linking school implementation with university supported coordination. Several undergraduate students from Faculty of Engineering, Universiti Malaysia Sarawak (UNIMAS) served as research coordinators. Their roles are to guide students step-by-step, help organize and monitor the projects, as well as support school students in presenting their findings clearly in ways that relate to community needs.

We hope this proceeding will nurture sustained interest in STEM among school students in Sarawak rural areas by showing that scientific investigation is accessible, purposeful, and locally relevant.

Acknowledgements

The Editorial Board of Proceedings of the Science, Technology and Innovation (STI) 100^3 Programme: Applied Research on Environmental Sustainability at SMK Engkilili, Sri Aman, Sarawak expresses its sincere appreciation to all parties whose guidance, support, and cooperation enabled the completion of this proceeding book.

A sincere appreciation is also extended to the Ministry of Science, Technology, and Innovation Malaysia (MOSTI) for the trust and direction provided through the appointment of scientists to implement the Science, Technology, and Innovation (STI) 100^3 Programme.

The Editorial Board extends its sincere appreciation to the Department of Chemical Engineering, Faculty of Engineering, Universiti Malaysia Sarawak for its institutional support and contribution towards the successful implementation of the programme.

Special thanks are expressed to Sekolah Menengah Kebangsaan (SMK) Engkilili, Sri Aman, Sarawak for strong willingness to cooperate throughout the programme. The Editorial Board records special appreciation to the school leadership and wider community, particularly the Principal, Mr Haji Hamdam bin Haji Juli, and all teachers of SMK Engkilili for facilitating implementation and sustaining student participation.

Heartfelt appreciation is extended to the UNIMAS Yellowhippo STEM Squad for dedicated volunteerism services and professionalism, particularly in supporting programme delivery as research coordinators at SMK Engkilili. Their teamwork and guidance strengthened student engagement and supported the successful completion of the research activities documented in this proceeding book.

Preface

The Science, Technology and Innovation (STI) 100^3 Programme is a national initiative led by the Ministry of Science, Technology and Innovation Malaysia (MOSTI) to strengthen STEM culture through structured research and innovation activities at school level. The programme provides a platform for students to experience inquiry-based learning, develop basic research competencies and translate classroom knowledge into applied investigations that respond to real community and environmental needs. In line with this purpose, the programme nurtures scientific thinking, teamwork and communication skills while strengthening partnerships between schools, universities and national STI stakeholders.

This proceeding book compiles the STI 100^3 Programme research activities conducted at Sekolah Menengah Kebangsaan (SMK) Engkilili, Sri Aman, Sarawak, with a focus on applied research on environmental sustainability. The programme was supported by the Department of Chemical Engineering, Universiti Malaysia Sarawak (UNIMAS) and facilitated by the UNIMAS YellowHippo STEM Squad, whose contributions strengthened student engagement and guided the implementation of project activities. This proceeding book was developed to provide a complete and structured record of the programme outputs, including student project documentation and related programme materials.

The proceedings book is structured into three main parts in order to ensure clear navigation and consistent presentation. **Part I** presents the *Energy Management Projects* which highlight student investigations and proposed solutions related to energy use, efficiency and practical improvements within the school environment. **Part II** covers the *Waste Management Projects*, documenting student work on waste identification, reduction strategies and sustainability focused practices. **Part III** compiles the *Experimental Research Projects*, which showcase laboratory and field-based activities that are not typically conducted in schools. These projects were included to expose students to hands on scientific practice through structured procedures, systematic observations and documented outputs.

The main purpose of this proceedings book is to demonstrate that scientific research should begin at school level, where early exposure is essential. Environmental sustainability remains a priority in education and community development, and this proceedings book provides a practical record of school-level scientific investigation and evidence-based interventions. Overall, this proceeding book is intended to encourage wider adoption of research-based learning approaches and nurture STEM education from school level in Sarawak rural areas.



PART I
ENERGY MANAGEMENT PROJECTS



Electrical Energy Consumption Identification and Analysis at Block Meranti of SMK Engkilili, Sri Aman, Sarawak

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Abstract

Electricity consumption in educational institutions continues to increase due to prolonged operating hours and extensive use of electrical appliances, contributing to higher operational costs and increased CO_2 emissions. This study focuses on Block Meranti, Sekolah Menengah Kebangsaan (SMK) Engkilili, Sri Aman, where inefficient energy usage and limited awareness among occupants were identified as key concerns. The research problem centres on the need to evaluate electricity consumption patterns and identify practical measures to reduce energy wastage and environmental impact. The aim of this study is to assess the electrical energy consumption of Block Meranti through a systematic energy audit in order to improve energy efficiency and reduce unnecessary electrical usage. The objectives are (i) to identify and document electrical appliances and their operating conditions, (ii) analyse electricity consumption and associated greenhouse gas emissions, and (iii) evaluate energy usage patterns and propose feasible energy saving strategies. A mixed method was adopted, involving site observation, equipment inventory, interviews, and questionnaire distribution. Collected data were analysed using spreadsheet software to calculate daily, monthly, and yearly energy consumption, as well as electricity cost, and CO_2 emissions. A comparison between actual and reduced energy scenarios was conducted to estimate potential reductions. The results indicated that split air conditioners were the major contributor to electricity consumption. The total annual energy consumption was significantly reduced after reduction, achieving an approximate 23.52% reduction. This reduction also led to substantial decreases in electricity cost and carbon emissions. In short, the study demonstrates that systematic energy audits combined with operational adjustments and improved user awareness can produce significant energy, environmental, and financial benefits, supporting energy management practices in school buildings.

Keywords: *Energy audits, electricity consumption, CO_2 emissions.*

1. Introduction

Electricity is an essential resource that supports daily activities in educational institutions, enabling teaching, learning, administration, and the operation of various facilities and equipment. However, prolonged operating hours can substantially increase energy consumption, which may lead to higher electricity costs, greater environmental impact, and reduced overall energy efficiency. Greenhouse gas levels have increased since pre-industrial times, causing global warming and climate change, with power generation encompassing both electricity and heat production-constitutes a primary source of CO_2 emissions resulting from fossil fuel combustion [1]. All countries contribute to the rise in greenhouse gas emission and consequently share the socioeconomic impacts associated with global warming [23]. Within Asia, Southeast Asia is considered the region most vulnerable to the effects of climate change. This vulnerability affects nations such as Myanmar, Cambodia, Brunei, Indonesia,

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Laos, Malaysia, the Philippines, Singapore, Thailand, and Vietnam [23]. Malaysia's annual CO_2 emissions have increased significantly over time, rising sharply from very low levels in the early 1900s to approximately 290.22 million tonnes in 2024, indicating a substantial growth in emissions over the past century [2]. In response to this upward trend, Malaysia has committed to achieving carbon neutrality by 2050 under the Twelfth Malaysia Plan (12MP), reflecting the nation's long term strategy to reduce greenhouse gas emissions and transition toward a more sustainable and low-carbon energy system [3].

Building represents a significant share of worldwide energy usage and greenhouse gas emissions, becoming essential focal points for decarbonization initiatives and national energy efficiency programs [7]. Improving energy efficiency is widely recognized as one of the most cost – effective strategies to mitigate climate change, as it reduces the dependence on fossil fuels – based electricity generation and lower greenhouse gas emissions. Efficiency reduces electricity demand and energy losses, contributing to direct energy bill savings, while energy efficient buildings can also lower the maintenance costs over time [8]. This may result in significant decreases in energy costs for both property owners and tenants, enhanced affordability, and diminished energy demand along with accompanying carbon emissions [8]. Additionally, energy efficient buildings show responsible resource management, promote long term institutional resilience, and assist global and national sustainability objectives. It is consequently advantageous for the economy and the environment to optimize energy use in institutional buildings.

For instance, educational institutions like school, as environments where students and teachers spend long hours daily, consume significant amounts of energy due to the operation of various systems such as heating, cooling, lighting, and equipment usage [4]. Schools play a crucial role within this framework, as they not only serve as high-energy-use facilities but also shape future citizens who can act as multipliers by extending energy-saving practices to their homes and communities [27]. Consequently, energy optimisation in school buildings contributes not only to reducing energy consumption within the educational sector but also to influencing long-term energy conservation in the wider residential sector [27]. Due to continuous daily activities and diverse operational needs, electricity consumption in schools can be relatively high. In many cases, appliances may be operated inefficiently or left running unnecessarily, leading to avoidable energy wastage and increased operational costs. An energy audit is a procedure used to identify operational issues, enhance occupant comfort, and maximize energy use in existing structures [5]. Recent studies have shown that energy audits can be further enhanced through the use of structured building data and real-time monitored data, enabling more accurate operational energy assessment and building performance classification [6]. Therefore, conducting an energy audit allows for the systematic identification of electricity consumption patterns and potential inefficiencies within the building.

Many schools lack detailed and structured evaluations of their electricity consumption patterns. Without a comprehensive energy audit supported by accurate real-time operation data, it is difficult to identify major energy-consuming systems, detect inefficiencies, and propose targeted energy saving measures. Consequently, there is a need to systematically assess electricity usage in school buildings to support energy optimization efforts and contribute to national sustainability goals. Therefore, the aim of this study is to assess the electrical energy consumption in selected school areas through an energy audit to improve energy efficiency and reduce energy wastage. Correspondingly, the objectives of this study are to (i) analyze how electricity is consumed based on room usage, appliance usage, and daily operating patterns, (ii) evaluate electricity usage patterns and estimate the associated greenhouse gas emissions based on recorded appliance usage data, and (iii) study the awareness of CO_2 emissions and recommend feasible energy-saving strategies to improve overall energy efficiency.

The scope of this study is focused on assessing the electrical energy consumption of Block Meranti as depicted in **Figure 1** at SMK Engkilili, Sri Aman through a detailed energy audit. The study covers all areas within Block Meranti, including classrooms, administrative offices, teacher's offices, and sewing room, with electricity usage analyzed based on room occupancy, appliances operations, and daily schedules. The study used site observation, interviews, and questionnaires to identify electrical appliances and collect data on operating hours and power ratings in Block Meranti. The collected data was analysed using developed spreadsheet software to estimate daily, monthly, and yearly electricity consumption, electricity cost, and carbon dioxide emissions. Additionally, actual energy consumption

was compared with optimized consumption scenarios to evaluate potential energy savings and develop practical energy-saving recommendations.

(a) Block Meranti's Building



(b) Block Meranti's Layout



Figure 1. Block Meranti's (a) Building and (b) Layout

2. Methodology

This section presents and discusses the stages of methodology that aligns with the aim and objectives of the study. A summary of the research process is presented in the flowchart as in **Figure 2** as follows.

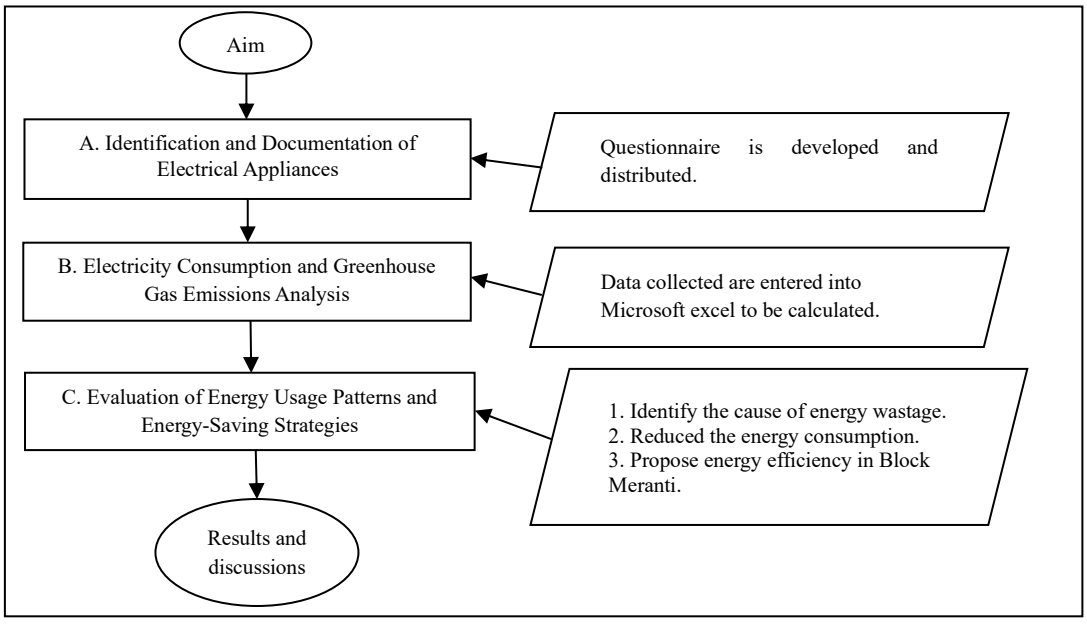


Figure 2. Flowchart of methodology

2.1 Identification and Documentation of Electrical Appliances

A structured questionnaire was developed and divided into four main sections to support the objectives of this study. The first section focuses on respondents' personal information to understand their demographic background and role within the school, enabling comparison of electricity usage patterns among students, academic staff and non-academic staff. The second section examines electrical appliances usage by identifying the types of equipment used in Block Meranti and their operating duration, which assist in estimating overall energy consumption. The third section explores energy usage behaviour to evaluate respondents' daily practices, such as switching off appliances when not in use, in order to assess the level of energy-saving habits. The final section assesses respondents' awareness of energy consumption and energy efficiency while also providing opportunities for them to suggest improvements for better energy management within Block Meranti.

Site observation was conducted to systematically identify and document all electrical appliances operating within Block Meranti, with each floor comprehensively audited to determine the types and quantities of equipment, their operating hours, and relevant electrical specifications. The equipment was divided into six categories: fluorescent light, ceiling fan, split air conditioner, desktop computer, laptop, and inkjet printer. Relevant information, including appliance type and rated power capacity, was obtained through direct visual inspection and verification of equipment label.

Additional details were gathered through interviews with building occupants such primarily the students, teachers, and non-academic staff. In addition, supplementary information on appliance usage patterns and operating hours were collected through distribution of questionnaires that have been developed beforehand and brief interviews with building occupants, including students, teachers, and non-academic staff. This approach proved to help provide a deeper insight into everyday social practices within the building environment, including patterns of interaction and participation, as well as instances of silences, caution, and implicit behaviours that are often informal, undocumented, and sometimes contradictory [9].

2.2 Electricity Consumption and Greenhouse Gas Emissions Analysis

The data collected from site observation and questionnaires were systematically analysed to determine the electricity consumption of each electrical appliance and the overall energy usage of Block Meranti. All calculations were performed using Microsoft Excel spreadsheet software to ensure accuracy, consistency, and ease of comparison between actual and optimized energy consumption scenarios.

The daily energy consumption for each appliance was calculated using **Equation 1** as follows [12]:

$$E_{daily} = \frac{P \times t \times n}{1000} \quad \text{.....} \quad (1)$$

where E_{daily} is the daily energy consumption (kWh/day), P is the rated power of the appliance (W), t is equal to operating hours per day (h/day), and n is the number of appliances. Monthly energy consumption was determined by **Equation 2** as follows [12]:

$$E_{monthly} = E_{daily} \times D \quad \text{.....} \quad (2)$$

where D in this equation represents days of usage per month. Using the monthly energy consumption, the monthly electricity cost can be estimated by multiplying $E_{monthly}$ with Malaysia's electricity tariff rate (RM/kWh) [10]. On the other hand, yearly energy consumption was then calculated as shown in **Equation 3**:

$$E_{yearly,\ actual} = E_{monthly} \times 12 \quad \text{.....} \quad (3)$$

This value represents the baseline annual electricity usage of each appliance and the total building consumption. Moreover, the annual carbon dioxide emissions associated with energy consumption is calculated as shown in **Equation 4**:

$$CO_2\ emission\ (kg) = E_{yearly} \times F \quad \text{.....} \quad (4)$$

$\boldsymbol{E_{yearly}}$ is equal to energy consumption per year (kWh) and F is equal to emission factor (kg CO_2/kWh).

These visualizations made it easier to identify places with high energy consumption, popular electrical appliances, and periods of peak use. Additionally, in order to clearly depict the potential energy savings and emission reductions, comparative graphs were created to show the differences between actual and reduced annual energy use. The graphical analysis supported data interpretation and facilitated the formulation of practical energy-saving recommendations for Block Meranti.

2.3 Evaluation of Energy Usage Patterns and Energy-Saving Strategies

The calculated electricity consumption data were systematically analysed to determine the overall energy performance of the building. This analysis focused on identifying major energy-consuming appliances, recognizing inefficient usage patterns, and examining the primary causes of energy wastage

based on questionnaire responses obtained from building occupants. In addition, the level of awareness regarding the relationship between electricity consumption and carbon dioxide (CO_2) emissions was evaluated to understand behavioural influences on energy use.

Energy consumption (kWh) per person can be calculated using **Equation 5** as follows to determine the next step of reducing energy consumption, n is the number of person.

$$\frac{E_{yearly}}{person} = \frac{E_{yearly}}{n} \quad \text{(5)}$$

A comparison was conducted between the actual yearly energy consumption and the reduced yearly energy consumption derived from improved operating conditions and usage practices to assess the potential energy consumption. This comparison enabled the estimation of achievable energy reduction and highlighted areas where efficiency improvements could produce meaningful environmental and economic benefits.

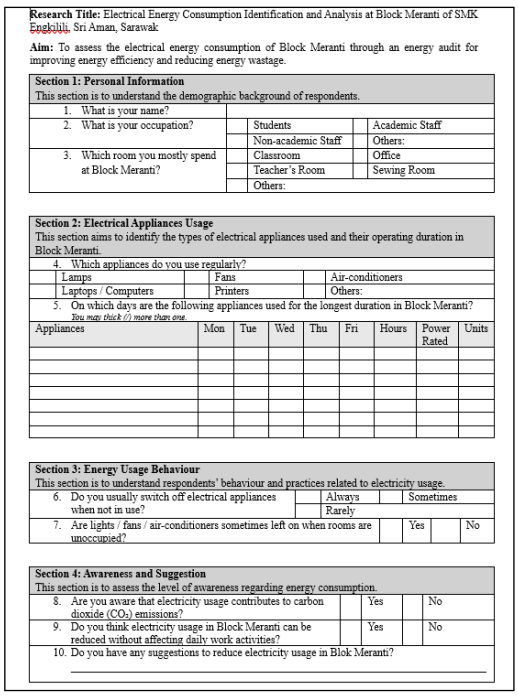
Based on the analytical findings, feasible and practical energy-saving measures were proposed to enhance overall energy efficiency within Block Meranti. These recommendations considered both technical adjustments and behaviour-based strategies to ensure that the proposed improvements are realistic, cost-effective, and sustainable for long-term energy management.

3.0 Results and Discussions

This section presents the findings obtained from the data collection process and discusses the patterns of electricity consumption observed in Block Meranti. The discussion is divided into three main sections: (i) electricity consumption characteristics of building spaces and equipment, (ii) overall power consumption and environmental impact, and (iii) energy consumption analysis and recommendations.

3.1 Electricity Consumption Characteristics of Building Spaces and Equipment

The analysis of electricity consumption in Block Meranti reveals a clear variation in energy usage across rooms, operating days, and types of electrical appliances. The results were collected on 11th February 2026 from 2:30 PM to 4:30 PM by distributing questionnaire as shown in **Figure 3** and brief interviews among the building occupants. These patterns provide important insight into the main contributors to overall building energy demand and highlight potential areas for energy efficiency.



Research Title: Electrical Energy Consumption Identification and Analysis at Block Meranti of SMK Engkilili, Sri Aman, Sarawak

Aim: To assess the electrical energy consumption of Block Meranti through an energy audit for improving energy efficiency and reducing energy wastage.

Section 1: Personal Information
This section is to understand the demographic background of respondents.

1. What is your name? _____
2. What is your occupation? ☐ Students ☐ Academic Staff ☐ Non-academic Staff ☐ Others: _____
3. Which room you mostly spend at Block Meranti? ☐ Classroom ☐ Office ☐ Teacher's Room ☐ Sewing Room ☐ Others: _____

Section 2: Electrical Appliances Usage
This section aims to identify the types of electrical appliances used and their operating duration in Block Meranti.

4. Which appliances do you use regularly?
☐ Lamps ☐ Fans ☐ Air-conditioners
☐ Laptops / Computers ☐ Printers ☐ Others: _____
5. On which days are the following appliances used for the longest duration in Block Meranti?
You may tick (/) more than one.

Appliances	Mon	Tue	Wed	Thu	Fri	Hours	Power Rated	Units

Section 3: Energy Usage Behaviour
This section is to understand respondents' behaviour and practices related to electricity usage.

6. Do you usually switch off electrical appliances when not in use? ☐ Always ☐ Sometimes ☐ Rarely
7. Are lights / fans / air-conditioners sometimes left on when rooms are unoccupied? ☐ Yes ☐ No

Section 4: Awareness and Suggestion
This section is to assess the level of awareness regarding energy consumption.

8. Are you aware that electricity usage contributes to carbon dioxide (CO_2) emissions? ☐ Yes ☐ No
9. Do you think electricity usage in Block Meranti can be reduced without affecting daily work activities? ☐ Yes ☐ No
10. Do you have any suggestions to reduce electricity usage in Blok Meranti? _____

Figure 3. Questionnaire Form

3.1.1 Comparison of Energy Consumption Across Building Spaces

Block Meranti consists of two main levels with different functional spaces. Level 1 accommodates administrative and support spaces. These include the teacher's room, the main office area which comprises the *Pengetua Office* and *Guru Penolong Kanan's Office*, as well as several other functional rooms such as sewing room, *Bilik Penolong Kanan Tingkatan 6*, and *Bilik Guru Kanan*. Level 2, on the other hand, is allocated for classrooms, where teaching and learning activities are conducted throughout the school operating hours. Due to the continuous occupancy during class sessions, this level is expected to demonstrate consistent electricity usage. Compared to Level 2, electricity consumption at this level may vary depending on administrative schedules, meetings, and specific room activities.

Table 1 illustrates the total annual power consumption across different floors, and it is found that Level 2 exhibits the highest annual electricity of 36, 714.8 kWh compared to Level 1 which is 5, 913.6 kWh. It can be seen from **Table 1** and **Figure 4**, the teacher's room exhibits the highest annual electricity consumption of 20, 054.4 kWh, followed by the office at around 11,419.2 kWh. According to Umunandi K. [11], the standard of education and training received by youth is strongly influenced by institutions' ability to modify their learning content in response to changing national skill needs. He also mentioned that teachers' application of suitable teaching aids and tools in electricity less promotes understanding and enhances student achievement [11]. Hence, resulting in highest energy consumption within Block Meranti, as the probability of continuous use of electrical equipment and teaching aids. In contrast, classroom and other categories show significantly lower consumption levels with both remaining low 6 000 kWh per year. This marked variation indicates that energy demand is not uniformly distributed across functional spaces within the building.

Table 1. Total power consumption per year in different floors

Floors	Type of Rooms	Total Power per Year (kWh)	Total (kWh)
Level 1	Classrooms	5, 913.6	5, 913.6
Level 2	Teacher's room	20, 054.4	36, 714.8
	Office	11, 419.2	
	Others	5, 241.6	
Overall			**42, 628.8**

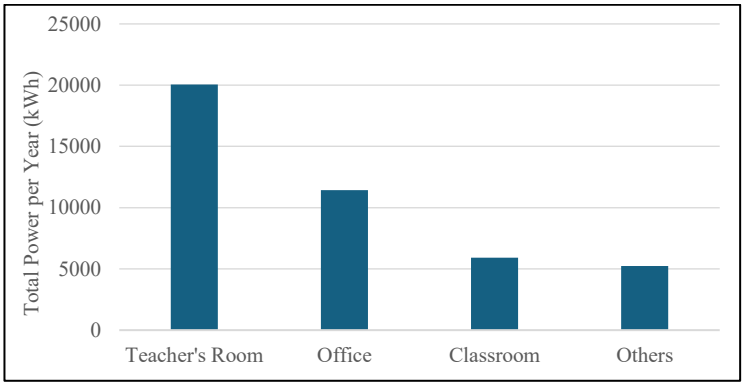


Figure 4. Annual total power consumption by room type

Figure 5 provides a breakdown of electricity usage by specific equipment types in each room category. The most dominant energy consumer is the split air conditioner, particularly in the teacher's room with a total of 12, 398.4 kWh, followed by office around 5, 510.4 kWh. This suggests that cooling systems are the primary source of electricity consumption in the building. All rooms have a moderate contribution and similar value in terms of electricity utilization for fluorescent light and ceiling fan. However, the classroom fans are using slightly more electricity than the offices. As a result of administrative and academic job activities, laptops and desktop computers also make up a sizable portion, particularly in the teacher's office and classroom.

This findings align with the other studies which state that energy usage in building has increased over the past two decades due to the growing demand for buildings, enhanced services, and higher comfort expectations [24]. Petri et al. [24] also mentioned that the growth is further influenced by people spending more time indoors, along with the continuous expansion of the global population, which collectively contributes to greater overall energy use. In this case, the continuous operation of air-conditioning systems to maintain thermal comfort, even when occupancy is low, reflects how comfort-driven energy demand significantly contributes to higher electricity consumption in buildings.

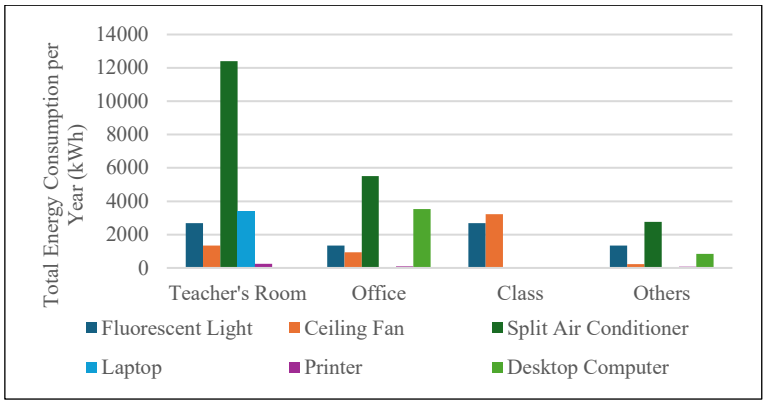


Figure 5. Annual electricity consumption (kWh) by equipment type for different room categories

3.1.2 Daily Power Consumption Pattern by Room Type

The investigation of electricity consumption across weekdays reveals noticeable temporal variation in building energy demand, primarily driven by the scheduled timetable of academic and administrative activities. **Figure 6** presents daily power consumption trends from Monday to Friday for each room category, along with the total daily consumption. Overall, total energy use remains relatively stable throughout the week, fluctuating slightly between 194.29 kWh and 212.79 kWh per day. However, a noticeable peak occurs midweek, which is on Wednesday, while the rest show comparable values. This is attributed to co-curricular activities held every Wednesday from 1:30 PM to 4:30 PM, which extended the operating hours of both classrooms and teacher's room.

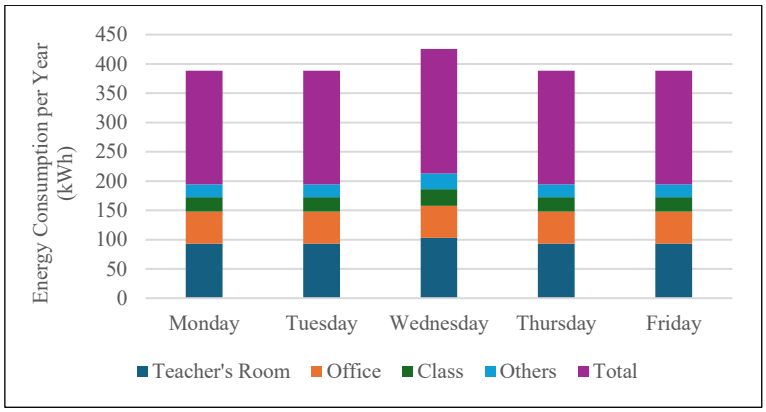


Figure 6. Weekly Variation in Electricity Consumption

3.1.3 Distribution of Power Consumption by Electrical Equipment

Since each electrical appliance operates at different power ratings and usage durations, the total energy consumption varies significantly depending on the type of equipment used. From **Figure 7**, it can be observed that the split air conditioner accounts for the largest share contributing nearly half of the total energy consumption, approximately 48%. This dominance underscores the significant energy demand associated with cooling system in institutional buildings. According to Azman et al. [13], the

weather and economic expansion discourage the need for electricity and owing to Malaysia's humid tropical climate, approximately 40% of the total energy demand in the commercial sector is allocated to space cooling [13,14].

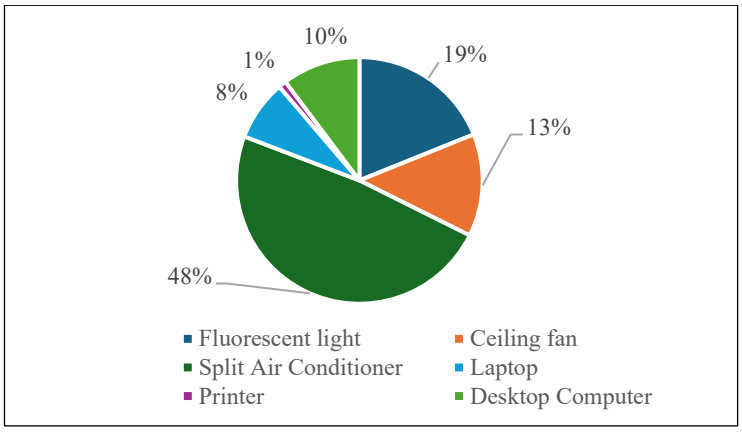


Figure 7. Energy consumption in percentage by appliances used

Fluorescent light and ceiling fans represent the next two largest shares, contributing around 19% and 13% respectively. These figures indicate that lighting and computing infrastructure together account for a substantial portion of the building's energy use. This result is consistent with Zakaria's [16], which discovered that 20% of Malaysian buildings use artificial lighting consumption. Studies also found that lights account for almost 13% of the energy consumption in the garment buildings and are the second highest energy consumer [17,12]. Laptop and desktop computer on the other hand, each contributing around 10% and 8% respectively. Studies by Roth et al., [15] proved that personal computers, monitors, and server systems persist in leading electricity use in office and telecommunication equipment. Due to their widespread presence in various rooms and prolonged functioning hours, their total energy consumption becomes substantial. In contrast, printers contribute smaller proportions, with a total below 5% suggesting comparatively lower energy intensity or shorter usage duration.

3.2 Overall Power Consumption and Environmental Impact

Figure 8 shows that the actual total power consumption per year is significantly high, reaching 42, 652.8 kWh, as presented in **Table 2**. This indicates that Block Meranti consumes substantial amounts of electricity annually, reflecting continuous usage of electrical equipment throughout the year. Correspondingly, the actual total of CO_2 emissions per year is 31, 989.6 kg, demonstrating a significant environmental impact associated with the level of electricity consumption. This trend aligns with research made by Mezghani and Ben Haddad [28] that explained how positive shocks to power usage affect endogenous CO_2 emissions.

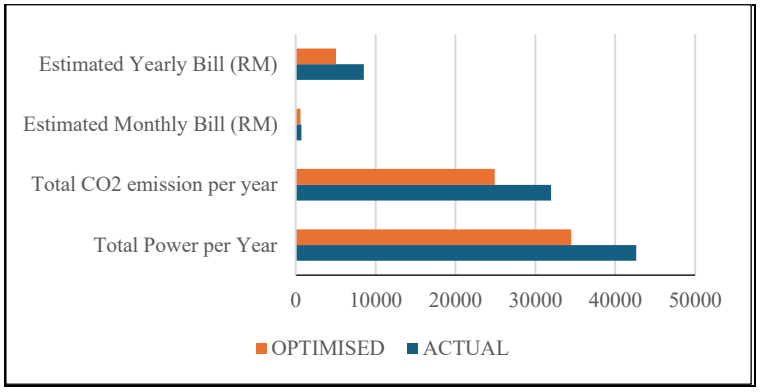


Figure 8. Comparison of actual and optimised energy consumption, CO_2 emissions, and electricity cost of Block Meranti

Table 2. Summary of actual energy performance

Actual	
Total power per year (kWh)	42, 652.8
Total CO_2 emission per year (kg)	31, 989.6
Estimated monthly bill (RM)	710.88
Estimated yearly bill (RM)	8, 350.56

In terms of cost, the actual estimated monthly electricity bill is RM 710.88 which is a total of RM 8,350.56 for the estimated yearly electricity bill. Although electricity is essential for supporting teaching and learning activities, its operational cost can place a financial burden on educational institutions. For instance, previous studies have reported that in some regions, such as South America, electricity accounts for a disproportionately high percentage of school operational costs despite representing a smaller share of total energy use, making it an expensive energy source for school [18]. This suggests that managing electricity consumption is crucial to ensure that financial resources can be allocated efficiently without compromising educational quality.

3. 3 Energy Consumption Analysis and Recommendations

This section analyses the overall energy performance of Block Meranti and outlines strategic improvements to optimise electricity usage and minimise operational expenses.

3.3.1 Behavioural Factors Affecting Energy Use

Based on the findings presented in Discussion Section 3.1, it is evidence that the primary contributor to energy consumption within Block Meranti is the split air conditioner installed in the teacher's room, recording a total annual energy usage of 12,398.4 kWh. The high demand is likely due to prolonged occupancy and continuous operation throughout the school day, which results in substantial cumulative energy consumption and making it the dominant contributor to the building's electricity usage.

Survey findings, as in **Figure 9**, further indicate that among students, 13% reported that they always switch off electrical appliances when not in use, while 16% indicated that they sometimes do so. However, the highest percentage, 19%, stated that they never switch off appliances. However, for academic staff or also known as teachers, 19% reported that they always switched off the appliances when not in use which is the highest percentage among the groups. Meanwhile 6% stated that they sometimes do so and 16% admitted that they never switched off the electrical appliances. In contrast, 10% of non-academic staff reported that they always switched off the electrical appliances. These findings highlight the need for greater awareness campaigns and energy management initiatives, particularly targeting students, to encourage more responsible electricity usage in Block Meranti.

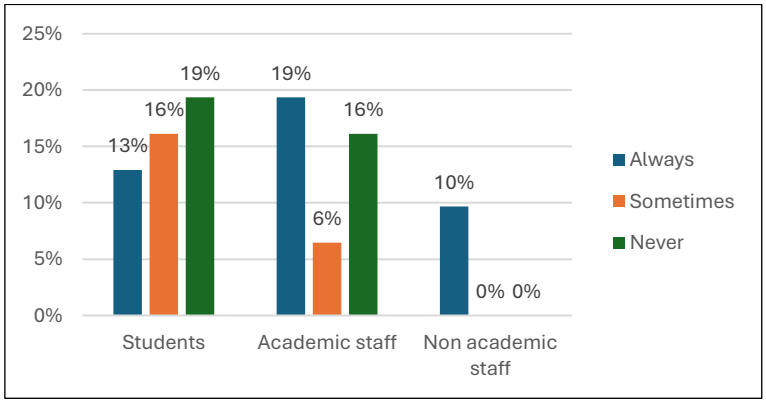


Figure 9. The frequency of switching off electrical appliances when not in use

Previous studies have emphasized that energy conservation strategies should prioritize the identification of 'low hanging fruit', whereby simple interventions, such as switch-off campaigns, are

adopted as the first step toward reducing energy use within organizations [19]. According to findings from Kemp-Hesterman et al. [20], the year following the implementation of charrette demonstrated noticeable electricity savings, with eight out of twelve months recording lower adjusted kWh consumption compared to the year prior to the charrette. However, data from two years after the charrette indicate a continued reduction in overall electricity consumption [20] demonstrating that this approach yields both short-term and long term improvements in electricity performance.

Figure 10 illustrates the level of awareness regarding CO_2 emissions among students, academic staff, and non-academic staff. The majority of students demonstrate a relatively low level of awareness, with 32% responding "Yes" and 16% responding "No." Although the percentage of "Yes" responses is higher, a significant portion of students still lack awareness of CO_2 emissions. In contrast, 26% of academic staff responded "Yes," compared to 16% who answered "No," suggesting that academic staff are generally more informed about CO_2 emissions, possibly due to their educational background and professional exposure. For non-academic staff, the overall percentages are comparatively lower, with 6% indicating that they are aware and 3% stating that they are not aware of this issue.

These findings showed that it is crucial to understand and be aware of how CO_2 emissions are linked to energy consumption and how they negatively impact the atmosphere, contributing to air pollution. This lack of awareness can directly limit individuals' ability to make informed, sustainable choices in their daily lives. Awareness and understanding of environmental issues are critical in shaping consumption patterns [21,22]. Moreover, increasing individual's sense of well-being and security may further encourage pro-environmental actions, suggesting that both knowledge and personal factors jointly influence the adoption of greener lifestyles [22]. Therefore, enhancing both environmental knowledge and personal wellbeing is essential for fostering more informed, sustainable, and pro-environmental behaviours among individuals.

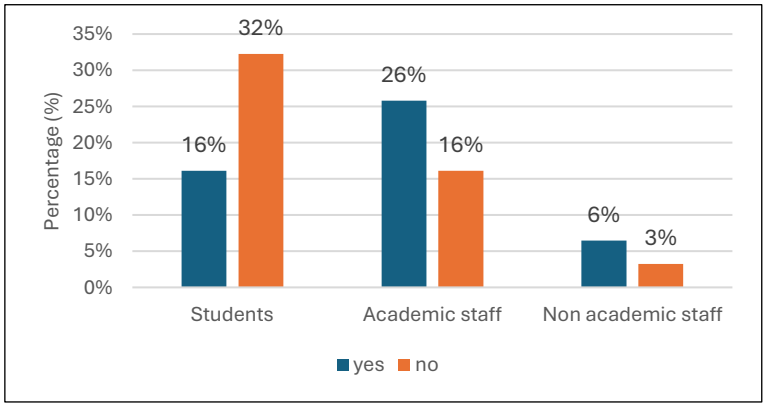


Figure 10. The awareness of the building occupants regarding CO_2 emissions

3.3.2 Reduced Energy Consumption and Equipment Evaluation

Several initiatives were considered to reduce the energy audit. It was found that teacher's room contributes significantly to the overall energy consumption, particularly due to the extensive use of split air conditioner units. An analysis of energy consumption per person was conducted using **Equation 5** to provide a more representative assessment of usage intensity. Based on available data, the total number of teachers at SMK Engkilili is 94 as shown in **Table 4**.

Table 4. Energy consumption per person in teacher's room

Rooms	Energy consumption per person (kWh/person)
Teacher's room	131.94

Studies made by Yuan Y. et al. [41] showed that energy consumption per person is 46.84 to 1883.7 kWh/person with an average of 464.7 kWh/person. Thus, the energy consumption per capita in the teacher's room is below the overall average, indicating that the existing number of air-conditioning units

is proportionate to the occupancy level. Therefore, reducing the number of air conditioners in this space is not necessary, as the current provision does not suggest excessive or inefficient energy use. However, the usage of split air conditioners in the teacher's room and office could be reduced by implementing a habit of switching off the air conditioner an hour before going home, complemented by using ceiling fans continuously during the working hour. Next, during the site observation, it was noted that four classrooms each had one additional ceiling fan, leading to uneven distribution of energy consumption. Therefore, one ceiling fan can be removed from each of these classrooms to ensure a more balanced and efficient use of energy. The operating hours of other electrical appliances like fluorescent lights, desktop computers, and printers could also be adjusted to achieve a greater reduction in electricity consumption.

The results presented in **Table 5** demonstrate a substantial improvement in energy performance after implementing the proposed optimization measures. The total annual electricity consumption decreased from 42,652.8 kWh under the actual condition to 30,969.6 kWh. Correspondingly, the total annual CO_2 emissions decreased from 31,989.6 kg to 22,269.6 kg, indicating a considerable environmental impact. This observation is consistent with findings by Wang Y. et al. [25] which stated that the biggest contributor to decreasing CO_2 emissions is energy intensity. Improving energy efficiency in buildings provides an important economic benefit by lowering energy-related expenses [8]. Enhanced efficiency translates into direct financial gains for decision-makers through reduced energy consumption and avoided operational expenses. Consequently, both building owners and occupants can experience significant reductions in energy bills, improved affordability, decreased overall energy demand, and lower associated carbon emissions [8].

Table 5. Summary of actual and optimised data values

	Actual	Reduced
Total power per year (kWh)	42, 652.8	34, 512
Total CO_2 emission per year (kg)	31, 989.6	24, 962.4
Estimated monthly bill (RM)	710.88	575.20
Estimated yearly bill (RM)	8, 530.56	5, 048.64
Overall reduction (%)	**23.52**	

These advantages are clearly reflected in the results of this study. The implementation of optimization measures produced substantial financial savings, as evidenced by the marked reduction in electricity costs. The estimated monthly electricity bill dropped from RM 710.88 to RM 575.20, while the estimated annual electricity bill decreased from RM8,530.56 to RM5,048.64. An approximate 23.52% reduction in annual energy consumption was achieved through the implementation of the proposed measures, demonstrating that relatively simple operational adjustments can yield substantial energy, environmental, and financial benefits. These outcomes also consistent with a two-year field study conducted by Pandey et al. [26] on a dormitory retrofit demonstrated a 77.8% reduction in total HVAC electricity consumption and a 57.7% decrease in indoor CO_2-related metrics following the implementation of measures such as reducing the number of air conditioners, limiting operating hours, and optimizing fan placement.

Figure 11 and **Table 6** show that the split air conditioner recorded the highest annual energy consumption under actual conditions which is 41, 334 kWh, and it also achive the greatest reduction after optimisation which is 56.20%. Fluorescent lights and printers also demonstrated significant reductions of 52.38% and 35.29%, respectively, while fans and desktop computers showed smaller improvements. In contrast, laptop energy energy consumption remained unchanged, indicating limited potential for optimisation compared to high-power equipment such as air conditioners. Overall, the data indicate that substantial energy savings can be achieved by adjusting operating hours and improving usage practices, particularly for high-consumption appliances.

This finding is consistent with the study by Bastien et al. [29], which reported that the installation of real-time CO_2 monitoring displays in 60 student residences encouraged more than 95% of households to reduce their median indoor CO_2 concentrations. The study demonstrates that simple feedback and awareness mechanisms can influence user behaviour, leading to measurable reductions in emissions. Similarly, the optimisation measures applied in Block Meranti show that improving operational control

and increasing awareness can significantly lower electricity consumption and associated carbon dioxide emissions.

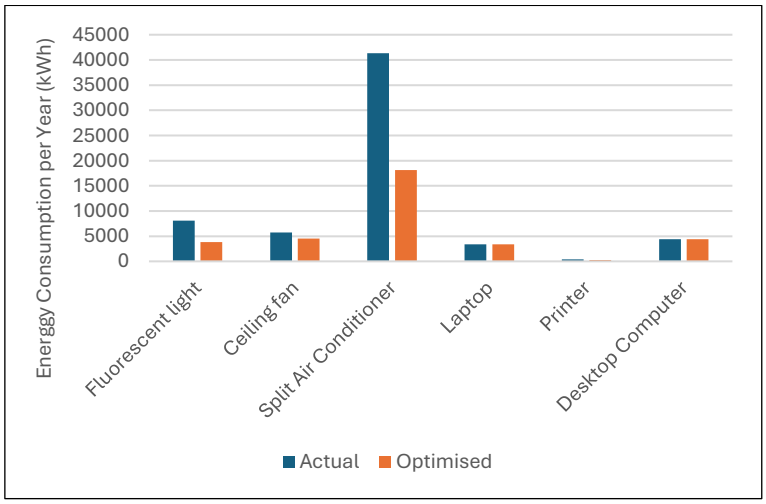


Figure 11. Comparison of actual and optimised energy consumption of electrical equipment

Table 6. Summary of actual and optimised data values of electrical equipments

Equipments	Energy consumption per year (kWh)		
	Actual	Optimised	Reduction (%)
Fluorescent light	8, 064	3, 840	52.38
Ceiling fan	5, 740.8	4, 550.4	20.74
Split air conditioner	41, 334	18, 105.6	56.20
Laptop	3, 384	3, 384	0.00
Printer	432	264	35.29
Desktop computer	4, 368	4, 368	0.00

3.3.3 Proposed Energy-Saving Measure

This section of the discussion examines several potential measures that can be considered to enhance energy savings. Some of the proposed strategies were derived from questionnaire responses and are further elaborated upon in this section.

1. Sustainable User Practices

This aspect of discussion has been implicitly addressed several times throughout the manuscript, and it is further supported by feedback from several respondents who proposed this approach as a potential energy-saving measure. Such as turning off lights, fans, air conditioners, and other electrical appliances when not in use is a simple yet highly effective way to reduce energy consumption in buildings. This is due to electrical equipment continuing to consume power as long as it is switched on, even if it is not actively serving its intended function.

In addition, attention should be given to phantom or standby power consumption. Standby power or often referred to as vampire power, is the electricity consumed by an electrical appliance when it remains plugged in but is switched off or not actively performing its main function [30]. According to Chakraborty and Pfaelzer [31], although a certain level of standby energy consumption is unavoidable due to support functions such as remote controls, safety features, and security systems, standby mode is still not fully energy efficient in many domestic and office appliances. Despite consuming less electricity than active operating mode, the accumulated energy use from multiple devices over time can contribute significantly to overall electricity wastage [31]. The One Watt Initiative, launched by the Global Energy Savior Institute, is a widely supported effort to limit appliances' standby power to one watt or less, promoting a unified approach to reducing electricity consumption during inactive periods [30, 31]. However, a simple and effective way to eliminate standby power consumption of an appliance is to

switch it off or unplug it from the power outlet when the device is not in use [30]. Promoting sustainable user practices plays an important role in reducing unnecessary energy consumption in buildings. Encouraging occupants to switch off or unplug electrical devices when they are not in use can significantly minimize standby power losses.

2. Solar Panel Generation

The questionnaire results indicated that a majority of respondents favoured the use of solar panel technology as a sustainable energy solution for reducing electricity consumption. Many studies agree that renewable energy has many beneficial impacts [32,33], particularly in reducing dependence on convectional grid electricity and lowering long-term operational costs. However, it is important to acknowledge that solar panel systems require a relatively high on initial investment [35]. In many cases, particularly for building-mounted systems, the installation cost can be comparable to the cost of the panels themselves [35]. Nevertheless, Photovoltaic (PV) panel prices have steadily declined over time, improving their economic feasibility for institutional applications [35]. Break-even analysis made by Sodhi M. et al. [35] further indicates that the initial investment can be recovered through long-term electricity savings, making solar adoption financially viable for school. This financial consideration may present a challenge for schools with limited budgets.

Despite the high upfront cost, the long-term advantages often outweigh the initial expenditure. Once installed, solar panel systems can significantly reduce monthly electricity bills and provide a stable source of renewable energy during school operating hours. This not only lowers recurring utility expenses but also protects schools from future electricity tariff increases, thereby improving financial predictability in budget planning. Furthermore, this perspective is supported by empirical evidence showing that renewable energy consumption contributes to a reduction in CO_2 emissions [33]. Similarly, long-term analyses conducted in China indicate that increased renewable energy utilization has a significant negative relationship with CO_2 emissions [33], reinforcing the environmental benefits of transitioning to sustainable energy sources.

In addition, smaller or modular solar systems may offer a more affordable and flexible alternative, as they can be installed progressively or used to power specific equipment, [35] especially in areas where electricity is limited. Schools may begin with partial installations, such as powering administrative offices, teacher's room or lighting systems, before expanding the system based on available funding. The successful implementation of the School Solar Panel System (SSPS) at SDN 4 Mesuji Timur, as reported by Dadi et al. [34], demonstrates that solar adoption in schools can enhance electricity availability, support teachers' professional tasks, and improve overall effectiveness of classroom learning. A total of 43 rural schools in Sarawak have been equipped with hybrid solar energy systems under a government-led initiative known as the Sarawak Rural Schools Hybrid Solar Project, aiming to enhance energy accessibility and sustainability in rural educational institutions by integrating renewable energy technologies with conventional power supply systems [42].This case study further suggests that solar energy integration not only delivers economic benefits but also strengthens educational infrastructure and learning outcomes in the long term.

3. Potentials of Light-Emitting Diode (LED)

LED lighting systems offer several operational advantages beyond energy efficiency, such as lower heat emission, reduced risk of ignition from dust and particle accumulation, and enhanced colour rendering that improves overall lighting quality [38]. Moreover, LEDs produce minimal ultraviolet radiation, which helps reduce insect attraction and product deterioration in sensitive environments [38]. These features make LED lighting suitable for school use by providing better lighting quality, reducing heat emission, and supporting a more comfortable learning environment. Notably, a well-designed LED lighting system can achieve operational lifespan exceeding 100,000 hours, allowing the lighting infrastructure to function for nearly a decade without major maintenance requirements [38]. On the technological font, LED has rapidly emerged as a widely used solid-state technology for general illumination applications [40]. This is mainly attributed to its longer operational lifespan, lower power consumption, and the absence of toxic mercury content, unlike conventional fluorescent lamps [40].

These advantages further support the adoption of LED technology in modern lighting applications. LED-based systems are no longer limited to orientation and architectural lighting, by increasingly being used for general illumination applications as well [37]. According to a survey conducted by the International Facility Management Association on energy efficiency, lighting retrofit was identified as the most widely implemented energy-saving measure within the past 12 months, with approximately 73% of respondents adopting more energy-efficient lighting systems [38]. In addition, LED downlights surpass traditional compact fluorescent lamps in terms of energy efficiency and lighting quality [37]. Luminaries based on LEDs are becoming widely available [36] as a more energy efficient and sustainable lighting technology compared to conventional fluorescent lighting systems.

Overall, LED lighting demonstrated strong potential for applications in school environments due to its superior energy efficiency, improved lighting quality, and long operational lifespan, which help reduce electricity consumption and maintenance costs. Its high energy efficiency helps reduce electricity consumption, which can lower operational costs for schools over the long term. The extended lifespan of LED systems also minimizes the need for frequent maintenance and replacement, making it a practical lighting solution for school facilities. Overall, the use of LED lighting supports sustainable energy management in schools and aligns with sustainability goals promoted by the Ministry of Education Malaysia which is *"to ensure an inclusive and equitable quality education and promote lifelong learning opportunities for all"* [39].

4. Conclusion

This study successfully achieved its aim of assessing the electrical energy consumption of Block Meranti through a detailed energy audit to improve energy efficiency and reduce energy wastage. The analysis of room usage, appliance distribution, and daily operating patterns revealed that split air conditioners were the primary contributors to electricity consumption, while lighting, fans, and computing equipment also represented significant energy loads. The evaluation of electricity consumption trends made it possible to estimate the related greenhouse gas emissions, which in real-world circumstances were 31,971.6 kg of CO_2 per year. The results of the questionnaire also revealed behavioral characteristics that affect energy use, specifically low awareness and irregular switch-off behaviors among building residents. The study showed that practical operational changes, such cutting back on air conditioning, modifying operating hours, and enhancing appliance management, might result in a 23.52% decrease in yearly energy use by comparing real and optimized energy scenarios. These findings demonstrate that systematic energy audits, when paired with useful technical and behavioral methods, can drastically cut carbon emissions, electricity costs, and promote long-term sustainability objectives at educational institutions.

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Assessment and Reduction of Electricity Consumption in Dahlia, Kemuning and Kemboja Buildings at SMK Engkilili, Sarawak

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Abstract

This study presents a block-level energy audit conducted at SMK Engkilili, Sri Aman, Sarawak, focusing on Dahlia, Kemuning and Kemboja buildings consisting of classrooms and facilities to evaluate electricity consumption patterns and identify feasible energy reduction strategies. The study was motivated by the limited availability of detailed appliance-level electricity usage data within the school, particularly in a rural region where efficient resource management is essential. Data was collected through on-site observation and questionnaires of selected students to document appliance types, quantities, rated power, and operating duration. Electricity consumption was calculated on daily, monthly, and yearly bases with associated carbon dioxide (CO_2) emissions using standard emission factors and electricity cost were estimated via electricity tariff provided by energy provider. The results indicated that the total annual energy consumption of the selected blocks was 5410.08 kWh, contributing to 4057.56 kg CO_2e emissions and an estimated annual electricity cost of RM1081.99. Subsequently, feasible energy-saving measures were proposed, including the reduction of ceiling fan operating hours and the replacement of conventional fluorescent lighting with energy-efficient LED lamps. The implementation of these measures resulted in a reduction of total energy consumption to 4754.40 kWh, representing a 12.12% decrease, alongside proportional reductions in emissions and electricity costs. The findings demonstrate that significant energy savings can be achieved through low-cost and practical interventions without compromising occupant comfort or productivity. The study demonstrates the effectiveness of a structured and data-driven energy audit in supporting informed decision-making and promoting sustainable energy management practices within a rural secondary school environment.

Keywords: *Energy Audit, Electricity Consumption, Greenhouse emissions*

1. Introduction

Energy consumption in educational institutions has become an important area of concern due to increasing electricity demand, rising operational costs and growing awareness of environmental sustainability. Continuous usage of electrical energy for lighting, ventilation, and educational equipment in schools contribute significantly to overall energy consumption [1]. However, in many cases, electricity usage is only monitored at an aggregated level which limits the ability to understand detailed consumption patterns and identify specific areas for improvement. As a result, opportunities for enhancing energy efficiency and reducing unnecessary energy usage often remain underexplored. An energy audit is a systematic approach utilised to evaluate energy flows, identify major sources of consumption, and recommend strategies for improving energy efficiency [2]. Through the collection and analysis of data on appliance usage, typical operating duration and power ratings of each equipment, energy audits enable the quantification of electricity consumption cost and its associated environmental impacts, including greenhouse gas emissions of carbon dioxide, CO_2. This data-driven approach supports informed decision-making and facilitates the development of targeted energy conservation

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measures that are both practical and cost-effective without sacrificing comfort and productivity of students.

The importance of energy conservation is particularly critical as SMK Engkilili is identified as rural secondary school where financial and infrastructural resources are often limited. This issue necessitates efficient energy management practices for cost control and sustainability. The lack of detailed energy consumption analysis would hinder the identification, evaluation, and prioritisation of feasible energy conservation measures that could enhance energy efficiency and reduce operational costs. A systematic and data-driven energy audit is required to comprehensively evaluate electricity usage, quantify its environmental and economic impacts and support informed decision-making for the reductions of energy consumption within the selected school blocks [3]. Therefore, the aim of this study is to evaluate the feasibility of reducing energy consumption within the Dahlia, Kemuning, and Kemboja building blocks at SMK Engkilili, Sarawak. To achieve this, the objectives of this study are (i) To identify electrical appliances and utilities and collect electricity usage data including their rated power and typical operating period used within the school blocks, (ii) To analyse electricity consumption level by estimating daily, monthly and yearly power consumption as well as the corresponding greenhouse gas emissions and electricity cost based on the recorded usage data and (iii) To evaluate potential reductions in overall energy consumption, electricity cost and greenhouse gas emissions produced through feasible energy-saving measures.

The scope of this study focuses on conducting structured energy audits within selected areas of SMK Engkilili, Sarawak, specifically in Dahlia (3CL, 3DR classrooms), Kemuning (2AL classroom, Parent-Teacher association room, Cooperative room) and Kemboja (2EP, 2FG classrooms) building blocks. The study is limited to the assessment of electricity consumption associated with commonly used electrical appliances and utilities within these blocks including lighting systems and ceiling fans used by students. The study involves systematic collection of data through on-site observation and questionnaires administered to selected students to obtain information on appliance types, rated power, equipment quantity and average operating duration. The analysis is confined to estimate electricity consumption on a daily, monthly and yearly basis using standard energy calculation methods via Microsoft Excel. In addition, the study includes the estimation of associated greenhouse gas emissions and electricity costs based on the calculated energy usage with additional data of an emission factor of CO_2 and electricity tariff from energy provider, Sarawak Energy Berhad (SEB). Furthermore, the scope of this study extends to the evaluation and reduction of electricity consumption by identifying energy-intensive appliances, individual building electricity usage and electrical usage patterns. Feasible energy conservation measures are proposed based on the analysis with consideration given to practicality, cost-effectiveness and suitability for implementation in a rural school environment. However, this study does not include real-time energy monitoring using advanced instrumentation, detailed electrical design analysis or implementation of proposed solutions. The findings are therefore based on estimated data within the selected blocks and time frame of the study.

2. Methodology

This section discussed **Figure 1** which is the framework of the methodology categorized into 3 steps in this study.

2.1 Electrical units and usage data collection

The first step of this study involves the systematic identification of electrical appliances and utilities utilized within the Dahlia, Kemuning and Kemboja building blocks of SMK Engkilili, Sarawak. A comprehensive inventory of electrical units including ceiling fans, fluorescent lights, photocopier machines, public address (PA) system and air conditioning unit was established. Data collection was conducted through direct on-site observations to determine the quantity and type of equipment available in each block. In addition, questionnaires were carried out with selected students to estimate the typical duration of operation for each appliance on a daily and monthly basis. Key parameters recorded include

the number of units, rated power input (W), average hours of usage per day and frequency of usage per month.

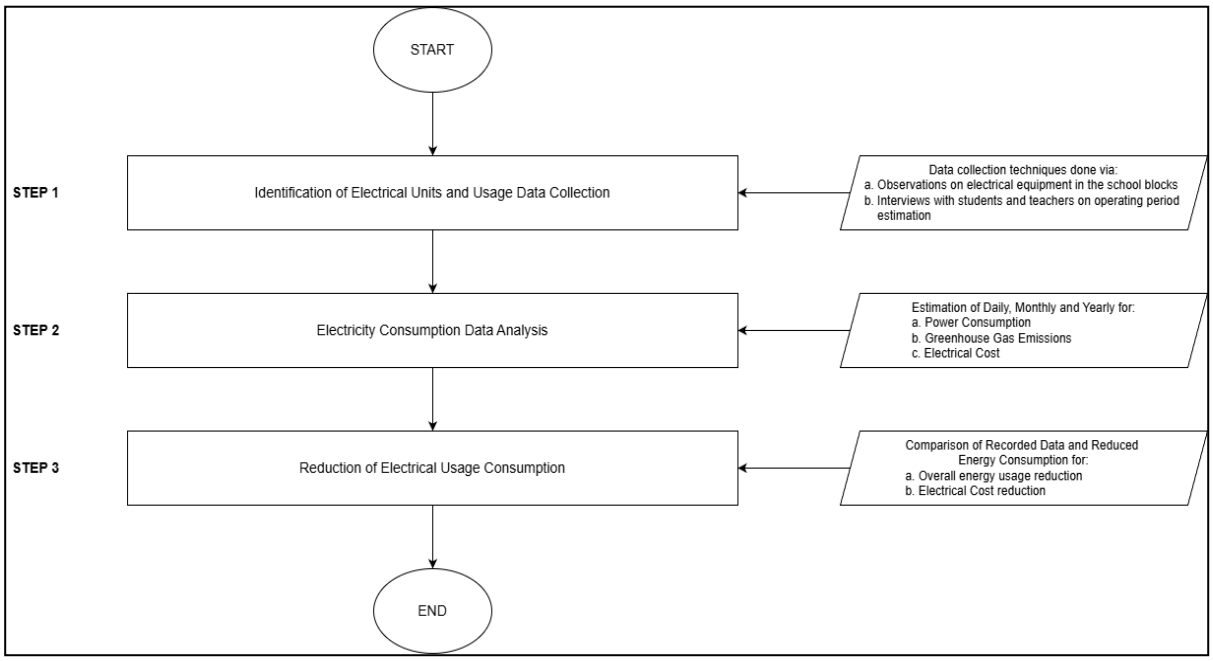


Figure 1: Framework of methodology

2.2 Electricity consumption data analysis

Following data collection, the electricity consumption analysis was performed to quantify energy usage across the identified electrical appliances. The total energy consumption was calculated in kilowatt-hours (kWh) using the standard relation between power rating, operating time and number of units. Daily energy consumption was first determined and subsequently extrapolated to monthly and yearly values. Furthermore, the estimated annual electricity cost was computed based on prevailing electricity tariffs of Sarawak Energy Berhad (SEB), as in **Table 1**, providing an economic perspective on energy usage. In addition to cost analysis, greenhouse gas emissions were estimated using appropriate emission factors to evaluate the environmental impact of electricity consumption. This comprehensive analysis enables the identification of major energy-consuming appliances and establishes a baseline for comparison with improved energy-saving scenarios.

Table 1: Electricity tariff and emission factor of CO_2

Item	Value
Domestic electricity tariff (RM/kWh)	0.18
Commercial electricity tariff (RM/kWh)	0.20
Emission factor for CO_2 (kg/kWh)	0.75

2.3 Reduction of Electrical Usage Consumption Analysis

The final step focuses on evaluating strategies to reduce overall electricity consumption without compromising user comfort and productivity. Adjustments were made to the operating duration of selected electrical appliances, particularly ceiling fans and lighting systems based on realistic and achievable usage reduction. A revised dataset representing reduced energy usage was developed and analysed using the same calculation methods as in the initial assessment. The recorded and reduced scenarios were then compared by blocks and individual equipment to determine the percentage reduction in energy consumption, electricity cost and greenhouse gas emissions. This comparative

analysis highlights the effectiveness of simple energy-saving measures and demonstrates their potential for practical implementation within the school.

3. Results and Discussion

This section presents the results obtained from the energy audit and provides a detailed discussion of electricity consumption patterns within the selected school blocks. Section 2.1 describes the identification of electrical units and the collection of usage duration data. Section 2.2 presents the analysis of electricity consumption including estimated daily, monthly, and yearly energy usage as well as associated emissions produced and electricity cost. Section 2.3 discusses the evaluation of energy reduction strategies by comparing actual and reduced consumption scenarios to assess potential energy savings and energy efficiency improvements.

3.1 Electrical appliances and utilities data

The data collected and presented in **Table 2** provides a comprehensive overview of the electrical appliances and utilities utilized across the Dahlia, Kemuning and Kemboja building blocks of the selected school. The data reveals that ceiling fans and fluorescent lighting systems constitute the most dominant electrical loads in classroom environments with consistent usage patterns of approximately 11 hours per day for fans and 6 hours per day for lighting across 24 operational days per month. This reflects the typical school operating schedule of daytime classes with evening study sessions and highlights the dependence on mechanical ventilation and artificial lighting to maintain a conducive learning environment particularly in tropical climates where thermal comfort is essential [6]. In contrast, facilities such as the Parent-Teacher Association (PTA) room and cooperative room demonstrate significantly lower usage durations ranging from 0.5 to 1 hour per day. However, these spaces introduce higher power-consuming equipment, such as public address (PA) system of 800 W rated, air conditioning unit of 750 W rated and photocopiers of 500 W rated, which contribute disproportionately to energy consumption despite shorter operating periods. This observation concluded that intermittent high-power devices can significantly influence total energy demand especially when not managed efficiently. Furthermore, variations in lighting configurations can be observed, particularly in the Kemboja block where one classroom of 2EP class utilizes six fluorescent light units compared to typical four units in other classrooms. Such discrepancies indicate differences in room size, layout or lighting requirements which can lead to uneven energy distribution across similar functional spaces. The presence of multiple units of low-wattage utilities, such as fluorescent lights rated at 11 W, also demonstrates how cumulative energy consumption can become substantial when operated continuously over extended periods. Overall, the collected data highlight that energy consumption within the school is primarily driven by prolonged usage of moderate power appliances rather than short-term operation of high-power equipment. This suggests that energy-saving strategies should prioritize reducing the usage durations and improving efficiency of frequently used appliances [7]. Additionally, the dataset establishes a critical baseline for subsequent energy consumption analysis and supports the identification of key areas where targeted interventions can yield meaningful reductions in electricity cost and associated environmental impacts

3.2 Electricity Consumption Analysis

The electricity consumption analysis presented in **Tables 3** and **Table 4** provides a quantitative assessment of energy usage patterns and associated environmental and economic impacts within the selected school blocks. The data indicated that the total estimated electricity consumption amounts to 19.17 kWh per day, 450.84 kWh per month and 5410.08 kWh annually which corresponding to approximately 4057.56 kg of CO_2 emissions and electricity cost of RM 1081.99 per year. These findings highlight the significant contribution of routine school operations to overall energy demand and carbon footprint even within a relatively small-scale institutional setting.

Table 2: Recorded electrical appliances and utilities usage data

Item	Equipment	Unit	Power input per unit (W)	Duration of usage per day (hours)	Duration of usage per month (days)
Dahlia Block					
i. 3DR Classroom					
1	Ceiling Fan	4	70	11	24
2	Fluorescent Light	4	11	6	24
ii. 3CL Classroom					
1	Ceiling Fan	4	70	11	24
2	Fluorescent Light	4	11	6	24
Kemuning Block					
i. 2AL Classroom					
1	Ceiling Fan	4	70	11	24
2	Fluorescent Light	4	11	6	24
ii. Parent-Teacher Association Room					
1	Ceiling Fan	1	70	0.5	20
2	Fluorescent Light	1	18	0.5	20
3	Public Address (PA) System	1	800	0.5	20
iii. Cooperative Room					
1	Ceiling Fan	1	70	1	20
2	Fluorescent Light	5	11	1	20
3	Air Conditioner	1	750	1	20
4	Photocopier Machine	2	500	1	20
Kemboja Block					
i. 2FG Classroom					
1	Ceiling Fan	4	70	11	24
2	Fluorescent Light	4	11	6	24
ii. 2EP Classroom					
1	Ceiling Fan	4	70	11	24
2	Fluorescent Light	6	11	6	24

Among the three blocks, the Kemboja Block exhibits the highest annual energy consumption at 1964.16 kWh, followed closely by the Dahlia Block at 1926.24 kWh. In contrast, the Kemuning Block records the lowest consumption at 1519.68 kWh. The higher consumption observed in Kemboja can be attributed primarily to increased lighting loads, particularly in the 2EP classroom, which utilizes a greater number of fluorescent light units. This observation indicating that lighting systems can account for a substantial proportion of electricity consumption in educational buildings especially when inefficient or excessive lighting configurations are employed. Moreover, the Kemuning Block presents a more diverse energy profile due to the presence of auxiliary facilities such as the PTA room and cooperative room. Although these spaces have shorter usage durations, the incorporation of high-power equipment such as air conditioners and photocopiers contribute notably to overall consumption. For instance, the photocopier alone accounts for 240 kWh annually, while the air conditioning unit contributes 180 kWh. This demonstrates that intermittent use of high-power devices can still exert a considerable influence on energy demand particularly when aggregated over time. Similar trends have been reported in institutional energy audits, where office equipment, lightings and cooling systems are identified as key contributors to peak energy loads [8].

A detailed examination of individual equipment contributions reveals that ceiling fans are the dominant energy consumers across all classroom settings with each classroom recording approximately 887.04 kWh annually from fan usage alone. This is largely due to their extended operating duration of 11 hours per day which outweighs their relatively moderate power rating. Such findings highlighted that prolonged usage of medium power appliances can surpass the impact of high-power appliances used intermittently. In comparison, fluorescent lighting contributes significantly less to total energy consumption with annual values ranging between 76.03 kWh and 114.05 kWh depending on the number of units installed. However, when aggregated across multiple classrooms, their cumulative impact becomes non-negligible. This reinforces the importance of efficient lighting design and the potential

benefits of adopting energy-efficient alternatives such as light emitting diode (LED) systems which have been shown to reduce lighting energy consumption by up to 80% [9].

Table 3: Daily, monthly and yearly power consumption with greenhouse gas emissions produced

Item	Equipment	Daily estimated power unit (kWh)	Monthly estimated power unit (kWh)	Yearly estimated power unit (kWh)	Emission of CO_2 per day (kg CO_2e)	Emission of CO_2 per month (kg CO_2e)	Emission of CO_2 per year (kg CO_2e)
Dahlia Block							
i.	**3DR Classroom**						
1	Ceiling Fan	3.08	73.92	887.04	2.31	55.44	665.28
2	Fluorescent Light	0.26	6.34	76.03	0.20	4.75	57.02
ii.	**3CL Classroom**						
1	Ceiling Fan	3.08	73.92	887.04	2.31	55.44	665.28
2	Fluorescent Light	0.26	6.34	76.03	0.20	4.75	57.02
Total		**6.68**	**160.52**	**1926.24**	**5.02**	**120.38**	**1444.56**
Kemuning Block							
i.	**2AL Classroom**						
1	Ceiling Fan	3.08	73.92	887.04	2.31	55.44	665.28
2	Fluorescent Light	0.26	6.34	76.03	0.20	4.75	57.02
ii.	**Parent-Teacher Association Room**						
1	Ceiling Fan	0.04	0.70	8.40	0.03	0.53	6.30
2	Fluorescent Light	0.009	0.18	2.16	0.007	0.14	1.62
3	Public Address (PA) System	0.40	8.00	96.00	0.30	6.00	72.00
iii.	**Cooperative Room**						
1	Ceiling Fan	0.07	1.40	16.80	0.05	1.05	12.60
2	Fluorescent Light	0.06	1.10	13.20	0.04	0.83	9.90
3	Air Conditioner	0.75	15.00	180.00	0.56	11.25	135.00
4	Photocopier Machine	1.00	20.00	240.00	0.75	15.00	180.00
Total		**5.67**	**126.64**	**1519.68**	**4.25**	**94.99**	**1139.88**
Kemboja Block							
2FG Classroom							
1	Ceiling Fan	3.08	73.92	887.04	2.31	55.44	665.28
2	Fluorescent Light	0.26	6.34	76.03	0.20	4.75	57.02
2EP Classroom							
1	Ceiling Fan	3.08	73.92	887.04	2.31	55.44	665.28
2	Fluorescent Light	0.40	9.50	114.05	0.30	7.13	85.54
Total		**6.82**	**163.68**	**1964.16**	**5.12**	**122.76**	**1473.12**
Overall		**19.17**	**450.84**	**5410.08**	**14.39**	**338.13**	**4057.56**

From an environmental perspective, the CO_2 emission analysis closely follows the energy consumption trends, with Kemboja Block generating the highest annual emissions of 1473.12 kg CO_2e, followed by Dahlia Block with 1444.56 kg CO_2e and Kemuning Block with 1139.88 kg CO_2e. The total annual emissions of 4057.56 kg CO_2e underscore the environmental implications of electricity usage in schools particularly in regions where electricity generation still relies on fossil fuels. These findings emphasize the role of energy efficiency in reducing greenhouse gas emissions and mitigating climate change impacts [10]. In terms of economic impact, the estimated electricity costs in **Table 4** reflect the consumption patterns observed across all the selected blocks. The Kemboja Block incurs the highest annual cost at RM 392.83, followed by Dahlia Block at RM 385.23, while Kemuning Block records the

lowest cost at RM 303.93. Although the differences may appear modest, they are significant within the context of rural schools where financial resources are often limited. Effective energy management strategies could therefore yield meaningful cost savings that can be redirected toward educational resources and infrastructure improvements.

Table 4: Recorded monthly and yearly electricity cost estimation

Building Block	Monthly estimated electricity bill (RM)	Yearly estimated electricity bill (RM)
Dahlia Block	32.10	385.23
Kemuning Block	25.33	303.93
Kemboja Block	32.74	392.83
Overall	90.17	1081.99

3.3 Feasible Measures for Reduction of Energy Consumption

The implementation of feasible energy-saving measures presented in **Table 5** reflects a targeted approach to reducing electricity consumption within the selected school blocks while maintaining operational effectiveness and occupant comfort. Two primary strategies are introduced in this study, namely the reduction of equipment operating duration and the substitution of conventional lighting systems with energy-efficient alternatives. These measures are designed based on the analysis of baseline energy consumption patterns, which identified ceiling fans and lighting systems as the dominant contributors to electricity usage in classroom environments. One of the key interventions involves reducing the operating duration of ceiling fans from 11 hours to 10 hours per day. This adjustment is considered practical and non-disruptive as it aligns with natural environmental conditions within the school setting. In the early morning, ambient temperatures are generally lower, reducing the immediate need for mechanical ventilation. Similarly, during certain periods such as recess or unoccupied classroom hours, fans can be switched off without compromising thermal comfort. Previous studies have shown that minor behavioral and operational adjustments can result in measurable energy savings without negatively affecting user productivity or comfort levels [11]. Therefore, this measure represents a low-cost and easily implementable strategy for reducing energy demand. In addition to operational usage reduction, significant energy savings are achieved through the replacement of fluorescent lighting with light emitting diode (LED) lamps. The transition from 11 W fluorescent lamps to 5 W LED lamps in classrooms, as well as from 18 W to 8 W in specific areas, demonstrates a substantial reduction in power consumption while maintaining equivalent or improved illumination levels [12]. LEDs are widely recognized for their superior luminous efficacy, longer lifespan, and lower heat generation compared to conventional lighting technologies [13]. This ensures that lighting quality is not compromised despite the reduction in power input. Furthermore, the slight reduction in lighting usage duration from 6 hours to 5.5 hours per day is justified by the availability of natural daylight, particularly during mid-day periods when sunlight can adequately illuminate classrooms. The integration of natural lighting has been identified as an effective strategy in reducing dependence on artificial lighting in educational buildings. The combination of technological improvement and behavioural adjustment enhances the overall effectiveness of the proposed energy-saving measures. While equipment such as air conditioner, photocopiers, and PA system remains unchanged due to their functional necessity and limited operating duration, the targeted optimization of high-frequency and long-duration appliances yields meaningful reductions in energy consumption.

The implementation of the proposed energy-saving measures has resulted in a noticeable reduction in electricity consumption, greenhouse gas emissions and operational costs across all evaluated school blocks as presented in **Table 6** and **Table 7**. The overall annual electricity consumption decreased from the baseline value to 4754.40 kWh accompanied by a reduction in total annual CO_2 emissions to 3565.80 kg CO_2e. At the block level, the Kemboja Block remains the highest energy consumer even after the implementation of reduction measures with an annual consumption of 1692.00 kWh, followed closely by the Dahlia Block at 1676.16 kWh while the Kemuning Block records the lowest consumption at 1386.24 kWh. Despite maintaining a similar ranking pattern as in the baseline scenario, all blocks exhibit a consistent decrease in energy usage, indicating that the applied measures are effective across different

building functions and electricity usage profiles. The reduction is particularly evident in classroom environments where ceiling fan operation and lighting systems dominate electricity demand.

Table 5: Electrical appliances and utilities usage data with energy reduction measures

Item	Equipment	Unit	Power input per unit (W)	Duration of usage per day (hours)	Duration of usage per month (days)
Dahlia Block					
iii.	**3DR Classroom**				
1	Ceiling Fan[a]	4	70	10	24
2	LED Lamp[b]	4	5	5.5	24
iv.	**3CL Classroom**				
1	Ceiling Fan[a]	4	70	10	24
2	LED Lamp[b]	4	5	5.5	24
Kemuning Block					
iv.	**2AL Classroom**				
1	Ceiling Fan[a]	4	70	10	24
2	LED Lamp[b]	4	5	5.5	24
v.	**Parent-Teacher Association Room**				
1	Ceiling Fan	1	70	0.5	20
2	LED Lamp[c]	1	8	0.5	20
3	Public Address (PA) System	1	800	0.5	20
vi.	**Cooperative Room**				
1	Ceiling Fan	1	70	1	20
2	LED Lamp[d]	5	5	1	20
3	Air Conditioner	1	750	1	20
4	Photocopier Machine	2	500	1	20
Kemboja Block					
iii.	**2FG Classroom**				
1	Ceiling Fan[a]	4	70	10	24
2	LED Lamp[b]	4	5	5.5	24
iv.	**2EP Classroom**				
1	Ceiling Fan[a]	4	70	10	24
2	LED Lamp[b]	6	5	5.5	24

Note: [a] the operating duration of ceiling fans is reduced from 11 hours to 10 hours per day
[b] the fluorescent lights are replaced with light emitting diode (LED) lamp from 11 W to 5 W and reduced operating duration from 6 hours to 5.5 hours per day
[c] the fluorescent light is replaced with light emitting diode (LED) lamp from 18 W to 8 W
[d] the fluorescent light is replaced with light emitting diode (LED) lamp from 11 W to 5 W

A detailed comparison of equipment performance shows that ceiling fans continue to be the primary contributors to energy consumption, although their annual usage has been reduced from 887.04 kWh to 806.40 kWh per classroom. This reduction is achieved through a one-hour decrease in daily operating time, highlighting the impact of behavioral and operational control strategies. Such findings are consistent with energy management studies, which emphasize that small adjustments in usage patterns can yield significant cumulative energy savings, especially for frequently used equipment [14]. More substantial improvements are observed in lighting systems following the replacement of fluorescent lamps with LED technology. The annual energy consumption of lighting in classrooms is significantly reduced due to both lower wattage and shorter operating duration. For example, LED lamps in standard classrooms consume only 31.68 kWh annually compared to higher values recorded for fluorescent systems in the baseline case. This reduction is supported by the high luminous efficacy of LEDs which can deliver equivalent or superior illumination at significantly lower energy input. Additionally, the use of natural daylight to supplement indoor lighting further contributes to reduced operating hours, reinforcing the role of passive design strategies in energy conservation [15].

Table 6: Daily, monthly and yearly power consumption with greenhouse gas emissions produced with energy reduction measures

Item	Equipment	Daily estimated power unit (kWh)	Monthly estimated power unit (kWh)	Yearly estimated power unit (kWh)	Emission of CO_2 per day (kg CO_2e)	Emission of CO_2 per month (kg CO_2e)	Emission of CO_2 per year (kg CO_2e)
Dahlia Block							
iii.	**3DR Classroom**						
1	Ceiling Fan	2.80	67.20	806.40	2.10	50.40	604.80
2	LED Lamp	0.11	2.64	31.68	0.08	1.98	23.76
iv.	**3CL Classroom**						
1	Ceiling Fan	2.80	67.20	806.40	2.10	50.40	604.80
2	LED Lamp	0.11	2.64	31.68	0.08	1.98	23.76
Total		**5.82**	**139.68**	**1676.16**	**4.36**	**104.76**	**1257.12**
Kemuning Block							
iv.	**2AL Classroom**						
1	Ceiling Fan	2.80	67.20	806.40	2.10	50.40	604.80
2	LED Lamp	0.11	2.64	31.68	0.08	1.98	23.76
v.	**Parent-Teacher Association Room**						
1	Ceiling Fan	0.04	0.70	8.40	0.03	0.53	6.30
2	LED Lamp	0.004	0.08	0.96	0.003	0.06	0.72
3	Public Address (PA) System	0.40	8.00	96.00	0.30	6.00	72.00
vi.	**Cooperative Room**						
1	Ceiling Fan	0.07	1.40	16.80	0.05	1.05	12.60
2	LED Lamp	0.03	0.50	6.00	0.02	0.38	4.50
3	Air Conditioner	0.75	15.00	180.00	0.56	11.25	135.00
4	Photocopier Machine	1.00	20.00	240.00	0.75	15.00	180.00
Total		**5.19**	**115.52**	**1386.24**	**3.89**	**86.65**	**1039.68**
Kemboja Block							
2FG Classroom							
1	Ceiling Fan	2.80	67.20	806.40	2.10	50.40	604.80
2	LED Lamp	0.11	2.64	31.68	0.08	1.98	23.76
2EP Classroom							
1	Ceiling Fan	2.80	67.20	806.40	2.10	50.40	604.80
2	LED Lamp	0.17	3.96	47.52	0.12	2.97	35.64
Total		**5.88**	**141.00**	**1692.00**	**4.40**	**105.75**	**1269.00**
Overall		**16.89**	**396.20**	**4754.40**	**12.65**	**297.16**	**3565.80**

Table 7: Monthly and yearly electricity cost estimation with energy reduction measures

Building Block	Monthly estimated electricity bill (RM)	Yearly estimated electricity bill (RM)
Dahlia Block	27.94	335.23
Kemuning Block	23.10	277.25
Kemboja Block	28.20	338.40
Overall	79.24	950.88

The impact of these measures is also reflected in the reduction of CO_2 emissions across all blocks. The total annual emissions decrease to 3565.80 kg CO_2e from 4057.56 kg CO_2e, representing a substantial improvement in environmental performance. This reduction is directly linked to decreased electricity consumption, particularly from power grid sources that are typically associated with carbon-intensive generation. From an economic perspective, the implementation of energy-saving measures

leads to a reduction in electricity costs with the total annual expenditure decreasing to RM 950.88 from RM 1081.99. Among the blocks, Kemboja records the highest annual cost of RM 338.40, followed by Dahlia with RM 335.23 and Kemuning with RM 277.25. Although the cost savings per block may appear modest, they are significant as rural schools where budget constraints necessitate efficient resource allocation. The relatively low implementation cost of the proposed measures, particularly LED replacement and operational adjustments, further enhances their feasibility and attractiveness.

