JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Optimizing Decentralized Food Waste With Innovative Waste Management Technologies In Smart Cities

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Abstract

Food waste is a significant global concern with environmental and economic consequences. Decentralized food waste management approaches, such as in-home composting and community programs, offer potential for localized solutions in smart cities. This research explores the optimization of decentralized food waste management through the integration of innovative waste management technologies. We investigate the potential of technologies like smart bins with sorting capabilities, apps for food waste tracking, and technologies for converting food waste into usable products. The research will analyze the effectiveness of these technologies in reducing waste, increasing resource recovery, and promoting user engagement in smart cities. We will also consider the economic feasibility, environmental benefits, and social acceptance of these approaches. A survey instrument assesses public awareness and preferences regarding these technologies. Additionally, the ultimate objective is to identify optimal strategies for integrating innovative technologies. By promoting efficient and sustainable solutions, this research seeks to contribute to a substantial reduction in food waste and its associated environmental burden. Furthermore, the research will consider social and economic factors by assessing public perception and willingness to adopt these innovative solutions. This research also contributes to the development of more effective and sustainable decentralized food waste management system in smart cities.

Keywords- *Eco-Fridenly, Sustainabilty, Decentralized, Integrated, Awarness, Emerging, Innovation, Technology.*

Introduction

Food waste is a critical issue that demands urgent attention, especially in urban areas like Agra, where the municipal solid waste generation is substantial. According to the latest records from the Agra Nagar Nigam (ANN), the city produces approximately 916 tonnes per day (TPD) of municipal solid waste (MSW), with a per capita waste generation of 0.48 kg. Despite efforts to manage this waste, bulk waste generators (BWGs) remain significant contributors, accounting for 30-40% of the total waste generated. With over 2,000 BWGs spread across the city, their role in Agra's waste management ecosystem cannot be overstated. While technology holds promise in addressing various aspects of waste management, the issue of food waste stands out prominently. Every day, a considerable amount of perfectly good food is wasted, despite the presence of

innovative solutions. Technology can play a crucial role in mitigating food waste through several avenues. Firstly, technology facilitates better meal planning, ensuring that available food resources are utilized efficiently. Meal planning apps empower individuals to strategize their meals, minimizing excess food purchases and subsequent wastage. Similarly, technology aids in optimizing food storage methods, prolonging the freshness of perishable items and reducing spoilage. By leveraging apps and websites dedicated to optimal food storage practices, individuals can minimize food waste significantly. Moreover, technology serves as a catalyst for food redistribution efforts, connecting surplus food with those in need. Various apps and platforms facilitate the donation of excess food from households, restaurants, supermarkets, and other sources to charitable organizations, ensuring that edible food is utilized effectively rather than ending up in landfills. The repercussions of food waste extend beyond the immediate environmental concerns to broader societal and economic impacts. The release of greenhouse gases from decomposing food waste contributes to climate change, exacerbating global challenges. Moreover, in a country like India, where millions suffer from hunger and malnutrition, the magnitude of food waste underscores the urgency for intervention. While traditional methods such as composting and landfilling have been the norm for food waste management, emerging technologies offer sustainable alternatives. Innovations such as anaerobic digestion for green fuel production and biochemical transformations demonstrate the potential to convert food waste into valuable resources, aligning with sustainable development goals. Food waste management practices vary across regions, with disposal typically occurring in landfills or through biological and chemical treatment methods. However, these traditional approaches pose significant environmental challenges due to the release of toxic gases, unpleasant odors, and pollution. The impact of food waste on our planet cannot be overstated, as the vast quantities of food ending up in landfills contribute to greenhouse gas emissions, exacerbating climate change. Annually, approximately 2.5 billion tons of food are wasted globally, with the United States alone responsible for over 120 billion pounds of this waste. Recognizing the severity of this issue, numerous companies are pioneering innovative solutions to address food waste on a global scale. By embracing these solutions and implementing changes in our daily routines, we can mitigate food loss and reduce the release of greenhouse gases into the atmosphere. Furthermore, food waste is increasingly viewed as a valuable resource, with emerging green technologies such as anaerobic digestion for green fuel production offering promising avenues for sustainable waste management. Despite the staggering scale of food waste worldwide, the problem is particularly acute in countries like India, China, the USA, and Brazil, which are among the top producers of food waste. In India alone, millions of people suffer from hunger while vast quantities of food go to waste, highlighting the urgent need for action. Food waste is prevalent in various sectors, including hostels, restaurants, supermarkets, residential areas, airlines, and food processing industries. The disparity in food waste between income groups further underscores the complexity of the issue, with high-income groups in India recording significantly higher levels of food waste compared to middle- and low-income groups. Despite limited research on food waste in India, available data paints a stark picture, with household food waste estimated to be nearly 68,760,163 tonnes per year. The Union Ministry of Environment, Forest, and Climate Change (MOEF & CC) has introduced regulations aimed at addressing food waste management, emphasizing the importance of segregation at the source and promoting waste-to-wealth initiatives. As India grapples with the challenge of food waste, there is a pressing need for concerted efforts to implement sustainable solutions and alleviate the profound social, economic, and environmental impacts of this global issue.

