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Towards a greener future and innovating solid waste management in higher education institutions: A review

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Abstract

Higher education institutions (HEIs) are becoming key players in promoting sustainable practices within their communities, often by embracing the "green university" concept. This review explores how HEIs manage solid waste, using methods that aim to reduce waste at the source and promote recycling, resource recovery, and reuse. It focuses particularly on how environmental education influences students' behaviors and raises awareness, helping foster a deeper commitment to sustainability on campuses. While many HEIs have made progress in implementing these strategies, various challenges remain, including limited resources, inadequate infrastructure, and gaps in campus-wide participation. This review provides a perspective by examining these practices within the unique context of HEIs and highlights the potential of integrated solid waste management (ISWM) to advance sustainability. Additionally, it identifies specific areas for improvement and emphasizes the important role of HEIs in shaping environmentally conscious individuals. Practical recommendations are offered to support HEIs in strengthening their waste management efforts, helping these institutions lead the way in environmental responsibility and instilling a culture of sustainability among students, faculty, and staff.

Keywords: Campus sustainability, Circular economy in HEIs, Environmental education, Student awareness, Waste reduction strategies.

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1. Introduction

Over the past few decades, the desire to protect the environment and preserve the earth's resources has significantly increased [1, 2]. Global awareness of sustainability practices has been influenced by concerns about the growing human population and the impacts of social structures, economic trends, and environmental changes [3]. Despite widespread knowledge and application of sustainable development (SD) practices by individuals and organizations worldwide, developing nations have shown low levels of awareness and action in preserving and sustaining natural resources [4]. In the Arab world, recent research has revealed a notable deficiency in sustainability knowledge, largely due to a prevailing focus on war and conflict. This focus has led to a troubling erosion of social, economic, and environmental sustainability, contributing to a broader state of systemic instability [5, 6]. The resolution of prevalent environmental issues, such as the risk of ecosystem collapse, requires substantial public investment. However, securing widespread public support for this investment depends on a comprehensive understanding of the issues at hand. Increased awareness is crucial for enhancing community backing for initiatives that address and mitigate these environmental challenges [7].

Numerous previous studies have focused on household attitudes toward waste reduction [8], intentions to minimize waste [9], composting behaviors [10], recycling attitudes [11], recycling intentions [12], and general waste behaviors [13]. While some research has explored solid waste management (SWM) values, there is a noticeable gap concerning the specific SWM values that influence behavior among college students. Investigating these values is crucial, as college students play multifaceted roles as academic pioneers, entrepreneurs, and consumers. Their behaviors and choices not only shape their immediate environment but also set a significant benchmark for others to follow. Therefore, further exploration of SWM values within this demographic is essential for a comprehensive understanding and effective implementation of sustainable waste management practices [14].

Due to their size, high population densities, and variety of domestic and scientific activities, university campuses are often referred to as "small cities." These campuses should integrate sustainability concepts into their operations and systems, serving as environments for hands-on learning and functioning as active laboratories [15]. Given the ethical and legal responsibilities of education concerning environmental stewardship, universities should proactively implement sustainable management strategies to fulfill their obligations and contribute to a more environmentally conscious future [16].

The novelty of this review lies in its comprehensive exploration of the intersection between sustainability, solid waste management, and higher education. While existing literature has addressed these topics individually, this review synthesizes and connects these areas to provide a holistic understanding. Additionally, it uniquely examines the specific influence of student knowledge, environmental education, and behavior on solid waste management awareness. The identification of gaps in current sustainable waste management practices within universities and the discussion of challenges in their implementation further enhance the distinctiveness of this work. By concluding with actionable recommendations for future initiatives, this review not only consolidates existing knowledge but also serves as a guide for advancing sustainable practices in higher education institutions [17]. The importance of this review can be clearly evidenced through the significant number of publications spanning from 2000 to 2023 as shown in Figure 1. Over the past two decades, the topic has gained increasing attention in the academic community, resulting in a substantial body of research that explores various aspects and implications. This surge in publications reflects the growing recognition of its relevance, as researchers aim to address emerging challenges, explore new methodologies, and refine existing theories.

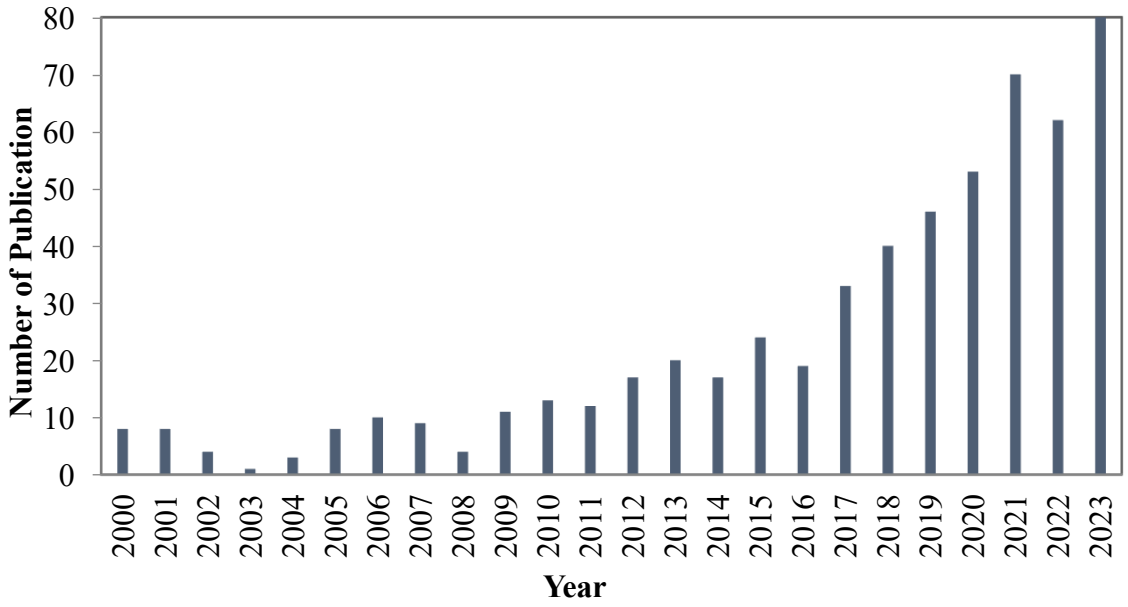

Figure 1.
Publication trends for the student awareness of SWM in HEIs based on Scopus.