The comparative analysis presented in **Table 8** and **Table 9** highlights the effectiveness of the implementation of energy reduction measures in lowering overall electricity consumption, operational costs and environmental impact within the selected school blocks. The total annual energy consumption decreased from 5410.08 kWh to 4754.40 kWh which corresponding to a reduction of 12.12%. This reduction is consistent across both economic and environmental indicators, with the annual electricity cost decreasing from RM 1081.99 to RM 950.88 and carbon emissions reducing from 4057.56 kg CO_2e to 3565.80 kg CO_2e. These results demonstrate that targeted energy efficiency interventions can yield significant cumulative benefits even when applied to relatively small-scale institutional settings. A detailed breakdown of individual equipment performance indicates that lighting systems achieved the highest percentage reduction of 58.20%, decreasing from 433.53 kWh to 181.20 kWh annually. In addition, the slight reduction in daily operating hours further enhances energy savings by utilizing natural daylight during peak sunlight periods. Ceiling fans, which represent the largest share of energy consumption, recorded a moderate reduction of 9.04%. Although the percentage reduction is relatively small, the absolute energy savings are significant due to the high baseline consumption of these appliances. This finding underscores the importance of targeting high-usage equipment in energy management strategies, as even minor efficiency improvements can lead to substantial overall reductions. In contrast, no reduction was observed for the PA system, air conditioner and photocopier machines as their operation is essential for maintaining core academic and administrative functions. Their relatively lower contribution to total energy consumption also suggests that prioritizing frequently used systems yields greater impact. The reduction in greenhouse gas emissions closely mirrors the decrease in electricity consumption, reflecting the direct relationship between energy usage and carbon output. Furthermore, the reduction in annual electricity costs provides additional economic justification for the adoption of these measures especially for rural schools where financial resources may be limited.

Table 8: Percentage difference for each equipment of recorded and reduced yearly energy consumption

Item	Equipment	Recorded Energy Consumption per year (kWh)	Reduced Energy Consumption per year (kWh)	Percentage Difference (%)
1	Ceiling Fans	4460.40	4057.20	9.04
2	Lighting Systems	433.53	181.20	58.20
3	Public Address (PA) System	96.00	96.00	0.00
4	Air Conditioner	180.00	180.00	0.00
5	Photocopier Machines	240.00	240.00	0.00
Total		**5410.08**	**4754.40**	**12.12**

Table 9: Yearly electricity cost and greenhouse gas emission of recorded and reduced energy consumption data

Criteria	Recorded Energy Consumption Data	Energy Reduction Measures Data	Total Percentage Difference (%)
Estimated annual bill (RM)	1081.99	950.88	**12.12**
Annual greenhouse gas emission (kg CO_2e)	4057.56	3565.80	

Further improvements in energy efficiency can be achieved through enhanced operational usage and behavioral strategies. Limiting the usage of high-power equipment, such as reducing air conditioning operation from extended periods to only necessary hours, can significantly lower energy demand

without requiring additional capital investment. Reducing the usage of ceiling fans can also be implemented without compromising student comfort by adopting adaptive ventilation strategies. For instance, utilizing natural ventilation through the opening of windows and doors during cooler periods allows sufficient airflow, thereby reducing reliance on mechanical cooling [16]. Classrooms can also benefit from improved air circulation through proper seating arrangements and unobstructed airflow pathways. Next, intermittent fan operation, such as using fans only during peak heat periods or when spaces are all occupied, can prevent unnecessary energy consumption while maintaining thermal comfort. The use of lower fan speed settings when full capacity is not required also contributes to energy savings. Importantly, fostering behavioral awareness among students and staff plays a crucial role as this encourages users to switch off electrical appliances when not in use can significantly enhance overall efficiency. Collectively, these measures ensure a balance between energy conservation and a conducive learning environment, supporting sustainable energy management practices without negatively affecting academic performance.

4. Conclusion

This study successfully evaluated the feasibility of reducing energy consumption within the Dahlia, Kemuning and Kemboja building blocks at SMK Engkilili, Sarawak, through a systematic energy audit framework. The identification of electrical appliances and the collection of detailed usage data enabled a comprehensive understanding of energy consumption patterns across the selected school areas. Subsequent analysis of daily, monthly and yearly electricity usage, along with associated greenhouse gas emissions and electricity costs, provided a clear baseline for assessing energy performance. The implementation of feasible energy-saving measures, including reducing equipment operating durations and adopting energy-efficient lighting systems, resulted in a significant reduction of 12.12% in total energy consumption, accompanied by corresponding decreases in annual electricity cost and carbon emissions. These findings confirm that practical and low-cost strategies can effectively enhance energy efficiency without disrupting the comfort and productivity of students and school staff. Overall, the study demonstrates the potential for educational institutions, particularly in rural settings, to adopt sustainable energy management practices, thereby contributing to cost savings and environmental sustainability.

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Energy Consumption in Educational Facilities: A Case Study of Energy Audit at SMK Engkilili, Sri Aman, Sarawak (Keruntum Block)

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Abstract

Electrical energy wastage in educational facilities is a growing concern due to inefficient use of electrical appliances, leading to increased operational costs and greenhouse gas emissions. This study presents a comprehensive energy audit of Keruntum Block at SMK Engkilili, Sri Aman, Sarawak, with the aim of assessing electricity consumption, estimating carbon dioxide (CO_2) emissions, and proposing feasible energy-saving measures. A systematic walkthrough inspection was conducted to identify electrical appliances across 14 rooms, including classrooms, laboratories, and administrative spaces. A total of 10 types of appliances were recorded, with fluorescent lights (45.95%) and ceiling fans (38.74%) being the most dominant. Energy consumption and CO_2 emissions were calculated using standard formulas and analyzed using Microsoft Excel. The results indicated that the ground floor accounted for the highest energy consumption (51.12%), primarily due to high-power equipment in specialized rooms. The Senior Assistant Co-curriculum (BPKKK) Room recorded the highest annual electricity consumption (3007.92 kWh) and CO_2 emissions (598.57 kg), mainly due to prolonged air-conditioner usage, while the Physics Laboratory showed high consumption due to a continuously operating refrigerator. Optimization strategies were then proposed and evaluated, resulting in significant energy reductions of 73.69% in the BPKKK Room and 57.06% in the Physics Laboratory. These improvements also led to notable reductions in electricity costs and carbon emissions. The study demonstrates that effective energy management through operational adjustments and equipment optimization can significantly improve energy efficiency and support environmental sustainability in educational facilities.

Keywords: *Energy Audit, Electricity Consumption, Greenhouse Gas*

1. Introduction

In Malaysia, nearly half of the electricity generated, approximately 48%, is consumed by buildings mainly due to extensive use of air conditioning and lighting systems [1,2]. Educational facilities, such as schools, also contribute to this demand as they have long operating hours and to accommodate both students and staff [3]. For instance, classrooms require consistent lighting to ease learning activities which resulted in high usage of electricity throughout the day. Classrooms, for instance, require continuous lighting and ventilation to ensure a conducive learning environment, which results in consistent electricity usage. In addition, the increasing integration of electrical appliances such as computers, projectors, and laboratory equipment further elevates energy consumption in school buildings. The combination of these factors results in steady electricity demand throughout the day, often leaving little opportunity for energy saving without systematic intervention.

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The growing reliance on electricity is closely related to greenhouse gas (GHG) emissions, particularly carbon dioxide (CO_2) since electric generation is still heavily depends on fossil fuels [4,5,6]. Therefore, high electrical consumption may lead to high GHG emissions and environmental impact. The increase in GHG concentrations elevates the greenhouse effect leading to global warming and subsequent climate change. As a result, there are visible changes in weather patterns, sea levels and other environmental aspects [7]. In addition, elevated CO_2 emissions affect local air quality, which can have direct health implications for students and staff, particularly in urban areas with high population density [14]. Schools, being one of the major public buildings with high energy use, can significantly influence the overall carbon footprint of the community. Consequently, efforts by schools to reduce electricity consumption contribute not only to environmental protection but also support broader national strategies aimed at lowering greenhouse gas emissions.

In response to address climate change issue, Malaysia aims to reduce GHG emissions by 45% by 2030 compared to 2005 levels as stated in Nationally Determined Contribution (NDC) [8]. In this context, lowering the electricity consumption in buildings is important to support national effort to reduce GHG emissions. Schools have the potential to act as models for energy-efficient practices, demonstrating sustainable behaviors that can influence both students and the wider community. Lowering electricity consumption in schools can contribute significantly to national climate objectives while also reducing operational costs for educational institutions. Promoting energy awareness through education and practical measures, such as encouraging responsible use of electrical equipment and integrating renewable energy sources where feasible, further strengthens the impact of sustainability initiatives. Hence, energy efficiency in schools is not only an operational necessity but also a strategic contribution to achieving Malaysia's broader climate goals.

Effective electricity management in schools requires a systematic approach to understand how electricity is used within school buildings. Energy audit is a systematic assessment to reduce operating costs by assessing electricity usage, identifying energy inefficiency and proposing viable solutions in reducing energy wastage [9,10]. The audit process typically involves detailed data collection on energy consumption patterns, measurement of equipment usage, inspection of electrical systems, and analysis of operational practices. Through this process, energy audits could uncover inefficiencies that may otherwise remain unnoticed, such as overuse of lighting, unnecessary standby power in electronic devices, or poorly maintained Heating, Ventilation, and Air Conditioning (HVAC) systems. By providing quantitative insights and evidence-based recommendations, energy audits allow schools to implement targeted interventions that can significantly improve energy efficiency.

Electrical energy wastage in Keruntum Block of Sekolah Menengah Kebangsaan (SMK) Engkilili occurs due to inefficient use of electrical appliances which leads to higher electricity costs and higher greenhouse gas emissions. In many cases, electricity consumption is not regularly monitored and lack of awareness among students and staff regarding their electricity usage contributes to higher energy consumption. Hence, conducting energy audits can help to assess electricity usage and provide practical strategies to increase energy efficiency of Keruntum Block. As such, the aim of this study is to assess electricity consumption, estimate carbon dioxide emissions in Keruntum Block of SMK Engkilili, Sri Aman and propose feasible energy savings measures. Correspondingly, the objectives of this study are to (i) identify and record electrical appliances used in Keruntum Block including their power rating and operating duration to determine the main contributors to energy consumption, (ii) calculate electricity consumption and estimate carbon dioxide gas emissions based on recorded usage data, and (iii) optimize electricity usage by evaluating and recommending feasible energy-saving strategies. The scope of this study is focused on the Keruntum Block of SMK Engkilili, covering classrooms, laboratories, administrative offices, and other functional areas within the block

2. Methodology

This section presents the devised methodology in accordance with the aim and objectives of the study. The methodology is structured into three main stages: (i) Site visit, (ii) Data collection, and (iii) Optimization and evaluation of energy-saving strategies. **Figure 1** shows the flow chart of the summary of the research process.

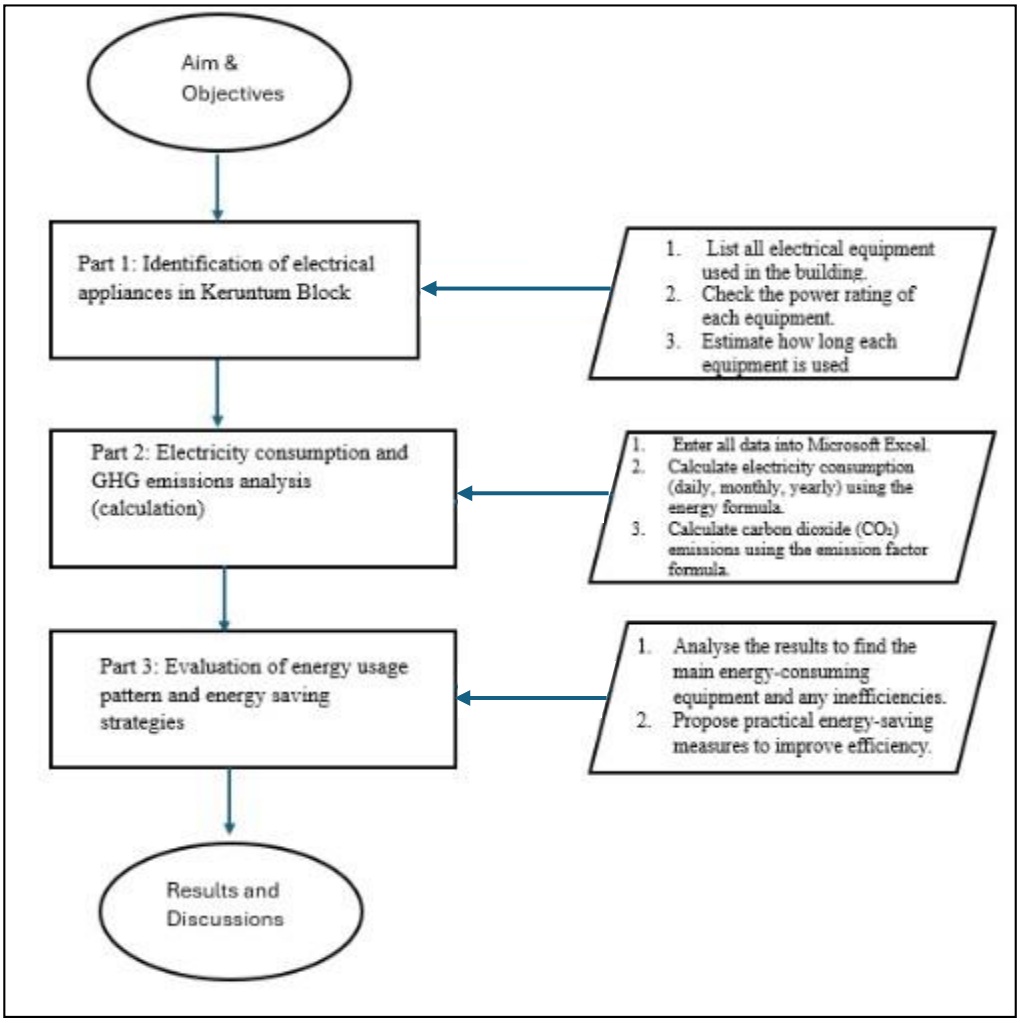


Figure 1. Flow chart of the research process

2.1. Site visit and equipment inventory

An initial assessment of Keruntum Block was conducted to obtain baseline information about the building and its electrical systems. The building location and facilities were identified. A walkthrough inspection was conducted to record all electrical equipment in each room of the building. The equipment type, quantity, operating hours and power rating were collected from the equipment nameplates and by interviewing the occupant of each room. Data collected were compiled in a standardized data collection table to support energy calculations.

2.2. Quantification of electrical consumption and CO_2 emissions

All collected data from equipment inventory were systematically entered into Microsoft Excel to calculate energy consumption by using energy **Equation 1** [11]. Energy consumption calculations were performed at multiple time scales which are daily, monthly and yearly.

$$E = \frac{P \times t}{1000} \quad \ldots\ldots\ldots (1)$$

Where E is energy consumption (kWh), P is power rating of an equipment (W) and t is usage duration (h). In addition, annual electricity costs were calculated by applying the electricity tariff structure for commercial consumers as established by Sarawak Energy Berhad. The current electricity tariff rate of

RM 0.20 per kWh was used to convert energy consumption values into monetary costs [12] as depicted by **Equation 2**.

$$MEB = E \times T \quad \text{..... (2)}$$

Where *MEB* is Monthly Electricity Bill (RM), *E* is total electricity consumption (kWh) and *T* is Tariff (RM/kWh). Carbon dioxide emissions associated with electricity consumption were calculated using the emission factor method as in **Equation 3**:

$$E_{CO_2} = E \times EF \quad \text{..... (3)}$$

Where E_{CO_2} is the emissions of CO_2 during electricity generation (kg CO_2e), E is total electricity consumption (kWh) and EF is emission factor (kg CO_2/kWh). The Sarawak grid emission factor was used to estimate total building emissions and emissions by equipment category. The value used was 0.199 kg CO_2/kWh [13].

2.3. Optimization and evaluation of energy saving strategies

The calculated electricity consumption was analyzed to identify the main energy-consuming equipment and operational inefficiencies in Keruntum Block, such as high-usage areas, equipment operating during unoccupied hours, and outdated appliances. Based on these findings, suitable energy-saving measures were proposed to increase energy efficiency. The effectiveness of each measure was evaluated using **Equation 4**:

$$\%\, Reduction = \frac{E_a - E_o}{E_a} \times 100 \quad \text{..... (4)}$$

Where E_a is actual electricity consumption obtained during site observation and interviews and E_o is optimized electricity consumption estimated after implementing the proposed energy-saving measures.

3. Results and discussions

This section presents and discusses the main findings pertaining to the energy audit of Keruntum Block at SMK Engkelili. Results were obtained on 11 February 2026 from 2:30 p.m. to 4:30 p.m. by interviewing students or staff that occupied each room and through site visit. The results are organized into three main parts: (i) site visit and equipment inventory, (ii) quantification of electrical consumption and CO_2 emissions, and (iii) optimization and evaluation of energy-saving strategies.

3.1. Site visit and equipment inventory

During site visit, it was revealed that Keruntum Block is a 3-story structure which consists of 14 rooms as shown in **Figure 2**. Examination Room (BPP), Senior Co-curricular Assistant Room (BPKKK), Physics Laboratory (MFIZ), Home Economics Room (BERT), Operation Room (BOP) and Disciplinary Room (BSRY) are on the ground floor. The first floor of the building consists of 4 classrooms which are 5AL, 5FG, 4AL and 4FG while the second floor consists of 4 Form 5 classrooms which are 5BG, 5CL, 5DR and 5EP. However, there were two rooms which energy audit was not performed as both were not actively used, namely, Operation Room and Home Economics Room.

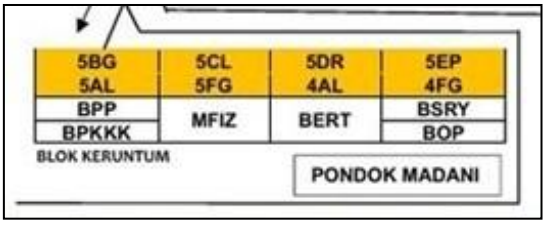


Figure 2. Layout of Keruntum Block

The comprehensive equipment inventory identified a total of 10 types of electrical appliances across all rooms in Keruntum Block. The appliances were fluorescent light (FL), ceiling fan (CF), speaker (SP), laptop (LP), split air-conditioner (AC), desktop computer (DC), refrigerator (RG), charger (CH), electric kettle (EK) and projector (PJ). **Table 1** presents the distribution of these appliances throughout the building. The inventory revealed a total of 51 fluorescent lights and 43 ceiling fans, representing 45.95% and 38.74% of all equipment respectively. These two appliance types dominate the building's electrical infrastructure, reflecting their role as basic necessities in educational facilities.

Table 1. Distribution of electrical appliances

Floor	Room/Appliances	FL	CF	SP	LP	AC	DC	RG	CH	EK	PJ
Ground	BPP	1	1			1					
	BPKKK	1	1		1	1	1			1	
	MFIZ	8	8		1			1	1		
	BSRY	1	1								
1	4AL	5	4	1							
	4FG	5	4	1							
	5AL	5	4	1							
	5FG	5	4	1							1
2	5BG	5	4	1							
	5CL	5	4	1							
	5DR	5	4	1							
	5EP	5	4	1							
Total		**51**	**43**	**8**	**2**	**2**	**1**	**1**	**1**	**1**	**1**

Figure 3 illustrates the distribution of electrical appliances across floors. The ground floor exhibits the most diverse equipment profile with 10 different appliance types, including specialized equipment such as air-conditioners, refrigerators, and desktop computers in the BPKKK and MFIZ rooms. In contrast, the first and second floors show more uniform distributions, consisting primarily of fluorescent lights, ceiling fans, speakers, and a single projector on the first floor. This pattern reflects the functional differences between floors, with the ground floor accommodating specialized administrative and laboratory spaces requiring higher-power equipment, while upper floors serve standard teaching functions with basic lighting and ventilation needs.

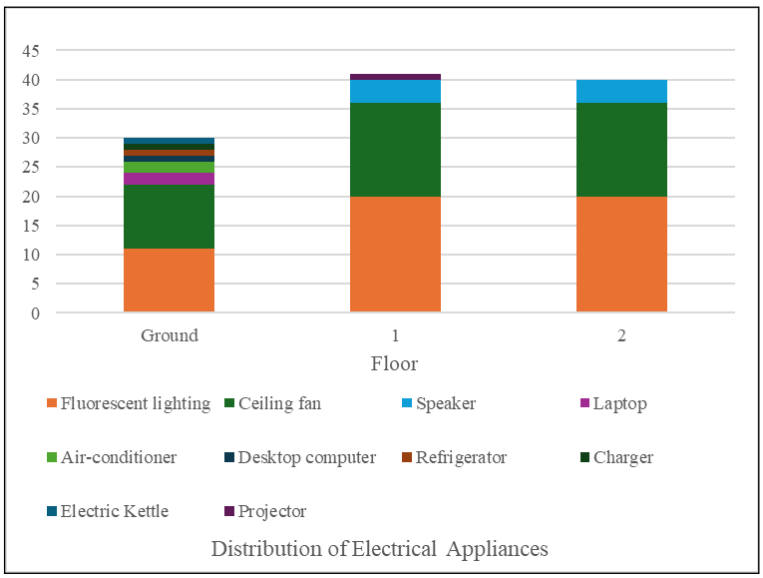


Figure 3. Distribution of electrical appliances number on each floor

3.2. Electrical consumption and CO_2 emissions analysis

The power ratings of all electrical appliances were documented in **Table 2**, revealing significant variations ranging from 30W for fluorescent lights to 1500W for the electric kettle. Air-conditioners (1000W), desktop computers (200W), and refrigerators (200W) represent the highest continuous-load equipment. Operating hours vary considerably across rooms and appliances, as in **Table 3**, reflecting diverse usage patterns. The BPKKK Room operates fluorescent lights for 10 hours daily and the air-conditioner for 10 hours, while the MFIZ refrigerator runs continuously at 24 hours daily. Classrooms show moderate operating hours, with ceiling fans running 9-14 hours daily and lights operating 3-4 hours daily.

Table 2. Power rating of electrical appliances

No.	Electrical Appliances	Power Rating (W)
1.	Fluorescent light	30
2.	Ceiling fan	51
3.	Speaker	100
4.	Laptop	45
5.	Split air-conditioner	1000
6.	Desktop computer	200
7.	Refrigerator	200
8.	Charger	240
9.	Electric kettle	1500
10.	Projector	425

Table 3. Operating hours (h) of electrical appliances

Floor	Room/Appliances	FL	CF	SP	LP	AC	DC	RG	CH	EK	PJ
Ground	BPP	1	1			1					
	BPKKK	10	3		4	10	8			0.167	
	MFIZ	2	2		4			24	3		
	BSRY	1	1								
1	4AL	3	9	2							
	5AL	3	9	2							
	4FG	4	14	2							
	5FG	3	10	2							2
2	5BG	3	10	2							
	5CL	3	10	2							
	5DR	3	10	2							
	5EP	3	10	2							

Figure 4 and **Figure 4** presents the annual electricity consumption and CO_2 emissions aggregated by floor, revealing stark disparities in energy usage across the building. The ground floor dominates total consumption, accounting for 51.12% of the building's total energy use despite housing fewer rooms than the combined upper floors. The first floor shows moderate consumption, while the second floor demonstrates the lowest usage. This hierarchical pattern highlights the disproportionate energy impact of specialized spaces compared to standard classrooms.

Figure 5 provides a room-by-room comparison of annual electricity consumption, visually emphasizing BPKKK's dominance followed by MFIZ. The BPKKK Room records the highest daily consumption at over 12 kWh, nearly double any other rooms. This dominance stems from the air-conditioner operating 10 hours daily as shown in **Table 5**, contributing approximately 80% of BPKKK's total consumption. The Physics Laboratory ranks second at 7 kWh daily, driven primarily by the continuously operating refrigerator which is 24 hours daily as stated in **Table 5**. The remaining rooms

are clustered at significantly lower levels, appearing relatively minor in comparison. Standard classrooms show modest consumption ranging from 2.5 to 3.7 kWh daily. The higher consumption in 4FG compared to other classrooms correlates with **Table 5** data showing 4FG extended operating hours suggesting after-school activities in that classroom. This visualization clearly illustrates that two specialized rooms, BPKKK and MFIZ, collectively consume 51% of total building energy, while the eight classrooms combined account for only 49%. The BPP and BSRY rooms show negligible consumption due to minimal usage, as confirmed by **Table 5** showing only 1 hour of operation per day for 3 days a year.

Table 4. Electricity consumption and CO_2 emissions of each room

Floor	Room	Electricity consumption per day (kWh)	Electricity consumption per year (kWh)	Emission of CO_2 per year (kg CO_2e)
Ground	BPP	1.080	3.240	0.645
	BPKKK	12.483	3007.920	598.576
	MFIZ	7.000	2250.430	447.836
	BSRY	0.080	9.720	1.934
1	4AL	2.490	549.040	109.975
	5AL			
	4FG	3.660	829.840	165.855
	5FG	3.540	720.400	144.076
2	5BG	2.690	598.000	119.718
	5CL			
	5DR			
	5EP			

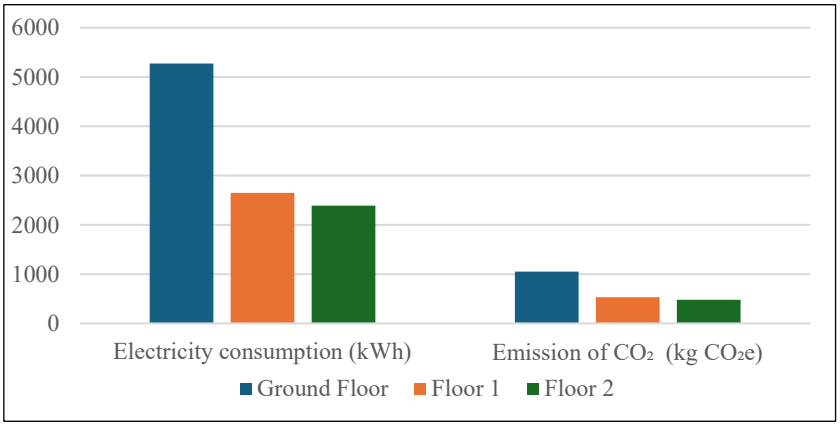


Figure 4. Electricity consumption and CO_2 emissions on each floor

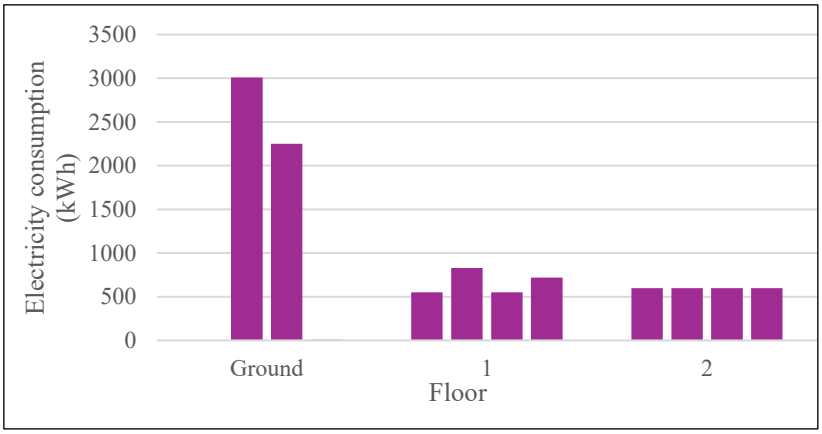


Figure 5. Electricity consumption per year of each room

Table 5. Yearly electricity consumption in KWh per year of each appliance

Appliances (in kWh)	Rooms							
	BPP	BPKKK	MFIZ	BSRY	4FG	5FG	4AL/5AL	5BG/5CL/ 5DR/5EP
Fluorescent light	0.090	72.000	115.200	3.600	115.200	86.400	86.400	86.400
Ceiling fan	0.153	36.720	195.840	6.120	856.800	550.800	550.800	612.000
Speaker					0.400	0.400	0.400	0.400
Laptop		43.200	43.200					
Split air-conditioner		2400.000						
Desktop computer		384.000						
Refrigerator			1785.600					
Charger			172.800					
Electric kettle		72.000						
Projector						122.400		

Figures 6, Figure 7, and **Figure 8** shows the consumption by appliance type within each room. Ceiling fans emerge as the largest cumulative consumer at 3063 kWh annually across all rooms, despite their relatively low 51W power rating. This results from high quantities of 43 units and long operating hours which are 9-14 hours daily in most classrooms. Air-conditioners, though only two units, contribute 2403 kWh annually, concentrated entirely in BPKKK (2400 kWh) and BPP (3 kWh). The Physics Laboratory refrigerator's continuous operation of 24 hours everyday yields 1785.6 kWh, representing 77.23% of the lab's consumption and exceeding the combined consumption of all second-floor classrooms.

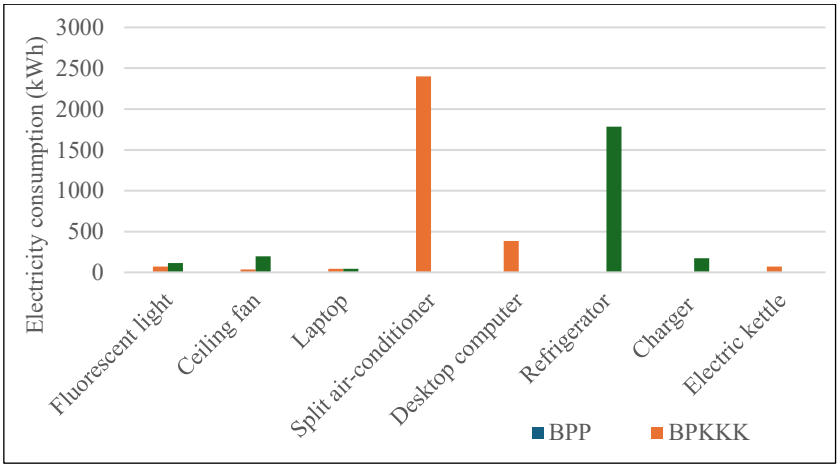


Figure 6. Estimation of yearly electricity consumption on ground floor

Fluorescent lights contribute 1067.85 kWh annually despite their modest 30W rating, due to high quantities of 51 units distributed across all rooms. Lower-power equipment shows minimal impact such as speakers (3.2 kWh/year, used only 2 times annually), laptops (86.4 kWh/year), desktop computer (384 kWh/year), charger (172.8 kWh/year), electric kettle (72 kWh/year), and projector (122.4 kWh/year). These findings demonstrate that cumulative consumption from numerous low-power, long-duration devices can exceed that of fewer high-power devices, while continuously operating equipment (refrigerators, air-conditioners) disproportionately impacts total consumption regardless of unit count.

3.3. Reduction and evaluation of energy saving strategies

Based on the consumption analysis, targeted optimization strategies were developed for the two highest-consuming rooms which are BPKKK and Physics Laboratory. These rooms collectively account for 5258.35 kWh annually, making them priority intervention targets. The original BPKKK operating schedule in **Table 3** was modified as shown in **Table 7** to reduce energy waste. The air-conditioner operation was drastically reduced from 10 hours to 1 hour daily, recognizing that continuous cooling

may exceed actual occupancy needs. This single change reduces air-conditioner consumption from 2400 kWh/year to 240 kWh/year, saving 2160 kWh annually. Desktop computer operating hours were reduced from 8 to 6 hours daily, assuming 2 hours of idle time can be eliminated through improved shutdown discipline, saving 96 kWh/year. Laptop usage was suggested to decrease from 4 to 3 hours daily, avoiding overcharging and unnecessary operation, saving 21.6 kWh/year.

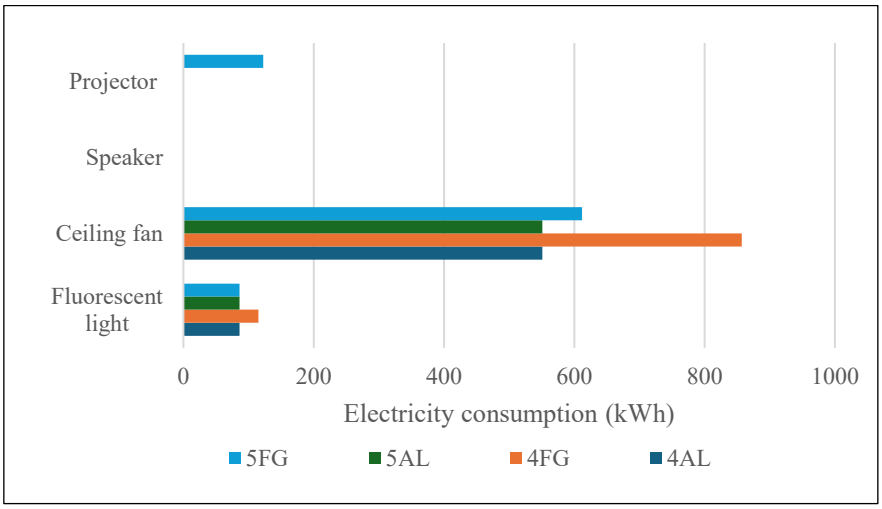


Figure 7. Estimation of yearly electricity consumption on first floor

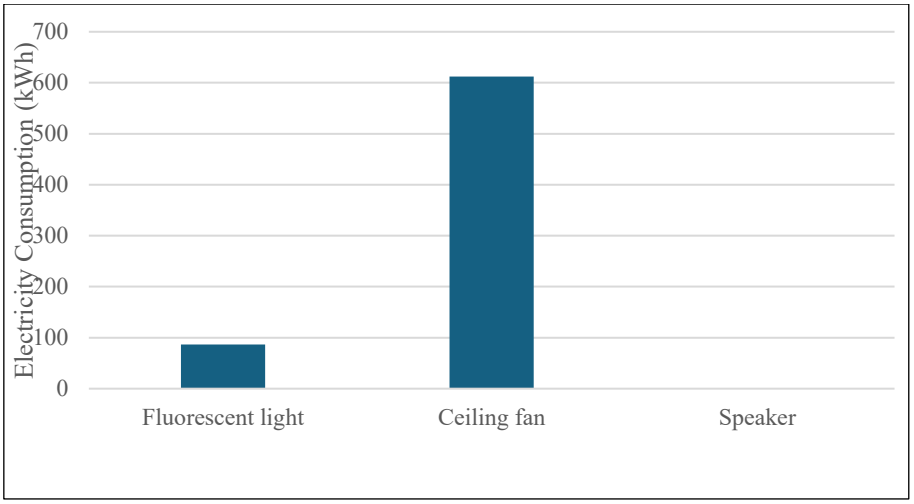


Figure 8. Estimation of yearly electricity consumption on first floor

Table 7. Reduced electrical appliance number and hourly usage of PKKK Room

Electrical Appliances	Quantity	Power Rating (W)	Operating hours (h)	Days of usage per month
Ceiling Fan	1	51	8	20
Fluorescent lamp	1	30	10	20
Split Air-Conditioner	1	1000	1	20
Laptop	1	45	3	20
Desktop Computer	1	200	6	20
Electric Kettle	1	1500	0.167	5

Table 8 and **Figure 9** present the optimization results. Total annual consumption decreases from 256.90 kWh to 68.90 kWh (note: these figures appear to represent monthly rather than annual values based on context), yielding a 73.18% reduction. The estimated yearly electricity bill drops from RM 601.58 to RM 158.30, saving RM 443.28 annually. Greenhouse gas emissions decline from 598.576 kg to 157.512 kg CO_{2e}, avoiding 441.064 kg annually. This dramatic improvement is achieved primarily through behavioral and operational changes (air-conditioner scheduling, computer shutdown discipline) requiring zero capital investment, demonstrating that management practices can deliver substantial savings before equipment upgrades are necessary.

Table 8. Actual and Optimised Consumption of BPKKK Room

	Actual	**Optimised**
Total Power (kWh)	256.90	68.90
Estimated yearly bill (RM)	4616.56	165.36
Greenhouse gas emission per year (kg)	613.477	164.533

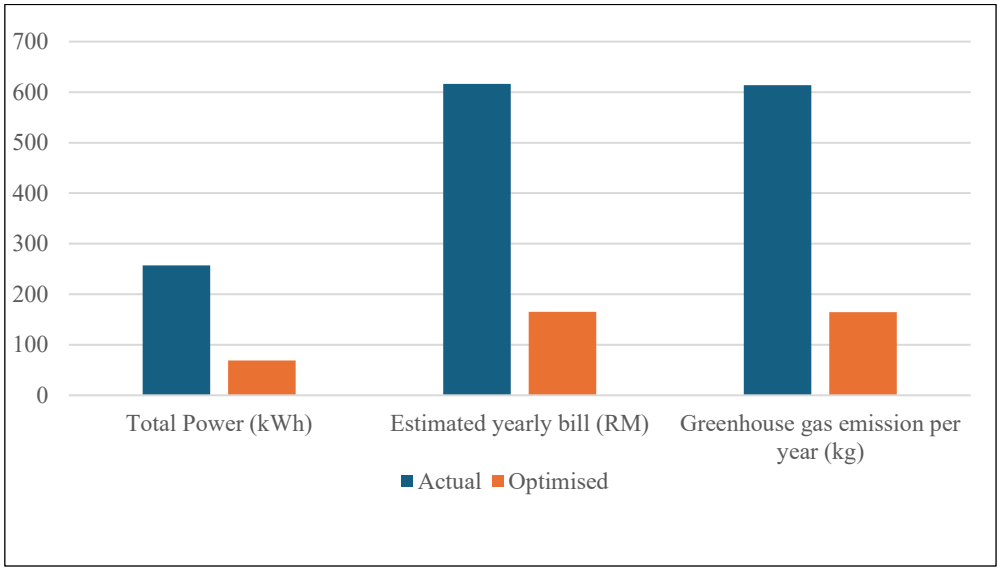


Figure 9. Actual and Optimised yearly energy consumption of PKKK Room

For Physics Laboratory, its location allows for sufficient natural lighting during the daytime, so artificial lighting can be reduced or switched off when adequate daylight is available, saving 115.2 kWh/year. Furthermore, ceiling fan quantity was reduced from 8 to 6 units since the laboratory is not fully occupied. The 200W refrigerator was replaced with an 85W energy-efficient model, reducing continuous load from 1785.6 kWh/year to 758.28 kWh/year, a savings of 1027.32 kWh annually. Lastly, laptop operating hours decreased from 4 to 3 hours daily (21.6 kWh/year saved), while charger usage was reduced from 3 to 2 hours daily (14.4 kWh/year saved) by disconnecting them once fully charged to prevent unnecessary energy consumption from continuous power draw.

Table 9, **Table 10** and **Figure 10** quantify the Physics Laboratory optimization outcomes. Annual consumption decreases from 187.540 kWh to 80.530 kWh (again, likely monthly values), achieving a 57.06% reduction. The yearly electricity bill falls from RM 450.09 to RM 193.28, saving RM 256.81 monthly. Emissions drop from 447.836 kg to 192.310 kg CO_{2e}, avoiding 255.526 kg annually. The lower percentage reduction compared to BPKKK reflects the Physics Laboratory's reliance on a continuously operating refrigerator, which limits optimization potential unless equipment replacement occurs. Nevertheless, the refrigerator upgrade alone delivers 57.5% savings in that appliance's consumption, underscoring the importance of energy-efficient equipment selection for continuous-operation devices.

Table 9. Optimized electrical appliance characteristics and usage of Physics Laboratory

Electrical Appliances	Quantity	Power Rating (W)	Operating hours (h)	Days of usage per month
Ceiling Fan	6	51	2	16
Fluorescent lamp	8	30	-	-
Refrigerator	1	85	24	31
Laptop	1	45	3	20
Charger (inkax)	1	240	2	20

Table 10. Actual and optimized data of Physics Laboratory

	Actual	Optimized
Total Power (kWh)	187.540	80.530
Estimated yearly bill (RM)	450.09	193.28
Greenhouse gas emission per year (kg)	447.836	192.310

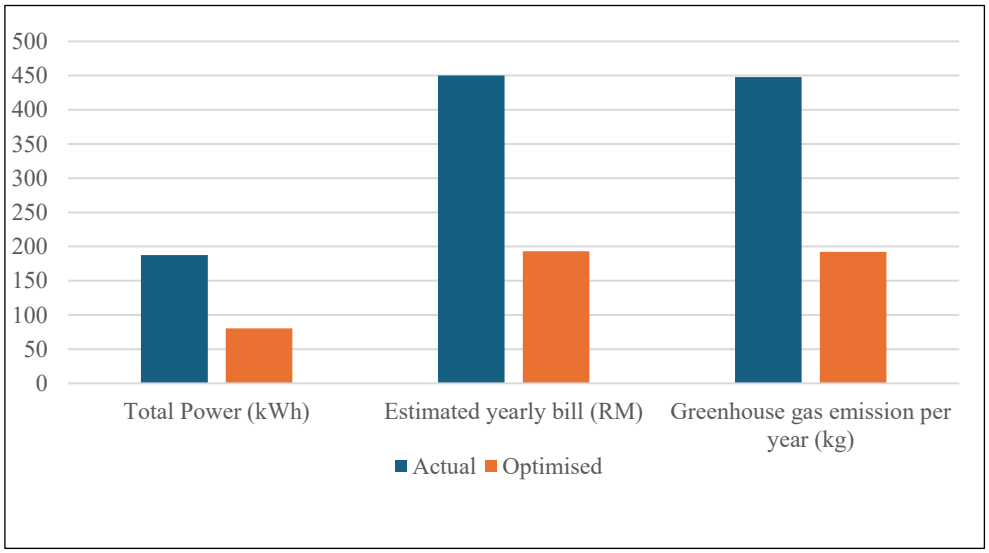


Figure 10. Actual and optimized yearly energy consumption of Physics Laboratory

4. Conclusion

This study successfully achieved all the stated objectives through a comprehensive energy audit of Keruntum Block at SMK Engkilili. The equipment inventory identified and recorded 10 types of equipment across 8 classrooms, 1 science laboratory, and 4 other rooms, with fluorescent lights with 45.95% and ceiling fans with 38.74% being the highest number of appliances. After calculating electricity consumption and CO_2 emissions using collected data, it was revealed that the ground floor contributed the highest energy usage at 51.12% of total energy, with the BPKKK Room recording the highest annual consumption at 3007.92 kWh and CO_2 emissions of 598.57 kg per year. The study also proposed and evaluated feasible energy-saving strategies. In term of consumption reduction measures, particularly in the BPKKK Room and Physics Laboratory, both rooms demonstrated significant reductions of up to 73.69% and 57.06% in energy consumption, respectively, along with substantial decreases in electricity costs and greenhouse gas emissions. Overall, the findings highlight that targeted operational improvements and efficient equipment usage can effectively enhance energy efficiency and reduce environmental impact in educational buildings.

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Electrical Energy Audit and Consumption Improvement at Non-Educational Building at SMK Engkilili Sri Aman Sarawak

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Abstract

Energy consumption in non-educational school facilities represents a significant operational and environmental concern that requires systematic investigation and intervention. This study conducted a comprehensive electrical energy audit of the dining hall, kitchen, and prayer room (surau) at SMK Engkilili in Sri Aman, Sarawak, Malaysia, to evaluate actual electricity consumption, identify major energy consumers, and propose practical energy-saving measures. Data was collected through direct site observation, recording the power ratings and daily operating hours of all appliances across the three facilities. The electricity consumptions were calculated by using standard energy equations, and CO_2 emissions were estimated using Malaysia's grid emission factor. The results show that the kitchen recorded the highest annual electricity consumption at 50,477.76 kWh/year, followed by the dining hall at 23,671.21 kWh/year and the surau at 5,901.98 kWh/year and the electricity consumption total of 80,050.95 kWh/year. The kitchen's had high consumption were attributed to the continuous 24-hour operation of refrigeration equipment. Following the proposed optimisation measures, including revised operating schedules and improved appliance management total annual consumption decreased to 40,137.83 kWh/year, representing an overall reduction of approximately 50%. Correspondingly, annual GHG emissions decreased across all facilities, with the dining hall reducing from 17,753.40 kg CO_2/year to 11,140.20 kg CO_2/year, the kitchen from 17,122.32 kg CO_2/year to 15,101.55 kg CO_2/year, and the surau from 4,426.48 kg CO_2/year to 2,867.00 kg CO_2/year. The findings demonstrate that systematic energy auditing and operational optimisation can significantly reduce electricity consumption, lower utility costs, and decrease carbon emissions in non-educational school facilities.

Keywords: *Energy audit, electricity consumption, energy efficiency, greenhouse gas emissions*

1. Introduction

Energy Audit is a crucial tool for both large organisations and smaller institutions, including school as it helps in understanding the current energy usage, identify the area of wastage and propose the strategies to reduce overall cost [1]. Electrical consumption in school contributes significantly to operational cost and environmental impact, particularly in high-usage areas such as dining hall, kitchens, and prayer halls (Surau). An energy audit is systematic process that identified the amount of energy consumed, the sources of wastage and the potential strategy for energy savings [2]. This area typically operated multiple electrical appliances for long durations, increasing the risk of energy wastage if usage was not monitored and optimised. Previous studies in Energy and Building [3], indicates that area such as kitchen and food preparation facilities typically consume excessive amounts of electricity due to heating elements and refrigeration systems. Non educational spaces such as dining hall and prayers room may also have same experience usage due to lighting and cooling systems operating. In this study, evaluate the electricity usage at SMK Engkilili was assessed through an energy audit. It is

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necessary to be able to know the status at which location that has been operates energy wise. A walk through evaluates the electricity was conducted in order to survey the critical point that could be seen directly upon inspection. Improving energy efficiency was widely recognised as one of the most cost – effective strategies to mitigate climate change, as it reduces the dependence on fossil fuels – based electricity generation and lower greenhouse gas emissions. Efficiency reduces electricity demand and energy losses, contributing to direct energy bill saving while energy efficient buildings can also lower the maintenance costs over time [4].

Electricity was used daily in non-educational buildings at SMK Engkilili, particularly in the dining hall, kitchen, and prayer room (surau), which were essential facilities for school operations. These areas operated various electrical appliances such as fluorescent lights, wall fans, projectors, refrigerators, freezers, air-conditioning units, and cooking equipment. The kitchen provided meal services to students and staff, and it required continuous cooling to maintain food safety. The prayer room (surau) operated air-conditioning systems and lighting to provide a comfortable environment for students and staff during prayer activities. Due to the frequent and prolonged use of these appliances throughout the school day, electricity consumption in these facilities contributed significantly to the overall operational energy demand of the school. Moreover, actual energy consumption in these facilities was not systematically monitored or recorded. Without proper monitoring, the school lacked baseline data to understand usage patterns or identify which appliances consumed the most electricity. Several equipment operated longer than necessary due to the absence of fixed schedules or lack of awareness regarding energy-efficient practices, resulting in unnecessary energy wastage. High electricity usage increased operational costs and placed financial pressure on limited resources. In addition, excessive energy consumption contributed to higher greenhouse gas emissions and environmental impacts. Therefore, a systematic energy audit was conducted to evaluate actual electricity usage, identify inefficiencies, and recommend practical energy-saving measures to improve energy management and reduce costs. The aim of this study was to evaluate electricity usage in the non-educational buildings—specifically the dining hall, kitchen, and prayer room (surau)—at SMK Engkilili through an energy audit. The objectives of this study were to (i) analyse electricity consumption (kWh) of electrical appliances, (ii) calculate electricity usage and associated greenhouse gas emissions, and (iii) evaluate electricity usage and recommend energy-saving measures to improve energy efficiency. The scope of this study focused on electricity usage in three areas: the dining hall, kitchen, and prayer room (surau). These facilities were chosen because they operated numerous electrical appliances daily. This included identifying the electrical appliances such as lights, fans, refrigerators, and kitchen equipment. Information such as power ratings and operating times was recorded to calculate daily and monthly electricity consumption. The study also estimated carbon emissions and proposed energy-saving actions.

2. Methodology

This study evaluated electricity usage in the surau, dining hall, and kitchen of SMK Engkilili. **Figure 1** showed that the study comprised three stages: (i) Stage 1: Identification of electrical appliances, (ii) Stage 2: Electricity consumption and cost analysis, and (iii) Stage 3: Evaluation of energy usage patterns and energy-saving strategies.

2.1 Identification of Electrical Appliances

A site observation was conducted to identify and record all electrical appliances operating in three non-educational facilities: the surau, dining hall, and kitchen. The audit determined the types and quantities of equipment, their operating hours, and relevant electrical specifications. The equipment was divided into eleven categories: fluorescent lights, ceiling fans, stand fans, wall fans, air-conditioning units, freezers, refrigerators, blenders, printers, projectors, and vacuum pumps. Relevant information, including appliance type and power rating, was obtained through direct visual inspection and verification of equipment labels.

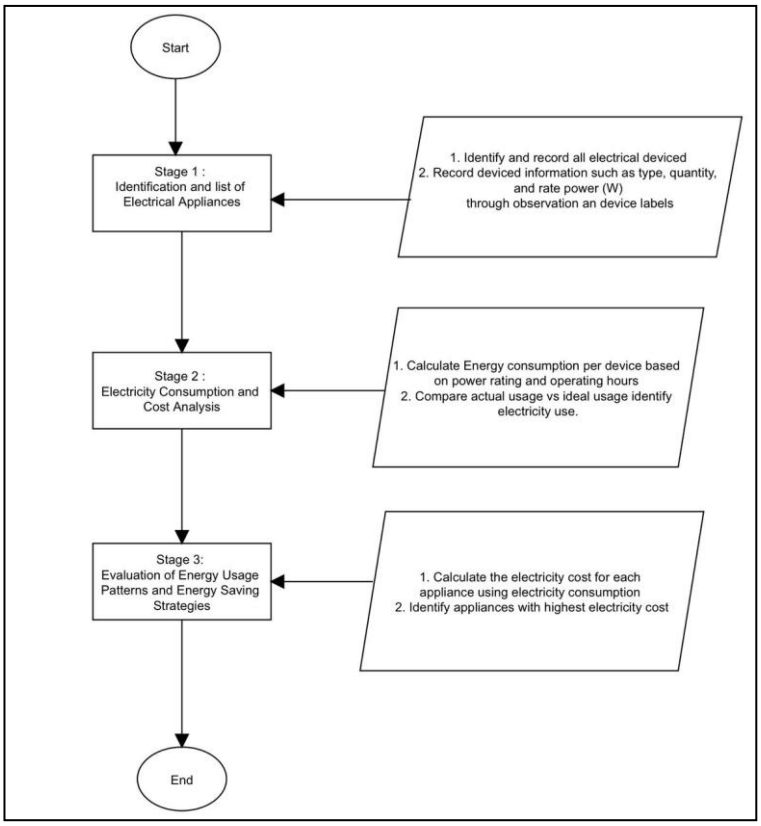


Figure 1: Process flow of methodology

2.2 Electricity Consumption and Greenhouse Gas Emissions Analysis

The data collected from site observation to determine the electricity consumption of each electrical appliance, and the overall energy usage at surau, dining hall, and kitchen. All calculations are perform using Microsoft Excel spreadsheet software to ensure accuracy, consistency, and ease of comparison between actual and optimized energy consumption scenarios. The daily energy consumption for each appliance was calculated using **Equation 1** [5].

$$E_{daily} = \frac{P \times t \times n}{1000} \quad (1)$$

Where, E_{daily} is the daily energy consumption (kWh/day), P is the rated power of the appliance (W), t is equal to operating hours per day (h/day), and n is the number of appliances. The monthly energy consumption was determined by using **Equation 2** [5].

$$E_{monthly} = E_{daily} \times D \quad (2)$$

Where, D in this equation represents days of usage per month. Using the monthly energy consumption, $E_{monthly}$, the monthly electricity cost was estimated by multiplying $E_{monthly}$ with Malaysia's electricity tariff rate (RM/kWh). On the other hand, yearly energy consumption was then calculated as **Equation 3** [6].

$$E_{yearly,\ actual} = E_{monthly} \times 12 \quad (3)$$

This value represents the baseline annual electricity usage of each appliance and the total building consumption. The annual carbon dioxide emissions associated with energy consumption was calculated as **Equation 4**.

$$CO_2\ emission\ (kg) = Energy\ (kWh) \times Emission\ Factor \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

2.3 Optimisation of Energy Consumption

The optimisation stage was conducted to evaluate the potential reductions in electricity consumption, operational cost, and carbon dioxide (CO_2) emission through improved appliances management and scheduling. The electricity cost was calculated by multiplying the total energy consumption (kWh) with electricity tariff rate provided by Sarawak Energy then calculated as **Equation 5** [6].

$$Cost\ (RM) = Energy\ (kWh) \times Tariff(RM/kWh) \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

The reduction in energy consumption directly conduct to the reduction in electricity cost due to the kWh consumption and billing charges. The reduction in energy consumption was calculated by deducting the optimised consumption from the actual consumption, while the efficiency improvement was evaluated through percentage reduction analysis.

3. Result and Discussion

The result and discussion was divided to several part which are (i) Facility Specific Electrical Usage Analysis, which presents an inventory of electrical appliances and their distribution across facilities, (ii) Overall Actual Electricity Usage, which analyses current electricity consumption, estimated costs, and greenhouse gas emissions, (iii) Overall Optimised Electricity Usage, which presents the projected energy consumption after implementing proposed energy-saving measures.

3.1 Facility Specific Electrical Usage Analysis

According to **Table 1**, the surau was equipped with 7 units of fluorescent lamps, 4 units of ceiling fans, 3 units of air-conditioning, and various other appliances, including standing fans, printers, projectors, and vacuum cleaner. The dining hall contained the highest number of fluorescent lamps, totalling up to 25 units, along with 11 units of ceiling fans and 12 units of wall fans. The kitchen included 13 units of fluorescent lamps, 5 units of freezers, and 2 units of refrigerators, reflecting the equipment required for food preparation and storage. This inventory provided essential baseline data for understanding facility-specific energy consumption patterns and for identifying opportunities for optimization.

3.1.1 Surau Electricity Consumption

Table 2 showed the electricity consumption analysis for the surau, including the power ratings of all installed equipment, their daily operating durations, monthly usage patterns, and calculated energy consumption in kilowatt-hours (kWh). This data enables identification of the major energy consumers and their contribution to the facility's total electricity demand. the surau contains 21 units of electrical appliances distributed across lighting, ventilation, cooling, and office equipment categories. The analysis reveals that different appliances operate for varying durations throughout the day, reflecting the facility's operational schedule aligned with prayer times and religious activities.

3.1.2 Dining Hall Electricity Consumption

Table 3 showed the number of electrical appliances in the selected facilities in SMK Engkilili. The dining hall operates with the highest number of electrical appliances among the selected facilities with 49 units focused primarily on lighting, ventilation, and projector. The operating durations show that lighting operates during mealtimes while fans operate continuously during service hours to maintain ventilation and comfort during lunch meal. This consumption pattern indicates opportunities for optimization through scheduling and equipment efficiency improvements.

Table 1: Number of electrical appliances at selected facilities in SMK Engkilili

Appliances	School Facilities		
	Surau	Dining hall	Kitchen
Fluorescent Lamp	7	25	13
Ceiling Fan	4	11	0
Stand Fan	2	0	2
Wall fan	1	12	1
Air conditioning	3	0	1
Printer	2	0	0
Projector	1	1	0
Vacuum	1	0	0
Blender	0	0	1
Freezer	0	0	5
Refrigerator	0	0	2
Total	**21**	**49**	**25**

Table 2: Surau Electricity Consumption

Electrical Appliances	Unit	Power input per unit	Duration usage per day (hour)	Duration usage per month	Total unit power per day (kWh)	Monthly estimated power unit (kWh)	Yearly estimated power unit (kWh)
Fluorescent Lamp	7	200	4	24	5.6	134.4	1612.8
Ceiling Fan	4	200	4	24	3.2	76.8	921.6
Wall fan	1	30	3	24	0.09	2.16	25.92
Printer	2	30	2	15	0.12	1.80	21.6
Air conditioning	3	899	3	24	10.78	258.912	3106.94
Projector	1	200	1	10	0.4	3.20	38.4
Total	**21**		**21**		**20.80**	**491.83**	**5,901.98**

Table 3: Dining Hall Electricity Consumption

Electrical Appliances	Unit	Power input per unit	Duration usage per day (hour)	Duration usage per month	Total unit power per day (kWh)	Monthly estimated power unit (kWh)	Yearly estimated power unit (kWh)
Fluorescent Lamp	25	200	7	30	35	1050	12600
Ceiling Fan	11	200	12	30	26.4	792	9504
Wall fan	12	30	12	30	4.32	129.6	1555.2
Projector	1	200	2	5	0.2	1	12
Total	**49**				**65.92**	**1,972.60**	**23,671.21**

3.1.3 Kitchen Electricity Consumption

Table 4 represented the electricity consumption analysis for the kitchen with the electrical appliances all equipment, their power ratings, operating hours, and calculated energy consumption. The kitchen equipment operates on different schedules, which is some equipment (refrigeration) operates 24 hours daily for food safety, while cooking equipment operates only during meal preparation times. The kitchen contains 25 units of electrical appliances with complex operational patterns reflecting food preparation requirements. The high-power ratings of freezers and refrigerators 800W and 500W combined with 24-hour operating schedules result in substantial annual energy consumption. Understanding the specific consumption patterns of kitchen equipment is critical for developing practical energy-saving recommendations that maintain food safety and operational functionality while reducing electricity usage.

Table 4: Kitchen Electricity Consumption

Electrical Appliances	Unit	Power input per unit	Duration usage per day (hour)	Duration usage per month	Total unit power per day (kWh)	Monthly estimated power unit (kWh)	Yearly estimated power unit (kWh)
Fluorescent Lamp	13	200	6	30	15.6	468	5616
Stand Fan	2	55	6	30	0.66	19.8	237.6
Wall fan	1	30	6	30	0.18	5.4	64.8
Blender	1	60	3	30	0.18	5.4	64.8
Freezer	5	800	24	30	96	2880	34560
Refrigerator	2	500	24	30	24	720	8640
Air-Conditioning	1	899	4	30	3.596	107.88	1294.56
Total	**25**				**63.42**	**1,902.48**	**22,829.76**

3.2 Facility Specific Gas Emission of CO_2

The electricity consumption analysis gas emissions associated with energy consumption were calculated to assess the environmental impact of each facility's operations. The following sections present detailed CO_2 emissions analysis for each facility, showing the daily, monthly, and annual greenhouse gas emissions generated by their electricity consumption.

3.2.1 Surau CO_2 Emission Analysis

Table 5 showed the detailed CO_2 emissions analysis for the surau, the surau generates about 4,426.48 kg of CO_2 emissions annually from its electricity consumption. The analysis shows that the air conditioning system is the largest contributor to emissions due to its high-power consumption (3,106.94 kWh annually), followed by fluorescent lighting systems. This emission profile highlights the environmental impact of the facility's energy use and identifies the priority equipment for emission reduction efforts through operational optimization and equipment efficiency improvements.

Table 5: Surau CO_2 Emission Analysis

Electrical Appliances	Unit	Power input per unit	Duration usage per day (hour)	Duration usage per month	Emission of CO_2 per day (kg CO_2)	Emission of CO_2 per month (kg CO_2)	Emission of CO_2 per year (kg CO_2)
Fluorescent Lamp	7	200	4	24	4.20	100.80	1209.60
Stand Fan	2	55	4	24	0.33	7.92	95.04
Wall fan	1	30	3	24	0.06	1.62	19.44
Printer	2	30	2	15	0.09	1.35	16.20
Ceiling Fan	4	200	4	24	2.40	57.60	691.20
Projector	1	200	2	10	0.30	3.00	36.00
Air conditioning	3	899	4	24	8.09	194.18	2330.20
Vacuum	1	80	2	10	0.12	2.40	28.80
Total	**21**		**21**		**15.59**	**368.87**	**4,426.48**

3.2.2 Dining Hall CO_2 Emission Analysis

Table 6 presented the detailed CO_2 emissions analysis for the dining hall, showing how the facility's energy consumption translates into environmental impact through carbon dioxide emissions. The larger quantity of appliances and higher overall electricity demand result in higher annual emissions. The dining hall generates about 17,753.4 kg of CO_2 emissions annually, which is four times higher than the surau despite both facilities serving non-educational functions. The analysis reveals that fluorescent lighting is the largest single contributor of emissions at 9,450 kg CO_2 per year, followed by ceiling fans at 7,128 kg CO_2 annually. These emission profiles demonstrate that lighting optimization represents the

most significant opportunity for reducing the dining hall's environmental footprint while maintaining operational functionality.

Table 6: Dining Hall CO_2 Emission Analysis

Electrical Appliances	Unit	Power input per unit	Duration usage per day (hour)	Duration usage per month	Emission of CO_2 per day (kg CO_2)	Emission of CO_2 per month (kg CO_2)	Emission of CO_2 per year (kg CO_2)
Fluorescent Lamp	25	200	7	30	26.25	787.5	9450
Ceiling Fan	11	200	12	30	19.8	594	7128
Wall fan	12	30	12	30	3.24	97.2	1166.40
Projector	1	200	2	5	0.15	0.75	9
Total	**49**				**49.44**	**1,749.45**	**17,753.4**

3.2.3 Kitchen CO_2 Emission Analysis

Table 7 show that the detailed CO_2 emissions analysis for the kitchen. The continuous operation of refrigeration equipment combined with high-power cooking equipment results in the largest environmental impact. The kitchen generates about 17,122.32 kg of CO_2 emissions annually from its electricity consumption. The refrigeration systems freezer and refrigerator together for 32,000 kg of potential emissions though operating at lower than 100% capacity and it represent the single largest source of emissions when combined. Fluorescent lighting contributes 4,212 kg CO_2 annually. The emission profile clearly indicates that refrigeration system optimization through proper maintenance, followed by LED lighting upgrades and cooking equipment scheduling, represents the most effective pathway for reducing the kitchen's environmental impact.

Table 7: Kitchen CO_2 Emission Analysis

Electrical Appliances	Unit	Power input per unit	Duration usage per day (hour)	Duration usage per month	Emission of CO_2 per day (kg CO_2)	Emission of CO_2 per month (kg CO_2)	Emission of CO_2 per year (kg CO_2)
Fluorescent Lamp	13	200	6	30	11.7	351	4212
Stand Fan	2	55	6	30	0.49	14.85	178.2
Wall fan	1	30	6	30	0.135	4.05	48.6
Blender	1	60	3	30	0.153	4.05	48.6
Freezer	5	800	24	30	72	2160	25920
Refrigerator	2	500	24	30	18	540	6480
Air-Conditioning	1	899	4	30	2.697	80.91	970.92
Total	**25**				**105.157**	**3,154.86**	**17,122.32**

3.3 Electricity Consumption and Emission Reduction Analysis

The electricity consumption and emission reduction analysis was conducted in three separate terms which are (I) electricity consumption (ii) electricity cost and (iii) greenhouse gas emission. **Figure 2** shows the bar chart comparison between the actual and the optimised yearly consumption for the surau, dining hall, and kitchen. The kitchen recorded the highest electricity consumption at actual condition at 50,477.76 kWh/year, followed by dining hall 23,671.21 kWh/year, and the surau at 5,901.98 kWh/year. This show that the kitchen is the most energy consumption in these three facilities. The high energy consumption in the kitchen is due to continuous operation of refrigeration and cooking equipment, which are known to contribute significantly to energy usage in commercial food preparation areas [7].

The reduction can be observed in the kitchen by appliances such as refrigerators, freezers, wall fan, stand fan, blender, and air-conditioning which is operate daily and often continuously. Refrigeration systems alone are known to account for a major portion of electricity consumption in food preparation facilities due to continuous compressor operation [8]. According to Thumann and Younger (2016) [9] that kitchens mostly represent the highest energy consumption in schools because of cooking equipment

and heat-producing devices. After optimisation, a reduction in electricity consumption can be observed and it show in the kitchen where usage decreased to 20,135.40 kWh/year. The dining hall also showed a reduction to 14,853.60 kWh/year, while the surau decreased slightly to 5,148.83 kWh/year. The greater reduction in the kitchen show that energy-saving measures such as reducing operating hours and improving equipment scheduling.

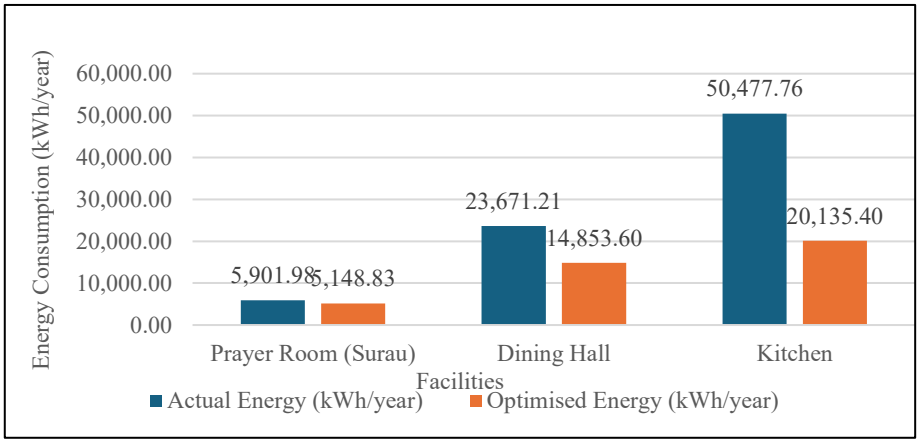


Figure 2: Yearly Energy Consumption (kWh/year)

Figure 3 show that the comparison between the actual and optimized estimated annual electricity costs for each facility. The dining hall recorded the highest annual cost at RM 4,734.24 followed by the kitchen which is at RM 4,565.95 while the surau had the lowest cost at RM 1,180.39. The dining hall cost decreased slightly to RM 2,970.72 per year while the kitchen reduced at RM 4,027.08. The dining hall cost decreased significantly to RM 2,970.72 per year, while the kitchen reduced to RM 4,027.08. The surau also experienced a reduction to RM 1,029.76 annually. These reductions highlight the financial benefits of implementing energy-efficient practices. According to the U.S. Department of Energy (2011) [10], operational control strategies such as load scheduling, preventive maintenance, and behavioural changes can reduce institutional electricity costs by 10–30% without requiring major capital investment. This suggests that even simple management improvements can generate measurable economic savings. From a financial sustainability perspective, reducing electricity costs is highly beneficial for educational institutions with limited operational budgets. According to Saidpur et al. (2009) [11], energy efficiency initiatives in public buildings not only reduce utility expenses but also improve long-term cost stability. For SMK Engkilili Sri Aman, the observed cost savings can be redirected toward improving educational facilities, maintenance, or student development programs. Therefore, energy management should be viewed not only as a technical strategy but also as a financial planning tool.

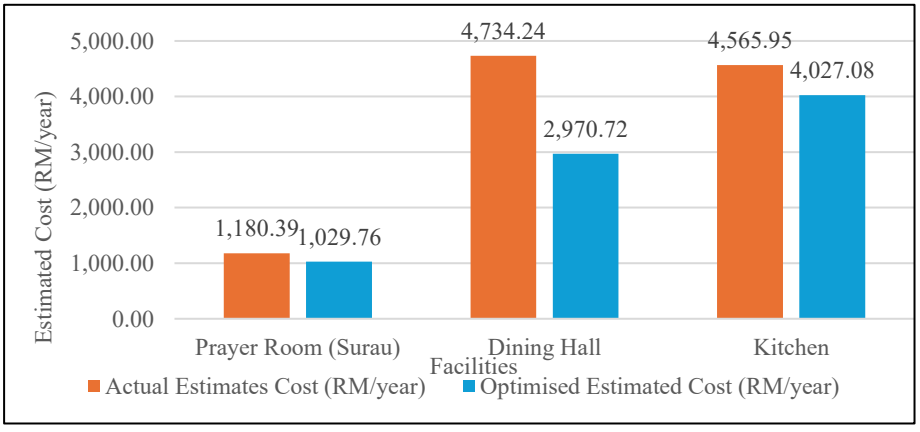


Figure 3: Overall Estimated Cost

The **Figure 4** show that the comparison of annual greenhouse gas (GHG) emissions generated from electricity consumption in the three facilities. The dining hall recorded the highest emissions at 17,753.40 kg CO_2/year, followed by the kitchen at 17,122.32 kg CO_2/year, while the surau show the lowest emissions at 4,426.48 kg CO_2/year. These values are directly proportional to electricity consumption. The higher kWh usage results in higher carbon dioxide emissions. After optimisation, emissions were reduced in all facilities. The dining hall emissions decreased to 11,140.20 kg CO_2/year, the kitchen reduced to 15,101.55 kg CO_2/year, and the surau decreased to 2,867.00 kg CO_2/year. This demonstrates that improving energy efficiency has both economic and environmental benefits. Since Malaysia's electricity generation mix still relies heavily on fossil fuels such as coal and natural gas, reducing electricity demand directly lowers CO_2 emissions [11].

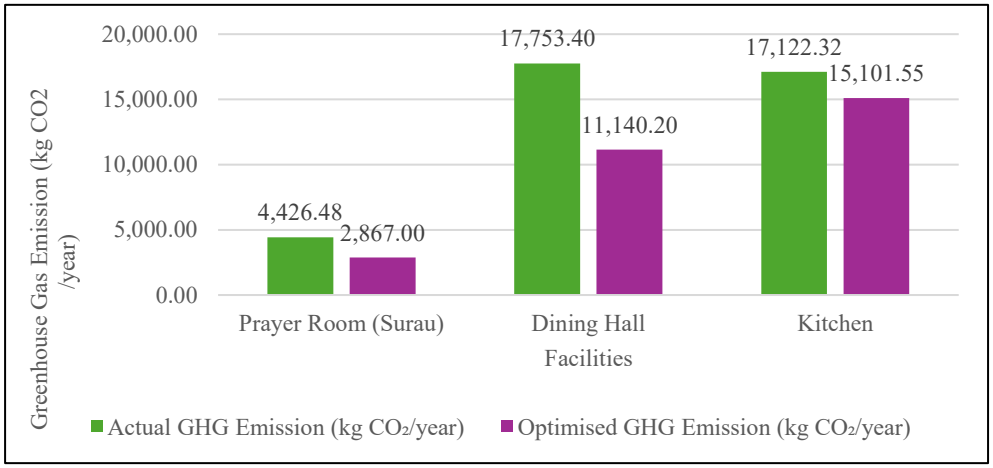


Figure 4: Greenhouse Gases Emission

The **Figure 5** below show the overall analysis of electricity consumption at SMK Engkilili Sri Aman shows a significant reduction after optimization at the surau, dining hall, and kitchen. The total annual electricity consumption decreased from 80,050.95 kWh/year to 40,137.83 kWh/year, for the three facilities, the kitchen was recorded the highest percentage reduction, which is at 60.1%, followed by the dining hall at 37.3%, and the surau at 12.8%. The result show that reduction in the kitchen was high-load areas and it have more potential for energy savings when proper appliance scheduling, operational control, and efficiency improvements are applied. This finding is consistent with previous studies which indicate that systematic energy audits and operational optimisation in non- educational buildings can reduce electricity consumption by 20–50% [8]. Therefore, the results confirm that energy management strategies are effective in significantly lowering overall electricity demand and improving building energy performance. [1].

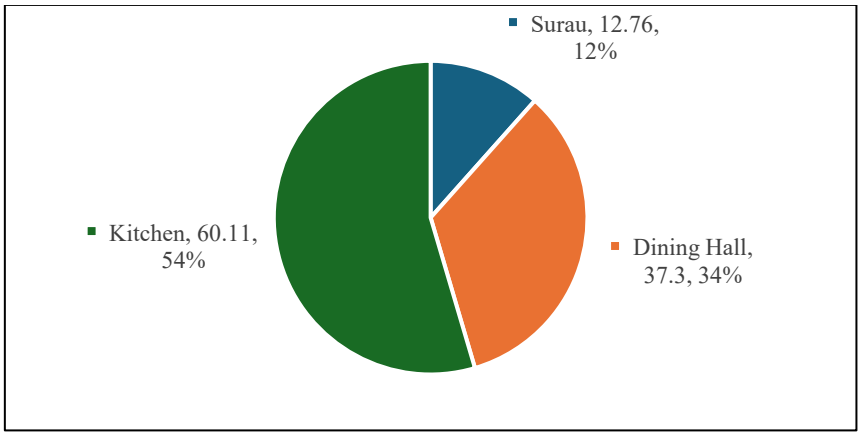


Figure 5: Overall Energy and greenhouse gas Reduction

4. Conclusion

This study conducted an electrical energy audit at non-educational building of SMK Engkilili focusing on the prayer room (surau), dining hall, and kitchen. The findings show that the kitchen was the highest energy consumer other than the dining hall and surau. The high consumption in the kitchen was due to the continuous operation of high-power appliances such as refrigerators, freezers, fluorescent light and fan due to food safety and preparation meal. After optimisation measures such as reducing operating hours and improving appliance schedule, the total annual electricity consumption decreased from 80,050.95 kWh/year to 40,137.83 kWh/year and the result for overall reduction of approximately 50%. This demonstrates that proper energy management strategies can significantly improve electricity efficiency in non-educational buildings. In addition, to reduce the electricity consumption the optimisation measures also include to lower annual electricity costs and reduced greenhouse gas (GHG) emissions. Since electricity generation in Malaysia still depends on fossil fuels, reducing electricity usage directly decreases carbon dioxide emissions and supports environmental sustainability [12]. The results of this study are consistent with previous research which states that systematic energy audits and behavioural improvements can effectively reduce energy consumption in public and non- educational facilities [8]. Therefore, energy efficiency initiatives should be continuously implemented and monitored to maintain long-term savings.

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Energy Assessment of Auxiliaries Educational Facilities at SMK Engkilili, Sri Aman, Sarawak.

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Abstract

The operational cost of energy consumption in educational buildings is a developing issue because based on the greenhouse gas emission rate, but the secondary schools in semi-rural areas are still underrepresented in the literature on energy assessment. This study is a systematic energy analysis of auxiliary electrical systems at the Ramin and Teratai blocks of SMK Engkilili, Sri Aman, Sarawak with the intention of analysing the electricity consumption and recommending any practical energy saving strategies that can suit a secondary school setting. Correspondingly, the study involved conducting the research in three phases, which included identification and recording of electrical appliances (rated power, quantity, and operating duration), calculation of the daily, monthly, and annual consumption of electricity, as well as estimation of the greenhouse gas emissions associated with the use of electrical appliances and appraisal of optimisation strategies that included consideration of low-cost behavioural and operational improvements. Subsequent, this study reports that the most important component of electricity loads in the two blocks are lighting systems, ventilation, and air-conditioning units, with operational patterns playing a significant role on the overall energy demand. The measured consumption records also prove that normal school operations also produce quantifiable carbon emissions, which confirms the applicability of energy management in secondary schools. As the optimisation analysis suggests, the potential to limit the electricity consumption without significant capitals is possible through structured monitoring and behavioural interventions. Overall, this paper provides location-specific baseline information of a Malaysian semi-rural secondary school and forms a reproducible template of energy auditing in other schools.

Keywords: *School, identification, calculation, electricity consumption, greenhouse gas emission*

1. Introduction

Educational buildings in the public sector are recognised as significant consumers of electricity due to the continuous operation of auxiliary systems such as lighting, ventilation, air-conditioning, and office or ICT equipment. These systems are essential for supporting teaching and administrative activities, particularly in secondary schools where classrooms, laboratories, and offices operate daily. Previous studies have shown that auxiliary electrical systems account for a large proportion of energy consumption in institutional buildings, especially in tropical climates where cooling demand is high [1], [8]. In Malaysia, energy efficiency initiatives have been promoted to reduce electricity use in public facilities. However, the effectiveness of such initiatives depends on accurate baseline consumption data and systematic monitoring [3], [7].

Despite the growing emphasis on energy efficiency, limited research has focused specifically on electricity consumption patterns in Malaysian secondary schools, particularly those located in semi-rural areas. Most literature concentrates on commercial buildings or tertiary institutions, leaving secondary schools underrepresented in energy benchmarking studies [3], [10]. In many schools, detailed

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documentation of appliance types, rated power, and operating duration is lacking, which restricts accurate assessment of electricity use and identification of inefficiencies. Furthermore, without quantifying associated greenhouse gas emissions, school administrators may underestimate the environmental impact of daily electricity consumption. Given Malaysia's carbon-intensive electricity grid, such gaps hinder effective sustainability planning and emission reduction efforts [1], [9]. As such, this study aims to investigate electricity consumption and greenhouse gas emissions in the Ramin–Teratai Block of Sekolah Menengah Kebangsaan Engkilili, Sri Aman, Sarawak. The objectives of this research are(i) to identify and record electrical appliances used in the Ramin–Teratai Block, including their rated power and operating duration, (ii) to calculate electricity consumption and estimate associated greenhouse gas emissions based on recorded usage data, (iii) to evaluate current practices and recommend feasible, low-cost energy-saving strategies suitable for a secondary school environment.

The scope of this study is limited to the evaluation of electricity consumption related to auxiliary electrical systems within the Ramin–Teratai Block of SMK Engkilili. The assessment includes documentation of appliance type, quantity, rated power, and estimated operating duration, followed by calculation of electricity use and greenhouse gas emissions using appropriate Malaysian grid emission factors. The study focuses solely on electricity-based consumption and excludes other energy sources such as fuel or renewable systems. In line with energy audit frameworks for institutional buildings [6], [8], the proposed optimisation measures are restricted to behavioural improvements and minor operational adjustments that are practical within the school context, without involving major infrastructure modifications.

2. Methodology

The methodology for this research is based on the objectives. According to **Figure 1**, the structural workflow was illustrated as to separate the 3 objectives. The methodology compiled the data based on the identification of the electrical appliances, the calculation for energy consumption and greenhouse gas emissions and the reduction of energy consumption in retention with the greenhouse gas emission reduction.