LITERATURE REVIEW

1. **Lozada, Velásquez, Cuevas. (2023) Prioritization of Waste-to-Energy Technologies Associated with the Utilization of Food Waste.** The study systematically examined various waste-to-energy (WtE) options for repurposing food waste, pinpointing anaerobic digestion, gasification, incineration, and biogas recovery from landfills as the primary technologies. They established criteria and subcriteria related to environmental, social, and technical considerations using the prospective MIC-MAC method and analytical hierarchical process.

2. **Żmieńka, Staniszewski, (2020). Food management innovations for reducing food wastage – a systematic literature review.** The research analysed 107 articles to assess trends in food waste management innovations, revealing a focus on the final stages of the supply chain and highlighting a gap in waste-reduction technologies at earlier stages. It emphasized the importance of addressing food waste in production's early phases, especially in countries facing food shortages.

3. **Kavitha, Srilatha, Gayathri, Varun, Amrutha, (2022). Food Waste Management System.** The web-based application's goal is to reduce food waste by enabling restaurants and function halls to donate excess food to NGOs for distribution to those in need.

4. **Nenciu, Stanciulescu, Vlad, Gabur, Turcu, Apostol, Vladut, Cocarta, Stan, (2022). Decentralized Processing Performance of Fruit and Vegetable Waste Discarded from Retail, Using an Automated Thermophilic Composting Technology.** The research paper delves into the substantial impact of fresh fruit and vegetables on total waste generated at the retail level, supported by statistical evidence. It underscores the benefits of closed reactor composting, such as mitigating bioaerosol risks and enhancing operational efficiency through automation features like sensor-driven autonomous operation.

5. **Rajabov, (2023). Utilizing digital technologies for waste management.** The paper concentrates on enhancing an automated control system by implementing methods for repurposing waste into valuable products and fostering innovative projects within the digital economy.

6. **Rather, Farooq, Padder, Baba, Sharma, Mubarak, Khan, Singh, Ara. (2023). New insights in food security and environmental sustainability through waste food management.** Food waste, accounting for one-third of annual food production, poses a global challenge necessitating sustainable management technologies to achieve sustainability objectives. The paper explores food waste's implications on food security, sustainability, and safety, underscoring the necessity for innovative waste treatment approaches and energy conversion. Developed nations, with higher per capita income, generate more household waste due to excessive purchasing, disposal based on expiration dates, and inadequate storage practices.

7. **Peydayesh, Bagnani, Soon, Mezzenga. (2022). Turning Food Protein Waste into Sustainable Technologies.** Food protein waste is a major contributor to environmental problems and climate change, yet it holds potential for sustainable technology development, such as biodegradable plastics, water purification, and renewable energy. While protein-based materials have been employed for renewable energy, leveraging food proteins from waste remains largely untapped. Dairy wastewater's whey proteins offer opportunities for recovery and utilization in diverse applications, including nutritious food products and protein supplements.