The review is organized into several sections for a comprehensive exploration of sustainability and solid waste management in higher education. Section 2 focuses on the principles of sustainability and green initiatives within university settings. In Section 3, attention is turned to a critical examination of the solid waste generated on university campuses. Campus waste management practices are discussed in Section 4. Section 5 delves into the influence of student knowledge, environmental education, and behavior on their awareness of solid waste management and recycling practices. The review then moves on to address existing gaps in sustainable waste management within universities in Section 6, followed by a scrutiny of challenges associated with practical implementation in Section 7. Finally, the concluding section not only summarizes key findings but also presents recommendations for future actions aimed at enhancing student awareness and fostering sustainable solid waste management practices in higher education institutions.

2. Green Campus Initiatives

While the commission on SD defines sustainable development as "the development that meets the needs of the current world population without compromising the needs of the world's population in the future [18], sustainability is primarily concerned with the condition of Earth's biophysical environment and the responsible use of natural resources [1]. However, many perceive the term "sustainability" as complex, and there is a lack of consensus among environmental, economic, and societal viewpoints regarding its causes, effects, roles, and strategies. Through knowledge-sharing, the concept of SD is promoted to underscore the importance of achieving a balance between the environment, the economy, and society. HEIs play a pivotal role in this process by bridging scientific understanding with practical application and common sense. They serve as key players in advocating for and advancing sustainable practices across various sectors [19].

The focus on sustainability within college campuses has garnered global attention, particularly with the increasing influence of the pro-sustainability movement [20]. To advance SD, HEIs are establishing Green Campus Initiatives (GCIs). These initiatives are aimed at creating sustainable infrastructure, reducing negative environmental impacts and financial expenses, and educating students about the principles of SD [21, 22].

HEIs are recognized as hubs for cultivating future leaders capable of communicating principles of sustainable management to stakeholders and decision-makers [23]. Motivating faculty, staff, and students to embrace sustainability's core principles and adapt their daily behaviors is crucial to advancing sustainability goals and initiatives. Through such engagement, students can emerge as advocates for the most effective sustainability initiatives [24, 25].

The objective of green campus initiatives is to reduce the carbon footprint of higher education institutions while increasing student knowledge and attitudes toward sustainability. College campuses serve as active laboratories, providing numerous opportunities to promote sustainable education and awareness. In this context, the adoption of an environmental management system within higher education, often termed "greening," represents a comprehensive approach aimed at educating the next generation of societal leaders about environmental stewardship. Universities must capitalize on sustainability projects to meet the demand for student training, recognizing them as fundamental to the education of future leaders [26].

The green campus concept aims to address both engineering facets, such as water treatment, waste treatment, and air pollution control, as well as individual aspects, including fostering a laissez-faire attitude towards sustainability [27]. Green campus assessment tools for higher education typically encompass evaluations in site and planning management, energy efficiency, waste management, water efficiency and conservation, sustainable transportation, material and resource management, indoor environmental quality, green innovation, and green education. By prioritizing these key areas, we aim to develop targeted interventions and solutions that can effectively advance the sustainability agenda within higher education institutions [28].

Table 1.
Comprehensive classification of solid waste types (adopted from [29]).

Category	Type of Waste	Characteristics	Examples
Clinical Waste	Waste from healthcare facilities	May be infectious or hazardous	Medical instruments, blood waste
Domestic Waste	Waste from residential areas	Biodegradable and non-biodegradable	Food scraps, plastic packaging
Agricultural Waste	Waste from farming and animal husbandry	Biodegradable	Crop residues, animal waste
Industrial Waste	Waste from manufacturing and construction sites	Can be toxic or combustible	Metal scrap, chemical byproducts
Nuclear Waste	Waste from nuclear facilities	Radioactive and hazardous	Spent fuel rods
Electronic Waste	Waste from electronic devices	Contains toxic materials	Old computers, mobile phones
Hazardous Waste	Waste with harmful chemical properties	Toxic, flammable	Chemicals, batteries
Recyclable Waste	Waste that can be processed and reuse	Non-biodegradable	Paper, glass, plastics
Non-Recyclable Waste	Waste that cannot be reused	Non-biodegradable	Certain plastics, metal waste

3. Solid Waste

Solid waste can be systematically categorized based on various criteria, including origin, physical state, and inherent properties. As shown in Table 1, solid waste includes several categories.

Furthermore, solid waste can be distinguished by its material composition, falling into categories of solid, liquid, or gaseous states. Additionally, it can be further classified based on specific characteristics, such as being inert, toxic, combustible, biodegradable, or carcinogenic. It is important to note that many types of waste may exhibit characteristics that place them into multiple subcategories simultaneously. For instance, plastic waste, commonly encountered in various sectors including domestic, commercial, and industrial settings, is predominantly non-biodegradable, underscoring its enduring environmental impact. This systematic classification of solid waste serves to facilitate effective waste management strategies tailored to the unique properties and challenges posed by different waste types. By understanding the diverse nature of solid waste and its various classifications, stakeholders can devise targeted approaches for waste reduction, recycling, and disposal, ultimately contributing to more sustainable environmental practices [29]. Traditionally, sustainable waste management involves establishing infrastructure, tools, technologies, and practices to create a sustainable system. Guided by ISWM principles, every plan must encompass strategies like waste prevention, reduction, reuse, recycling, anaerobic fermentation, and proper disposal. These principles ensure consideration of environmental, economic, and social factors unique to each location [30-33]. The effectiveness of ISWM in HEIs is well-supported by both case studies and quantitative data. One significant example comes from the Middle East Technical University (METU) in Turkey, where a comprehensive ISWM strategy led to measurable improvements in waste management. Through targeted recycling programs and waste reduction initiatives, METU reported significant increases in recycling rates alongside a noticeable reduction in waste sent to landfills, highlighting the practical impact of a well-coordinated ISWM approach [5]. Similarly, studies conducted at Chinese universities have demonstrated how ISWM initiatives, when combined with educational campaigns, can positively influence student behaviors toward waste sorting and recycling. For instance, a survey among university students revealed that ISWM programs enhanced their participation in recycling activities, ultimately reducing campus waste generation. Such findings underscore the importance of integrating educational elements within ISWM frameworks to foster sustainable practices among students [34]. In developing regions, empirical data also support the value of ISWM. The University of Lagos in Nigeria, for instance, conducted a detailed waste characterization study as part of its ISWM implementation. This study not only provided essential data on waste types and volumes but also helped the university tailor its waste management practices, achieving a marked improvement in resource recovery and reduction of waste [32].