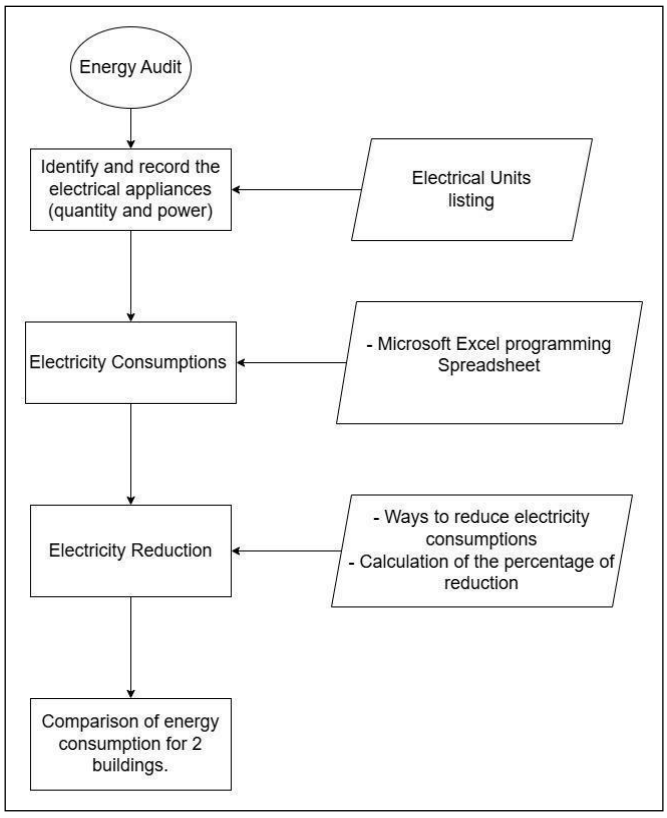


Figure 1. Energy audit methodology workflow.

In the first phase, all electrical appliances within the Ramin and Teratai blocks were physically identified and recorded. The recorded parameters included the number of units installed, rated power input per unit (W), estimated operating duration per day (hours), and number of operating days per month. The monthly electricity consumption for each appliance category was calculated using **Equation 1** below. This equation is commonly applied in building energy auditing and appliance-level consumption analysis [6], [8].

$$E = \frac{X \times Ei \times t}{1000} \times d \qquad \text{.....(1)}$$

Where, $E,$ is total energy consumption per month (kWh), X is unit, Ei is power input per unit (W), t is duration of usage per day (Hours) and d is days of usage per month (Day).The estimated monthly electricity bill was calculated using **Equation 2** below. For this study, the Sarawak commercial electricity tariff was taken as RM0.20/kWh [14]. This value was applied consistently across both blocks to enable comparative cost analysis.

$$B, month = E \times C1 \qquad \text{.....(2)}$$

Where, $B, month$ is estimated monthly bill, $E,$ is total energy consumption per month (kWh) and $C1$ is commercial electricity tariff. To evaluate potential reduction strategies, the operating duration of selected appliances particularly lighting and air-conditioning systems was reduced. The reduction in electricity consumption was determined using **Equation 3**.

$$\%\ of\ reduction = \frac{\alpha - \beta}{\alpha} \times 100\% \qquad \text{.....(3)}$$

Where, α is actual energy consumption per month (kWh) and β is reduced energy consumption per month (kWh). Greenhouse gas emissions associated with electricity consumption were estimated using **Equation 4**.

$$GHG = E, month \times GEF \qquad \text{.....(4)}$$

Where, GHG is greenhouse gas emission (kg CO2/kWh), $E,$ is total energy consumption per month (kWh) and GEF is grid emission factor for CO_2 (kg/kWh). A Sarawak grid emission factor of 0.75 kg CO_2/kWh was adopted in this study to reflect the carbon intensity of electricity generation [13]. This emission-factor-based estimation method is consistent with carbon accounting approaches recommended in building sector emission studies [1], [9].

3. Results and Discussion

In the analysis of the energy of Ramin-Teratai Block at SMK Engkilili, Sri Aman, Sarawak. SMK Engkilili is located at a rural area called Engkilili as shown in **Figure 2** below. It is possible to note that the use of electricity is mostly controlled by the lighting systems, ceiling fans and air-conditioning units, which are used all day long during the time of school. Lighting fixtures were also a substantial source of the daily consumption of electricity based on the inventory of appliances and the time it was operating, as it records a lot of hours of operation in the classroom and administrative areas. This has been also found in the literature in building energy studies where lighting constitutes a significant portion of load in learning institutions [1], [8].

3.1 Ramin-Teratai Block Actual Energy Consumption

The appliance-level energy assessment revealed a substantial variation in electricity consumption between the Ramin and Teratai blocks at SMK Engkilili, Sri Aman, Sarawak. **Table 1** presents the appliance-level calculation of monthly electricity consumption for the Ramin block using **Equation 1,** where energy consumption is determined from the number of units, rated power, daily operating duration, and monthly operating days. For fluorescent lighting, 23 units rated at 36 W operate for 6 hours per day over 20 days per month in cumulative based on the 2026 school calendar [12]. Substituting these values into **Equation 1** results in 99.36 kWh per month. Although each unit has relatively low

power input, the cumulative effect of multiple units and consistent usage produces a noticeable contribution to total consumption. This reflects the common characteristic of lighting systems in educational buildings, where distributed low-power loads collectively become significant. Ceiling fans, consisting of 17 units rated at 50 W operating 3 hours per day, contribute 51.00 kWh per month. Compared to lighting, fans operate fewer hours and therefore consume less energy. Similarly, wall fans (2 units at 54 W) contribute only 6.48 kWh monthly due to their limited quantity and operating hours. The split air-conditioning units show substantially higher energy consumption. Two units rated at 1119 W consume 268.56 kWh per month, while two units rated at 1864 W consume 447.36 kWh per month. Another single 1491 W unit contributes 178.92 kWh monthly. The high rated power combined with 6 operating hours daily explains their dominant contribution. This demonstrates the strong influence of cooling systems on electricity demand in tropical school environments.

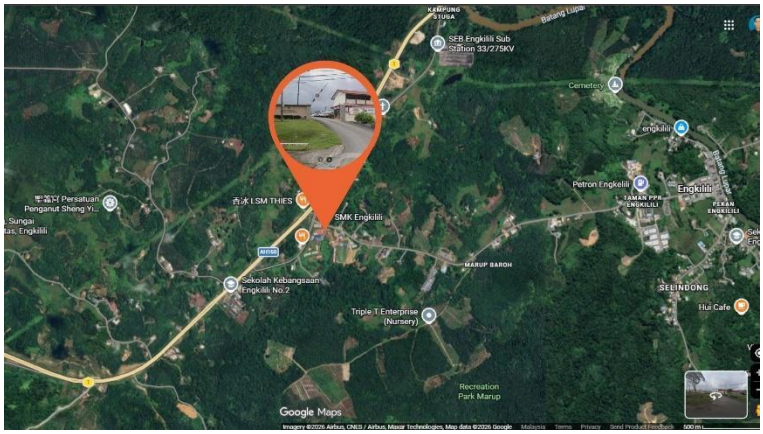


Figure 2. SMK Engkilili location [11].

Table 1. Ramin block list of electrical equipment and actual estimated energy usage.

Equipment	Unit, *X*	Power input per unit, *Ei* (W)	Duration of usage per day, *t* (Hours)	Days of usage per month, *d* (Days)	Monthly energy consumption, *E,month* (kWh)
Fluorescent Light	23	36	6	20	99.36
Ceiling Fan	17	50	3	20	51.00
Wall Fan	2	54	3	20	6.48
Split Air Conditioner	2	1119	6	20	268.56
Split Air Conditioner	2	1864	6	20	447.36
Split Air Conditioner	1	1491	6	20	178.92

Table 2 presents the same calculation approach applied to the Teratai block using **Equation 1**. However, the load composition differs significantly. Fluorescent lighting in this block consists of 120 units operating 6 hours daily, resulting in 518.4 kWh per month. The larger number of units explain the higher lighting consumption compared to the Ramin block. The most striking values in **Table 2** are the desktop computers and monitors. Each category includes 40 units rated at 2500 W operating 2 hours per day. Each contributes 4000 kWh per month. These ICT-related loads dominate the energy profile of the Teratai block. Even though their operating duration is shorter than lighting or air-conditioning, their extremely high rated power results in substantial energy use. The split air-conditioning units (rated between 2450 W and 2983 W) consume between 294 kWh and 357.96 kWh monthly per unit. Although fewer in number, their high rated power makes them significant contributors. **Table 3** summarises the total electrical units, total power input, monthly energy consumption, and estimated monthly bill for both blocks. The Ramin block contains 47 total electrical units with total power input of 4614 W, whereas the Teratai block contains 203 units with total power input of 13369 W. Using **Equation 2** with the tariff of RM0.20/kWh, the estimated monthly bills are RM210.34 for Ramin and RM1903.72 for Teratai. It demonstrates how increased equipment quantity and higher power ratings directly translate into higher operational costs. **Figure 3** visually compares total installed power between the two blocks.

The graphical representation highlights the substantial difference in total power input, with the Teratai block showing a significantly higher installed capacity. The figure reinforces the data in **Table 3** by illustrating that the higher total power rating in Teratai corresponds to its higher electricity consumption calculated through **Equation 1**.

Table 2. Teratai block list of electrical equipment and actual estimated energy usage.

Equipment	Unit, *X*	Power input per unit, *Ei* (W)	Duration of usage per day, *t* (Hours)	Days of usage per month, *d* (Days)	Monthly energy consumption, *E,month* (kWh)
Fluorescent Light	120	36	6	20	518.4
Desktop Computer	40	2500	2	20	4000
Monitor	40	2500	2	20	4000
Split Air Conditioner	1	2900	6	20	348
Split Air Conditioner	1	2450	6	20	294
Split Air Conditioner	1	2983	6	20	357.96

Table 3. Ramin-Teratai block overall actual energy consumption comparison.

Electrical Parameter	Ramin Block	Teratai Block
Total electrical unit, *Xt*	47	203
Total power input, *Ei,t* (W)	4614	13369
Total energy consumption per month, *E* (kWh)	1051.68	9518.36
Estimated monthly bill, *B,month*,(RM)	210.34	1903.72

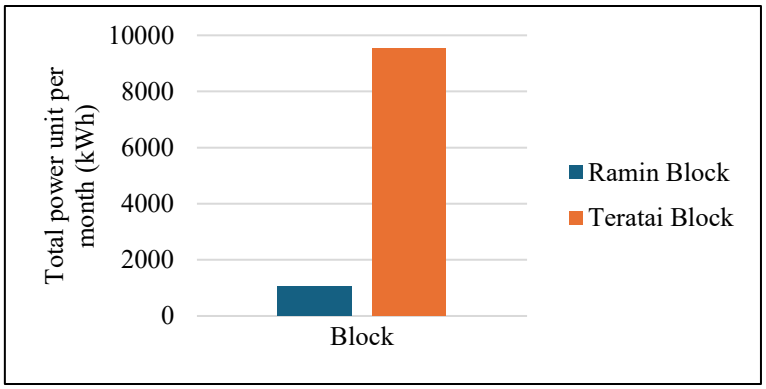


Figure 3. Overall comparison for actual total power unit in different blocks.

3.2 Ramin-Teratai Block Reduced Energy Consumption

After considering few factors, the energy consumption in Ramin-Teratai block was reduced especially at the part of the duration energy usage per day. The data was tabulated in **Table 4** and **Table 5** below which the durations of usage per day were changed. Energy consumption for the Ramin block after reducing operating hours for lighting and air-conditioning systems was tabulated in **Table 4**. Fluorescent lighting operation was reduced from 6 hours to 3 hours daily, lowering monthly consumption from 99.36 kWh to 49.68 kWh. This demonstrates the direct proportionality between operating duration and energy consumption in **Equation 1**. Air-conditioning units were reduced from 6 hours to 4 hours daily. For example, the 1864 W units decreased from 447.36 kWh to 298.24 kWh per month. This confirms that cooling systems are highly sensitive to operating time adjustments. Ceiling fans and wall fans remained unchanged and the energy values remain constant.

Table 5 shows reduced operating durations primarily for lighting and air-conditioning in Teratai. Fluorescent lighting consumption decreased from 518.4 kWh to 345.6 kWh due to reduced daily operation from 6 hours to 4 hours. Air-conditioning units also show reduced consumption proportional

to their shortened operating time. However, desktop computers and monitors remain unchanged at 4000 kWh each. This explains why overall reduction in Teratai is less significant than in Ramin. **Table 6** compares total consumption after optimisation. B using **Equation 3**, the energy difference reflects the impact of behavioural changes. The Ramin block shows a noticeable reduction due to its controllable load structure. The Teratai block shows smaller relative reduction because of fixed ICT loads. **Figure 4** visually compares reduced consumption between the blocks. The figure highlights the reduction trend but also shows that Teratai remains significantly higher in total consumption despite reduction.

Table 4. Ramin block electrical equipment and reduced estimated energy usage.

Equipment	Unit, *X*	Power input per unit, *Ei* (W)	Duration of usage per day, *t* (Hours)	Days of usage per month, *d* (Days)	Monthly energy consumption, *E,month* (kWh)
Fluorescent Light	23	36	3	20	49.68
Ceiling Fan	17	50	3	20	51
Wall Fan	2	54	3	20	6.48
Split Air Conditioner	2	1119	4	20	179.04
Split Air Conditioner	2	1864	4	20	298.24
Split Air Conditioner	1	1491	4	20	119.28

Table 5. Teratai block electrical equipment and reduced estimated energy usage.

Equipment	Unit, *X*	Power input per unit, *Ei* (W)	Duration of usage per day, *t* (Hours)	Days of usage per month, *d* (Days)	Monthly energy consumption, *E,month* (kWh)
Fluorescent Light	120	36	4	20	345.6
Desktop Computer	40	2500	2	20	4000
Monitor	40	2500	2	20	4000
Split Air Conditioner	1	2900	4	20	232
Split Air Conditioner	1	2450	4	20	196
Split Air Conditioner	1	2983	4	20	238.64

Table 6. Ramin-Teratai block overall reduced energy consumption comparison.

Electrical Parameter	Ramin Block	Teratai Block
Total electrical unit, *Xt*	47	203
Total power input, *Ei,t* (W)	4614	13369
Total energy consumption per month, *E* (kWh)	703.72	9012.24
Estimated monthly bill, *B,month,* (RM)	140.74	1802.448

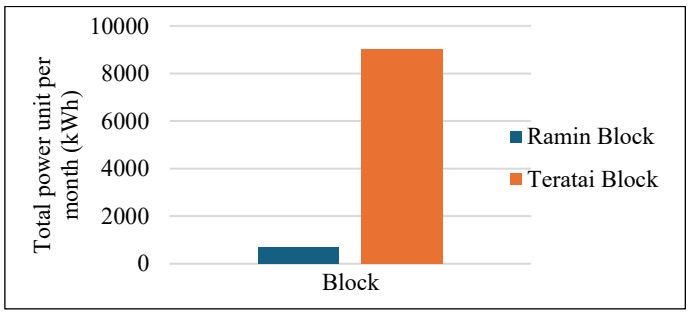


Figure 4. Overall comparison for reduced total power unit in different blocks.

3.3 Ramin-Teratai Block Percentage of Reduction for Energy Consumption

Table 7 quantifies percentage reduction for each appliance category using **Equation 3**. Lighting achieved 50% reduction, while air-conditioning units achieved approximately 33.33% reduction. Fans showed 0% reduction because operating hours were unchanged. **Table 8** shows that lighting and air-conditioning achieved 33.33% reduction, while computers and monitors show 0% reduction. This reinforces the conclusion that ICT loads limit reduction effectiveness. **Table 9** presents the total percentage reduction for each block. Ramin achieved 33.086% reduction, while Teratai achieved 5.317%. **Figure 5** visually presents percentage reduction between the blocks.

Table 7. Ramin block percentage of reduction after reducing energy consumption.

Equipment	Actual Energy Consumption per month (kWh)	Reduced Energy Consumption per month (kWh)	% Reduction
Fluorescent Light	99.36	49.68	50.00
Ceiling Fan	51.00	51.00	0.00
Wall Fan	6.48	6.48	0.00
Split Air Conditioner	268.56	179.04	33.33
Split Air Conditioner	447.36	298.24	33.33
Split Air Conditioner	178.92	119.28	33.33

Table 8. Teratai block percentage of reduction after reducing energy consumption.

Equipment	Actual Energy Consumption per month (kWh)	Reduced Energy Consumption per month (kWh)	% Reduction
Fluorescent Light	518.4	345.6	33.33
Desktop Computer	4000	4000	0.00
Monitor	4000	4000	0.00
Split Air Conditioner	348	232	33.33
Split Air Conditioner	294	196	33.33
Split Air Conditioner	357.96	238.64	33.33

Table 9. Ramin-Teratai block energy reduction comparison.

Electrical Parameter	Ramin Block	Teratai Block
Actual Energy Consumption per month, α (kWh)	1051.68	9518.36
Reduced Energy Consumption per month, β (kWh)	703.72	9012.24
Overall Reduction (%)	33.086	5.317

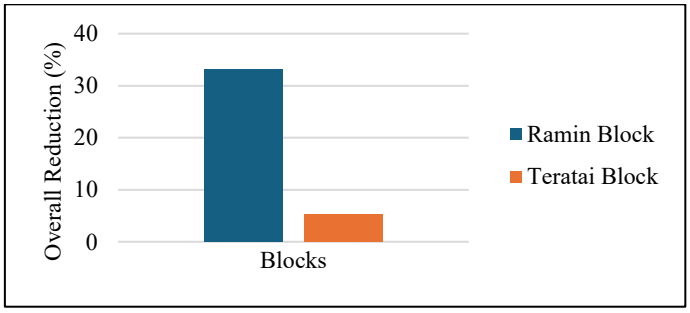


Figure 5. Ramin-Teratai block overall reduction comparison.

3.4 Ramin-Teratai block greenhouse gas emission.

Using **Equation 4** with emission factor 0.75 kg CO_2/kWh, emissions were calculated for each appliance. For example, fluorescent lighting emitted 74.52 kg CO_2 before reduction and 37.26 kg CO_2

after reduction. Air-conditioning units show proportional reductions consistent with their energy reductions. **Table 10** below shows the difference between actual emission and reduced emission for Ramin block. Similarly, emissions from desktop computers and monitors are each 3000 kg CO_2 monthly due to high electricity use. These values remain unchanged in reduced scenarios because energy consumption was unchanged. This mentioned in **Table 11** below for Teratai block.

Table 10. Ramin block greenhouse gas emission.

Equipment	Actual emission of CO_2 per month (kg CO_2e)	Reduced emission of CO_2 per month (kg CO_2e)
Fluorescent Light	74.52	37.26
Ceiling Fan	38.25	38.25
Wall Fan	4.86	4.86
Split Air Conditioner	201.42	134.28
Split Air Conditioner	335.52	223.68
Split Air Conditioner	134.19	89.46

Table 11. Teratai block greenhouse gas emission.

Equipment	Actual emission of CO_2 per month (kg CO_2e)	Reduced emission of CO_2 per month (kg CO_2e)
Fluorescent Light	388.8	259.2
Desktop Computer	3000	3000
Monitor	3000	3000
Split Air Conditioner	261	174
Split Air Conditioner	220.5	147
Split Air Conditioner	268.47	178.98

Table 12 summarises total emissions. The Ramin block shows substantial emission reduction due to effective energy reduction, while Teratai shows moderate reduction proportional to its limited energy savings. **Figure 6** graphically compares emissions between blocks and reduction scenarios. The figure clearly illustrates the environmental impact difference driven by energy consumption patterns

Table 12. Overall Ramin-Teratai block greenhouse gas emission.

Electrical Parameter	Ramin Block	Teratai Block
Total actual emission of CO_2 per month (kgCO_2/kWh)	788.76	7,138.77
Total reduced emission of CO_2 per month (kgCO_2/kWh)	527.79	6,759.18

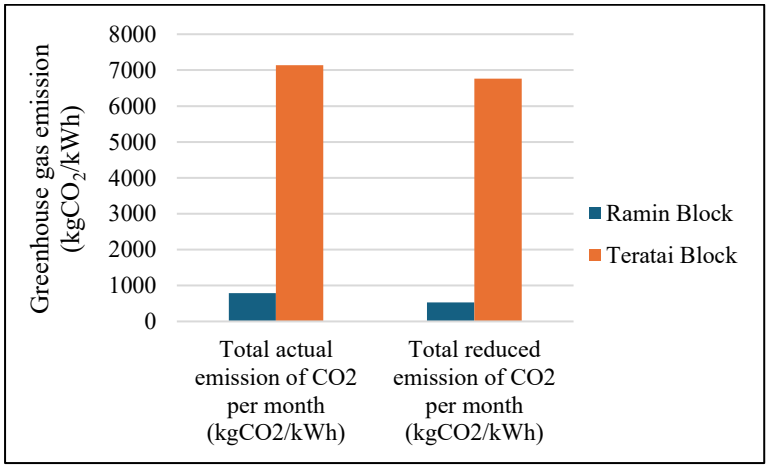


Figure 6. Ramin-Teratai greenhouse gas emissions comparison for different blocks.

4. Conclusion

The first objective of this study was successfully achieved through the systematic identification and documentation of electrical appliances in the Ramin–Teratai Block of SMK Engkilili, Sri Aman, Sarawak. All major auxiliary systems, including lighting, fans, air-conditioning units, desktop computers, and monitors, were recorded together with their rated power and operating duration. The second objective was fulfilled by calculating the monthly electricity consumption and estimating the associated greenhouse gas emissions using the Sarawak grid emission factor of 0.75 kg CO_2/kWh. The analysis showed that the Ramin block's energy demand is primarily influenced by lighting and air-conditioning systems, while the Teratai block is dominated by ICT-related loads, leading to significantly higher electricity consumption and carbon emissions. The third objective was addressed by evaluating feasible energy-saving strategies, where reducing operating hours of selected appliances demonstrated measurable reductions in electricity use, operational cost, and emissions, particularly in the Ramin block where loads are more flexible. Overall, these findings collectively achieve the aim of this research, which was to investigate electricity consumption and greenhouse gas emissions in the Ramin–Teratai Block of SMK Engkilili and to determine practical, low-cost optimisation strategies suitable for a secondary school environment. The study confirms that structured energy auditing and behavioural adjustments can effectively support sustainability and energy management efforts in Malaysian public educational facilities.

Acknowledgements

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Energy Audit for Electricity Consumption and Greenhouse Gas Emission Reduction in SMK Engkilili Dormitories

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Abstract

In this study, a systematic energy audit was carried out in the boys' and girls' dormitory of SMK Engkilili to provide insights on the electricity usage pattern and estimation of Greenhouse Gas (GHG) emissions due to its electricity consumption. The aim of the study was to pinpoint the highest contributors to energy consumption and present feasible optimization methods in minimizing power demand and environmental impact. The data collection was implemented via site surveys and interviews, highlighting electrical appliances capacity, quantity and operational time were recorded. The main products found were LED tubes and ceiling fans in different models, with various power ranges. In order to estimate energy consumed, Microsoft Excel was employed to tabulate daily, monthly, and yearly electricity usage. Electricity monthly costs were calculated with reference to the commercial tariff offered by Sarawak Energy Berhad. Carbon dioxide (CO_2) emissions were calculated based on the Grid Emission Factor (GEF) for Malaysia of 0.75 kg CO_2e/kWh in order to determine the environmental impact due to electricity usage. Results show that ceiling fans are the most significant contributors to total energy consumption for both dormitories, because of long operation hours and larger power ratings. Between the dormitories, it was Asrama Wong that produced the highest CO_2 emissions annually and Asrama Puteri with the lowest CO_2 emissions annually. There is a significant positive correlation between both electricity utilization and CO_2 emissions. Optimisation initiatives, such as the reduction in ceiling fan operating hours from 15 kWh to 12 kWh per day contributed to measurable results. Boys' dormitory had 18% reduction in energy, cost and emission, while girls' dormitories accounted 17%.The results, in sum, illustrate that organized energy audits and applied behavioural changes can greatly enhance energy efficiency and drive sustainability on the campus of a university.

Keywords: *Energy Audit, greenhouse emission, optimization, energy consumption*

1. Introduction

An energy audit is a systematic evaluation of an organization's past and present energy consumption. Its main purpose is to identify and measure areas where energy is being used inefficiently or wasted. This process is ideally conducted by a qualified and accredited energy auditor [1]. An energy diagnosis provides the benchmark for better energy performance. It offers a systematic and comprehensive method for discovering feasible opportunities to improve energy efficiency [2]. Energy audits are important for organization that aims to reduce operating costs and environmental impact [3] . By identifying waste and unnecessary use of energy, organization can make focused improvements that result in substantial savings. Moreover, energy audits help to reduce greenhouse gas emissions, support sustainability efforts and encourage responsible use of energy. Through the capture of heat from the sun, greenhouse gases have maintained Earth's climate as hospitable to mankind and millions of other species. According to [4], the greenhouse effect concept dates back to the 19th century, when French mathematician Joseph

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Fourier in 1824 estimated that Earth would be far colder if it had no atmosphere. The idea of carbon dioxide gas from burning fossil fuels producing a warming effect was first proposed by the Swedish scientist Svante Arrhenius in 1896. Carbon dioxide is the main greenhouse gas, accounting for about three-quarters of emissions [4]. It can persist in the atmosphere for millennia. The bulk of carbon dioxide emissions result from burning organic matter such as coal, oil, gas, wood and solid waste. Greenhouse gases have wide-ranging effects on the environment and health. They are drivers of climate change because they trap heat, and they are also a key contributor to respiratory disease from smog and air pollution. Extreme weather, food-supply disruptions and more wildfires are other effects of climate change related to greenhouse gases.

Reducing domestic demand for energy is crucial to the broader fight against climate change and achieving a more sustainable energy future in the long run. It refers to the energy required to heat and cool homes, keep the lights on, as well as power appliances. Patterns of consumption are driven by a complex mix of factors including local climate, family size and economic status, as well as how efficiently homes and appliances are built or maintained [5]. Understanding these usage patterns can enable the development of demand-side management schemes such as demand response, where consumers reduce energy utilization in response to signals provided by utilities [6]. The lack of systematic energy monitoring system makes it difficult to identify area with abnormal energy consumption. By having a systematic energy monitoring system, potential energy wastage could also be identified. This may occur due to several factors such as the condition of the appliances, weather and usage pattern. Ultimately, the absence of systematic energy management makes it difficult to propose optimization strategies. The aim of this research is to perform energy audit for both the boys' and girls' dormitories in SMK Engkilili to determine the electricity consumption and propose optimization strategies to reduce the energy consumption. Aligned with the aim of this research, the objectives for this research are to identify and record the electrical appliances used in the dormitories, to calculate the energy usage and estimate the greenhouse gas emission using Excel and to identify and propose strategies to reduce electricity consumption based on retrieved data. This research focuses on the electricity consumption in dormitories located at SMK Engkilili. Due to continuous usage especially during weekends, the cost of electricity for the dormitories alone can quite high. Furthermore, appliances that are left to operates unattended would also leads to high electricity consumption

2.0 Methodology

This section discusses the methodology used in this research. A summary of the process is shown in **Figure 1**.

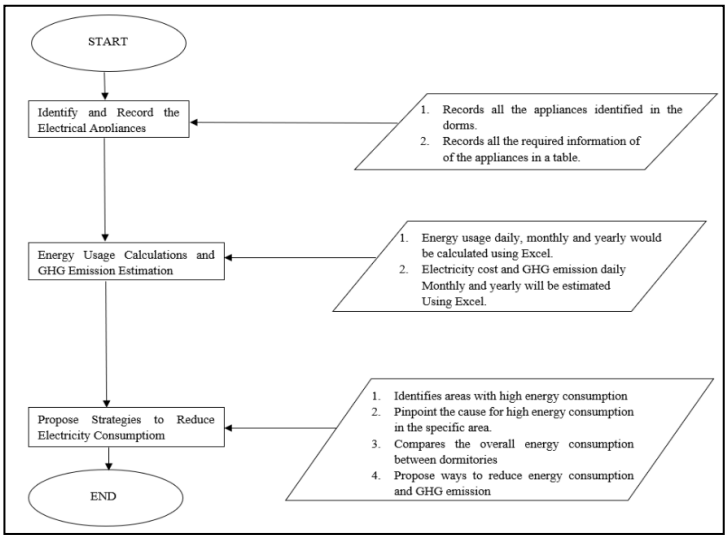


Figure 1. Flow Chart of Methodology

2.1 Identification and Recording of Electrical Appliances

The list of appliances commonly found in dormitories is presented in **Table 1**, which summarises the main items typically used by residents for daily living, study activities, and basic personal comfort. Each of the appliance's ratings would also be recorded to calculate the overall power rating. Relevant information such as operating hours of the appliances was determined via oral interview with a few students living in the dormitories.

Table 1. List of Appliances

Category	Appliances/Equipment	Remarks
Lighting	LED Light (Tube/Bar)	Fixed lighting
Lighting	LED Light (Bulb)	Room lamp / ceiling bulb
Ventilation	Ceiling Fan	Standard fan unit
Other	Other appliances (specify)	Charger, iron, kettle

2.2 Energy Usage Calculation and Greenhouse Gas Emissions Estimation using Excel

The data obtained and recorded would then be calculated using Excel programming. The daily, monthly and annual energy consumption would be calculated. Moreover, the estimated CO_2 emissions based on energy consumption would also be calculated using Excel programming. The daily energy consumption per hour of each equipment is determined using **Equation 1** [7];

$$E_{daily}\left(\frac{kWh}{day}\right) = \frac{P(t)(n)}{1000} \quad \textbf{(1)}$$

Where P is the power rating of the equipment or appliances, t is the duration of the appliances being used in hour and n is the number of the appliances. Then the monthly energy consumption can be determined using **Equation 2**.

$$E_{monthly}\,(kWh) = E_{daily} \times D \quad \textbf{(2)}$$

Where D represents the number of days the appliances operate. Then, the monthly electricity cost can be estimated by multiplying the calculated monthly energy and multiplying it with the latest tariff retrieved from local energy supplier which in this case is Sarawak Energy Berhad. **Equation 3** for electricity cost is shown below.

$$E_{cost} = E_{monthly}(Electrical\ Tariff) \quad \textbf{(3)}$$

Then, the annual energy consumption can be calculated using **Equation 4**, based on the rated power of each appliance and its typical operating hours, and summed across all listed items to obtain the total yearly electricity use for the dormitory.

$$E_{yearly} = E_{monthly}(12) \quad \textbf{(4)}$$

The latest electricity tariff applicable to commercial buildings, including schools, is presented in **Table 2** below, which provides the relevant rate structure used in this study to estimate the electricity cost based on the calculated annual energy consumption. It shows the C1 Commercial electricity tariff, where the rate per unit (kWh) depends on the total number of units consumed. As consumption increases from 1–100 units (20.0 sen/unit) up to 1–10,000 units (32.0 sen/unit), the price per unit generally rises, indicating a higher electricity cost for users with greater demand. After that, the tariff becomes slightly lower, at 31.0 sen/unit for 1–20,000 units and 30 sen/unit for above 20,000 units, which suggests some cost relief at very high consumption levels. Regardless of usage, a minimum monthly charge of RM 10.00 applies, meaning the consumer will still be billed at least this amount even if monthly electricity consumption is low. In this study, the tariff table is used to convert the estimated energy consumption (kWh) into an annual electricity cost by matching the calculated usage range to the corresponding rate and applying the minimum charge where relevant.

Table 2. Electricity Tariff Schedule for C1 Commercial Category (Applicable to Schools) [8]

Tariff Category	Consumption Range (units)	Rate per Unit
C1 – Commercial	1 – 100	20.0 sen
C1 – Commercial	1 – 200	24.0 sen
C1 – Commercial	1 – 300	26.0 sen
C1 – Commercial	1 – 400	28.0 sen
C1 – Commercial	1 – 500	30.0 sen
C1 – Commercial	1 – 3,000	31.5 sen
C1 – Commercial	1 – 10,000	32.0 sen
C1 – Commercial	1 – 20,000	31.0 sen
C1 – Commercial	Above 20,000	30.0 sen
Minimum Monthly Charge	–	RM 10.00

2.3 Identify and Propose Strategies to Reduce Electricity Consumption

The data obtained are used to identify and prioritise areas with high energy consumption for further evaluation. The assessment focuses on usage patterns, operating hours, and total energy consumption in each area, enabling the main energy intensive zones to be determined more clearly. This provides a practical basis for targeting the largest sources of electricity use, rather than applying general measures with limited impact. The identified high consumption areas support the formulation of strategies to reduce power wastage and lower operational costs while maintaining normal dormitory activities.

3.0 Results and Discussion

This section discusses the result and findings obtained during the site visit. The calculated energy consumption and estimated CO_2 emissions would also be discussed in this section

3.1 Types of Appliances and Energy Consumption

SMK Engkilili is a school located near the Pan Borneo Highway [11]. This study was done at SMK Engkilili's dormitories. Based on site visits conducted on 11th of February 2026, there were 5 dormitories in this school, as shown by **Figure 2**, **Figure 3**, **Figure 4**, **Figure 5**, **Figure 6**, and **Figure 7**.

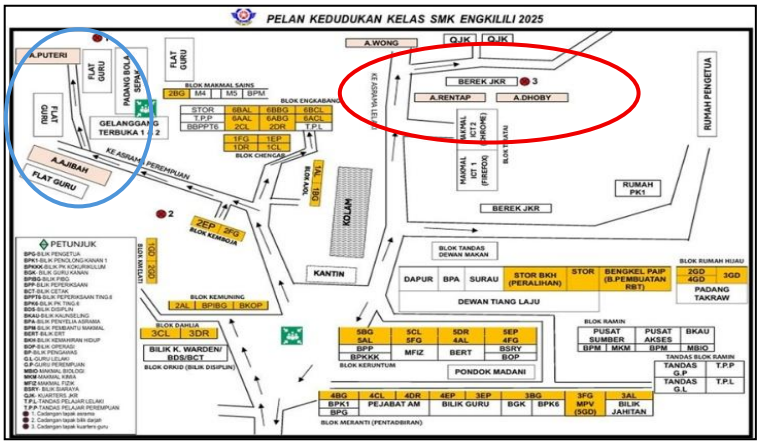


Figure 2. SMK Engkilili Map

Two main appliances are found in each dormitory: LED lights and ceiling fans. However, several variations are observed across rooms. Some rooms use LED lights (bulb type) instead of LED tube or bar lights, and one room uses a stand fan. In addition, the girls' dormitories use a different fan type. All girls' dormitory rooms are observed to use orbiting ceiling fans. These variations are expected to influence overall energy consumption. **Table 3** summarizes all appliances recorded across the dormitories. Asrama Wong records the highest number of appliances compared to the other dormitories.

This higher dormitory capacity helps explain its greater overall energy demand. According to [9], space cooling accounts for the largest share of energy use (16.2%), which is largely influenced by Malaysia's hot and humid climate [10]. **Figure 8** shows the location of SMK Engkilili as retrieved from [11].



Figure 3: Asrama Wong



Figure 4: Asrama Dhobi



Figure 5: Asrama Rentap



Figure 6: Asrama Puteri



Figure 7. Asrama Ajibah

Table 3. List of Appliances

Equipment/Appliances	Asrama Wong	Asrama Rentap	Asrama Dhoby	Asrama Puteri	Asrama Ajibah	Total
LED Light	43	15	22	34	21	**135**
LED Light (Bulb)	-	10	-	-	-	**10**
Ceiling Fan	25	15	17	-	-	**57**
Ceiling Fan (Orbit Fan)	-	-	-	16	20	**36**
Stand Fan	-	-	1	-	-	**1**



Figure 8. Location of SMK Engkilili retrieved from [11]

The dormitories' proximity to the Pan Borneo Highway partly explains why space cooling equipment, such as ceiling fans, contributes substantially to overall energy consumption. The school's location near a major roadway increases exposure to the urban heat island effect, where built surfaces such as roads and buildings absorb and re radiate solar heat more than natural landscapes such as forests and water bodies [12]. According to [12], common urban materials, including asphalt, pavement, and roofing, generally have lower solar reflectance than trees and other natural surfaces, causing them to absorb and release more heat. As a result, the surrounding environment becomes warmer than areas with greater greenery or vegetation, which can increase the need for ventilation and cooling in dormitory spaces. **Table 4** presents the power ratings of each appliance found in the dormitories. Among the listed items, the standard ceiling fan has the highest rated power (80 W), while the LED lights have lower power ratings (20–22 W), reflecting their higher efficiency for lighting. The orbiting ceiling fan (50 W) and desk or table fan (39 W) fall in between, indicating that differences in fan type can meaningfully affect total electricity use when operated for long hours.

Table 4. List of Appliances and Their Power Rating (W)

Category	Appliance/Equipment	Rated Power, *P* (W)
Lighting	LED light (tube/bar)	22
Lighting	LED light (bulb)	20
Ventilation	Ceiling fan (standard)	80
Ventilation	Ceiling fan (orbiting type)	50
Ventilation	Desk/table fan	39

Table 5 presents the rated power of the ceiling fans installed in the boys' dormitories, which is used to estimate their electricity consumption based on operating hours. This value represents the fan's electrical demand under typical operation and is a key input for calculating energy use at the dormitory level. By reporting the fan power rating separately for the boys' dormitories, the analysis can compare cooling related energy consumption across dormitory blocks and assess how appliance type influences total usage.

Table 5. Power Rating for Ceiling Fan (Model CF618) [13]

Fan Speed	Low: 130 rpm, High: 290 rpm
Power	80W
Star Rating	5-Star
Noise Level	<62 dB
Power Consumption	Low: 24W, High: 80W

The girls' dormitories use orbiting ceiling fans in all rooms. The technical specifications of the selected orbiting fan model, including fan speed, rated power, star rating, noise level, and power consumption at low and high settings, are summarised in **Table 6**. These specifications are used as input parameters for estimating ventilation related energy consumption in the girls' dormitory blocks.

Table 6. Power Rating for Ceiling Fan (Orbiting Type) [14]

Fan Speed	Low: 1050 rpm, High: 1350 rpm
Power	50W
Star Rating	3-Star
Noise Level	60 dB
Power Consumption	Low: 25W, High: 56W

3.2 Energy Use and CO_2 Emission Estimation Using Microsoft Excel

The annual energy usage for both boys and girls dormitories were calculated using Excel Programming. **Figure 9** and **Figure 10** illustrate the annual energy consumption for both dormitories. Based on Figure 8 above, it clearly shows that the ceiling fan dominates the overall energy consumption in the boys' dormitories. The ceiling fan used 24624 kWh of energy annually or 66.86% of the overall annual energy consumption. The Bulb type LED Light consumed only 2.93% of the annual energy consumption. **Figure 10** shows the pie chart of the overall energy consumption in the girls' dormitories.

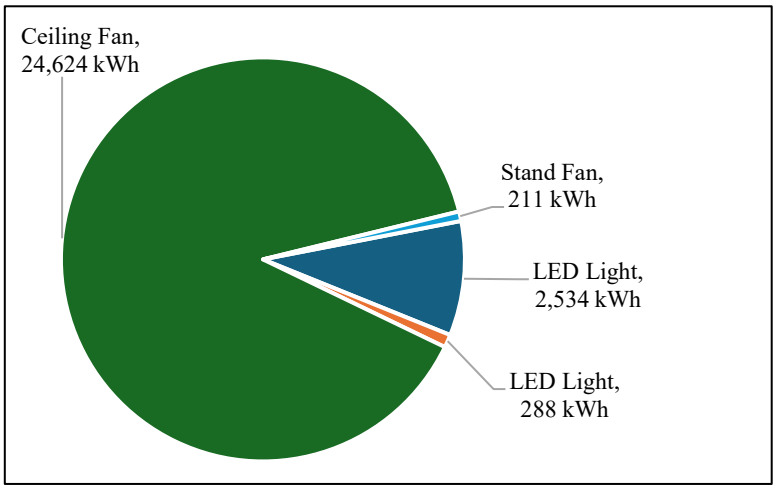


Figure 9. Annual Energy Consumption (kWh) of Each Appliances in Boys' Dormitories

Figure 10 illustrates the annual energy consumption of each appliance in the girls' dormitories. The ceiling fan used in the girls' dormitories used 4320 kWh of energy annually. Comparing this with the boys' dormitories, the number is quite low. This is due to the type of fan used in the girls' dormitories is different from the boys' dormitories. Furthermore, the power rating of these two fans is also different. So, this explains why the energy usage in the girls' dormitories is lower than the boys' dormitories. More than 40% of CO_2 emissions come from the burning of fossil fuels that are used for electricity generation [15]. The greenhouse effect is the result of some gases in the Earth's atmosphere that permits incoming solar short-wave radiation, but blocks outgoing long-wave thermal radiation from its surface. This is what makes the Earth habitable. Without it, the night would be too cold. But an accumulation of greenhouse gases, particularly CO_2, is resulting into the warming of the climate across the planet. It is human action, not nature, that is primarily responsible for the increasing concentration of greenhouse gases (GHGs) in our atmosphere. These gases are emitted during electricity generation, industrial processes, domestic energy use, agricultural & waste activities and land-use changes [16]. Combined, these gases enhance the greenhouse effect that causes global warming. Table 5 shows the summary of

the CO_2 emissions for boys. dormitories, meanwhile, Table 6 shows the total emission for the girls' dormitories.

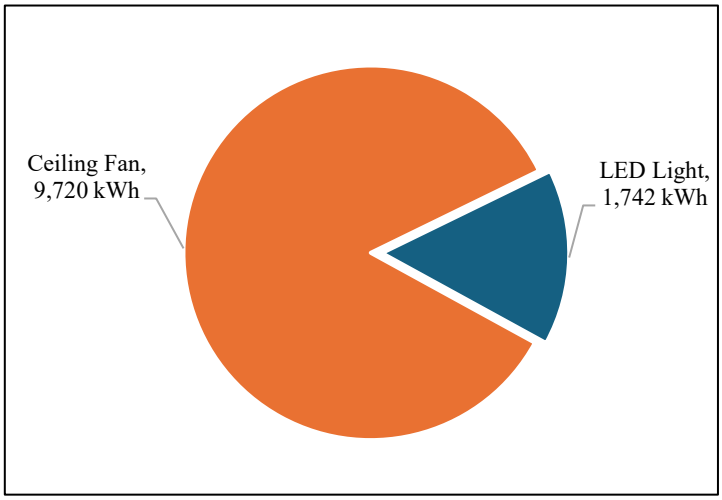


Figure 10. Annual Energy Consumption (kWh) of Each Appliances in Girl's Dormitories

As shown by **Table 7**, Asrama Wong records the highest annual CO_2 emissions at 9,121.68 kg CO_2, indicating that it contributes the largest share of the dormitory related carbon footprint. In contrast, **Table 8** shows that Asrama Puteri has the lowest annual CO_2 emissions, with 4,047.84 kg CO_2, reflecting comparatively lower electricity demand and or shorter operating hours. **Table 9** summarises the CO_2 emissions for both boys' and girls' dormitories, allowing a direct comparison of their overall contributions. The results show that the boys' dormitories dominate total energy use and associated emissions, which is consistent with their higher number of appliances, larger dormitory capacity, and greater reliance on ventilation equipment. This comparison provides a clear basis for prioritising energy efficiency measures in the higher emitting dormitory blocks because it identifies where electricity use, and therefore emissions and cost, are concentrated. When interventions are applied to the largest contributors, the absolute savings per action are typically greater, since even small percentage reductions translate into a larger reduction in kWh and CO_2. In practical terms, this supports targeted actions such as improving operating hour discipline, reducing unnecessary lighting and fan usage, and upgrading inefficient appliances first in the dormitories with the highest consumption. It also helps school management allocate resources more effectively by focusing budget, monitoring efforts, and awareness programmes on the blocks where measurable reductions are most likely to occur.

Table 7. Total CO_2 Emissions of Boys' Dormitories

CO_2 Emissions (kg CO_2e)	**Asrama Wong**	**Asrama Rentap**	**Asrama Dhoby**	**Total**
Daily	25.34	15.09	17.19	57.62
Monthly	760.14	452.70	515.72	1728.56
Annually	9121.68	5432.40	6188.67	20742.75

Table 8. Total CO_2 Emission of Girls' Dormitories

CO_2 Emissions (kg CO_2e)	**Asrama Puteri**	**Asrama Ajibah**	**Total**
Daily	11.24	12.64	23.88
Monthly	337.62	379.08	716.70
Annually	4,047.84	4,548.96	8,596.80

The CO_2 emission is calculated using the **Equation 5** below by converting the estimated electricity consumption into an equivalent amount of carbon dioxide released during electricity generation. In this calculation, the total energy use (typically in kWh) is multiplied by the grid emission factor, which

represents the average mass of CO_2 emitted per unit of electricity supplied. This approach enables the annual carbon footprint of each dormitory to be quantified based on its measured or estimated electricity usage and provides a consistent basis for comparing emissions across dormitory blocks.

Table 9. Total CO_2 Emission for Boys' and Girls' Dormitories

CO_2 Emissions (kg CO_2e)	Boys' Dormitories	Girls' Dormitories	Total
Daily	57.62	23.88	81.50
Monthly	1,728.56	716.70	2,445.26
Annually	20,742.75	8,596.80	29,339.55

$$CO_2 Emission\ per\ Day\ \left(\frac{kg\ CO_2e}{day}\right) = E_{daily}\ \times GEF \qquad \text{.....(5)}$$

Where *GEF* stands for Grid Emission Factor (GEF). The GEF for Malaysia is usually around 0.75 [17]. GEF is the generation weighted-average of GHG emission per unit of electricity generated from all generating power plants feeding the electric grid (GHG intensity of the grid electricity), including Renewable Energy (RE) power plants that could also qualifies for Renewable Energy Certificate (REC) [17]. When analysing energy consumption in the boys' and girls' dormitories, the ceiling fan represents highest electricity user for both cases with much higher annual consumption in the boys' dormitory attributable to variation of fan type as well as power rating. Only a tiny proportion of energy consumption is used by LED lighting. As the power generated in Malaysia is sourced mainly from fossil fuels, increased energy consumption would translate to growing CO_2 emissions. The calculated emissions based on national GEF of 0.75 kg CO_2e/kWh showed that Asrama Wong generated the highest emission of annual CO2 as compared to others and followed by Asrama Puteri which produced the lowest annual CO2 emission. In general, the results show a strong correlation between electricity usage and carbon emissions, thus indicating that it becomes crucial to employ energy management policies in order to curtail energy costs and environmental influences.

3.3 Strategies to Reduce Electricity Consumption

Based off the energy audit process, ceiling fans are the main ones responsible for consuming electricity in the dorms. Energy efficient fans are effective to reduce consumption and consider timed operation or regulated operation to avoid excessive use of these appliances. According to one of the students, Esila Rabai (Personal Communication, February 11, 2026), the fans at the dorm are usually turned off during class session which is from 6.30 a.m. to 1.30 p.m. and during the night study session from 6.45 p.m. to 8.45 p.m. Other than the specified time, the fans are usually left to be operated. This clearly shows that the habit also plays a major role in the energy consumption. The first strategies to reduce the energy consumption in the dorms is to install timer controls. Timer switch is an electronic module which switches a circuit on or off at the time that has been set. The function of timer switch is to avoid the operation of equipment that should not be operated by turn-on time period during which it can reduce waste of electric energy and the electricity cost [18].

The installation of energy efficient appliances could also reduce the electricity consumption. Energy efficient appliances contain advanced technology that allows them to do the same job as a regular version but use less electricity [19]. Energy Efficiency is a term used to describe how efficiently the appliance performs its function using electricity. An efficient appliance will do the same work for less power, have lower power bills and a smaller impact on the environment. Switching to energy-efficient appliances saves money on the electricity bill by using less power. High efficiency models tend to be more expensive initially, although the amount of money saved on energy costs over time generally makes up for the extra cost. Furthermore, to encourage the usage of energy efficient appliances, the Sustainable Energy Development Authority (SEDA) has launched The Sustainability Achieved Via Energy Efficiency (SAVE) 4.0 [20] program. This program offers RM 400 e-rebate for the purchase of energy efficient appliances that had gone performance test and obtained 4- or 5-star energy efficiency

labels from the Energy Commission (ST) [20]. This program was done mainly to increase public awareness to encourage the purchase of energy efficient appliances. For both the girls' and boys' dormitories, reducing the ceiling fan usage hour is the most feasible strategies to reduce the energy consumption as well as the electricity costs. Reducing the ceiling fan usage from 15 hours a day to 12 hours a day would result in the decrease of the overall energy consumption and their cost. Furthermore, reducing the overall energy consumption would also result in the decrease of the CO_2 emission. **Figure 11** and **Figure 12** illustrate the difference between the actual overall energy consumption and the optimised energy consumption for of the girls' and boys' dormitories.

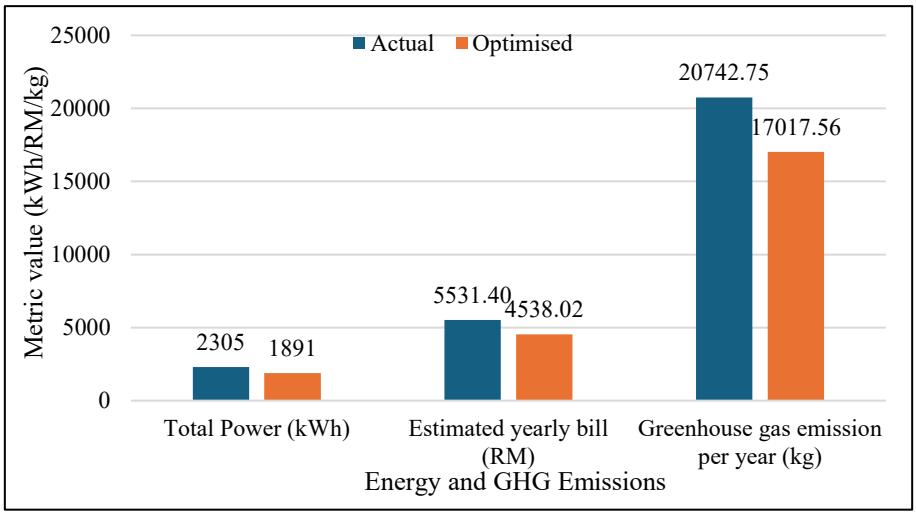


Figure 11. Actual Annual Energy Consumption vs Optimised Annual Energy Consumption in the Boys' Dormitories

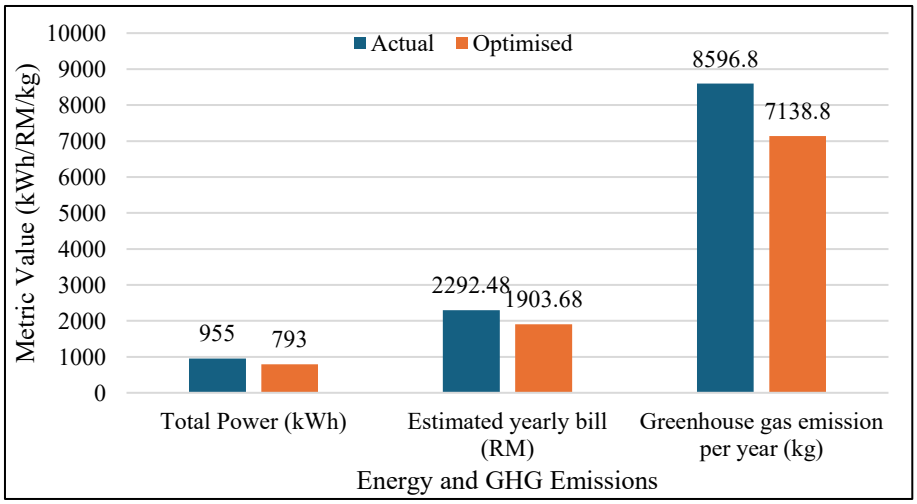


Figure 12. Actual Energy Consumption vs Optimised Energy Consumption in Girls' Dormitories

Figure 11 presents a comparison of the actual and optimised annual energy performance for the boys' dormitory. After optimisation, the annual total electricity consumption was reduced from 2,305 kWh to 1,891 kWh in year, a reduction of approximately 18%. This decrease then subsequently lowers the calculated annual electricity cost to RM 4,538.02 from RM 5,531.40 which represents an equivalent reduction of 18%.Additionally, annual CO_2 emissions were reduced from 20,742.75 kg to 17,017.56 kg which is an 18% reduction in carbon footprint. The optimisation solutions in general indicate that there are consistent and marginally progressive savings over energy consumption, operational costs and emissions. The findings demonstrate that measures to improve the energy efficiency of the boys' dormitory would bring economic savings and mitigating the Greenhouse Gas (GHG) emissions. **Figure**

12 illustrates the actual and optimised annual energy performance for the girls' dormitories. After optimisation measures were applied, the annual electricity demand was reduced from 955 kWh to 793 kWh, which is about a reduction of nearly 17%. Therefore, with this lower energy consumption, the estimated annual electricity cost was also proportionally reduced by RM 2,292.48 to RM 1,903.68 which also 17% saving in cost. Similarly, the GHG also experienced 17% drop of annual emissions. The GHG emissions was reduced from 8,596.8 kg to 7,138.8 kg of annual GHG emissions.

4. Conclusions

This study had successfully carried out an energy audit on boys' and girls' dormitory of SMK Engkilili to evaluate the electricity consumption and its GHG emission. The results reveal that ceiling fans represent the largest proportion in terms of power consumption for both dormitories as a result of its long operation duration and higher power rating. The computed values indicated a positive relation between the consumption of electricity and CO_2 emissions. Both Asrama Wong and Puteri had the highest and lowest annual energy consumption and emissions, respectively. This difference is due to the quantity of appliances, dormitory occupation and fan typology. This had measurable positive effects when optimisation measures were applied, primarily in the form of cut fan operating hours. The energy consumption, electricity cost and carbon emissions of the boys' freestanding dormitory all reduced by about 18%, and those of the girls' freestanding dormitories all decreased by about 17%. These findings suggest that behavioural changes and better energy management can lead to significant energy savings without sacrificing comfort. In summary, energy monitoring and simple optimisation measures can lead to significant economic and environmental benefits. The research demonstrates the need for universities to adopt a culture of energy awareness and management with sustainability at its heart.

Acknowledgements

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PART II
WASTE MANAGEMENT PROJECTS



Quantitative Analysis of Food Waste Generation and Optimization Strategies within SMK Engkelili's Dining Hall

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Abstract

Food waste in educational institutions represents a significant intersection of economic inefficiency and environmental degradation. This study investigates food waste patterns at SMK Engkilili, Sarawak, evaluating both a primary sample of 50 students and an extrapolated population of 1,068 students. Using a conservative baseline of 10g of waste per student to ensure realistic estimates, the research identified a staggering institutional annual financial loss of RM 35,696.39. Furthermore, the environmental impact was quantified at 2,279.5 kg of CO_2 annually, based on a conversion factor of 1.0 kg CO_2 per kg of plate waste. A cost-to-mass paradox was observed: while mixed vegetables contributed the highest waste volume, Indian Mackerel accounted for most of the financial loss (RM 21,388.50) due to high unit costs and a 90% rejection rate attributed to poor sensory properties. These findings align with previous research indicating that portion size and food texture are primary drivers of institutional waste. To mitigate these impacts, this study proposes a multi-tiered optimization plan. Strategies include menu engineering to improve protein palatability, adaptive portioning for carbohydrates, and the establishment of a circular waste economy. The school can also potentially generate new revenue stream by reselling food waste to farmers or even resort to composting which will reduce the environmental impact and carbon footprint. This study demonstrates a viable approach for local schools to mitigate financial deficits while simultaneously reducing their institutional carbon footprint.

Keywords: *Food waste, mealtime, operating costs, carbon footprint.*

1. Introduction

Food waste is a critical global challenge that causes environmental and financial worry. Total global food waste accounted for an estimated 1.05 billion tons in 2024, representing the combined contributions of residential, commercial, and retail sectors [1]. Malaysia generates over 11 million tonnes of municipal solid waste each year [2]. When food is dumped into landfills, it rots and releases CO_2. Every kilogram of food thrown away represents wasted money that could have been spent on better school facilities or improved meal quality. Moreover, food loss leads to substantial financial setbacks for farmers, manufacturers, and retailers, while also creating serious environmental and social consequences. Food waste increases greenhouse gas emissions, places additional strain on land and water resources, and worsens food insecurity and hunger across many parts of the world [3]. At SMK Engkilili, the dining hall operates as a high-volume catering facility, serving 1,068 of students daily [4]. However, there is currently an absence of a systematic assessment system to monitor the volume of waste generated. Without data, the school cannot identify whether the waste comes from oversized portions, poor taste, or preparation errors.

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To address this problem, this study aims to quantify food waste at SMK Engkilili's dining hall and propose management strategies to reduce environmental impact and operational cost. The main objectives of this study are (i) to quantify and categorize food waste across different mealtimes; (ii) to identify primary causes of food rejection and evaluate the economic and environmental effects; and (iii) to propose a strategic optimization plan to reduce institutional waste and operating costs. The scope of this study is focused on the food waste generated by students within the dining hall of SMK Engkilili, Sri Aman, Sarawak, which accommodates 570 students living in hostel daily. This study also examines and evaluates the environmental impact and carbon footprint.

2. Methodology

The research methodology is structured into three phases for data collection, statistical calculations and evaluation of operational costs and environmental impact, and the development of an optimization plan. This process begins with primary data gathering from students and ends with a strategic proposal for the school administration. The overall workflow of the study is summarized in the flowchart as shown in **Figure 1**:

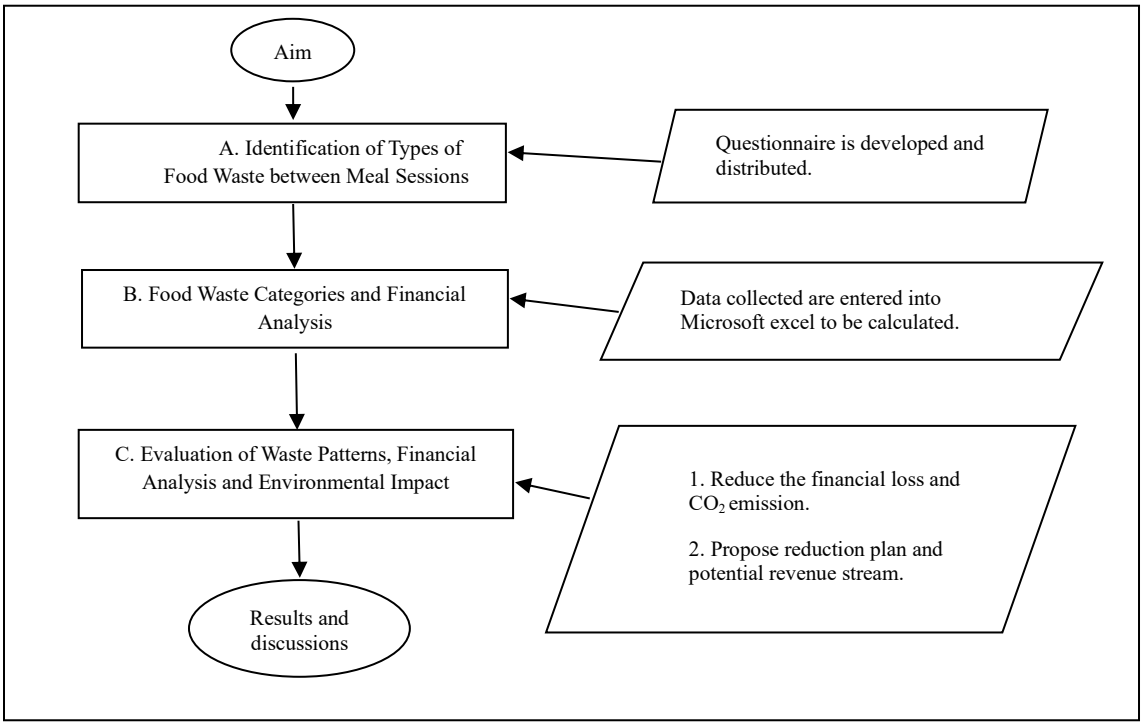


Figure 1. Process Flow of Methodology.

2.1 Data Collection

The study was conducted within the school compound, with an emphasis on the food waste generated in the school's dining hall. The first phase involves a structured questionnaire distributed to students at the SMK Engkilili's dining hall to identify food waste patterns across three daily meal sessions: breakfast, lunch, and dinner. To categorize waste types, the questionnaire focuses on categories such as carbohydrates, protein, and vegetables. Students are asked to provide a visual estimation of their leftovers, which allows the research team to quantify waste volume efficiently without the use of physical scales, verify waste patterns and estimate financial and environmental impact.

2.2 Statistical Calculations and Evaluation of Operational Costs and Environmental Impact

In the second phase of this study, the data retrieved from the survey is utilized to estimate the physical mass of daily food waste generated across all three meal sessions. This information is systematically

categorized to determine the total mass of each specific type of food waste. A critical component of this phase is the financial impact. To determine the monetary value of the discarded food, price index for each food category were sourced from official government databases, including the Department of Statistics Malaysia (DOSM) and the Ministry of Domestic Trade and Cost of Living (KPDN). By calculating the cost per gram for items like King Fish, chicken, white rice etc, the research team determined the daily financial loss. These figures were then extrapolated across the 194-day 2025 academic calendar to project the total annual financial lost for SMK Engkilili. Finally, the waste totals are used to estimate the environmental footprint. Using global standard emission factors, the study calculates the potential Carbon Dioxide (CO_2) equivalent emissions that result from this volume of waste decomposing in a landfill. This phase bridges the gap between physical waste, economic loss, and environmental damage which helps provide a comprehensive view of this problem.

2.3 Proposed Optimization Plan and Operational Cost Reduction

The final phase focuses on identifying root causes and financial solutions based on student feedback regarding portion sizes, taste, and time constraints. The research team will analyze the relationship between the most wasted food categories and student suggestions, such as introducing self-service portioning or onsite composting. An optimization plan will be proposed to the school administration, focusing on reducing financial loss and potential revenue streams, such as selling organic waste to local farmers as animal feed.

3. Results and Discussion

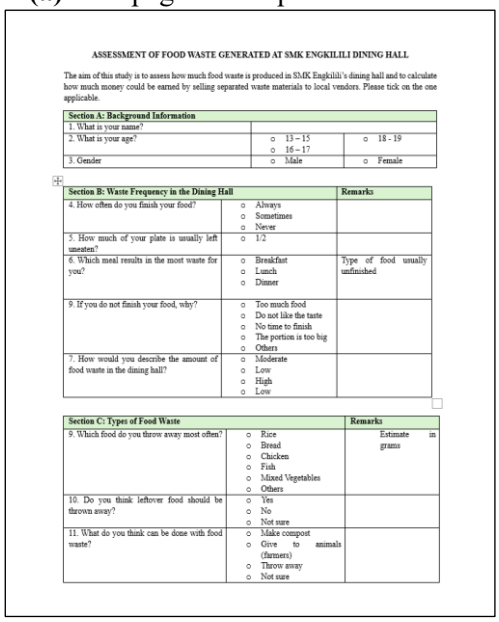
The findings of this study provide a comprehensive look at the food waste ecosystem at SMK Engkilili. The food waste habits of 50 students living in the hostel was analyzed during a three-hour data collection period on 11 February (2:00 PM – 5:00 PM). The research highlights a significant discrepancy between current portioning and actual student consumption. The average waste volume reported by respondents in the survey was 50g, which was utilized as the baseline of the data calculation. The following discussion is structured according to the three primary research objectives: the quantification of waste patterns, the evaluation of economic and environmental impact, and the proposal of a strategic optimization plan.

3.1. Quantification of Food Waste Patterns

This study was done by first developing a detailed questionnaire which was then distributed to 50 students at SMK Engkilili Dining Hall. The questionnaire was focused on identifying the types of food waste, mealtimes behavior and the patterns of food disposal between different genders and age groups. The developed questionnaire is as shown in **Figure 2.** The data reveals that food waste is not distributed evenly across mealtimes. The most significant waste peak occurs during lunch, primarily within the vegetable and protein categories. The data gathered from a sample of 50 students (ages 13–15 and 16–17), reveals distinct waste patterns across the three daily mealtimes. This data was then extrapolated to the total number of students living in the school hostel which was 570 students which was later further categorised by gender and age group. At breakfast and dinner, carbohydrates were the most discarded category. This means that for every 570 students, 79 of them would discard carbohydrate from their plate for breakfast. This aligns with the "too much rice" remarks provided by students, suggesting that the kitchen's portion sizes consistently exceed student intake capacity. However, the lunch period showed a shift in waste composition, with vegetables and proteins emerging as the primary discarded items. This comparison confirmed that while the menu varies, the consistent presence of rice, mixed vegetables, and fish creates a recurring cycle of waste that can be tracked and predicted across all mealtimes. Regarding vegetables, the high waste volume during lunch is consistent with existing literature on adolescent dietary habits. Studies show that one of the main obstacles to vegetable consumption among adolescents is their unfavourable sensory characteristics especially bitter flavours which frequently result in instant rejection during school meals [5]. Earlier studies indicate that higher

vegetable intake is linked to a reduced risk of various negative health conditions, such as ischemic heart disease (IHD), stroke, type 2 diabetes, and esophageal cancer [6]. Furthermore, when vegetables are served as a standardized side dish rather than an integrated part of the meal, students likely felt overwhelmed over the portion, leading to higher plate waste.

(a) First page of the questionnaire



ASSESSMENT OF FOOD WASTE GENERATED AT SMK ENGKILILI DINING HALL

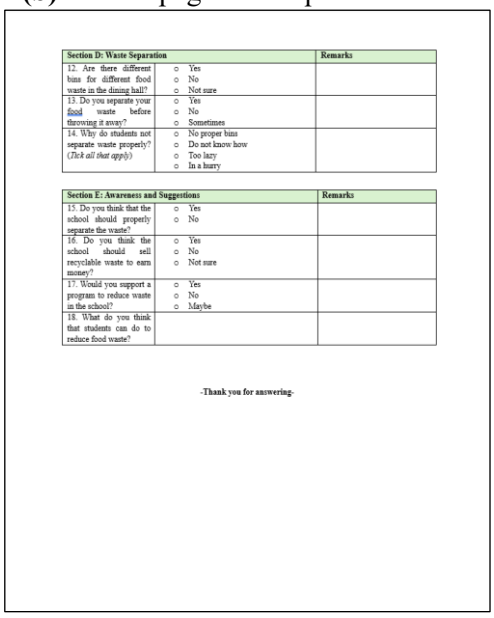
The aim of this study is to assess how much food waste is produced in SMK Engkilili's dining hall and to calculate how much money could be earned by selling separated waste materials to local vendors. Please tick on the one applicable.

Section A: Background Information		
1. What is your name?		
2. What is your age?	o 13 – 15 o 16 – 17	o 18 - 19
3. Gender	o Male	o Female

Section B: Waste Frequency in the Dining Hall		Remarks
4. How often do you finish your food?	o Always o Sometimes o Never	
5. How much of your plate is usually left uneaten?	o 1/2	
6. Which meal results in the most waste for you?	o Breakfast o Lunch o Dinner	Type of food usually unfinished
9. If you do not finish your food, why?	o Too much food o Do not like the taste o No time to finish o The portion is too big o Others	
7. How would you describe the amount of food waste in the dining hall?	o Moderate o Low o High o Low	

Section C: Types of Food Waste		Remarks
9. Which food do you throw away most often?	o Rice o Bread o Chicken o Fish o Mixed Vegetables o Others	Estimate in grams
10. Do you think leftover food should be thrown away?	o Yes o No o Not sure	
11. What do you think can be done with food waste?	o Make compost o Give to animals (farmers) o Throw away o Not sure	

(b) Second page of the questionnaire



Section D: Waste Separation		Remarks
12. Are there different bins for different food waste in the dining hall?	o Yes o No o Not sure	
13. Do you separate your food waste before throwing it away?	o Yes o No o Sometimes	
14. Why do students not separate waste properly? (*Tick all that apply*)	o No proper bins o Do not know how o Too lazy o In a hurry	

Section E: Awareness and Suggestions		Remarks
15. Do you think that the school should properly separate the waste?	o Yes o No	
16. Do you think the school should sell recyclable waste to earn money?	o Yes o No o Not sure	
17. Would you support a program to reduce waste in the school?	o Yes o No o Maybe	
18. What do you think that students can do to reduce food waste?		

-Thank you for answering.

Figure 2. Questionnaire developed.

The data reveals that food waste is not distributed evenly across mealtimes as shown in **Table 1** and **Figure 3**. The most significant waste peak occurs during lunch, primarily within the vegetable and protein categories. The data gathered from a sample of 50 students (ages 13–15 and 16–17), reveals distinct waste patterns across the three daily mealtimes. This data was then extrapolated to the total number of students living in the school hostel which was 570 students which was later further categorised by gender and age group. At breakfast and dinner, carbohydrates were the most discarded category. This means that for every 570 students, 79 of them would discard carbohydrate from their plate for breakfast. This aligns with the "too much rice" remarks provided by students, suggesting that the kitchen's portion sizes consistently exceed student intake capacity. However, the lunch period showed a shift in waste composition, with vegetables and proteins emerging as the primary discarded items. This comparison confirmed that while the menu varies, the consistent presence of rice, mixed vegetables, and fish creates a recurring cycle of waste that can be tracked and predicted across all mealtimes. Regarding vegetables, the high waste volume during lunch is consistent with existing literature on adolescent dietary habits. Studies show that one of the main obstacles to vegetable consumption among adolescents is their unfavourable sensory characteristics especially bitter flavours which frequently result in instant rejection during school meals [5]. Earlier studies indicate that higher vegetable intake is linked to a reduced risk of various negative health conditions, such as ischemic heart disease (IHD), stroke, type 2 diabetes, and esophageal cancer [6]. Furthermore, when vegetables are served as a standardized side dish rather than an integrated part of the meal, students likely felt overwhelmed over the portion, leading to higher plate waste. Based on **Figure 4**, the total daily mass of food waste at SMK Engkilili reveals a significant concentration within specific food categories. The most striking finding within the protein category was the difference between chicken and fish discarded. This is very crucial as protein consumption is important for health and student growth by providing the necessary nutrients.

Table 1. Amount of food waste generated over different mealtimes for 570 students.

Type of Food	Frequency		
	Breakfast	Lunch	Dinner
Carbohydrate	79	22	102
Protein	22	91	91
Vegetables	0	125	45

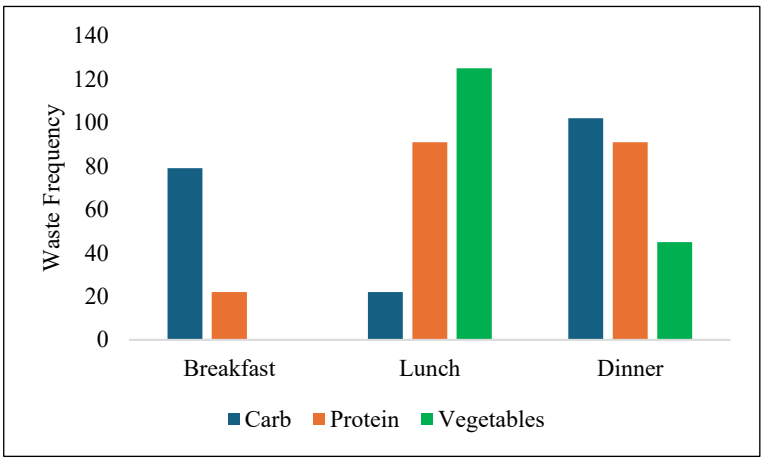


Figure 3. Different category of food discarded during different mealtimes.

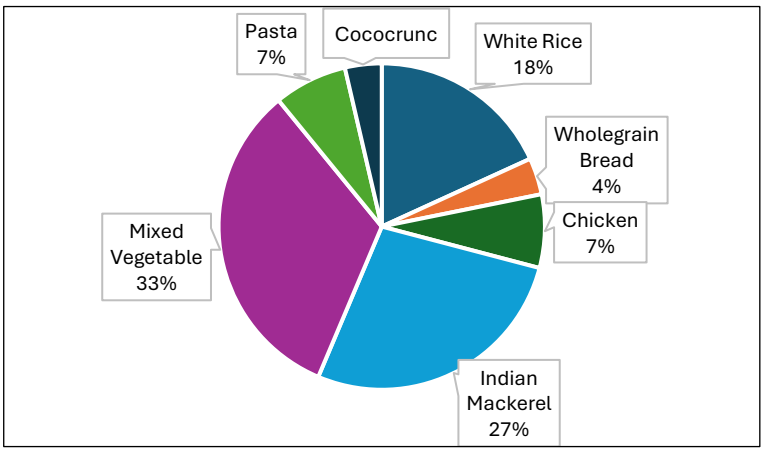


Figure 4. Pie chart for daily mass of different food waste.

Sufficient protein consumption plays a crucial role in preserving skeletal muscle mass by promoting muscle protein synthesis [7]. It was determined that Indian Mackerel contributed up to 88.88% of wasted protein. Student remarks provided a clear reason for this data point: the "hard skin texture" after cooking rendered the fish unappealing or difficult to consume. In a school setting where lunch breaks are timed, students are likely to discard items that require excessive effort to eat. Beyond food quality, the physical and environmental conditions of the dining experience play a significant role in how much food ends up in the bin. Factors such as portion size, background noise, length of the meal period, and students' age significantly influence food waste in primary schools [8]. Vegetables contribute a consistently high volume to the daily waste mass. When these items are not prepared in a manner that appeals to students, they are treated as an optional component of the meal and discarded in bulk, leading to loss of essential fibre and micronutrients. In contrast, carbohydrates such as white rice and bread products show a high daily waste mass that is driven by operational factors rather than taste preferences. Student feedback suggests that portion sizes often exceed their appetite, resulting in an accumulation of waste mass that increases the school's environmental footprint and the total volume of waste. Conversely, the data

identifies chicken as the food item with the lowest daily waste mass. This confirms that when the protein source provides a familiar and accessible texture, students are highly likely to consume the entire portion. This difference between the acceptance of chicken and the rejection of Indian Mackerel highlights that waste mass is not just a matter of quantity, but how well the food preparation meets student needs. The data presented in **Table 2** provides a comparative analysis of waste generation among 570 students, categorized by gender.

Table 2. Average waste for 570 students according to gender.

Gender	Daily Average Waste per Student (kg)	Weekly Average Waste per Student (kg)	Annual Average Waste per Student (kg)
Female	0.065	0.456	18.584
Male	0.048	0.336	13.719

The total food waste for the entire hostel population was determined through a two-step calculation: first, by calculating the mean waste per respondent from the 50-student sample data, and second, by extrapolating that average to the total population of 570 students. To find the average waste for a single student, the total waste from the sample was divided by the number of respondents using **Equation 1** shown below:

$$Average\ Waste\ per\ Student = \frac{\sum Waste\ of\ 50\ students}{50} \quad \text{..... (1)}$$

This average was then multiplied by the total number of students living in hostel, to estimate the impact on the entire institution, by using **Equation 2.**

$$Total\ Population\ Waste = Average\ Waste\ per\ Student \times 570 \quad \text{..... (2)}$$

The study population is evenly divided into two groups of 285 female students and 285 male students, allowing for a direct and balanced comparison. The primary data recorded are the average waste produced per student in grams (g) and the cumulative total waste for each demographic. As shown by **Figure 4**, female students generated a significantly higher volume of waste, with an average of 65.21g per person, resulting in a group total of 18,584.85g. In contrast, male students produced a lower average of 48.14g per person, contributing a total of 13,719.90g. The discrepancy between the two groups is obvious when examining the daily averages. Female students produced 17.07g more waste per person than male students, which represents an approximate 35.5% increase in waste volume. This gap is visually emphasized in the accompanying bar chart, where the red column representing the female average stands substantially higher than the teal column for the male average. In terms of total weight, the female students produced nearly 5,000g more waste than male students over the same period.

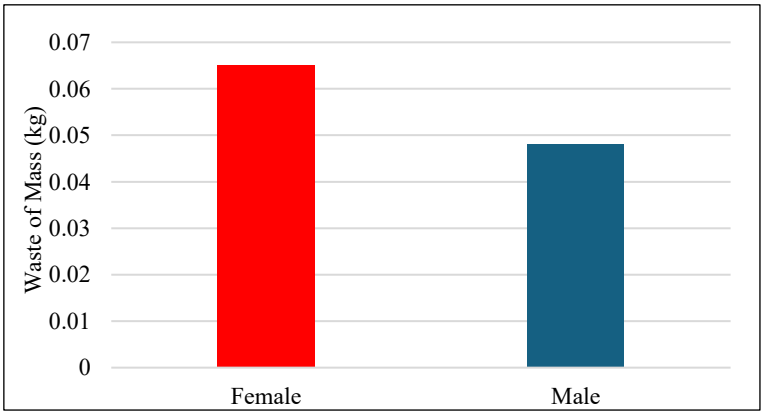


Figure 4. Comparison for daily average mass of waste for female and male students.

When examining the waste habits of the 50 students by age group consisting of 42 students aged 13–15 and 8 students aged 16–17, there are clear differences in terms of composition as tabulated in **Table**

3. As shown by **Table 3**, the younger age group (13–15) wastes significantly more protein, averaging 20.25g per student, whereas the older students (16–17) recorded zero protein waste. However, the older students waste a much larger number of vegetables, averaging 37.5g per person, which is more than double the 14.25g wasted by the younger group. Carbohydrate waste is also higher among the 13–15 age group at an average of 17.85g compared to 12.5g for those aged 16–17. These patterns suggest that younger students may find protein portions too large or unappealing, while older students are specifically prone to discarding their vegetable servings. **Figure 5** and **Figure 6** depict a clear understanding of the differences between age group and their eating habits. The detailed breakdown of waste generation per mealtime as shown in **Table 4**, offers a deeper understanding of the behaviour between male and female students.

Table 3. Type of food waste based on age group.

Age Group	Carbohydrate (g)	Protein (g)	Vegetables (g)
13-15	17.85	20.25	14.25
16-17	12.5	0	37.5

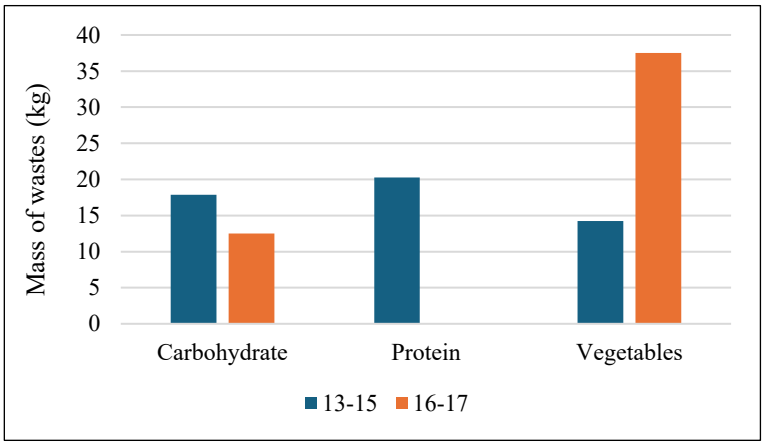


Figure 5. Different type of food waste categorised by age group.

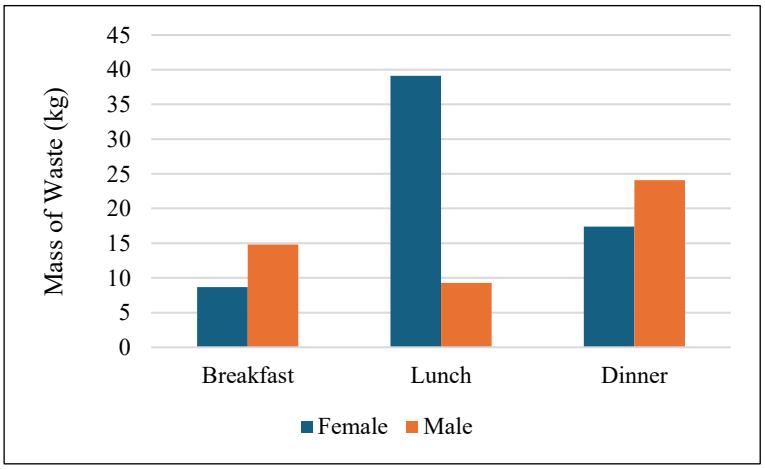


Figure 6. Average food waste difference between male and female students throughout different mealtimes.

