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Eco-Cycle: Organic Waste Processing and Sustainable Energy Development through Collaborative Institutional Engagement

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Abstract: *Educational institutions generate substantial organic waste, contributing to environmental challenges such as overflowing landfills and methane emissions. Globally, food waste alone accounts for an estimated 8-10% of greenhouse gas emissions, and in Malaysia, nearly 45% of municipal solid waste is organic material. To address these issues, an international community engagement project was implemented as a collaboration between Universitas Muslim Indonesia (UMI) and a higher education institution in Malaysia. The project aimed to develop a sustainable campus waste-management model by converting organic waste into valuable resources (biogas for energy and compost for agriculture) while fostering cross-border academic cooperation. Due to logistical constraints, the program was conducted via virtual platforms, involving webinars, workshops, and digital campaigns that engaged over 60 participants (students, faculty, and staff) from both institutions. The project combined technical planning—such as proposing an anaerobic digestion system for biogas production—with a virtual community outreach approach to educate and involve stakeholders in organic waste management best practices. It serves as a replicable model for other institutions seeking to integrate community engagement with sustainability initiatives. The international collaboration not only advanced knowledge and awareness of organic waste management but also strengthened bilateral ties, demonstrating how virtual engagement can overcome geographical barriers to promote global sustainability goals. The outcomes suggest that with further support, this initiative can evolve into a fully operational waste-to-energy program, exemplifying how universities can act as living laboratories for circular economy practices.*

Keywords: *Campus organic waste, Anaerobic digestion (biogas), Composting, Agriculture, Virtual international collaboration*.

1. Introduction

Organic waste management has become a pressing global concern as growing populations and changing consumption patterns lead to increasing volumes of biodegradable waste [1][2]. Improper disposal of organic waste (food scraps, yard waste, paper, etc.) in landfills results in anaerobic decomposition that produces methane, a greenhouse gas over 25 times more potent than carbon dioxide in warming the atmosphere. The waste sector - including solid waste landfills and wastewater – accounts for roughly 20% of human-related methane emissions worldwide [3]. Addressing organic waste is therefore seen as a crucial strategy for climate change mitigation and sustainable resource management. Notably, food loss and waste are estimated to contribute about 8–10% of total global greenhouse gas emissions [4], underscoring the significant impact that better waste handling can have on environmental outcomes.

In Malaysia, the challenge of organic waste is acute. Malaysian municipal solid waste (MSW) contains an organic fraction as high as 45% [2], the largest component of the waste stream. Much of this organic waste is disposed of in open dumps or landfills, where it decomposes and emits methane, contributing to both local environmental problems and global climate change. Despite growing awareness of the benefits of composting and biogas recovery, a considerable portion of Malaysia's organic waste is still not managed sustainably [5]. This represents missed opportunities for resource recovery and renewable energy generation. For example, landfill gas from organic waste is a potential energy source, and waste-to-energy technologies can help reduce the volume of waste while producing power [6].

Within academic institutions, these issues are manifest in campus operations. University campuses generate significant quantities of organic waste daily from dining halls, residential colleges, research facilities, and landscaping activities [7]. If not properly managed, campus waste can strain local waste management infrastructure and conflict with universities' educational missions to model sustainability. A higher education institution in Malaysia exemplified this situation. As a growing institution with diverse activities, this university was experiencing mounting volumes of food waste and yard clippings. However, prior to this project, most of that organic waste was handled via conventional disposal (landfilling or incineration), due to limited on-site processing capacity. This not only contributed to environmental issues like overflowing waste bins and unpleasant odors, but also meant the campus was foregoing the chance to recover valuable resources contained in the waste. Similar challenges are echoed at many universities worldwide.

In parallel with the waste management challenge, universities are increasingly seen as pivotal players in demonstrating and propagating sustainable practices. The concept of a "green campus" or sustainable campus has gained traction globally in the last decade [8]. Universities have implemented various initiatives—ranging from reducing energy and water use to promoting recycling—in pursuit of sustainability goals [9]. Organic waste management presents an opportunity for campuses to achieve multiple objectives: reducing waste sent to landfills, lowering their carbon footprint, providing hands-on educational experiences, and even generating cost savings or energy for campus use. Anaerobic digestion (AD) and composting are two proven technologies for extracting value from organic waste. AD is a microbial process that breaks down organic matter in the absence of oxygen, yielding biogas (a mixture of methane and CO_2) and a nutrient-rich digestate fertilizer [10]. Composting is the aerobic decomposition of organic matter, resulting in humus-like compost that can enrich soils [11]. Both processes "close the loop "by turning waste into useful products, exemplifying circular economy principles. Many studies have highlighted these benefits: AD can significantly reduce waste volume and produce renewable energy, while compost returns nutrients to the soil and can reduce reliance on chemical fertilizers [12][13].

Yet, implementing such solutions in a campus setting requires not just technical infrastructure, but also community engagement and behavior change. University communities consist of students, faculty, staff, and sometimes residential populations, whose buy-in is essential for programs like waste segregation at source, composting, or operating a biogas unit. Prior experiences show that awareness and education are key to success. For example, universities in Brazil have integrated environmental management topics into daily teaching to spread the concept of sustainability [14]. In China, the development of ecological campuses often begins with technology demonstration projects that double as educational tools [15]. Campuses serve as "small cities" where sustainable innovations can be tested and showcased, influencing broader society [16].