4. HEIs Solid Waste: Characteristics and Management

Characterizing campus waste is a critical step toward achieving sustainable waste management. By analyzing the composition of waste generated on university grounds, institutions can develop targeted strategies for recycling, reduction, and reuse [35]. Paper waste typically originates from lecture halls, offices, and photocopy centers, while food-related garbage is primarily produced by campus restaurants and dormitories. Additionally, plastic waste is commonly generated in laboratories, markets, and residential areas on campus. This detailed understanding of waste sources enables universities to implement more effective and sustainable waste management practices [36]. Figure 2, 3 and Table 2 show the HEIs main solid waste categories and Composition.

Figure 2.
HEIs main solid waste categories.

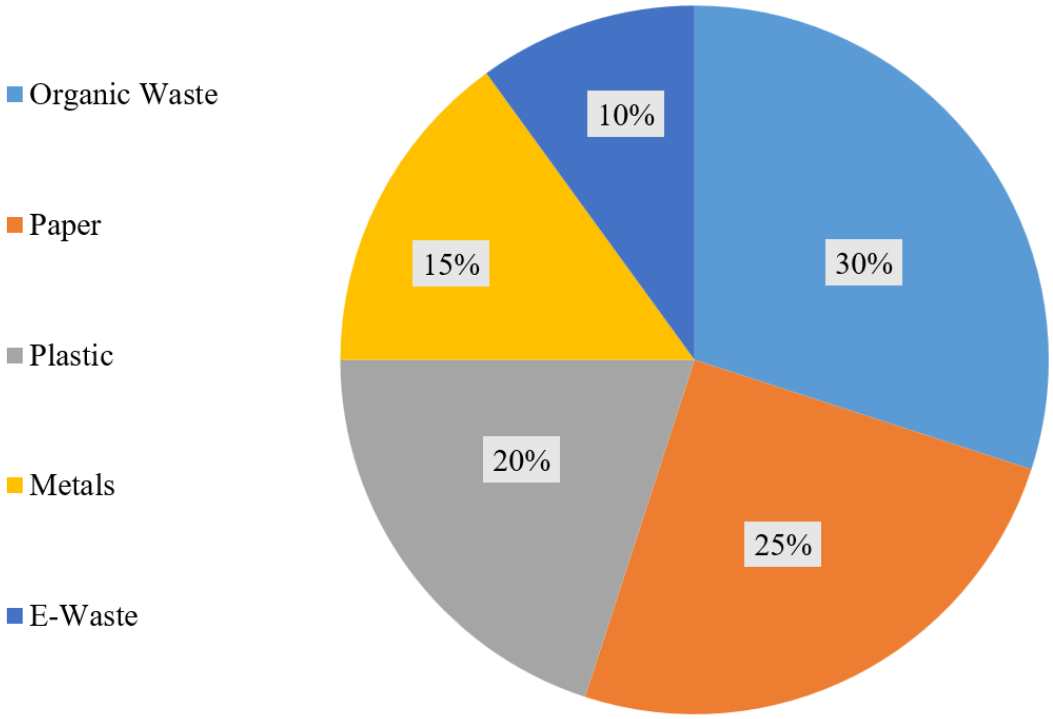

Figure 3.
HEIs main solid waste composition.

Table 2.
IHEs main solid waste categories (adopted from).

Solid waste type	Source	Description	Recyclability	Management strategy
Paper	Office, mini market, photocopy centers, lecture rooms, lecture quarters and hostel	Cardboards, wrappers, cartons, cement bags, tissue papers, packages-carbon papers, allied, and papers.	Recyclable	Separation, recyclable, and reuse.
Organic waste (garbage)	lecturer quarters and hostels, refectories, restaurants, markets, bread/cake production and consumption from kitchens	left over from dead animals, peel and leaves from fruits and vegetable, uneaten sandwiches, cakes, bread, soups, food, sauces, meat and cheese.	Recyclable	Compost, Feed for livestock, energy generation
Plastic	Medical center/hospital market, and laboratories.	Waterproof bags, caps, bags, Plastic materials-cans bucket, syringes beakers, spoilt plastic chairs, pipettes and burrettes automobile tyres, tubes, cables, and ball pens	Recyclable	recyclable
Metals	guest houses, hostels, markets, and vehicles (very plenty at works department)	lorries, Disused cars, automobile junks, buses, cans, metal cups, plates, spoons, plates, pots, buckets, boxes, pots, aluminum, scrap electronic equipment.	Recyclable	Source separation, Recyclable Reusable.
E-waste	electrical appliances/ parts and results from quarters, hostels and commercial areas.	Printers cartridge, electric cables, phones accessories.	Recyclable	Reusable, recyclable.

Source: Ugwu, et al. [29].

4.1. Organic Wastes

The primary sources of institutional waste are residence halls, cafeterias, social clubs, and residential premises. These sources predominantly generate organic waste, including food leftovers [37]. Organic waste incurs the highest disposal costs. It also poses the most significant threat in terms of greenhouse gas emissions [38]. Unmanaged biological decomposition processes lead to the emission of landfill gases. These waste gases primarily consist of methane, carbon dioxide, and other trace gases. However, organic waste can be repurposed through three main secondary applications: soil

enrichment, composting, and energy production. By implementing these strategies, institutions can mitigate the environmental impact of organic waste and contribute to sustainable waste management practices [39]. Composting practices emerge as a promising strategy for universities to effectively manage their organic waste. To address this need, university administrators could implement dedicated composting sections, which serve not only as a means of waste management but also as a way to foster reforestation and preserve green spaces on campus. Notably, studies such as those conducted by Ng and Yusoff [40] have demonstrated the success of initiatives focused on reforestation and green space preservation within university settings. These findings underscore the potential positive impact of integrating composting into the sustainability framework of educational institutions.

Constant awareness-raising and sensitization efforts highlight the costs and environmental benefits of proper organic waste management. Organic waste can be utilized to produce biogas or to enhance soil quality for use by local farmers both on-site and in surrounding areas. Additionally, anaerobic digestion using a wetland wastewater system can be integrated with the university sewage system to process organic waste [41]. This procedure produces methane gas, which is essential for electricity generation. According to the EPA, anaerobic digestion from wastewater has roughly three times the capacity to produce methane gas compared to solid waste alone. Notably, 100 to 105 tons of organic waste can generate enough electricity each day to power approximately 1,000 homes. These practices underscore the significant potential of organic waste management in contributing to energy production and environmental sustainability [29].