8. **Kaur, Lasaridi, W C Wong. (2021). Sustainable Food Waste Management: An Introduction.** Food waste, a valuable but underutilized resource worldwide, can be harnessed for energy, chemical, and material production. Traditional management methods, such as anaerobic digestion, composting, and animal feed, are common. However, innovative approaches enable the extraction of high-value products like platform chemicals, biomaterials, biofuels, biochar, and biooil through diverse biological, thermal, and chemical transformations.

9. **Babu, Kavya, Harshitha, (2021). Food wastage reduction.** The paper discusses the need to reduce food waste in the foodservice industry and the overlooked role of innovation in waste management. It explores how foodservice operations and waste management innovations are linked, including both incremental and radical innovations. Research shows that in Finland, households waste 5% of

purchased food annually, with each person discarding an average of 20-30 kg. The project aims to help users manage food inventory, reduce household food waste, and facilitate donations to organizations in need.

10. **Xu, Sun, Yan, Wong, (2021). Emerging Technologies for the Treatment of Food Waste.** The paper explores the potential of deriving high-value products from food waste through combined biochemical, chemical, or thermal/physical methods, including biodrying as a viable option for treating humid waste to generate high-quality refuse-derived fuel. It also discusses the feasibility of integrating food waste into domestic wastewater treatment plants through various scenarios.

OBJECTIVES

1. Investigate the current state of decentralized food waste management systems in smart cities to identify challenges and opportunities for optimization.

2. Explore the various emerging innovative food waste management technologies.

3. Enhancing the public awareness, sustainability & resilience in urban food waste management by integrating innovative technology, policy interventions, and stakeholder collaboration to optimize decentralized food waste management in smart cities

RESEARCH METHODOLOGY

This research employs a mixed-methods approach to tackle the issue of food waste in smart cities by reviewing existing literature, newspaper, social media, field visit etc and gathering quantitative and qualitative data. Quantitative analysis is then conducted to gather data on food waste generation rates, followed by qualitative interviews with stakeholders to understand their perspectives. By evaluating innovative technologies, the research seeks to propose effective strategies for optimizing food waste management.

RESEARCH GAP

The research paper aims to explore how innovative waste management technologies can efficiently manage decentralized food waste in smart cities. Despite the increasing focus on sustainability and smart city initiatives, there's a lack of understanding on integrating these technologies for decentralized food waste management. This research seeks to fill this gap by investigating the integration of innovative waste management technologies within the context of smart city development to optimize decentralized food waste management.

SAMPLE AREA

This research paper sample area is semi urban Agra smart city it explores the optimization of decentralized food waste management within the context of smart cities. By leveraging innovative waste management technologies, the study aims to address the challenges associated with food waste in urban environments, ultimately contributing to a more sustainable and efficient waste management system.

ACKNOWLEDGEMENT

My deepest gratitude to my supervisor Dr. Pallavi Mehta, for their guidance and support. Thanks to Rajasthan governments & Local residents of Kota and Jaipur for providing data and resources. I appreciate Ayushi,

Kaushiki, Ajay, Chandan, Akash, Khushi, help with editing, collecting data and information or also moral support. This research wouldn't have been possible without them.

There Is Some Emerging Innovative Technology to Reduce Food Waste and Enhance Circular Economy for Future Sustainability

Lomi

It presents an electric food recycler that transforms food scraps into homemade fertilizer, reducing greenhouse gas emissions and accelerating decomposition. Partnered with Pela, known for compostable phone cases, its aims to divert 10 billion pounds of food waste from landfills by 2028. Its innovative approach promotes a circular economy, fostering sustainable consumption and waste management practices. Lomi embodies a commitment to environmental stewardship, offering a practical solution for individuals and businesses seeking to minimize their ecological footprint.

Apeel

It introduces a natural coating derived from fruit and vegetable materials to enhance their freshness. This invisible layer preserves moisture and blocks oxygen, doubling the shelf life of produce. Apeel's plant-based formula ensures safety for consumption while reducing food waste. By extending the lifespan of perishables, it contributes to sustainability and minimizes landfill waste.