It was against this backdrop that the **"Eco Cycle: Organic Waste Processing and Sustainable Energy Development"** project was conceived. The initiative was a collaboration between Universitas Muslim Indonesia (UMI) - a prominent private university in Makassar, Indonesia - and a higher education institution in Malaysia. The primary goal was to create a model for sustainable organic waste management on campus that would not only reduce waste and generate biogas energy, but also serve as an educational platform for students and a demonstration project for other institutions. Crucially, this project was framed as a community partnership program (in Indonesian terms, a *Program Kemitraan Masyarakat* or PKM) with an international scope, meaning that knowledge exchange and mutual learning between the Indonesian and Malaysian partners were core objectives.

the increasing amount of organic waste generated on its The Eco-Cycle project aimed to integrate three main components: **technology, education, and collaboration.** On the technology side, the project proposed to establish an organic waste processing system combining anaerobic digestion for biogas production and composting for solid residues. By doing so, the campus could treat its food scraps, green waste, and other organics on-site or locally, producing biogas that could potentially be used for cooking in the cafeteria or for electricity generation, and compost to support landscaping or community gardens. Successful examples in literature guided this approach – for instance, a study at an academic campus in India demonstrated that one ton of organic waste can yield about 50 m^3 of biogas (enough to generate ~160 kWh of electricity) and 200 kg of compost. This illustrates the tangible resource value in campus waste streams. On the education side, Eco-Cycle sought to involve students and faculty in the project implementation, offering workshops and hands-on (or in this case, virtual) training in waste auditing, waste separation, and the science of anaerobic digestion and composting. By treating the campus as a "living laboratory" for sustainability, the project aligns with pedagogical approaches that emphasize experiential learning and community engagement in higher education. Finally, on collaboration, the project leveraged the strengths of both UMI and a higher education institution in Malaysia. It was designed to enhance international cooperation, where UMI's expertise in community outreach and Alfa College's local context in Malaysia's sustainability initiatives would complement each other. Such cross-border academic partnerships are increasingly important for tackling global issues like climate change and waste management, as they allow sharing of best practices and create a network of informed change agents.

The timing of the project also presented unique circumstances. Initially planned as an on-site implementation (with physical installation of a biogas digester at a higher education institution in Malaysia), the program had to be adjusted to a fully virtual format. This was largely due to external constraints on travel and in-person gatherings. The COVID-19 pandemic and related restrictions, which persisted into the mid-2020s, had spurred many universities to adapt their community engagement and service-learning projects to online modes. Instead of postponing or cancelling the project, the team pivoted to an online delivery model. This approach aligned with broader trends in 2020–2022 where institutions experimented with virtual community engagement strategies. Researchers have noted that while moving community-university partnerships online can be challenging (due to issues of equitable access, reduced hands-on interaction, etc.), it can still achieve meaningful outcomes if carefully designed. The Eco-Cycle project thus became not only a case study in sustainable waste management, but also an example of how international community engagement can be sustained through virtual platforms.

2. Methods

2.1 Project Design and Technological Approach

The Eco-Cycle project was designed as a campus-based sustainability intervention focusing on organic waste-to-energy conversion. The initial phase of the project involved a thorough assessment of the context at a higher education institution in Malaysia to inform technology selection and planning. A waste audit was conceptualized to quantify and characterize the organic waste generated on campus – including food waste from canteens, green waste from landscape maintenance, and other biodegradable materials. This audit would establish a baseline (e.g., kilograms of organic waste per day) and help identify suitable sites for waste processing facilities. **Anaerobic digestion (AD)** was selected as the core technology for treating the wet, high-moisture organic waste (like food scraps), due to AD's dual benefit of waste reduction and biogas production [17]. The project proposal included plans for a small-scale biogas digester unit capable of handling campus waste. Such a digester would operate in airtight conditions, utilizing microbial activity to break down organic matter and emit biogas (primarily methane). The biogas, in turn, could be captured and used as a renewable energy source – for instance, to generate electricity for campus lighting or to fuel kitchen stoves – thereby substituting a portion of fossil fuel use with clean energy. Meanwhile, the solid by-product of AD (digestate) can be dried or composted to create a nutrient-rich soil amendment. In addition to AD, the project envisioned **composting** of drier organic waste (leaf litter, paper, etc.) and as a backup for any excess digester effluent. Composting is simpler and low-cost, producing organic fertilizer that could be utilized in the university's gardens or donated to local farmers, closing the loop in the nutrient cycle.

The technological approach was informed by examples of similar projects. A case study analysis at the University of Cincinnati (USA) had evaluated a food waste AD project on campus, projecting that about 146 tones/year of food waste could yield enough biogas to replace ~12,767 m^3 of natural gas annually. Although the payback period for that project was estimated at around 6 years, it demonstrated the feasibility and environmental benefit (reducing campus greenhouse gas emissions by over 11 tones CO_2-equivalent per year in that case). Another relevant example comes from campus systems in rural China: Zhu *et al.* (2020) analyzed two biogas-linked campus ecosystems (integrated with farming) and found that such systems can be economically viable if operational costs (especially labor and transportation of waste) are well managed. Their techno-economic analysis indicated that revenue from energy and fertilizer, plus savings from avoided waste disposal, can make small-scale campus AD systems self-sustaining in the long run. These precedents guided the Eco-Cycle project's methodology – emphasizing not just the installation of technology, but also careful planning for operational logistics (waste collection routines, labor responsibilities) and the incorporation of an educational component to ensure sustained engagement and correct usage.