4.2. Plastic

Polyethylene terephthalate (PET) bottles are widely used to store water and other beverages. Many colleges have significant amounts of polyethylene in their waste streams. In developing countries, the increased volume of polyethylene bag waste is due to the lower-cost of plastic water bottle [29]. Additionally, polyethylene bags are frequently used to package goods in commercial settings, further contributing to this high volume. The devastating environmental impacts of this waste necessitate urgent control and reduction measures [42]. Universities should focus on recycling this massive amount of polyethylene to use in their various water brands. Furthermore, policies such as imposing additional taxes on polyethylene packaging can help reduce this waste. Some universities in developed countries have effectively implemented such strategies, which explains the minimal presence of polyethylene in studies conducted in these regions. These approaches will simplify waste collection, discourage the use of polyethylene-packaged water in certain areas, and make clean water more affordable. Since most plastics are non-biodegradable, they pose a significant threat to the local environment [43]. However, many of these plastics have a high potential for reuse within both the institution and the local communities. One of the most effective ways to collect them is by separating them at the source [33]. Nevertheless, a sizable portion of PET bottles is often unaccounted for because local consumers retrieve them from shops or make purchases. Selling PET bottles to local markets in the host community is a primary method for managing plastic waste. Recycling methods, such as mechanical and chemical processes, are essential for repurposing plastic products for various applications. These techniques play a crucial role in transforming discarded plastics into reusable materials, contributing to a more sustainable and circular approach to plastic usage [44].

4.3. Paper Waste

In comparison to the other main waste categories produced in universities, paper waste disposal is relatively small. This may be due to some university employees and cleaners directly selling paper refuse to recycling companies [32, 33]. Additionally, the distribution of exams and lesson notes in electronic form has reduced paper use, although the exact impact of these methods hasn't been quantified. Universities should encourage and promote paperless practices, such as distributing lecture notes electronically, registering students for classes online, disseminating memos via email, posting results online, sharing seminar papers digitally, and coordinating proper paper recycling by concerned staff. Implementing strategies like creating copies of documents and reports on unused paper sides for internal use and selling uncontaminated papers directly to recyclers can also decrease paper waste. Using electronic messaging as the primary method of information distribution and utilizing double-sided printers can further help reduce paper waste [40]. Separate containers for collecting paper waste should be provided to minimize contamination by organic waste, as papers found in dumpsters are typically contaminated with other waste categories, particularly organic wastes, rendering them unfit for sale to recyclers. This technique would increase the recovery potential of paper waste. The cautious application of the 3R strategy (Reduce, Reuse, Recycle) could result in cost savings and other significant benefits from appropriate waste management techniques [29].

4.4. E-Waste

Waste electric and electronic equipment (e-waste) refers to products that rely on electrical currents or electromagnetic fields to operate but are no longer wanted, functional, or have become obsolete [45]. E-waste includes a variety of discarded appliances such as laptops, computers, mobile phones, TVs, DVD players, refrigerators, freezers, washing machines, medical devices, and information technology and telecommunication systems. These appliances, having reached the end of their usable life, are discarded by their original users. Notably, e-waste contains hazardous elements like lead, mercury, arsenic, cadmium, polyvinyl chloride, and various classes of brominated flame retardants [46]. Proper disposal of e-waste is crucial to prevent adverse impacts on the environment and human health, as improper disposal in landfills or incinerators can pose severe threats. Factors contributing to the e-waste issue include constant product substitution driven by upgrades, rapid price decreases, shorter product lifespans, changing consumer preferences, and swift economic growth [47]. Study by Msengi, et al. [48] indicated that a significant number of students lack awareness of e-waste recycling on

campus, despite restrictions on free printing in computer labs. Similarly, Islam, et al. [49] found that young consumers widely use laptops but have limited knowledge about e-waste recycling programs and collection point locations Arain, et al. [50]. evaluated consumer behaviors related to e-waste recycling at a large Midwestern university in the United States, highlighting factors such as free access to disposal, consumer knowledge gaps about products and disposal sites, and the importance of having recycling facilities within a reasonable distance. Policymakers and waste management professionals should focus on promoting e-waste recycling behaviors by enhancing access to free or low-cost recycling and creating incentives for recycling initiatives.

5. Enhancing SWM Practices in Universities and HEIs

In recent decades, there has been a noticeable surge in waste management programs within HEIs, indicating a growing interest in sustainable practices. Existing literature focuses on workplace recycling practices, particularly within college and institutional settings, providing compelling evidence of this trend [51-53]. The increasing involvement of institutions in sustainability tracking, assessment, and rating system underscores the heightened emphasis on waste minimization and diversion within higher education [54]. However, the decision to implement and support comprehensive waste management programs, such as recycling and composting, is no longer as straightforward as it once was. Waste management presents a pertinent case study due to the challenges and costs associated with such programs, compounded by evolving market dynamics. For instance, China's "Operation Green Fence" and "National Sword" policies have significantly impacted the value of recyclable materials, undermining the environmental benefits of recycling programs lacking viable markets for recycled materials [54]. In light of these challenges, administrators must reconsider their approach to investing in waste management initiatives, taking into account variables such as fluctuating oil prices, which affect the value of recycled plastics. Within higher education, waste management emerges as a crucial component of SD strategies, essential for comprehensive environmental protection and garnering international attention. Success in waste management initiatives hinges on various factors, including engagement, knowledge dissemination, and fostering environmentally responsible behaviors. These efforts are facilitated within the higher education setting through supportive campus policies and initiatives [55]. Table 3 provides a summary of recent studies that have examined the behavior of students in IHEs regarding solid waste management.

5.1. Knowledge and Awareness of Solid Waste Management

Engaging individuals in proactive participation and educating them about environmental responsibility are fundamental pillars of a successful ISWM approach [56]. To effectively implement ISWM initiatives within large campuses, fostering environmental awareness and competence is paramount. Ramayah, et al. [57] underscores the interplay between information dissemination, awareness, attitude formation, and social norms. Hence, instilling sustainable attitudes across university members relies on ongoing environmental education efforts.

The overarching goal of educational endeavors and communication structures on campus is to ensure universal involvement in sustainable practices. Recognizing that both passive disengagement and active participation influence individuals, these endeavors strive to cultivate collective motivation towards sustainability within the campus community [5]. The ISWM strategy should encompass organizing awareness campaigns, including general lectures, posters, and dissemination of educational materials campus-wide [16]. Environmental audits serve as invaluable tools for illustrating the outcomes of the program, showcasing both successes and challenges, and pinpointing areas for improvement [58].