Full Harvest

It is an online B2B marketplace connecting businesses with surplus and imperfect produce, preventing food waste. Farmers list available items, and businesses can purchase them, supported by convenient delivery options. Full Harvest's Verified Rescued Produce seal assures customers of their contribution to reducing food loss. Their mission is to empower sustainability by ensuring that no fresh produce goes to waste, striving for a world with 0% food waste and 100% full harvest.

Hungry Harvest

It delivers surplus and imperfect produce via subscription boxes, promoting food sustainability. Customers enjoy diverse meals with unfamiliar produce and grocery staples delivered to their doorsteps. The company's user-friendly online platform allows for easy customization and convenient delivery. With a mission to combat food waste and bring "plant power to the people," Hungry Harvest has rescued over 27 million pounds of produce since 2014, donating a significant portion to local charities.

Imperfect Foods

It offers weekly subscription boxes filled with imperfect and surplus groceries sourced directly from farmers and brands. Customers receive affordable, sustainable products delivered to their doorsteps, with last week's box recycled upon delivery. With a focus on fighting food waste, Imperfect Foods' subscriptions enable customers to make a significant impact, potentially saving hundreds of pounds of food and reducing water consumption and CO2 emissions.

Wasteless

It is an AI-driven platform for supermarkets to minimize food waste and boost profits. By tracking buying trends, their Pricing Engine optimizes prices for maximum profitability, helping stores improve revenue and reduce waste. Wasteless aims to revolutionize grocery management by offering a one-stop solution that enhances profitability, reduces food waste, and improves the overall customer experience.

Neurolabs ReShelf

It is an automated retail tool that monitors products on shelves, predicting sales patterns and optimizing inventory management. By tracking buying trends and shelf life, it ensures popular items remain stocked while minimizing waste. Their use of Synthetic Computer Vision aims to revolutionize retail by automating root cause analysis and maximizing product availability.

Tenzo

It provides restaurant analytics software for informed decision-making. It offers detailed insights into financial performance and ingredient usage, helping businesses reduce waste and optimize operations. With an automated AI-forecasting platform, Tenzo guides restaurateurs in making cost-effective decisions based on sales patterns. Their aim is to revolutionize data utilization in the industry, enabling businesses to become more efficient and sustainable.

Winnow

It utilizes AI technology to tackle food waste in restaurant kitchens. Their system tracks discarded food, providing analytics for informed decision-making on ingredient purchases and freshness management. With a motion sensor camera and scale, Winnow displays real-time data, empowering kitchens to reduce waste and improve efficiency. Their efforts have saved millions of dollars, prevented millions of meals from being wasted, and reduced carbon emissions, aligning with their mission to promote sustainability in commercial kitchens.

Too Good to Go

It is an app allowing users to buy surplus food from local businesses at discounted rates. Businesses list surplus items as Surprise Bags for users to purchase and collect, reducing waste and attracting new customers. Since its launch, the app has garnered millions of users, onboarded numerous businesses, and saved millions of meals, making a significant impact on food waste reduction.

Copia

It connects restaurants and hospitality businesses with nearby non-profits, allowing them to donate excess food conveniently. The platform provides valuable data on food waste and assists with tax deductions, helping businesses give back to the community. Since its launch, Copia has recovered over 4 million pounds of food, delivered 3.5 million meals, and diverted over 18 million pounds of CO2e, advancing its mission to eliminate world hunger.

Dehydration Technology

This technology centred on bio-dehydration. The food waste typically contains high moisture levels, their approach involves grinding and drying the waste, swiftly reducing its volume. This process transforms it into a more manageable form, providing greater flexibility for potential reuse.

Enzymatic Breakdown - Grey Water Strategy

The genesis of restaurant-level waste technology can be traced to South Korea, it developed a keen interest in methane emission solutions. Pressman discovered a system marketed by ExBio in South Korea, which establishes a warm, oxygen-rich environment. Within this setup, a unique consortium of microorganisms efficiently digest waste, converting it into a form suitable for disposal as "grey water" down the drain.