2.2 Virtual Community Engagement Strategy

While the technological blueprint of Eco-Cycle was being formulated, equal attention was given to the **community engagement and educational outreach strategy**. A distinctive aspect of this project was its execution via virtual platforms. This shift to an online format was decided early in the project's timeline due to international travel limitations and campus access restrictions in 2025. Rather than delay the initiative, the team adopted a virtual implementation model, aligning with innovative practices of "virtual community engaged learning" that emerged during the pandemic era.

The engagement strategy was multi-pronged:

Webinars and Expert Talks: The core of the program consisted of a series of webinars jointly hosted by UMI and ACU. These webinars were designed to introduce key concepts and practical knowledge about organic waste processing. For example, a keynote lecture titled *"Sustainable Organic Waste Processing and Renewable Energy Linkages"* was delivered by an expert in waste-to-energy technologies, highlighting how campus waste can be transformed into biogas and compost, and how this contributes to broader sustainability goals. Lecturers from a higher education institution in Malaysia and UMI prepared presentations on topics such as the basics of anaerobic digestion, composting techniques, and case studies of campus sustainability initiatives. By leveraging online meeting platforms (such as Zoom), the project could feature **binational panels** of speakers and reach a broad audience without physical venue constraints.

Virtual Workshops: In addition to lectures, interactive virtual workshops were conducted to simulate practical activities. For instance, one workshop demonstrated household-scale composting methods – the facilitator broadcasted live from a compost setup, showing participants how to layer organic materials, maintain aeration, and identify when compost is ready. Another session provided a virtual tour of a small biogas digester (via video demonstration), explaining its components (feedstock inlet, reactor tank, biogas collection dome, slurry outlet) and operating principles. Participants were encouraged to ask questions and discuss how such a system might be implemented on their own campus or even at home. Breakout discussion sessions were used to allow Indonesian and Malaysian participants to exchange ideas and local experiences, enhancing peer learning.

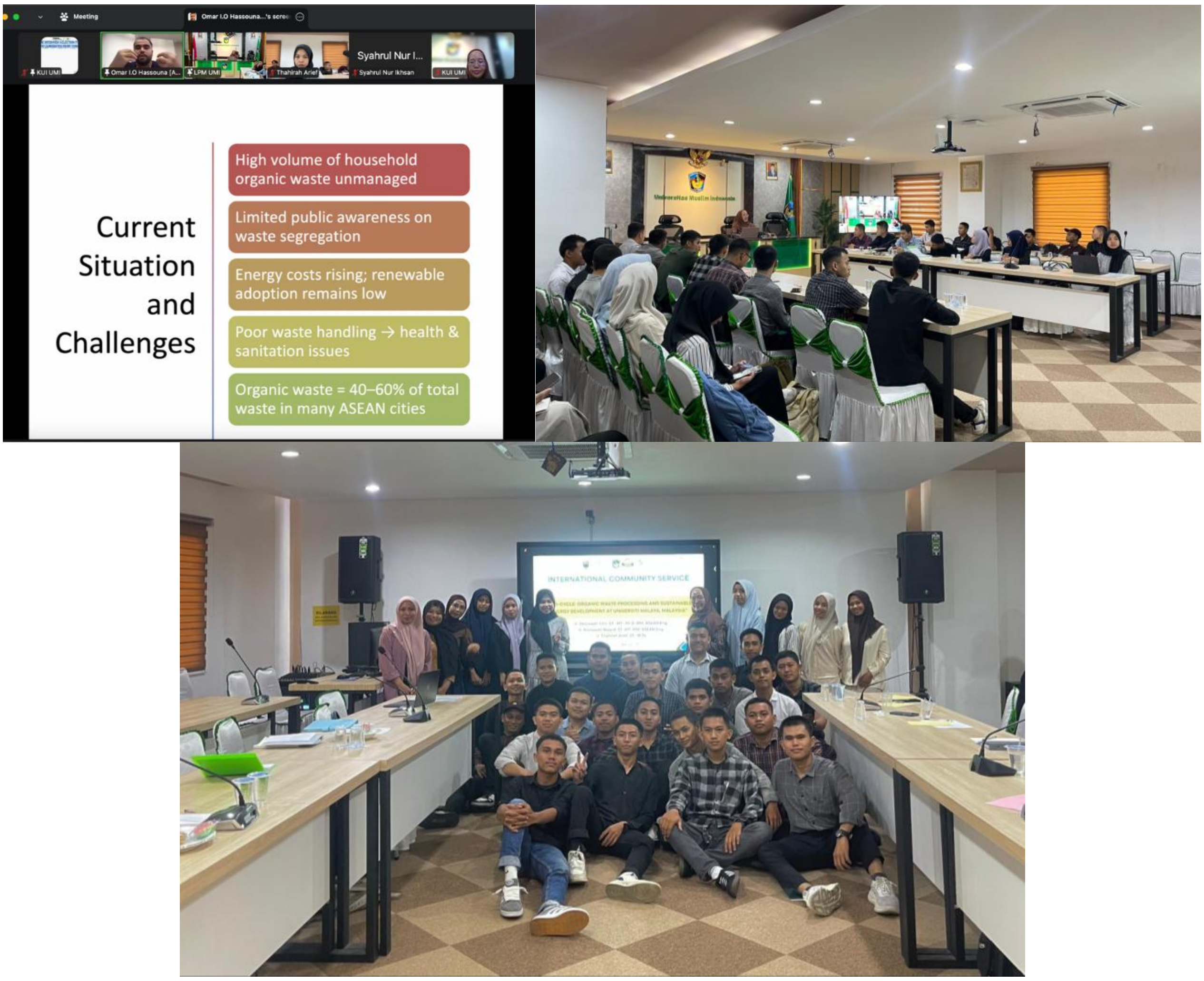

Figure 1. Online socialization UMI and a higher education institution in Malaysia