In many contexts, particularly in developing nations, education emerges as a pivotal method for raising environmental awareness among the populace [55]. Environmental education not only equips students with critical thinking skills, problem-solving abilities, and decision-making acumen but also imparts comprehensive knowledge about environmental issues [59]. formed decision-making stems from heightened environmental consciousness, augmented knowledge, and facilitation of information exchange and discourse. By fostering a culture of informed awareness, individuals are empowered to make conscientious choices, thereby contributing to proactive environmental stewardship [60]. Environmental literacy plays a crucial role in shaping attitudes and behaviors towards the environment [61], while environmental education aims to deepen understanding and promote positive human-environment interactions [62]. Within higher education, nurturing students' comprehension of the environment, essential for sustaining life, holds utmost significance [63]. Increasing environmental literacy correlates with improved waste management understanding [64] and a broader comprehension of environmental issues, empowering individuals to take action to safeguard ecosystems [65]. Moreover, students' awareness of environmental concerns and waste management practices varies depending on their academic disciplines and existing knowledge. Tailoring educational initiatives to address specific needs within diverse academic fields is imperative to effectively engage students with varying levels of familiarity [66]. As outlined in Table 4, HEIs have implemented various awareness programs targeting different campus groups to enhance waste management knowledge and practices. These programs, ranging from workshops to community projects, have resulted in positive outcomes, including increased recycling participation, improved waste sorting, and stronger community involvement in sustainability efforts.

Table 3.
Summary of recent research on the behavior of students in IHEs towards SWM.

Country	Sample size	Method	Main results	Reference
China	562	Survey	The study, conducted with 562 Chinese high school students, investigated their motivation towards solid waste separation on campus, utilizing the Theory of Planned Behaviour alongside environmental education and knowledge as explanatory frameworks. The findings highlight that environmental education is pivotal in shaping students' knowledge and fostering positive attitudes towards solid waste separation. Notably, knowledge was identified as the most significant predictor of students' behavior in waste separation practices.	Liao and Li [67]
Turkey	355	Survey	A study involving 335 middle school students in Eskişehir examined the relationship between environmental literacy, attitudes, awareness, and behavior in the context of purchasing environmentally friendly products. The findings revealed that environmental illiteracy had no significant impact on students' attitudes or purchasing decisions regarding such products. However, environmental awareness positively influenced pro-environmental attitudes towards purchasing eco-friendly products. The study also demonstrated that awareness fosters positive environmental attitudes, which, in turn, lead to pro-environmental behavior and the adoption of environmentally friendly products.	Varoglu, et al. [68]
Nigeria	470	Mix-method	A study investigating SWM practices in public secondary schools found that teachers generally demonstrated a positive level of awareness, attitudes, and practices regarding SWM. However, the findings indicated that SWM practices were more effectively implemented in certain schools compared to others.	Ifegbesan, et al. [69]
Ghana	120	Survey	The study aimed to assess waste management practices within a community in Ghana. A survey of 120 randomly selected participants, conducted through a structured questionnaire, revealed that although the majority of individuals were aware of SWM, they rarely put this knowledge into practice. Attitudes towards social responsibility and participation in waste management were generally weak. Additionally, the study identified a significant lack of awareness regarding electronic waste (e-waste), highlighting the need to address the gap between knowledge and practice in the community.	K [70]
Ethiopia	392	Survey	A study involving 392 randomly selected community members from Kometa Kebele in Southwest Ethiopia was conducted to assess their knowledge, practices, and attitudes towards waste disposal management. The findings revealed that the majority of participants demonstrated good knowledge, positive attitudes, and effective practices related to waste management. Notably, most respondents were married and predominantly female.	Shewasinad, et al. [71]
Indonesia	65	Mix-method	A study was conducted to assess environmental literacy in terms of knowledge, awareness, and concern among 66 selected senior high school students in Indonesia. The results indicated that 80% of the students exhibited inadequate environmental literacy. This deficiency was attributed to insufficient information and the use of inappropriate lesson plans in their education.	Gustria and Fauzi [72]
Philippines	253	Survey	A study involving 253 randomly selected students was conducted to examine the relationship between SWM awareness and practice. The findings revealed a high level of awareness among the students, accompanied by effective practices in waste separation, reduction, and recycling. While SWM awareness did not significantly influence disposal practices, it had a notable impact on students' behaviors regarding sorting, recycling, reducing, and reusing waste	Paghasian [73]
China	434	Survey	This study integrates environmental concern and knowledge into an expanded model of planned behavior to explore waste management behavior. Surveying 434 university students in China, it found that subjective norms, perceived behavioral control, personal norms, and environmental knowledge were significant predictors of waste management behavior. Attitude had no direct effect. Environmental concern and subjective norms influenced behavior through personal norms, while environmental knowledge affected behavior indirectly	Wu, et al. [34]

			through concern, norms, and control.	
India	1,105	Survey	The findings indicate that intention, subjective norms, perceived behavioral control, and attitude significantly positively influence waste management behavior. Biospheric and altruistic values positively correlate with belief, while moral norms and environmental knowledge are crucial in shaping attitudes. These results can inform governments, policymakers, and researchers in designing and implementing effective waste management systems.	Raghu and Rodrigues [74]
South Africa	376	Survey	The results indicate that students' knowledge of solid waste management was low and inadequate. Despite this, students are eager to engage in recycling projects to enhance the institution's environmental condition. The study also found that 41% of students need motivation, such as economic incentives, to participate in recycling schemes. It is recommended to increase environmental education awareness, implement participatory environmental programs, and strengthen key sustainability competencies to facilitate the transition to a circular economy. Further research into gamified learning for CE and capital generation from waste for capacity building is suggested.	Owojori, et al. [75]
Indonesia.	279	Mix-method	The results revealed that students generally exhibit strong environmental attitudes, engagement, and knowledge regarding waste management, supported by various existing policies and programs. Students majoring in social sciences had higher environmental behavior scores, while those majoring in sciences demonstrated greater engagement and knowledge. These findings underscore the importance of environmental conservation programs and policies in enhancing environmental behavior, engagement, and knowledge for SD. Educational institutions should, therefore, implement comprehensive environmental education to foster a waste-free environment.	Yusuf and Fajri [55]
China	814	Survey	Factors influencing students' willingness to separate waste include their attitudes, situational factors, and the effectiveness of publicity and education. These factors encompass students' attitudes towards waste separation, the cleanliness of the surrounding environment, the convenience of waste separation, the clarity of waste separation labels, and the level of school-based education and awareness. The study recommends four measures to enhance students' willingness to separate municipal waste.	Yang, et al. [76]

Table 4.
Knowledge and awareness of SWM programs in HEIs.