While the initial data indicated that female students produce more waste overall, this meal-specific analysis reveals that the trend is not uniform throughout the day. During breakfast, male students generated a higher average amount of food waste at 14.81g, compared to 8.69g produced by female students. This trend continues during dinner, where male students again recorded a higher average of

24.07g of waste, while female students averaged 17.39g. These figures suggest that for breakfast and dinner, male students exhibit a higher tendency for food waste, which may be caused different meal preferences during these periods. However, the most significant outlier in the dataset occurs during lunch, which serves as the primary driver for the higher overall female waste average. Female students produced a substantial average of 39.13g of waste during lunch, which is way larger the 9.26g produced by male students during the same mealtime. This dramatic spike in the female lunch category is the only instance across all three mealtimes where female waste exceeds male waste, yet it is sufficient to overcome the lower averages recorded by females at breakfast and dinner

Table 4. Average student food waste generation categorized by gender and mealtime.

Mealtime	Gender	Average Waste per Student (g)
Breakfast	Female	8.69
	Male	14.81
Lunch	Female	39.13
	Male	9.26
Dinner	Female	17.39
	Male	24.07

The visual representation, as shown in **Figure 5** and **Figure 6**, reinforces this pattern more clearly by translating the numerical differences into an immediately interpretable bar chart. In particular, the bar representing female waste during lunch rises to almost twice the height of any other category, making the lunchtime disparity the most visually dominant feature in the figure. This pronounced concentration of waste during the lunch hour among female students may be linked to multiple interacting factors, including the portion size and menu composition, the availability of packaged items, and the tendency for certain lunch foods to generate more unavoidable leftovers. In addition, social dining behaviours may influence waste levels, as group eating patterns can shape ordering choices, sharing practices, and the likelihood of food being left unfinished, especially when lunch is treated as a social break rather than solely a meal. Food preference trends could also contribute, where specific items more commonly selected by female students might be less likely to be fully consumed or may involve more wrappers, containers, and disposable components that accumulate rapidly within a short period.

3.2. Evaluation of Economic and Environmental Impact

To determine the individual economic loss for each food category, the daily waste mass recorded from the 50-student sample was multiplied by the corresponding market price per gram as obtained from the DOSM January 2025 report. The formula used to calculate the mass to cost conversion is as shown in **Equation 3** below:

$$Daily\ Loss\ (RM) = Daily\ Waste\ Mass\ (g) \times Market\ Price\ (RM) \quad \text{…….. } \mathbf{(3)}$$

Once the daily financial loss was established, the figures were scaled to determine the weekly loss by multiplying the daily total by 7 days for hostel residents, and the total annual loss was subsequently calculated by multiplying the daily loss by the 194 schooling days. The data reveals a cost-to-mass paradox where the physical volume of waste does not correlate with economic loss. This is shown by the fact that while Mixed Vegetables contribute the largest physical volume at 900g (32.7% of total mass), they only account for RM 7.20 of daily loss due to a low unit price of RM 0.008/g. In contrast, the economic drain is primarily driven by White Rice which, despite having a lower waste mass of 500g (18.2% of total), carries the highest market price in this study at RM 0.03652 per gram. The market prices for raw ingredients used in these calculations were obtained from the Consumer Price Index (CPI) report by the Department of Statistics Malaysia (DOSM) in January 2025 [9]. **Table 5** and **Table 6** shows the financial analysis for samples of 50 students and 570 students respectively.

Table 5. Financial analysis for sample of 50 students.

Food waste	Daily mass (g)	Price (RM/g)	Daily Loss (RM)	Weekly Loss (RM)	Annual Loss (RM)
White Rice	500	0.03652	18.30	91.30	3542.40
Wholegrain Bread	100	0.01050	1.05	5.25	203.70
Chicken	200	0.01358	2.70	13.60	526.90
Indian Mackerel	750	0.01673	12.55	62.75	2434.20
Mixed Vegetable	900	0.00800	7.20	36.00	1396.80
Pasta	200	0.01400	2.80	14.00	543.20
Cococrunch	100	0.03110	3.10	15.55	603.30
Total	**2750**		**44.60**	**238.40**	**9250.60**

Table 6. Financial analysis for sample of 570 students living in hostel.

Food waste	Daily mass (g)	Price (RM/g)	Daily Loss (RM)	Weekly Loss (RM)	Annual Loss (RM)
White Rice	5700	0.03652	208.20	1040.80	40383.80
Wholegrain Bread	1140	0.01050	12.00	59.85	2322.20
Chicken	2280	0.01358	31.00	154.81	6006.70
Indian Mackerel	8550	0.01673	143.00	715.20	27750.05
Mixed Vegetable	10260	0.00800	82.10	410.40	15923.50
Pasta	2280	0.01400	31.90	159.60	6192.50
Coco crunch	1140	0.03110	35.45	177.30	6878.10
Total	**11550**		**508.10**	**2717.95**	**105456.80**

Since White Rice is the highest-priced item on the menu, it resulted in a daily loss of RM 18.26 and a significant annual loss of RM 3,542.44 for just the sample of 50 students. This means White Rice alone is responsible for approximately 40.9% of the total daily financial loss of RM 44.57 and roughly 38.3% of the total annual waste cost for the sample group. Indian Mackerel follows as the second-largest contributor, with an annual loss of RM 2,434.22. The financial inefficiency becomes exponentially more severe when these numbers are extrapolated to the total number of students living in the hostel (570 students), where the daily food waste mass escalates to 31.35kg, resulting in a daily loss of RM 508.14 and a weekly loss of RM 2,717.96. On an institutional scale, this culminates in an annual financial loss of RM 105,456.83, which represents a per-capita loss of RM 185.01 per student annually. Comparing high-value items further highlights the disparity where the annual loss for White Rice reaches RM 40,383.82, which is 1.45 times the annual loss of Indian Mackerel (RM 27,750.05) and over 6.7 times the loss of Chicken (RM 6,006.71).

The environmental analysis of food waste at SMK Engkilili reveals a significant "Carbon Debt" that scales rapidly alongside the student population. The daily environmental impact can be quantified by applying a conversion factor of 1.0 kg CO_2 per 1.0 kg of plate waste [10]. For the primary sample of 50 students, the 2.75 kg of daily waste generates 2.75 kg of CO_2 totalling 533.50 kg annually. However, when scaled to the total hostel population of 570 students, the projected daily waste mass of 11.55 kg results in a staggering 2,240 kg of CO_2 emissions per academic year. This accumulation of greenhouse gases represents a significant threat, given that food waste emissions have been shown to exceed the environmental impact of coal-fired power plants under certain conditions [11].

3.3 Proposal of Strategic Optimisation Plan

A systematic approach to canteen management is essential to mitigate the RM 40,383.82 annual loss attributed to White Rice and the RM 27,750.05 loss from Indian Mackerel. First, the White Rice issue must be prioritized through the implementation of individual portioning to address over-serving, as

multiple students reported receiving "too much rice." This is a critical given that rice represents the single largest financial drain on the institution's budget. Secondly, the Indian Mackerel problem which is the second-highest source of economic loss should be addressed by substituting this fish with more palatable proteins or replacing it with chicken. This strategy is supported by the data showing that 88.88% of proteins discarded consist of Indian Mackerel. An alternative to substitution is improving the fish preparation specifically to resolve the texture problems that lead to high rejection rates. Based on the data for food waste over different mealtimes, lunchtime is the peak for vegetables discarded, while carbohydrates are most wasted during breakfast and dinner.

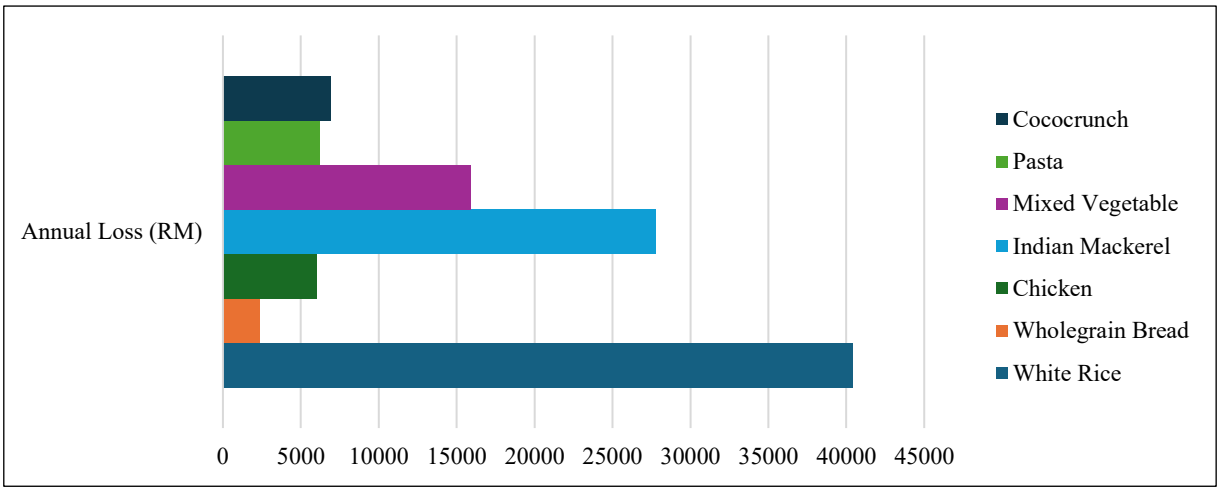


Figure 7. Annual financial loss by food category for 570 students living in hostel.

School management should address this by reconstructing the menu, preferably avoiding serving vegetables as a whole side dish and instead using them as a side garnish. Regarding carbohydrates, the canteen should consider replacing wholegrain bread with other varieties that appeal more to students while still maintaining nutritional balance. It is also observed that female students waste more food daily on average. Data shows that female students produce an average of 65.21g of waste daily, which is significantly higher than the 48.14g produced by male students. This gap is largest during lunch, where females leave behind 39.13g of food waste compared to only 9.26g for males. To address this, the school should consider reducing lunch portion sizes for female students to better match their actual consumption habits. Implementation of a reusable waste system is essential for managing unavoidable waste and achieving a reduction in carbon footprint. By selling organic waste to local farmers as animal feed, the institution can generate a new revenue stream to counter these financial losses. Additionally, any remaining waste should be processed via composting for school gardens. Reusing waste in this manner directly reduces the carbon footprint by preventing methane emissions from landfills.

4. Conclusion

This study provides a comprehensive analysis of the food waste ecosystem within SMK Engkilili's dining hall, revealing critical intersections between student consumption habits, economic efficiency, and environmental responsibility. Data categorization across daily meal sessions indicates that lunch serves as the primary peak for waste generation, with female students producing a substantial average of 39.13g of waste during this period. While mixed vegetables and carbohydrates like white rice constitute the highest overall waste volumes, the research highlights a distinct disparity in protein acceptance, where Indian Mackerel accounts for 88.88% of discarded proteins due to unappealing sensory properties and difficult texture. The socio-economic and environmental consequences of these patterns are significant. The projected annual financial loss reaches RM 105,456.80, with white rice alone contributing approximately RM 40,383.82 to this deficit. Furthermore, the environmental "carbon debt" associated with this volume of waste is quantified at approximately 2,240 kg of CO_2 emissions

annually, indicating the urgency for institutional intervention. These losses are primarily driven by operational factors such as standardized portioning that exceeds student intake capacity and preparation methods that result in high rejection rates for specific food categories. To address these challenges, an optimization framework is essential. Implementing data-driven strategies such as individual and adaptive portioning specifically tailored to gender-based consumption patterns during peak mealtimes can directly reduce the volume of food waste. Furthermore, menu engineering focused on improving the palatability of high-cost proteins or substituting them with more accepted alternatives can mitigate financial drainage. Finally, the establishment of a circular waste economy through on-site composting and the repurposing of unavoidable waste as animal feed offers a sustainable pathway to eliminate landfill-bound emissions while potentially generating new revenue streams. Overall, this research establishes a scalable model for Malaysian schools to align fiscal management with global sustainability goals.

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Assessment of Solid Waste Generated at SMK Engkilili Canteen and the Wastes Potential Recyclability

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Abstract

This study assesses the quantity, composition and economic potential of solid waste generated at the canteen of SMK Engkilili, Sri Aman, Sarawak. The research focuses on four principal waste categories that are food waste, plastics, paper and metals. Data were collected through a structured questionnaire distributed to 40 respondents consisting of 30 students and 10 school staff, the waste weight was estimated based on purchasing patterns and proportional plate waste analysis. The findings indicate that approximately 244.75 kg of solid waste is generated daily with food waste constituting the dominant fraction at more than 95% of total waste. Revenue estimation was conducted using prevailing local recycling market rates and an assumed selling price for food waste supplied to animal farmers. Under 100% participation, the total potential revenue is estimated at RM149.32 per day, with food waste contributing the largest share. Scenario analysis with varying involvement levels further demonstrates the financial feasibility of systematic waste segregation. The study highlights that structured segregation, portion control, and improved food quality can significantly enhance both environmental sustainability and economic returns within the school waste management framework.

Keywords: *Solid waste assessment, food waste, waste segregation, recycling revenue, school canteen sustainability*

1. Introduction

Solid waste generation in school canteens, including food leftovers, plastic packaging, paper materials, and metal containers poses significant environmental challenges due to improper management leading to pollution and increased disposal costs [1]. Food waste in school canteens is substantial, often representing 20-53% of the food served, with plate waste being the largest contributor [2]. Proper segregation and repurposing of food waste, such as supplying it to local animal farmers or composting into fertilizers, can reduce landfill waste and support local agriculture [3]. Assessing the types and quantities of waste generated is essential for improving management practices and promoting sustainability within schools [4]. Economic benefits can be realized through the sale of recyclable materials and food waste reduction measures, which also lower environmental impacts like greenhouse gas emissions [5]. Educational interventions and standardized audit tools have proven effective in raising awareness and reducing food waste in school settings [6]. Factors influencing food waste include foodservice provider practices, serving size, menu composition, and kitchen location [7]. Public initiatives such as donation programs and regular monitoring can help to increase awareness especially among students and minimize food waste generation in schools [1]. This study aims to evaluate solid waste generation in the school and to assess the potential economic value obtained through the segregation and sale of recyclable materials and food waste to local animal farmers, promoting public awareness, sustainability and environmental responsibility.

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The lack of effective solid waste management systems in schools, especially in canteens, leads to improper segregation and disposal of food leftovers, plastics, paper and metals, increasing landfill waste and environmental pollution. Studies show that a significant portion of school-generated waste is recyclable or compostable, highlighting missed opportunities for recycling, composting, and reuse as animal feed that could reduce waste and generate income for schools [8]. Challenges include inadequate infrastructure, limited resources, poor stakeholder support, and low awareness or behavioral issues among students and staff [9]. Effective strategies involve implementing clear waste segregation policies, educational programs to raise awareness and change behavior, community involvement, and partnerships with local organizations or farmers for food waste utilization [10]. Schools that integrate environmental education into their curricula and promote student-led initiatives tend to have better waste management outcomes. Therefore, assessing the types and quantities of solid waste produced is essential to tailor feasible management options like composting organic waste, reselling recyclables, and collaborating with local animal farmers to foster sustainable practices.

As such, this study aims to quantify the amount of solid waste generated in the school canteen and to estimate the potential revenue that could be obtained from selling properly segregated waste materials to local vendors. Specifically, the study seeks to document the various waste categories present in the canteen, including organic waste as well as recyclable and non-recyclable materials, to measure the quantity of each waste type collected within a fixed monitoring period and to evaluate the financial potential of recyclable materials by comparing the collected quantities with prevailing local recycling market rates. The scope of study covers the assessment of solid waste generated within the school compound with particular emphasis on waste produced from the school canteen. The scope includes the identification and classification of waste into categories such as food waste, plastics, paper and metals. The study also evaluates the potential economic value of segregated recyclable materials based on prevailing local market prices, as well as the feasibility of reusing food waste through composting or supplying it to local animal farmers.

2. Methodology

This chapter describes the research methodology adopted to achieve the objectives of the study. It outlines the research design, data collection procedures and methods of analysis used to assess the composition and quantity of solid waste generated at the SMK Engkilili canteen, as well as its economic potential. **Figure 1** shows the structured flow of work for this research project.

2.1 Study Area and Waste Data Collection

This study was conducted within the school compound, with particular emphasis on waste generated from the school canteen. The school canteen was selected as one of the study areas due to its high concentration of daily activities from food and beverage purchasing which contribute significantly to solid waste generation. A structured questionnaire was prepared to ensure that the collected data accurately represented normal school operations. The questionnaire was distributed among the people that visit the canteen, particularly the students and school staff. **Figure 2** shows the front image of SMK Engkilili school canteen building.

2.2 Waste Identification and Classification

Waste identification and classification were carried out using a structured questionnaire to determine the composition and characteristics of solid waste generated within the school environment. A systematic classification of waste streams is fundamental to effective waste management planning, as it enables the identification of dominant waste types and supports the selection of appropriate treatment strategies such as recycling or selling as animal food. By establishing a clear waste profile, the study provides a data-driven basis for improving current disposal practices. Solid waste was categorized into four principal groups which are food waste, plastics, paper, and metals. The classification data was

obtained directly from survey responses, reflecting the types of waste most frequently generated and disposed of within the school canteen area. The identification of dominant waste streams was based on the highest frequency of observed and reported disposal activities. Subsequently, a frequency distribution analysis was conducted for each waste category to quantify its relative occurrence. The classified data were then systematically summarized to provide a comprehensive overview of the overall waste composition and its characteristics. This analytical approach facilitates a clearer understanding of waste generation patterns and supports the development of targeted and sustainable waste management interventions within the school.

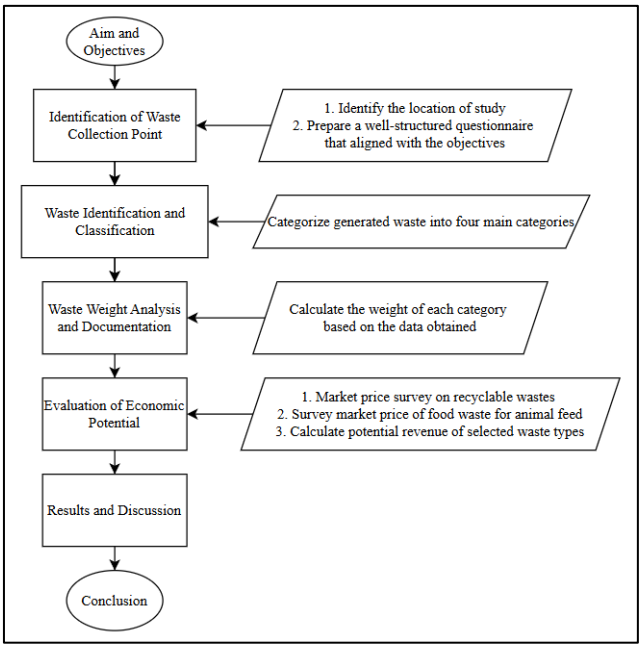


Figure 1. Research Workflow

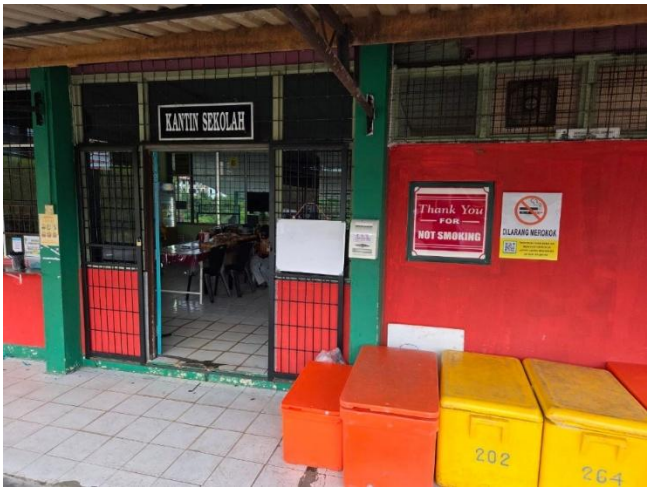


Figure 2. SMK Engkilili Canteen Front Entrance

2.3 Waste Weight Analysis and Documentation

The amount of waste generated in the school was assessed through a structured questionnaire. Instead of directly measuring waste using weighing equipment, data collection was conducted to estimate the relative quantity of waste produced in grams based on responses from students and school staff. From the questionnaire data, the estimated daily weight of each waste category was derived by analyzing the

types and quantities of food purchased, together with the associated packaging materials for each item. By identifying commonly sold food items and estimating their corresponding waste components, the study was able to approximate the daily generation of plastics, paper, metal and food waste.

For food waste specifically, the daily weight generated was estimated based on the quantity of leftover food discarded from each plate into the rubbish bin. The estimation process began by determining the average weight of one full plate of food, which was used as a reference value. Observations were then conducted to assess the proportion of food thrown away, categorised as none, partially consumed, approximately half remaining or fully discarded. The estimated food waste weight was calculated proportionally by relating the observed leftover portion to the average full-plate weight. For instance, if half of the food remained, the waste generated was estimated as 50% of the full-plate weight. By aggregating these proportional estimates across daily observations, the total daily food waste generation was approximated. This approach provided a practical and cost-effective method for evaluating waste generation patterns without requiring technical equipment. Additionally, periodic photographs were taken to support the questionnaire findings, serving as visual documentation of waste accumulation and enhancing the reliability of the estimated data.

2.4 Evaluation of Economic and Environmental Potential

The evaluation of economic and environmental potential was conducted to determine the financial feasibility and sustainability benefits of implementing systematic waste segregation and resource recovery practices within the school. This assessment focused on recyclable materials namely plastics, paper and metals as well as food waste that could be diverted from landfill through resale to local animal farmers. A market-based analytical approach was adopted to estimate potential revenue generation based on prevailing local prices, thereby linking waste management performance to measurable economic returns. Market price information was obtained through online searches and survey-based data collection. Online sources were used to identify current market rates offered by recycling companies and waste collectors while surveys were conducted with selected local recycling vendors and animal farmers to verify and validate the prevailing prices. This combined approach ensured that the price data reflected realistic and locally applicable market conditions. The evaluation assumed that all waste materials were properly segregated at source and free from contamination, as clean and well-sorted materials generally command higher resale value. Based on the previously estimated daily waste quantities for each category, the potential revenue was calculated using the standard economic as shown by **Equation 1**.

$$Revenue = Mass\ (kg) \times Price\ (RM/kg) \quad \text{..... (1)}$$

For each waste category plastics, paper, metals, and food waste the measured or estimated quantity was multiplied by its corresponding market price to determine the daily revenue potential. Where necessary, projected weekly or monthly revenue was calculated by multiplying the daily revenue by the number of operating days. Food waste was evaluated in terms of its suitability for compost production or direct resale as animal feedstock, and its potential value was determined using the same calculation method. The estimated revenue values for each main waste category were then computed individually and aggregated to determine the total potential revenue. It is noted that visit rate to the canteen by students and school staff is not fully 100% as not all students or school staff visits the canteen daily. The visit rate is estimated ranging from 10%, 30%, 50% and 80% to observe the pattern of the potential revenue based on the visit rate to the canteen. The estimated revenue based on the visit rate was calculated using **Equation 2**.

$$Estimated\ Revenue = 100\%\ Visit\ Revenue\ (RM) \times Visit\ Rate\ (\%) \quad \text{..... (2)}$$

This systematic and formula-based evaluation provides a transparent and replicable method for assessing the economic viability of structured waste segregation practices. In addition to financial

returns, the analysis highlights environmental benefits such as reduced landfill disposal, improved resource recovery efficiency and enhanced sustainability performance within the school environment.

3. Results and Discussion

This section presents the results obtained from the questionnaire survey conducted at SMK Engkilili canteen. The objectives of the study were to assess the types and quantity of solid waste generated and to evaluate the potential recyclability and revenue generation from waste materials. A total of 40 respondents with 30 students and 10 school staffs participated in the survey. The questionnaire was distributed and filled on 11th February 2026 during the afternoon at 2:00 pm to 4:30 pm. The data were analysed using descriptive statistical methods, primarily frequency distribution and percentage analysis. The findings are discussed in relation to waste generation behaviour, separation practices and financial feasibility of recycling.

3.1 Waste Classification

The composition of solid waste generated at the SMK Engkilili canteen was classified into four principal categories that are **food waste, plastics, paper and metal.** These categories were selected to represent the dominant waste streams typically associated with school food service operations and to facilitate quantitative assessment of recyclability potential. The questionnaire employed a multiple-response format, allowing respondents to select more than one waste category. Consequently, the resulting dataset reflects cumulative response frequencies rather than mutually exclusive proportions. The data obtained was categorized into two groups for students and school staff to observe the different solid waste generation trends at the canteen, as shown by **Figure 3** and **Figure 4**.

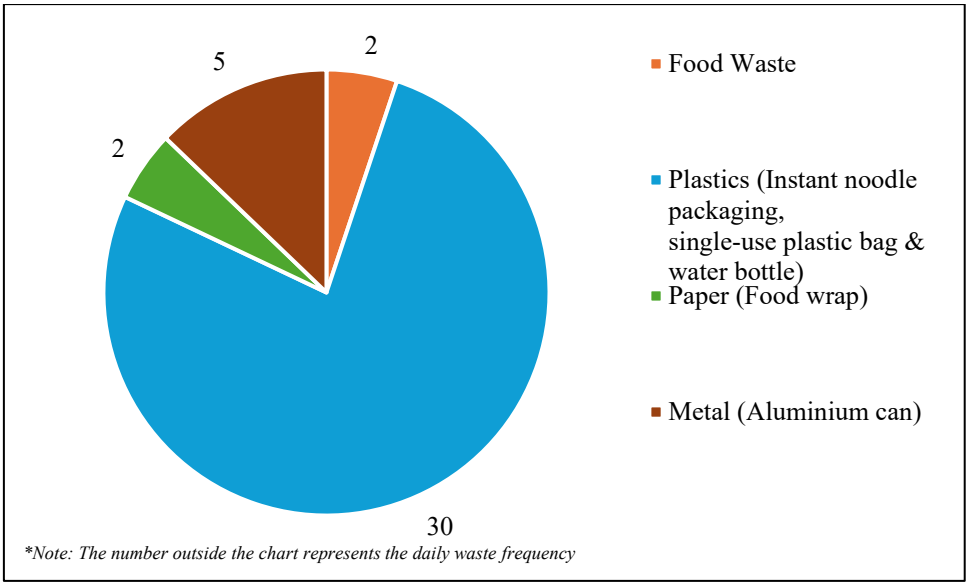


Figure 3. Solid Waste Generated by Students at SMK Engkilili Canteen

The findings presented in **Figure 3** indicate that plastics is the most observed solid waste generated at the canteen answered by students. The survey recorded a frequency of 30 units, plastic waste comprising instant noodle packaging, single-use plastic bags, and water bottles dominate the overall waste composition. In contrast, food waste and paper waste each recorded only 2 units, while metal waste which is aluminium cans accounted for 5 units. This distribution clearly demonstrates that students' consumption patterns are heavily dependent on pre-packaged and single-use plastic products, resulting in a significantly higher generation of non-biodegradable waste compared to biodegradable or recyclable materials.

A comparative analysis between students and staff highlights a significant variation in dominant waste categories. Students primarily contribute to plastic waste, whereas school staff contribute more to food waste. From a waste management perspective, this distinction is important for designing targeted waste reduction strategies. For students, interventions should focus on reducing single-use plastics through awareness campaigns, encouraging reusable containers and improving recycling systems. For staff, strategies such as portion control and food seasonings improvement may be more effective. Therefore, understanding the composition and source of solid waste is essential in developing an efficient and sustainable waste management framework for the school canteen.

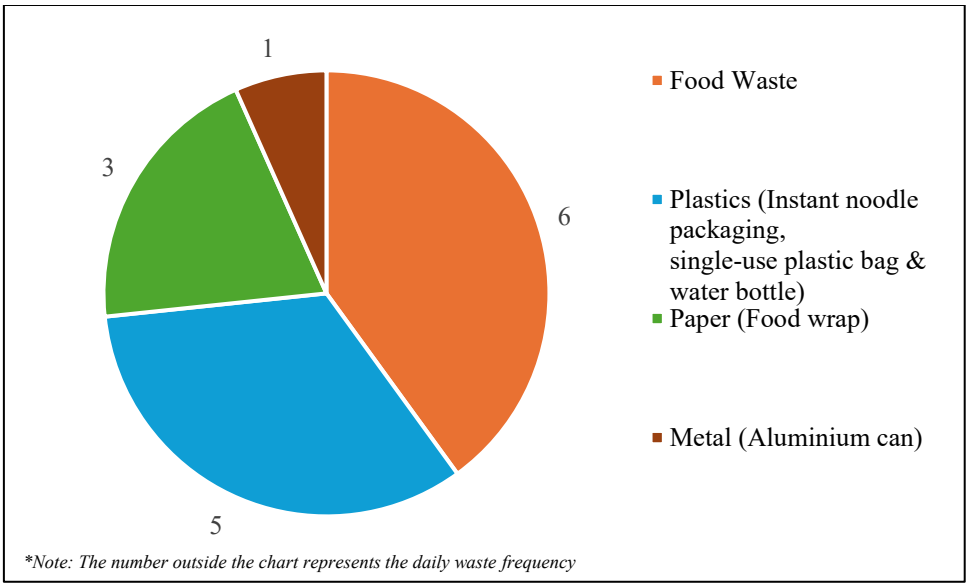


Figure 4. Solid Waste Generated by School Staff at SMK Engkilili Canteen

3.2 Wastes Weight Analysis

This section estimated the total daily solid waste generated in the school canteen by analysing the average waste weight per person. The calculation was standardised by assuming that each individual contributes one disposal event per day. A total of 1040 students were considered, while the staff population consisted of 100 individuals, comprising 94 teachers, 2 security guards and 4 canteen workers. It should be noted that other personnel such as cleaners, gardeners and additional dining hall staffs were not included in this estimation. Therefore, the actual total waste generated within the school may be slightly higher than the values reported. **Table 1** presents the food purchasing frequency among the 30 respondents that are students. The data obtained from the questionnaire are transferred into the table to show the type of food purchased by the respondents and enable the classification of waste type generated. In addition, **Table 2** presented the average waste weight per person for respondent comprising of students.

Referring to **Table 3**, the total daily waste generated by students is estimated at approximately 224.35 kg per day. Food waste constitutes the largest proportion, contributing about 214.5 kg per day, which accounts for more than 95% of the total student waste. This clearly indicates that organic waste dominates the waste stream among students. The substantial quantity of food waste suggests that plate waste, unfinished meals, not tasty food and portion sizes are significant factors influencing overall waste generation. In contrast, non-organic materials such as aluminium cans, instant noodle packaging, water bottles, paper wrap and thin plastic bags represent only a small fraction of the total waste. Although their mass contribution is relatively low, these materials retain recycling value and recovery potential.

Table 1. Frequency of Food Purchasing at SMK Canteen for 30 Respondents

Number of Respondent	Food Category					
	Instant noodle	'Kuih-muih'	Burger	Can beverage	Water bottle (500mL)	Plate-served food
1		1				
2	1					1
3					1	
4					1	
5				1		
6		1			1	
7			1			1
8		1				
9				1		
10				1		1
11				1		1
12				1		
13				1		
14				1		
15				1		
16				1		
17				1		1
18	1		1	1		
19		1				
20		1		1		
21	1					
22		1				1
23			1			
24	1					
25		1				
26				1		
27				1		
28				1		
29				1		
30				1		1
Total	**4**	**7**	**3**	**16**	**3**	**7**

Table 2. Daily Generated Waste Weight by 30 Respondents

Waste	Waste Weight (g)	Total Waste Weight (g)	Average per Student (g)
Instant noodle packaging	4.5	18.0	0.60
Thin plastic bag	1.0	7.0	0.23
Paper wrap	5.0	15.0	0.50
Aluminium Cans	14.0	224.0	7.47
Water bottle (500mL)	10.0	20.0	0.67
Food waste	400.0	6187.5	206.25

Table 3. Total Daily Waste Weight Generated by 1,040 Students

Waste	Total Weight (g)	Total Weight (kg)
Instant noodle packaging	624.0	0.62
Thin plastic bag	239.2	0.24
Paper wrap	520.0	0.52
Aluminium Cans	7768.8	7.77
Water bottle (500mL)	696.8	0.70
Food waste	214500.0	214.5
Total (kg)		**224.35**

Table 4 shows the food purchasing frequency answered by 10 respondents consisting of teachers, security guards and canteen workers. The data shows the purchasing pattern by the school staff in a day. In addition, **Table 5** presented the average waste weight per person for respondent comprising of school staff. Similarly, based on **Table 6**, the estimated total waste generated by school staff is approximately 20.4 kg per day. Food waste again represents the dominant component, contributing around 20.0 kg per day, which accounts for approximately 97% of the total staff waste generation. This pattern is consistent with the student findings, demonstrating that organic waste is the primary contributor within the canteen environment. Non-organic waste generated by staff, including aluminium cans, paper wrap, water bottles, instant noodle packaging and thin plastic bags, contributes only minimal quantities. Despite their smaller volumes, proper segregation of these materials could support recycling efforts and resource recovery.

Table 4. Frequency of Food Purchasing at SMK Canteen for 10 Respondents

Number of Respondent	Food Category					
	Instant noodle	'Kuih-muih'	Burger	Can beverage	Water bottle (500mL)	Plate-served food
1						1
2		1				
3	1					1
4						1
5		1				1
6			1			
7				1		1
8			1			
9	1		1			
10					1	1
Total	**2**	**2**	**3**	**1**	**1**	**6**

Table 5. Daily Generated Waste Weight by 10 Respondents

Waste	Waste Weight (g)	Total Waste Weight (g)	Average per Staff (g)
Instant noodle packaging	4.5	9.0	0.09
Thin plastic bag	1.0	2.0	0.02
Paper wrap	5.0	15.0	1.5
Aluminium Cans	14.0	14.0	1.4
Water bottle (500mL)	10.0	10.0	1.0
Food waste	400.0	2000.0	200.0

Table 6. Total Daily Waste Weight Generated by 100 Staffs

Waste	Total Weight (g)	Total Weight (kg)
Instant noodle packaging	9.0	0.009
Thin plastic bag	2.0	0.002
Paper wrap	150.0	0.15
Aluminium Cans	140.0	0.14
Water bottle (500mL)	100.0	0.10
Food waste	20000.0	20.0
Total (kg)		**20.4**

Overall, while the total waste generated by students is significantly higher than that of school staff due to population size, both groups exhibit a similar waste composition pattern dominated by food waste. When combined, the estimated total waste generated in the school canteen is approximately 244.75 kg per day, with organic waste forming the overwhelming majority. These findings indicate that food waste management should be prioritised as the primary strategy for waste reduction. Concurrently,

implementing an effective waste segregation system would enhance recyclable recovery, reduce landfill disposal and improve the environmental and economic sustainability of the school's waste management practices.

3.3 Wastes Economic Potential Analysis

Economic potential exists within each category of waste generated at the school canteen, particularly when the waste is properly classified into recyclable and organic fractions. Recyclable wastes, including plastics, paper and metal possess measurable market value when segregated and sold to local recycling centres. These facilities typically offer a payment based on weight (RM/kg), providing an opportunity to convert discarded materials into a modest but consistent source of income. Although the monetary return may not be substantial daily, the cumulative financial benefit over a week, month or year can be meaningful. More importantly, this approach reinforces the principles of resource recovery and circular economy where materials are reintroduced into the production cycle rather than being disposed of in landfills.

Other than recyclable wastes, food waste also presents economic potential. Due to its substantial daily mass, food waste can be sold to local animal farmers at a negotiable price particularly when it is suitable for livestock feed. The large volume generated daily increases its potential economic contribution despite having a lower unit price compared to recyclable materials. Furthermore, diverting food waste to animal farming reduces organic waste accumulation in landfill sites, minimising odour issues and methane emissions associated with decomposition. Therefore, both recyclable and organic waste streams contribute to the overall economic and environmental sustainability of the school canteen waste management system.

The data on the waste weight from the school staff and students was combined and grouped into 4 main categories which are plastics, paper, metal and food waste. The analysis based on **Table 7** clearly indicates that combined weight of food waste from students and school staff can generate roughly RM 117.25 daily revenue under full attendance of 1040 students and 100 school staff by not considering personnel such as cleaners, gardener or dining hall workers. This outcome is primarily attributed to its substantially large daily mass which compensates for its relatively moderate selling price of RM 0.50 per kilogram which still can be negotiable with the buyer. The total estimated revenue that could be generated from all waste categories is around RM 149.32 per day. However, it is not totally possible to achieve 100% of visit rate from the students and school staff. In practice, some students may bring food from home, some school staff may not purchase meals daily and segregation efficiency may not reach 100%. Additionally, market prices for recyclable materials and food waste may fluctuate. Therefore, the projected revenue may represent an upper-bound estimate.

Table 7. Waste Category with Estimated Daily Revenue for 100% Visit Rate

Waste Category	*Estimated Price (RM/kg)	Total Weight by Students (kg)	Total Weight by School Staff (kg)	Total Revenue by Students (RM)	Total Revenue by Staff (RM)	Overall Revenue (RM)
Plastics	0.20	1.56	0.11	0.31	0.02	0.33
Paper	0.10	0.52	0.15	0.05	0.05	0.10
Metal	4.00	7.77	0.14	31.08	0.56	31.64
Food Waste	0.50	214.5	20.0	107.25	10.00	117.25
Total (RM)						**149.32**

*Note: *The price for recyclable materials was obtained from DBKU Recycling Campaign 2025 [11]. The price for food waste to sell to animal farmers is assumed to be RM0.50 per kg.*

The realistic estimated daily revenue from selling waste can be calculated by assuming the percentage of visit rate ranging from 10%, 30%, 50% and 80%. **Table 8** shows the total estimated revenue that can be projected by considering incomplete visit from the students and school staff. In addition, **Figure 5** represents the statistic graph of the estimated daily revenue with different visit rate from the students and school staff. Meanwhile, **Figure 6** represents the weekly estimated revenue, **Figure 7** shows for monthly while **Figure 8** shows for yearly. Based on the data on estimated revenue over time periods with varies visit rate from the students and school staff, the statistic trend can be observed to be increasing with the visit rate.

Table 8. Estimated Daily Waste Revenue for Different Visit Rate

Visit Rate (%)	Waste Revenue (RM)				Total Estimated Revenue (RM)
	Plastics	Paper	Metal	Food Waste	
10	0.03	0.01	3.16	11.73	14.93
30	0.10	0.03	9.50	35.18	44.81
50	0.17	0.05	15.82	58.63	74.67
80	0.26	0.08	25.31	93.80	119.45
100	0.33	0.10	31.64	117.25	149.32

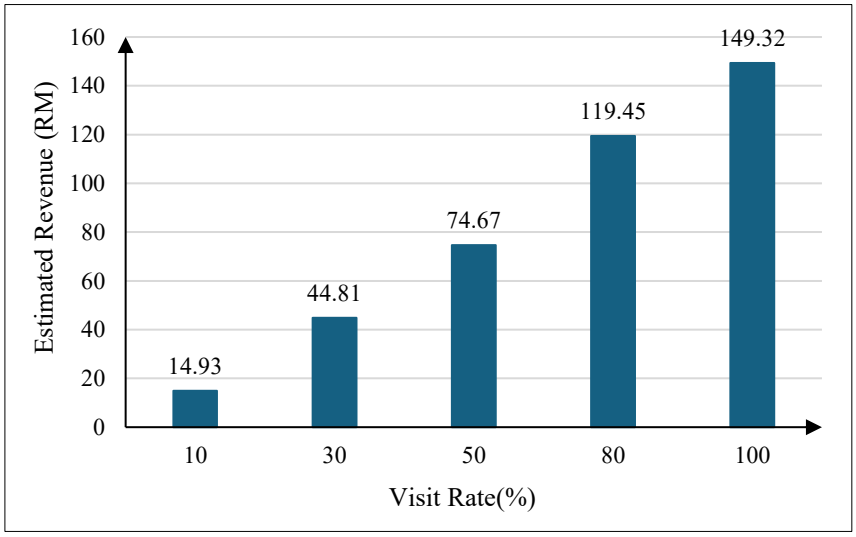


Figure 5. Daily Estimated Revenue with Different Visit Rate

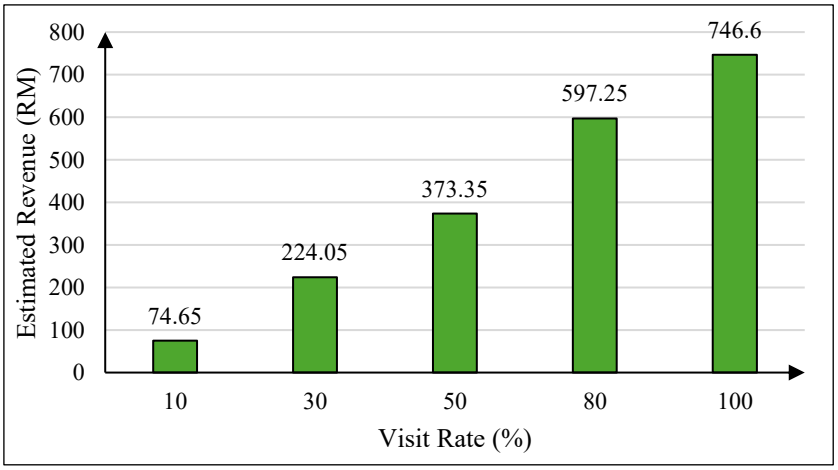


Figure 6. Weekly Estimated Revenue with Different Visit Rate

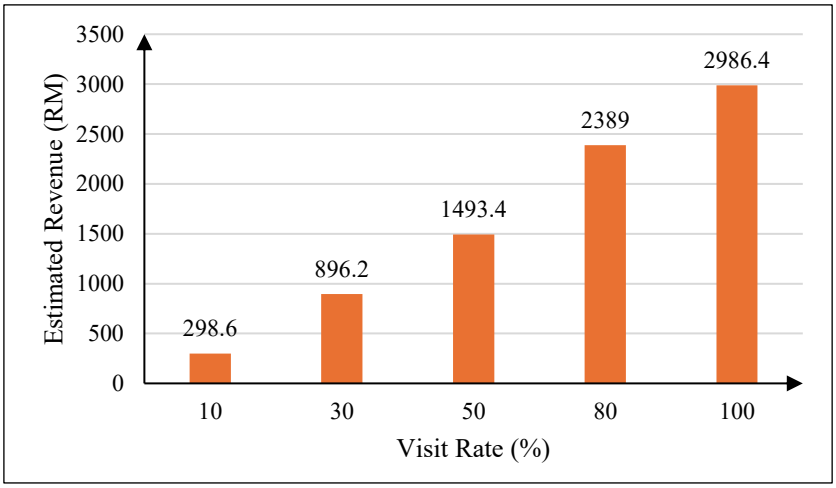


Figure 7. Monthly Estimated Revenue with Different Visit Rate

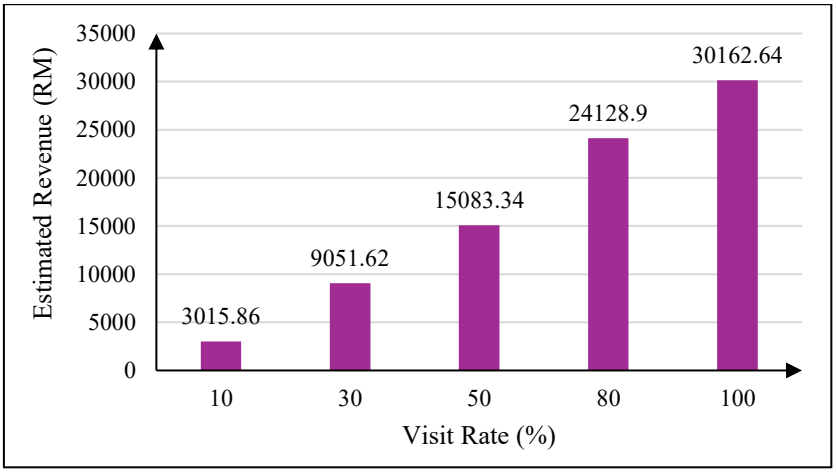


Figure 8. Yearly Estimated Revenue with Different Visit Rate

The strategy of selling waste serves not only as a revenue-generating initiative but also as an educational mechanism. It promotes environmental awareness among students and school staff by demonstrating that waste materials retain economic value when managed responsibly. Instead of viewing waste solely as an environmental burden, students and school staff are encouraged to recognise it as a recoverable resource. This mindset shift supports sustainable waste management practices while reducing environmental pollution caused by improper disposal.

3.4 Suggestions and Improvement

Based on the questionnaire results, all respondents agreed that there are no dedicated recycling bins at the canteen. As a result, waste is disposed of without proper segregation, leading to a high volume of mixed waste. This situation discourages sustainable recycling practices and limits the economic potential of recyclable materials. Installing clearly labelled bins for plastics, paper, metal, and food waste would enable systematic separation at the source. Proper segregation reduces contamination, improves recycling efficiency, and enhances material recovery value. Separating food waste is especially important due to its large daily contribution, as it can be redirected for animal feed or composting, reducing landfill disposal and environmental impacts.

Most respondents also agreed that food quality and portion size contribute to food waste. Many stated that the food is not well seasoned, causing them to leave unfinished meals. Others mentioned that portions are too large for normal consumption. Adjusting portion sizes to match consumption needs and improving food quality can significantly reduce plate waste. These improvements address food waste directly at the source. Providing dedicated bins also promotes environmental awareness and responsible disposal habits among students. Behavioural participation is essential for an effective waste management system. By combining proper segregation practices with improvements in food quality and portion control, the school can reduce landfill waste and increase recycling value. This integrated approach supports environmental sustainability and enhances overall resource recovery efficiency.

4. Conclusion

This study successfully achieved its aim and objectives by quantifying the amount of solid waste generated at the SMK Engkilili canteen, classifying the waste into four main categories and estimating the potential economic value of properly segregated materials. The analysis confirmed that food waste is the dominant waste stream, contributing the majority of the estimated 244.75 kg of daily waste generated at the canteen under full visit rate from the students and school staff. Different visit rate from the students and school staff can also affects the total estimated revenue over time periods. Through revenue calculations based on prevailing local market prices, the study demonstrated that structured waste segregation and resource recovery could generate meaningful financial returns while reducing landfill disposal. The results provide clear evidence that implementing dedicated recycling bins, improving food portion control and enhancing food quality can support sustainable waste management practices. Therefore, the research not only fulfilled its intended objectives but also provides a practical and data-driven foundation for improving environmental sustainability and economic efficiency within the school canteen system.

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Food Waste Generation and Disposal at School Kitchen of SMK Engkilili, Sri Aman, Sarawak

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Abstract

Food waste has become an increasing environmental concern, particularly in institutional settings such as school hostels where large quantities of food are prepared daily. In Malaysia, limited recording of actual food usage and waste in school kitchens makes it difficult to estimate food distribution patterns and potential organic waste generation. Therefore, this study was conducted to estimate the total food prepared and edible food available in a secondary school hostel accommodating 570 students. The study focuses on analysing weekly menu data to determine food quantity by category and to identify the difference between total food prepared and edible portion. A spreadsheet programme was developed using Microsoft Excel to calculate total food prepared based on portion size per student and to convert raw food quantities into edible weight using standard edible portion factors. Based on the result obtained, grains and rice contributed the highest proportion of total edible food prepared, followed by fruits and vegetables, while poultry and seafood represented moderate quantities. The comparison indicates the presence of non-edible components such as bones and peels. This study also demonstrates a simple estimation approach that can be applied in school settings to improve awareness of food waste management practices and to support future planning for food waste reduction strategies, including composting or biogas production.

Keywords: *Food waste, School kitchen, Organic waste, Management practices*

1. Introduction

Food waste has become a global concern due to its economic, social and environmental impacts. The increasing demand for food, driven by population growth and urbanization, has led to higher levels of food production and consumption. However, inefficient food management systems, poor storage practices and over-preparation have contributed to rising food waste generation [1]. This not only reduces food availability but also affects food security, especially in developing countries where access to food resources may already be limited [2]. Reducing food waste is therefore an important step toward achieving sustainable development and responsible consumption. Furthermore, improper disposal of food waste can strain waste management systems and increase the burden on landfills. When food waste is mixed with general solid waste, it becomes more difficult to recover resources such as compost or energy. Many countries are now encouraging waste reduction strategies, including better planning, portion control and awareness programs, to minimize food waste at the source [3].

In school environments, food waste is commonly generated in the school kitchen during preparation and from leftover food after meals. Factors such as food preferences, portion size, student attendance and lack of awareness among students can contribute to the generation of food waste in educational institutions [4]. When students do not finish their meals or when food is over-prepared, a significant amount of leftover food may be generated. Without proper monitoring and recording, it is difficult to identify the main cause and types of food waste in the school kitchen.

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At Sekolah Menengah Kebangsaan Engkilili (SMK Engkilili), food preparation activities in the school kitchen may result in food waste such as leftover rice, vegetables, fruits and more. However, the amount and types of food waste produced are often not recorded or studied. The absence of structured daily data limits understanding of how menu variation affects the quantity and type of food waste produced. Consequently, effective strategies to reduce food waste such as composting or biogas production cannot be properly developed. As such, the aim of this research is to investigate food waste generation in the school kitchen of SMK Engkilili. The objectives of this research are (i) to identify and categories the types of food waste generated in the school kitchen, such as leftover rice, vegetables, fruits, and more, (ii) to measure the quantity of food waste produced over a selected monitoring period and (iii) to examine the potential reuse or value of food waste through composting or other suitable waste management method.

2. Methodology

This section explained the methods used to carry out the study on food waste generation in the school kitchen of SMK Engkilili. The methodology described how the data were prepared, collected, and analyzed systematically, as shown in **Figure 1**. The study involved three main stages, (i) questionnaire development, (ii) data collection, and (iii) data analysis.

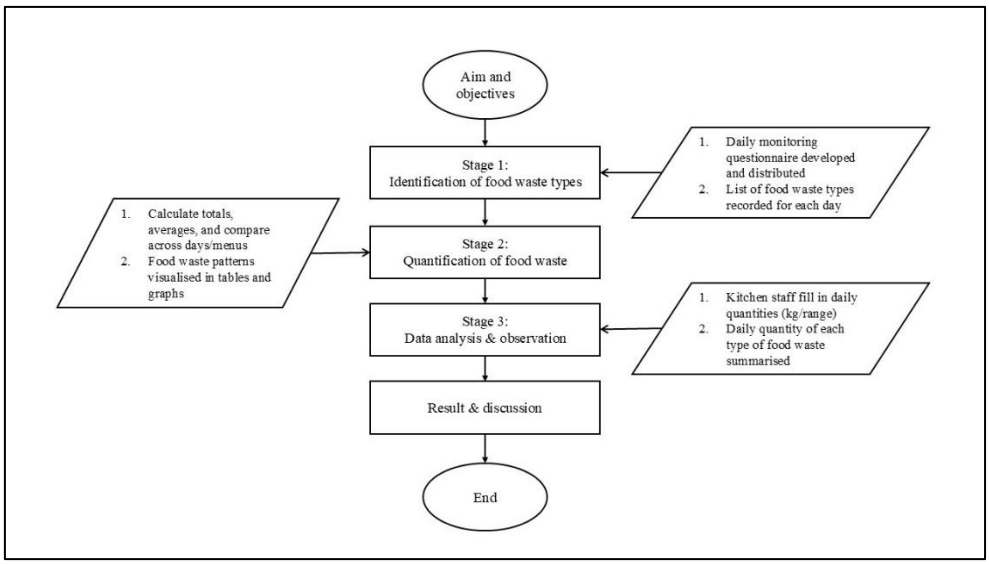


Figure 1. Research methodology flowchart

2.1 Development of questionnaire

A daily food waste questionnaire was developed to systematically record food waste generated at the school kitchen. The questionnaire was designed to collect information related to menu variation, quantity of food prepared and wasted under the following categories: vegetables, poultry, beef, seafood, grains and rice, fruits, eggs, legumes, dairy, and processed food or snacks. It also included information on types of food waste, causes of waste, and student acceptance of the menu.

The development process involved identifying key variables related to food waste in the school kitchen, designing the questionnaire in a table format with monitoring days as columns, using category ranges for food quantity to simplify estimation by kitchen staff, and reviewing the questionnaire to ensure clarity and consistency.

2.2 Data collection

A daily food waste recording form was prepared to collect information about food preparation and waste in the school kitchen. The form was designed to record the menu served each day, the estimated

number of students, the quantity of food prepared, the type and estimated amount of food waste and possible reasons for food waste. The important variables related to food waste in the school kitchen were recorded using simple estimation ranges. The form was reviewed to make sure the questions were clear and easy to understand. In addition, Microsoft Excel was used to develop a spreadsheet for calculating the total food prepared. The calculation was based on portion size per student and the total number of students. Edible portion percentages were also included to estimate edible weight and non-edible parts such as bones and peels.

2.3 Data analysis

The collected data were analyzed using descriptive analysis. All recorded information was entered into Microsoft Excel and organized into tables. The analysis involved grouping of food waste according to type such as rice, vegetables, fruits, poultry, seafood and others, calculating the total quantity of food prepared and wasted, comparing food waste amounts based on different menus and identifying simple patterns and trends. The results were presented using tables and simple graphical representations such as bar charts and pie charts to make the findings easier to understand. Below were equations used. **Equation 1** was used to determine the combined daily waste generated from both preparation and leftover sources.

$$W_d = W_{prep,d} + W_{left,d} \quad \text{..... (1)}$$

Where, W_d represented the total waste daily (kg), $W_{prep,d}$ represented the preparation waste for daily (kg) and $W_{left,d}$ represented the leftover waste for daily (kg).

Total waste accumulated over one operational week **was** calculated by using **Equation 2.**

$$W_w = \sum_{d=1}^{n} W_d \quad \text{..... (2)}$$

Where, W_w represented the total weekly waste (kg), W_d represented total waste daily (kg) and n represented the number of monitoring days in one week.

Individual food category accumulated waste was calculated by **Equation 3.**

$$W_c = \sum_{d=1}^{n} W_{c,d} \quad \text{..... (3)}$$

Where, W_c represented the total waste for food category (kg) and $W_{c,d}$ represented waste of category daily (kg).

Equation 4 was used to determine proportional contribution of each food category to total waste, while **Equation 5** was used to quantify the relative dominance of leftover waste compared to preparation waste. The weekly waste projection was determined by employing **Equation 6** and **Equation 7** was used to estimate monthly waste based on four operational weeks. Lastly, **Equation 8** was used to estimate annual waste to academic calendar duration.

$$P_c = \left(\frac{W_c}{W_{tot}}\right) \times 100 \quad \text{..... (4)}$$

Where, P_c represented the percentage contribution of category (%), W_c represented total waste of category (kg) and W_{tot} represented total overall waste (kg).

$$D\% = \left(\frac{W_{left} - W_{prep}}{W_{prep}}\right) \times 100 \quad \text{..... (5)}$$

Where, $D\%$ represented percentage difference (%), W_{left} represenetd the total leftover waste (kg) and W_{prep} represented the total preparation waste (kg).

$$\overline{W}_w = \left(\frac{\sum_{i=1}^{m} W_{w,i}}{m}\right) \quad \text{..... (6)}$$

Where, $\bar{W}_w$ represented the average weekly waste (kg), $W_{w,i}$ represented the total waste for week (kg) and m represented number of observed weeks.

$$W_{month} = \bar{W}_w \times 4 \quad \text{..... (7)}$$

Where, W_{month} represented projected monthly waste (kg) and $\bar{W}_w$ represented the average weekly waste (kg/week).

$$W_{year} = \bar{W}_w \times N_{op} \quad \text{..... (8)}$$

Where, W_{year} is the projected yearly waste (kg) and N_{op} is the number of operational school weeks per year (40 weeks).

3. Results and Discussion

This section presents the findings obtained based on questionnaire for food waste generation at the school kitchen and discussed the observed patterns in relation to operational practices and sustainability considerations. The analysis focuses on the total waste, comparison between preparation and leftover waste, weekly trends and waste composition by food category. The results are interpreted to identify key contributors to waste generation and to evaluate potential areas for improvement within the school food service system.

3.1 Amount of Waste Generation

The four-week period data recorded from the questionnaire given to the kitchen helper at school kitchen and recorded a total food waste generation of 6557.89 kg as shown in **Table 1**. Waste was categorised into preparation waste and leftover waste to differentiate between unavoidable and avoidable losses within the school food service system.

Table 1. Weekly total waste per week

Week	Weekly Total Waste (kg)	Total Overall
Week 1	1595.88	6557.89
Week 2	1641.43	
Week 3	1647.13	
Week 4	1673.45	

Shown in **Table 2** and **Table 3**, the leftover waste contributed 3449.19 kg (52.6%), while preparation waste accounted for 3108.71 kg (47.4%). This indicated that leftover waste was higher than preparation waste overall. The dominance of leftover waste suggested that post-cooking losses, rather than raw material trimming, were the primary contributors to total waste generation.

Table 2. Weekly total leftover waste per week

Week	Weekly Total Leftover Waste (kg)	Total Overall
Week 1	834.23	3449.19
Week 2	865.73	
Week 3	851.4	
Week 4	897.83	

The data covered four weeks (28 days) of menu schedules, including weekends, which were prepared for approximately 570 students daily. The average daily wasted across 28 monitoring days was 234.21 kg per day. On average, daily leftovers were 123.19 kg, while preparation waste averaged 111.02 kg. Although the numerical difference appeared moderate, the consistent excess of leftover waste across

most observation days indicated systematic overproduction or mismatch between supply and student consumption.

Table 3. Weekly total preparation waste per week

Week	Weekly Total Preparation Waste (kg)	Total Overall
Week 1	761.65	3108.71
Week 2	775.7	
Week 3	795.73	
Week 4	775.63	

3.2 Daily Waste Patterns

The total daily food waste consisted of two components, preparation waste and estimated leftover waste. Preparation waste referred to food removed during processing, such as vegetable peels, meat bones, and trimming, while leftover waste represented the portion of food prepared but not consumed by students. Across the four-week period, preparation waste ranged from 86.75 kg to 123.75 kg per day, while estimated leftover waste varied from 99.38 kg to 156.75 kg per day. In terms of percentages, estimated leftover waste contributed approximately 52% to 55% more than prepared waste on average daily, indicating that over-preparation and student food preference play an important role in waste generation. **Figure 2** shows the total daily leftofver waste and total daily preparation waste per day.

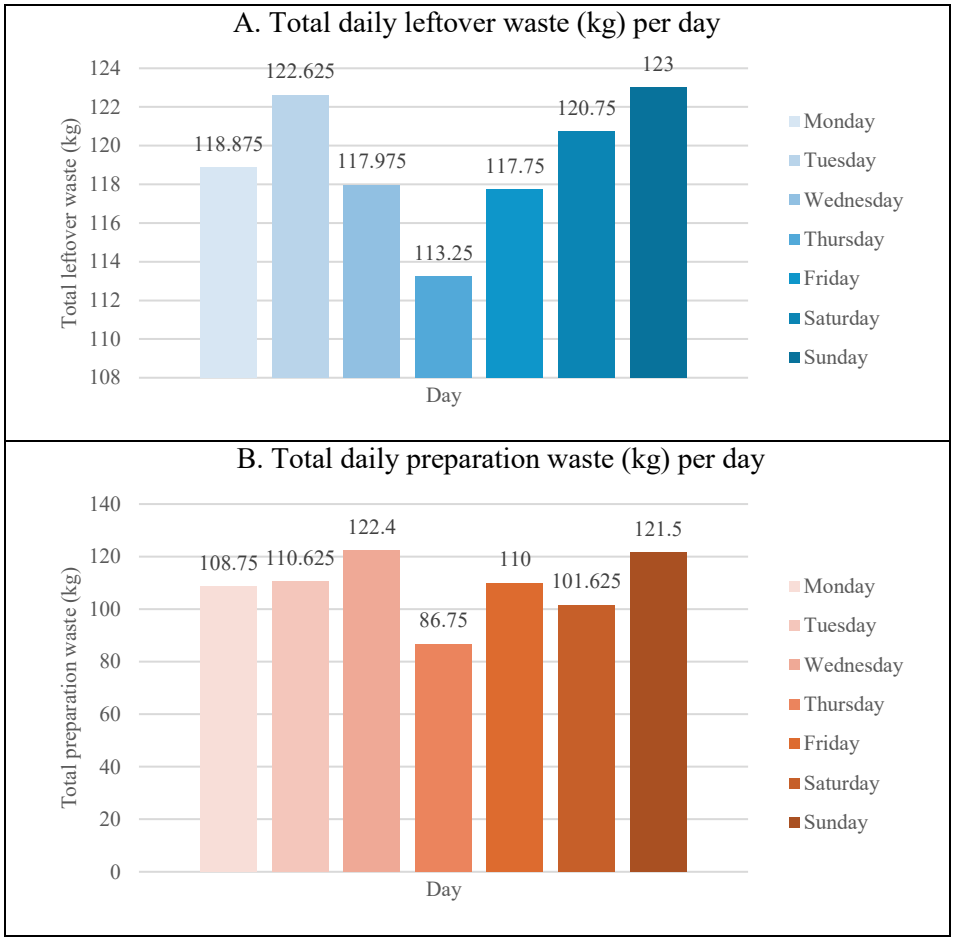


Figure 2. Total daily leftover and total daily preparation waste for a week

For example, as shown in **Figure 2**, on Monday of Week 1, preparation waste was recorded at 108.75 kg, while estimated leftover waste reached 118.88 kg, resulting in a total daily waste of 227.63 kg shown

in **Figure 3**. From **Figure 4**, similar trends were observed for the rest of the week, with fruits contributing the highest proportion of leftover waste, while grains and rice, despite being the largest portion of procurement, showed minimal leftovers. This reflects the high acceptability of staple foods among students, consistent with findings in institutional food studies [5].

The waste composition graph, **Figure 4**, indicated variation among food categories. Based on the accumulated data, fruit contributes 448 kg (28.07%), representing the highest proportion of leftover waste. Vegetables also showed significant trimming waste during preparation. This indicates that the high fruit waste may be attributed to lower student preference, over-portioning, or spoilage sensitivity, as fruits are highly perishable and easily rejected if appearance or ripeness is unsatisfactory. The second highest contributor was grains and rice which is 302.63 kg (18.96%). Although rice is generally well-accepted, the relatively high accumulated values suggest that even small daily leftovers of staple foods can accumulate significantly over a full week. Given that rice is prepared in bulk quantities, minor estimation errors can result in noticeable waste volume. Vegetables contributed 266.88 kg (16.73%), which is likely dominated by preparation waste such as peels, and trimming losses. Unlike fruits, vegetables waste is partially unavoidable due to inedible portions. However, inefficient trimming practices may also contribute. Poultry contributed 212.63 kg (13.32&) and seafood equivalent to 211.25 kg (13.24%) showed that nearly equal contributions. Lower contributions were observed for beef with value of 45 kg (2.8%), processed food or snacks contributed 47.25 kg (2.96%), legumes equal to 33.75 kg (2.11%) and eggs 28.5 kg (1.8%).

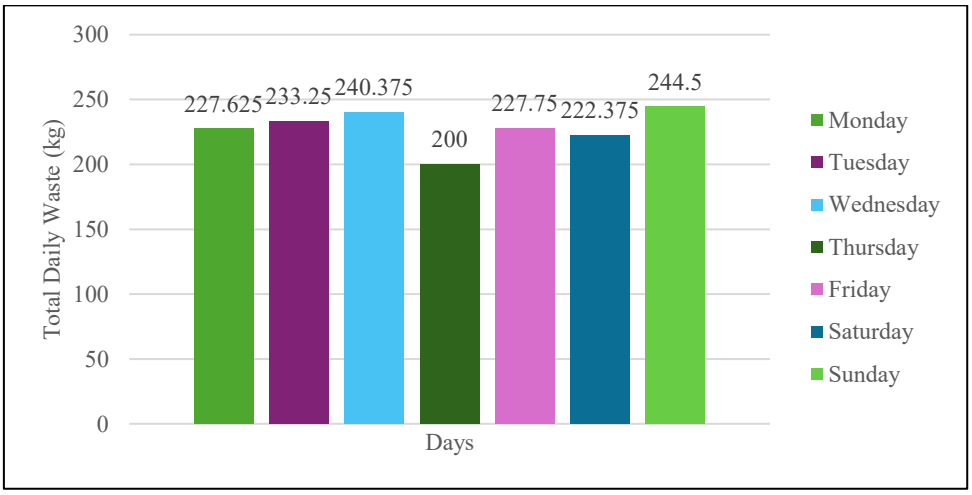


Figure 3. Total daily waste (kg) per day

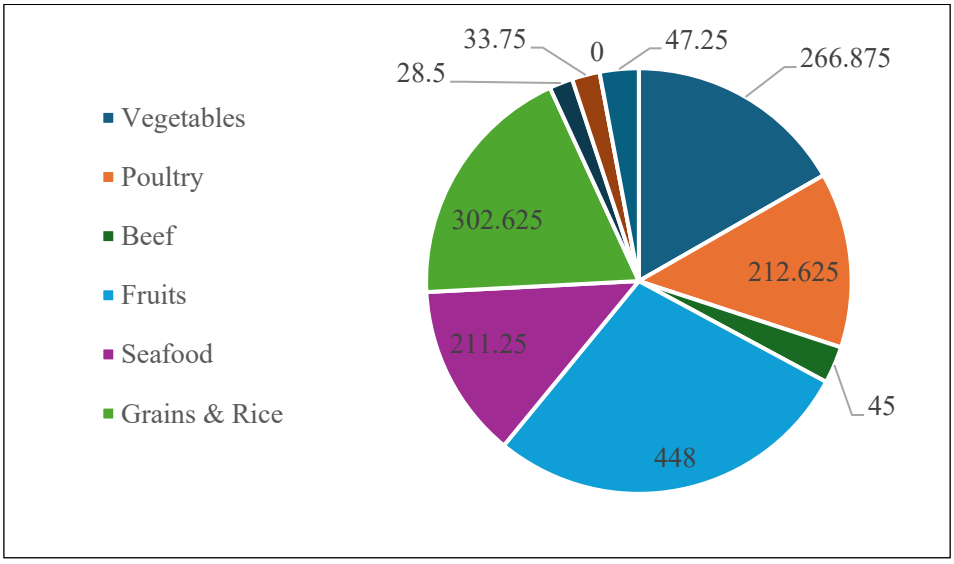


Figure 4. Waste composition by food category

3.3 Weekly Food Waste Analysis

Weekly food waste was determined by summing the total daily preparation waste and total daily leftover waste for each week. Three graphical representations were developed to (i) illustrate total preparation waste per week, (ii) total leftover waste per week, and (iii) total overall waste per week. The analysis across four weeks provides a clearer understanding of waste generation trends under different weekly menu variations.

From **Figure 5**, for Week 1, the total preparation waste was recorded at 761.65 kg, while the total leftover waste amounted to 834.23 kg, resulting in an overall weekly waste at 1595.88 kg. Leftover waste exceeded preparation waste by 72.58 kg, representing a 9.5% higher contribution compared to preparation losses. This indicates that the plate waste and unconsumed cooked food were slightly more significant than trimming and processing losses. According to respondent A, the students tend to be selective about what they eat. In Week 2, preparation waste increased to 775.7 kg and leftover waste rose to 865.23 kg. The total weekly waste therefore reached 1641.43 kg. The difference between leftover and preparation waste was 89.53 kg, corresponding to a 10.3% higher leftover contribution. Compared to Week 1, this reflects a noticeable increase in both components, suggesting that menu variation or higher quantities of perishable food items such as poultry, seafood, and vegetables may have contributed to greater discarded rates.

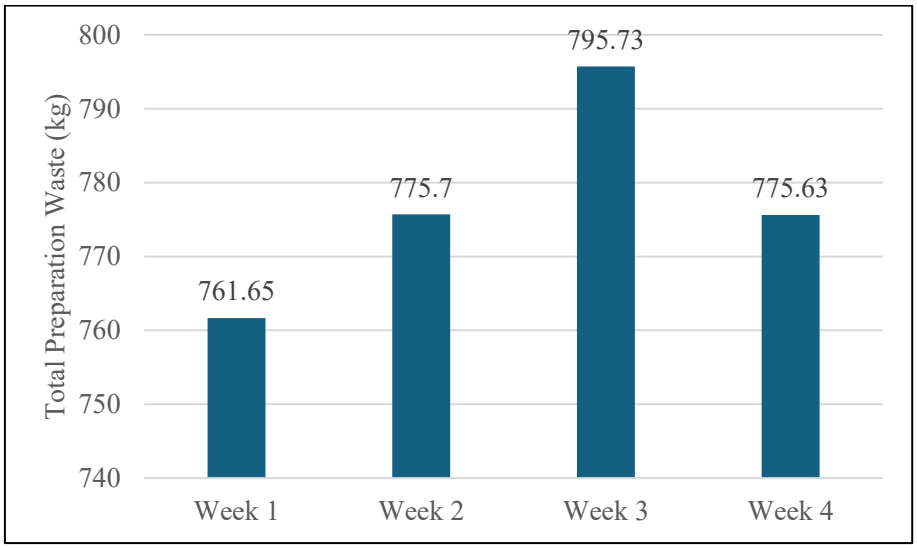


Figure 5. Total preparation waste (kg) per week

From **Figure 6** and **Figure 7**, week 3 was recorded the highest preparation waste at 795.73 kg, while leftover waste was 851.40 kg. The total weekly waste was 1647.13 kg. Although preparation waste was the highest among all weeks, leftover waste still exceeded preparation waste by 55.67 kg, equivalent to 7.0% difference. The smaller percentage gap compared to week 2 suggests relatively better balance between preparation efficiency and food consumption during that week. Week 4 showed preparation waste of 775.63 kg and the highest leftover waste among all weeks at 897.83 kg. This resulted in the highest total weekly waste of 1673.45 kg. The difference between leftover and preparation waste was 122.20 kg, corresponding to a 15.8% higher leftover waste. This significant gap shows that student consumption variability or over-preparation may have been more pronounced during that week.

When comparing all four weeks collectively, leftover waste consistently exceeded preparation waste. The percentage difference ranged from 7.0% to 15.8%, with an average difference of approximately 11%. This trend clearly demonstrates that post-cooking losses uneaten food contributes more total waste than unavoidable preparation losses such as vegetable peels, fruit skins, bones and trimming residues [6]. The graphical trends further support this observation. While preparation waste remained relatively stable across weeks, leftover waste showed greater fluctuation. This indicates that preparation waste is

relatively predictable and depends mainly on raw materials type and edible portion percentage, whereas leftover waste is influenced more strongly by student attendance, portion size and menu acceptance [7].

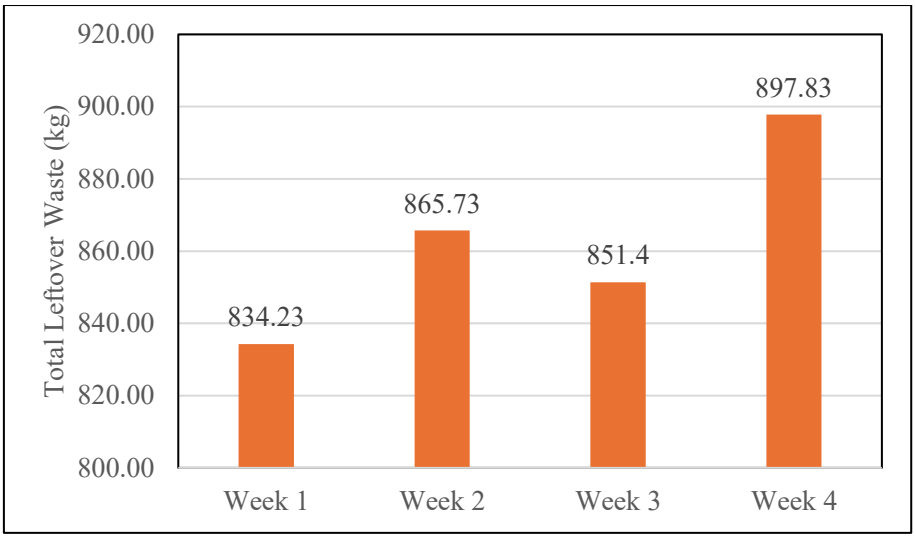


Figure 6. Total leftover waste (kg) per week

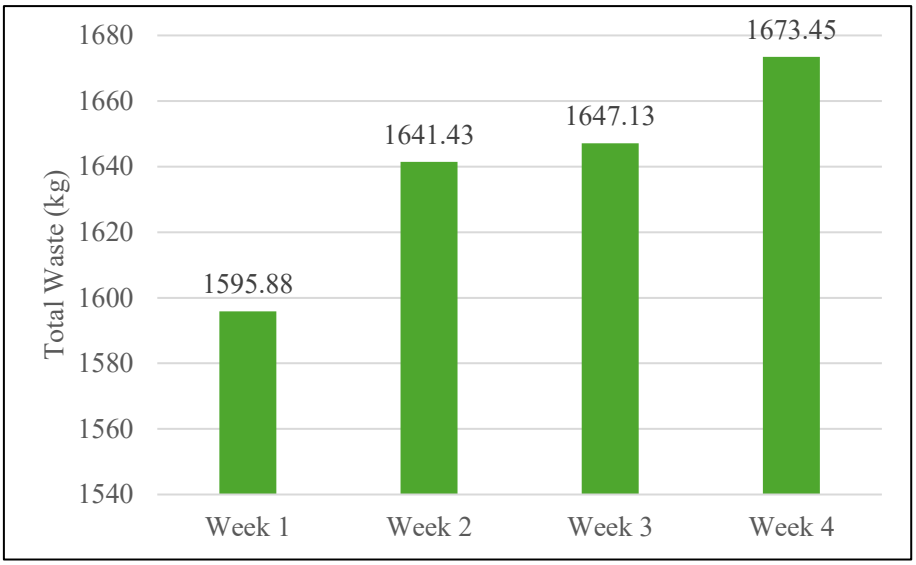


Figure 7. Total waste generated

Although this projection is based on estimation rather than direct measurement, the relatively small variation between weekly totals suggests that the four-week sample estimation provides a reasonable representation of normal kitchen operations. The difference between the lowest and highest weekly waste was only 77.57 kg corresponding to a variation of 4.9%. This consistency strengthens the reliability of the monthly scaling approach. When projected over one academic year, adjustments were made according to the school academic calendar for Sarawak, which operates approximately 40 active schooling weeks annually, excluding semester breaks and long holidays. Using this operational duration, the total annual food waste is estimated at 65578.80 kg (as shown in **Table 4**), equivalent to approximately 65.58 tons per year.

This yearly data highlights the cumulative of food waste in institutional settings. While daily and weekly values may appear manageable, the long-term accumulation is important. For example, 65.58 tons of food waste annually represents a significant loss of resources including raw food materials, water, energy used in cooking, and labor. Furthermore, if disposed of landfills, decomposing organic

waste contributes to methane emissions, a greenhouse gas with higher global warming potential than carbon dioxide [8].

Table 4. Monthly and yearly food waste projection based on average weekly waste

Parameter	Value (kg)
Average weekly waste	1639.47
Estimated monthly waste (4 weeks)	6557.88
Estimated yearly waste (40 week)	65578.80

3.5 Implications for Waste Management and SDGs

The results emphasize the importance of targeted strategies to reduce food waste in schools. Reducing over-preparation, introducing portion control, and improving storage for perishable items such as poultry, seafood, and vegetables could reduce daily waste by up to 10-15%. Additionally, leftover food can be diverted to composting or biogas production, contributing to SDG 12: Responsible Consumption and Production and SDG 13: Climate Action by reducing resource inefficiency and greenhouse gas emissions from food disposal [9]. Incorporating these strategies not only supports environmental sustainability but also enhances operational efficiency and resource management in the school kitchen [10]. Overall, the monthly and yearly confirms that food waste generation in the school kitchen is systematic rather than incidental. Even moderate weekly waste, when accumulated across operational weeks, results in annual material loss. These findings prove the importance of preventive strategies focusing particularly on reducing leftover waste, which remains the dominant contributor.

4. Conclusion

This study successfully estimated food waste generation in the school kitchen through a structured questionnaire and descriptive analysis. The results showed that average weekly food waste was approximately 1639.47 kg, which is equivalent to an estimated 6557.88 kg per month and about 65.6 tons annually based on 40 operational school weeks. Leftover waste consistently exceeded preparation waste, indicating that post-serving factors such as portion control and menu acceptance significantly influence total waste generation. In terms of composition, fruits, grains and rice, and protein sources were the main contributor to overall waste. Overall, the study achieved its objectives by identifying waste patterns by type, category, and operational scale. The findings provide baseline data to support improved food planning and waste reduction strategies in school food service operations.

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Investigative Study on Solid Waste Management and Potential Revenue within Teacher's Workspace at SMK Engkilili

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Abstract

Solid waste management has become an increasingly critical global benchmark as urbanization and population growth continue to jeopardize the environment through improper disposal and leachate contamination. At SMK Engkilili, the Teacher's Workspace currently lacks a sustainable framework, leading to a significant loss of potential revenue and a lack of organized disposal practices within the staff community. This study was conducted to investigate local solid waste generation patterns and propose a management strategy that maximizes resource recovery. The primary objectives involved characterizing the types and quantifying the volume of waste generated, evaluating the financial loss from current practices, and designing a practical framework for the school community. The study followed a three-stage methodology starting with survey-based identification of waste types, followed by mathematical quantification of mass using Microsoft Excel, and concluding with an economic valuation based on local market prices. Results from the analysis identified white paper and plastics as the major contributors to the waste stream. While the total recorded waste weight was 2.75 kg, the estimated annual revenue reached RM 4,166.70, with tin cans contributing approximately 72.16% of the total financial value despite their lower volume. Overall, this study concludes that the primary barrier to recycling is a lack of infrastructure, suggesting that providing more recycling bins and launching awareness campaigns will foster healthy disposal habits in SMK Engkilili.

Keywords: *Solid waste management, recycling, revenue recovery*

1. Introduction

Solid waste management systems are crucially needed everywhere as it is increasingly challenging with population growth and urbanization because the waste that is generated locally serves as a critical benchmark within global environmental system. Globally, municipal solid waste (MSW) is already at 2 to 2.3 billion tons per year and is projected to reach 3.8 billion tons by 2050 [2,3,4]. Solid waste commonly accumulates in residential areas, contaminates water, air and soil which are jeopardizing the ecosystem and polluting the area. When the solid waste is not managed appropriately, it will undergo through chemical and physical degradation which will lead to leachate and soil contamination. Leachate is the liquid that percolates through waste in landfills, dissolving organic matter, inorganic salts, heavy metals, and a wide range of xenobiotic compounds [5]. The fluid seeps into underground water or runs off into local water resources, polluting the water and risking human health. Despite the global urgency for waste management system, the Sri Aman district authorities rely solely on low-cost methods such as open burning of solid waste and disposal of waste at landfills [6]. SMK Engkilili Teacher's Workspace generates a substantial amount of solid waste that often disposes into general waste stream, leading to

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the loss of potential recyclables revenue. **Figure 1** below shows the geographical location of SMK Engkilili.