Digital Campaign and Socialization: To reinforce learning and reach a wider community, the project ran a digital media campaign. Infographics and short video clips were created in bilingual format (Bahasa Indonesia and English) to explain the Eco-Cycle concept and simple actions for sustainable waste management (like separating organic waste). These were disseminated through social media channels and university networks. A dedicated WhatsApp group and a Facebook page were set up for participants and interested stakeholders, where regular tips, quizzes, and updates were posted throughout the project period to sustain engagement. This approach aligns with known strategies in sustainability education that stress continuous engagement and bite-sized learning, even when face-to-face interaction is limited.

Collaborative Tasks: As part of the virtual engagement, participants were invited to partake in collaborative assignments. One such task was a “Waste Audit at Home” exercise: students and staff were guided on how to audit their household or dormitory waste for a week, categorizing how much organic waste they generate. They then shared their data and reflections during a webinar, which helped personalize the issue and allowed comparison of waste generation patterns between Indonesia and Malaysia. Another task was a group project where mixed teams (including members from both universities) designed a mini proposal for improving waste management on their respective campuses, applying the knowledge learned. These proposals were presented in the final webinar session, fostering a sense of active participation and ownership among the participants.

Throughout these activities, an emphasis was placed on bilateral collaboration. All sessions were comodulated by representatives from UMI and ACU. Planning meetings between the two institutions were held weekly via video conference in the month leading up to the event to coordinate agendas, speakers, and technical arrangements. Despite a one-hour time difference and differing academic calendars, the teams synchronized schedules to maximize live participation. Materials and content were also jointly developed – for example, UMI team members created an zoom meeting on composting in Bahasa Indonesia, which ACU team members translated and adapted with local Malaysian context examples. This collaborative content creation ensured that the program was relevant to both locales and that language would not be a barrier to understanding. It also built capacity among the organizers themselves, as they learned from each other's expertise (UMI had prior experience in community outreach projects, while ACU faculty contributed local data and technical insights on Malaysian waste management policies).

To evaluate the effectiveness of the engagement, the project incorporated feedback and assessment mechanisms:

Pre-and Post-Surveys: Attendees were asked to fill a pre-webinar survey gauging their baseline knowledge (e.g., "Do you know how biogas is produced?") and attitudes ("How important is recycling to you personally?"). After the conclusion of the program, a post-survey repeated key questions and added items to measure self-reported learning and intended behavior changes. This allowed the team to quantify knowledge improvement and shifts in perspectives attributable to the program.

Interactive Q&A and Quizzes: During sessions, live polls and quizzes were used (via Zoom polling and Multimeter) to keep the audience engaged and to do on-the-spot assessment of comprehension. For instance, after a segment on anaerobic digestion, a quick quiz asked participants to identify optimal conditions for biogas production (temperature, moisture, C:N ratio, etc.), which over 80% answered correctly – indicating effective knowledge transfer. The Q&A portions also revealed common concerns (some participants asked about odor control in composting, safety of biogas systems, etc.), which were addressed by experts, thereby clearing misconceptions that could be barriers to acceptance.

Follow-up Communication: One metric of success for community engagement is continued interaction even after formal activities end. The project team tracked the activity in the social media groups and email queries received after the workshops, to gauge sustained interest. Indeed, the Facebook page saw a growth in followers over the project duration, and participants from both countries continued to share related news and personal waste reduction efforts – a qualitative indicator of community building.

In summary, the Methods employed in this project blend technical planning for a campus waste-to-energy system with an innovative virtual delivery of community engagement and education. Table 1 provides an overview of key activities and outputs in the implementation process, highlighting the timeline and collaborative nature of each component.

Table 1. Key Implementation Activities of the Eco-Cycle Project (August–November 2025).

Stage (Month 2025)	Activity	Description and Outputs
Stage 1 (August)	Planning & Coordination Meetings	UMI and ACU teams held joint Zoom meetings to plan content, schedule, and roles. Established online platforms (registration forms, social media pages). Output: detailed work plan; outreach materials preparation.
Stage 2 (August)	Material Development	Created bilingual educational materials (slides, infographics, video demos). Tested virtual tools and did a technical run-through. Output: e-booklet on organic waste management. scheduled webinar agenda.
Stage 3	Online	Conducted international webinar "Eco-Cycle: Organic Waste

Stage (Month 2025)	Activity	Description and Outputs
(September)	Socialization & Webinar Sessions	Processing and Renewable Energy for Sustainable Campus Development." Included expert keynote, panel discussions by UMI & ACU lecturers, and interactive Q&A. Output: ~60 participants engaged live; recording available online.
Stage 4 (October)	Virtual Workshop and Digital Campaign	Ran virtual hands-on workshops (composting demo, AD system tour) and launched a month-long social media campaign (weekly challenges, informational posts). Output: high participant interaction; increased social media engagement (share/likes); community building.
Stage 5 (November)	Evaluation and Reporting	Collected post-surveys and feedback. Team analyzed results and compiled project report. Also produced a short highlights video summarizing activity. Prepared a draft academic article for publication. Output: Survey data on knowledge gain; final report; video on YouTube; article submitted to journal.