Institution	Awareness Program	Target Audience	Outcome	Reference
University of Cape Town (South Africa)	Workshops on waste reduction and recycling	Students and staff	Increased recycling participation, reduced waste generation	Michael and Elser [54]
Kyoto University (Japan)	Campus-wide waste management awareness campaigns	Entire campus community	Improved waste sorting and reduction behaviors	Gustria and Fauzi [72]
National University of Singapore (Singapore)	Integration of sustainability topics in orientation sessions	New students and staff	Early engagement in sustainable practices	Zen, et al. [56]
Technical University of Kenya	Community service projects on waste collection and recycling	Students, faculty, and local communities	Enhanced community involvement and awareness in waste management	Varela-Candamio, et al. [63]

5.2. Attitudes Towards Solid Waste Management

Drawing from psychological insights, waste behaviors rooted in knowledge tend to be reliable and enduring [77]. However, previous research has left a critical gap in understanding the relationship between environmental knowledge and Solid Waste Management Behavior (SWMB). Bridging this gap, a collaborative study conducted in both the USA and Spain unveiled a significant correlation between students' recycling practices and their environmental knowledge levels [78]. Similarly, Barr [80] discovered that, contrary to the influence of environmental consequences on individuals' intentions, awareness of policy measures aimed at waste reduction actually increased waste behaviors. This suggests that the link between knowledge and wasteful behaviors may not be straightforward; rather, knowledge could potentially mediate attitudes rather than intentions and behaviors. Recognizing that SWM skills signify a positive mindset [8], and considering SWMB as a scientific knowledge-driven activity [74], it becomes evident that enhancing individuals' environmental knowledge could serve as a catalyst for fostering more sustainable waste management practices.

5.3. Environmental Education Effect on Student Awareness Towards Solid Waste Management

Higher education plays a pivotal role in cultivating an environmentally conscious population [79]. Environmental awareness serves as a platform for raising environmental awareness through dedicated coursework and initiatives [80, 81]. However, there are critical issues within the environmental education curriculum at the higher education level [82]. Firstly, research indicates that numerous everyday actions significantly contribute to waste and pollution concerns [83]. Secondly, to ensure sustainability post-graduation, environmental education should integrate relevant issues, actions, and knowledge into students' future professional contexts [84]. Students, as a distinct group with a wealth of information, wield significant influence over environmental awareness and behaviors [85]. The vital role of higher education in nurturing talent for society underscores the importance of addressing environmental concerns on campuses [86]. However, campuses often face challenges in effectively incorporating SD practices [87]. Environmental cleanliness is essential for creating conducive learning environments, and addressing environmental knowledge gaps is crucial. Studies have revealed shortcomings in students' factual understanding, comprehension of global issues, and knowledge of waste management [14]. Notably, students from non-science majors require special attention, given variations in environmental knowledge across disciplines [66].

Environmental education emerged in response to growing public awareness of environmental issues and the pursuit of healthier living environments [88]. It is influenced by factors such as environmental knowledge, attitudes, and behaviors [89] aiming to provide solutions to environmental challenges and cultivate individuals capable of policymaking and action for SD [90]. Over the past decade, environmental education has evolved to emphasize the development of responsible conduct, equipping students with the necessary information, attitudes, values, commitments, and problem-solving skills [91, 92]. Guidelines for shaping the scope of environmental education emphasize the enhancement of knowledge, skills, attitudes, and behaviors, fostering a caring attitude, curiosity, and concern for the world [93]. Environmental education has transitioned from a mere pedagogical field to a policy implemented within colleges and universities [55]. In the subsequent paragraph, we delve further into the importance of researching involvement, behavior, and environmental understanding. As shown in Table 5, various HEIs have implemented environmental education initiatives tailored to increase sustainability awareness and foster long-term sustainable behaviors. These programs have demonstrated positive outcomes, including enhanced recycling rates, improved waste management behaviors, and increased participation in sustainability practices

Table 5.
Comparative analysis of environmental education programs in HEIs.

Institution	Environmental Education Initiative	Objective	Outcome	Reference
Chinese Universities	Campus-wide sustainability campaigns	Increase student awareness	Enhanced recycling rates, reduced waste	Wu, et al. [34]
University of Southern Santa Catarina (Brazil)	Integration of sustainability in curriculum	Foster long-term sustainable behaviors	Improved waste management behaviors on campus	Ribeiro, et al. [22]
University of Lagos (Nigeria)	Workshops and information sessions on waste separation and recycling	Build foundational waste knowledge	Increased participation in waste separation activities	Adeniran, et al. [32]
American University of Sharjah (UAE)	Campus campaigns and seminars on sustainability	Promote awareness on waste practices	Higher awareness and behavioral change among students	Thukral, et al. [47]

5.4. Environmental Behavior in Solid Waste Management

Numerous studies suggest that gender significantly influences environmental behavior, particularly among women who are more receptive to environmental issues. These women often display specific environmental behaviors, which may contrast with the broader community's insufficient awareness or understanding [94]. Additionally, environmental behavior is frequently linked to a general lack of community knowledge [60] , while other research highlights the positive impact of incorporating environmental education into curricula [95]. As a result, both students and teachers often exhibit commendable waste management practices and possess substantial environmental knowledge.

Some studies also explore the influence of traditional community values on environmental behavior [54, 96, 97]. There is a need for a thorough investigation into how student programs align with campus environmental policies. Human behavior patterns significantly impact the quality of the immediate environment. The younger generation of students must address the environmental neglect of both past and present generations [98]. Many environmental issues stem from human behavior, and it is believed that promoting ethical behavior can mitigate these problems [99].

many research has been conducted on the environmental behaviors of various social groups, particularly students [55, 100, 101]. The success of waste management initiatives is closely tied to the environmental behaviors that support these efforts. Findings indicate that environmental behavior is crucial for achieving a zero-waste ecosystem [102]. Given their roles as future guardians, planners, decision-makers, and educators on environmental issues, studying environmental behaviors of students is essential [55].

5.5. Recycling Behavior for Sustainable Solid Waste Management

Recycling is one of the most straightforward and effective ways for individuals and families to contribute to environmental protection, and it has garnered significant research attention [103]. Recycling not only helps mitigate health and environmental risks but also creates opportunities for sustainable business and employment [104]. According to Zhang, et al. [105], college students are typically early adopters and enthusiastic supporters of recycling practices. This suggests that university campuses could play a leading role in promoting waste separation and enhancing recycling behavior. Most college students are highly educated and young, which positions them well to adopt new environmental sustainability practices and understand proper waste classification and recycling resources. Furthermore, the recycling and waste separation behaviors of college students can influence the behaviors of both older and younger generations. Therefore, it is essential to understand the factors that influence college students' recycling and composting behaviors [52].