Benefits of This Technology in Business & Government Sector

Technology plays a pivotal role in combating food waste through various innovative solutions. One approach involves facilitating surplus food donation by connecting businesses with local charities and food banks through apps and websites, ensuring efficient redistribution to those in need. The technology aids individuals in minimizing food waste at home by offering meal planning apps and devices like the LG Insta View Door-in-Door fridge, which enhances visibility and freshness, reducing the likelihood of forgotten items. Moreover, it supports composting efforts with home composting devices and apps guiding users to nearby composting facilities.

Besides individual efforts, government initiatives such as the USDA's Save the Food campaign and the Food Waste Reduction Alliance highlight collaborative efforts to raise awareness, provide resources, and engage businesses in reducing food waste through education and technical assistance, emphasizing the importance of collective action in addressing this global challenge. The global issue of food waste necessitates proactive measures from businesses to mitigate its impact. Operational adjustments, such as revising food preparation methods and optimizing packaging, can enhance efficiency and minimize waste.

Additionally, investment in innovative technologies, like sensor-equipped refrigerators and inventory-tracking apps, empowers businesses to preserve food quality and utilize surplus ingredients effectively. The reshaping attitudes towards food and fostering a culture of value are crucial aims. Businesses are pivotal in spearheading these efforts, leading the charge towards a more sustainable approach to food management.

DATA ANALYSIS

Table No.1

Gender		**Age**	
Male	34.1 %	18-24	43.9%
Female	65.9%	24-34	41.5%
other		34-44	12.2%
		44-54	7.3 %
		55+	

The data reveals a skewed gender distribution, with 65.9% female and 34.1% male representation. Among age groups, 18-24 dominates with 43.9%, followed closely by 24-34 at 41.5%. Smaller proportions are seen in the 34-44 age group (12.2%) and 44-54 age group (7.3%). Further analysis could explore interactions between gender and age for deeper insights.

Table No.2

Uneaten Food				
Daily	Several times a week	Once a week	Less than once a week	Never
12.2 %	12.2 %	26.8 %	36.6 %	14.6%
Urban Communities				
Reduced greenhouse gas emissions	Renewable energy	Soil enrichment through composting	Cost savings for municipalities	Promotion of circular economy practices
48.8%	34.1%	53.7%	29.3%	26.8%
Food Waste Generation				
Overproduction	Consumer behaviour	Supply chain inefficiencies	Lack of infrastructure for surplus food redistribution	Insufficient cold chain logistics
34.1 %	53.7 %	31.7 %	26.8 %	17.1%

Technologies				
Composting	Anaerobic digestion	Recycling	Food waste-to-energy conversion	Smart bins with automated sorting capabilities
22 %	14.6 %	46.3 %	58.5 %	29.3%

Food waste occurs mostly less than once a week (36.6%) and once a week (26.8%), while daily waste is at 12.2%. Urban communities prioritize composting (53.7%) and reducing greenhouse gas emissions (48.8%). Consumer behaviour (53.7%) and overproduction (34.1%) are primary food waste drivers. Food waste-to-energy conversion (58.5%) and recycling (46.3%) are favoured technologies, indicating a focus on energy recovery and waste management efficiency.