This systematic approach ensured that, despite being an online program, the Eco-Cycle project was executed with rigor comparable to an on-site intervention. Critical success factors included active coordination between the international partners, the use of engaging digital content to substitute for physical demonstrations, and the integration of evaluation methods to measure impact.

3. Results and Discussion

3.1 Participation and Engagement Outcomes

The Eco-Cycle program successfully attracted a diverse group of participants from both Indonesia and Malaysia, indicating strong interest and reach. In total, the live webinar sessions and workshops were attended by **approximately 70 participants**, exceeding the initial target of 60. These included university lecturers, researchers, undergraduate and graduate students, campus facility staff, and a few members of local communities associated with the institutions. This level of attendance, achieved without the incentive of in-person events, underscores the advantage of virtual formats in breaking down geographical barriers – individuals could join from Makassar, Kuala Lumpur, or elsewhere, as long as they had internet access. Indeed, the online approach enabled participants who might not have been able to travel to a single physical venue to all be present together in the virtual space. This outcome aligns with observations in other virtual community engagement initiatives, where remote formats, when well-organized, can broaden participation and inclusivity.

Engagement during the sessions was high. On average, about 90% of attendees remained for the full duration of each webinar (based on Zoom attendance logs), and the Q&A sessions were lively – moderators often had to manage a queue of questions. Participants from a higher education institution in Malaysia were particularly interested in practical aspects (e.g., "How would a biogas unit be maintained on our campus and who would operate it?"), whereas participants from UMI often brought up questions around community adoption (e.g.,"How do we encourage students to separate their waste properly?"). This mix enriched the discussion and allowed cross-pollination of ideas between the two groups. The collaborative tasks described in the Methods also yielded positive results. The waste audit exercise revealed interesting comparisons: Malaysian participants reported higher proportions of food waste in their bins (likely due to campus cafeteria use), whereas Indonesian participants (including those who lived off-campus) noted significant yard/garden waste. Such differences led to discussions on how solutions might need to be tailored (for instance, composting might handle garden waste well, whereas anaerobic digesters thrive on food waste slurry). The small group proposal presentations at the end showcased the creativity and learning of the teams – proposals ranged from starting a vermicomposting project in student dorms to integrating waste management topics into the curriculum of engineering courses. The enthusiasm and quality of these proposals suggest that the program not only imparted knowledge but also stimulated proactive thinking among participants.

To quantitatively assess knowledge gains, we examine the pre- and post-program survey data. While detailed statistical results are compiled in the project's internal assessment, a summary of key indicators is as follows: Prior to the webinars, only about 40% of respondents could correctly identify anaerobic digestion as a process that produces methane from organic waste; this jumped to 85% in the post-survey. Similarly, when asked to rate their understanding of composting on a 5-point scale (1 = very poor, 5 = very good), the average self-rating rose from 2.8 before the program to 4.3 after. These figures corroborate the participants' self-reported experiences – a majority indicated that they learned "a great deal" about sustainable waste management practices through the program. One specific survey item asked participant to list one practical change they intend to make after the program; common responses included starting to separate organic waste at source, initiating compost piles at home, and advocating for better recycling facilities on campus. This reflects a positive shift towards action-oriented attitudes, which is a desirable outcome for community engagement endeavors.

The improvement in knowledge and awareness is also evidenced by qualitative feedback. For example, a student participant from ACU commented that before the program they were unaware that food waste in landfills produced methane gas and were surprised to learn how much energy could potentially be harnessed from it; they stated they would now support efforts to implement a biogas system on campus. A faculty member from UMI noted that the collaboration itself was enlightening – seeing how Malaysian and Indonesian institutions can jointly tackle environmental problems gave them new ideas for curriculum development and research (such as comparative studies on waste composition). These testimonials illustrate the **academic enrichment** dimension of the outcomes: beyond facts and figures, the project broadened participants' perspectives on international cooperation and interdisciplinary approaches to sustainability.

One of the notable results of the Eco-Cycle project is its contribution to **institutional partnership and reputation**. The successful execution of a collaborative program, even if virtual, has strengthened the ties between UMI and a higher education institution in Malaysia. Administrators from both sides acknowledged that this PKM (community service) initiative has opened doors for future joint projects – discussions are already underway to perhaps pursue funding for a pilot biogas reactor installation at ACU with technical advice from UMI's engineering faculty. In terms of visibility, the project was featured in local media in both countries: a press release was published on an Indonesian news site highlighting "Senior lecturer from UMI successfully conducts community service program in Malaysia," and a Malaysian online portal reported on the "Malaysia's virtual Eco-Cycle program". Such media exposure not only celebrates the achievement but also enhances the public image of the universities as active contributors to sustainability and community well-being. From a reputation standpoint, UMI's profile as a regionally engaged university was bolstered, aligning with its mission to extend impact beyond campus. A higher education institution in Malaysia, on the other hand, positioned itself as a forward-looking institution ready to embrace green innovation – an important narrative as Malaysia, like many countries, pushes its higher education sector towards supporting national sustainability agendas.

3.2 Comparative Analysis with Other Sustainable Campus Initiatives

It is instructive to compare the outcomes and approach of Eco-Cycle with other case studies and research findings on sustainable organic waste management in academic settings. **Table 2** provides a summary of several relevant initiatives and studies from different contexts, highlighting their approaches and key outcomes. This comparative lens helps in understanding the strengths of the Eco-Cycle model and areas for future improvement.