Recycling is a task that requires proper knowledge for accurate execution. Although it may seem less complex than other sustainable behaviors, such as green purchasing and education, effective recycling demands a thorough understanding of processes and guidelines to achieve optimal environmental impact [106]. In addition, environmental behaviors like recycling are challenging to predict due to various situational or contextual factors [107]. Despite these inconsistencies in understanding recycling behavior, recycling remains one of the most effective methods to reduce the environmental impact of waste. However, recycling success depends on the cooperation and active involvement of stakeholders, particularly students on campus [108].

Higher education institutions serve as pivotal social change agents in promoting environmental sustainability [64]. Colleges and universities are regarded as role models for their communities as they are responsible for educating the community about environmental protection and fostering a positive social image [64]. Promoting and embodying sustainable behaviors, particularly campus recycling, is crucial for several reasons. Primarily, campus recycling significantly impacts the waste stream of the surrounding community, which is especially important in smaller cities where university stakeholders, including students and staff, constitute a substantial portion of the population. This highlights the pivotal role universities play in fostering environmentally responsible practices within their localities [108].

5.6. Solid Waste Sorting-Separation Behavior of University Students

Waste sorting is considered an effective strategy for promoting recycling and reducing environmental pollution [109]. Since public participation is essential, it is crucial to understand waste sorting and the factors influencing it [110]. Numerous studies have used questionnaires to explore this topic, as they are cost-effective and affordable [67, 111].

However, accurately representing actual sorting behavior through questionnaires is challenging [112]. While key variables influencing waste sorting behavior have been analyzed, the understanding remains somewhat unclear. Current studies often use Likert scales in surveys to analyze sorting behaviors, but further exploration and refinement of methodologies are needed to precisely identify and understand these influential variables [113].

Academics frequently use the frequency of sorting as a proxy for actual behavior [114]. Questionnaires typically include multiple questions about sorting regularity, asking subjects to rate their behavior [115]. However, scales are not ideal for evaluating sorting habits can introduce inaccuracies due to biases. First, individuals may have different internal standards for frequency [116]. Second, scales struggle to capture nuanced behavioral characteristics. Questionnaires often lack quantitative data on aspects such as waste weight and time spent sorting refuse [117]. The use of self-reporting in questionnaire-based assessments of waste sorting behavior introduces inherent challenges. This method is prone to issues such as subjects consciously altering their reported conduct, leading to potential inaccuracies due to masking and memory biases [112]. This problem has hindered the field of environmental psychology. While some academics argue that frequency-based self-reported waste sorting behavior is accurate [118], others believe self-reported behavior is ultimately subjective [119]. Consequently, many academics prefer to focus on the intention to sort waste rather than the actual behavior [120].

6. Barriers to Solid Waste Management Sustainability in Universities

Sustainable solid waste management in universities is crucial for minimizing environmental impact, promoting resource conservation, and fostering a culture of responsibility. However, numerous barriers can impede the achievement of sustainability goals in this context. Sustainable waste management is essential for minimizing environmental impact, but several barriers hinder progress. Table 6 summarizes these barriers and their implications.

Table 6.
The barriers to stia sellect sustainable waste management in Universities.

Barrier	Details	Reference
Lack of Awareness and Education	Universities often struggle with insufficient initiatives to inform and educate students, faculty, and staff about the importance of sustainable waste disposal and recycling. Without a foundation of understanding, individuals may unknowingly contribute to improper waste handling, hindering overall sustainability efforts.	Molina and Catan [121]
Inadequate Infrastructure	Insufficient investment in recycling bins, composting facilities, and waste separation systems on campus can impede the implementation of sustainable waste management practices. The absence of essential infrastructure makes it challenging to establish efficient waste collection and recycling processes.	Ugwu, et al. [33]
Budget Constraints	Limited financial resources can restrict the implementation of advanced waste management technologies and comprehensive sustainability programs. Despite the long-term benefits of sustainable practices, immediate budgetary concerns may take precedence.	Filho, et al. [122]
Limited Research and Data	Comprehensive data on waste composition and its environmental impact are crucial for developing effective waste management strategies. Without this knowledge, universities may struggle to implement targeted and sustainable solutions.	Atici, et al. [123]
Inadequate Training for Staff	Staff may lack proper training, leading to suboptimal waste management practices.	Bahçelioğlu, et al. [5] and Ribeiro, et al. [22]

Proper training is crucial for ensuring that staff members are well-equipped to implement and maintain effective waste management procedures. For instance, METU in Turkey tackled infrastructure limitations by investing in accessible recycling facilities and waste separation systems across campus. This improvement significantly increased recycling rates and reduced landfill contributions, demonstrating how resource allocation can overcome infrastructure-related barriers [5]. Similarly, the University of Southern Santa Catarina in Brazil addressed budgetary constraints by integrating low-cost sustainability initiatives, such as composting and waste minimization practices, into its campus operations. This approach allowed the university to achieve measurable waste reductions without large capital investments, highlighting an effective strategy for budget-limited institutions [22]. Additionally, Chinese universities have addressed the barrier of low engagement through student-centered educational campaigns, which have effectively increased awareness and participation in recycling efforts. These campaigns created a stronger culture of sustainability on campuses, showing how targeted education can shift behavior and overcome awareness-related challenges [34]. Finally, to counteract a lack of data and research, the University of Lagos in Nigeria conducted waste characterization studies. These studies enabled the university to develop tailored waste management solutions, reinforcing the value of data-driven approaches to effective waste management practices in HEIs [32].

Addressing these barriers demands a multifaceted approach that includes educational campaigns, strategic investments in infrastructure, policy development, and a concerted effort to instill a culture of environmental responsibility within the

university community. Overcoming these challenges is essential for universities to realize their sustainability objectives and contribute to a healthier and more environmentally conscious future.

For the effective management of MSW generated within universities, there is a pressing need for a paradigm shift in conventional waste management procedures. The pivotal and foundational stage in any robust waste management program involves solid waste characterization studies. The inadequacy of attention given to sustainable management practices underscores the importance of prioritizing such studies. Furthermore, the efficacy and efficiency of any waste management technique hinge on a comprehensive understanding facilitated by proper waste characterization. Empirical evidence from various studies suggests that developed countries exhibit a higher level of efficiency in solid waste management compared to their developing counterparts. Many universities in developed countries have established sustainable programs that, for instance, demonstrate a notable reduction in polythene or plastic waste. An illustrative example is the successful implementation of a tax on polythene used for packaging goods on campus, a measure that has contributed to the feasibility and success of sustainable waste management initiatives. Figure 4 shows the key barriers to effective waste management in HEIs.