Table No.3

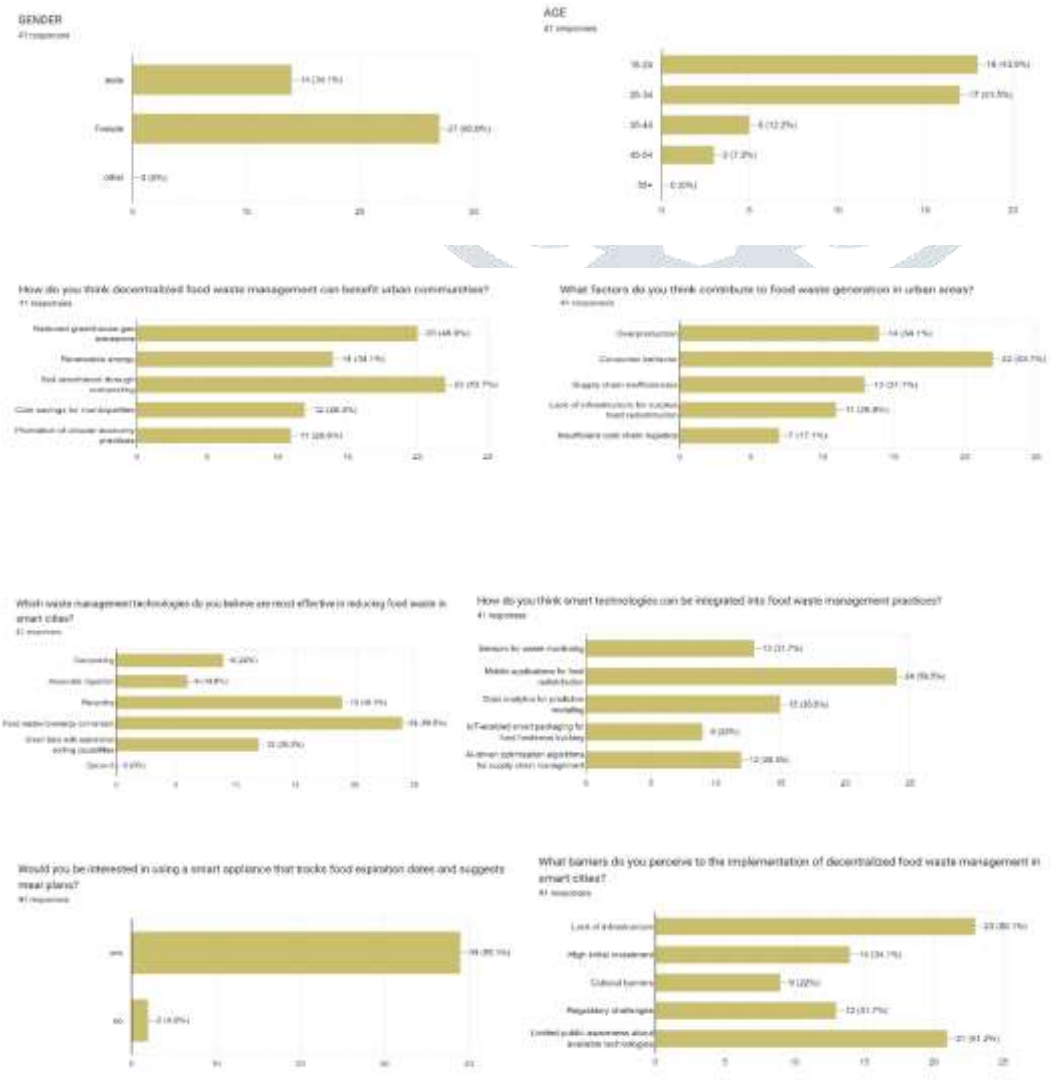
Mobile applications for food redistribution are widely adopted (58.5%), while decentralized food waste faces infrastructure challenges (56.1%). Smart appliances for food tracking are prevalent (95.1%), indicating a readiness for technology integration. Despite barriers, such as high initial investment (34.1%), there is a strong willingness to participate in pilot programs (90.2%). Understanding these dynamics can inform effective strategies for food waste management.