Table 2. Examples of Campus Organic Waste-to-Energy Initiatives in Different Contexts.

Institution (Country)	Initiative Description	Key Outcomes / Findings
A Higher Education Institution in Malaysia & UMI (Malaysia/ Indonesia	*Eco-Cycle virtual community engagement program:* joint webinars and workshops on organic waste management; proposed AD & composting system (2025).	~70 participants engaged online; significant increase in waste management knowledge; produced digital learning resources; established international partnership as a model for cross border sustainability education.
Dilla University (Ethiopia) [18][19].	*Biogas production experiment:* Co digestion of campus food waste with cow manure and other organics in lab-scale digesters (60-day trial).	Co-digestion improved biogas yield and waste reduction compared to single-feedstock digestion. Recommended scaling up the optimized mix to a pilot biogas plant on campus for educational demonstration; highlighted need for on-site training in AD technology.
FJZ & XDZ Rural Schools (China)	*Integrated eco-campus biogas systems:* Small scale AD units integrated with school farming activities (breeding biogas-planting system); Techno-economic case study (2020).	Both systems produced renewable energy and reduced waste: economic analysis showed controlling labor and transport costs is crucial. One school's system achieved higher net present value after accounting for savings from waste disposal avoidance. Demonstrated viability of biogas systems in rural campus settings and served as a sustainability showcases for the community.
Univ. of Cincinnati (USA)	*Campus waste-to energy initiative:* Evaluation of converting various campus wastes to energy (including AD of food waste) – feasibility study (2015).	Food waste AD could generate ~12,800 m³ biogas/ year, replacing natural gas and cutting ~11.4 tones CO_2-eq emissions annually. Payback period for a campus digester was ~74 months. Emphasized a multi-pronged approach (biodiesel from waste cooking oil, fuel pellets from paper waste) to maximize waste-to-energy impact on campus sustainability.

Several insights emerge from the above comparisons. First, the **educational dimension** is a common thread. Whether it's a virtual program like Eco-Cycle or a physical pilot plant in Ethiopia, the impetus often includes using the project as a training and demonstration tool. The other University case explicitly mentions the plan to use a scaled-up biogas plant for education and community demonstration. This resonates with the Eco-Cycle outcome where even without a physical plant, the program created a "digital learning legacy– materials and videos that can be reused in classes or future training. In terms of pure knowledge gain, a virtual program can hold its own: while a hands-on project offers tactile learning, a well-designed virtual curriculum can cover the theoretical and awareness aspects effectively, as evidenced by the strong knowledge improvements recorded in Eco-Cycle's surveys.

Second, the **technical viability and impact** of campus biogas systems is supported by multiple sources. The University of Cincinnati study and the Chinese cases both show that significant energy can be generated from campus organic waste. Wang *et al.* (2023) further broadened this perspective by estimating that across China's 2344 universities, campus canteen waste could generate on the order of 10^8 cubic meters of biomethane per year [20]. This points to a vast untapped potential in the campus sector globally for contributing to renewable energy production and emissions reduction. If a higher education institution in Malaysia were to implement the Eco-Cycle system physically, these studies suggest the returns could be meaningful. For instance, if ACU generates, say, 150–200 tons of food waste per year (a figure plausible for a medium-sized campus), a biogas system could produce on the order of 10^4 m³ of biogas annually (using Cincinnati's ratio as a rough proxy. This could offset a portion of the campus's LPG or natural gas use, contributing to energy cost savings and lower carbon footprint. Additionally, a few hundred kilograms of compost per week could be produced, potentially replacing purchased fertilizers for campus landscaping, or supporting urban farming projects in the community.

However, **implementation challenges** should not be underestimated. The Eco-Cycle project in its current phase avoided many practical hurdles by being virtual. If it moves to installation, it will need to consider issues such as regulatory approvals (installing a digester may require safety inspections), operational management (who will run the digester daily and feed it with waste), and maintenance (handling of digestate, prevention of odors or pests, etc.). The rural China case study by Zhu *et al.* highlights that even when technology works, the economics can be sensitive to operational costs. In a university context, this might translate to the need for either dedicated staff or integration with academic programs (e.g., students running the system as part of internships or coursework) to keep labor costs low and engagement high. Another constraint is space – many urban campuses (like a higher education institution in Malaysia, which is in an urban setting) have limited room for waste processing facilities. The Chinese analysis noted that urban schools might struggle to allocate space for ecological facilities due to land scarcity. Innovative solutions, such as compact digesters, or locating the facility off-campus at a nearby waste center, might be considered. These discussions were in fact initiated during the Eco-Cycle webinars: ACU facility managers expressed concern about space and suggested possibly using a corner of the cafeteria's service area for a small digester, while others mentioned partnering with the city to treat campus waste in a municipal digester.