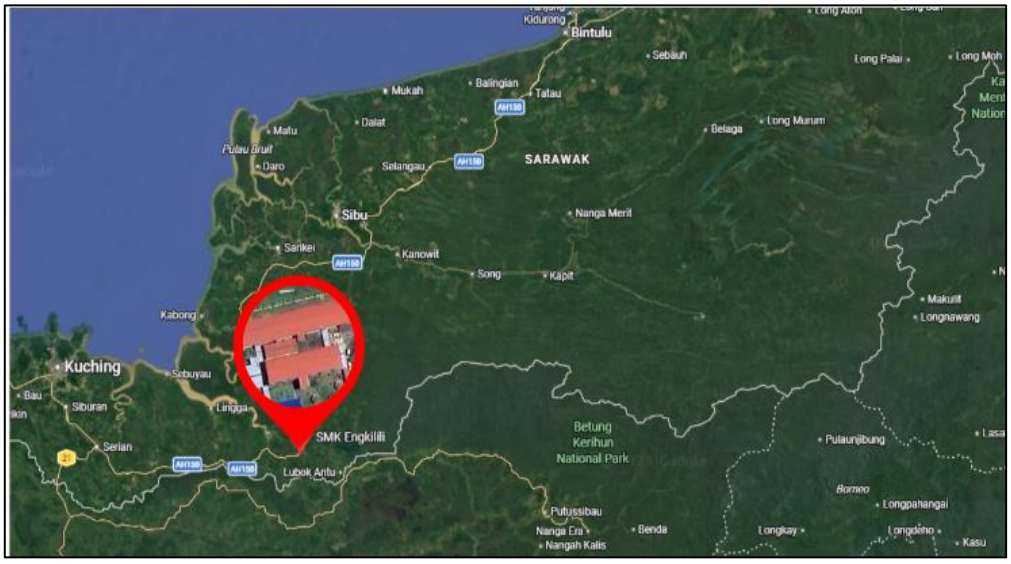


Figure 1. Geographical location of SMK Engkilili

This study addresses the lack of waste management systems and quantitative data regarding the economic value of solid waste generated by school staff. It has become a concern that the workspace lacks a waste management system although it holds a huge number of people inside. The school had lost a tremendous amount of potential revenue from the absence of sustainable practices within the school staff community. To address these concerns, this study aims to quantify the weekly solid waste stream and conduct an analysis of revenue recovery of recyclables at Teacher's Workspace which include the Teacher's Room and general office as the Administrative Room. The specific objectives are: (i) to categorize the variation of solid waste produced in the Teacher's Workspace; (ii) to measure and record the weight of each waste category generated in the Teacher's Workspace; and (iii) to evaluate the potential revenue by comparing the collected mass data with the current market buy-back rates in Sarawak specifically Sri Aman district and propose a sustainable waste management strategy. This investigation is limited to the solid waste produced within the Teacher's Workspace at SMK Engkilili, Sri Aman, Sarawak which accommodates ninety-four teachers [1]. It focuses on waste generated by teachers and staff members and excludes the student generated waste within the scope area.

2. Methodology

This section presents the devised methodology in accordance with the aim and objectives of the study. The methodology is structured into three main stages: (i) identification of type and amount of solid waste, (ii) calculation and quantification of each waste category generated, and (iii) determination of the potential resale value of segregated recyclables, as shown in **Figure 2**.

2.1 Identification of type and amount of solid waste

The first phase focuses on identification of type and amount of solid waste generated within Teacher's Workspace through survey-based investigation, where students identified which categories does the waste the teachers generate such as paper, plastics, and tin can. This study implemented the data gathered through the distribution of a questionnaire interview developed by students at SMK Engkilili to a diverse group of teachers varying in age group and gender to ensure comprehensive data set. The research questionnaire is divided into 5 sections. Section A gathers useful personal information, such as gender and age, to understand the demographic background of the survey participant. Section B focuses on the types and quantities of solid waste generated daily, where it allows researchers to

categorize the waste into three main streams, paper, plastics and tin can. Section C assesses current recycling practices and problems experienced, while Section D assesses general awareness and attitudes toward waste segregation. Section E provides a platform for participants to suggest improvements, such as reward systems or increased awareness campaigns, to enhance the school's overall waste management framework. The questionnaire was designed to analyze critical data point which allows researchers to understand the teacher's daily disposal habits. By analyzing these habits, the study provides a basic understanding of the waste composition required for later quantification and assessment.

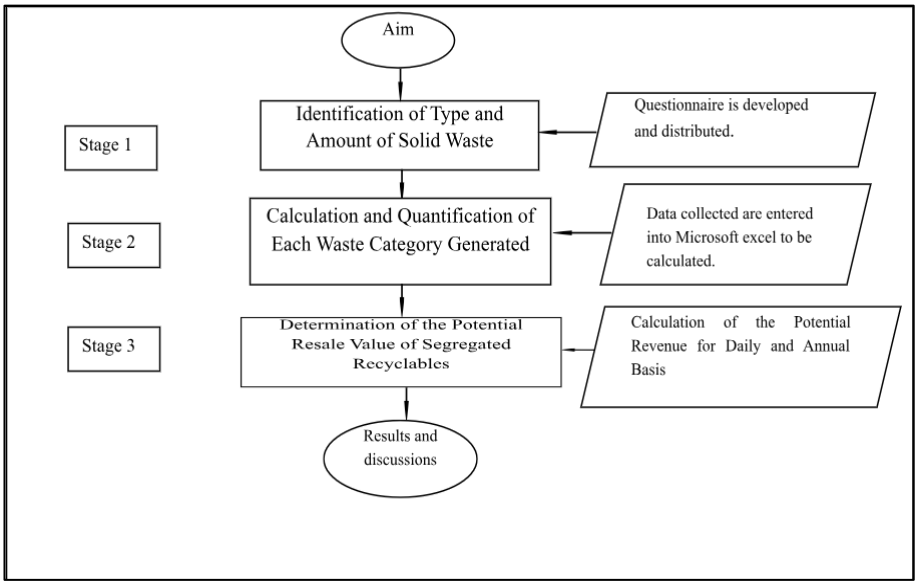


Figure 2. Research Methodology Flowchart

2.2 Calculation and quantification of each waste category generated

The second phase entails the calculation and quantification of waste generation through mathematical estimation based on the questionnaire data. To establish an accurate baseline of trash generation, the volume of waste is estimated by multiplying the quantity of waste reported by the teachers with their respective standard unit weights, rather than by weighing it physically. For instance, the total mass of plastics can be calculated by multiplying the number of bottles recorded by a standard weight of an empty water bottles approximately 15 g per bottle. Then, the individual calculations are compiled in Microsoft excel to estimate the total solid waste produce on daily and annual basis within the Teacher's Workspace. This computational method facilitates waste generation in graphical representations to visually illustrate trends and variations in waste distribution across distinct categories. The standard weight used for these calculations was tabulated as shown in **Table 1**.

Table 1. Standard unit weight for waste estimation

Waste Category	Type of waste	Estimated Standard Unit Weight (kg)
Plastics	A piece of paper [14]	0.015
White Paper	Plastic Water Bottles (500 mL) [15]	0.005
Tin Can	Aluminum Can Beverages (300 ml) [16]	0.046

2.3 Determination of the potential resale value of the segregated recyclables

The final phase of the methodology involves determining the potential resale value of the segregated recyclables to ascertain the economic feasibility of a sustainable waste management system within the school. This stage utilizes the estimation data recorded from the previous phase to calculate the potential

revenue from the generated waste. The potential revenue can be estimated using a specific formula shown in **Equation 1.**

$$V = W \times MP \quad \text{……(1)}$$

Where,
V = Resale Value (RM)
W = Weight of the segregated waste (kg)
MP = Market Price of the segregated waste (RM/kg)

By applying this formula to the calculated weights of paper, plastics, and tin can, the study provides a numerical evaluation of the financial resources currently being lost through non-sustainable disposal. Finally, a comparison study is conducted using the information gathered from the teacher surveys and these revenue estimates. This comparison demonstrates the concrete financial benefits of implementing a recovery framework, which effectively bridges the gap between current disposal habits and a sustainable circular economy for the SMK Engkilili teacher community. To further understand the demographic influences on waste production, the following formula shown in **Equation 2** are used in the dataset.

$$AW = \frac{\sum WG}{N} \quad \text{……..(2)}$$

Where,
AW = Average Waste per Gender (kg)
WG = Waste accumulates per Gender (kg)
N = Number of Participants per Gender

3. Results and Discussion

This section presents and discusses the key findings that address the aims and objectives of the study. The results are segmented into three main parts which are (i) identification of type and amount of solid waste, (ii)calculation and quantification of each waste category generated, and (iii) determination of the potential resale value of segregated recyclables.

3.1 Identification of type and amount of solid waste

The first phase of the study focused on identifying waste generation patterns through an interview questionnaire. The questionnaire is developed and distributed among the teachers. The questionnaire was used as a systematic tool to help researchers to distinguish the factor influences the disposal habits and to capture a comprehensive dataset. To ensure its accuracy, the questionnaire was divided into five sections, where section A focuses on personal information to capture the demographic background. While section B focused on identifying the type and quantity of the waste generated. Section C assesses current recycling practices and problems experienced, while Section D assesses general awareness and attitudes toward waste segregation. Finally, Section E gathered the improvements suggested by survey participants**. Figure 3** showed the developed questionnaire used in this study, which was structured to capture respondents' knowledge, attitudes, and self-reported practices related to waste management and recycling.

Using the developed questionnaire data, the Teacher's Room was identified as the main spot for waste accumulation, which shows a much higher frequency of disposal compared to the Administrative Room. The teachers' Room accounted for 78.9% of the solid waste segregated while the Administrative Room hosted only 21.1% of the waste segregated. As shown in **Figure 4**, in the Teacher's Room, participants reported a high frequency of paper disposal, with some staff recording up to one hundred pieces of paper, leading to the highest single-location volume of 0.6 kg. Conversely, the Administrative Room showed lower frequencies, with the highest single output reaching only 0.2 kg. The disparity

between the locations suggests that the Teacher's Room should be prioritized as the main location to put up a recycling bin as it can increase recycling rate systematically. **Table 2** showed the frequency analysis of generated waste by location.

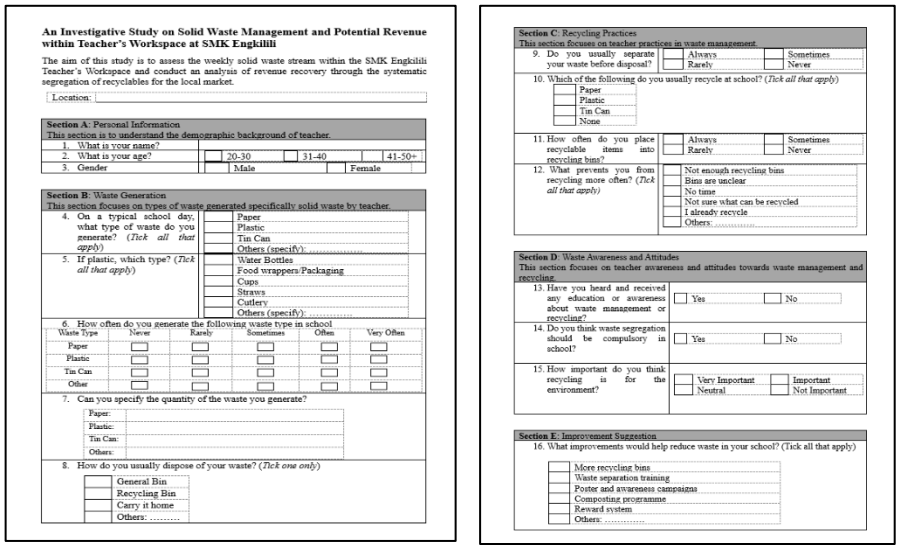


Figure 3. Interview questionnaire

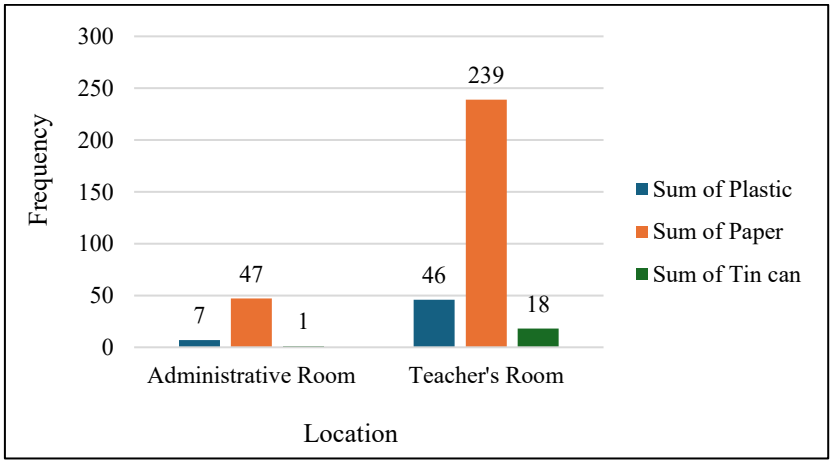


Figure 4. Frequency of waste generated by two different locations

Table 2. Frequency analysis of generated waste by location

Location	Sum of Plastics	Sum of Paper	Sum of Tin can
Administrative Room	7	47	1
Teacher's Room	46	239	18
Total	**53**	**286**	**19**

Demographically, the study revealed a significant gender imbalance, with female staff consisting 89.5% of the respondents compared to 10.5% for male participants. Despite this gap, the frequency data provided a diverse range of disposal habits, where female participants recorded paper disposal frequencies ranging from a single piece of paper to 100 pieces, whereas male participants showed more moderate behavior with counts around 10 pieces. **Table 3** showed the sum of waste generated by two genders. This high frequency of paper disposal among the majority group directly aligns with the 1.51 kg of white paper recorded, which represents nearly 55% of the total waste mass. **Figure 5** showed the frequency of waste generated by two genders.

Table 3. Sum of waste generated by two genders

Gender	Sum of Plastics	Sum of Paper	Sum of Tin can
Female	51	274	18
Male	2	12	1
Total	**53**	**286**	**19**

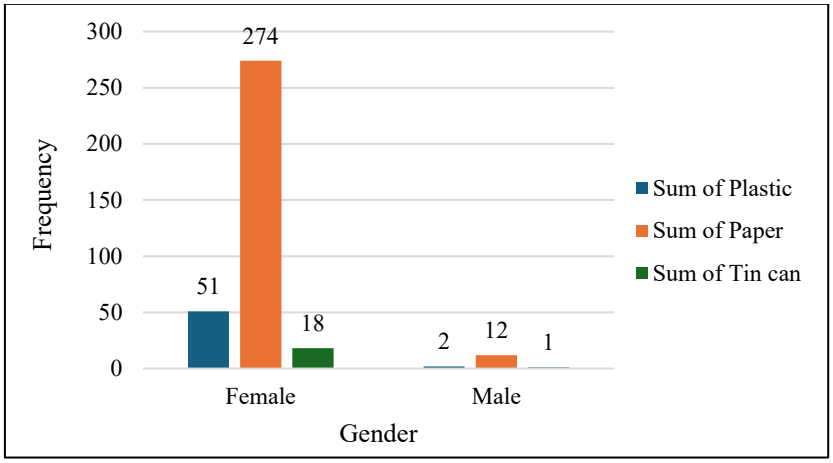


Figure 5. Frequency of waste generated by two genders

The findings indicate that most of the waste is generated by staff in the 31–40 age bracket, which forms approximately 47.4% of the participants, as this group shows the most active disposal behaviour across the measured waste categories. A similarly substantial contribution is also observed from the 41–50+ bracket, which represents 42.1% of the participants, suggesting that waste generation is concentrated among older working age groups rather than being evenly distributed across all ages. **Table 4** showed the sum of waste generated by three different age groups. Identifying that 90% of the regular waste producers are over the age of 30 and located in the Teacher's Room, the school can tailor its awareness campaigns and healthy disposal practice initiatives to specifically focus on these dominant groups. Participants in the 31–40 age group demonstrated the highest intensity of material use, as illustrated in Figure 6, where their disposal behaviour stands out clearly compared with the other age categories. This pattern is further supported by the dataset, in which the frequency counts for plastic and paper in the 31–40 group increase in a way that aligns directly with the larger individual mass totals recorded in the Excel analysis, specifically 0.60 kg for plastic and 0.56 kg for paper. In practical terms, this indicates that higher disposal frequency in this group was not merely occasional or incidental but translated into a measurable increase in total waste mass, suggesting more consistent consumption and disposal activity over the observation period.

Table 4. Sum of waste generated by three different age groups

Age Group	Sum of Plastics	Sum of Paper	Sum of Tin can
20-30	4	100	0
31-40	30	142	8
41-50+	19	44	11
Total	**53**	**286**	**19**

3.2 Calculation and quantification of each waste category generated

In this study, the data gathered from the questionnaire interview indicates that waste generation habits are significantly influenced by demographic factors (as shown in **Figure 6**) and workspace locations (as shown in **Figure 7**). Based on **Figure 7** shown below, the teacher's room generates 0.225 kg of plastics, 3.585 kg of paper and 0.828 kg of tin can which contribute 86.5%, 83.6%, and 94.7% of the solid waste generated, respectively. Data analysis shows that the Teacher's Room is the main spot for waste to accumulate compared to the Administrative Room given that the Teacher's Room accommodates more

people than the Administrative Room. Considering that the highest individual contribution of 1.525 kg accumulate waste recorded within the Teacher's Room, the place requires immediate intervention for systematic waste management. **Table 5** showed the analysis of segregated solid waste comparison by location.

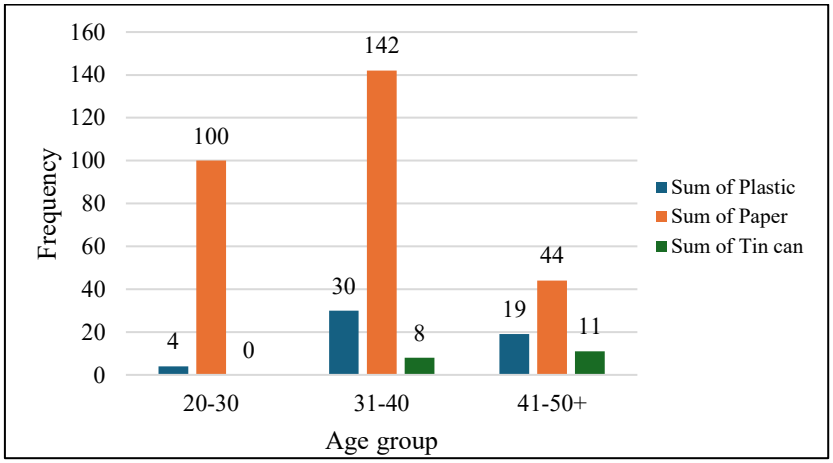


Figure 6. Frequency of waste generated by three different age groups

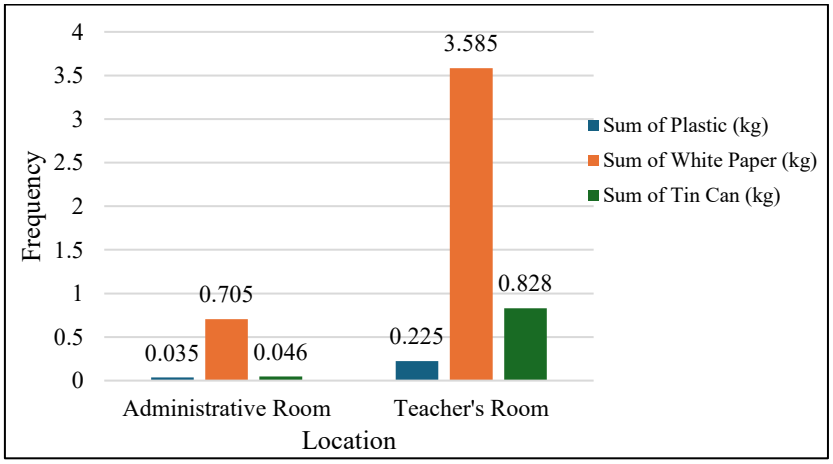


Figure 7. Analysis of segregated solid waste comparison by location

Table 5. Analysis of segregated solid waste comparison by location

Location	Plastics (kg)	Paper (kg)	Tin can (kg)
Administrative Room	0.035	0.705	0.046
Teacher's Room	0.225	3.585	0.828
Total	0.26	4.29	0.874

As of for demographic factor specifically in terms of gender, the study observed the contribution from both male and female staff members, providing a broader insights of disposal habits across the school community. While female staff constituted most of the surveyed sample, significant individual contributions were noted across the board, including a 0.236 kg total from a male participant located in the Administrative Room shown in **Figure 8**. Given the data, the total number of teachers in the government is 181,134 teaching in secondary level. Female teachers account for approximately 72% of the total workforce, while male teachers make up only 28% [7,8]. It shows the female staff contribute majority of the waste accumulation within the Teacher's Workspace. **Table 6** showed the comparison of solid waste contribution by gender.

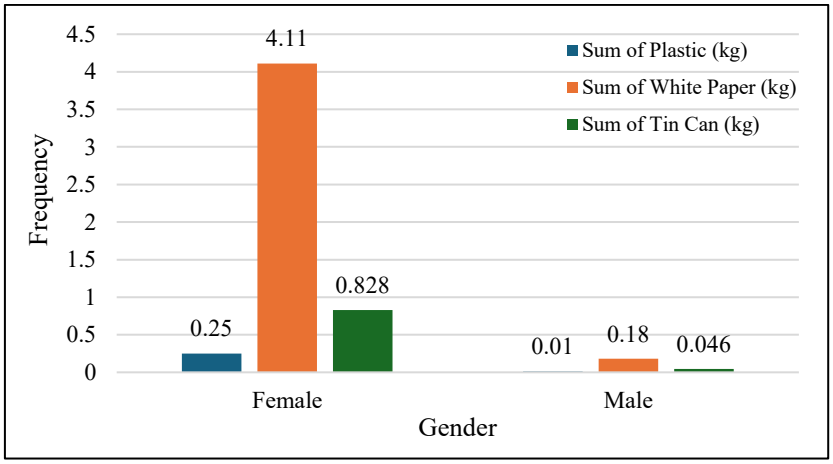


Figure 8. Comparison by gender in contribution of solid waste accumulation

Table 6. Comparison of solid waste contribution by gender

Gender	Plastics (kg)	Paper (kg)	Tin can (kg)
Female	0.25	4.11	0.828
Male	0.01	0.18	0.046
Total	**0.26**	**4.29**	**0.874**

In terms of the age group, where the age group are divided into three specific age brackets which are 20-30, 31-40 and 41-50+. As shown in **Figure 9** shown below, the analysis demonstrates that staff members in the 31-40 and 41-50+ brackets are the largest contributor in generators of solid waste. Individuals in the 31-40 age group recorded particularly high individual outputs, with specific records showing totals such as 1.525 kg.

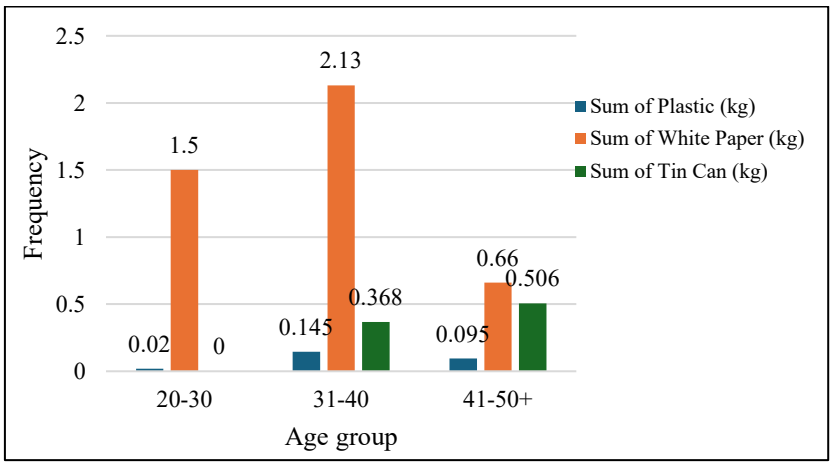


Figure 9. Comparison of age group variation in waste accumulation

The 41–50+ age group is the clear dominant demographic in this dataset, where it represents nearly 60% of the entire teaching population [7,8]. Although it holds most of the population, the groups did not account for the major contributor for the waste accumulation. The 31-40 age brackets record as the main contributor for accumulating solid waste within the Teacher's Workspace. **Table 7** showed a comparison of waste accumulation across age groups.

The second stage of the research focused on the categorization and mathematical quantification of the waste stream to identify the primary contributors to the school's refuse. The quantification process identified white paper as the dominant contributor to the waste stream by weight, totaling 4.29 kg, which accounts for approximately 79.1% of the overall 5.424 kg collected, as shown in **Figure 10**. Plastics represent the second-largest category at 0.874 kg, or 16.11% of the total mass, while tin cans contribute

the remaining 0.26 kg, which account for approximately 4.79%. This distribution highlights that 93% of the waste generated by the school staff is comprised of paper and plastics materials, which are highly recyclable. This indicates that improving source segregation and providing clearly labelled recycling bins could immediately divert a large proportion of staff generated waste away from general disposal with minimal operational changes.

Table 7. Comparison of waste accumulation across age groups

Age Group	Plastics (kg)	Paper (kg)	Tin can (kg)
20-30	0.02	1.5	0
31-40	0.145	2.13	0.368
41-50+	0.095	0.66	0.506
Total	**0.26**	**4.29**	**0.874**

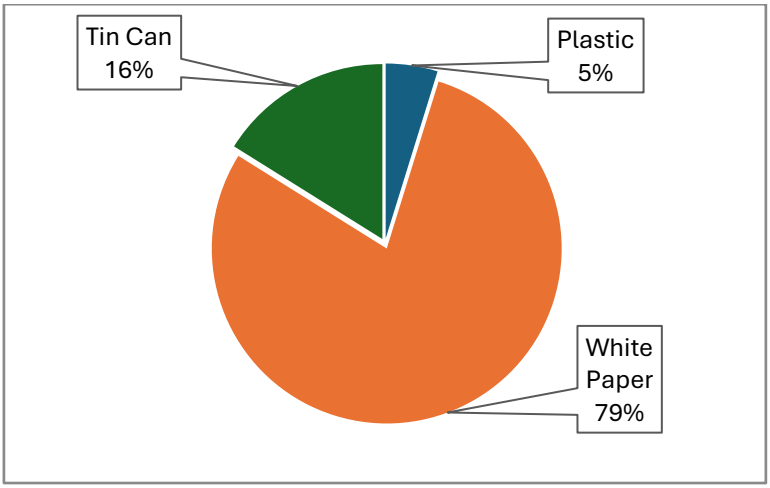


Figure 10. Waste composition within the Teacher's workspace

Table 8 showed the analysis of waste composition within the teachers' workspace. By focusing on these major contributors, specifically the paper and plastic streams, the school can address the bulk of its environmental footprint through a targeted recovery system.

Table 8. Analysis of waste composition within the teachers' workspace

Waste Type	Total (kg)
Plastic	0.26
White Paper	4.29
Tin Can	0.87
All Waste	**5.42**

3.3 Determination of the potential resale value of segregated recyclables

The shift to a sustainable waste framework is supported by a financial assessment that translates waste volume into potential revenue. From the general formula below, the formula can be expanded and utilized to determine the total revenue for the recycling segregated from each solid waste category. The following comprehensive revenue formula, **Equation 3** was applied to the dataset, shown in **Equation 4.**

$$V = W \times MP \qquad \text{.....(3)}$$

$$Value = (Weight_{paper} \times price_{paper}) + (Weight_{plastics} \times price_{plastics}) + (Weight_{tin} \times price_{tin}) \quad \text{.....(4)}$$

The market price for each category of solid waste was compiled and tabulated in **Table 9** to provide a clear reference for comparing material values and supporting accurate cost interpretation based on the current market rate.

Table 9. Market price for each category of solid waste [9]

Waste Category	Market Price (RM)
White Paper	0.3
Plastics	0.2
Aluminum Tin Can	4.00

The separate waste weight and total revenue for both male and female participant were shown in **Table 10** and **Table 11** respectively.

Table 10. Male participant separate waste weight and revenue

Participant	Plastic (kg)	White Paper (kg)	Tin Can (kg)	Total revenue (RM)
1	0.01	0.03	0.046	0.20
2	0	0.15	0	0.04

Table 11. Female participant separate waste weight and revenue

Participant	Plastic (kg)	White Paper (kg)	Tin Can (kg)	Total revenue (RM)
1	0.005	0.015	0	0.005
2	0.02	0.015	0.046	0.1925
3	0.005	0	0	0.001
4	0.02	0.03	0.092	0.381
5	0.015	0.15	0	0.048
6	0.025	1.5	0	0.455
7	0.01	0.015	0	0.0065
8	0.015	0.03	0	0.012
9	0.01	0.015	0	0.0065
10	0.01	0.015	0.368	1.4785
11	0.015	1.5	0	0.453
12	0.025	0.075	0.23	0.9475
13	0.05	0.15	0.092	0.423
14	0.025	0.15	0	0.05
15	0	0.3	0	0.09
16	0	0.075	0	0.0225
17	0	0.075	0	0.0225

This study calculated that the total estimated revenue for the recorded waste is RM 4.85, as shown in **Table 12**. Analysis of the individual revenue streams reveals that while tin cans represent only 16.11% of the waste weight, they have a disproportionately high impact on the total revenue due to their higher market value per kilogram. The market prices are RM 0.3/kg of white paper, RM 0.2/kg of plastics and RM4/kg of aluminum tin can [9]. For instance, one participant's contribution of mixed materials yielded a significant individual revenue of RM 1.48, illustrating how regular recycling of valuable items such as tin can accumulate. When analyzed on weekly basis, the data show the weekly potential revenue within the Teacher's Workspace is approximately RM 24.25 for 19 survey participants. Scaling these weekly figures to an annual projection suggests that SMK Engkilili could recover significant funds that are currently lost through conventional disposal methods, providing concrete economic motivation for the school community to embrace healthier disposal practices.

To further refine the findings on the economic analysis and relate it with demographic factors in phase 1 and 2, specific formulas were applied to the data to compare the contribution levels between gender groups, the average waste generation was calculated using **Equation 5.**

Table 12. Waste composition and potential revenue for daily accumulation

Waste Category	Total Weight (kg)	Market Price (RM)	Estimated Revenue (RM)
White Paper	4.29	0.3	1.30
Plastics	0.26	0.2	0.05
Aluminum Tin Can	0.874	4.00	3.50
Total	**5.424**	**-**	**4.85**

$$AW = \frac{\sum WG}{N} \quad \text{……(5)}$$

Applying the formula to the dataset reveals a significant difference in waste generated contributions between the male and female participants, as shown in **Table 13**. The two male participants produced a total of 0.236 kg of waste, which is 0.118 kg of solid waste on average. At the same time, the seventeen female participants accumulate a total of 5.188 kg of solid waste, which resulting in much higher average of 0.305 kg per female participants. The average female participants solid waste produced is almost equivalent to two male participants. It indicates that, on average, a female participant generates approximately 2.6 times more waste than a male participant. The results are assessed to calculate the long-term economic viability of the project. The male participant can generate daily potential revenue of RM 0.12 per male participant, whereas female participant daily potential revenue was RM 0.27 per female participant, which two times more than the male participant, as shown in **Table 14**. By scaling on weekly basis, male teachers which is around 40 potential revenue is RM 24.00 and for female teachers is approximately RM72.90. The school could recover a total of 96.90 in one week alone. If this framework expanded to annual basis, the school could recover RM 4,166.70 where 75.23% contributed by the female teachers.

Table 13. Estimation of daily potential revenue for both female and male participants

Gender	Number of Participants	Daily Total Weight (kg)	Average Daily Revenue per Person (RM)	Daily Revenue (RM)
Male	2	0.236	0.12	0.24
Female	17	5.188	0.27	4.59

Table 14. Potential revenue for both female and male teachers for weekly and annual basis

Gender	Number of Teachers	Average Daily Revenue per Person (RM)	Daily Revenue (RM)	Weekly Revenue (RM) (5 days)	Annual Revenue (43 weeks)
Male	40	0.12	4.80	24.00	1,032.00
Female	54	0.27	14.58	72.90	3,134.70

3.4 Recycling practices and waste awareness among teachers

The data recorded in the questionnaire section C and D focuses on the recycling practices and waste awareness among survey participants. From section C, 21% of the participant always separate their waste before disposal, 16% of the participant rarely separate their waste, and 63% of the participant sometimes separate their waste before disposal, as shown in **Figure 11.**

As shown by **Figure 11,** recycling behaviour appears inconsistent, with most participants recycling only occasionally rather than practicing regular or consistent recycling. **Table 15** showed the percentage of the recycling habits among teachers. Data reveals that 63.16% of the participants use it sometimes, 15.79% of the participants rarely use the recycling bin and 21.05% of the participants always use the recycling bin, as shown in **Figure 12**. The dataset was highly influenced by the lack of systematic waste management systems and lack of recycling bins.

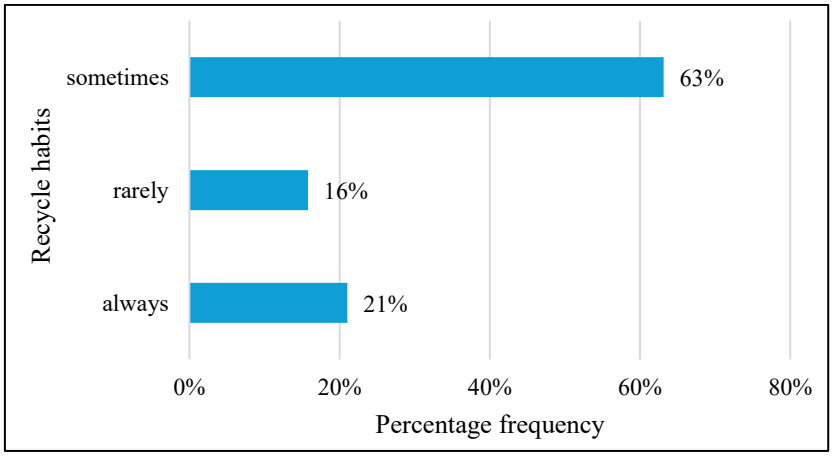


Figure 11. Recycle habits among teachers

Table 15. Percentage of the recycling habits among teachers

Frequency	Percentage (%)
Always	21.05
Rarely	15.79
Sometimes	63.16
Total	100

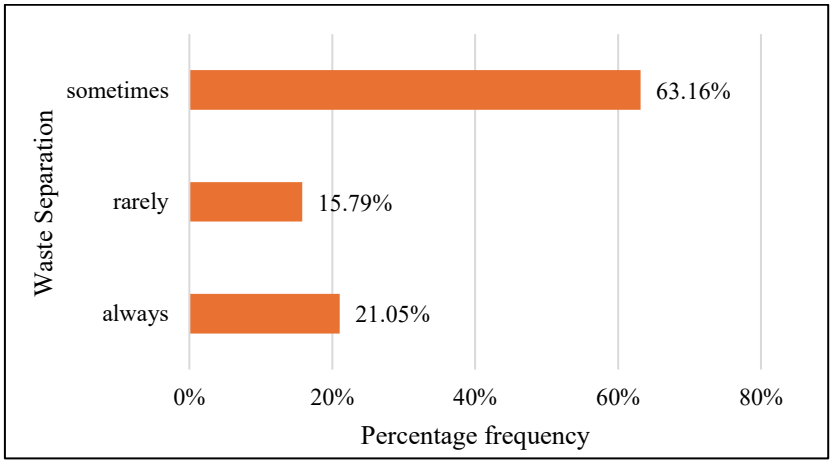


Figure 12. Percentage of teacher practices waste separation before disposal

This study found that the Section D questionnaire results, which assess teachers' awareness of waste management and recycling, indicate a high level of awareness of the school's waste management system. All the participants answered 'yes' when they asked about the education and awareness about the waste management system and would it be compulsory in school to have the system. It shows that all the teachers are aware of the recycling problem at the school, but the party responsible lacks the solution to this problem. In **Figure 13**, about 89.47% of the participants voted 'very important' and 10.53% vote 'important' on the questionnaire section on how important recycling for the environment is. The data tells how much the teachers emphasize recycling habits for the environment. **Table 17** showed the percentage of teachers aware of the importance of recycling.

3.5 Strategic improvement

The data gathered from the student questionnaires provides critical insights into the current barriers to effective waste management at SMK Engkilili. The main obstacles in implementing recycling habits among the school community are lack of sufficient recycling bins. Furthermore, majority of the teachers'

answers to improve the current waste management system pointed toward a multi-faceted approach involving infrastructure, education, and incentives. Since the Teacher's Room was identified as the primary area for waste generation specifically for paper and plastic, the school should install specialized, color-coded recycling bins directly within this workspace to ensure the recycling rate can be maximized. Place clearly labeled recycling containers at every high-traffic spot such as the Teacher's Rooms and use the same colors school-wide to reduce confusion [11].To supplement the new infrastructure, posters and awareness campaigns should be implemented to clearly communicate what materials are recyclable and why segregation is necessary. Developed an eye-catching poster that teaches healthy disposal habits are crucial to catch the attention of passersby.

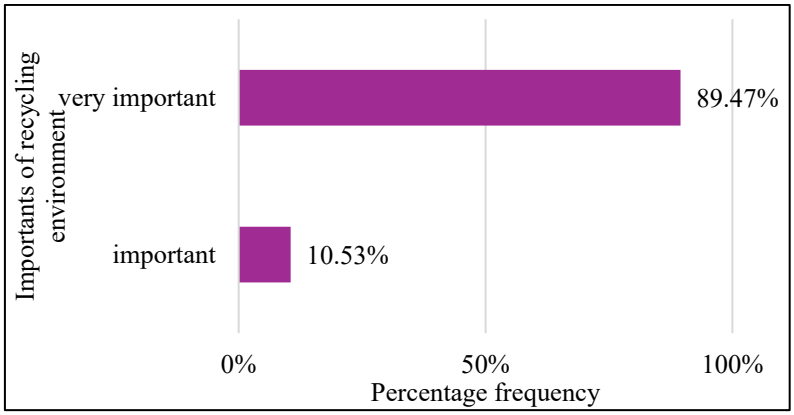


Figure 13. Percentage of teachers understand the importance of recycling environment

Table 17. Percentage of teachers aware of the importance of recycling

Category	Percentage (%)
Important	10.53
Very Important	89.47
Total	100

Run a short-term campaign such as a "Recycle Right" week that pairs educational talks with student-made displays. It has been shown to raise correct-use rates from 28 % to 52 % in one school [12]. This specifically addresses the questionnaire findings where some of the participants were unsure of correct recycling procedures or found bin labels unclear. Teachers can also run a quiz show about reducing waste and recycling at lunch, in classrooms, or at an assembly [10]. This will help teachers and staff to visualize and serve a broader educational goal in fostering a culture of sustainability. Lastly, a reward system should be introduced to recognize students and staff efforts where both consistently practice healthy disposal habits. Established a point-based system where teachers and students earn "green points" for each correctly sorted load. The teachers or class with the highest number of recyclables would get a certificate or an appreciation token in the form of money [13]. Having a reward and incentive system will motivate and encourage teachers and staff to practice recycle more often and a long-term shift in behaviour.

4. Conclusion

This study characterized the solid waste profile of the SMK Engkilili teacher community and evaluated its economic potential. The study concluded that location and demographic variables significantly influence waste production, with the Teacher's Room and staff aged 31–40 acting as the largest contributors to the waste stream. Quantitatively, white paper and plastics were found to be the most prevalent materials, though aluminum tin cans represent the highest individual economic value per kilogram. Based on the participants' feedback, the absence of sufficient recycling bins is the major obstacle to effective waste segregation. However, the calculated annual potential revenue of RM 4,166.70 provides a clear financial incentive for the school to adopt a circular economy model. By

implementing the proposed improvements such as strategic bin placement, reward systems and awareness posters, SMK Engkilili can transition toward a more sustainable waste management system. Overall, this project demonstrates that even small-scale recovery efforts can yield tangible environmental and economic benefits, serving as a model for healthy disposal habits among students and the wider school community.

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Garden Waste Management for Environmental Sustainability at SMK Engkilili, Sri Aman, Sarawak

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Abstract

The study investigates Garden waste management as a pressing issue in institutional environments where routine landscaping generates large volumes of biodegradable material, often disposed through landfills that contribute to greenhouse gas emissions and resource inefficiency. This study at SMK Engkilili, Sri Aman, Sarawak, explored composting as a sustainable alternative, combining questionnaire surveys and interviews with six gardeners to categorize waste into grass clippings, dry leaves, weeds, and plant trimmings. Annual garden waste generation was estimated at 82,910.02 kg, with plant trimmings contributing the largest share (35,633.03 kg/year). Of this, 49,832.41 kg was suitable for composting, yielding approximately 33,077.61 kg of compost annually. Greenhouse gas analysis revealed that landfill disposal produced 15,309.04 kg CO2-equivalent emissions per year, while composting reduced this to 3,964.73 kg CO2-equivalent, representing a 74.10% reduction. The findings demonstrate that composting is both environmentally and economically viable, offering emission reductions, cost savings, and resource recovery. By integrating composting into routine landscaping, SMK Engkilili can transform waste into a valuable resource.

Keywords: *Garden waste management, Composting, Greenhouse gas emissions, Fertilizer substitution*

1. Introduction

Garden waste (GW) is a component of municipal solid waste, primarily consisting of biodegradable organic materials such as grass clippings, leaves, weeds, and plant trimmings [1]. Improper disposal of garden waste through open burning, incineration, or landfill dumping can contribute to environmental pollution, greenhouse gas emissions, and inefficient resource utilisation [2]. In order to mitigate these impacts, garden waste can be sustainably managed through composting processes, which allow organic materials to be converted into useful soil amendments. Composting is a natural biological process in which microorganisms decompose organic matter, and it is widely recognized as an effective method for managing yard waste while producing fertilizer suitable for landscaping applications. [3].

Garden waste is continuously generated in school environments due to routine landscaping and maintenance activities. In schools, including SMK Engkilili, garden waste is often managed through conventional disposal methods without systematic assessment of its quantity or potential reuse. The absence of proper documentation and evaluation may result in inefficient waste handling practices and missed opportunities for resource recovery. Hence, the aim of this study is to investigate the economic potential of alternative disposal (composting) of garden waste generated at SMK Engkilili, Sri Aman, Sarawak. To solve the problem stated in the problem statement, the objectives are: (i) to identify and categorize the types of garden waste generated within the school, including grass clippings, dry leaves, weeds, and plant trimmings, (ii) to analyze garden waste generation, projected compost production, fertilizer usage and cost and the potential reduction in greenhouse gas emissions (CO_2) associated with composting (iii) to propose suitable garden waste management strategies, including alternative disposal,

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based on waste generation findings and fertilizer cost analysis. This study is conducted at SMK Engkilili and focuses specifically on garden waste generated from routine landscaping and maintenance activities. The types of garden waste included grass clipping, dry leaves, weeds, and plant trimmings which are collected within the school compound during the study period.

Garden waste is broadly identified as fallen leaves, branches, tree trimmings, shrub trimmings, lawn clippings, and other plant residues generated during both natural processes and routine maintenance of urban green spaces, with maintenance activities occurring regularly as part of landscaping schedules that vary by city but generally follow seasonal cycles to manage growth and aesthetics. When untreated, this waste is often disposed of through landfill or incineration leading to resource loss and environmental pollution. Composting and organic covering are increasingly promoted, with mulch used to enrich soil fertility, inhibit weeds, and improve soil porosity, while biomass energy projects demonstrate how garden waste can be harnessed for heating and fuel production. Events that generate large amounts of garden waste include seasonal pruning, park maintenance, and urban greening expansions [1].

Waste generated daily from leaves, branches, grass, and miscellaneous fruit, and when combined with food waste if unmanaged, this organic waste contributes to greenhouse gas (GHG) emissions, particularly methane, when disposed of in landfills under anaerobic conditions [5]. Methane is a potent greenhouse gas with a global warming potential many times higher than carbon dioxide, making the current practice of disposal through contractors a source of environmental concern. Composting, however, offers a projection of reduced GHG emissions by diverting this organic matter from landfill and instead channeling it into aerobic decomposition, which primarily produces carbon dioxide and water vapor, gases with far lower climate impact compared to methane [2].

Alternative disposal of garden waste goes beyond the conventional reliance on landfills and incineration and instead explores several sustainable pathways that align with low-carbon development goals. Traditionally, garden waste has been dumped in landfills or openly burned, both of which contribute significantly to greenhouse gas emissions and air pollution [6]. However, composting and anaerobic digestion present viable alternatives: composting uses aerobic microbes to convert garden waste into nutrient-rich fertilizer, reducing waste volume and returning organic matter to the soil, while anaerobic digestion produces biogas primarily methane and carbon dioxide that can be harnessed as renewable energy, The disposal alternatives addresses the challenge of reducing environmental pollution and creating economic value, transforming garden waste from a burden into a resource [4].

2. Methodology

In this section, the methodology was divided into three main stages: data collection, data analysis, and recommendations, as illustrated in **Figure 1.**

2.1 Stage 1: Data Source Identification

As shown in **Figure 1**, primary data was obtained using questionnaire and direct interviews with the school's gardeners to gather information on type of garden waste generated in the school, frequency of garden maintenance, waste collection method and fertilizer application rate and frequency. The questionnaire mainly consists of 4 sections, which are Section A, Section B, Section C and Section D. Section A consists of questions related to garden waste generated in SMK Engkilili with its amount, frequency per week or per month and a remark section for the respondents to write additional information about garden waste in the school. Section B tells us about the current waste management practice in the school. Choices of answers including collected and disposed of, open burning, left to decompose naturally and transported to landfill. Next, Section C is about fertilizer usage and cost. Data needed is the type of fertilizer the school uses for their garden and its amount and frequency of fertilizer application. Lastly, awareness and potential improvement is the last section of the questionnaire which is Section D. This section wanted to see whether the respondents are aware of the garden waste potential that can be reused as compost thus reducing fertilizer usage and costing. Regardless of the yes and no answer, their reasons need to be stated to test their awareness on the matter. After questionnaire survey with the respondents, garden waste was visually identified and categorized into four groups: grass

clippings, dry leaves, weeds, and plant trimmings (including stems, flowers, hedges, small branches and twigs) that can be found. Pictures of each garden waste type were taken and categorized in a table.

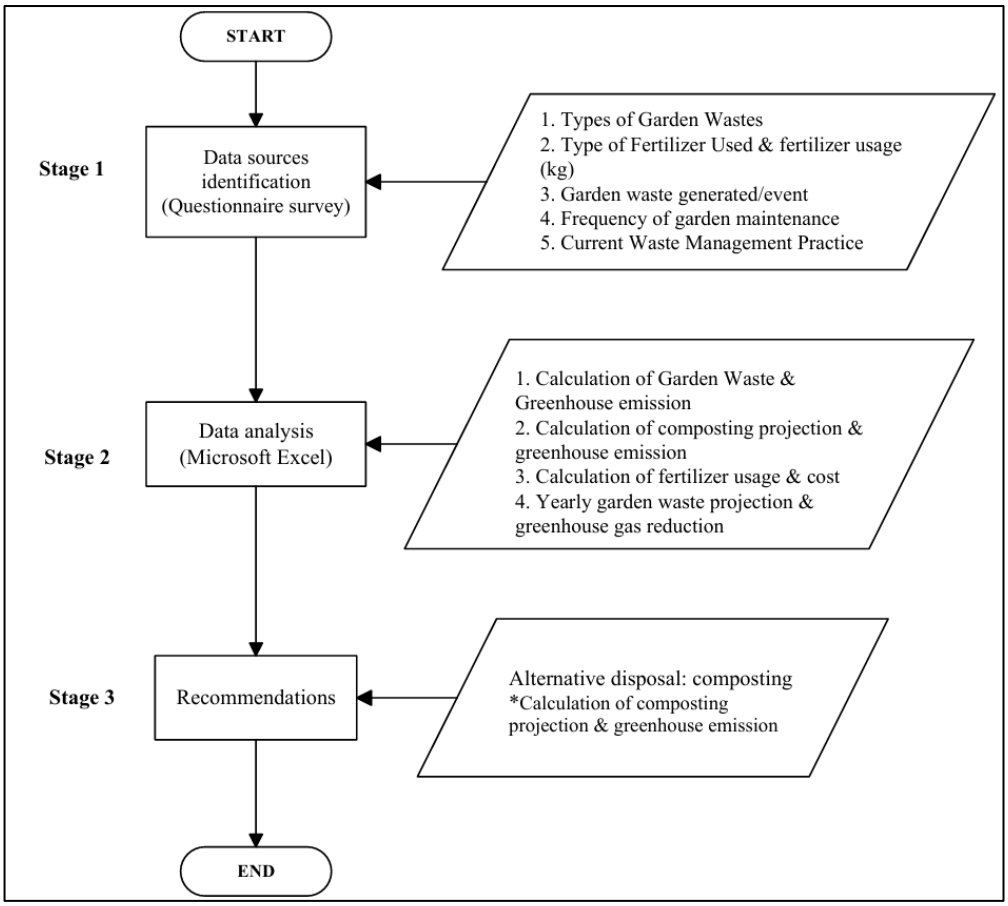


Figure 1. Flow Chart of Study

2.2 Stage 2: Data Analysis

After Data Identification from Stage 1, data analysis was analysed using Microsoft Excel. Garden waste generation was estimated using maintenance frequency, and the corresponding daily, monthly, and yearly waste quantities were calculated accordingly. Composting projections were estimated by applying a conversion factor to total garden waste, while greenhouse gas (GHG) emissions were calculated in terms of carbon dioxide equivalent (CO/e) using appropriate emission factors [5]. Yearly projections of garden waste generation and potential greenhouse gas reduction through composting were subsequently determined. **Equation 1**, **Equation 2** and **Equation 3** is used for calculating actual and composting projection for GHG emissions particularly carbon dioxide, CO_2 in term of daily, monthly and yearly respectively, whereas **Equation 4** is used for overall reduction in GHG emissions between before and after composting.

$$Daily\ CO_2\ emission\ (kg\ CO_{2e}) = Waste\ per\ event\ (\frac{kg}{event})\ \times CO_2\ emission\ factor \quad \text{.....(1)}$$

$$Monthly\ CO_2\ emission\ (kg\ CO_2e) = \ Monthly\ garden\ waste\ \left(\frac{kg}{month}\right) \times CO_2\ emission\ factor \quad \text{.....(2)}$$

$$Yearly\ CO_2\ emission\ (kg\ CO_{2e}) = Monthly\ CO_2\ emission\ \times 12 \quad \text{.....(3)}$$

$$Overall\ Reduction\ (\%) = \frac{Initial\ (Without\ Composting) - Final\ (With\ Composting)}{Initial\ (Without\ Composting} \times 100\% \quad \text{.....(4)}$$

2.3 Stage 3: Recommendation

After finalizing Stage 2, on the final stage, composting was assessed as an alternative garden waste disposal method based on the results obtained in Stage 2. The projected compost production, greenhouse gas emission reduction, and potential fertilizer savings were evaluated to determine the environmental and economic benefits of implementing composting practices. Fertilizer usage and associated costs were also calculated based on reported application rates in the questionnaire survey. The calculation of fertilizer cost is as shown in **Equation 5**, whereas the calculation of expected compost fertilizer profit is as shown in **Equation 6**. The potential compost profit is then calculated based on **Equation 7**. Comparisons were made between the current waste management approach and the proposed composting scenario to identify possible improvements. Based on these findings, practical recommendations were developed to enhance garden waste management, promote resource recovery, reduce dependency on chemical fertilizers, and support environmental sustainability.

$$Fertilizer\ cost\ per\ year = Amount\ of\ fertilizer\ used \times Fertilizer\ cost \quad \text{.....(5)}$$

$$Expected\ compost\ fertilizer = Amount\ compost\ produced \times Compost\ Fertilizer\ cost \quad \text{.....(6)}$$

$$Potential\ compost\ profit = Expected\ compost\ cost - fertilizer\ cost \quad \text{.....(7)}$$

3. Results and Discussion

In this section, results and discussions are divided into (i) garden waste generation, (ii) compost potential and greenhouse gas emission reduction and (iii) fertilizer substitution and economic implications.

3.1 Garden Waste Generation

The distribution of garden waste types (grass clippings, dry leaves, weeds, and plant trimmings as shown in **Figure 2** demonstrates that plant trimmings contributed the highest proportion by mass, followed by grass clippings and dry leaves as shown in **Table 1**. These findings were based on questionnaire survey and interview with the school's gardeners. This composition is favorable for composting due to a relatively balanced carbon-to-nitrogen ratio when mixed appropriately. The dominance of lignocellulosic fractions such as leaves and trimmings suggests that process optimization such as shredding and moisture control would be necessary to ensure efficient decomposition rates.

Table 1 presents the annual garden waste generation by six gardeners at SMK Engkilili. Variations in waste quantities were observed among gardeners, likely due to differences in assigned work areas, plant growth coverage, and maintenance activities. Plant trimmings recorded the highest total annual mass (35,633.03 kg/year), followed by grass clippings (19,916.4 kg/year), dry leaves (16,536.58 kg/year), and weeds (10,823.8 kg/year). This indicates that plant trimmings contribute most significantly to overall garden waste generation within the school compound.

Figure 3 illustrates the composition and annual distribution of garden waste types in kg per year. Plant trimmings recorded the highest quantity (35,633.03 kg/year), followed by grass clippings (19,916.4 kg/year), dry leaves (16,536.58 kg/year), and weeds (10,823.8 kg/year). The highest contribution from plant trimmings suggests that pruning activities, including hedge and shrub maintenance, are the main sources of garden waste within the school compound. Grass clippings and dry leaves also accounted for substantial portions of the total waste, reflecting routine mowing and seasonal vegetation shedding, while weed generation remained comparatively

Individual differences were also evident, with Donny generating the highest amount of plant trimmings annually, while Bragai recorded the highest weed generation. In contrast, weed generation was negligible for some gardeners, suggesting uneven weed distribution across landscaped areas. The results demonstrate that a substantial quantity of biodegradable garden waste is produced annually during routine maintenance activities, highlighting strong potential for composting as a sustainable garden waste management strategy at SMK Engkilili.

lower.

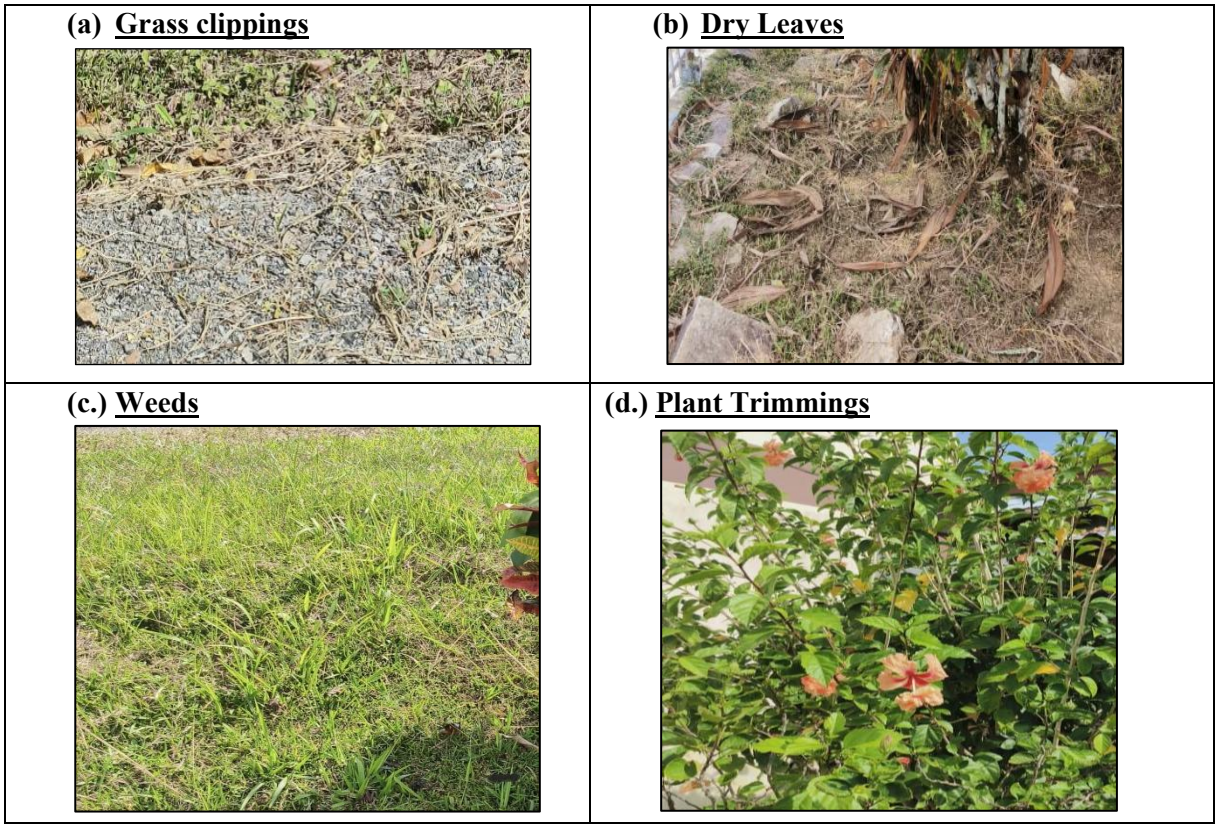


Figure 2. Categorization of Garden Waste Types Generated in SMK Engkilili.

Table 1. Garden waste types generated among gardeners at SMK Engkilili.

Garden Waste Types	Gardeners						Total (kg/year)
	Nyelang	Donny	Bragai	Moh	Luli	Malisa	
Grass clippings	1738.80	7329.60	5011.20	1612.80	2443.20	1780.80	**19916.4**
Dry leaves	1450.18	6768	2380.80	1680.00	2443.20	1814.40	**16536.58**
Weeds	0	0	3316.60	2352.00	3004.80	2150.40	**10823.8**
Plant trimmings (stems, flowers, hedges)	2513.99	15959.52	4492.80	4233.60	3850.08	4583.04	**35633.03**

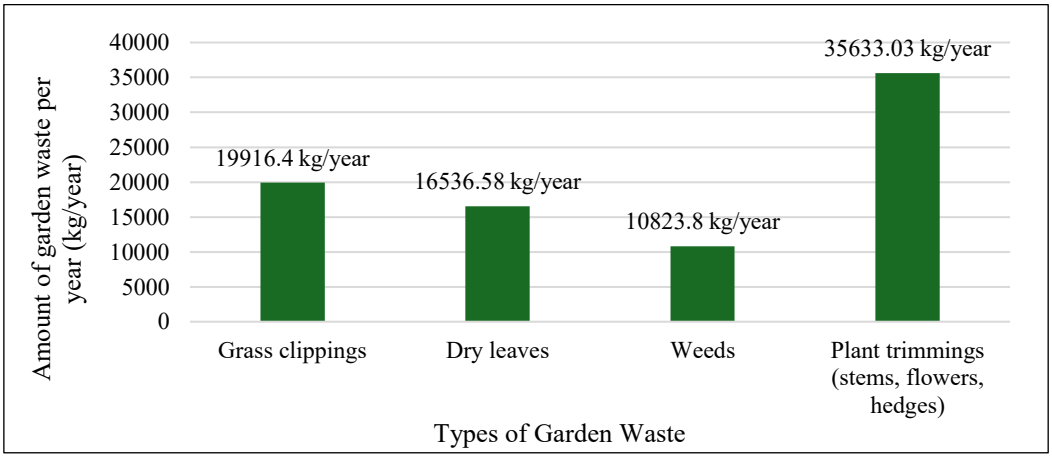


Figure 3. Composition and annual quantity of garden waste by type (grass clippings, dry leaves, weeds, and plant trimmings) in kg per year.

Overall, the distribution indicates that most of the annual garden waste consists of biodegradable organic materials suitable for composting. The combination of carbon-rich materials such as dry leaves and plant trimmings with nitrogen-rich components such as grass clippings and weeds provides favorable conditions for compost production when appropriately managed. Similar findings have been reported in previous studies, where garden and green waste were identified as suitable feedstock for composting and shown to reduce greenhouse gas emissions when diverted from landfill disposal [7]. These results highlight strong potential for diverting garden waste from landfill disposal and implementing composting as a sustainable waste management strategy within the school environment.

3.2 Compost Potential and Greenhouse Gas Emission Reduction

Table 2 and **Table 3** compare the actual annual garden waste generation and greenhouse gas emissions without composting and the projected outcomes under composting conditions at SMK Engkilili. According to the gardeners during questionnaire survey, transported to landfill was their selection when asked about the current waste management practice in SMK Engkilili. Under the current waste management approach (Table 2), a total of 82,910.02 kg of garden waste generated annually resulted in cumulative daily and monthly emissions of 233.33 kg CO_2e and 1,275.75 kg CO_2e, respectively. Differences in emission levels were observed among gardeners, with Bragai recording the highest daily CO_2e emission (50.28 kg CO_2e) corresponding to higher annual waste generation, while Nyelang recorded the lowest daily emission (16.91 kg CO_2e). These variations reflect differences in assigned work areas, plant growth coverage, and maintenance intensity across the school compound. In contrast, implementation of composting reduced total daily CO_2e emissions to 62.24 kg, with monthly emissions decreasing to 331.29 kg CO_2e, despite the same quantity of garden waste being managed. This represents a substantial reduction in greenhouse gas emissions compared to the existing disposal method. Although the total annual garden waste remained unchanged, the treatment method significantly influenced emission levels. The reduction can be attributed to diverting biodegradable garden waste from conventional disposal to composting, which limits greenhouse gas formation during organic waste degradation. Similar reductions in CO_2-equivalent emissions through composting garden waste and landfilling have been reported in previous studies [8]. GHG footprint of GHG management significantly reduced when compared to landfill, making it a more sustainable option [8].

Table 2. Actual annual garden waste and GHG emissions without composting.

No.	Gardener	Daily garden waste (kg/year)	Monthly garden waste (kg/year)	Yearly garden waste (kg/year)	Daily CO_2e emission (kg CO_2e)	Monthly CO_2e emission (kg CO_2e)	Yearly CO_2e emission (kg CO_2e)
1	Nyelang	158.41604	475.24812	5702.98	16.91	50.73	608.79
2	Donny	208.73	2504.76	30057.12	39.70	476.37	5716.47
3	Bragai	264.5	1266.8	15201.60	50.28	242.88	2914.61
4	Moh	205.8	823.2	9878.40	39.09	156.35	1876.22
5	Luli	244.61	978.44	11741.28	46.48	185.90	2230.84
6	Malisa	215.18	860.72	10328.64	40.88	163.51	1962.11
SUM TOTAL		**1297.24**	**6909.17**	**82910.02**	**233.33**	**1275.75**	**15309.04**

Note: CO_2e = Carbon dioxide emission

Overall, the comparison between **Table 2** and **Table 3** demonstrates that composting substantially reduces greenhouse gas emissions while maintaining effective management of the same volume of garden waste. These findings reinforce composting as an environmentally sustainable alternative to conventional disposal within institutional settings and highlight its potential role in supporting climate mitigation and resource recovery efforts at SMK Engkilili. To further illustrate **Table 2** and **Table 3**, **Figure 4** presents the proportion of annual greenhouse gas emissions under non-composting and composting scenarios at SMK Engkilili. Under the current waste management approach (without composting), annual emissions accounted for approximately 15309.04 kg CO_2 emissions, while composting scenario contributed reduction of 73.34%. This difference highlights the significant impact of treatment method on overall emissions levels, despite the same quantity of garden waste being

generated annually. The reduction in annual CO_2 emissions reflect the benefits of separating biodegradable organic waste from conventional disposal methods, which most schools decided to transport to landfill. Composting offers several advantages over traditional landfilling by promoting the efficient and complete decomposition of organic waste through enhanced microbial activity, resulting in higher-quality, stable, and humified compost. It maintains a stable environment with optimal temperature and pH conditions, leading to more effective organic matter degradation, nitrogen retention, and reduction of harmful odors and greenhouse gases. Unlike landfills, which trap waste and can produce methane and leachate, composting accelerates organic recycling, lowers environmental impact, and produces valuable soil amendments, making it a sustainable and environmentally friendly waste management method [9].

Table 3. Composting Projection and GHG emissions with composting.

No.	Gardener	Daily garden waste (kg/year)	Monthly garden waste (kg/year)	Yearly garden waste (kg/year)	Daily CO_2e emission (kg CO_2e)	Monthly CO_2e emission (kg CO_2e)	Yearly CO_2e emission (kg CO_2e)
1	Nyelang	158.416	475.25	5702.98	6.34	19.01	228.12
2	Donny	208.73	2504.76	30057.12	8.35	100.19	1202.28
3	Bragai	264.5	1266.8	15201.60	10.58	50.67	608.06
4	Moh	205.8	823.20	9878.40	8.23	32.93	395.14
5	Luli	244.61	978.44	11741.28	9.78	39.14	469.65
6	Malisa	215.18	860.72	10328.64	8.61	34.43	413.15
SUM TOTAL		**1297.24**	**6909.17**	**82910.02**	**51.89**	**276.37**	**3316.40**

Note: CO_2e = Carbon dioxide emission

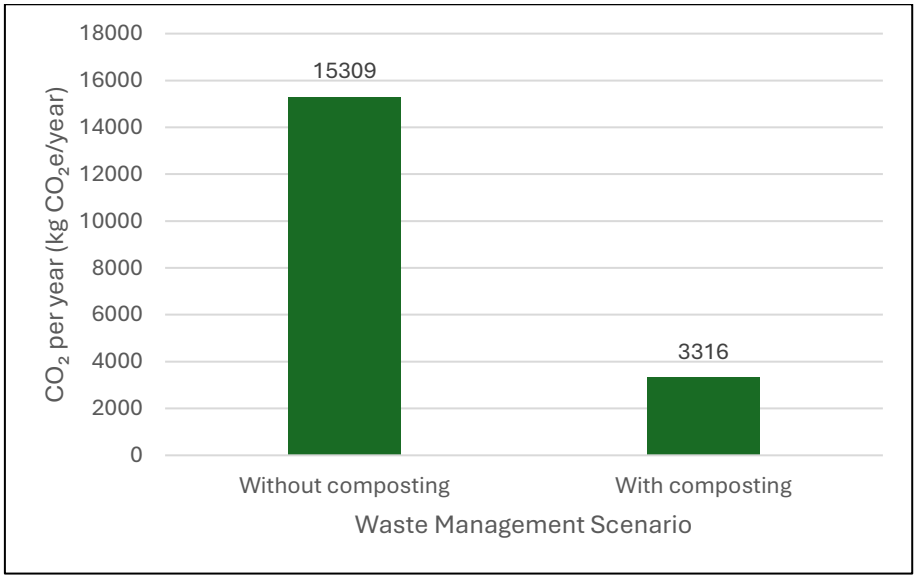


Figure 4. Annual greenhouse gas emissions under non-composting and composting scenarios (kg CO_2-equivalent per year).

3.3 Fertilizer Substitution and Economic Implications

SMK Engkilili currently utilizes approximately 768 kg of commercial fertilizer annually, at a total cost of RM384.00 per year. The projected compost production (13,266 kg usable compost fraction) exceeds the annual fertilizer requirement in terms of application volume as shown in **Table 4**. When monetized based on fertilizer replacement value, the estimated equivalent fertilizer value of compost produced is RM1,058.48 per year. This translates into a potential net economic benefit of RM677.25 annually as shown in **Figure 5**. The positive balance indicates that composting not only provides environmental advantages but also generates financial savings through partial or complete substitution

of synthetic fertilizers. It is important to note that compost and synthetic fertilizers differ in nutrient concentration and release rates. Compost typically has lower nutrient density but improves soil structure, moisture retention, and microbial activity [10]. Therefore, the economic valuation presented reflects replacement potential rather than direct nutrient equivalency. Long-term agronomic benefits, such as improved soil health and reduced dependency on chemical inputs, may further enhance the overall economic return beyond the direct cost savings estimated in this study.

Table 4. Fertilizer Cost Reduction.

Economic Evaluation	Value
Total amount fertilizer used per year (kg)	768
Composed produced (kg)	13266
Fertilizer costs per year (RM)	RM384.00
Expected compost fertilizer produced cost per year (RM)	RM1,061.25
Potential Compose Profit	**RM677.25**

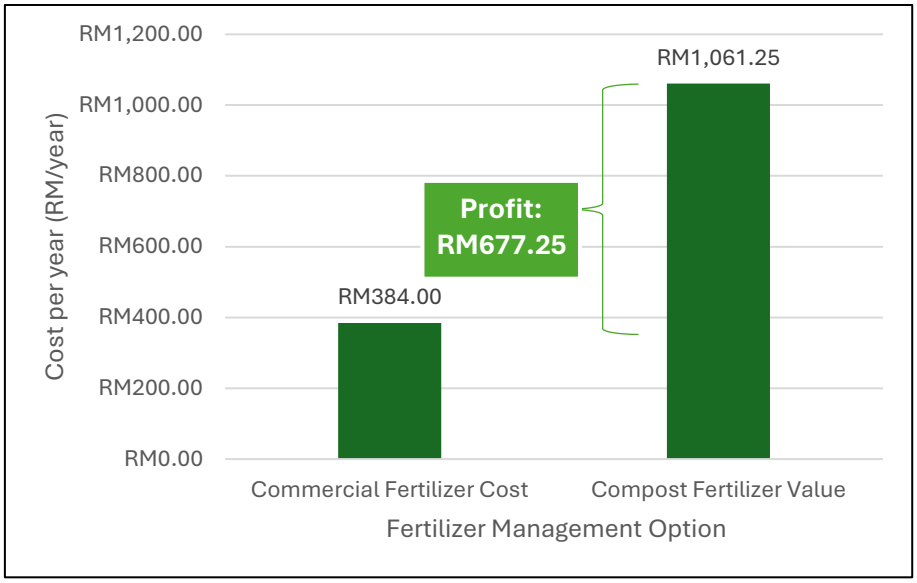


Figure 5. Comparison of commercial fertilizer cost and compost fertilizer value.

4. Conclusion and Recommendations

This study identified and categorized the main garden waste types generated at SMK Engkilili, namely grass clippings, dry leaves, weeds, and plant trimmings, with plant trimmings contributing the largest proportion of annual waste. Analysis of garden waste generation showed that a substantial quantity of biodegradable material is produced through routine maintenance activities, indicating strong potential for compost recovery. The composting assessment demonstrated a significant reduction in carbon dioxide emission compared to the current disposal practice, alongside the ability to substitute commercial fertilizer use and generate measurable cost savings. Based on these findings, composting is proposed as a suitable garden waste management strategy for the school, offering both environmental benefits through emission reduction and economic advantages through fertilizer cost reduction. Overall, the study achieves its aim by demonstrating that composting represents a viable and economically beneficial alternative disposal method for garden waste generated at SMK Engkilili, Sri Aman, Sarawak, supporting more sustainable waste management practices within the school environment. Based on the findings of this study, it is recommended that SMK Engkilili implement on-site composting as a regular garden waste management to reduce landfill disposal and GHG emissions while producing usable compost for landscaping purposes. Garden waste should be segregated at source to improve compost quality and processing efficiency, supported by basic training and awareness programs for the gardeners and school staff. The compost produced can be applied within the school compound to partially or fully

replace commercial fertilizers, thereby reducing maintenance costs. Continuous monitoring of waste generation and compost output is also recommended to optimize the system, with future studies encouraged to evaluate compost quality and explore the inclusion of other biodegradable wastes to further enhance environmental and economic benefits.

Acknowledgements

The author gratefully acknowledges the support and cooperation of Universiti Malaysia Sarawak, Ministry of Science, Technology and Innovation (MOSTI), and SMK Engkilili in facilitating this study. Sincere appreciation is extended to the gardeners and staff of SMK Engkilili for their assistance during data collection. Special thanks are also given to the student group members from SMK Engkilili for their valuable support in questionnaire distribution and fieldwork activities. The author would further like to express heartfelt gratitude to the YellowHippo members for their significant involvement and continuous assistance throughout the project. Finally, appreciation is extended to friends and family members for their encouragement and support during the completion of this work.

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An Assessment of Generation, Segregation and Sustainable Management Practices Among Students in SMK. Engkilili

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Abstract

Solid waste generation in educational institutions represents a measurable environmental and resource management challenge, particularly in rural areas with limited infrastructure. This study investigated the composition, mass distribution, recycling value and awareness and attitudes of student generated waste at Sekolah Menengah Kebangsaan Engkilili, Sarawak, Malaysia. A mixed method approach was employed, combining questionnaire-based assessment and quantitative waste mass estimation using standardized unit weights. Plastic recorded the highest disposal frequency at 45%, followed by paper at 38% and tin cans at 17%. However, mass-based analysis showed tin cans contributed the largest proportion of total weight at 59%, followed by plastic 26% and paper at 15%. Despite 100% recycling awareness, only 8.57% of students consistently practiced waste separation. Economic projection estimated a potential annual recycling value of RM 58461.11. The findings provide quantitative data to support systematic segregation planning and behavioural patterns of waste management strategies for rural secondary schools.

Keywords: *Solid waste management, student awareness, sustainability, student attitudes, recycling*

1. Introduction

Every school day, hundreds of small actions buying drinks, opening food packaging, using worksheets and throwing away cans quietly contribute to a growing pile of waste, specifically solid waste within the school compound. Although these actions may appear insignificant individually, together they create a significant amount of solid waste that often goes unnoticed. In secondary school, waste is generated continuously through students' daily consumption and academic activities, making schools an important setting for studying waste generation patterns and management practices. In 2022 approximately 189,658 students were enrolled in government school across Sarawak [1] and Sekolah Menengah Kebangsaan Engkilili (SMK Engkilili) recorded an enrollment of 1040 students as of 2026 [2]. Consequently, as the student population increases and packaged products become more common in school, the challenge of segregating and managing solid waste has become more crucial.

In many school environments, recyclable materials such as plastic, paper and aluminium can are commonly generated. Increases in municipal solid waste in Malaysia has become one of the greatest environmental problems that need to be solved immediately [3]. However, most waste is disposed of in general bins without separation at source, resulting in recyclable materials being mixed with non-recyclable waste [4]. This issue becomes more significant in rural school settings where access to recycling facilities and structured waste monitoring systems may be limited [5]. Despite daily waste generation within SMK Engkilili, limited quantitative data exists regarding the composition, volume and dominant waste categories produced by students. The absence of reliable baseline data restricts evidence-based planning and limits the effectiveness of targeted waste reduction strategies.

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Additionally, effective waste management does not depend fully on infrastructure but also student awareness, attitudes and daily activities [6]. Even when recycling bins are provided, sustainable outcomes cannot be achieved without consistent participation and responsible behavior.

Therefore, this study aims to assess solid waste generation among students in SMK Engkilili and evaluate the potential economic value of recyclable materials through improved segregation practices. Specifically, the objectives of the study are to (i) identify the dominant types of solid waste generated, (ii) quantify each waste category over a monitoring period and (iii) estimate the potential resale value of segregated recyclable materials based on current local market prices. The scope of the study is limited to students aged 13-18 years in SMK Engkilili and focuses on three primary waste categories plastic, paper and aluminium cans.

2. Methodology

The process flow of this study is represented in **Figure 1**. The methodology was designed to systematically quantify solid waste generation and evaluate the potential economic value of recyclable materials within the study area. The study consisted of structured data collection, waste classification, weight estimation, and analysis using Excel.

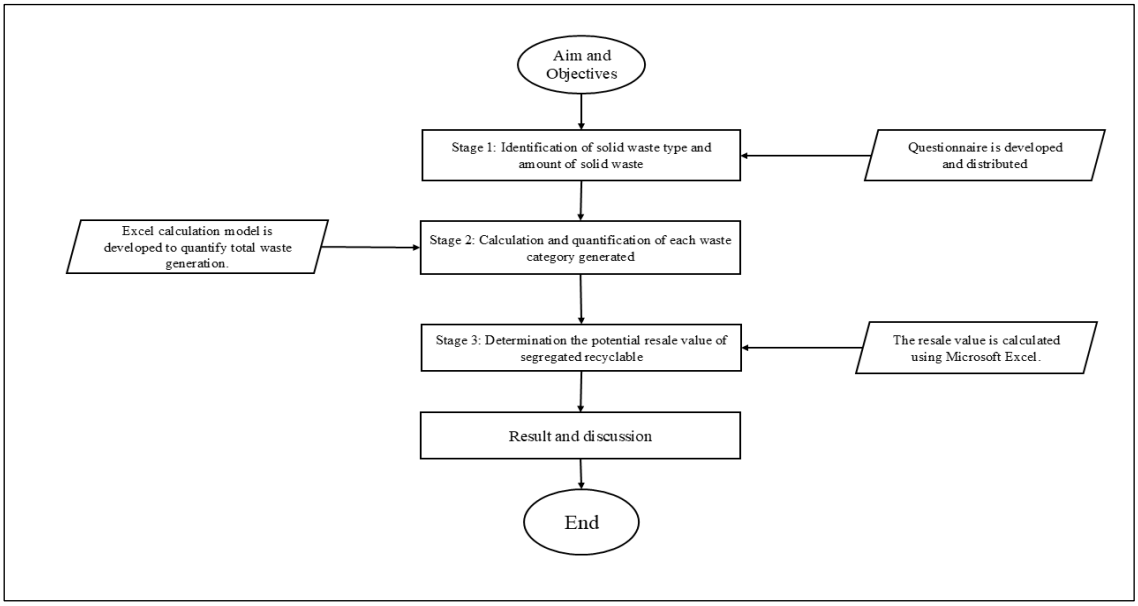


Figure 1. Research methodology flowchart

2.1 Identification of Type and Amount of Solid Waste

The identification of waste types generated among students was conducted through the distribution of structured questionnaires to students present during the study period. In section A, students are required to specify their class, age group and gender. In section B, questionnaire required students to indicate the type of solid waste they commonly generated during school hours in one day. This includes paper such as worksheets and notebooks, plastic such as water bottles, food packaging, cups, straws, cutlery and aluminum cans from canned beverages. Students were also asked to identify the locations where waste was most frequently generated such as classroom, canteen, hostel and other school areas. In section C and D, the questionnaire includes an assessment of student awareness and attitudes that focus on recycling practices. The collected responses allowed the classification of waste into clearly defined categories for systematic quantification and comparison in subsequent analysis.

2.2 Calculation and Quantification of Waste Categories

The quantification of waste categories was performed using data obtained from questionnaires combined with estimated average weights for each reported waste item. The estimated weight for each type of waste is listed below in **Table 1.**

Table 1. Estimated weight (kg) for each type of waste

Waste Categories	Type of waste	Estimated weight (kg)
Paper	A piece of A4 Paper [7]	0.005
Plastic	Plastic Water Bottle (500ml) [8]	0.015
	Food Packaging/ Wrappers [9]	0.001
	Plastic Cup (240ml) [10]	0.0057
	Plastic Straw [9]	0.004
	Plastic Cutlery [11]	0.005
Metal	Aluminium Can beverages (300ml) [12]	0.046

All data was entered into a specifically developed Microsoft Excel spreadsheet for calculation and analysis for this study. The spreadsheet was used to calculate the total waste generated per day, total waste generated per student age group and percentage contribution of each waste type to the overall solid waste stream. Waste generation was also compared across different age groups to determine which group contributed to the highest amount of waste. Graphical representation that includes bar charts and pie charts were generated to visualize waste distribution patterns.