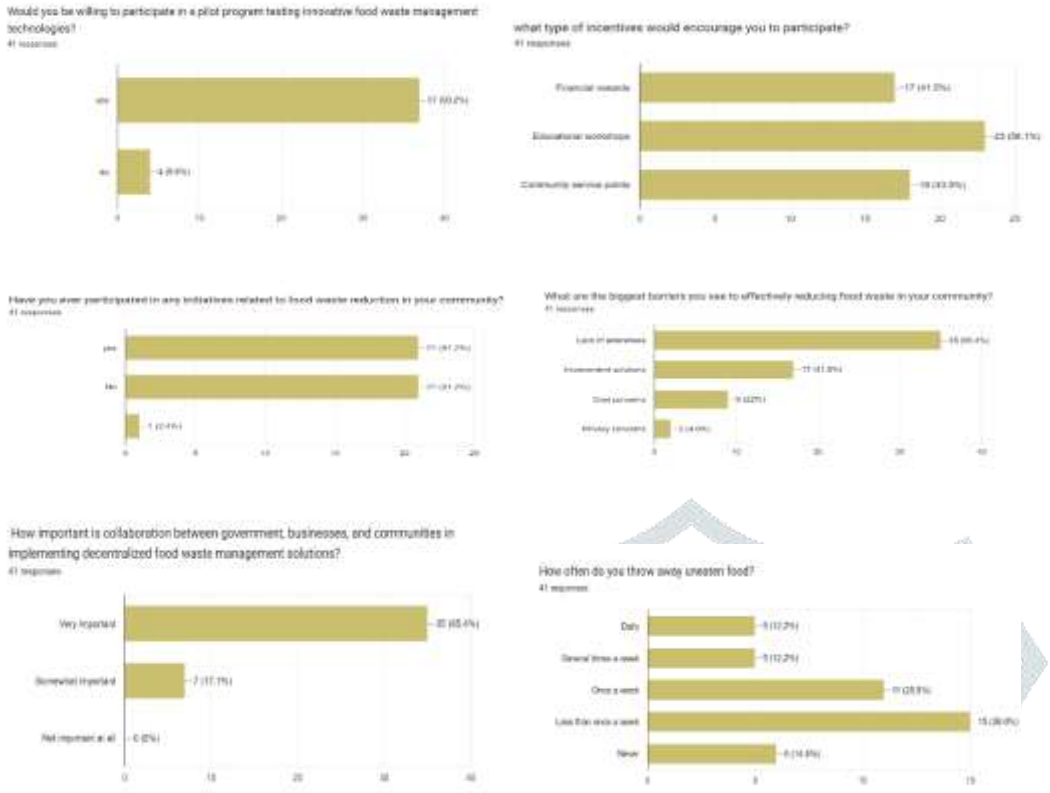
Integrated into Food Waste Management				
Sensors for waste monitoring	Mobile applications for food redistribution	Data analytics for predictive modeling	IoT-enabled smart packaging for food freshness tracking	AI-driven optimization algorithms for supply chain management
31.7 %	58.5 %	36.6 %	22 %	29.3%
Implementation of Decentralized Food Waste				
Lack of infrastructure	High initial investment	Cultural barriers	Regulatory challenges	Limited public awareness about available technologies
56.1 %	34.1 %	22 %	31.7 %	51.2%
Smart Appliance That Tracks Food				
Yes	No			
95.1%	4.9%			
Participate in A Pilot Program				
Yes	No			
90.2%	9.8%			

Table No.4

Incentives Would Encourage			
Financial rewards	Educational workshops	Community service points	
41.5 %	56.1 %	43.9%	
Food Waste Reduction in Your Community			
Yes	No		
51.2%	51.2%		
Biggest Barriers			
Lack of awareness	Inconvenient solutions	Cost concerns	Privacy concerns
85.4%	41.5%	22%	4.9%
Collaboration Between Government, Businesses, And Communities			
Very important	Somewhat important	Not important at all	
85.4 %	17.1%	0%	

Educational workshops (56.1%) and community service points (43.9%) are favoured incentives for encouraging food waste reduction. Lack of awareness (85.4%) emerges as the biggest barrier, highlighting the need for targeted educational efforts. Collaboration between government, businesses, and communities is deemed very important by a vast majority (85.4%), underscoring the recognition of shared responsibility in addressing food waste. Understanding these dynamics can inform effective strategies for fostering behaviour change and promoting sustainable practices in food waste management.





CONCLUSION

This research underscores the pressing global concern of food waste and its multifaceted impacts on the environment and economy. Decentralized food waste management presents a promising avenue for localized solutions, particularly in the context of smart cities. It aims to optimize waste reduction, resource recovery, and user engagement while considering economic feasibility, environmental benefits, and social acceptance. By integrating innovative waste management technologies, such as smart bins and food waste conversion technologies, Our investigation will assess the effectiveness of these technologies in waste reduction, resource recovery, and user engagement within smart city environments. Ultimately, this research seeks to identify integrating innovative technologies into decentralized food waste management systems, thereby contributing to substantial reductions in food waste and its environmental burden.

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