One unique aspect of Eco-Cycle is the **international collaboration and virtual execution**, which is not directly paralleled in the other case studies listed. Most documented projects involve a single campus or local community. The success of Eco-Cycle's cross-border model serves as a proof-of-concept for virtual international community service programs. It demonstrates that meaningful outcomes – such as increased environmental literacy and even tangible outputs like publications – can be achieved without in person interaction. This is particularly encouraging for universities seeking to internationalize their community engagement or serve regions beyond their immediate vicinity. A 2022 study by Knifed and Choe-Smith discusses how the pandemic forced community-engaged learning to go virtual and suggests lessons for ensuring mutual benefit in such partnerships. The Eco-Cycle project contributes to this emerging body of practice by providing a concrete example in the sustainability domain. One lesson learned was the importance of active facilitation: unlike physical workshops where materials and hands-on activities naturally keep participants busy, virtual sessions require constant stimulation (via polls, questions, visuals) to prevent drop-off in attention. The Eco-Cycle team's efforts in this regard paid off in maintaining high engagement. Another insight is that some activities are harder to replace virtually – for instance, participants could not physically build a compost pile or inspect a digester's components with their own hands. This limitation was noted by some participants who felt they would need a future on-site session to feel fully confident in the techniques. To address this, the team recommended in its report that when conditions allow, a follow-up physical workshop be organized at ACU where UMI experts could travel to Malaysia (or vice versa) to conduct live demonstrations. In essence, the virtual format was an excellent catalyst and enabler under the circumstances, but hybrid models might be ideal initial virtual education followed by optional in-person practice for a core group of implementers.

3.3 Environmental and Social Impacts

While the Eco-Cycle project was primarily educational in this phase, it aimed to indirectly drive environmental and social impacts on campus. There are early indications of positive change. For example, after the program, the higher education institution in Malaysia cafeteria management reported that more students were inquiring about proper waste bins for organics and whether composting could be done with dining scraps. This anecdotal evidence suggests that the awareness raised is translating into increased demand for sustainable practices. If the university administration responds by, say, placing separate bins for food waste and arranging for their composting or digestion, the immediate environmental impact would be a reduction in waste sent to landfill. Even a modest pilot could divert a few tonnes of waste and prevent methane emissions. In the long run, the project's biggest environmental benefit may be its role in advocating for and laying groundwork towards a campus that manages its waste sustainably – a steppingstone to a "zero organic waste" campus goal, which some universities (like the case of a campus housing 350 families in India) have pursued through intensive segregation and treatment programs.

From a social perspective, Eco-Cycle contributed to community empowerment and collaboration. Students from UMI and ACU formed networks that can continue to share sustainability ideas. Such peer networks are invaluable; they often lead to student-led initiatives, environmental clubs, or joint research projects. The project explicitly emphasized the theme of a circular economy and community responsibility, framing waste not as someone else's problem but as a collective responsibility and a resource to harness. Participants resonated with this message the post-event feedback included comments like "I've started teaching my family about separating organic waste for compost" and "This program made me realize that small actions, like what we do with our cafeteria leftovers, matter." These attitude shifts, though intangible, are critical in seeding a culture of sustainability. They align with the concept that universities should instill not only knowledge in students but also values and habits that they carry into their future workplaces and homes.

The bilateral nature of the project also had a positive social impact by fostering cross-cultural understanding and solidarity in addressing environmental issues. In a time when travel and face-to-face exchange were limited, students in Indonesia and Malaysia could interact and learn about each other's contexts. It became apparent through discussions that while local conditions differ (for instance, waste regulations and infrastructure in Malaysia are somewhat more developed than in parts of Indonesia, whereas community-led initiatives in Indonesia can be very strong), the fundamental challenges of sustainability are shared. This realization builds empathy and a sense of global citizenship among participants – a valuable outcome consistent with the objectives of international education and engagement.

The outreach program engaged approximately 70 participants through online delivery, encompassing audiences from academic institutions and community groups. Across the two scheduled sessions, participant retention remained notably high, with Zoom analytics indicating that around 90% of attendees remained connected for the entirety of each event. The interaction levels were substantial, as evidenced by the volume of questions submitted during the discussion segments, which frequently required moderated queuing. To enhance broader accessibility, the program produced a suite of digital learning materials—including slide presentations, informational summaries, and full-session recordings—which were made available for continued use. The initiative also facilitated the establishment of a cross-national collaboration involving two partner institutions from two countries, enabling coordinated preparation of educational content and harmonized messaging on sustainability themes.

Quantitative evidence from pre- and post-program surveys indicates measurable improvements in participant knowledge. Prior to the sessions, only 40% of respondents correctly identified anaerobic digestion as a biological process that generates methane from organic waste; this proportion increased to 85% following program completion. Participants' self-assessed understanding of composting, rose from an average of 2.8 before the program to 4.3 afterward. A substantial share of respondents reported acquiring significant new insights related to sustainable waste management. When prompted to indicate one practical behavioral change they intended to adopt, common responses included implementing source-level separation of organic waste, initiating household composting practices, and advocating for improved recycling facilities within their institutions. Collectively, these metrics demonstrate not only enhanced knowledge but also a positive shift toward pro-environmental behavioral intentions.