2.3 Determination of Potential Resale Value of Segregated Recyclable Materials

The estimation of resale value enables the evaluation of economic feasibility associated with improved segregation practices. Current local market price (RM/kilogram) is listed below in **Table 2.**

Table 2. Market Prices for Each Waste Type [13]

Type of Waste	Market Price (RM/kg)
Mix Paper	0.10
Mix Plastic	0.20
Aluminium Can	4.00

The potential resale value of each recyclable category was calculated using **Equation 1.**

$$\text{Value (RM)} = \text{Weight (kg)} \times \text{Market Price (RM/kg)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The total potential revenue was calculated by summing up the resale values of all recyclable waste. This economic evaluation provided an estimation of the financial benefits that could be achieved through proper waste segregation. The result was presented in summarised tables to illustrate the potential economic impact of improved waste management practices.

3. Result and Discussion

The demographic of the respondents was summarized in **Table 3.** and **Table 4**. As shown in **Table 3**, the age group of 13-14 years old showed a high percentage of participation, 54.30%, followed by 15-16 years old 31.42% and lastly 14.28% of 17-18 years old. In terms of gender shown in **Table 4.** 60% of the total participants were male and the female involved consist of 40% respondent.

3.1 Composition of Student Generated Waste Based on Daily Item Frequency

From **Table 5,** analysis of daily waste generation indicated that plastic materials were generated in the highest quantity with the frequency of 123 out of 275 or 45% from the total responses obtained in

terms of number of items disposed per day. Based on the recorded responses, plastic waste such as water bottles, food packaging, plastic cups, straw and cutlery appeared most frequently among the student waste generation. Second most frequent waste disposed of is paper 106 or 38% and lastly is aluminium can at 46 frequency or at 17% of total waste disposed.

Table 3. Respondents demographic profile (Age Group)

Age Group	Frequency	Percentage (%)
13-14	19	54.30
15-16	11	31.42
17-18	5	14.28
Total	**35**	**100**

Table 4. Respondents demographic profile (Gender)

Gender	Frequency	Percentage (%)
Female	14	40
Male	21	60
Total	**35**	**100**

Table 5. Frequency and percentage of Each Type of Waste Generation Daily by students

Type of Waste	Frequency	Percentage (%)
Paper	106	38
Plastic	123	45
Aluminium Can	46	17
Total	**275**	**100**

This finding reflects the daily consumption pattern of students in SMK Engkilili. Students relied heavily on packaged and ready-to-go products sold at the school canteen and nearby small shops. Plastic packaging is lightweight, inexpensive and is commonly used for food and beverages storage, it is more accessible material for vendors [14]. Although each individual plastic item has a relatively small mass, the high frequency of disposal contributes to its dominance in daily waste counts. The high percentage of plastic has shown that students purchase drinks in small plastic bottles, used plastic straw and disposed of single use packaging daily. Additionally, from the management perspective it is important to not only focus on the waste segregation program that is on total weight. Although plastics may not contribute to the greatest mass, their high number can increase the littering risk and pollution within the school compound [15].

Figure 2. shows the frequency of waste generated across three age groups such as 13-14, 15-16 and 17-18 for paper, plastic and aluminium can categories. The results show a declining trend in waste generation frequency with increasing age across all waste materials. Students aged 13-14 recorded the highest frequency in all three waste categories, with plastic waste being the highest, followed by paper and aluminium cans. The 15-16 age group shows a decrease in frequency across all materials, while the 17-18 group exhibited the lowest overall waste generation. The decreasing pattern can be seen in plastic waste where it shows a drastic drop from the youngest to oldest. This reflects directly their differences in consumption behavior, habits and environmental awareness across age groups. Younger students may rely heavily on pre-packaged food and beverages. This contributes to higher plastic waste. This contrasts with their older peers that generates less waste. Overall, this indicates that age is a contributing factor for waste generation. It highlights the importance of implementing early-stage environmental education particularly among lower secondary students.

Figure 3. illustrates the frequency of waste generated by gender across three material categories paper, plastic and aluminium can. The result showed that male students exhibit higher waste generation frequencies across all categories compared to female students. Plastic waste shows the highest in male students compared to female students. This trend shows that consumption of packaged beverages and single-use plastic products is more common among the male students. Paper waste among the male

students is the second highest while among female students it is the highest. For aluminium cans it is the lowest frequency in both categories. This difference reflects their purchasing habits, lifestyle, dietary or snack and beverages preferences. Previous studies have shown that consumption driven waste generation is strongly influenced by individual habits and environmental awareness levels [16]. Therefore, the higher frequencies recorded among male students indicates the difference in level awareness towards recycling.

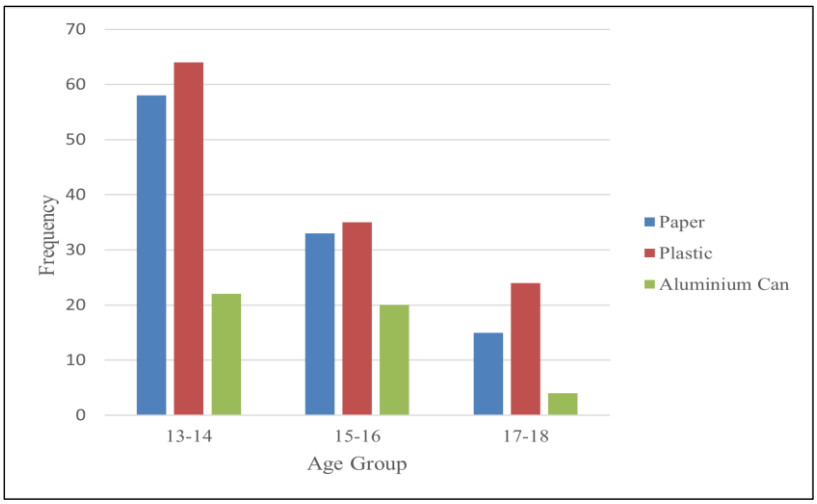


Figure 2. Frequency of waste generated by three different age groups

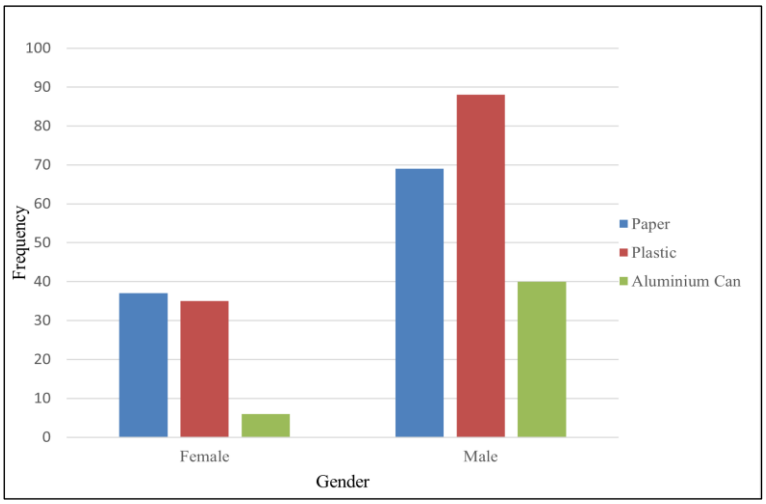


Figure 3. Frequency of waste generated by gender

3.2 Mass Contribution and Weight Distribution of Waste Categories

From a mass-based perspective, the analysis of total waste (kg) was presented in **Table 6** and **Table 7** provides a different insight compared to frequency data. **Table 6** show a total weight of each waste type by age group for 35 respondents. Paper waste generated by 13-14 age group is 0.29 kg, for 15-16 age group 0.165 kg, 17-18 age group is 0.0897 kg. Plastic waste generated by 13-14 age group was 0.482 kg, 15-16 age group 0.278 kg followed by 17-18 age group 0.161 kg. Aluminium can waste generated by age group 14-15 was 1.012 kg, followed by 15-16 age group 0.92 kg, while 17-18 age group was 0.184 kg.

Table 7 shows a total weight estimated by 1028 students. The total mass was calculated using estimated standard weights, aluminium cans have shown as the largest contributor of total 62.150 kg, followed by plastic 27.045 kg and lastly paper 15.99 kg. The data shown in **Table 7** were illustrated in **Figure 4**. Aluminium cans were not disposed of as frequently as plastic items, it has significantly higher

mass compared to plastic and paper. Across three age group aluminium can is the highest total weight generated. Although plastic and paper typically contribute the most waste, especially from school, the unusually high proportion of tin cans has shown a strong consumption of canned beverages. Study has shown the increase in the percentage of canned beverages in Malaysia adolescent in the past 5 years due to rapid urbanization, availability of the beverages at home, dietary or exposure to social media could be the contributing factors [17]. Additionally, it also reflects in the areas where the school is located, canned beverages have longer shelf life and are more stable during transportation compared to carton-based drinks. Limited availability of fresh beverages alternatives may increase reliance on canned drinks, particularly in school canteens.

Table 6. Total weight (kg) for each type of waste per day of 35 respondents

Student Age Group	Respondent	Paper	Plastic	Aluminium Can
13-14	19	0.29	0.482	1.012
15-16	11	0.165	0.278	0.92
17-18	5	0.0897	0.161	0.184
Total	**35**	**0.5447**	**0.9208**	**2.116**

Table 7. Total weight (kg) for each type of waste day per age group daily

Student Age Group	Number of students	Paper	Plastic	Aluminium can
13-14	387	5.907	9.818	20.613
15-16	346	5.190	8.744	28.938
17-18	295	5.292	9.499	10.856
Total	**1028**	**15.999**	**27.045**	**62.150**

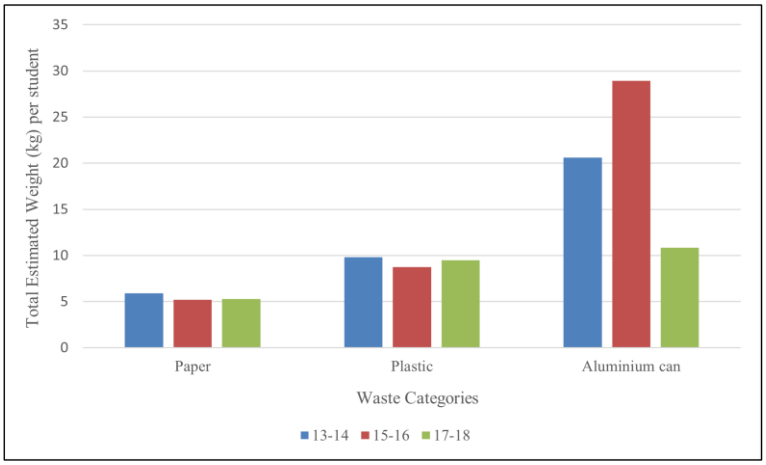


Figure 4. Waste generated by three different age groups

Table 8 shows the total estimated waste generated (kg) by gender across three material categories. The data shown in the table was illustrated in **Figure 5**. The findings indicate that male students generate higher quantities of waste across all categories, particularly aluminium cans, which contribute the largest proportion of total waste. This suggests differences in consumption behavior between male and female students, especially in beverage choices. Male student paper waste generated approximately 7.56 kg meanwhile female student 8.18 kg. Male students generated approximately 15.245 kg of paper waste compared to 0.20 kg by female students. A similar pattern was observed for plastic weight, where male produced about 15.245 kg compared to 10.520 kg among females. The highest difference is shown in aluminium can waste, with male students generating approximately 10.48 kg, meanwhile female students contributed only 43.634 kg. Aluminium can dominate the waste material among the male and female students in terms of mass, despite plastic being the highest frequency in earlier analysis.

Table 8. Total weight (kg) for each type of waste by gender daily

Student Age Group	Respondent	Paper	Plastic	Aluminium can
Female	530	7.560	10.520	10.448
Male	498	8.181	15.245	43.634
Total	**1028**	**15.998**	**27.044**	**62.149**

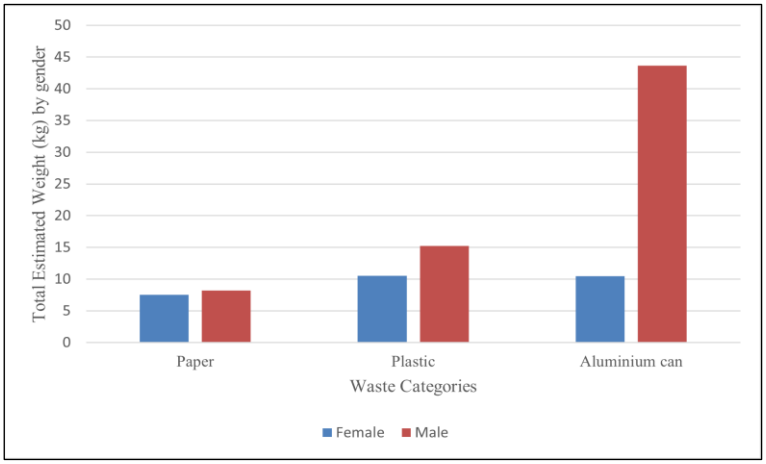


Figure 5. Total waste generated (kg) by gender

3.3 Potential Resale Value

Following the quantification of solid waste by type and total weight, an economic evaluation was conducted to determine the potential resale value of recyclable materials generated by students in SMK Engkilili. The potential resale value is summarized in **Table 9.**

Table 9. Estimation of resale value of total waste generated recyclable daily

Student Age Group	Number of students	Paper (RM)	Plastic (RM)	Aluminium Can (RM)
13-14	387	0.59	1.96	82.45
15-16	346	0.52	1.75	115.75
17-18	295	0.53	1.90	43.42
Total (RM)	**1028**	**1.60**	**5.41**	**248.60**

Based on the results shown in **Table 9**, aluminium can have the highest potential resale value of RM 248.60, despite not being the only most frequently generated waste type. Followed by plastic with RM 5.41 while paper RM 1.60. This was due to the heavier mass of canned beverages and their higher market price per kilogram compared to paper and plastic. Although plastic waste was generated in greater quantities due to its lower density and lower resale value, it reduced the estimation of economic contribution. This shows that from an economic perspective, metal waste recovery offers the greatest financial potential for the school despite its not having the highest in numbers. From the recycling market trends metal typically has a higher recycling price due to their material recovery value. Additionally, the structured recycling initiatives may be limited by the accessibility to recycling centers and transportation as SMK Engkilili is not near the city. By implementing this waste segregation practices, the small amount of funds can be recovered to support school initiative and sustainability programs.

Although the selected waste categories are technically recyclable, it is assumed that only 70-80% of the waste of paper generated can be effectively recovered for sale [18]. Plastic and aluminium can have 100% can be recovered for sale. This adjustment accounts for materials contamination and improper segregation commonly reduce the proportion of marketable recyclable materials under practical

conditions. **Table 10** shows the 80% paper, 100% plastic and aluminiun can weight of waste that can be recycle for sales.

Table 10. Total weight (kg) for 80% paper, 100% plastic and aluminium can

Student Age Group	Number of students	Paper	Plastic	Aluminium can
13-14	387	4.725	9.818	20.613
15-16	346	4.152	8.744	28.938
17-18	295	4.234	9.499	10.856
Total	**1028**	**12.799**	**27.045**	**62.150**

Based on the recorded daily waste generation of paper only 80% is saleable for recycling. Therefore, only 12.799 kg of waste can be recyclable and saleable for profit. **Table 11** below shows the estimation resale value for 80% paper, 100% plastic and aluminium can.

Table 11. Estimated potential value (RM) for 80% paper, 100% plastic and aluminium can

Student Age Group	Number of students	Paper (RM)	Plastic (RM)	Aluminium can (RM)
13-14	387	0.47	1.96	82.45
15-16	346	0.42	1.75	115.75
17-18	295	0.42	1.90	43.42
Total	**1028**	**1.28**	**5.41**	**248.60**

The projections for recyclable and saleable waste were summarized in **Table 12** using academic calendar of secondary school. This trend is consistent from daily to yearly projection, indicating that aluminium cans have a significantly higher market value per unit compared to plastic and paper. On daily basis, aluminium can generate extremely high value compared to other materials. During weekdays (5 days), aluminium cans continue to dominate the total value. The weekly accumulation significantly increases the revenue, especially for aluminium. The overwhelming amount of resale value for aluminium can by year (229 days) is RM 56,929.35. Furthermore, by summing up all the waste categories the resale value annually is RM 58,461.11 Based on this data the school can introduce aluminium collection bins around the school. Additionally, schools should implement incentive programs for example reward systems for aluminium collection.

Table 12. Projection of waste generation and recycling value over different time periods

Period of times	Paper (RM)	Plastic (RM)	Aluminium Can (RM)
Daily (1 day)	1.28	5.41	248.60
Weekdays (5 days)	63.99	27.05	1,243.00
Month (23 days)	29.43	124.41	5,717.79
Year (229 days)	293.09	1,238.67	56,929.35

3.4 Analysis of student recycling practices and awareness

Based on **Figure 7** below only 8.57% of students ‘always’ separate their waste before disposal, while most students separate waste ‘sometimes’ 37.14%, ‘rarely’ 25.17% and ‘never’ 28.57%. This result shows that waste segregation is practice by some students, however the consistent separation behavior remains low. The high percentage of ‘sometimes’ responses indicates irregular behavior rather than ‘never’. This pattern reflects what is commonly described in environmental behavior studies as the attitude behavior gap. It is when individuals express positive views toward environmental protection but do not consistently practice it. Environmental knowledge and positive attitudes do not automatically lead to consistent pro-environmental behavior due to external barriers such as convenience, infrastructure and social influence [19]. Low percentage of students who choose ‘always’ when separating waste may be due to limited recycling bin availability across the school compound. However,

the schools do provide recycling bins despite the provided bin students are not motivated to recycle their waste.

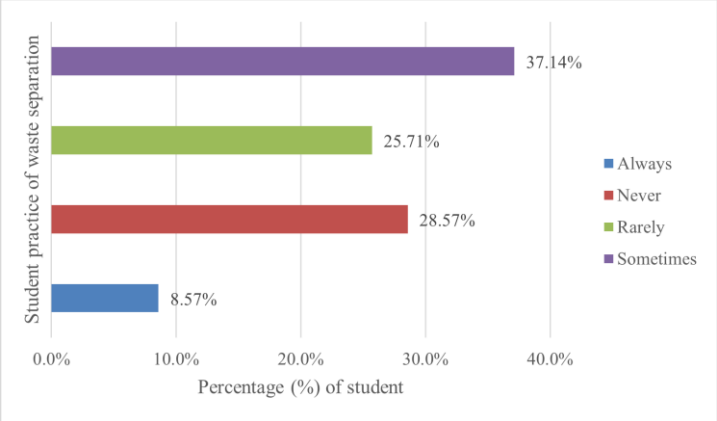


Figure 7. Percentage (%) of student practices toward waste separation before disposal

Table 9 shows that 100% of students reported that they have heard or received education about waste management. This indicates that environmental waste education within SMK Engkilili is well established. This high level of awareness may be due to school education, national environmental campaigns or media exposure. Malaysia has also implemented several recycling awareness initiatives through Solid Waste and Public Cleansing Management Corporation (SWCorp) [20], which may contribute to widespread knowledge among students. However, despite 100% awareness, consistent separation behavior remains low only 8.57% always 'separate'. This has shown that awareness alone is not enough for them to comply with recycling behaviors. **Figure 8** shows the percentage of students understanding the importance of recycling.

Table 9. Percentage (%) of awareness of recycling among students

Awareness of recycling	Frequency	Percentage (%)
Yes	35	100
No	0	0

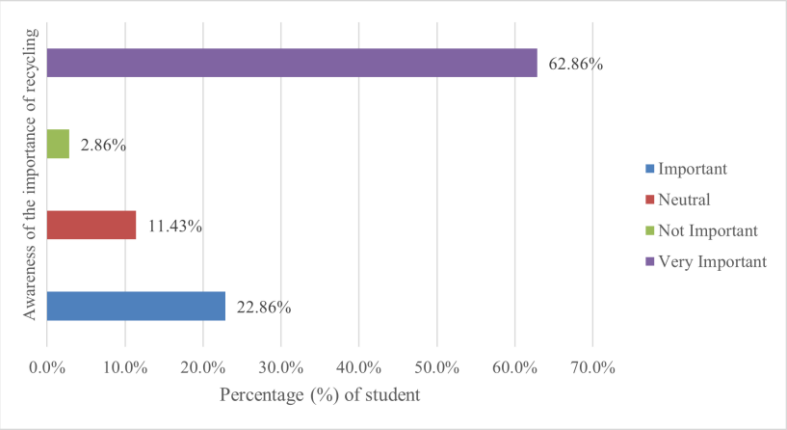


Figure 8. Percentage (%) of students understanding of importance of recycling

Result in **Figure 8** indicates that 62.86% of students consider recycling to be very important, 22.86% consider it important, 11.43% are neutral and a small minority 2.86% consider it is not important. Majority of students hold positive environmental attitudes. In SMK Engkilili specifically students clearly recognize the importance of recycling, but the lower percentage of consistent waste separation shows that structural or situational barriers limit full behavioral expression. Studies on the 3Rs behavior in Malaysia indicate that attitude, normative influence and perceived behavioral control significantly

affect recycling and plastic usage behavior supporting the idea that awareness alone is not enough to drive consistent practice [21].

4. Conclusion

In conclusion, waste generation, segregation practices and potential economic value of solid waste produced by students in SMK Engkilili is successfully assessed. The finding clearly demonstrated that plastic waste was generated in the highest quantity in terms of number of items, while aluminium cans contributed the highest total weight. Although 100% of respondents reported being aware of recycling, only a small percentage consistently practiced waste separation before disposal. This shows the attitude behavior gap, where students understand the importance of recycling but do not always apply it in daily practice. The awareness alone is insufficient to ensure effective waste segregation, structural support and systematic waste management are equally important. The waste management system can be improved despite the limitations, adding more recycling bins that are clearly labelled in the classroom. Since classrooms generate the highest amount of waste, placing color coded and labelled recycling bins directly inside the class would increase convenience and integrate into their habits. Teachers also can initiate a program that regularly wastes audits and recycling competitions between classes to encourage their participation. Since recyclable materials such as tin cans, plastic and paper have resale value, the school could arrange a collaboration with local recycling centers to implement a collection system every week.

Acknowledgements

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PART III
EXPERIMENTAL RESEARCH PROJECTS



Turning Waste into Energy: A Comparative Analysis of Biodiesel Extract from Used Cooking Oil and New Cooking Oil

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Abstract

This study investigates the feasibility and efficiency of biodiesel production from new and used cooking oil collected at the school pantry of school kitchen in SMK Engkilili. Through a three-stage methodology involving oil usage quantification, experimental biodiesel synthesis, and analysis of operational parameters, the research compares biodiesel yield and pH characteristics under varying reaction temperatures and methanol-oil ratios. The findings of the study shows that new cooking oil produced a better biodiesel yield compared to treated used cooking oil, primarily because fresh oil contains fewer impurities and lower levels of free fatty acids (FFAs), which allows for more efficient transesterification and results in a higher conversion rate with more neutral pH values. The pretreatment of used cooking oil is therefore important that involves both filtrations to remove suspended solid particles and heating up to 104°C to effectively evaporate water content. Although the treated used cooking oil still produced lower yields than fresh oil, the pretreatment process has improved its conversion efficiency making it a valuable feedstock for biodiesel production within a school-based sustainability framework.

Keywords: *Biodiesel, new cooking oil, used cooking oil, pH, reaction temperature, free fatty acids (FFAs).*

1. Introduction

Biodiesel production has gained increasing attention as a renewable energy source that can reduce dependence on fossil fuels and promote sustainable waste management. In a school kitchen setting, cooking oil is used extensively for food preparation, creating both opportunities and challenges for biodiesel research. This study focuses on a comparative analysis of biodiesel yield from new and used cooking oil collected in the school canteen. New cooking oil, being free from impurities anddegradation, is expected to provide higher and more consistent yields, while used cooking oil represents a practical feedstock that supports waste reduction and cost savings. By examining the performance of both oil types under controlled transesterification conditions [1], the study aims to determine the feasibility of converting everyday kitchen waste into biodiesel and to identify the optimal operating parameters for maximum yield. The findings will not only highlight the potential of biodiesel production as a sustainable practice within the school environment but also contribute to estimating the amount of biodiesel can be produced in a period of time at the school pantry (school kitchen) of SMK Engkilili as depicted in **Figure 1**. As such, the aim of the study is to do comparative analysis on biodiesel extract from used cooking oil and new cooking oil at the school kitchen of SMK Engkilili. The objectives of the study are (i) to quantify the amount of used cooking oil generated by the school pantry (school kitchen) over a defined period, to conduct biodiesel production experiment based on availability waste

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cooking oil and new cooking oil, and to analyze biodiesel production operating conditions by analyzing the effect of selected operational parameter on both used and new cooking oil's pH. The study is conducted in school pantry (school kitchen) at SMK Engkilili. The study focused on estimating amount of biodiesel can be produced based on the usage of new cooking oil and new cooking oil at SMK Engkilili. This study used new cooking oil and untreated used cooking oil. This untreated used cooking oil was obtained from school kitchen of SMK Engkilili as referred in **Figure 1**.

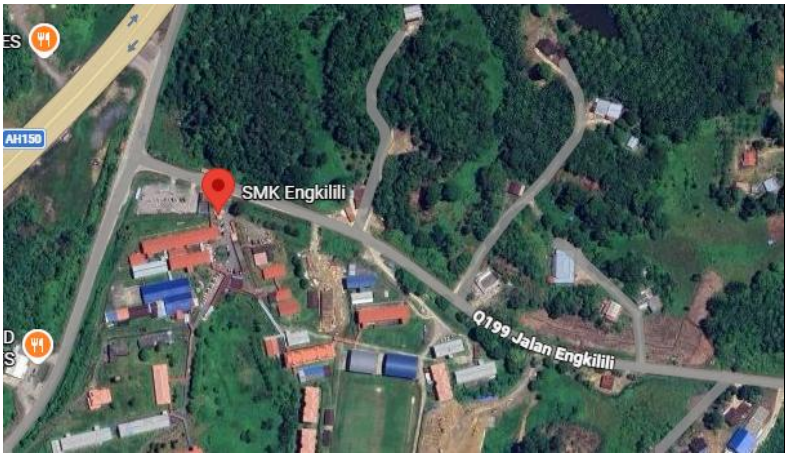


Figure 1. Location of SMK Engkilili [11]

2. Methodology

Pretreatment or waste cooking oil (WCO) is a crucial step before it can be used for biodiesel production because the oil typically contains high levels of free fatty acids (FFAs), water and impurities that interfere with transesterification. Pretreatment generally involves removing water and solid residues through filtration and heating. This step ensures that the oil becomes suitable for transesterification which improves conversion efficiency and lowers production costs [6]. According to Chhetri, Watts, and Islam [2], high FFA levels are problematic in base-catalyzed transesterification because they react with alkaline catalyst such as sodium hydroxide to form soap, which reduces biodiesel yield and complicates separation of glycerin and esters.

The methodology of biodiesel production from used cooking oil is significant because it directly addresses the challenges posed by impurities, water content, and high free fatty acid (FFA) levels that accumulate during frying. Alkaline catalysis, most commonly using NaOH, is the industry standard due to its high reaction rates and relatively low cost, but it is highly sensitive to FFAs and water, which can lead to soap formation and poor separation of biodiesel and glycerol, though it requires shorter reaction times and higher alcohol-to-oil ratios [3].

In the transesterification process, sodium hydroxide (NaOH) is one of the most widely used homogeneous catalysts because it is inexpensive, readily available, and highly effective at promoting the conversion of triglycerides in oils into fatty acid methyl esters (biodiesel). According to [4], NaOH works well when the feedstock oil has low free fatty acid (FFA) content, since FFAs react with NaOH to form soap, which reduces biodiesel yield and complicates separation of glycerol and esters. For waste cooking oil, which often contains more than 2% FFAs, pretreatment such as acid esterification is usually required before NaOH can be applied effectively. The advantages of NaOH include fast reaction rates, relatively mild operating conditions, and high conversion efficiency when the oil is properly pretreated. However, its limitations are sensitivity to water and FFAs, which can lead to saponification, emulsions, and difficulties in biodiesel purification [4].

Figure 2 shows the methodology of the study can be understood as a structured, three-stage process, each stage building upon the previous one to ensure that the findings are both reliable and meaningful.

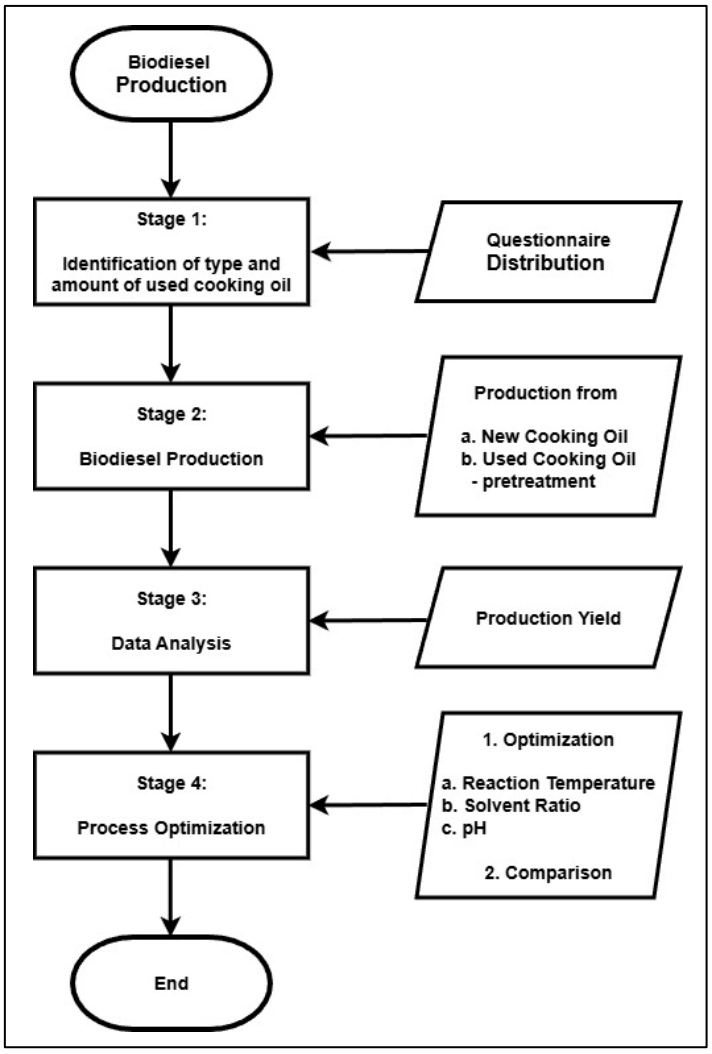


Figure 2. The process flow of the methodology

In the first stage, the research began with a survey conducted among the staff working in the school kitchen of the school kitchen, which is responsible for preparing meals for hostel students. This survey was designed as a short questionnaire, focusing specifically on the estimation of the amount of used cooking oil generated by the school kitchen. The purpose of this stage was establishing a baseline understanding of the volume of waste oil produced in a typical operational cycle. By engaging directly with the pantry staff, who are most familiar with the daily cooking practices and waste generation, the study ensured that the data collected was grounded in practical experience rather than assumptions. This stage was crucial because it provided quantitative foundation. The quantification of usage of new cooking oil and its waste is recorded annually of 229 schooling days.

The second stage of the methodology transitioned from data collection to hands-on experimentation. The experimental setup for biodiesel production is as shown in **Figure 3**. Pretreatment of used cooking oil which is shown in **Figure 4** through heating and filtration is a crucial step to improve its quality before reuse for biodiesel production. The oil is first gently heated up to more than 100°C, which lowers its viscosity, evaporates residual water, and loosens suspended impurities without causing thermal degradation. Once warmed, the oil is passed through filter paper, as in **Figure 5**, to remove food particles, carbonized residues, and other solid contaminants that could interfere with chemical reactions or damage equipment. Together, these steps enhance clarity, reduce contamination, and ensure that the oil is cleaner and more consistent, ultimately leading to higher efficiency and better-quality biodiesel or other downstream products.



Figure 3. Experimental of biodiesel production setup apparatus

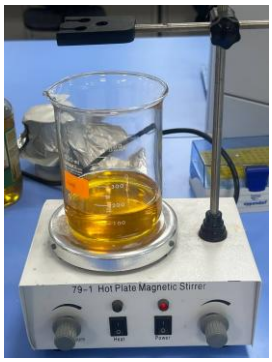


Figure 4. Pretreatment of used cooking oil

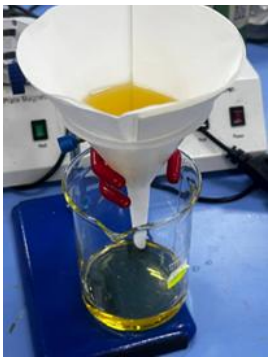


Figure 5. Solid filtration using filter paper

The procedure of biodiesel production begins by mixing the fresh cooking oil with sodium methoxide, which acts as a strong base catalyst to initiate the reaction between triglycerides in the oil and methanol. The mixture is then heated to a temperature range of approximately 50 to 65°C, a range chosen to accelerate the reaction without causing thermal degradation of the oil. During heating, the solution is continuously stirred using a magnetic stirrer for about 20 minutes, ensuring proper mixing and uniform contact between the reactants. After the stirring period, the reaction mixture is transferred into a separating funnel, where it is allowed to stand undisturbed for 10 to 15 minutes. During this settling phase, clear stratification occurs: the upper layer consists of biodiesel, while the denser glycerol by-product settles at the bottom. The biodiesel layer is then carefully collected, and its volume is measured and recorded to determine the yield. This systematic approach not only ensures efficient conversion of oil into biodiesel but also provides reproducible data for further analysis and optimization of reaction conditions. These procedures were repeated for used cooking oil experimentation.

The biodiesel yields produced calculated by using **Equation 1**.

$$Biodiesel\ Yield\ (\%) = \frac{Initial\ cooking\ oil - Biodiesel\ produced}{initial\ cooking\ oil} \times 100 \qquad \text{.....(1)}$$

The amount of biodiesel produced from cooking oil for both new and used cooking oil as follows:

$$\text{Variation of new and used cooking oil } (50, 70, 100\ \text{ml}) \xrightarrow{\text{Catalyst}} \text{Biodiesel} \qquad \text{.....(2)}$$

The third stage of the methodology focused on analysis, where the variations in operating variables were examined to understand their impact on biodiesel yield. This analytical stage was essential because biodiesel production is influenced by multiple factors, including reaction time, temperature, catalyst concentration, and the ratio of alcohol to oil. By systematically analyzing how these variables affected the yield, the study was able to identify optimal conditions for maximizing biodiesel output. This stage

transformed raw experimental results into actionable insights, highlighting the efficiency and limitations of the process under different conditions. The analysis not only quantified the yield but also provided a deeper understanding of the sensitivity of biodiesel production to operational changes. The varied variable investigated were reaction time which are varied from 45 to 70℃ and the ratio of oil to methanol which are varied from 1:1, 1:3, and 1:5 respectively.

The equation of biodiesel estimation over a period is calculated by using **Equation 3**.

$$Biodiesel\ Production = Amount\ of\ cooking\ oil \times Yield \times Time \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

The estimation of biodiesel produced are calculated based on the usage cooking and waste cooking oil per day, per month, and annually with consideration of yield obtained from experimental results.

3. Results and Discussions

The results of the study are correlation between Stage 1, Stage 2, and Stage 3. The discussions are divided into 3 parts: Quantification of cooking oil usage of school pantry (Dewan Makan), Experimental results on biodiesel production, and analysis of the variation of operating variables on biodiesel production yield.

3.1 Quantification of cooking oil usage at school pantry (School Kitchen)

The quantification of cooking oil usage at the school kitchen was conducted by interviewing the pantry staff at school kitchen. The questions asked were the average litre of cooking oil usage, frequency of cooking oil replaced or discarded, approximation amount of cooking oil is discarded. Most of the staff indicated that more than 20 litres of cooking oil were used per day in preparation of food for the students who live in the school hostel, approximately 140 litres usage per week. According to the pantry staff of the kitchen, around 39 litres of used oil was discarded every 2-3 days, which translates to approximately 13 litres of waste cooking oil is discarded per day. This showed that about 65% of the cooking oil is disposed of as used oil. This finding suggests that the recorded survey about the amount of waste cooking oil can be converted into useful energy such as biodiesel production which is possibly produced in school for 229 days of school excluding school holidays. **Table 1** shows that the school pantry at SMK Engkilili consumes a total of 4580 litres of new oil and 2977 litres of used oil annually across 229 school days.

Table 1. Quantification of cooking oil usage at school pantry

Cooking Oil	Daily (Litres)	Annually (litres)[1]
New	20	4580
Used	13	2977

Note: [1] The number of schooling days per year is 229 days

Figure 5 indicates that new cooking oil accounts for the majority of consumption, representing 61% of the total, while used cooking oil makes up 39%. The predominance of new oil highlights the school's reliance on fresh supplies for food preparation, but the significant proportion of used oil also suggests a considerable potential for recycling and biodiesel production. By quantifying both streams, the data provides a clear picture of resource availability, showing that while fresh oil ensures quality in cooking, the substantial volume of used oil could be strategically harnessed for sustainable energy initiatives, turning waste into a valuable feedstock for biodiesel.

As depicted by **Table 2** and **Figure 6**, the comparison of cooking oil usage across the two school terms reveals a consistent trend where new cooking oil dominates consumption, while used cooking oil makes up a smaller but still significant portion. In the first school term, 98 days, the pantry consumed 1,960 litres of new oil as compared to 1,274 litres of used oil produced. In the second school term, 147 days, with new oil consumption rising to 2,940 litres and used oil to 1,911 litres. The proportional

increase in both categories reflects the longer duration of the second term, but the ratio between new and used oil remained relatively stable, with new oil consistently representing about 61% of total usage and used oil around 39%. This steady trend highlights the school's reliance on fresh oil for food preparation, while also indicating a substantial and predictable stream of used oil that could be harnessed for biodiesel production. The data suggests that while new oil ensures cooking quality, the recurring volume of used oil provides a reliable feedstock for sustainability initiatives, making the school pantry a practical model for integrating waste-to-energy practices.

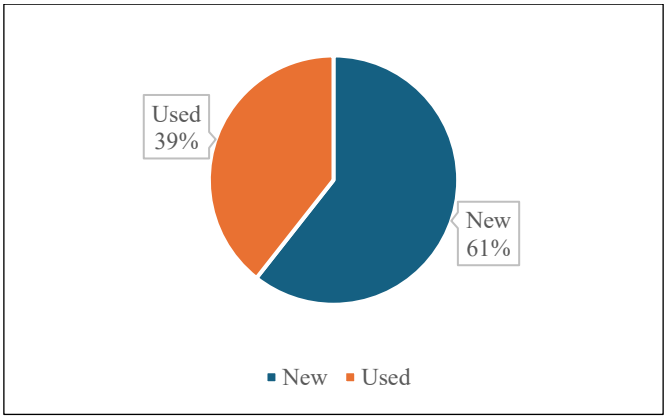


Figure 5. Percentage of amount of usage of new cooking oil and used cooking oil being discarded

Table 2. Comparison of amount of cooking oil (new and used) based on school term

Cooking Oil	Daily (Litres)	1st School Terms *98 days	2nd School Terms *147 days
New	20	1960	2940
Used	13	1274	1911

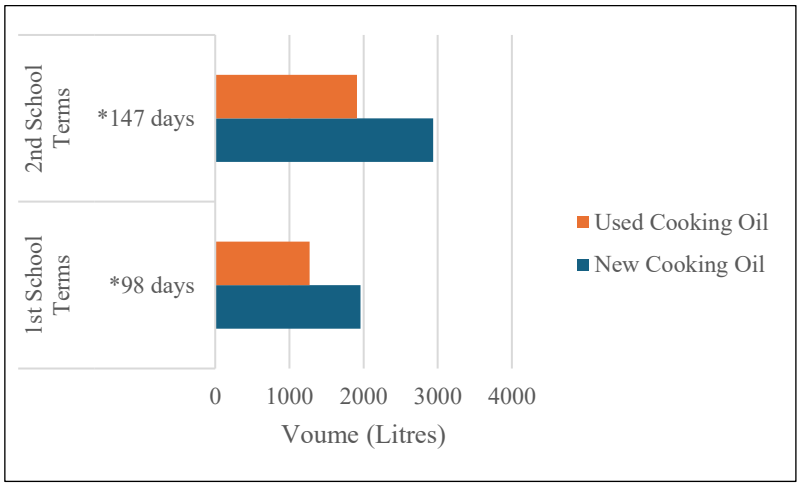


Figure 6. Comparison for the amount of cooking oil for 1st term and 2nd term of school days

3.2. Experimental results on biodiesel production

The experimental production of biodiesel using both new and used cooking oil in varying volumes is significant because it allows for a direct comparison of how feedstock quality influences the efficiency and outcome of the transesterification process. New cooking oil, being relatively pure, contains fewer free fatty acids, water, and impurities, which makes the reaction more predictable and ensures smoother

separation of biodiesel from glycerol. In contrast, used cooking oil undergoes chemical changes during frying—such as oxidation, polymerization, and hydrolysis—that increase its free fatty acid content and introduce residual food particles, all of which complicate the reaction. These differences are critical because high free fatty acid levels in used oil can react with alkaline catalysts like sodium methoxide to form soap, reducing biodiesel yield and making purification more difficult.

By testing both oil types under identical conditions—mixing with sodium methoxide at a 1:5 ratio, heating at 50–60 °C for 20 minutes, as in **Figure 7**, and repeating the procedure with 70 ml and 100 ml volumes—the experiment highlights how feedstock composition directly impacts conversion efficiency, yield percentages, and the quality of the final biodiesel. Recording the biodiesel volumes produced, as in **Figure 8**, provides quantitative evidence of these differences, showing that while new oil consistently delivers higher yields, used oil requires careful pretreatment to achieve acceptable results. This methodology not only demonstrates the technical challenges of working with degraded oils but also underscores the sustainability potential of converting waste into energy, as even lower-yield used oil can be transformed into a renewable fuel source when properly managed.

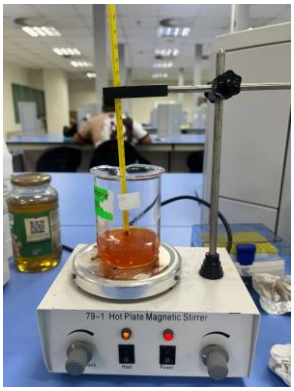


Figure 7. Cooking oil was heated in a controlled temperature for a period of time



Figure 8. Biodiesel was collected from the upper layer of the separation process

In addition, the comparative analysis between new and used oils provides valuable insight into the broader implications of biodiesel production. By quantifying yield differences and observing variations in conversion efficiency, the experiment highlights the importance of feedstock selection in both laboratory-scale trials and industrial applications [9]. The reduced performance of used oil emphasizes the role of contaminants, free fatty acids, and degradation products, which can hinder transesterification unless properly addressed through pretreatment methods such as filtration, neutralization, or degumming. This reinforces the dual challenge of biodiesel research: optimizing chemical processes for maximum efficiency while simultaneously advancing sustainable practices that valorize waste streams.

As depicted by **Table 3,** the trend observed in biodiesel production from varying amounts of new cooking oil shows a clear positive relationship between the volume of oil used and the amount of biodiesel produced, with yields improving slightly as the oil volume increases. At 50 ml of new oil, the biodiesel output was 30 ml, corresponding to a yield of 60%. When the oil volume was increased to 70 ml, biodiesel production rose to 45 ml, with a yield of 64.29%, indicating better conversion efficiency. At the highest tested volume of 100 ml, biodiesel production reached 65 ml, with a yield of 65%, showing that larger volumes of oil not only produce more biodiesel but also achieve marginally higher yields. The line graph in **Figure 9** shows this upward trend, depicting a near-linear increase in biodiesel output as the input volume of new oil rises. This suggests that the transesterification process scales effectively with greater oil quantities, maintaining consistent efficiency while maximizing biodiesel recovery [9]. The results highlight that new cooking oil, due to its lower impurity and free fatty acid content, provides stable and predictable yields, making it a reliable feedstock for biodiesel production experiments. The average yield of the amount biodiesel produced from new oil is 59.76%.

Table 3. Biodiesel production on varies amount of new cooking oil used

Volume of New Oil (ml)	Amount of Biodiesel Produced (ml)	Yield (%)
50	30	60
70	45	64.29
100	65	65

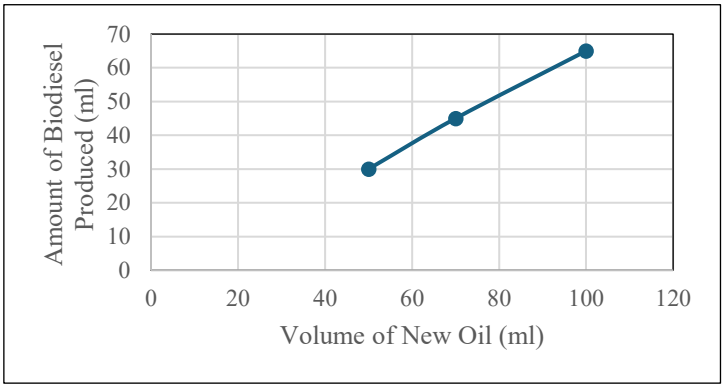


Figure 9. Volume of new cooking oil vs Amount of biodiesel produced

Table 4 and **Figure 10** show a general increase in biodiesel output as the input volume rises, but the yields are noticeably lower and less consistent compared to new cooking oil. At 50 ml of used oil, biodiesel production was 27.5 ml with a yield of 45%, which is significantly lower than the yield achieved with fresh oil under similar conditions. Increasing the volume to 70 ml improved the biodiesel output to 35 ml and raised the yield to 50%, showing that pretreatment and larger input volumes can enhance conversion efficiency. However, when the oil volume was further increased to 100 ml, biodiesel production rose to 52 ml, but the yield dropped slightly to 48%, indicating that impurities and higher free fatty acid content in used oil can interfere with the reaction and limit efficiency despite larger feedstock volumes. The plotted trend in Figure 8 demonstrates that while more used oil generally produces more biodiesel, the conversion efficiency fluctuates and remains lower than that of new oil, underscoring the importance of thorough pretreatment to reduce water, solid residues, and FFAs [10]. The average yield of the three trials is 47.67%.

Table 4. Biodiesel production on varies amount of used cooking oil used

Volume of Used Oil (ml)	Amount of Biodiesel Produced (ml)	Yield (%)
50	27.5	45
70	35	50
100	52	48

For both new cooking oil and used cooking oil, the yield of biodiesel production for new cooking has better yield than used cooking oil due to new cooking oil does not contain impurities that may affect the effectiveness of the biodiesel production yield.

3.3 Analysis of the effect of variation of reaction temperature on pH of biodiesel produced

In this analysis, the focus is placed on understanding how three critical parameters—reaction temperature, methanol-to-oil ratio, and pH—interact to influence the quality and yield of biodiesel. Reaction temperature plays a central role because it directly affects the rate of the transesterification

reaction. the interplay between temperature, methanol ratio, and pH provides valuable insight into the efficiency of the process, guiding adjustments that maximize yield while ensuring the biodiesel meets quality standards.

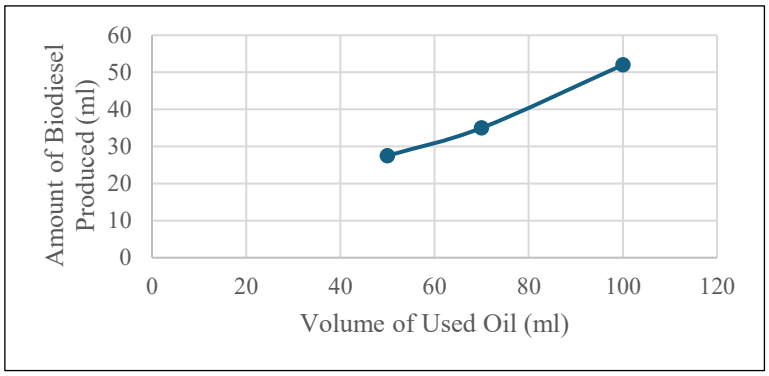


Figure 10. Volume of used cooking oil vs Amount of biodiesel produced

Table 5 and **Figure 11** show the effect of reaction temperature and methanol-oil ratio influence the pH of biodiesel produced from used cooking oil in 3-dimensional (3D) form. As the reaction temperature increases from 49°C to 67.5°C and the methanol-oil ratio rises from 1:1 to 1:5, the pH of the resulting biodiesel steadily increases from 5.7 to 7.0. This trend indicates that higher temperatures and greater solvent availability enhance the transesterification process, reducing the free fatty acid content and producing biodiesel with a more neutral pH, which indicates an important factor for fuel quality and engine compatibility [8]. The 3D graph visualizes the effect of the pH biodiesel produced from new cooking oil varies with changes in reaction temperature and methanol-oil ratio. The surface plot a clear upward trend as the reaction temperature increases from 49°C to 67.5°C and the methanol ratio increases, eventually also the pH values rise from 6.3 to 7.3. the colour coded surface further emphasizes this trend, with cooler colors representing lower pH zones and warmer tones marking areas of higher pH, highlighting optimal conditions for producing biodiesel with near-neutral pH.

Table 5. The effect of reaction temperature on pH value of biodiesel produced for new cooking oil

Reaction Temperature (°C)	Ratio 1:1	Ratio 1:3	Ratio 1:5
49	6.3	6.7	7
57	6.5	7	7.2
67.5	6.6	7.1	7.3

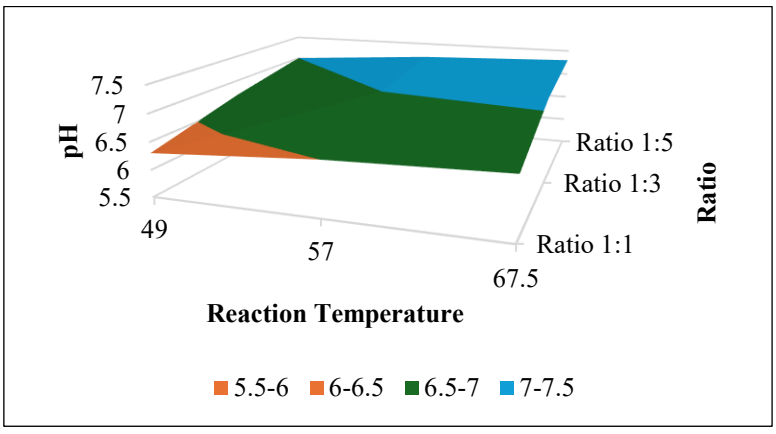


Figure 11. Reaction temperature vs methanol-oil ratio vs pH for new cooking oil

Table 6 shows the influence of reaction temperature and methanol-oil ratio on the pH of biodiesel produced from used cooking oil. As the reaction temperature increases from 49℃ to 67.5℃ and the methanol-oil ratio rises from 1:1 to 1:5, the pH of the resulting biodiesel steadily increases. Used cooking oil shows a similar trend with increasing temperature and methanol-oil ratio, but its values remain lower from 6.7 to 7.0 reflecting the higher FFA content and potential impurities. This is due to a lack of procedure whereby a pretreatment or rewash should be done before using the used cooking oil in biodiesel production [10]. Visually, in **Figure 12**, the used oil graph has a steeper incline, especially at higher ratios and temperatures, this shows that it requires more aggressive conditions to approach the pH neutrality achieved more easily if compared with new cooking oil

Table 6. The effect of reaction temperature on pH value of biodiesel produced for used cooking oil

Reaction Temperature (℃)	Ratio 1:1	Ratio 1:3	Ratio 1:5
49	5.7	6.2	6.5
57	5.9	6.5	6.9
67.5	6	6.6	7

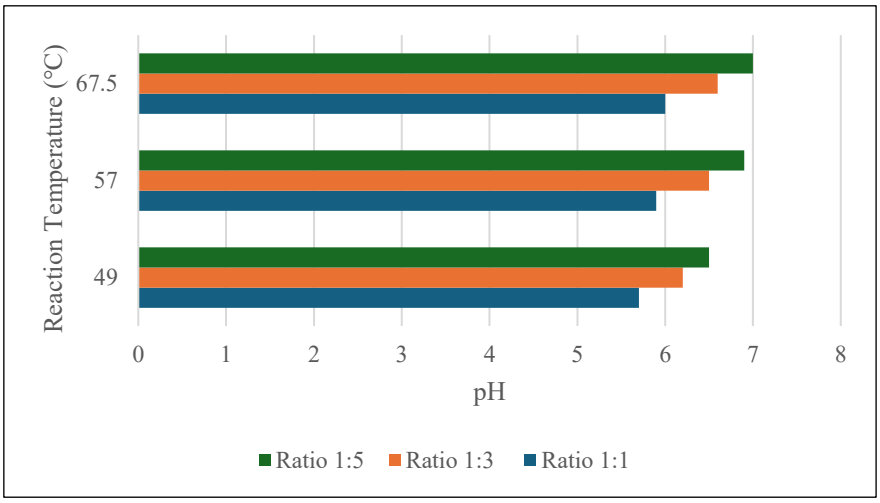


Figure 12. Reaction temperature vs methanol-oil ratio vs pH for used cooking oil

The comparison of temperature and solvent ratio against the pH value of biodiesel oil produced from new and used cooking oil revealed a clear distinction in quality between the two sources. Biodiesel derived from new cooking oil consistently showed a pH value closer to neutral, almost at 7, indicating a more stable and balanced product with fewer residual free fatty acids or alkaline by-products. In contrast, biodiesel produced from used cooking oil tends to have a lower pH, nearer to 6, which suggests the presence of impurities, incomplete conversion, or higher levels of free fatty acids carried over from prior usage. This difference highlights that while both types of oil can be successfully converted into biodiesel, new cooking oil provides a cleaner feedstock that results in better pH stability, whereas used cooking oil requires more careful pretreatment and optimization of reaction conditions to achieve comparable quality.

As depicted in **Table 7**, the trend in biodiesel oil production based on the percentage of students living in hostels clearly demonstrates a direct and proportional relationship between student participation and the volume of biodiesel generated, with distinct differences observed between new and used cooking oil. At lower hostel occupancy levels, such as 20%, the production capacity is relatively modest, yielding 2.38 ml per day and 546.85 ml annually from new cooking oil, while used cooking oil contributes 1.24 ml daily and 283.82 ml annually. As the percentage of hostel residents increases to 50%, the production scales up significantly, with new oil generating 5.97 ml daily and 1,367.13 ml

annually, compared to 3.09 ml daily and 709.56 ml annually from used oil. At full occupancy, where 100% of students live in hostels, the potential biodiesel production reaches its maximum, with new oil producing 11.94 ml daily and 2,734.26 ml annually, while used oil yields 6.20 ml daily and 1,419.14 ml annually. This consistent upward trend highlights the scalability of biodiesel production in relation to hostel population size, while also emphasizing the higher yield efficiency of new cooking oil (59.7%) compared to used cooking oil (47.67%). Nevertheless, the contribution of used oil remains significant, as it represents a sustainable waste-to-energy pathway that reduces environmental impact while supplementing overall biodiesel output.

Table 7. Estimation of biodiesel produced based on number of hostel students

Type of biodiesel oil produced	Percentage of students who lived in hostel (%)[1]	Estimated amount of biodiesel can be produced by new cooking oil per day (ml)	Estimated amount of biodiesel can be produced by new cooking oil annually (ml)
New Oil Yield = 59.7%	20	2.38	546.85
	50	5.97	1367.13
	100	11.94	2734.26
Used Oil Yield = 47.67%	20	1.24	283.82
	50	3.09	709.56
	100	6.20	1419.14

Note: [1] Total students = 1040

4. Conclusion

The survey results from pantry staff of the school kitchen are used for the estimation of biodiesel yield produced in SMK Engkilili. The experimental results for the production of biodiesel of new cooking oil and new cooking oil shows that new cooking oil has better yield production rather than used cooking oil, due to used cooking oil does not undergo pretreatment for effectiveness in biodiesel production. For further study, a pretreatment process must be included to rewash and filter out all the impurities in used cooking oil before being used in the biodiesel production process.

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Recycling Used Cooking Oil for Soap Production: An Environmental Solution

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Abstract

The improper disposal of used cooking oil contributed to environmental pollution and waste of potentially valuable resources. This study investigated the feasibility of recycling used cooking oil into soap through a saponification process. Used cooking oil was collected, filtered, and converted into soap using varying concentrations of sodium hydroxide (0.2, 0.3, and 0.4). The quality of the produced soap was evaluated based on pH level, foaming stability, and water content, and the results were compared with soap produced from fresh cooking oil. The findings showed that increasing NaOH concentration led to higher pH values, improved foaming stability, and increased moisture content for both oil types. Soap produced from used cooking oil exhibited pH values within the acceptable commercial range and demonstrated comparable or superior foaming performance relative to fresh oil soap. An economic analysis revealed that producing soap from 5 kg of used cooking oil could generate a daily profit of RM54.60, indicating good economic viability for small-scale production. Overall, the study demonstrated that recycling used cooking oil into soap was an environmentally sustainable and economically feasible approach that supports waste reduction and resource reuse.

Keywords: *Used cooking oil, Soap production, Saponification, Environmental sustainability*

1. Introduction

Biofuel, hydropower, solar energy and wind energy are becoming more important as alternatives to fossil fuels [1]. Among these renewable options, biodiesel has gained attention as a possible replacement for diesel fuel. Biodiesel is mainly made of fatty acid methyl esters (FAME) which come from renewable sources like animal fats or plant oils [2]. Biodiesel is produced through a chemical reaction with short-chain alcohols, usually methanol or ethanol, using a suitable catalyst [2]. The main method is the transesterification reaction as shown in **Equation 1** where triglycerides (TG) are converted into FAME and glycerol.

$$TG + 3CH_3OH \xrightarrow{Catalyst} 3RCOOCH_3 + Glycerol \quad \text{.....(1)}$$

The efficiency of this process depends on the type of catalyst. Commercial plants usually use homogeneous alkaline catalysts like sodium hydroxide (NaOH) or sodium methoxide ($NaOCH_3$) because the process is faster and simpler [2]. These catalysts can also cause soap formation which is a mixture of sodium or potassium salts of long-chain fatty acids [3]. Low-quality oils such as beef fat tallow may contain non-saponifiable fatty acids which can reduce the quality of the soap. Soap formation is also affected by impurities like moisture and free fatty acids (FFA) and leftover alkali can be harmful because it is corrosive and may irritate the skin or lungs [3]. This study aims to produce soap using biodiesel as the main source of fatty acids. The biodiesel will be saponified using an alkaline catalyst

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and the soap will be checked for quality including texture, hardness and leftover alkali.

Used cooking oil is commonly disposed of as waste and can cause environmental problems if not properly managed. Previous studies have shown that used cooking oils can be used as raw materials to produce laundry soap with physicochemical properties comparable to commercial soap products [4]. Although cooking oil can be converted into biodiesel, impurities in used cooking oil and leftover alkali from processing may affect the quality and safety of products made from it. In soap production, these factors can lead to poor texture and unsafe pH levels. Therefore, there is a need to study the production of soap from biodiesel derived from used cooking oil and to evaluate its quality to ensure it is safe and suitable for use. Hence, the aim of this study is to produce soap using biodiesel derived from used cooking oil as the main source of fatty acids. Thus, the objectives of the study are: (i) to identify and purify used cooking oil from SMK Engkilili canteen for suitability in soap production, (ii) to produce soap from biodiesel obtained from used cooking oil through the saponification reaction and to evaluate the quality of the soap produced based on pH value, foaming stability, and presence of moisture, (iii) to conduct economic analysis on the suitability of soap production from used cooking oil.

The scope of this study focuses on the production of soap from used cooking oil through the saponification process as a sustainable waste management approach. The study will be carried out at SMK Engkilili, utilizing used cooking oil collected from the school community as the primary raw material. The scope of study involves the purification of used cooking oil, the formulation of soap using sodium hydroxide as the alkali, and the observation of the saponification reaction. Basic analysis tests, such as cleansing efficiency and pH levels will be conducted to evaluate the product safety and effectiveness. This study does not involve large-scale industrial manufacturing, instead of dealing with small-scale experimental soap production which is ideal for educational and community usage. The findings aim to prove the feasibility of transforming used cooking oil into useful soap products while also raising environmental awareness among students.

2. Methodology

This chapter presented and discussed the research findings in relation to the objectives of the study. It consisted of several stages, including the collection and preparation of used cooking oil, soap production through the saponification process, and the analysis of soap quality such as pH level, foaming stability, and water content test, as shown in **Figure 1**. The final section presented the economic analysis of the soap produced. The overall findings and conclusions of the study were discussed at the end of the chapter.

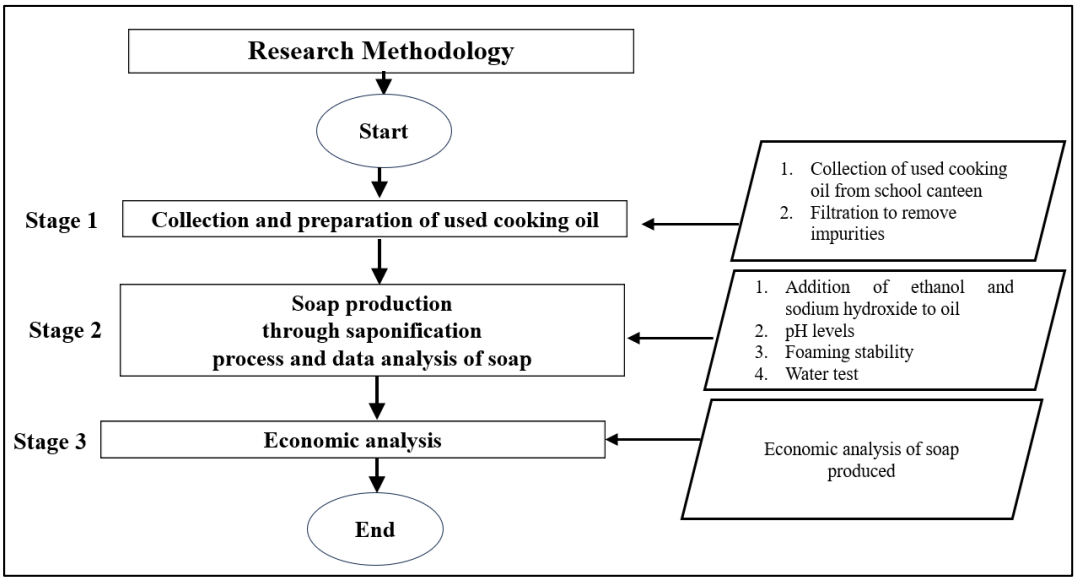


Figure 1. Methodology flowchart of research

2.1 Collection and preparation of used cooking oil

The study began with a site visit to SMK Engkilili to observe the sources of used cooking oil. The primary raw material for production of soap was used cooking oil, which was mainly collected from the school canteen. The collected oil was then filtered to eliminate residues, suspended particles, and other apparent contaminants to obtain cleaner oil for the saponification process.

2.2 Soap production through saponification process and data analysis of soap

The saponification process and data analysis were divided into two parts, which were soap production process and evaluation of quality of soap produced.

2.2.1 Soap production through saponification process

The method for soap production through saponification process was adapted from Laboratory manual from Department of Chemical Engineering and Energy Sustainability, UNIMAS [5] where the experiment began with 25g of purified used cooking oil added into a 150mL clean beaker along with 15mL of ethanol and 15mL of 20% sodium hydroxide solution. The oil mixture was heated and stirred continuously for 30 minutes until it became clearer with no separate layers observed. Small amounts of ethanol-water mixture were added into the mixture to maintain the volume of the mixture, as the volume possibly decreased during the heating process. The hot soap mixture was slowly poured into 50mL of sodium chloride solution and stirred gently to obtain the soap precipitation. The mixture was then cooled in an ice-water bath until it reached room temperature. The solid soap was rinsed with distilled water and collected using a spatula. The soap was transferred into a plastic mold for the drying process before handling. The experiment was then repeated using different concentrations of NaOH solution at 30% and 40%.

2.3.2 Data analysis of soap

The data analysis of soap produced was divided into 3 analyses, which were: (i) pH levels, (ii) foaming stability, and (iii) water content.

i. pH level

The analysis of pH levels was adapted from Wahyudi et al. [6] where the procedure began by weighing 1 gram of soap, followed by adding 100 mL of distilled water into a beaker and stirring until it becomes homogeneous. The pH of the solution was then measured using a calibrated pH meter. The pH meter was immersed into the beaker containing the soap solution and allowed to stabilize until the pH value remained constant. This procedure was repeated for each variation and the obtained pH values were recorded.

ii. Foaming stability

The analysis of foaming stability was adapted from Abera et al. [7] where the foam formation and stability were evaluated by adding 4g of soap and 400mL of tap water into a beaker. The mixture was then continuously stirred to generate foams and observed for 2 minutes to assess foam formation. It was subsequently left undisturbed for 10 minutes to evaluate the stability of the foam.

iii. Water content

The analysis of water content was adapted from Abera et al. [7] where for the determination of water content in the soap, 5g of soap was precisely weighed into a clean, dried dish. The sample was then dried in an oven at 105°C for 30 minutes until a constant mass was obtained. The percentage moisture content was then determined. The moisture content was calculated using **Equation 2** as follow:

$$\%MC = \frac{m_1 - m_2}{m_1 - m_0} \times 100 \qquad \text{.....(2)}$$

where: m_0 was the mass in grams of the petri dish, m_1 was the mass in g of the dish and the test portion before heating, and m_2 was the mass in g of the dish and the test portion after heating.

2.3 Economic analysis

The economic analysis was conducted to evaluate the production cost and profitability of soap produced using used cooking oil. The calculation was based on a daily production capacity of 5 kg of used cooking oil, where 0.025 kg of oil was required to produce one soap bar. The total number of soap bars produced were determined by using **Equation 3**:

$$Number\ of\ soaps\ produced\ = \frac{Total\ oil\ used\ (kg)}{Oil\ required\ per\ soap\ (kg)} \quad \text{.....(3)}$$

The production cost was calculated by summing the cost of all raw materials, including ethanol, NaOH, and NaCl. The cost of each material was determined using **Equation 4**:

$$Material\ cost\ =\ Quantity\ of\ material\ used\ \times\ Unit\ price \quad \text{.....(4)}$$

The total production cost for 200 soap bars was obtained by adding all material costs. The selling price per soap was calculated based on the market price per kilogram by using **Equation 5**:

$$Price\ per\ soap\ =\ Weight\ per\ soap\ (kg)\ \times\ Market\ price\ \left(\frac{RM}{kg}\right) \quad \text{.....(5)}$$

Total revenue was then calculated using **Equation 6**:

$$Total\ revenue\ =\ Selling\ price\ per\ soap\ \times\ Total\ number\ of\ soaps\ produced \quad \text{.....(6)}$$

The profit from soap production was determined by using **Equation 7**:

$$Profit\ =\ Total\ revenue\ -\ Total\ production\ cost \quad \text{.....(7)}$$

Daily, monthly, and yearly profits were estimated by multiplying the daily profit by 20 days and 12 months, respectively. This method provided a clear evaluation of the financial feasibility and economic potential of producing soap from used cooking oil.

3. Results and Discussion

This chapter presented and discussed the research findings in relation to the objectives of the study. It focused on the production of soap using used and fresh cooking oil and evaluated the quality of the soap produced. The results were analyzed based on several parameters, including the concentration of NaOH used in the saponification process, pH levels, water content, and foaming stability, as shown in **Table 1**. A comparative analysis was conducted to determine the effect of different oil types on soap quality and performance. In addition, an economic analysis was carried out to evaluate the production cost and potential profitability of soap produced from used cooking oil. The chapter concluded with a summary of the overall findings and discussed the feasibility and practicality of utilizing used cooking oil for sustainable soap production.

3.1 pH levels

The graph shown in **Figure 2** represented the pH of soap created from used and fresh cooking oil with different NaOH concentrations (0.2, 0.3, and 0.4). Overall, the pH of both soaps increased as the concentration of NaOH increased. Soap typically had an alkaline pH range of 8-10, allowing it to solidify and efficiently wash, but a pH above 11 was too harsh and could damage the skin, and a pH below 8 lacked adequate cleaning power [8].The pH of soap made from used cooking oil increased from roughly 9.78 at 0.2 to around 9.98 at 0.4. A similar trend was observed in soap made from fresh cooking oil, where the pH increased from roughly 9.68 at 0.2 to around 9.80 at 0.4.

Table 1. Summary table of effect of different NaOH concentration on pH levels, water content, and foaming stability for both used and fresh cooking oil

Type of oil	Concentration of NaOH (%)	pH levels	Water content (%)	Foaming stability (cm)
Used cooking oil	0.2	9.78	27.0059	0.5
	0.3	9.8	29.4921	0.8
	0.4	9.98	32.3471	1.1
Fresh cooking oil	0.2	9.68	23.9012	0.6
	0.3	9.75	24.9804	0.62
	0.4	9.8	27.0493	0.7

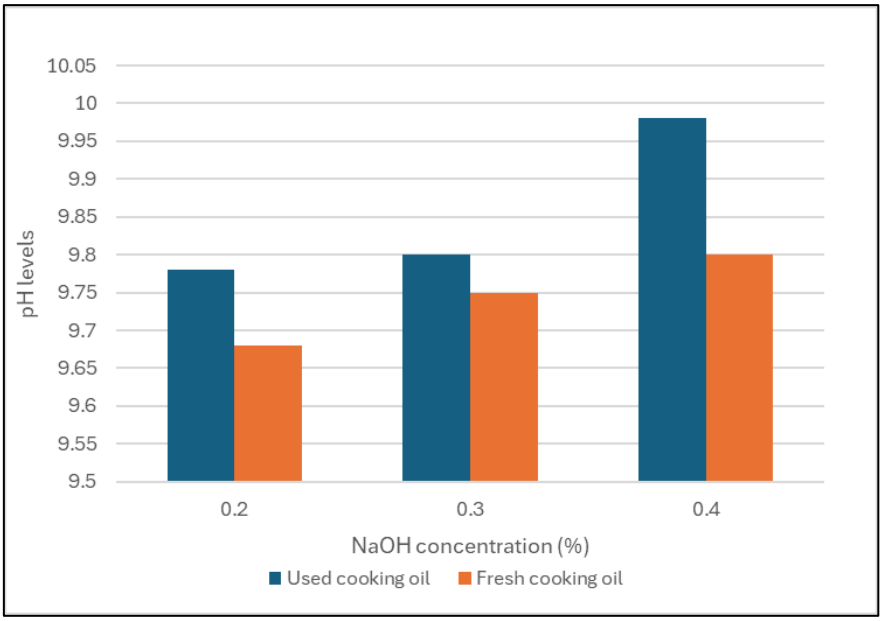


Figure 2. Effect of NaOH concentration on soap pH from used vs fresh cooking oil

In contrast, soap produced from used cooking oil exhibited slightly higher pH values than soap made from fresh oil at all NaOH concentrations. This was attributed to the presence of contaminants in the used oil, which could affect the saponification reaction and alkalinity of the finished product. Used cooking oil experienced increased acidity through hydrolysis, which increased the quantity of free fatty acids (FFA), whereas untreated oil contained fatty acids mostly in triglyceride form [9]. However, all recorded pH values were within the standard pH range of commercial soap (about pH 9-10), indicating that both oil types were able to produce soap with an acceptable alkalinity. The findings indicated that NaOH concentration had a direct influence on pH level, while the type of oil caused only minor variations in the final pH of the soap produced.

3.2 Foaming stability

The graph displayed in **Figure 3** showed the foaming stability of soap made with used and fresh cooking oil at three different NaOH concentrations (0.2, 0.3, and 0.4). In general, foaming stability improved with increasing NaOH content in both types of oil. The higher the foam height, the better the soap lathered [7]. The foam height of soap made from used cooking oil increased significantly from around 0.5 cm at 0.2 concentration to about 1.1 cm at 0.4 concentration. Similarly, soap produced from fresh oil showed gradual increase in foaming stability, from roughly 0.6 cm at 0.2 to around 0.7 cm at 0.4. At a lower NaOH concentration (0.2), fresh oil soap produced slightly more stable foam compared to used oil soap. However, at higher concentrations (0.3 and 0.4), soap made from used cooking oil exhibited significantly stronger foaming stability than fresh oil. This was likely due to changes in fatty acid content of used oil after repeated heating, which affected soap structure and foam generation. The

use of 100% fresh cooking oil resulted in lower lathering performance, whereas the use of used oil enhanced lather formation due to the presence of free fatty acid, which promoted foam formation [10]. Overall, the findings demonstrated that increasing the NaOH concentration improved foaming stability and that used cooking oil had the potential to produce soap with equivalent or even superior foaming performance than fresh oil under specific conditions.

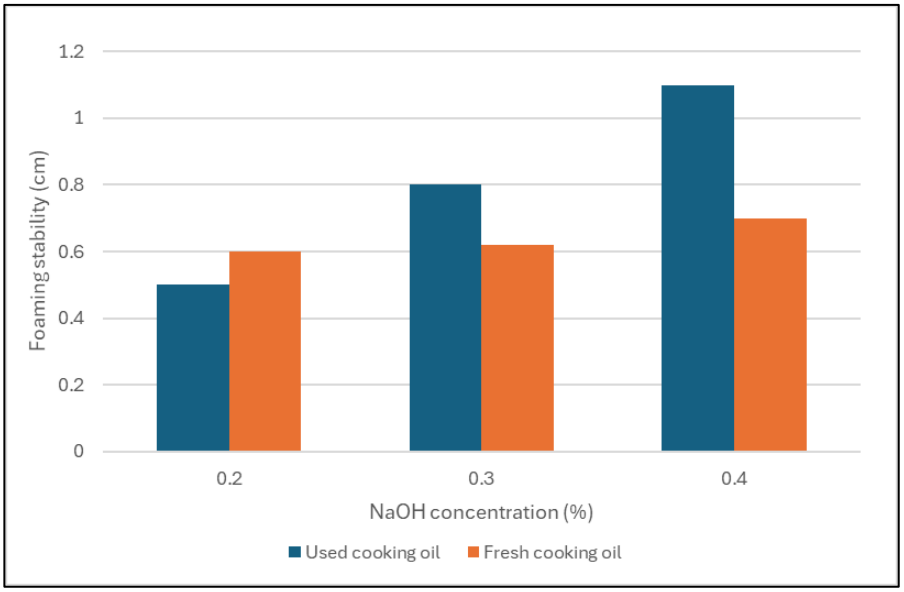


Figure 3. Effect of NaOH concentration on foaming stability of soap from used vs fresh cooking oil

3.3 Water content test

The graph shown in **Figure 4** represented the water content of soap made from used and fresh cooking oil under different NaOH concentrations (0.2, 0.3, and 0.4). The data indicated that moisture content increased with increasing NaOH concentration for both types of oil. The moisture percentage of soap manufactured from used cooking oil increased from roughly 27% at 0.2 concentration to around 32% at 0.4 concentration. A similar upward trend was observed in soap made from fresh oil, where the moisture content increased from roughly 24% to around 27% as the NaOH concentration increased. Excess water could lead to soap spoilage due to hydrolysis of un-saponified fat, producing free fatty acids and glycerin [11].

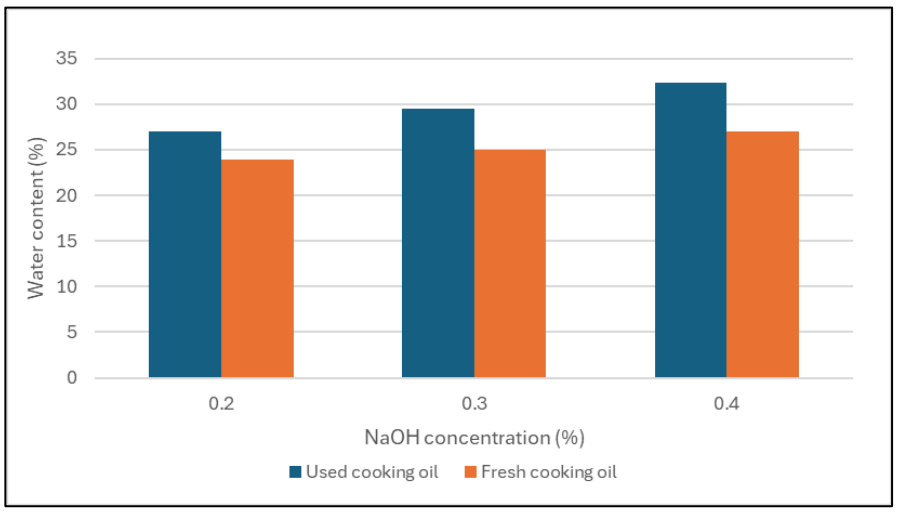


Figure 4. Effect of NaOH concentration on moisture content of soap from used vs fresh cooking oil

In comparison, soap formulated from used cooking oil consistently exhibited higher moisture content compared to soap made from fresh oil at all NaOH concentrations. This was attributed due to the presence of contaminants, degradation products, or residual water in the used frying oil, which influenced the soap's ultimate moisture content. Repeated frying increased the acid value of the oil, causing greater fatty acid saturation and resulted in a higher moisture content which also affected the color of the oil, changing it from brown to dark brown, due to water formed through hydrolysis that accelerated the degradation of the oil [12]. Higher moisture content reduced the hardness and durability of the soap, as soaps with higher moisture content were often softer and dissolved more rapidly during use. Overall, the results confirmed that both NaOH concentration and the type of oil affected the moisture content of the final soap product.

3.4 Comparison graph

The NaOH concentration influenced soap quality because it affected pH, free fatty acids, free alkali, non-soapy fractions, fatty acid content, and water content, which ultimately determined the effectiveness of the saponification process and the overall quality of the soap produced [13]. The 3D surface graph for the used cooking oil showed that increasing the NaOH concentration from 0.2 to 0.4 affected the water content and foaming stability at the same time, as shown in **Figure 5**. Along the vertical axis, a gradual increase in water content was observed as the NaOH concentration increased. This was possibly explained by the enhanced formation of a soap matrix that can hold moisture and the increased dissolution of NaOH in the reaction mixture. This was attributed to the higher steam produced during cooking, which increased the moisture content [14]. At the same time, higher levels of NaOH resulted in a significant improvement in foaming stability. This suggested that increased alkali concentration promoted more complete saponification of the free fatty acids and triglycerides present in used oil, thereby contributing to a higher concentration of soap molecules that enhanced foam film strength and micelle formation. Although the water content increased with NaOH concentration, the improvement in foaming stability indicated that the positive effects of enhanced soap formation outweighed any moisture-induced dilution. As a result, NaOH content had a significant impact on both the moisture properties and foaming performance of soap produced from used cooking oils.