Figure 4.
Key barriers to effective waste management in HEIs.

7. Recommendations and Future Prospective

7.1. Recommendations

A series of proactive measures that educational institutions can adopt to foster sustainability, literacy and behavior should be conducted. These include the implementation of mandatory sustainability courses, the promotion and acknowledgment of students' on- and off-campus activities that endorse sustainable behavior, and the adoption of resource-conserving measures alongside the incorporation of educational techniques aimed at altering student behaviors. These recommendations aim to create a culture of sustainability among students and staff while enhancing the overall effectiveness of waste management practices on campuses.

To bolster sustainable practices, universities should strategically place recycling bins throughout their campuses, facilitating convenient waste separation for students. Encouraging students to undertake capstone projects with a sustainability focus, potentially by offering financial support or other incentives, can further drive initiatives in areas such as clean energy, green structures, and environmental preservation. Recognizing the importance of local government involvement, suggestions include the strategic placement of recycling bins in public spaces, utilizing color-coded trash cans to segregate paper, plastic, and general waste, and reducing the frequency of waste collection to minimize environmental impact.

Recognizing the importance of local government collaboration is essential for effective waste management. Suggestions include the strategic placement of recycling bins in public spaces and reducing the frequency of waste collection to minimize environmental impacts while enhancing community participation in sustainability initiatives. By working with local authorities, HEIs can encourage a broader culture of sustainability that extends beyond campus boundaries.

In light of the insights derived from this review, the following recommendations are proposed: (1) conduct comprehensive training and seminars on solid waste management for college students on campus; (2) encourage the Office of Student Services and Welfare, in collaboration with the Campus Student Government, to develop student activities that provide firsthand learning experiences and in-depth information, particularly regarding students' roles in solid waste management; (3) task the coordinator of the solid waste management program with organizing programs that disseminate

knowledge about correct waste sorting, reduction, and reuse procedures, instilling sustainable habits among the student bod.

A triangular partnership model among HEIs, local governments, and industries is suggested to achieve an effective circular economy. This model would leverage the research capabilities of HEIs to develop innovative waste management technologies, providing local governments with academic insights and technical support. Local governments could facilitate policy support, financial incentives, and the necessary infrastructure for waste collection and recycling. Industries can also contribute by adopting circular practices, utilizing recycled materials from HEIs, and developing sustainable products that minimize waste. An example of such collaboration has been demonstrated by the University of Southern Santa Catarina, which partnered with local waste management authorities and recycling companies to create a closed-loop recycling system. Through this partnership, campus waste was processed at local facilities, reintroducing materials into the production cycle and fostering a circular economy [22]. Additionally, a public-private partnership model is recommended, wherein HEIs and industries collaborate on research and development for sustainable products and recycling technologies. HEIs may serve as testing grounds for new recycling methods, while industries support the scaling of successful projects. A similar approach has been employed in China, where collaborations between universities, industries, and local authorities on recycling initiatives have contributed significantly to waste reduction in surrounding communities [32]. These collaborative models provide structured approaches for integrating waste management across institutional, municipal, and industrial levels, facilitating a sustainable and circular use of resources.

7.2. Future Prospects

The future of sustainable waste management in HEIs is poised for significant advancement. As awareness of environmental issues grows, there is an urgent need for educational institutions to integrate sustainability into their core missions. This integration involves redefining the role of HEIs, not merely as centers for academic learning but as leaders in promoting sustainable practices. One critical avenue for fostering this transformation is through the enhancement of educational programs focused on sustainability. Institutions can develop comprehensive curricula that emphasize the principles of sustainable development, environmental stewardship, and responsible resource management. By promoting interdisciplinary approaches, HEIs can engage students from various academic backgrounds—such as environmental science, engineering, business, and social sciences—encouraging collaboration and innovation in addressing waste management challenges. Moreover, the rapid evolution of technology presents HEIs with unparalleled opportunities to implement innovative solutions for waste management. For instance, the adoption of smart waste management systems can revolutionize how waste is collected, sorted, and processed. These systems can utilize sensors and the Internet of Things (IoT) to monitor waste levels in real-time, optimize collection routes, and reduce operational costs.

Additionally, leveraging data analytics can enhance the characterization of waste streams. By analyzing data related to waste generation patterns, institutions can identify areas for improvement, develop targeted interventions, and track progress over time. This data-driven approach can lead to more effective recycling programs and waste reduction strategies. Exploring advanced recycling technologies is another crucial aspect of evolving waste management practices. Innovations such as chemical recycling, which can break down plastics into their molecular components for reuse, represent a significant advancement in waste processing. By investing in such technologies, HEIs can not only reduce their own waste footprint but also serve as research hubs for developing and testing new sustainable practices.

In conclusion, by embracing these recommendations and actively pursuing future prospects, HEIs can substantially enhance their contributions to sustainability. This commitment will not only improve waste management practices on their campuses but will also cultivate a culture of sustainability that resonates within their local communities. By acting as catalysts for change, HEIs can inspire responsible resource use and foster effective waste management practices, ultimately benefiting society as a whole and contributing to a more sustainable future.

8. Conclusion

This review underscores the essential contribution of HEIs to advancing sustainable waste management and fostering a culture of environmental responsibility. Through the adoption of ISWM frameworks, HEIs are shown to effectively tackle diverse waste management challenges, promoting waste reduction, recycling, and resource recovery. Findings demonstrate that ISWM not only reduces environmental impacts but also significantly enhances awareness and engagement among students and staff, embedding sustainable practices deeply within campus culture. The integration of ISWM within HEIs signals a progressive shift toward more circular waste practices, where waste is minimized, and resources are reintroduced into the lifecycle. This review emphasizes the importance of strategic collaboration among HEIs, local governments, and industry partners, which can create an extended impact, promoting circular economy principles that reach beyond campus boundaries. Moving forward, the role of HEIs in environmental stewardship will be pivotal, as they lead by example and drive broader societal shifts toward sustainability. Ultimately, the continued commitment to sustainable waste management in HEIs will not only contribute to meeting institutional sustainability goals but also inspire and influence communities toward responsible resource use and waste practices. This leadership from HEIs can serve as a powerful catalyst for SD in the wider society.

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