3.4 Challenges and Lessons Learned

Despite the many successes, the Eco-Cycle project encountered challenges that offer lessons for future implementations:

1. Technical Hurdles in Virtual Delivery: As anticipated, there were occasional technical issues during the online sessions, such as unstable internet connections causing some participants (especially those in remote areas) to drop out temporarily. The organizers mitigated this by recording all sessions and sharing the recordings promptly, so those who missed parts could catch up. Additionally, slides and resource packs were emailed in advance so that even if someone's video feed froze, they could follow along with the materials offline. The lesson here is the importance of backup plans and ensuring content accessibility in varying bandwidth scenarios.
2. Time Zone and Scheduling: Coordinating live events across countries required careful timing. The team chose times that fell within work hours in both countries, but for some participants, this overlapped with other responsibilities. A few participants from UMI noted they had to juggle class schedules to attend. Flexibility (such as offering two repeat sessions or staggered timings) could be explored in the future to maximize live participation. In this project, one compromise was to keep sessions concise (no more than 2 hours at a time) and schedule them on weekends when possible.
3. Lack of Hands-on Practice: As mentioned, the inability to conduct physical demonstrations or site visits was a limitation. Although virtual tours provide useful visual exposure, they do not offer the level of experiential learning afforded by physically interacting with or directly observing a functioning system. To address this, the project team in their follow-up plans included a recommendation for establishing a mini demonstration corner at a higher education institution in Malaysia – perhaps a small compost bin or a transparent model of a biogas digester that can be used in future in-person workshops for students. Even a modest investment in such a tangible element can greatly enhance understanding and retention of knowledge for participants who are more kinesthetic learners.

Building on this limitation, the project team has incorporated a more concrete follow-up plan to enhance future implementations. In collaboration with partner institutions, the team has initiated discussions on developing a small-scale demonstration biogas digester on campus. This unit is intended to serve as a practical teaching tool that complements the theoretical content delivered through the socialization sessions. The installation would allow students and community participants to observe the anaerobic digestion process in real time, thereby strengthening experiential learning and supporting the long-term sustainability of the Eco-Cycle initiative.

Sustaining Momentum: After the flurry of activity during the project months, a challenge is maintaining the momentum. Participants may move on to other things, and without continued engagement, the initial enthusiasm could wane. The Eco-Cycle team tried to counter this by creating enduring outputs: the YouTube video that encapsulates the program can continue to inspire viewers; the educational materials were made open-access so other instructors or student clubs could use them; and, importantly, an article (such as this one) was prepared to disseminate the experience to a wider academic audience. By documenting and publishing the results, the project not only shares knowledge but also holds the institutions accountable to their commitments (since it is now on record). Another step being taken is to integrate some content from Eco-Cycle into UMI's and ACU's academic curriculum (for example, a module on "campus sustainability" in an environmental engineering course), thereby keeping the topic alive year after year.

In reflecting on these results and challenges, it becomes clear that the Eco-Cycle initiative achieved more than just the sum of its parts. It delivered immediate educational benefits and started a ripple of longer-term change. It joined a growing number of university-led projects proving that campuses can be testbeds for sustainability solutions that marry technical innovation with community engagement. For a higher education institution in Malaysia, this project is a steppingstone toward becoming a greener campus – one that not only teaches sustainability but *practices* it. For Universitas Muslim Indonesia, it demonstrates the impact of extending their community service ethos beyond national borders, enhancing their experience and reputation in international collaboration.

Finally, the project contributes to broader objectives such as the United Nations Sustainable Development Goals (SDGs). By focusing on waste reduction, renewable energy (biogas), and partnerships, Eco-Cycle touches on SDG 7 (Affordable and Clean Energy), SDG 11 (Sustainable Cities and Communities), and SDG 12 (Responsible Consumption and Production). It provides a concrete example of how institutions of higher education can participate in achieving these goals through community-engaged initiatives. The replicability of the Eco-Cycle model means that other universities – particularly those in developing countries where organic waste is abundant and often problematic – can draw lessons and adapt similar programs. Whether entirely virtual, entirely on-site, or a hybrid of the two, the critical elements will likely remain: a clear focus on turning waste into a resource, active involvement of the campus population in the solution, and collaboration (be it interdisciplinary, institutional, or international) to broaden the impact.

4. Conclusion

In concluding, we emphasize that the Eco-Cycle project was as much about people as it was about technology. One of the overriding lessons is that sustainable solutions in waste management require an integrated approach: the best technology will not sustain itself without an informed and motivated community, and conversely, an educated community can be hamstrung without viable technical options to implement. The project's success stemmed from addressing both dimensions concurrently - educating the community while plotting a technical path forward. This holistic approach is recommended for any institution aiming to transition to sustainable operations. Developing a feasibility study for installing a small-scale anaerobic digester at a higher education institution in Malaysia, using data gathered and the interest generated to support administrative decision-making. Expertise from UMI and possibly other local universities will be sought to ensure a sound design. Continuing the virtual exchange in the form of a "Green Campus Forum" between UMI and ACU, perhaps expanded to include additional universities in Southeast Asia. This forum can meet periodically online to share progress, challenges, and new ideas on campus sustainability projects (creating a community of practice). Integrating the learnings into curricula: for example, introducing project-based learning assignments where students audit waste or design mini biogas systems as part of their coursework, thereby institutionalizing what was initially an extracurricular activity. - Measuring long-term impact: conducting follow-up surveys or interviews a year down the line to see if participants have maintained the behaviors and initiatives sparked by the program. This will help in understanding the durability of impact from a virtual engagement and guide improvements in program design.

In summary, the Eco-Cycle initiative demonstrates that with collaborative spirit and adaptive strategies, universities can turn environmental challenges into educational and societal opportunities. By harnessing organic waste for energy and learning, and by linking communities across borders in the quest for sustainability, the project contributes a small but noteworthy step toward more sustainable and connected campuses. We conclude that the model is highly relevant in today's context and recommend its adoption and adaptation in other settings. The authors hope that this detailed account encourages and informs similar endeavors, ultimately advancing the role of higher education institutions as leaders in community engagement and environmental sustainability.

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