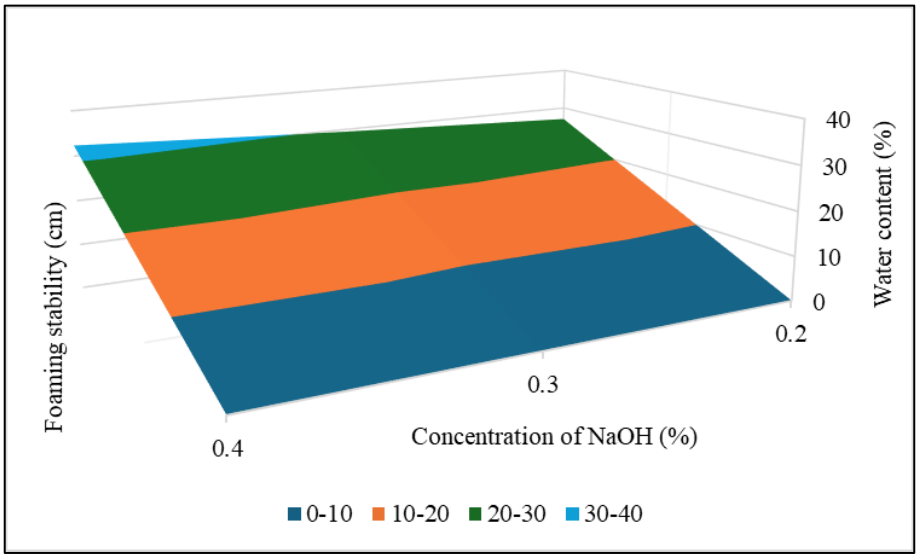


Figure 5. Effect of NaOH concentration on water content and foaming stability of soap from used cooking oil

For fresh cooking oil, a similar but more consistent tendency was observed, as shown in **Figure 6**. As the NaOH concentration increased from 0.2 to 0.4, both water content and foaming stability increased steadily. The increase in water content was attributed to the incorporation of moisture into the soap structure during saponification. Meanwhile, increased alkali availability allowed for more effective

conversion of triglycerides into sodium salts of fatty acids, which resulted in improved foaming stability. Compared to used oil, the surface trend for fresh oil appeared smoother and more uniform, indicating a better-controlled reaction process with fewer interfering contaminants. The simultaneous increase in water content and foaming stability demonstrated that NaOH concentration had a substantial impact on the final soap product's physicochemical qualities. One of the factors affecting foam stability was the soap formulation, particularly the ratio between base concentration and fatty acids or oils used, as stronger interactions between Na^+ ions and fatty acids could reduce foam production [15]. In summary, increased NaOH concentrations improved soap production efficiency, resulting in enhanced foam stability despite an increase in moisture content.

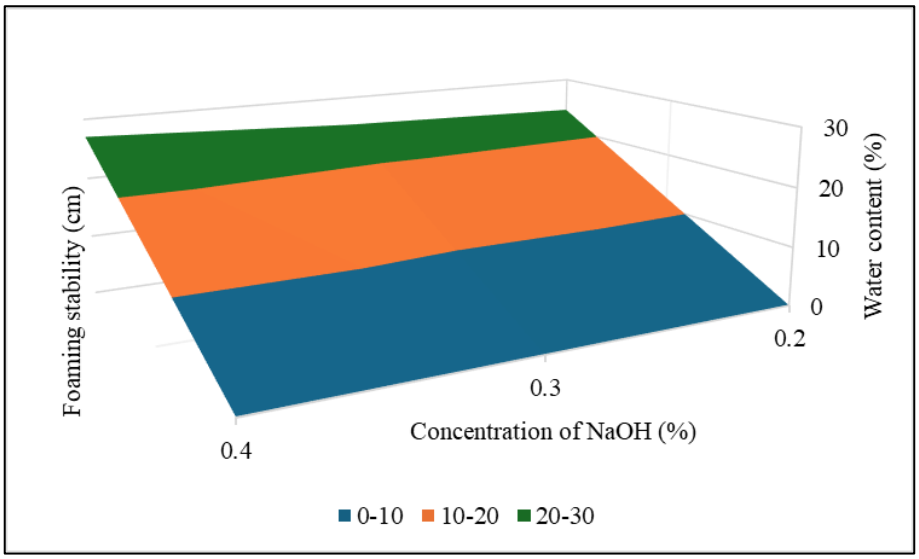


Figure 6. Effect of NaOH concentration on water content and foaming stability of soap from fresh cooking oil

3.5 Economic analysis

Table 2 shows the summary of estimated profits from soap production. Based on a daily input of 5kg of used cooking oil, a total of 200 soap bars were produced. Each soap bar had an average weight of 0.0216kg which gave a total soap production of 4.32kg per day. The selling price was RM30.00 per kg, giving a price of RM0.65 per soap bar. This resulted in a total daily revenue of RM129.60. The total cost of materials needed for producing 200 soap bars was RM75.00 per day. After subtracting the production cost from the revenue, the net profit obtained was RM54.60 per day. Based on this value, the estimated profit was RM1,092.00 per month and RM 13,104.00 per year. The results indicated that used cooking oil could be converted into a valuable product, which was a better approach compared to reselling the used cooking oil at RM2.00 per kg. The low material cost and relatively high revenue supported the suitability of this method for small scale production. In addition to economic benefits, this approach supported waste reduction and promoted resource reuse.

Table 2. Summary table of estimated profits of soap produced

Parameters	Amount
Used cooking oil collected / day	5kg
Soap produced from 5kg oil	200 soap bars
Total revenue / day	RM129.60
Total cost of materials / day	RM75.00
Daily estimated profit	RM54.60
Monthly estimated profit	RM1,092.00
Yearly estimated profit	RM13,104.00

Table 3 presented a comparison between reselling used cooking oil and converting it into soap. When 5 kg of used cooking oil was sold at RM2 per kg, the total revenue was RM10.00 per day, equivalent to RM200.00 per month and RM2,400.00 per year. In contrast, soap production using the same 5kg of used cooking oil produced 200 soap bars with a total weight of 4.32 kg. At a market price of RM30.00 per kg, the total revenue was RM 129.60 per day. After subtracting the material cost of RM75.00 the net profit was RM54.60 per day, corresponding to RM1,092.00 per month and RM13,104.00 per year. The profit obtained from soap production was significantly higher than that from reselling used cooking oil, with an increase in profit of RM44.60 per day. These findings demonstrated that converting used cooking oil into soap increased its economic value and provided better economic return.

Table 3. Comparison of Profit Between Used Cooking Oil Resale and Soap Production

Parameter	Reselling Used Cooking Oil	Produce and Sell soap
Amount of used cooking oil (kg/day)	5.00	5.00
Total product weight (kg)	5.00	4.32
Selling price /kg	RM2.00	RM30.00
Total revenue per day	RM10.00	RM129.60
Total material cost per day	-	RM75.00
Net profit per day	RM10.00	RM54.60
Net profir per month	RM200.00	RM1,092.00
Net profit per year	**RM2,400.00**	**RM13,104.00**

4. Conclusion and Recommendations

This study showed that used cooking oil could be converted into soap with acceptable quality and properties. The pH values were within the standard range for commercial soap. Higher NaOH concentration increased pH level, foam stability and moisture content. Soap produced from used oil exhibited comparable performance to soap produced from fresh oil. The economic evaluation showed a daily profit of RM54.60 from the production of 200 soap bars, indicating that the process is economically sustainable. Recycling used cooking oil into soap reduces waste and creates value from discarded materials. For future recommendations, improvements to the purification process of used cooking oil were recommended to enhance soap hardness and reduce moisture content. Additional tests such as hardness assessment and cleansing efficiency evaluation should be conducted. Furthermore, larger-scale production studies were recommended to evaluate the practical implementation of this process at community level.

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Batch Electrocoagulation Using Aluminium Electrodes for Water Treatment of Batang Lupar River at Engkilili, Sri Aman, Sarawak

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Abstract

River water remains an important freshwater resource in rural Sarawak and its quality can be affected by natural processes and human activities such as agricultural runoff and domestic discharge. The Batang Lupar River system exhibits elevated suspended solids and unstable water conditions that may limit suitability for domestic use. As such, this study aims to evaluate the effectiveness of a batch electrocoagulation treatment system using aluminium electrodes in improving the water quality of Batang Lupar. Correspondingly, the objectives of this study are to: (i) evaluate the initial water quality characteristics of Batang Lupar, (ii) conduct electrocoagulation treatment experiments under controlled conditions, and (iii) analyse operating conditions to achieve effective treatment performance. The experiments are performed using varying current intensities (1.0 A, 2.0 A, and 3.0 A) and treatment durations (5 min, 10 min, and 15 min), while turbidity, total suspended solids (TSS), and pH are selected as key water quality indicators. The results demonstrate that treatment time and current intensity significantly influenced water quality improvement, with progressive reductions in turbidity and TSS observed alongside gradual pH stabilisation towards neutral conditions. The most favourable operating condition is obtained at 3.0 A with a treatment duration of 15 minutes, producing the lowest turbidity and TSS values and achieving compliance with the National Water Quality Standards (NWQS). Moreover, this condition results in the highest removal efficiencies for turbidity, TSS, and pH, reaching 95.36%, 85.92%, and 27.64%, respectively. These findings indicate that electrocoagulation offers a practical and effective approach for improving river water quality.

Keywords: *Batang Lupar water, electrocoagulation, aluminium electrodes, water treatment*

1. Introduction

Rivers represent essential components of natural freshwater systems that sustain human activities, ecological balance, and economic development [1]. Sarawak is characterised by an extensive river network that spans diverse geographical landscapes across the state [2]. The rivers are associated with domestic water use, fisheries, agriculture, aquaculture practices, and river transportation along riparian areas of Sarawak [3]. These activities contribute to variations in river water quality and influence its overall suitability for various applications [4]. As such, various water treatment technologies have been developed to address water quality challenges [5]. Among these approaches, electrocoagulation has gained as an alternative for water treatment, where it is a treatment process in which in situ coagulant formation promotes the destabilisation and removal of suspended contaminants from water [6]. This method has been explored for its effectiveness in improving water clarity and reducing particulate impurities in natural water systems [7].

Reliance on untreated river water for domestic use remains common among rural communities, and river systems such as Batang Lupar River form part of this freshwater reliance [8]. Alarmingly, traces of heavy metal contamination have been identified within the Batang Lupar River system due to discharges from industrial, municipal, and agricultural sources, including farming-related wastewater from Sri Aman [9]. The occurrence of heavy metals in river water raises concerns given to their toxic,

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persistent, and bioaccumulative characteristics, which may result in organ dysfunction, neurological impairment, and an elevated risk of carcinogenic effects following prolonged exposure through contaminated water and food sources [10].

This study aims to evaluate the effectiveness of a batch electrocoagulation system using aluminium electrodes in improving the water quality of Batang Lupar. In accordance with the aim of this research, the objectives are devised as follow: (i) to evaluate initial water quality parameters of Batang Lupar as a baseline for electrocoagulation treatment performance assessment, (ii) to conduct electrocoagulation treatment experiments under controlled conditions and monitor changes in water quality. (ii) to analyse operating conditions of electrocoagulation treatment system in achieving optimal treatment performance with high removal efficiency. The scope of the study is on the treatment of river water from Batang Lupar by using the batch electrocoagulation treatment system with aluminium electrodes. The study is conducted under laboratory-scale conditions within a controlled experimental environment.

2. Methodology

The research methodology consists of a structured sequence of methods designed to achieve the main aim and objectives of the study, as illustrated in **Figure 1**. The study is divided into five main stages that align with the research objectives. The stages consist of (i) water sample collection, (ii) raw water quality analysis, (iii) experimental work, (iv) treated water quality evaluation, and (v) results and discussion. The first stage involves collecting water samples for experimental work. The second stage is the raw water quality analysis, where baseline parameters including turbidity, pH, and total suspended solids (TSS) are evaluated prior to the treatment. The third stage compromises the experimental work, which involves electrocoagulation treatment under selected operating conditions such as varying current density and treatment time. The fourth stage focuses on treated water quality evaluation to determine changes in turbidity, pH, and TSS after treatment. The final stage presents the result and discussion, including comparison with the National Water Quality Standards (NWQS) in Malaysia and analysis of operating conditions associated with treatment performance.

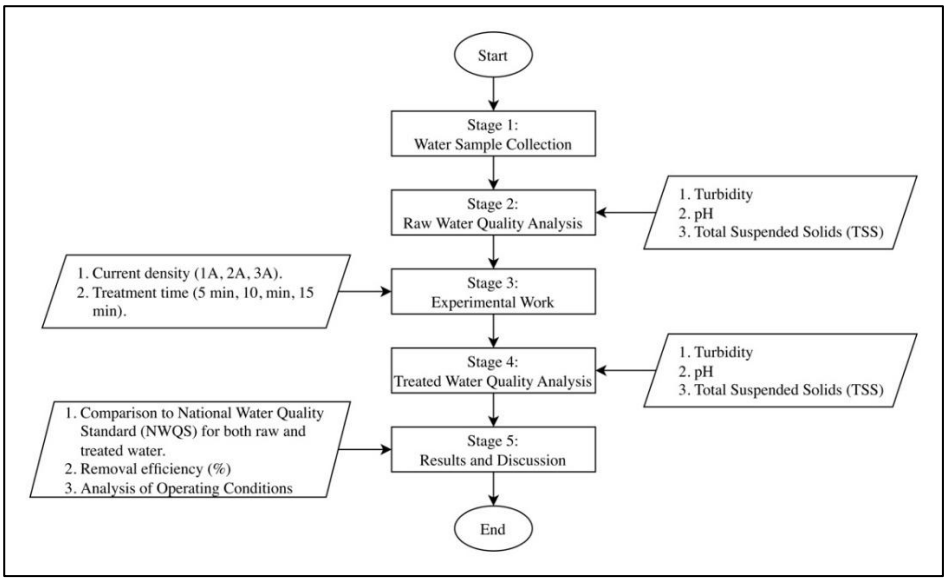


Figure 1. Structure of methodology.

2.1. Stage 1: Water Sample Collection

Water sample collection is conducted at Batang Lupar River at Engkilili, Sri Aman, Sarawak. It is located approximately 211 km southeast of Kuching City, or about three hours drive from Kuching, as shown in **Figure 2**. The water sample is collected from this location with the aim of supporting sustainability efforts, as the treated water may potentially be reused for domestic use. It is taken for

further laboratory analysis, and all collected samples from the designated sampling stations were stored in sealed plastic containers for Stage 1 of the study.



Figure 2. Location of water sample collection at Engkilili, Sri Aman, Sarawak [11].

2.2. Stage 2: Raw Water Quality Analysis

In this stage, the initial parameters of the water samples are measured before using the electrocoagulation process. The parameters analysed using the Hach DR 900 for turbidity and TSS, and pH meter for measuring pH. Each parameter is analysed using a specific method, as summarized in **Table 1**.

The analysis of turbidity and TSS concentrations was conducted using the analysis of turbidity and TSS concentrations was conducted using the absorptiometry method and photometric method, respectively. First, distilled water was used to clean and rinse all sample bottles. Sample vials containing 10 mL of distilled water and 10 mL of each water sample were then prepared. For each parameter, distilled water was used as the reference, and the turbidity and TSS readings were recorded accordingly. Samples exceeding the instrument range were diluted by a factor of 0.5. The pH measurements were obtained using a calibrated pH meter. Distilled water and sample solutions were prepared, and the electrode was rinsed with distilled water before measuring each sample. The procedure was repeated for all samples.

Table 1. Main parameters for water sample analysis.

Parameter	Method	Apparatus model
Turbidity	Absorptiometry Method	Multiparameter portable colorimeter (Hach DR 900)
pH	Electrometric Method	pH meter (AB150)
Total suspended solids (TSS)	Photometric Method	Multiparameter portable colorimeter (Hach DR 900)

2.3. Stage 3: Experimental Work

This stage aims to examine and evaluate the practicality of using a batch electrocoagulation system for treating Batang Lupar water. The experimental study investigates the effects of applied current and treatment time on the performance of the electrocoagulation process. The system is designed in batch mode, meaning that the untreated river water is introduced into the system before the treatment process begins. As shown in **Figure 3**, the electrocoagulation setup consists of aluminium electrodes, 500 mL beaker, connecting wires, and a DC power supply to energize the electrodes. Additionally, two aluminium electrode plates are spaced 0.5 cm apart, which represents the inter-electrode distance (IED),

defined as the gap between the anode and cathode plates. Aluminium plates are selected as the electrode material due to their availability, low-cost and ease of procurement.

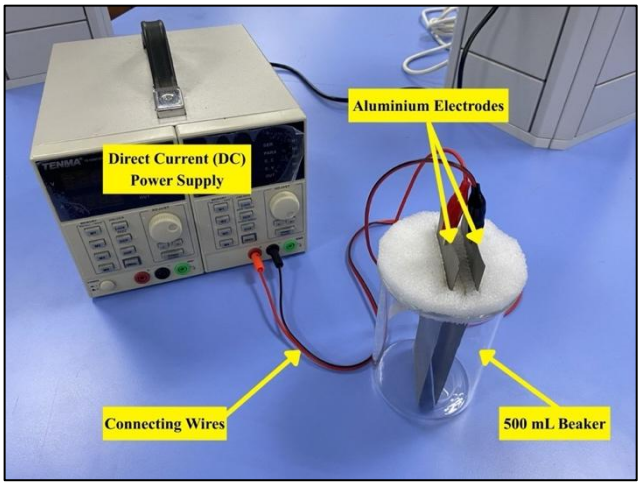


Figure 3. Setup of batch electrocoagulation treatment system for Batang Lupar water.

The constant parameters in this experiment are the number of electrodes, the Inter-Electrode Distance (IED), applied voltage, and volume of river water. The effects of current intensity and treatment time on the selected performance indicators are evaluated using batch electrocoagulation under carious combinations of current intensity, and treatment time. A 5-minute interval is maintained between each treatment session. The dependent or manipulated parameters used in this study are listed in **Table 2**.

Table 2. List of constant and manipulated variables.

Constant Variables	
Number of electrodes	2
Inter-Electrode Distance (IED)	0.5 cm
Material of electrode	Aluminium
Volume of river water	200 mL
Voltage applied	30 V
Dependent Variables	
Current intensity	1.0 A interval up to 3.0 A
Treatment time	5-min intervals for 30 minutes

2.4. Stage 4: Treated Water Quality Analysis

Following electrocoagulation treatment, water quality evaluation is performed on the treated samples using the same analytical procedures outlined in the Stage 2. Turbidity, pH, and TSS are measured to determine changes after treatment. Removal efficiency equation is applied to evaluate pollutant reduction and identify operating conditions associated with improved treatment performance, as expressed in equation (1) [12].

$$\text{Removal Efficiency (\%)} = \frac{C_0 - C_t}{C_0} \times 100 \qquad \text{.....(1)}$$

Where C_t is the concentration after electrocoagulation treatment and C_0 is the concentration before electrocoagulation treatment. This phase also evaluates the quality of both untreated and treated river water using the selected National Water Quality Standards (NWQS), as presented in **Table 3**. Following the assessment, the water classification is determined by referring to the corresponding water classification table, as shown in **Table 4.**

Table 3. Selected National Water Quality Standards (NWQS) [13].

Parameter	Unit	Class					
		I	IIA	IIB	III	IV	V
Turbidity	NTU	5	50	50	-	-	-
pH	-	6.5–8.5	6–9	6–9	5–9	5–9	-
Total Suspended Solids	mg/l	25	50	50	150	300	300

Table 4. Water classifications [13].

Class	Uses
I	Conservation of natural environment. Water Supply I – Practically no treatment necessary Fishery I – Very sensitive aquatic species
IIA	Water Supply II – Conventional treatment required Fishery II – Sensitive aquatic species
IIB	Recreational use with body contact
III	Water Supply III – Extensive treatment required Fishery III- Common of economic value and tolerant species, livestock drinking.
IV	Irrigation
V	None of the above

2.5. Stage 5: Results and Discussion

The final stage involves the presentation and interpretation of findings obtained from the experimental study. Experimental data are organised and processed for analysis, and graphical representations are generated using Microsoft Excel to support visual interpretation of treatment behaviour. The graphical trends facilitate examination of performance variations under different operating conditions and assist in identifying conditions associated with optimal electrocoagulation treatment performance. The analysed results are subsequently discussed with the reference to the National Water Quality Standards (NWQS) to determine the corresponding water classification. Justifications of the observed trends are provided through comparison with relevant electrocoagulation principles and supporting literature.

3. Results and Discussion

The experimental studies on the electrocoagulation process for treating Batang Lupar water emphasises assessing how key operational factors influence the effectiveness of the treatment. Specifically, the factors investigated are the applied current and duration of treatment. Three different experimental sets are carried out with various current levels of 1.0 A, 2.0 A, and 3.0 A across three treatment time settings: 5 min, 10 min, 15 min, to examine the factors. The current adjustments are made by modifying the output from the DC power supply. The number of electrodes remains unchanged throughout the experiments, utilizing 2 aluminium electrodes in the batch electrocoagulation configuration. The changes in water quality parameters of treated water samples are analysed at regular intervals of 5 minutes during each experiment, including turbidity, pH, and total suspended solids (TSS).

3.1. Initial Water Quality Parameters of Batang Lupar Water

The initial water quality of the untreated Batang Lupar water samples collected are tabulated in **Table 5**. This study observes that the untreated Batang Lupar water is not complying with Class I, and Class II standards for all tested water parameters such as turbidity, pH, and TSS. The initial water quality of Batang Lupar exhibited elevated turbidity of 151 NTU, exceeding the NWQS limits for both Class I (5 NTU) and Class II (50 NTU). High turbidity reflects the presence of suspended particles that reduce

water clarity and light penetration. The measured TSS concentration of 142 mg/L also surpasses the permissible limits of 25 mg/L for Class I and 50 mg/L for Class II, indicating particulate matter associated with runoff and riverbed disturbance. In addition, the pH value of 5.55 demonstrates slightly acidic conditions and fell below the acceptable NWQS range for both classes. This acidity may be associated with organic and wastewater inputs originating from agricultural, municipal, and farming activities within the river catchment. This indicates that the river water necessitates more extensive treatments due to its high levels of turbidity and TSS, as well as its acidic condition.

Table 5. Initial water quality parameters of Batang Lupar water.

Water Quality Parameter	Batang Lupar River Water	National Water Quality Standard (NWQS) Limits		Compliance with both Classes
		Class I	Class IIA/IIB	
Turbidity (NTU)	151	5	50	No
pH	5.55	6.5–8.5	6–9	No
TSS (mg/L)	142	25	50	No

3.2. Batch Electrocoagulation Treatment

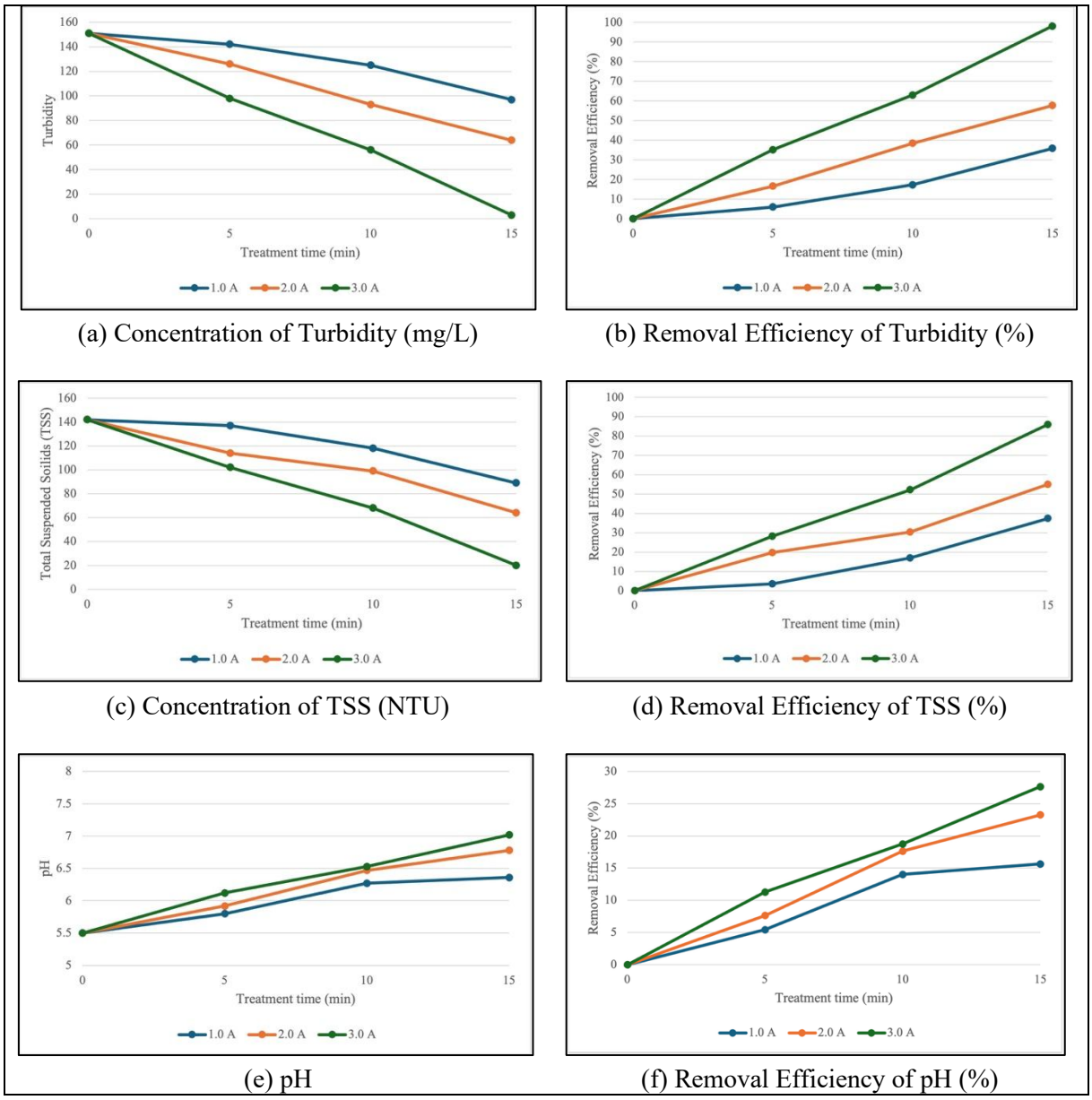
As indicated in **Figure 4(a**), the initial turbidity concentration of raw water from Batang Lupar was measured at 151 NTU. Following treatment at the highest current setting (3.0 A for 15 minutes), turbidity markedly decreases to 7 NTU, demonstrating a 95.36% reduction. In contrast, applying the lowest current (1.0 A for 15 minutes), resulted in a turbidity of 97 NTU, corresponding to an 35.76% reduction as in **Figure 4(b).** This suggests that higher current levels enhance removal efficiency. This result complies with the National Water Quality Standard (NWQS)'s guideline for turbidity, which is under 50 NTU for Class II standards. However, with treatment limited to only 3.0 A for 5 minutes, the turbidity reduction was only 35.10%. This outcome aligns with the research conducted by Hashim et al. (2020) [14], who pointed out that both the intensity of the current and duration of expose are critical factors for effective turbidity reduction.

Total suspended solid (TSS) exhibits a similar pattern to turbidity, as illustrated in **Figure 4(c).** The initial level of TSS was recorded at 142 mg/L and decreased rapidly, particularly in the first 5 minutes of treatment when currents of 3.0 A are applied. This rapid drop is likely due to the immediate neutralization of particle charges. The most effective outcome is noted at 3.0 A for 15 minutes, with TSS reduced to 20 mg/L, equivalent to an 85.92% removal rate, which aligns with NWQS's Class I standard of 25 mg/L. At 1.0 A, the remaining TSS level was 89 mg/L, indicating a removal rate of 37.32%. as in **Figure 4(d).** These findings align with Abdul Rahman et al (2024) [12], who reported that current exceeding 3.0 A and higher greatly enhance TSS removal.

The behaviour of pH with treatment time is presented in **Figure 4(e).** The initial pH of water was recorded at 5.55, indicating acidic conditions. A gradual increase in pH was observed as treatment time increased for all current intensities. The highest pH value of 7.02 was obtained at 3.0 A for 15 minutes equivalent to a 27.64% removal rate, approaching neutral conditions and aligns with NWQS's Class I standard of 6.5 to 8.5 as in **Figure 4(f).** These findings align with Al-Ajmi et al. (2024) [15], who reported that higher current intensity contributes to increasing in pH of the water.

3.3. Optimum Operating Condition

Analysis of removal trends indicates that the combination of 3.0 A current intensity and 15 minutes treatment time represents the optimum operating condition in this study. This condition produces the lowest turbidity and TSS values of 7 NTU and 20 mg/L, respectively, along with pH stabilisation towards near-neutral conditions. The highest removal efficiencies are recorded for turbidity, TSS, and pH at 95.36%, 85.92%, and 27.64%, respectively. These findings demonstrate that increased current intensity and longer treatment duration contributed to the improvement of removal performance.



(a) Concentration of Turbidity (mg/L)

(b) Removal Efficiency of Turbidity (%)

(c) Concentration of TSS (NTU)

(d) Removal Efficiency of TSS (%)

(e) pH

(f) Removal Efficiency of pH (%)

Figure 4. Water quality parameters against the time treatment time with different applied current.

4. Conclusion

This study investigates the effectiveness of electrocoagulation in improving the water quality of Batang Lupar River under laboratory-scale conditions. The initial assessment indicates high turbidity and total suspended solids together with acidic water conditions, confirming the need for treatment. Electrocoagulation experiments are conducted under controlled conditions showing progressive reductions in turbidity and TSS as treatment time and current intensity increased which is accompanied by gradual pH stabilisation towards neutral values. Analysis of operating conditions reveals that higher current intensity combined with sufficient treatment duration enhanced removal efficiency, with 3.0 A and 15 minutes producing the most favourable performance and achieving compliance with the National Water Quality Standards. Overall, these findings demonstrate the practicality of batch electrocoagulation for river water treatment.

Acknowledgements

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Experimental Analysis of Batch Electrocoagulation Water Treatment System for Peat Water within Engkilili, Sri Aman, Sarawak

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Abstract

Peat water is a dark brown, acidic, and organic-rich surface water commonly found in peatland areas of Sarawak, particularly in rural regions such as Engkilili, Sri Aman. Its high colour intensity, elevated suspended solids, and low pH present significant challenges to conventional water treatment processes, which often require high chemical dosages and multiple treatment stages. In rural communities where access to centralized treatment facilities remains limited, there is a need for simple, cost-effective, and decentralised treatment alternatives. This study aimed to analyse the efficiency of a batch electrocoagulation process using aluminium electrodes in improving the quality of peat water sourced from Engkilili. A laboratory-scale batch reactor was designed and fabricated using locally available materials. The experimental investigation evaluated the effects of applied current (A, 2 A, and 3A) and treatment time (5, 10, and 15 minutes) on selected water quality parameters, namely turbidity, Total Suspended Solids (TSS), and pH. The treated water quality was compared with the National Water Quality Standards established by the Department of Environment Malaysia. The results demonstrated that increasing current intensity and treatment time significantly enhanced pollutant removal efficiency. The optimal operating condition was achieved at 3 A and 15 minutes, yielding turbidity and TSS removal efficiencies of 90.12% and 91.78%, respectively, with pH improving from 6.31 to 7.15. The findings indicate that electrocoagulation effectively reduces suspended solids and neutralises acidic peat water under optimised conditions.

Keywords: *Peat Water, Electrocoagulation Water Treatment, SMK Engkilili, Aluminium Electrodes*

1. Introduction

Peat water is a naturally occurring surface water commonly found in peatland areas, such as in parts of Sarawak such as Engkilili, Sri Aman [1]. It is typically dark brown in colour, acidic in nature, and rich in organic matter. Peat water is formed when rainwater percolates through layers of decomposed vegetation in peat soils, dissolving humic acids, tannins, and dissolved iron compounds. As a result, peat water is characterised by high colour intensity, low pH, elevated chemical oxygen demand (COD), and significant concentrations of dissolved organic matter [2]. Therefore, these distinctive characteristics of peat water pose major challenges to conventional water treatment processes. The high organic content and strong colour often require large dosages of chemical coagulants such as alum or ferric salts, as well as multiple treatment stages including coagulation, flocculation, sedimentation, and filtration. These requirements increase operational costs, sludge production, and system complexity [3]. Therefore, in rural and remote areas, such treatment systems may be difficult to implement and maintain due to limited infrastructure, technical expertise, and financial resources. Moreover, access to clean and safe water remains uneven in Sarawak, particularly in rural communities such as Engkilili in Sri Aman. Some communities still rely on untreated river water or harvested rainwater for daily domestic activities due to geographical isolation, infrastructural limitations, and socio-economic constraints [4]. Despite

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government initiatives, increased funding, and institutional restructuring efforts, the provision of reliable treated water supply to remote areas continues to face logistical, maintenance, and manpower challenges [5]. Therefore, there is a pressing need to explore alternative water treatment technologies that are simple, cost-effective, and suitable for decentralised rural applications.

Electrocoagulation (EC), an electrochemical process that generates coagulant species in situ through the dissolution of sacrificial metal electrodes, has emerged as a promising alternative water treatment technology [6]. When an electric current is applied, metal ions are released from the anode and subsequently react with hydroxide ions in water to form metal hydroxides. These hydroxides act as coagulants that destabilise suspended particles, colloids, and dissolved pollutants, facilitating their aggregation and removal [7]. The EC process offers several advantages, including reduced chemical usage, lower sludge production, operational simplicity, and potential effectiveness in removing colour, turbidity, and organic contaminants from peat water [8].

This study aimed to analyse the efficiency of a batch EC process in improving the quality of peat water collected from Engkilili, Sri Aman, using aluminium electrodes. To achieve this aim, several objectives is established: (i) to design a low-cost batch electrocoagulation reactor using locally sourced materials and aluminium electrodes, (ii) to conduct an experimental investigation of the batch electrocoagulation process and perform comprehensive water quality analysis, and (iii) to analyse the operating conditions of the electrocoagulation system in order to determine optimal treatment performance. The scope of this study is limited to the treatment of peat water sourced specifically from Engkilili. The EC reactor is designed as a batch system to ensure simplicity and affordability, making it suitable for rural implementation. Only aluminium plates were to be used as electrodes in the reactor design. The treated water quality is evaluated against the Department of Environment Malaysia (DOE) National Water Quality Standards (NWQS) to determine its suitability for daily and domestic usage.

2. Methodology

This study was conducted based on a structured methodological framework consisting of three main stages, as illustrated in **Figure 1**. Each stage was developed to correspond directly with the research objectives, beginning with reactor design, followed by experimental investigation, and concluding with performance analysis of the electrocoagulation system.

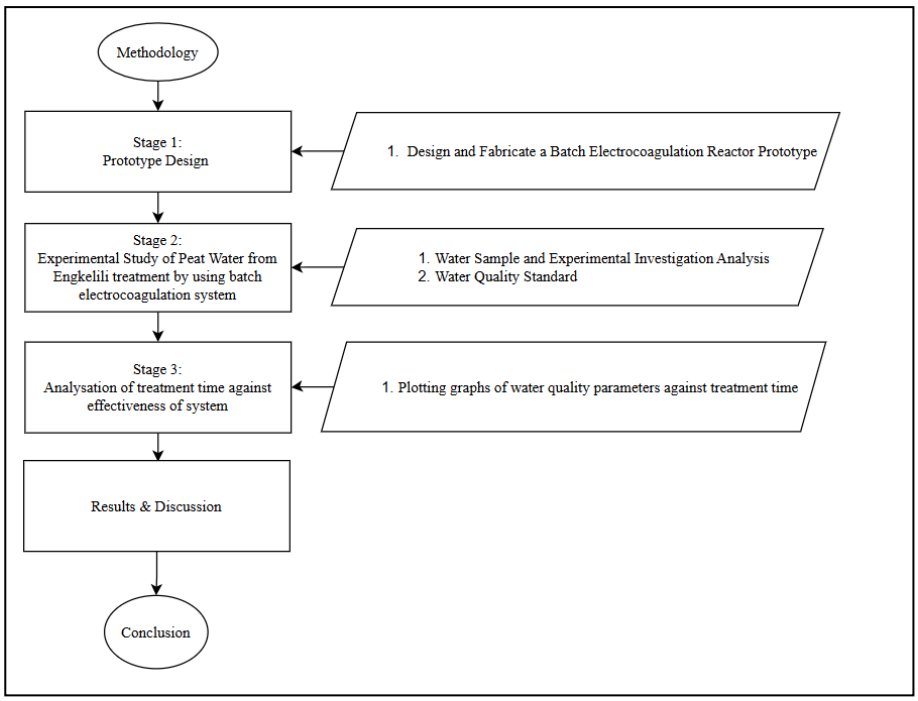


Figure 1. Flow chart of the methodology

2.1. Stage 1: Design and Fabrication of Batch Electrocoagulation Reactor

The first stage of this study focused on the design and fabrication of a laboratory-scale batch EC reactor prototype. The system was developed as a low-cost and simple design using locally sourced materials to ensure suitability for rural applications, while prioritizing ease of construction, material accessibility, and simplified maintenance. This approach enhances feasibility for broader implementation by minimizing reliance on complex components and specialized technical expertise.

The main apparatus and materials used in constructing and operating the batch reactor included a DC power supply, 500 mL beaker, aluminium plate electrodes, connecting wires, an electrode holder, and a filter funnel with filter paper. As shown in **Figure 2**, the electrodes were connected to the DC power supply using conductive wires to allow controlled current flow through a fixed volume (500 mL) of peat water. The treatment was conducted in batch mode, where the sample was treated for a predetermined duration under controlled electrical conditions. Moreover, the EC water treatment system consists of an EC reactor of a 500ml beaker with aluminium plate electrodes and a direct current (DC) power supply to energize the electrodes during operation. Aluminium plates were selected as sacrificial electrodes due to their affordability, local availability in hardware stores, and effectiveness in producing aluminium hydroxide flocs during the electrocoagulation process.

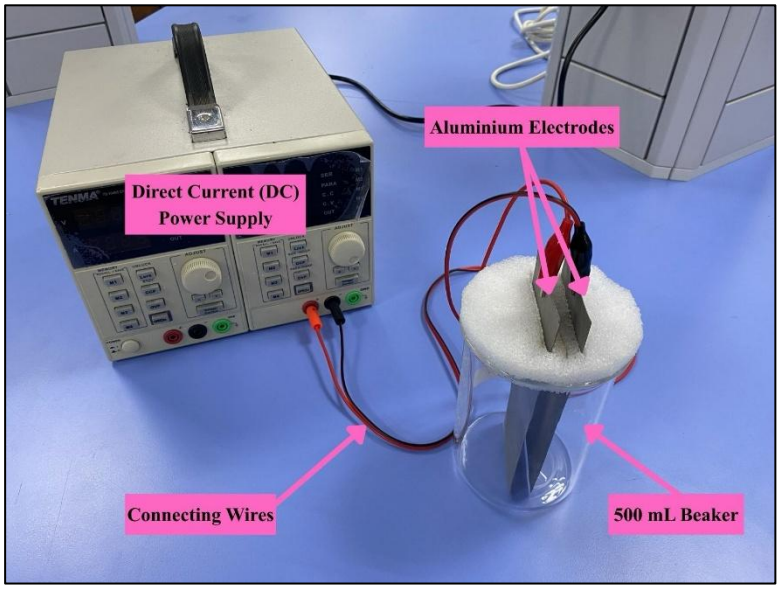


Figure 2. Experimental setup of batch electrocoagulation treatment of peat water in Engkilili

2.2. Stage 2: Experimental Study of Peat Water Treatment

This stage involved the experimental investigation of peat water treatment using the fabricated laboratory-scale batch EC system. Raw peat water was locally sourced from Engkilili, Sarawak, and used directly in the treatment experiments. The purpose of this stage was to conduct an analysis on the water quality parameters before and after treating under various current density and treatment time. Initial water sample analysis was conducted to determine the baseline characteristics of the raw water. The parameters analysed included pH, turbidity, and Total Suspended Solids (TSS) were measured using a Multiparameter Portable Colorimeter (Hach DR 900) and pH meter.

In order to assess system performance, two main operational variables were investigated: applied current (1 A, 2 A, and 3 A) and treatment time (5, 10, and 15 minutes). Operating voltage (30 V) and inter-electrode distance (0.5 cm) were maintained constant to ensure controlled experimental conditions. For each combination of current and treatment duration, a fixed volume of 200ml peat water was treated in batch mode, and the corresponding water quality parameters were measured. The treated water quality

results were subsequently compared with the NWQS established by DOE as shown in **Table 1** and **Table 2** to assess suitability for domestic and daily use.

Table 1. National Water Quality Standard (NWQS) [9]

Parameter	Unit	Class					
		I	IIA	IIB	III	IV	V
Ammoniacal Nitrogen	mg/l	0.1	0.3	0.3	0.9	2.7	>2.7
Biochemical Oxygen Demand	mg/l	1	3	3	6	12	>12
Chemical Oxygen Demand	mg/l	10	25	25	50	100	>100
Dissolved Oxygen	mg/l	7	5–7	5–7	3–5	<3	<1
pH	-	6.5–8.5	6–9	6–9	5–9	5–9	-
Colour	TCU	15	150	150	-	-	-
Electrical Conductivity*	S/cm	1000	1000	1000	-	-	6000
Floatable	-	N	N	N	-	-	-
Odour	-	N	N	N	-	-	-
Salinity	%	0.5	1	1	-	-	2
Taste	-	N	N	N	-	-	-
Total Dissolved Solids	mg/l	500	1000	1000	-	-	4000
Total Suspended Solids	mg/l	25	50	50	150	300	300
Temperature	°C	Normal	Normal +2°C	-	-	-	-
Turbidity	NTU	5	50	50	-	-	-
Fecal Coliform**	count/100ml	10	100	400	5000	500 (20000)[a]	-
Total Coliform	count/100ml	100	5000	5000	50 000	50 000	>50000

Notes:
N: No visible floatable materials or debris, no objectional odour or no objectional taste
*: Related parameters, only one recommended for use
**: Geometric mean
a: Maximum not to be exceeded

Table 2. Water Classifications [9]

Class	Uses
I	Conservation of natural environment. Water Supply I – Practically no treatment necessary Fishery I – Very sensitive aquatic species
IIA	Water Supply II – Conventional treatment required Fishery II – Sensitive aquatic species
IIB	Recreational use with body contact
III	Water Supply III – Extensive treatment required Fishery III- Common of economic value and tolerant species, livestock drinking.
IV	Irrigation
V	None of the above

2.3. Stage 3: Analysis of Treatment Performance

The final stage of the methodology focused on evaluating the removal effectiveness of the batch EC system and analysing its operating conditions to determine optimal treatment performance. This stage emphasized assessing how variations in applied current and treatment time influenced pollutant removal efficiency and overall system performance. Graphs were plotted to illustrate the variation of current density and treatment time affecting the key water quality parameters like pH, TSS, and turbidity. These graphical analyses enabled clear visualization of treatment trends and the relationship between operational parameters and pollutant reduction.

Removal efficiency (RE) for each parameter was calculated using **Equation 1** [10]. The RE (%) was determined by comparing initial and final concentrations before and after treatment. This quantitative evaluation reflects the system's ability to eliminate pollutants and serves as the primary basis for identifying optimal operating conditions. The analysis focused on determining the most effective applied current for maximizing pollutant removal, evaluating the stability of pH and overall treated water quality, and assessing compliance with the standards of the NWQS and the findings from this stage formed the basis for the Results and Discussion section.

$$RE(\%) = \frac{C_0 - C_1}{C_0}(100\%) \qquad \text{.....(1)}$$

C_1 refers to the concentration of component after treatment (mg/L), C_0 represent the concentration of component before treatment (mg/L) and RE (%) denotes the efficiency of removal.

3. Results and Discussion

The performance of the batch EC system was evaluated based on changes in turbidity, pH, and TSS at different current intensities (1A, 2A, and 3A) and treatment times (5, 10, and 15 minutes). The untreated peat water collected from Engkilili, Sarawak showed the following initial characteristics in **Table 3**. The reading confirm that the peat water had relatively high turbidity and suspended solids, along with slightly acidic conditions. These characteristics are consistent with typical peat water properties, which contain high levels of dissolved organic matter and fine suspended particles.

Table 3. Initial characteristics of raw peat water in Engkilili

Parameter	Value
Turbidity	81 NTU
pH	6.31
TSS	73 mg/L

3.1. Effect of Current Density and Treatment Time on Turbidity Removal

A consistent reduction in turbidity was observed with increasing treatment time and applied current as shown in **Figure 2** The highest removal efficiency was obtained at 3 A for 15 minutes, where turbidity decreased from 81 NTU to 8 NTU. The results indicate that increasing current intensity enhances the dissolution of aluminium ions from the sacrificial electrodes. These ions form aluminium hydroxide flocs, which effectively destabilise and aggregate suspended particles. Longer treatment times allow more floc formation and improved pollutant removal through sedimentation [11].

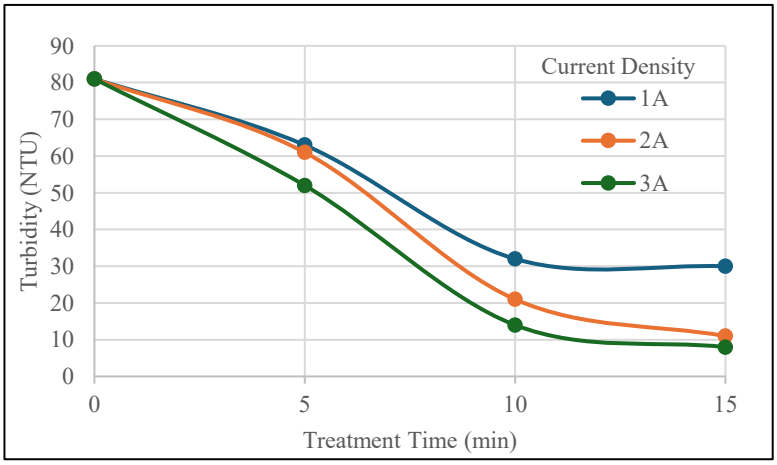


Figure 2. Graph of Turbidity Against Treatment Time

3.2. Effect of Current Density and Treatment Time on Effect on TSS

As shown in **Figure 3**, a similar trend was observed for TSS removal, the lowest TSS value recorded was 6 mg/L at 3 A for 15 minutes. The improved removal at higher currents can be attributed to enhanced coagulant generation and increased bubble formation (hydrogen gas), which assists in the flotation and separation of flocs [12].

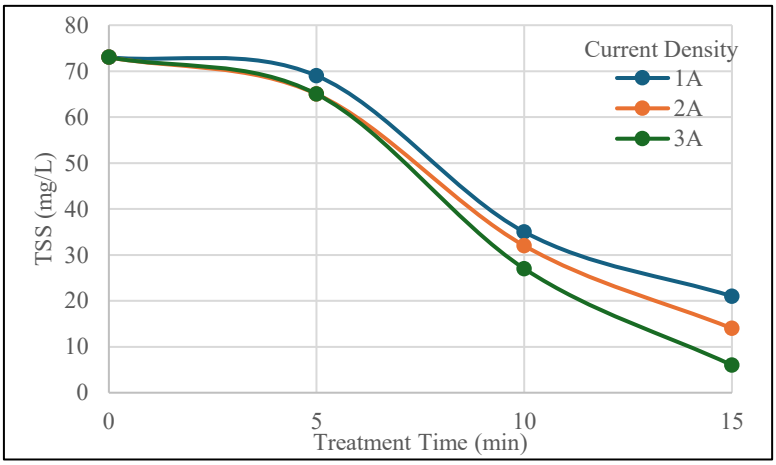


Figure 3. Graph of TSS against Treatment Time

3.3. Effect of Current Density and Treatment Time on Effect on pH Value

The pH of the treated water showed a gradual increase with increasing current and treatment time as shown in **Figure 4**. The gradual increase in pH indicates that the electrocoagulation process contributed to neutralising the acidic peat water. This occurs due to the formation of hydroxide ions at the cathode during electrolysis, which increases alkalinity [13]. The final pH values approached neutral conditions, which is favourable for domestic water use.

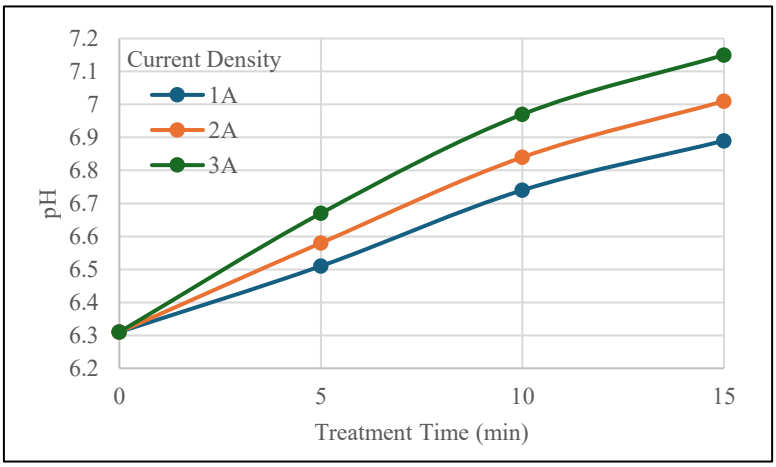


Figure 4. Graph of pH against Treatment Time

3.4. Removal Efficiency of Batch Electrocoagulation Treatment of Peat Water in Engkilili

As shown in **Figure 5**, the turbidity RE increased consistently with both treatment time and applied current. The results clearly show that increasing current intensity significantly enhanced turbidity removal. At higher current, more aluminium ions were released from the anode, leading to greater formation of aluminium hydroxide flocs. These flocs destabilised suspended colloidal particles more

effectively, resulting in higher aggregation and removal. The RE also increased with treatment time, indicating that longer electrolysis duration allows sufficient floc formation, particle collision, and settling. However, the improvement between 10 and 15 minutes at 1 A was relatively small, suggesting that low current limits coagulant generation even if treatment time is extended.

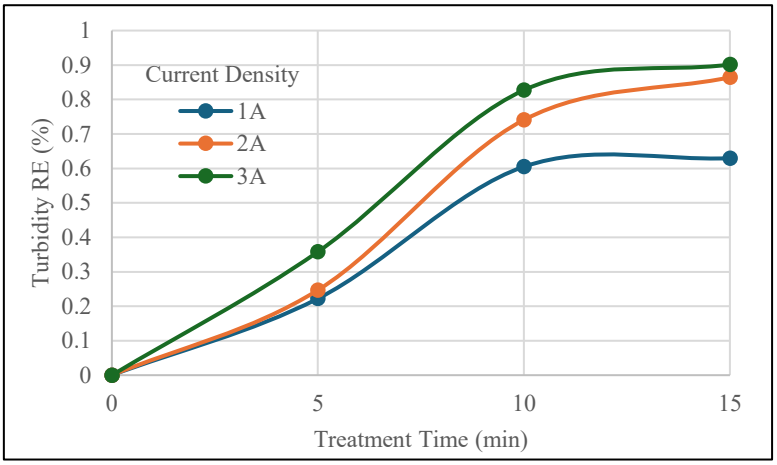


Figure 5. Graph of Turbidity RE against Treatment Time

Similarly, an increasing trend was observed for TSS as shown in **Figure 6**. The maximum TSS removal efficiency of 91.78% was achieved at 3 A and 15 minutes, indicating that higher current density significantly improves suspended solids removal. The enhanced performance at higher currents can be attributed to an increased dissolution rate of aluminium electrodes, greater production of $Al(OH)_3$ coagulant species, increased hydrogen bubble formation, aiding flotation of suspended solids. Compared to turbidity removal, TSS removal showed slightly slower improvement at lower treatment times, suggesting that sufficient electrolysis duration is required to form stable and settleable flocs.

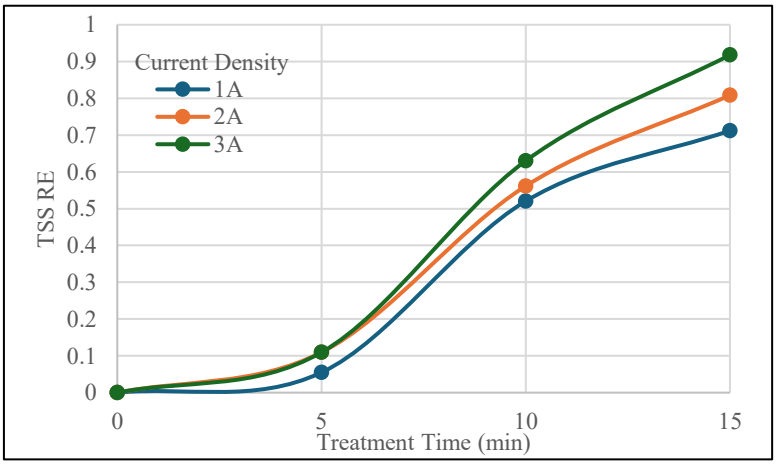


Figure 6. Graph of TSS RE against Treatment Time

Although pH is not a pollutant removal parameter, its relative improvement indicates the neutralisation effect of the electrocoagulation process. As indicated in **Figure 7** the gradual increase in pH confirms that electrocoagulation contributes to reducing the acidity of peat water. Hydroxide ion generation at the cathode increases alkalinity, shifting the water condition toward neutral pH levels. The highest pH improvement was observed at 3 A for 15 minutes, consistent with the overall trend of increased treatment effectiveness at higher current and longer exposure time.

From the removal efficiency analysis, it is evident that both turbidity and TSS removal improved significantly with increasing current and treatment duration. The optimal operating condition identified in this study was 3 A with 15 minutes of treatment, which produced the highest removal efficiencies for

turbidity (90.12%) and TSS (91.78%), along with the greatest pH stabilisation. These findings confirm that the batch electrocoagulation system using aluminium electrodes is effective in enhancing peat water quality and demonstrates strong potential for small-scale rural water treatment applications in Sarawak. Overall, following treatment under the optimal condition of 3 A at 15 min, the post-treatment water quality parameters for the Engkilili peat water sample (turbidity 8 NTU, TSS 6 mg/L, and pH 7.15) meet the Class I limits of the National Water Quality Standards (NWQS). The limits of Class I as established by DOE includes turbidity at 5 NTU, TSS at 25 mg/L, and pH levels between 6.5-7.5 [9].

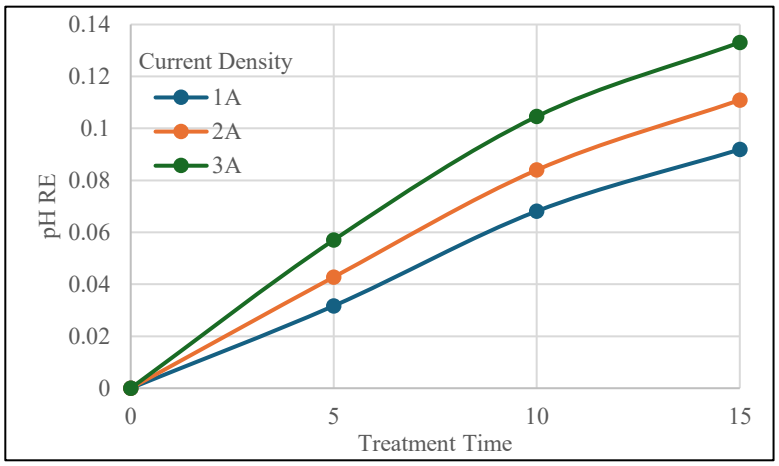


Figure 7. Graph of pH RE against Treatment Time

4. Conclusion

This study successfully evaluated the performance of a low-cost, laboratory-scale batch electrocoagulation system for treating peat water from Engkilili, Sri Aman, Sarawak. The reactor was fabricated using locally sourced materials and aluminium electrodes, ensuring a simple, practical, and rural-applicable design. Experimental results showed that the system effectively improved peat water quality, particularly turbidity, TSS, and ph. The raw peat water exhibited high turbidity (81 NTU), elevated TSS (73 mg/L), and slightly acidic conditions (pH 6.31), reflecting typical challenges of peat water treatment. Both higher applied current and longer treatment time significantly enhanced pollutant removal. The optimal operating condition was 3 A for 15 minutes, achieving a turbidity of 8 NTU (90.12% removal), TSS of 6 mg/L (91.78% removal), and a near-neutral pH of 7.15. The improved performance at higher currents is attributed to increased aluminium dissolution and floc formation, while longer treatment times allowed sufficient aggregation and separation of contaminants. These findings confirm that the system's efficiency is strongly dependent on operating conditions, highlighting the importance of parameter optimisation. Overall, the study demonstrates that the batch electrocoagulation system is an effective, cost-efficient, and decentralised water treatment alternative for rural peatland communities. The treated water showed significant improvement toward compliance with the NWQS. Future research could focus on optimising electrode spacing, reducing energy consumption, and scaling up the system for continuous operation to enhance practical applicability.

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Hydrodistillation of Pandanus Amaryllifolius Leaf Puree for Hydrosol Recovery

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Abstract

Hydrosol is an aromatic aqueous distillate produced during hydrodistillation and contains water-soluble volatile compounds that contribute to its mild fragrance and functional properties. This study investigated the extraction of hydrosol from Pandanus amaryllifolius leaf puree using hydrodistillation under controlled laboratory conditions. The effects of plant concentration from the range of 0.04 to 0.20 g/mL and extraction time from the range of 5 to 25 minutes on percentage hydrosol yield were evaluated while maintaining a constant water volume of 500 mL and a boiling temperature of approximately 100°C. Fresh pandan leaves were washed, blended, and subjected to hydrodistillation using a spiral condenser system. Hydrosol volume was measured volumetrically and expressed as percentage hydrosol yield. Results showed that hydrosol yield increased consistently with both increasing concentration and extraction time. The highest yield of 13.2% was obtained at 0.20 g/mL after 25 minutes of extraction. The findings indicate that both concentration and extraction duration significantly influence hydrosol recovery due to enhanced mass transfer and diffusion of volatile compounds. No equilibrium condition was reached within the investigated time range, suggesting that further extraction time may increase yield. This study demonstrates the practicality of hydrodistillation for extracting hydrosol from locally available pandan leaves and highlights the importance of optimizing operating parameters to improve extraction efficiency.

Keywords: *Hydrodistillation, pandanus amaryllifolius, hydrosol yield, extraction time, process optimization*

1. Introduction

Hydrosol is the aromatic aqueous distillate obtained during hydro distillation or steam distillation and contains water-soluble plant compounds together with trace amounts of volatile constituents which gives a mild fragrance [1]. *Pandanus amaryllifolius* is a locally available aromatic plant whose leaves contain key volatile compounds such as 2-acetyl-1-pyrroline which contributes to its characteristic fragrance and makes it suitable for aroma extraction studies [2]. Hydrodistillation is a conventional extraction technique in which plant material is immersed directly in water and heated to boiling which allow volatile compounds to evaporate with water vapour before being condensed into distillate [3]. Distillation methods are widely used for recovering volatile plant compounds and producing distillates such as hydrosols [4]. In this study, hydrodistillation was used to investigate how a local plant such as *Pandanus Amaryllifolius* leaf puree concentration and extraction time affects hydrosol yield while maintaining a constant water volume of 500 mL and a constant boiling temperature of approximately 100°C throughout the experimental process. The local aromatic plants such as *Pandanus Amaryllifolius* are easily available but the hydrosol extraction using hydrodistillation is not widely explored due to lack of technical processing skills [1]. Within educational and practical contexts, there is lack of empirical

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data and standardized procedures for extracting hydrosol using hydrodistillation equipment such as a spiral condenser [5]. There is limited baseline data on how *Pandanus Amaryllifolius* concentration and extraction time affect the normalized hydrosol yield produced from pandan leaves [6]. Hence, the aim for this project is to extract aromatic hydrosol from *Pandanus Amaryllifolius* leaves using hydro distillation. The research aim was operationalized through the following experimental objectives: (i) to prepare *Pandanus Amaryllifolius* leaves by washing and blending them with a constant water volume (500mL), (ii) to conduct hydrodistillation by varying concentration of *Pandanus Amaryllifolius* and extraction time under constant temperature conditions and determine hydrosol yield by measuring hydrosol volume collected and calculating percentage hydrosol yield (%), (iii) to analyse the effect of concentration and extraction time on percentage hydrosol yield through graphical evaluation. Hence, the study utilized a local *Pandanus Amaryllifolius* leaves.

2. Methodology

This chapter describes the experimental procedures used to extract hydrosol from *Pandanus amaryllifolius* leaves using hydrodistillation. The study examined the effects of concentration and extraction time on percentage hydrosol yield under controlled temperature conditions. Hydrosol volume was measured and analysed to evaluate extraction performance using 3D surface graph.

2.1 Flowchart of Experimental Procedures

The experimental flowchart illustrates the overall procedure followed in this study beginning from sample preparation to data analysis. It provides a systematic representation of the steps involved in extracting hydrosol from *Pandanus Amaryllifolius* leaf puree using hydrodistillation as shown in **Figure 1**. The process begins with the preparation of pandan leaves, including washing, cutting, weighing according to the selected concentration such as 20 g, 40 g, 60 g, 80 g, and 100 g. Hence, it will continue by blending with a constant water volume of 500 mL. The prepared puree is then transferred into a 1000 mL round-bottom flask for hydrodistillation. The hydrodistillation setup includes a heat source and a spiral condenser for vapour condensation. The mixture is heated under constant temperature conditions and extraction time are varied at 5, 10, 15, 20, and 25 minutes. The condensed vapour which is hydrosol is collected and measured volumetrically. Finally, percentage hydrosol yield (%) is calculated and the data are analysed to determine the effect of pandan concentration and extraction time. The flowchart ensures clarity of experimental steps and demonstrates the systematic approach adopted to achieve the study objectives.

2.2 Collection and Preparation of Pandanus Amaryllifolius Sample

Fresh *Pandanus amaryllifolius* leaves were collected directly from the source to ensure maximum freshness and aroma intensity. The leaves were carefully selected based on their physical appearance, including colour, texture and absence of visible contamination or damage to ensure consistency in extraction performance. The selected leaves were washed thoroughly with clean water and cut into small pieces of approximately 1 to 2 inches in length to increase surface area and enhance mass transfer during hydro distillation. The prepared leaves were then weighed using a weight balance at five different mass levels: 20 g, 40 g, 60 g, 80 g and 100 g. Each weighed sample was blended separately with a constant water volume of 500 mL to produce a uniform leaf puree. By doing this, it is to ensure in maintaining a constant water volume-controlled variation in concentration. The corresponding concentrations were 0.04 g/mL, 0.08 g/mL, 0.12 g/mL, 0.16 g/mL, and 0.20 g/mL. Each sample is blended separately with a constant water volume of 500 mL to obtain a homogeneous leaf puree and to ensure that the only experimental variable is the mass of leaves used. Maintaining a fixed water volume enables a concentration controlled design, where changes in extraction performance can be attributed more confidently to the raw material loading rather than dilution effects. Based on this preparation method, the corresponding concentrations are 0.04 g/mL, 0.08 g/mL, 0.12 g/mL, 0.16 g/mL, and 0.20 g/mL, which are then used as the defined input concentrations for the hydro distillation experiments.

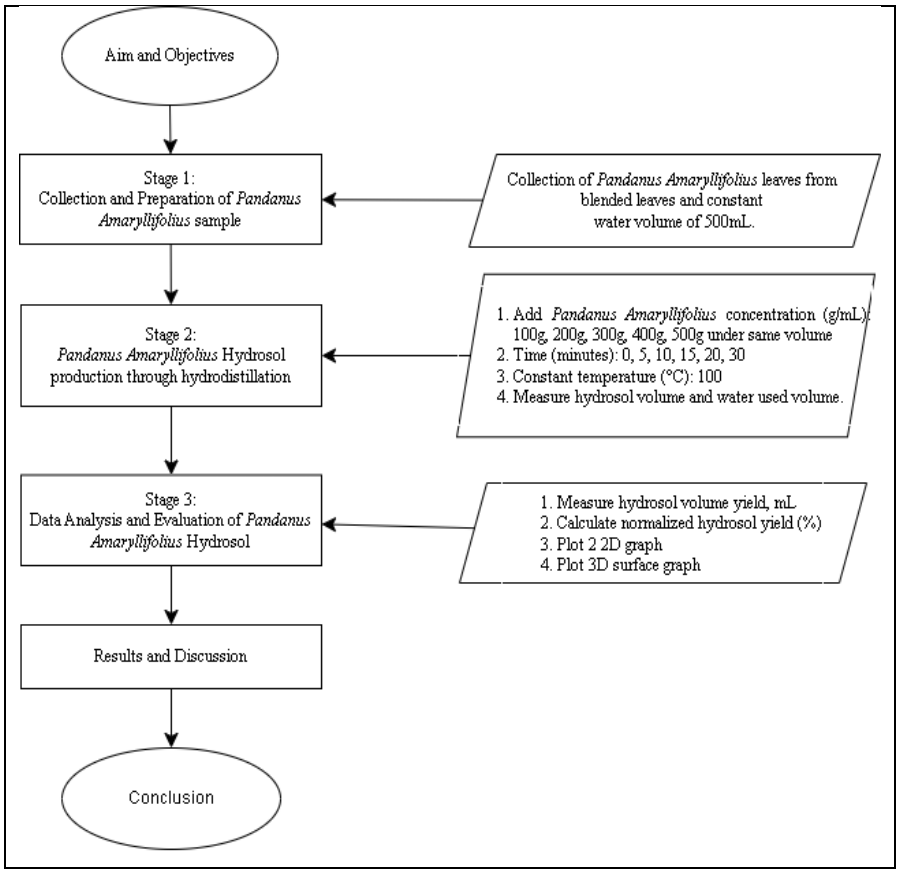


Figure 1. Experimental Procedures

2.3 Hydrodistillation Hydrosol Extraction on *Pandanus Amaryllifolius* Leaves Puree

Hydrodistillation is a conventional distillation method in which plant material is submerged in water and boiled, so that volatile compounds evaporate with water vapour and are later condensed and collected as distillate [8] as shown in **Figure 2**.

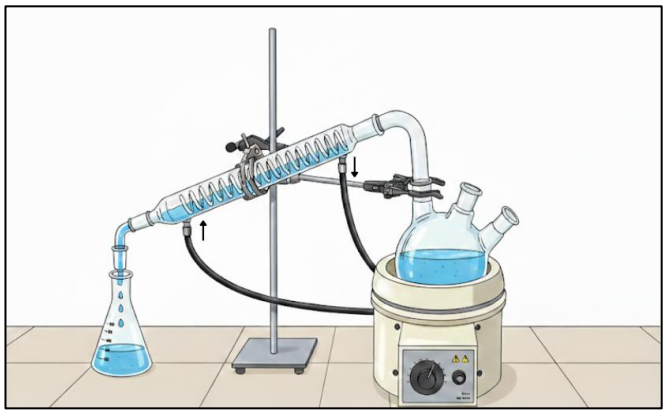


Figure 2. Schematic Diagram of Experimental Setup

Hydrosol or also known as is the aqueous distillate produced from hydrodistillation, consisting of distillation water that retains small amounts of volatile/essential oil components [9]. For each experimental run, the prepared *Pandanus amaryllifolius* leaf puree was placed in a round bottom flask with a constant water volume of 500 mL, then heated until boiling. Temperature was monitored by

inserting a thermometer into the flask to ensure the system reached a stable boiling condition of approximately 100°C [8]. The vapour produced during boiling was directed into a spiral (coil-type) condenser, where cooling water removed heat from the vapour and converted it back into liquid distillate for collection [10]. Hydrosol collection and timing began only after continuous condensation was observed and the system remained at boiling temperature. Extraction time was recorded at 5, 10, 15, 20, and 25 minutes. At the end of each time interval, the distillate or hydrosol collected was measured using a measuring cylinder and recorded as hydrosol volume, V_h. Hydrosol yield was later expressed as normalized hydrosol yield (%) to compare extraction performance across different concentrations and extraction times [1].

2.4 Data Analysis and Evaluation of *Pandanus Amaryllifolius* Hydrosol

Pandanus amaryllifolius leaf puree was prepared at five different mass concentrations: 20 g, 40 g, 60 g, 80 g, and 100 g, each blended with a constant water volume of 500 mL. These correspond to 0.04 g/mL, 0.08 g/mL, 0.12 g/mL, 0.16 g/mL, and 0.20 g/mL, respectively. Hydrodistillation was performed at a constant boiling temperature of approximately 100°C, and extraction time was varied at 5, 10, 15, 20, and 25 minutes. Plant concentration is an important factor influencing hydrodistillation performance because increasing the solid-to-liquid ratio increases the availability of volatile compounds for transfer into the vapour phase [6]. Similarly, extraction time affects the extent of volatile compound release, as longer boiling allows greater contact between plant material and water, enhancing mass transfer [11]. In order to evaluate extraction performance under different experimental conditions, hydrosol yield was expressed as Percentage Hydrosol Yield (%). Yield calculation in extraction studies is commonly defined as the ratio of collected product to a reference quantity multiplied by 100 [12]. Following this principle, percentage hydrosol yield was calculated using **Equation 1**.

$$\text{Percentage Hydrosol Yield (\%)} = \left(\frac{V_h}{V_w}\right) \times 100 \qquad \text{.....(1)}$$

Where V_h is hydrosol volume collected (mL) and V_w is water volume used constant to 500 mL to ensure the consistency performance. Percentage-based yield calculation is widely applied in hydro distillation extraction studies to enable comparison of extraction efficiency under varying operational parameters [12]. Since the water volume remained constant at 500 mL throughout this study, expressing hydrosol yield as a percentage allowed direct comparison across different pandan concentrations and extraction times.

3. Results and Discussion

This section discusses the results obtained from the hydrodistillation of *Pandanus amaryllifolius* leaf puree and discusses the effects of pandan concentration and extraction time on percentage hydrosol yield. The data are analysed to identify trends and determine the optimal extraction conditions under constant temperature and water volume.

3.1 Characterization of Pandanus Amaryllifolius Plant

Pandanus amaryllifolius, commonly known as pandan, is a tropical aromatic plant belonging to the family Pandanaceae. It is widely cultivated in Southeast Asia and is valued for its characteristic fragrance [2]. The plant produces long, narrow, dark-green leaves that are commonly used in food and fragrance applications due to their natural aroma [7]. The distinctive scent of pandan leaves is mainly attributed to the volatile compound 2-acetyl-1-pyrroline (2AP), which is responsible for its strong and sweet aroma [2]. The presence of volatile aromatic compounds makes pandan leaves suitable for extraction using hydrodistillation methods. According to [7], the extraction efficiency of pandan leaves depends on preparation method and processing conditions, which supports their suitability for experimental hydrosol extraction studies. As shown by **Figure 3**, the preparation were made because fresh leaves were

selected and characterized based on their physical appearance, aroma intensity and absence of visible contamination to ensure consistency in extraction performance.



Figure 3. Preparation of Pandanua Amaryllifolius leaves sample

3.2 Extraction of *Pandanus Amaryllifolius* Hydrosol

This section provides the total hydrosol volume obtained during hydrodistollation at different concentrations and extraction times. The results provide an initial overview of hydrosol production behavious under controlled temperature conditions. **Table 1** summarises the total hydrosol volume obtained from hydrodistillation of *Pandanus amaryllifolius* leaf puree at different concentrations and extraction times. **Figure 4** visualises the same dataset to illustrate the extraction trend across the investigated conditions. The results demonstrate a consistent increase in hydrosol volume with increasing extraction time across all concentration levels. For example, at 0.20 g/mL, hydrosol volume increased from 33 mL at 5 minutes to 66 mL at 25 minutes. This trend indicates continuous release and transfer of volatile compounds into the vapour phase during hydrodistillation. The positive relationship between extraction time and hydrosol volume is consistent with hydrodistillation theory, where prolonged heating enhances mass transfer of volatile components from plant matrices into boiling water and subsequently into condensed distillate [11]. Longer distillation time allows more complete rupture of plant cell structures which facilitating the diffusion of aromatic compounds into the surrounding water phase, as similarly reported by [13] in a review of phytochemical extraction methods. In addition to time, pandan concentration significantly influenced hydrosol production. At every extraction interval, higher concentrations produced greater hydrosol volume. At 25 minutes, hydrosol volume increased from 43 mL at 0.04 g/mL to 66 mL at 0.20 g/mL. This suggests that increasing the concentration enhances the availability of extractable volatile compounds where it also improving overall distillation efficiency. Similar observations have been reported in hydrodistillation studies, where higher plant loading increases the concentration gradient driving mass transfer of essential oil components [6]. Within the tested experimental range, no apparent equilibrium condition was reached in hydrosol volume was observed up to 25 minutes which indicate that volatile compound release was still progressing. The highest hydrosol volume was obtained at 0.20 g/mL after 25 minutes of extraction. These findings suggest that both concentration and extraction time play significant roles in hydrosol recovery and the optimal operating conditions may occur at higher concentration and extended extraction duration under controlled temperature conditions.

3.2 Effect of Concentration of *Pandanus Amaryllifolius* on Percentage Hydrosol Yield

This section examines the influence of pandan concentration on percentage hydrosol yield. The analysis focuses on how variations in concentration affect extraction efficiency under constant operating

conditions. **Table 2** summarises the effect of pandan concentration on percentage hydrosol yield at various extraction times during hydrodistillation.

Table 1. Total volume of hydrosol extraction over period time at different concentrations

Concentration of Pandanus Amaryllifolius (g/mL)	Time (min)	Volume of Hydrosol Obtained (mL)
0.04	0	0
	5	21
	10	26
	15	28
	20	30
	25	33
0.08	0	0
	5	25
	10	34
	15	36
	20	41
	25	46
0.12	0	0
	5	30
	10	42
	15	46
	20	48
	25	52
0.16	0	0
	5	36
	10	48
	15	54
	20	56
	25	59
0.2	0	0
	5	43
	10	52
	15	57
	20	59
	25	66

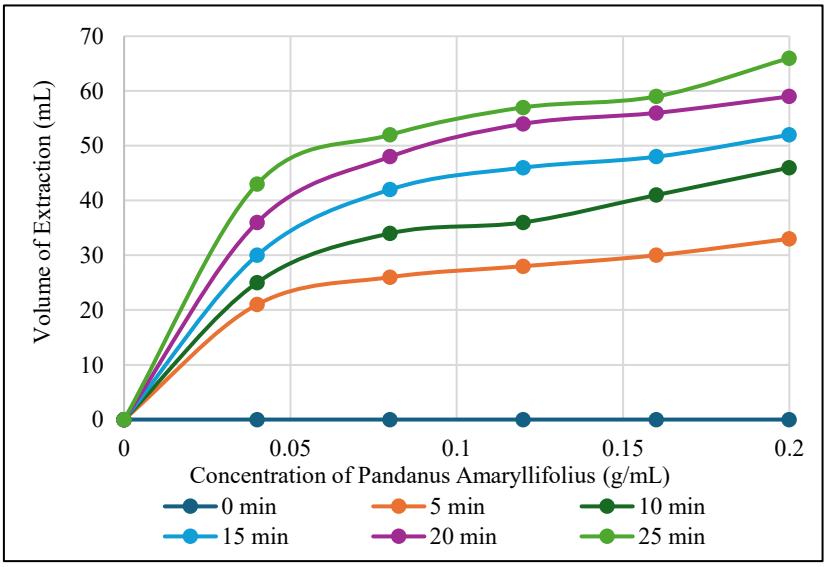


Figure 4. Response of volume of hydrosol extraction to concentration of *Pandanus Amaryllifolius*

Table 2. Percentage Hydrosol Yield obtained at varying *Pandanus Amaryllifolius* Concentrations and Extraction Times during Hydrodistillation

Concentration of *Pandanus Amaryllifolius* (g/mL)	**Percentage Hydrosol Yield (%)**				
0.04	4.2	5	6	7.2	8.6
0.08	5.2	6.8	8.4	9.6	10.4
0.12	5.6	7.2	9.2	10.8	11.4
0.16	6	8.2	9.6	11.2	11.8
0.2	6.6	9.2	10.4	11.8	13.2

Figure 5 illustrates the same the same trend to highlight how hydrosol yield changes across concentration levels over time. The results demonstrate a consistent in hydrosol yield as the concentration increased from 0.04 g/mL to 0.20 g/mL across all extraction durations. At 25 minutes, the percentage hydrosol yield increased from 8.6% to 13.2%, representing an approximately 53% increase in yield over the tested concentration range. The observed trend can be explained based on mass transfer and diffusion principles governing hydrodistillation processes. Increasing the solid-to-liquid ratio enhances the availability of volatile aromatic compounds within the system, thereby increasing the concentration gradient between the plant matrix and the surrounding boiling water [14]. According to diffusion theory, the rate of mass transfer is proportional to this concentration gradient, which serves as the primary driving force for solute transport [14]. During hydrodistillation, thermal energy facilitates cell rupture and volatilization of aromatic compounds, which are subsequently transferred into the vapour phase and condensed as hydrosol [4]. Similar findings have been reported where increasing plant loading improved extraction yield due to enhanced mass transfer dynamics [6].

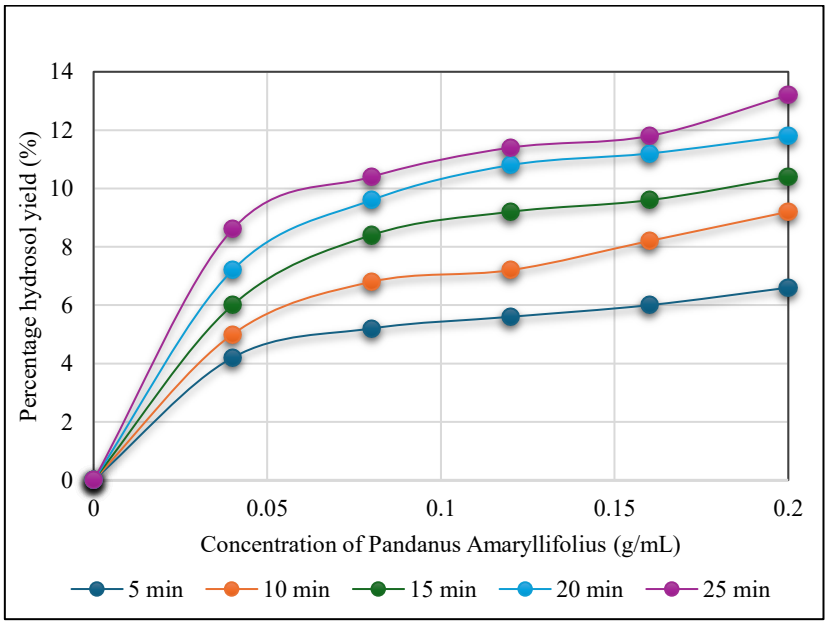


Figure 5. Response of Percentage Hydrosol Yield in Increasing Concentration Under Time-Dependent hydrodistillation conditions

Although the yield increased steadily within the tested concentration range, the rate of increase appears to slightly diminish at higher concentrations especially at the range of 0.16 to 0.20 g/mL of concentration. This may suggest the onset of internal mass transfer resistance or limited heat distribution within denser plant matrices. Overall, the findings confirm that concentration is a critical operating parameter in hydrodistillation of *Pandanus amaryllifolius* leaf puree. Within the investigated range, higher concentrations consistently produced greater hydrosol yield which indicating that the extraction efficiency had not yet reached a limiting point under the selected experimental conditions.

3.3 Effect of Pandanus Amaryllifolius Concentration and Extraction Time on Hydrosol Yield

This subsection evaluates the combined effect of concentration and extraction time on percentage hydrosol yield. The interaction between these two operating parameters is analysed to determine their synergistic influence on extraction performance. **Table 3** presents the combined data illustrating the influence of pandan concentration and extraction time on percentage hydrosol yield obtained through hydrodistillation.

Table 3. Experimental interaction combined data effects of concentration and extraction duration on hydrosol recovery efficiency

Concentration of Pandanus Amaryllifolius (g/mL)	Time (min)	Percentage Hydrosol Yield (%)
0.04	0	0
	5	4.2
	10	5.2
	15	5.6
	20	6
	25	6.6
0.08	0	0
	5	5
	10	6.8
	15	7.2
	20	8.2
	25	9.2
0.12	0	0
	5	6
	10	8.4
	15	9.2
	20	9.6
	25	10.4
0.16	0	0
	5	7.2
	10	9.6
	15	10.8
	20	11.2
	25	11.8
0.20	0	0
	5	8.6
	10	10.4
	15	11.4
	20	11.8
	25	13.2

Figure 6 provides a three-dimensional surface representation of the interaction between these two operating parameters. The results demonstrate a synergistic effect between concentration and extraction duration. At all concentration levels, percentage hydrosol yield increased progressively with extraction time. Similarly, at every time interval, increasing concentration resulted in higher hydrosol yield. The highest yield, 13.2% was obtained at 0.20 g/mL after 25 minutes, indicating that maximum extraction efficiency within the tested range occurred under conditions of both high solid loading and extended extraction time. The interaction behaviour observed in the surface plot suggests that hydrosol recovery is governed by both mass transfer driving force and extraction kinetics. By increasing concentration enhances the availability of volatile compounds and strengthens the concentration gradient between plant matrix and surrounding boiling water, which acts as the primary driving force for diffusion [14]. Simultaneously, increasing extraction time allows prolonged thermal disruption of plant cells and facilitates continuous release of volatile constituents into the vapour phase [11].

From a kinetic modelling perspective, hydrodistillation of *Pandanus amaryllifolius* can be described using a first-order extraction model, where the rate of volatile release is proportional to the remaining extractable compounds within the plant matrix. The extraction behaviour observed in this study follows

a typical exponential growth pattern toward equilibrium. The initial rapid increase in percentage hydrosol yield was in the range of 5 to 15 minutes corresponds to the washing stage, where easily accessible volatile compounds are quickly transferred into the vapour phase. As extraction progresses from 20 to 25 minutes, the rate of increase gradually slows, indicating the transition to a diffusion-controlled regime. This behaviour is consistent with kinetic extraction models described in plant distillation literature [15]. In the present study, no apparent equilibrium condition was observed within 25 minutes which suggests that complete exhaustion of volatile compounds had not yet been reached under the tested conditions. The three-dimensional surface plot further confirms that concentration and time do not operate independently. Hence, their combined increase amplifies hydrosol recovery. This interaction indicates that optimizing only one parameter may not yield maximum extraction efficiency. Optimal performance is achieved when enough plant material was used and the extraction was allowed to proceed for a longer period. Overall, the results demonstrate that percentage hydrosol yield is strongly dependent on the combined effect of concentration and extraction duration under constant temperature conditions.

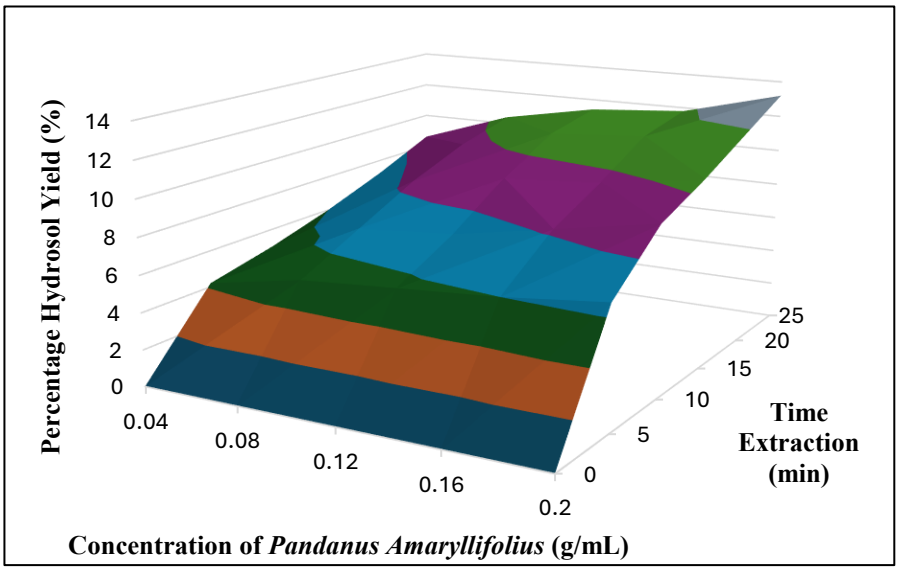


Figure 6. Three-dimensional response surface of the combined effect *Pandanus Amaryllifolius* concentration and extraction time on percentage hydrosol yield

4. Conclusion

This study successfully achieved its objective of extracting hydrosol from *Pandanus Amaryllifolius* leaf puree using hydrodistillation and evaluating the influence of concentration and extraction time on percentage hydrosol yield under controlled laboratory conditions. The findings clearly demonstrate that both operating parameters significantly affect hydrosol recovery. An increase in *Pandanus Amaryllifolius* concentration from 0.04 g/mL to 0.20 g/mL consistently enhanced percentage hydrosol yield which indicating that higher concentration improved the availability of volatile aromatic compounds and strengthened the concentration gradient driving mass transfer. Similarly, extending extraction time from 5 to 25 minutes resulted in progressive increases in hydrosol yield, reflecting continued diffusion and volatilization of aromatic compound. The highest yield such as 13.2% was obtained at 0.20 g/mL after 25 minutes which representing the optimal operating condition within the investigated experimental range. The interaction analysis has shown that concentration and extraction time act synchronously rather than independently. Efficient hydrosol recovery requires both sufficient plant loading and enough extraction duration to maximize volatile compound release. No equilibrium condition was reached within 25 minutes which suggesting that complete exhaustion of extractable components had not yet occurred and that further time optimization may increase yield. Overall, this study provides baseline experimental data for hydrosol production from locally available *Pandanus*

Amaryllifolius and demonstrates the feasibility of applying hydrodistillation in educational laboratory settings. The results contribute to a better understanding of extraction parameter optimization and offer practical insight for small-scale aromatic distillation applications.

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Volumetric Characterization and Performances of *Cymbopogon Citratus* (Lemongrass) Hydrosol Extraction

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Abstract

This study main aim is to evaluate the factors influencing the extraction performance of hydrosol from local Cymbopogon Citratus (lemongrass) to determine the most efficient configuration. The research followed three objectives: identifying and preparing local samples through grinding, conducting hydro distillation experiments to measure volumetric yield, and analyzing the relationships between distillation time, solid-to-solvent ratio, and hydrosol volume. Standardized 100g lemongrass samples were hydro distilled with a spiral condenser at different solid-to-solvent ratios (1:1 to 1:5) and extraction times (5 to 20 minutes). The results showed that the solid-to-solvent ratio has a significant effect on productivity; raising the ratio from 1:1 to 1:5 resulted in a yield increase of 22.0% to 42.0%. This improvement is due to lower slurry viscosity and a higher concentration gradient, which facilitates the efficient recovery of volatile chemicals. Graphical and 3D surface analysis demonstrated a faster initial extraction phase, with the 1:5 ratio achieving a 23.4% yield in 10 minutes, exceeding the 1:1 ratio's total yield of 20 minutes. These results suggest that the solvent ratio is a more important determinant in extraction efficiency than residence time. The study concludes that an optimal operational window exists at a 1:5 ratio with a 10 to 15-minute duration. Implementing these criteria reduces extraction time by 50%, lowering energy usage and reducing heat degradation of the hydrosol. This study provides a technical foundation for improving distillation efficiency by balancing maximal volumetric output with lower operational energy demands.

Keywords: *Cymbopogon Citratus, Hydro distillation, Solid-to-solvent ratio, Extraction yield, Volume optimization*

1. Introduction

Cymbopogon Citratus (Lemongrass) is well known for its high concentration of essential oil, which is commonly used in a variety of businesses across the world. It is a prevalent aromatic plant in tropical regions and perennial aromatic grass in the *Poaceae/Gramineae* family, widely known as lemongrass or citronella grass [1]. Beyond its fragrance applications in aromatherapy, these bioactive compounds serve as effective natural preservatives in food and offer sustainable, eco-friendly solutions for the formulation of organic pesticides [2]. Natural aromatic resources such as lemongrass are abundant in many local environments but often remain unutilized due to a lack of technical processing skills [3]. This mismatch between technical know-how and resource availability leads towards the loss of valuable organic molecules that may be used in a variety of real-world applications. Within educational and practical contexts, there is a significant lack of empirical data and standardized

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procedures regarding the extraction of botanical compounds or the effective use of specialized laboratory equipment [4]. Moreover, there is no established baseline for the volume production of hydrosol (scented water) or its production dynamics under varying conditions [5]. Therefore, the main aim of this study is to evaluate the factors influencing the extraction performance of hydrosol from local lemongrass. I n order to achieve the aim of this study, several objectives has been established as follows: (i) to identify local lemongrass samples and document their characteristics, including fresh mass and preparation through grinding, (ii) to conduct hydro distillation experiments using a spiral condenser and measure the volume of hydrosol produced to calculate the total yield percentage based on the starting mass, (iii) to reduce the extraction process by analyzing the relationship between distillation time, solid-to-solvent ratio, and hydrosol volume through graphical analysis. For this study, the scope is limited to locally sourced lemongrass to ensure consistency and relevancy to local context.

2. Methodology

This section presents an experimental investigation into the use of a hydrodistillation setup to extract hydrosol from Cymbopogon Citratus (Lemongrass) as illustrated in **Figure 1**. The experimental activities involve sample preparation, experimental work, and a thorough analysis of production dynamics.

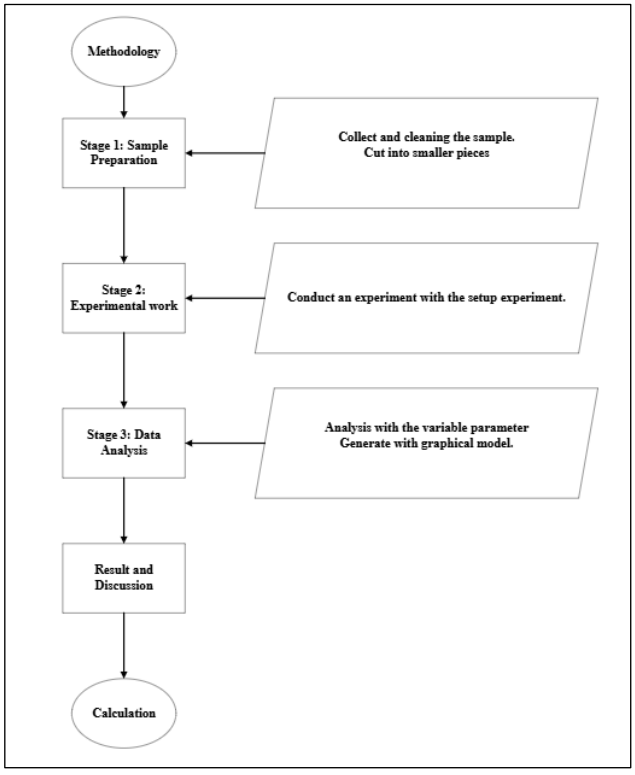


Figure 1. Study Flowchart.

2.1 Stage 1: Preparation of local *Cymbopogon Citratus* (Lemongrass) sample.

This process begins with selecting and preparing local lemongrass (*Cymbopogon Citratus*) samples. This initial phase is crucial for setting a standard for raw material purity and consistency. By capturing physical features such as leaf color, texture, and initial hydration state, the study ensures that the starting biomass is typical of high-quality local resources, lowering experimental error in subsequent distillation phases. Once selected, the lemongrass leaves go through a cutting process. The lengthy, fibrous leaves and stalks are manually cut into smaller parts. This mechanical preparation is required to facilitate the

subsequent blending process. The sectioned samples are next mechanically blended to convert the biomass into a coarse paste. This process is scientifically important because it ruptures the plant's interior oil-bearing trichomes and cell walls, increasing the specific surface area available for the extraction solvent. During this stage, the sample is integrated with the aqueous solvent in accordance with the experiment's precise solid-to-solvent ratios, which range from 1:1 to 1:5. For example for ratio 1.1, a 100g of lemongrass ground paste mixed with 100 mL of water.

The volatile essential oil of *Cymbopogon Citratus*, which is mainly composed of the isomeric dicarbaldehydes known as citral, dominates the plant's chemical composition. This citral content is a synergistic combination of geranial (citral a) and neral (citral b), which combined give the plant its distinctive lemon-like smell and a variety of biological functions [6]. According to research by Oladeji et al. [7], citral is the main component (often surpassing 70%), but a complex range of monoterpenes and sesquiterpenes, including myrcene, geraniol, and limonene, as well as different flavonoids and phenolic compounds, like luteolin and quercetin, support the hydrosol's overall effectiveness. Specialized parenchymatous cells and oil glands produce and store these bioactive components. Since the effective release and recovery of these compounds into the hydrosol during the distillation process depends on the rupture of these internal structures, the maturity and mechanical preparation of the plant have a significant impact on the specific concentration and purity of these chemicals, as these studies have shown.

2.2 Stage 2: Experimental work.

The extraction is carried out using a hydro-distillation process. Hydro-distillation was chosen over other procedures because it is a reliable and accessible process for extracting volatile organic chemicals while preserving the hydrosol's chemical fingerprint. The experimental setup is shown in **Figure 2**. According to Van and Vu [8], hydro-distillation is especially successful at extracting polar and aromatic chemicals into the aqueous phase, which is critical for producing high-quality hydrosols. Furthermore, the submerged nature of the biomass in hydro-distillation prevents localized overheating of the powdered paste, which can occur with dry steam techniques [9].

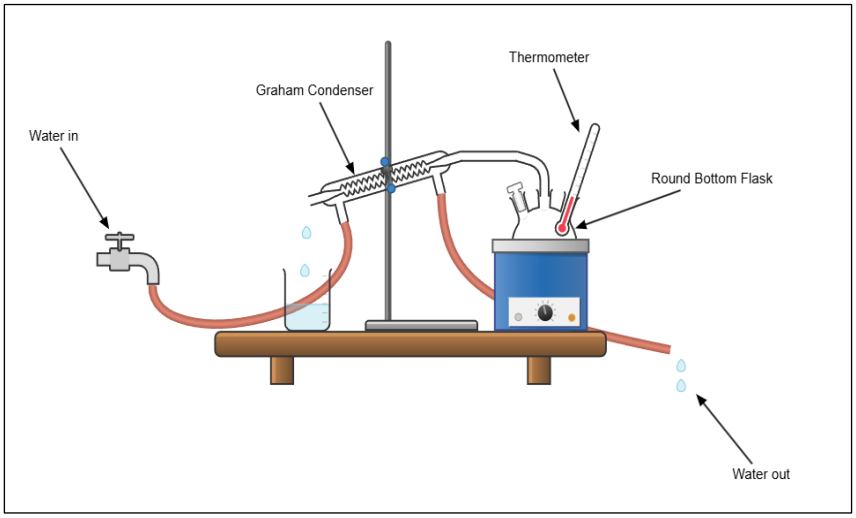


Figure 2. Schematic Diagram of Hydro distillation

The round-bottom flask carrying the 1:1 to 1:5 slurry is loaded with anti-bumping granules and put under a temperature-controlled heating mantle, ensuring a steady and safe distillation. The system is sealed with ground-glass joints to prevent volatile molecules from escaping, and a thermometer is placed at the still head to measure the vapor temperature. The distillation is timed at 5-minute intervals for a total of 20 minutes, with the cumulative volume recorded in a graduated cylinder.

2.3 Stage 3: Data Analysis

The cumulative volume (V) is calculated by measuring the collected hydrosol at the end of each five-minute distillation interval. A Percentage Yield (%Y) is created from the raw volume to give a consistent way to compare extraction effectiveness across various solid-to-solvent ratios using **Equation 1** [10].

$$\left(\%Yield\ \left(\frac{v}{w}\right)\right) = \frac{Volume\ \ of\ extraction}{Weight\ of\ plan\ used} \times 100 \qquad \text{..... (1)}$$

3. Results and discussion

This section presents and discusses the major findings which are pertinent to the aim and objectives of the study, which are as follows.

3.1 Physical Characterization of Blended Lemongrass Slurry

The lemongrass (*Cymbopogon Citratus*) was made into five different slurries before the hydro-distillation procedure. These samples are organized from left to right in **Figure 3**, illustrating the rise in water content from a 1:1 ratio (left) to a 1:5 ratio (right). A fixed mass of 100g of ground lemongrass is present in every sample, whereas the volume of distilled water increases throughout the set. The initial preparation of the lemongrass (*Cymbopogon Citratus*) results in five distinct mixtures with varying physical properties. The sample on the far left (1:1 ratio) has a dense, paste-like consistency and a high concentration. This slurry is noticeably thick and fibrous since the amounts of biomass and solvent (100g to 100mL) are equal. On the other hand, the mixtures show a distinct shift toward a more fluid, low-viscosity state when the solvent volume rises toward the proper (1:5 ratio). The lemongrass pieces are fully suspended in the aqueous medium in 1:5 configuration (100g to 500mL).

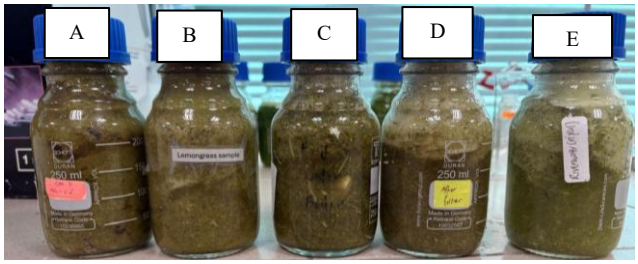


Figure 3. Sample of Blended Lemongrass Slurry with Ratio (A) 1:1, (B) 1:2, (C) 1:3, (D) 1:4 and (E) 1:5.

3.2 Experimental study analysis to reduce the extraction process.

The study's findings shed importance on the relationship between solvent volume and lemongrass (*Cymbopogon Citratus*) hydrosol recovery efficiency. The experiment was able to obtain a complete dataset that shows the fluctuations in cumulative volume and percentage yield (%Y) over a 20-minute period by carrying out the hydro distillation procedure across five different solid-to-solvent ratios. The raw data was combined for comparison analysis after the hydro distillation procedure was carried out methodically. The main findings are shown in **Table 1** and **Table 2**, which shows the total volume of lemongrass (*Cymbopogon Citratus*) hydrosol produced over a 20-minute period at five different solid-to-solvent ratios. According to the data in **Table 1**, productivity steadily rises when the water-to-plant ratio moves from 1:1 to 1:5. According to Siddiqui [11], the presence of more aqueous solvent promotes a more resilient steam production phase, which is necessary for the efficient mass transfer of volatile aromatic chemicals

Table 1. Total volume of hydrosol production over period time at different solid-to-solvent ratios.

Solid-to-Solvent Ratio	Time (min)	Volume of Extraction (ml)
1:1	0	0.0
	5	2.0
	10	10.0
	15	17.0
	20	22.0
1:2	0	0.0
	5	4.0
	10	12.0
	15	19.0
	20	26.0
1:3	0	0.0
	5	6.0
	10	14.5
	15	22.0
	20	30.0
1:4	0	0.0
	5	9.0
	10	19.6
	15	28.0
	20	36.0
1:5	0	0.0
	5	11.0
	10	23.4
	15	32.7
	20	42.0

Table 2. Percentage yield (%) of hydrosol recovered at different solid-to-solvent ratios.

Ratio	Percentage yield (%)				
1:1	0.0	2.0	10.0	17.0	22.0
1:2	0.0	4.0	12.0	19.0	26.0
1:3	0.0	6.0	14.5	22.0	30.0
1:4	0.0	9.0	19.6	28.0	36.0
1:5	0.0	11.0	23.4	32.7	42.0

3.4 Effects of Extraction Time on Volume of Production

The Rate of Production graph as shown in **Figure 4** and **Table 1** identifies the rate of hydrosol collected at specific intervals. The data shows that the highest rate of extraction occurs between the 5-minute and 15-minute marks. For instance, in the 1:5 ratio, the production jumps significantly during the middle of the experiment before the curve begins to level off. According to the results, the maximum rate of extraction occurs during the first 10 to 15 minutes. This pattern is consistent with known kinetics of herbal extraction, in which the initial volume of production rises quickly due to the easy vaporization and condensation of aromatic substances at the surface. A similar tendency was seen in the extraction of soybean polyphenols, where 82–94% of the total yield was recovered in the first third of the process [12]. The most intense mass transfer takes place in the first 10 minutes of this experiment, as seen by the 1:5 ratio reaching more than 55% of its total volume in that time.

The volume production at the 1:1 ratio is much slower and more limited during the experiment. This is literally proven by the 1:1 slurry high physical density and viscosity (100g of lemongrass to 100mL

of water). The mixture stayed as a thick and fibrous paste rather than a fluid solution because the biomass and solvent are in equal amounts.

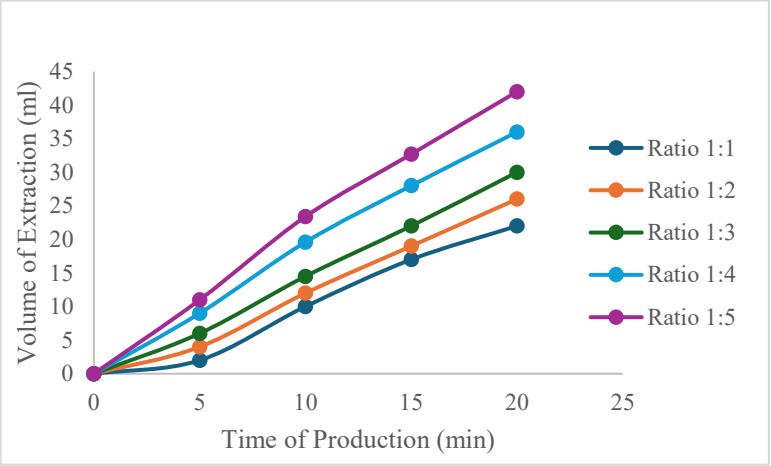


Figure 4. Volume of Production versus Time Production (min)

The data also depicted that continuing the extraction beyond the 20-minute mark may lead to lower returns. Long extraction periods may lower the production volume or decrease the hydrosol quality. According to Kenari and Dehghan [13], extending extraction time beyond an optimum can decrease oil yield due to solvent loss through evaporation.

3.5 Effect of Solid-to-Solvent Ratio on Volume of Production.

The relationship between the solid-to-solvent ratio and the volumetric output of *Cymbopogon Citratus* hydrosol in **Figure 5** demonstrates a significant correlation, as evidenced by the progression from 22.0 mL at a 1:1 ratio to 42.0 mL at a 1:5 ratio. The result is consistent with Siddiqui [11], who observed that extraction yield is generally improved by increasing solvent volume at a fixed solid mass. Technically, this happens by lowering the slurry's viscosity while simultaneously raising the concentration gradient between the solvent and the plant matrix. Internal resistance was reduced in this study by switching from a dense 1:1 paste to a fluid 1:5 suspension, which increased the overall mass transfer efficiency.

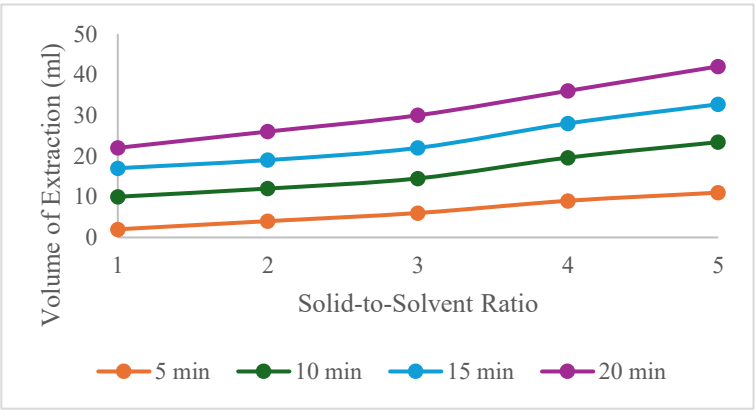


Figure 5. Effect of Solid-to-Solvent Ratio on Volume of Production.

The amount of water used in hydro distillation has two functions that are its acts as a medium for heat transfer and a transporter of volatile molecules. Ntalikwa [14] states that the stripping of volatiles from the biomass is typically made faster by a higher water charge at a constant plant mass. This is

supported by the statistics, which showed that the 1:5 ratio supplied enough liquid to completely suspend the lemongrass, ensuring even heating and efficient vapor production. However, it is important to consider the non-linear nature of this effect while yield increases up to an optimum, Ntalikwa [14] suggests that once enough water is present to efficiently suspend the biomass, additional water may primarily increase the total distillate volume without a proportional increase in the concentration of essential oil productivity.

3.6 Effect of Extraction Time and Solid-to-Solvent Ratio on Volume of Production.

This study finds that the solvent-to-solid ratio has a major impact on the extraction efficiency of lemongrass hydrosol, as shown in **Figure 6**. It is observed that when the ratio increases from 1:1 to 1:5, the percentage yield increases from 22% to 42% at a constant mass of 100g. However, the 3D surface plot shows a uniform result, indicating that the rate of recovery stabilizes after the 1:5 limit is reached, even though volume increases with solvent. According to a related study by Siddiqui [11], increasing the solvent volume enhances mass transfer by lowering the viscosity of the slurry and raising the concentration gradient, enabling more effective stripping of volatiles.

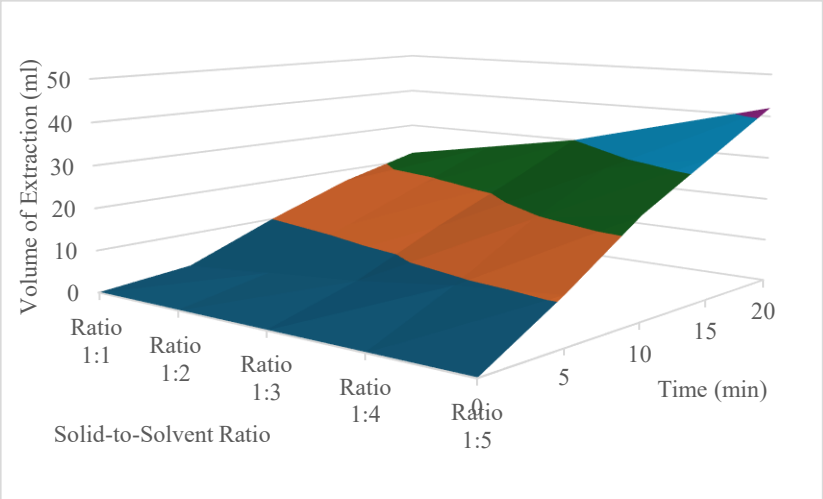


Figure 6. Effect of Extraction Time and Solid-to-Solvent Ratio on Volume of Production.

The 3D surface analysis also shows that a high yield may be obtained at larger ratios considerably earlier at 10 minutes, the 1:5 ratio (23.4%) performs better than the 1:1 ratio (22%). This indicates that when it comes to extraction optimization, the solvent ratio is a more important factor than time. On the other hand, less effective recovery results from long extraction durations or inadequate solvent ratios (such as 1:1). While over-extraction past the saturation limits may result in the heat loss of sensitive aromatic compounds and needless energy consumption, inadequate water creates a dense, fibrous matrix that traps volatiles [14].

4. Conclusion

The findings of this study successfully validate the optimized parameters for the hydro distillation of lemongrass (*Cymbopogon Citratus*), fulfilling all stated research objectives. 100g of standardized lemongrass samples were prepared. This mechanical intervention was important as it enhanced the surface area for the quick release of volatile chemicals by rupturing the cell walls and oil glands. The experiments using a spiral condenser produced production volumes ranging from 22.0 mL to 42.0 mL, with the 1:5 ratio reaching a maximum yield of 42.0% while the 1:1 ratio only reached 22.0%. This highlights how the hydrosol may be stripped from the plant matrix more successfully when the solvent-to-solid ratio is higher since it enhances the concentration gradient and reduces slurry viscosity. The graphical and 3D surface analysis revealed a technological pathway for process reduction, demonstrating that a 1:5 ratio at 10 minutes (23.4%) outperforms a 1:1 ratio at 20 minutes (22.0%). This

shows that the main factor influencing efficiency is the solvent ratio rather than time. In conclusion, the aim of this study, which was to evaluate the factors influencing the hydrosol extraction performance from the local *Cymbopogon Citratus* (lemongrass), has been accomplished.

Acknowledgements

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Comparative Analysis of Harvested Rainwater and Tap Water Quality at SMK Engkilili Dormitory

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Abstract

Water supply reliability remains a challenge in rural and semi-rural areas despite Malaysia's high annual rainfall, highlighting the need for sustainable alternative water resources. This study evaluates the feasibility of implementing a rooftop rainwater harvesting (RWH) system at the dormitories of SMK Engkilili, Sri Aman, Sarawak through water quality assessment and system design analysis. Rainwater and tap water samples were analyzed for pH, turbidity, total suspended solids (TSS), and total dissolved solids (TDS) and compared against the National Water Quality Standards for Malaysia. Results indicated that harvested rainwater exhibited near-neutral pH (7.42) and low TDS (15 mg/L), comparable to tap water values, while turbidity (7 NTU) and TSS (31 mg/L) were higher, suggesting the need for simple treatment prior to domestic use. Roof catchment assessment identified effective areas ranging from 365.01 m² to 449.36 m² across dormitory buildings using a runoff coefficient of 0.85. Based on an annual rainfall of 2908 mm, harvested rainwater volumes were estimated between 955.30 m³/year and 1,176.08 m³/year, equivalent to average daily yields of 2,617–3,222 L/day. Comparison with dormitory water demand, estimated at 43,725 L/day for 265 students per dormitory using WHO consumption standards, revealed that harvested rainwater could supply only about 6–7% of total demand. Storage tank analysis indicated that a configuration of 3000 L tanks, requiring six units for boys' dormitories and four units for girls' dormitories, provided optimal storage capacity. Overall, the findings demonstrate that rooftop rainwater harvesting can effectively supplement non-potable water demand and enhance water sustainability within institutional dormitory settings.

Keywords: *Rainwater harvesting, water quality assessment, roof catchment area, storage tank sizing, water demand analysis*

1. Introduction

Water scarcity has emerged as a significant global issue driven by population growth, rapid urbanization, and the impacts of climate change, all of which place increasing pressure on limited freshwater resources. These challenges align closely with the objectives of Sustainable Development Goal 6 (SDG 6), which emphasizes the need for sustainable and resilient water management strategies [1]. In this context, rainwater harvesting (RWH) has gained attention as a practical and sustainable alternative that can supplement conventional water supplies. By collecting and storing rainwater from roof catchment surfaces, RWH systems can enhance water resilience, reduce dependency on treated municipal water, and support efficient water resource management, particularly in high-demand or water-stressed areas [2].

Despite Malaysia receiving relatively high annual rainfall, water scarcity and intermittent supply disruptions still occur, especially in rural and semi-rural regions. This situation highlights ongoing challenges in ensuring reliable access to freshwater resources and reinforces the need for alternative water supply solutions such as rainwater harvesting systems [4, 9]. However, the feasibility of

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implementing RWH systems is often constrained by limited local data on the quality of harvested rainwater. Key water quality parameters such as pH, turbidity, total dissolved solids (TDS), and total suspended solids (TSS) could be influenced by environmental conditions and rainfall characteristics, potentially affecting suitability for non-potable uses [4, 10]. Consequently, a comprehensive assessment of catchment potential, water demand, storage requirements, and water quality is required to evaluate the viability of RWH systems in institutional settings such as student dormitories.

The main aim of this research is to design an appropriate rainwater harvesting system for school dormitories at SMK Engkilili. To achieve this aim, there are several objectives which are (i) to compare the water quality harvested rainwater and tap water according to the National Water Quality Standards (NWQS), (ii) to determine the most appropriate roof catchment surfaces and estimate the water demand for dormitory usage, and (iii) to estimate the available rainwater harvest and size required storage tanks using rainfall patterns and catchment characteristics. The scope of this study is limited to harvested rainwater and tap water samples collected from the SMK Engkilili dormitory, which serve as the primary sources for water quality analysis. The research focuses on evaluating the feasibility of a rainwater harvesting system designed specifically for hostel students, with emphasis on meeting non-potable water demands within the dormitory environment. The assessment includes system design considerations, water demand estimation, storage capacity requirements, and comparative water quality analysis to determine the applicability of rainwater harvesting as a supplementary water supply for the school dormitory.

2. Methodology

This section discussed **Figure 1**, which is the framework of the methodology divided into three stages used in this study.

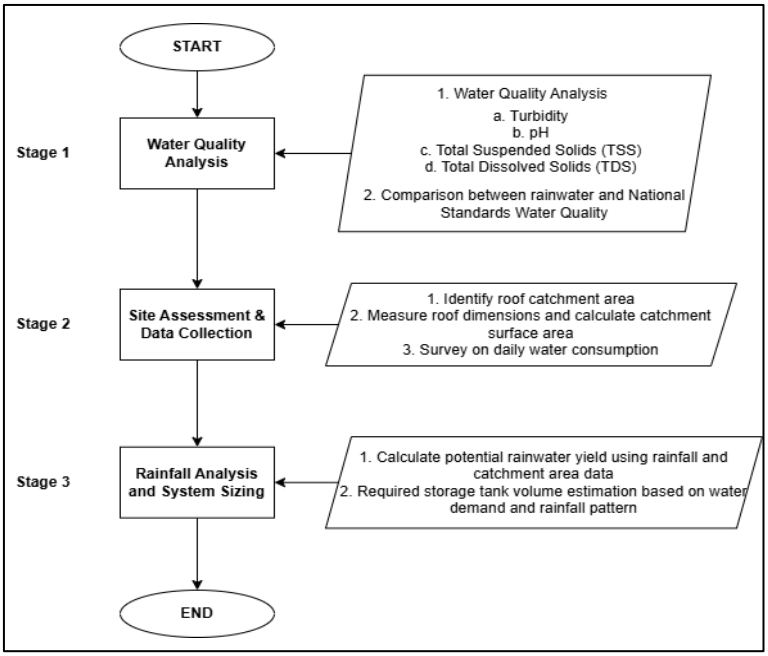


Figure 1. Structure of Methodology.

2.1 Water Sampling and Quality Analysis

Rainwater samples were collected at the student's dormitory of SMK Engkilili and tap water samples were collected from the building to serve as reference for water quality comparison. Four key quality parameters were analysed such as turbidity, total suspended solids, total dissolved solids, and pH. The results for both rainwater and tap water are evaluated against the National Water Quality Standards for

Malaysia (NWQS) in **Table 1** and **Table 2** to determine compliance classification and suitability for non-potable application.

Table 1. Malaysia National Water Quality Standards for Malaysia [19]

Parameter	Unit	Class					
		I	IIA	IIB	III	IV	V
pH	-	6.5-8.5	6 - 9	6 - 9	5- 9	5 - 9	-
Total Suspended Solids	mg/L	25	50	50	150	300	300
Turbidity	NTU	5	50	50	-	-	-
Total Dissolved Solids	mg/L	500	1000	-	-	4000	-

Table 2. Water Classification [19]

Class	Uses
Class I	Water Supply I – No treatment necessary Fishery I – Very sensitive aquatic species
Class IIA	Water Supply II – Conventional treatment required Fishery II – Sensitive aquatic species
Class II B	Recreational use with body contact
Class III	Water Supply III – Extensive treatment required Fishery III – Common economic value and tolerant species; livestock drinking
Class IV	Irrigation
Class V	None of the above

2.2 Roof Catchment Assessment

Figure 2 shows the effective roof catchment area of students' dormitory of SMK Engkilili through the physical measurement of building rooftop dimension was determined by using Google Maps. The total effective catchment area is calculated in square meters (m^2) with metal roof surface runoff coefficient was considered to include minor losses due to evaporation, splash and leaking [20].



Figure 2. Location of SMK Engkilili, Sri Aman, Sarawak

2.3 Rainfall Data Analysis and Storage Tank Sizing

The roof area is calculated by using **Equation 1**. The annual rainfall for Sri Aman Division is 2908 mm therefore the total volume estimated of rainwater harvested annually can be obtained by **Equation 2** [21, 22].

$$\text{Roof Area } (m^2) = \text{Roof length} \times \text{Roof width} \quad \text{..... (1)}$$

$$Rainwater\ harvested = A_r \times Annual\ rainfall \times Runoff\ coefficient \quad \text{..... (2)}$$

The storage capacity is determined by **Equation 3** where the tank size in Malaysia regardless of its location is $1m^3$ for roof area of $100m^2$ [19]. This is equivalent to store 10mm of rainfall with 100 m^2 of roof area. The number of storage tanks required is determined by **Equation 4**. The water demand was determined using **Equation 5** by using the standard water consumption stated by the World Health Organization which is 165 L/day, and the number of students for each boys' and girls' dormitory are 285 respectively.

$$S_t = 0.01\ A_r \quad \text{..... (3)}$$

$$\text{No of tank required} = \frac{Total\ required\ storage\ volume\ (m^3)}{Capacity\ per\ tank\ (m^3)} \quad \text{..... (4)}$$

$$\text{Total daily water demand} = \text{Number of student} \times \text{Standard water consumption} \quad \text{..... (5)}$$

3. Results and Discussion

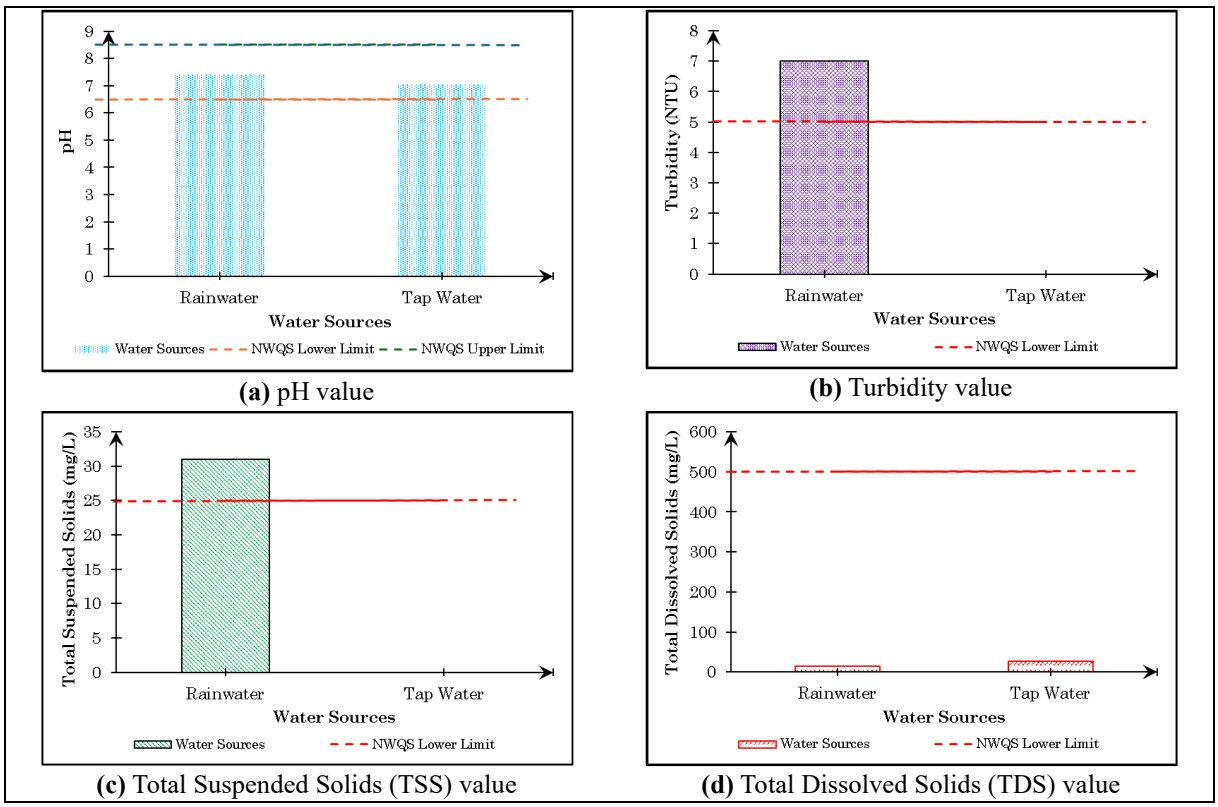
This section discusses the results of the water quality assessment, including pH, turbidity, total suspended solids (TSS), and total dissolved solids (TDS) for both harvested rainwater and tap water. It also presents the roof catchment area, estimated harvested rainwater volume, water demand, feasibility analysis, and storage tank sizing.

3.1 Water Quality Assessment

Based on **Table 3**, The water quality assessment indicates clear differences between harvested rainwater and tap water in terms of physical and chemical characteristics. Both rainwater and tap water exhibited near-neutral pH values of 7.42 and 7.04 falling within recommended guideline ranges as shown in **Figure 3(a)**, although the slightly higher pH of rainwater suggests buffering effects from roof contact and environmental particulates after deposition [12]. In contrast, turbidity and total suspended solids (TSS) were noticeably higher in harvested rainwater, with values of 7 NTU based on **Figure 3(b)** and 31 mg/L based on **Figure 3(c)**, reflecting the influence of atmospheric dust, roof runoff, and catchment contamination commonly reported in rainwater harvesting studies. Tap water, on the other hand, recorded zero turbidity and negligible suspended solids, demonstrating the effectiveness of conventional treatment processes. Total dissolved solids (TDS) were relatively low for both water sources, with rainwater at 15 mg/L and tap water at 27 mg/L based on **Figure 3(d)**, consistent with the naturally low ionic content of rainwater and the presence of dissolved minerals in treated municipal supplies. Overall, these results indicate that while harvested rainwater meets acceptable pH and TDS conditions, further treatment is required to reduce turbidity and TSS before domestic use [13].

Table 3. Characterization of rainwater and tap water quality.

Parameters	Rainwater	Tap Water
pH	7.42	7.04
Turbidity	4	0
Total Suspended Solids	31	0
Total Dissolved Solids	15	27



(a) pH value **(b)** Turbidity value

(c) Total Suspended Solids (TSS) value **(d)** Total Dissolved Solids (TDS) value

Figure 3. Comparison between rainwater and tap water.

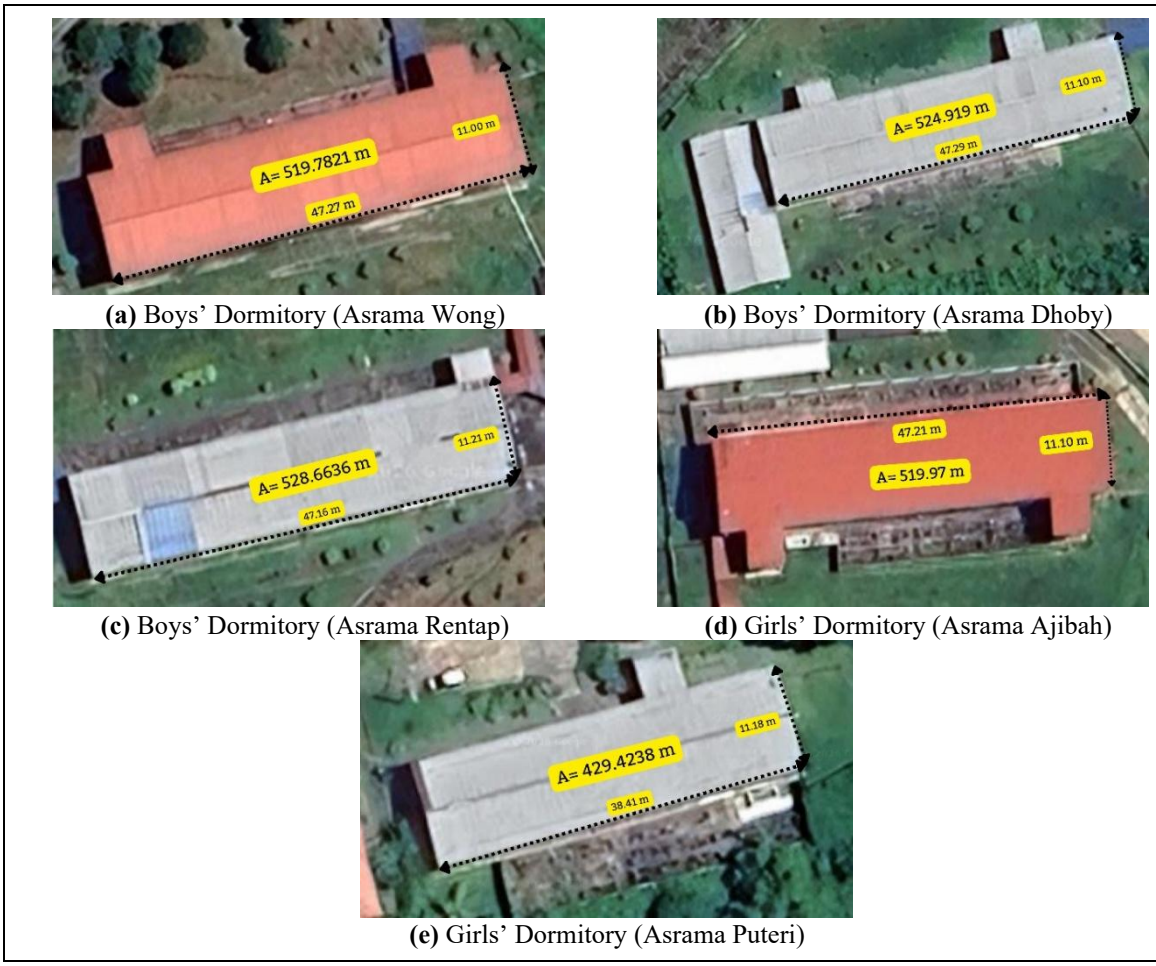
3.2 Roof Catchment Assessment

The assessment of roof catchment areas, as illustrated in **Figure 4** and summarised in **Table 4**, indicates that the dormitory buildings at SMK Engkilili possess favourable characteristics for rainwater harvesting implementation. The measured roof areas ranged from 429.42 m² to 528.66 m² across the selected dormitories **Table 4**, resulting in effective catchment areas between 365.01 m² and 449.36 m² after applying a runoff coefficient of 0.85 to account for minor losses. The reduction from total roof area to effective catchment area reflects realistic system behaviour, considering evaporation, splash, and retention losses that occur during rainfall events, which are commonly represented through the runoff coefficient in rainwater harvesting design. Recent studies emphasised that the runoff coefficient is a critical parameter that accounts for hydrological losses and enables accurate estimation of effective runoff from roof surfaces [24].

The suitability of rooftop catchments is further supported by using metal roofing materials, as observed in **Figure 4**, which are hard, smooth, and non-porous surfaces known to produce high runoff efficiency and relatively clean harvested water compared to ground-level catchments. Hydrological investigations indicate that metal sheet roofs typically exhibit runoff coefficients between approximately 0.75 and 0.90, demonstrating their effectiveness for rainwater collection and supporting their widespread use in rainwater harvesting systems [25]. Additionally, roof material and size are recognised as key determinants of rainwater harvesting potential, as the volume of collected rainwater is directly proportional to the roof plan area and rainfall intensity [26].

Moreover, only roof sections capable of efficiently conveying runoff to guttering systems were included in the effective catchment estimation to ensure realistic performance assumptions. Such consideration aligns with recent modelling studies highlighting that rainwater harvesting efficiency depends strongly on the interaction between roof catchment area, runoff characteristics, and system configuration [27]. Overall, the evaluated roof catchment areas confirm the feasibility of rooftop

rainwater harvesting at the SMK Engkilili dormitories, as the available surface area is sufficiently large to generate meaningful rainwater yield and provide a reliable basis for subsequent harvesting and storage design calculations.



(a) Boys' Dormitory (Asrama Wong)
(b) Boys' Dormitory (Asrama Dhoby)
(c) Boys' Dormitory (Asrama Rentap)
(d) Girls' Dormitory (Asrama Ajibah)
(e) Girls' Dormitory (Asrama Puteri)

Figure 4. SMK Engkilili Students' Dormitory.

Table 4. Size assessment for catchment area.

Parameters	Boys' Dormitory (Asrama Wong)	Boys' Dormitory (Asrama Dhoby)	Boys' Dormitory (Asrama Rentap)	Girls' Dormitory (Asrama Ajibah)	Girls' Dormitory (Asrama Puteri)
Roof Area (m^2)	519.7821	524.919	528.6636	519.97	429.4238
Runoff coefficient, C	0.85	0.85	0.85	0.85	0.85
Effective catchment area, A_e (m^2)	411.814785	446.18115	449.36406	411.9745	365.01023

3.3 Rainwater Harvesting Estimation

The estimation of harvested rainwater volumes according to **Table 5** demonstrates the potential contribution of rooftop rainwater harvesting to the dormitory water supply at SMK Engkilili. Using the effective roof catchment areas and an annual rainfall of 2908 mm, the calculated harvested rainwater ranged from approximately 955.30 m^3/year to 1,176.08 m^3/year across the selected dormitories. These results highlight the strong influence of rainfall magnitude and catchment area on rainwater yield, as rainwater harvesting potential is fundamentally governed by the interaction between precipitation patterns and available roof surfaces. Previous investigations have similarly reported that harvested rainwater volumes are directly proportional to rainfall depth and roof area, reinforcing the reliability of this estimation approach [28].

Table 5. Size assessment for storage tank requirement.

Harvested Volume	Boys' Dormitory (Asrama Wong)	Boys' Dormitory (Asrama Dhoby)	Boys' Dormitory (Asrama Rentap)	Girls' Dormitory (Asrama Ajibah)	Girls' Dormitory (Asrama Puteri)
Annual, V_{annual} (m^3//year)	1,156.3177	1,167.7453	1,176.0756	1,156.7357	955.3048
Average, V_{day} (L/day)	3,167.99	3,199.3022	3,222.1250	3,169.14	2,617.2734
Total rainwater harvested annually	3,5001386			2,112.0441	
Total rainwater harvested per day	9,589.4172			5,786.4134	

The average daily harvested volumes, ranging between approximately 2,617 L/day and 3,222 L/day, indicate that rooftop runoff can provide a consistent supplementary water source for non-potable uses within institutional buildings. Comparable studies conducted on residential and educational buildings have demonstrated that rooftop rainwater harvesting can produce meaningful water savings and reduce reliance on treated water supplies, particularly in tropical climates characterized by abundant rainfall [29, 26]. Furthermore, analyses of rooftop harvesting performance show that significant proportions of rainfall are typically lost as surface runoff in urban environments, suggesting that harvesting such runoff can enhance water resource efficiency while mitigating drainage losses [29].

Despite these promising yields, comparison with the estimated dormitory water demand indicates that harvested rainwater alone is insufficient to fully meet daily consumption requirements. Similar findings have been reported in institutional rainwater harvesting studies, where rooftop systems were shown to supplement only a fraction of total demand but remain effective in reducing potable water use for secondary applications such as toilet flushing, washing, and cleaning [28]. Consequently, the harvested rainwater obtained in this study confirms the feasibility of rooftop harvesting as a complementary water source rather than a primary supply, while still offering meaningful benefits in improving water sustainability and reducing dependence on municipal water systems.

3.4 Water Demand and Rainwater Harvesting System Feasibility

The evaluation of dormitory water demand provides an important basis for assessing the feasibility of rainwater harvesting as a supplementary supply. Based on the World Health Organization recommended domestic water consumption of 165 L per capita per day, the estimated daily water demand for both the boys' and girls' dormitories, each accommodating 265 students, was calculated at approximately 43,725 L/day. This estimation reflects typical residential water use requirements, including bathing, toilet flushing, laundry, and cleaning activities commonly observed in institutional housing environments. The WHO benchmark is widely applied in water supply planning studies as a representative minimum standard for adequate domestic water provision [30].

When compared with the harvested rainwater yield, a clear disparity between supply and demand is evident. The rooftop rainwater harvesting system for all three of the boys' dormitories produced 9,589.4172 L/day, while the other two girls' dormitories generated 5,786.4134 L/day. These volumes represent only about 6 to 7 % of the total daily water demand for each dormitory. Similar trends have been reported in rainwater harvesting studies conducted in institutional buildings, where rooftop systems were found insufficient to meet full domestic requirements but remained effective in offsetting potable water consumption for non-potable applications [28].

Despite the limited contribution relative to total demand, the harvested rainwater remains valuable for secondary uses such as toilet flushing, floor cleaning, and landscaping, which typically account for a substantial proportion of residential water consumption. Integrating rainwater harvesting as a complementary supply therefore enhances water resource efficiency and reduces dependence on treated municipal water, particularly in tropical regions with consistent rainfall. Consequently, while the harvested rainwater obtained in this study are inadequate to fully satisfy dormitory water demand, their

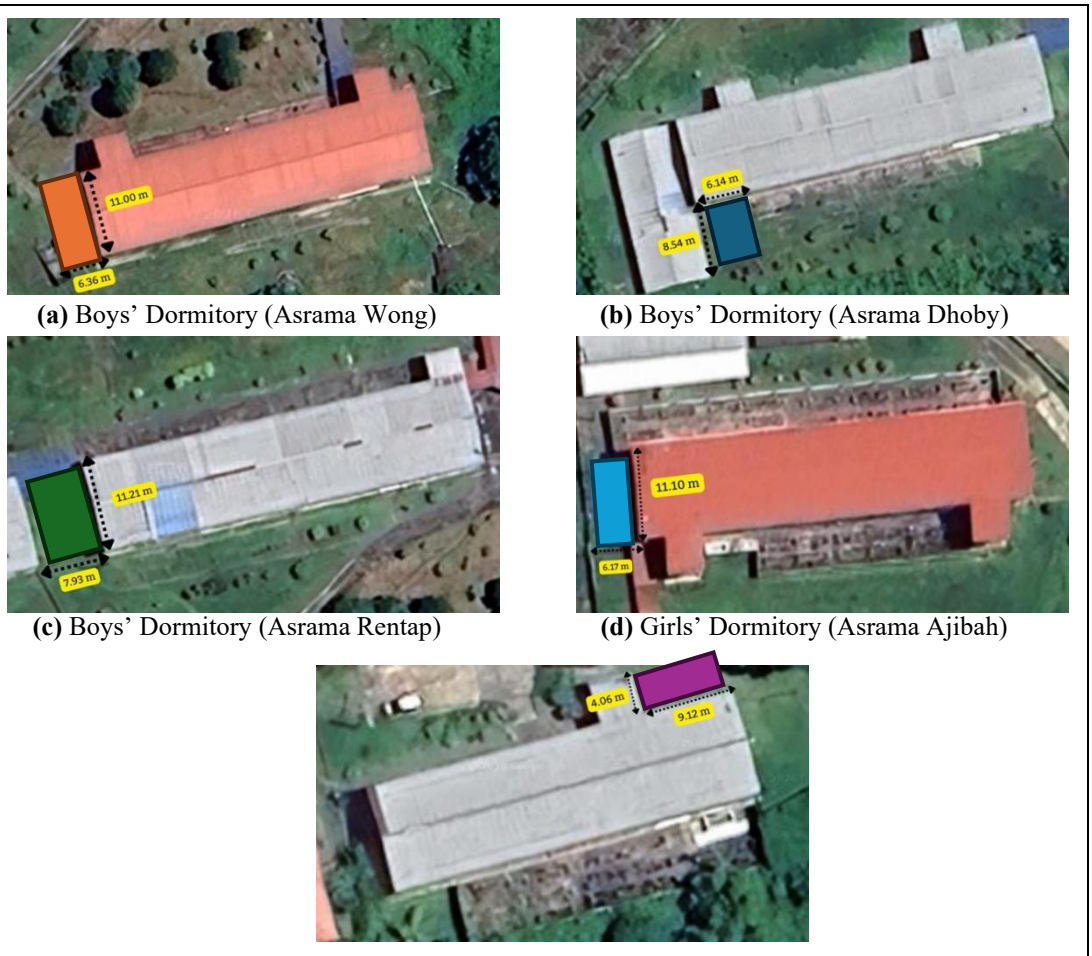
integration into non-potable applications represents a practical and sustainable strategy for improving water management within institutional settings.

3.5 Storage Tank Requirement

Based on **Table 6**, the storage tank requirement was evaluated based on the estimated harvested rainwater volumes and catchment characteristics of each dormitory. As shown in Table 5, different tank capacities were assessed, including 2000 L, 3000 L, and 4000 L configurations. The analysis indicated that using 2000 L tanks would require a larger number of units, with nine tanks needed for the boys' dormitories and five tanks for the girls' dormitories, which may increase installation complexity and space requirements. Conversely, the 4000 L tank option reduced the number of tanks but resulted in oversized storage capacity relative to the daily harvested volumes for certain dormitories. Based on **Figure 5**, the proposed area for tank placement and rainwater harvesting system are shown below.

Table 6. Size assessment for number of storage tanks required.

Tank Storage (L)	Boys' Dormitory (Asrama Wong)	Boys' Dormitory (Asrama Dhoby)	Boys' Dormitory (Asrama Rentap)	Girls' Dormitory (Asrama Ajibah)	Girls' Dormitory (Asrama Puteri)	Total tank needed for Boys' Dormitory	Total tank needed for Girls' Dormitory
2000	3	3	3	3	2	9	5
3000	2	2	2	2	2	6	4
4000	2	2	2	2	1	6	3



(a) Boys' Dormitory (Asrama Wong)

(b) Boys' Dormitory (Asrama Dhoby)

(c) Boys' Dormitory (Asrama Rentap)

(d) Girls' Dormitory (Asrama Ajibah)

(e) Girls' Dormitory (Asrama Puteri)

Figure 5. Proposed Tank Area for SMK Engkilili Students' Dormitory

The 3000 L tank configuration was therefore selected as the most appropriate storage option, requiring six tanks for the boys' dormitories and four tanks for the girls' dormitories. This arrangement provides sufficient storage to capture daily harvested rainwater while maintaining practical installation feasibility and operational flexibility. The use of multiple medium-sized tanks also facilitates easier maintenance, reduces the risk of stagnation, and improves system adaptability during fluctuating rainfall conditions. Consequently, the selected 3000 L storage tank configuration offers a balanced design solution that aligns with both technical requirements and practical implementation considerations for the dormitory rainwater harvesting system.

4. Conclusion

This study analyzes the water quality of harvested rainwater and taps water at SMK Engkilili dormitory. Water Quality Assessment shows showed that the turbidity and TSS levels in rainwater were higher compared to tap water with value of 7 NTU and 31 mg/L respectively, which is higher than the NQWS Class I standards and need for further treatment before it can be used domestically. The roof catchment area for both boys' and girls' dormitories were calculated and the rainwater collected can help to cover about 6% to 7% of the daily needs. Boys' dormitory harvested a total of 3,5001386 m^3 per year rainwater, while girls' dormitory on the other hand harvested 2,112.0441 m^3 per year and each dormitory requires 6 and 4 tanks respectively with the size 3000 L, to store the harvested rainwater.

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Feasibility Study of Rainwater Harvesting as a Sustainable Water Management Strategy at SMK Engkilili Administrative Building (Blok Meranti)

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Abstract

Increasing water demand and occasional supply disruptions highlight the need for sustainable alternative water sources. Rainwater harvesting (RWH) offers a practical solution to support treated municipal water especially for non-potable uses. This study evaluates the feasibility of implementing a rooftop rainwater harvesting system at the Administrative Building (Blok Meranti) of SMK Engkilili. The assessments focus on water quality analysis, roof catchment potential, rainfall yield estimation and storage tank sizing based on Malaysian guideline. Water quality parameters such as turbidity, total dissolved solids, total suspended solid and pH are analyzed and compared with the National Water Quality Standards for Malaysia (NWQS). The harvested rainwater exceeds the Class I of the NWQS limit for turbidity and total suspended solids while being in acceptable range for pH and total dissolved solids. The effective roof catchment is determined with runoff coefficient. Using the annual rainfall for Sri Aman Division, the estimated annual harvested volume is obtained and the suitable storage capacity is proposed to ensure system reliability and accommodate rainfall variability. Overall, the findings indicate that the rooftop rainwater harvesting is technically feasible for non-potable applications if methods like filtration are applied. Therefore, the system can reduce dependence on municipal water and improve sustainability within SMK Engkilili.

Keywords: *Rainwater, Water harvesting, Water quality, Water Sustainability*

1. Introduction

Engkilili in Sarawak has been experiencing prolonged clean water shortages for several weeks prompting calls for immediate action to restore stable supply and ease the difficulties faced by local residence [1]. This situation indicates the need for alternative and decentralized water sources to supplement conventionally treated water supply system and highlight the importance of United Nation Sustainable Development Goal 6 (SDG 6) [13,17,18]. Rainwater harvesting (RWH) is a practical and sustainable solution to reduce dependance on municipal water and promote a more efficient and responsible water resource management [12]. The rainwater harvesting system includes collection, conveyance, storage and reuse of rainwater from rooftop surfaces or other suitable catchment areas for various applications [11]. The performance of the rainwater harvesting system depends on the system design which is influenced by rainfall availability, catchment characteristics, storage capacity and

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system configuration. Proper sizing is essential to ensure operational efficiency, reliability and long-term performance [22].

In Malaysia, water scarcity and intermittent supply disruptions remain persistent challenges, particularly in rural and semi-rural regions [13]. Increasing water demand and occasional supply disruptions highlight the need for more sustainable water management practices [18]. In addition, limited information on the quality and suitability of harvested rainwater in Malaysia [20].

The aim of this study is to evaluate the feasibility of implementing a rainwater harvesting system at the Administrative Building (Block Meranti) of SMK Engkilili. The objectives of this study is (i) to evaluate the water quality parameter of harvested rainwater, (ii) to identify suitable roof catchment areas and (iii) to calculate potential rainwater yield and storage tank requirements based on rainfall and catchment data. The scope of this study is limited to rooftop rainwater harvesting at Blok Meranti of SMK Engkilili. The analysis focuses on the characterization of water quality parameters, evaluating the effective roof catchment area, estimating annual and daily rainwater yield determining the storage requirements. The system is to provide water for non-potable uses such as toilet flushing and gardening.

2. Methodology

This section discussed on **Figure 1** which is the framework of the methodology divided into three stages used in this study.

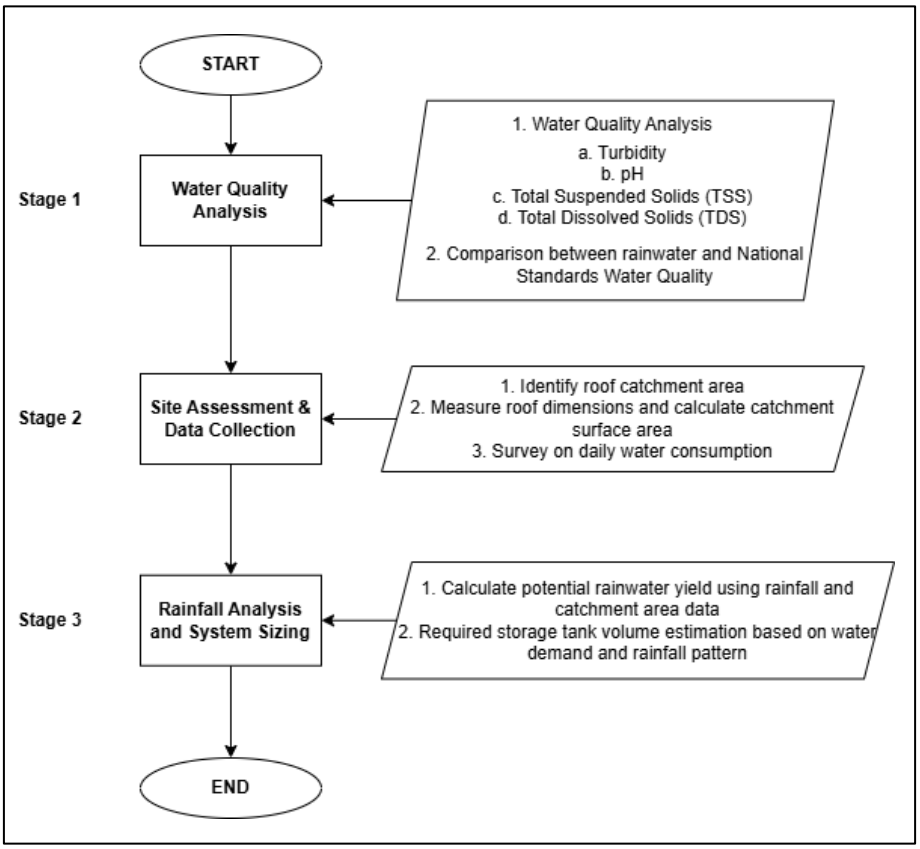


Figure 1. Methodology of Rainwater Harvesting System at Administrative Building at SMK Engkilili

2.1 Water Sampling and Quality Analysis

Rainwater samples are collected at the Administrative Building (Blok Meranti) of SMK Engkilili and tap water samples are collected from the building municipal water tap to serve as reference for water

quality comparison. Four key quality parameters are analyzed such as turbidity, total suspended solids, total dissolved solids and pH. The results for both rainwater and tap water are evaluated against the National Water Quality Standards for Malaysia (NWQS) in **Table 1** to determine compliance classification and suitability for non-potable application.

Table 1. Malaysia National Water Quality Standards for Malaysia [24]

Parameter	Unit	Class					
		I	IIA	IIB	III	IV	V
pH	-	6.5- 8.5	6 - 9	6 - 9	5- 9	5 - 9	-
Total Suspended Solids	mg/L	25	50	50	150	300	300
Turbidity	NTU	5	50	50	-	-	-
Total Dissolved Solids	mg/L	500	1000	-	-	4000	-

Class	Uses
Class I	Water Supply I – No treatment necessary Fishery I – Very sensitive aquatic species
Class IIA	Water Supply II – Conventional treatment required Fishery II – Sensitive aquatic species
Class II B	Recreational use with body contact
Class III	Water Supply III – Extensive treatment required Fishery III – Common economic value and tolerant species; livestock drinking
Class IV	Irrigation
Class V	None of the above

2.2 Roof Catchment Assessment

Figure 2 shows the effective roof catchment area of the the Administrative Building of SMK Engkilili through the physical measurement of building rooftop dimension was determined by using Google Maps. The total effective catchment area is calculated in square meters (m^2) with metal roof surface runoff coefficient was considered to include minor losses due to evaporation, splash and leaking [4].



Figure 2. Location of SMK Engkilili [25]

2.3 Rainfall Data Analysis and Storage Tank Sizing

The roof area of a building can be calculated using **Equation 1.** The annual rainfall for Sri Aman Division is 2908 mm therefore the total volume estimated of rainwater harvested annually can be obtained by **Equation 2** [5, 6].

$$Roof\ Area\ (m^2) = Roof\ length \times Roof\ width \quad \text{.....} \quad \textbf{(1)}$$

$$Rainwater\ Harvested = A_r \times Annual\ rainfall \times Runoff\ Coefficient \quad \text{.....} \quad \textbf{(2)}$$

The storage capacity is determined by **Equation 3** where the tank size in Malaysia regardless of its location is $1m^3$ for roof area of $100m^2$ [24]. This is equivalent to store 10mm of rainfall with 100 m^2 of roof area. The number of storage tanks required is determined by **Equation 4**. The average water consumption annually is determined by **Equation 5**.

$$S_t = 0.01A_r \quad \text{.....} \quad \textbf{(3)}$$

$$No\ of\ Tank\ Required = \frac{Total\ Required\ Storage\ Volume\ (m^3)}{Capacity\ per\ tank\ (m^3)} \quad \text{.....} \quad \textbf{(4)}$$

$$Average\ Water\ Consumption = No\ of\ people \times Water\ consumption \times Day \quad \text{.....} \quad \textbf{(5)}$$

3. Results and Discussion

This section is divided into three sections which are Stage 1 Water Quality Assessment, Stage 2: Size Assessment for Catchment Area and Water Demand, and Stage 3: Rainwater Yield Estimation and Storage Tank Requirement

3.1 Stage 1: Water Quality Assessment

This section discussed the characterization of the rainwater quality. **Table 2** shows the results obtained for the characterization of rainwater and tap water quality analysis and its comparison to the National Water Quality Standards (NWQS) Class I.

Table 2. Characterization of rainwater and tap water quality

Parameters	Rainwater	Tap Water	NWQS Class I
Turbidity	22	0	6.5 to 8.5
Total Supended Solids	28	0	5
pH	7.68	7.14	25
Total Dissolved Solids	19	28	15

The results show clear differences between harvested rainwater and tap water quality. Total Dissolved Solids depicted in **Figure 3 (a)** are low for both sources, with rainwater at 19 mg/L, slightly lower than tap water at 28 mg/L thus indicating minimal mineral content. For **Figure 3 (b)**, the pH values for both rainwater and tap water are 7.68 and 7.14 respectively which fall within the acceptable range, suggesting neutral and stable chemical conditions. Rainwater recorded higher turbidity of 22 NTU in **Figure 3 (c)** and Total Suspended Solids of 28 mg/L in **Figure 3 (d)**, indicating the presence of particles washed from roof surfaces while tap water showed negligible values due to prior treatment.

During dry periods, organic matter such as dust and other environmental pollutants accumulates on the roof surface [13, 20]. When rainfall begins, these particles are washed into the rainwater collection system resulting in higher particles compared to the treated tap water [9]. Total Suspended Solids causes light to scatter and increase turbidity readings and affect the effectiveness of disinfection [10]. Basic treatment methods such as using mesh filters and first-flush diverter can reduce turbidity and total suspended solids [19]. Alkaline rainwater occurs when rainwater contacted the roof surface where it may release trace alkaline constituents that neutralize weak acidity [7, 21]. Maintaining pH within the regulatory range is essential because highly alkaline water promotes scaling and mineral deposition [2]. The near-neutral pH of harvested rainwater indicates conditions that are unlikely to damage storage

tanks, pipes, or plumbing fixtures [20]. The low Total Dissolved Solids in rainwater is expected as precipitation contains minimal dissolved salts prior to surface contact [14]. In contrast, tap water contains higher dissolved solids due to mineral dissolution and treatment processes [3, 23]. High dissolved solid concentrations can lead to scaling, mineral accumulation and increased maintenance frequency [23]. The study shows that the harvested rainwater is proposed for non-potable uses such as cleaning, gardening and toilet flushing thus it does not require to meet drinking water standards [16].

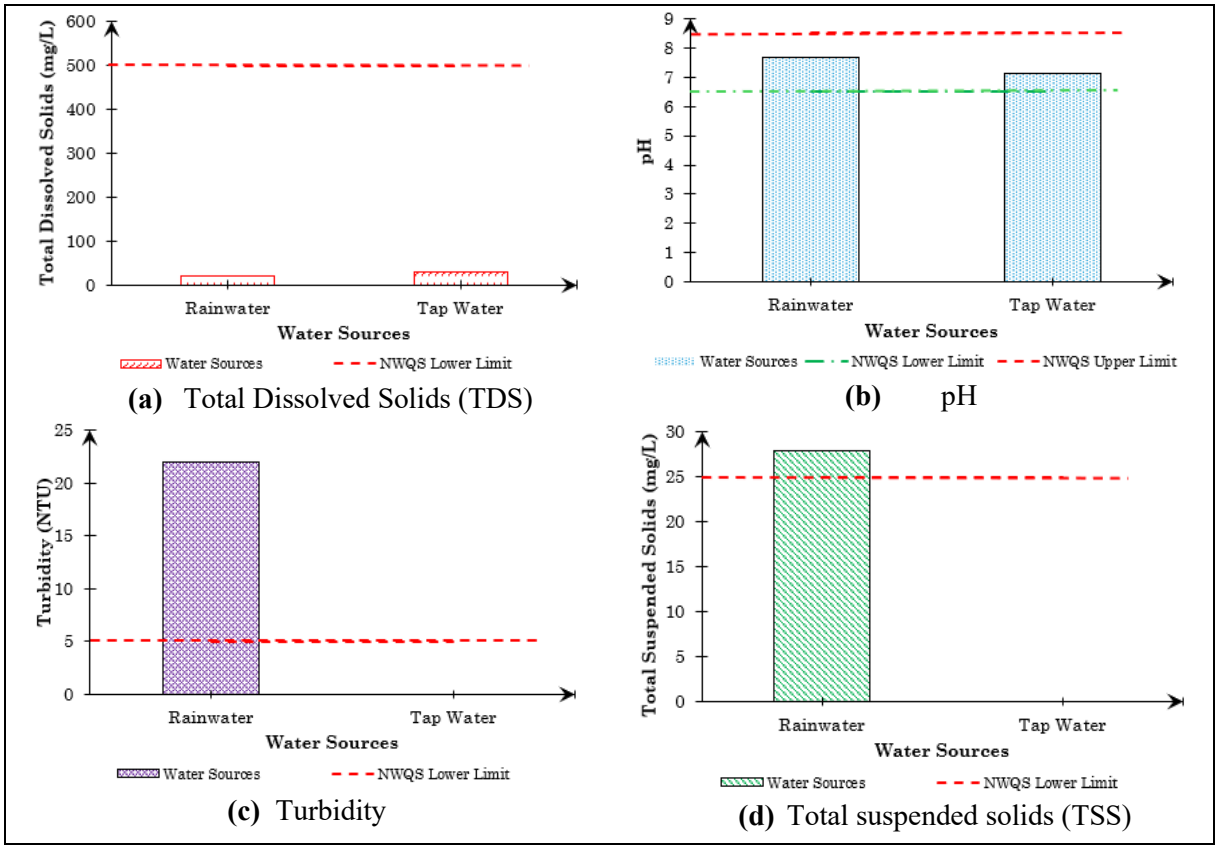


Figure 3. The water quality between rainwater and tap water and its comparison to the Class I limit of NWQS where **(a)** Total Dissolved Solids (TDS), **(b)** pH, **(c)** Turbidity and **(d)** Total Suspended Solids (TSS)

3.2 Stage 2: Size Assessment for Catchment Area and Water Demand

The suitability of the administrative building roof as a rainwater catchment surface was assessed based on its effective collection area, surface characteristic and drainage efficiency. From **Figure 4**, the total effective roof area available for the rainwater collection at Blok Meranti is measured to be 823.284 m^2 with the effective catchment area is 699.791 m^2. **Figure 5** shows the proposed area for rainwater harvesting system at 152.345 m^2. The data is represented by **Table 3** where it shows the size assessment for catchment area and proposed area for the rainwater harvesting system.

Only roof sections capable of efficiently conveying runoff to the guttering system are considered and selected due to their relatively clean runoff compared to the ground level catchments [17]. The roof surfaces help to minimize contamination and the material is metal thus its hard and non-porous demeanor produces high runoff efficiency thus making it suitable for rainwater collection [20]. The system also includes a loss of 10% due to the consideration of factors such as evaporation, splash losses and minor leakage within the conveyance system.



Figure 4. Area of roof for Administrative Building of SMK Engkilili [25]



Figure 5. Proposed area for rainwater harvesting system [25]

Table 3. Size assessment for catchment area

Parameters	Value
Roof Area (m^2)	823.284
Runoff coefficient, C	0.85[5]
Effective catchment area, A_e (m^2)	699.791
Proposed Area for Rainwater Harvesting System (m^2)	152.345

3.3 Stage 3: Rainwater Yield Estimation and Storage Tank Requirement

The potential rainwater yield is estimated using the long-term annual rainfall of 2908 mm for the Sri Aman Division which represents the regional climatic condition. **Table 4** shows the estimated annual harvested rainwater volume is 183,149 L where it leads to an average yield of 5017.791 L per day.

Table 4. Size assessment for storage tank requirement

Harvested Volume	Value (L)
Average, V_{day} (L/day)	5017.791
Annual, V_{annual} (L/year)	183,149

Table 5 shows the estimated of average water consumption at the Block Meranti at SMK Engkilili annually with the assumption where a teacher uses the toilet at least once per day. The average water consumption for toilet flushing of single flush is calculated by using **Equation 5** [26].

Table 5. Average consumption of water at the Administrative Building at SMK Engkilili

Average Consumption	Value
Number of Teachers	94
Number of school days	202
Toilet Usage (L/flush)	9
Total Annual Average Consumption (L/year)	170,892

The annual harvested rainwater volume could accommodate the needs for the average water consumption with 7% extra stored water to be used. The minimum required storage volume calculated is 6,998 L. For practical implementation, commercially available tank sizes were selected as shown in **Table 6**.

Table 6. Size assessment for number of storage tank required

Tank Storage (L)	Number of Tank Required
2000	4
3000	3
4000	2

The following **Figure 5** shows the proposed schematic diagram for rainwater harvesting system that connects the collection system of Blok Meranti to the distribution system of the toilet.

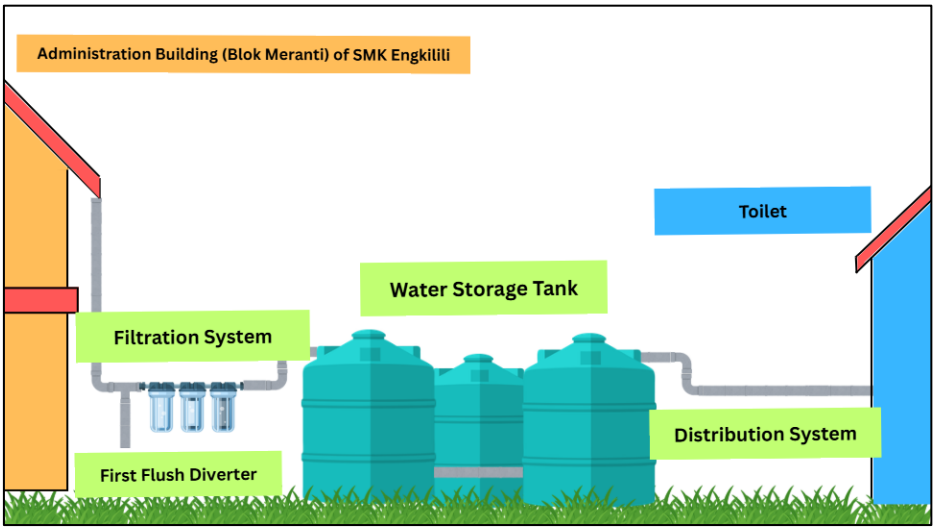


Figure 5. Proposed schematic design for rainwater harvesting system

Three storage tanks with a capacity of 3000 L each are proposed to provide a total storage volume of 9000 L. The selected storage capacity exceeds the minimum design requirement which allows temporary storage of excess runoff during high rainfall season and providing adequate water during dry season [27]. Multiple storage tank reduces the retention time and avoids pollutants from entering the system while single storage tank accumulate particulate matters thus allowing contaminants at outlet at high concentration [8]. Rainwater harvesting system designed by using moderate storage tank ranging from 2000 L to 5000 L could achieve high reliability when the rainfall distribution is consistent throughout the year [15]. Larger storage tanks will increase the capital and operational cost through transportation and maintenance where any leakage or cracks could affect the entire system operation [8]. Therefore, the selected storage capacity represented a balanced design that optimizes space, operational efficiency and cost.

4. Conclusion

This study is conducted to address the need for a sustainable alternative water source despite Malaysia's high annual rainfall and occasional water supply disruptions. The aim is to evaluate the feasibility of implementing a rooftop rainwater harvesting system at Blok Meranti of SMK Engkilili by assessing water quality, catchment potential, rainfall yield, and storage requirements. The methodology involves water quality analysis of turbidity, total suspended solids (TSS), total dissolved solids (TDS), and pH, roof catchment assessment, and rainfall-based yield estimation using Malaysian design guidelines. The results show that while turbidity (22 NTU) and TSS (28 mg/L) slightly exceeded Class I limits of the National Water Quality Standards (NWQS), pH and TDS are within acceptable ranges and the harvested rainwater remains suitable for non-potable uses with simple treatment measures. The estimated annual yield of 183,149 L and proposed 9000 L storage capacity further confirm that the system is technically feasible and capable of supplementing institutional water demand. Overall, the study demonstrates that rooftop rainwater harvesting is a practical and sustainable solution to enhance water management and reduce dependency on treated municipal supply.

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