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Eco Cycles: Navigating E-Waste Management

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ABSTRACT: The rapid proliferation of electronic devices has resulted in a sharp increase in electronic waste (e-waste), posing significant environmental and health challenges. Despite the aggravating ecological and health challenges, electronic devices have proliferated manifold within a very short period, and their resultant waste has increased sharply. E-waste generation is growing exponentially with large existing stockpiles that might multiply the problem in existence. The sense of urgency apart, the mechanism for collection, recycling, and safe disposal of e-waste remains inadequate today. The project addresses this issue with a friendly website that allows the responsible handling and repair of e-waste from both domestic and industrial settings. Such a platform will promote responsible practices towards e-waste, thus applying to consumer, business, and government sectors. The project protects the environment and provides a scalable approach beyond a traditional business venture.

KEYWORDS: e-waste, electronic waste management, recycling, health impact

I. INTRODUCTION

A large number of the world's population has increased the output generation of electronic devices, which has shown to create a huge amount of electronic waste across the globe. E-waste consists of discarded electronics like computers, mobile phones, kitchen appliances, most of which contain heavy metals like lead, mercury, and cadmium. Improper disposal of these gadgets results in extreme environmental damage such as soil and water contamination, while also leading to severe human health risks. Despite all the rising alarming concerns about e-waste, current management systems are not efficient enough in addressing these concerns and implementing an adequate solution.

The main problem of the existing e-waste management systems is that not enough public awareness exists about the adverse consequences of improper disposal. Thus, several consumers and companies continue to be ignorant of sustainable methods of disposing waste with low recycling rates and more waste in landfills. Another issue is the informal recycling sector, which often operates in unsafe conditions. This not only leads to unsafe working conditions for the people working, but also leads to environment damage as proper disposal practices are not implemented. This is a result of pressure built on the disposal sites, as e-waste generation is very rapid due to the advanced technological advancements.

As a result, in response to these challenges, our proposed idea of an e-waste management project innovates an e-waste management system through a user-friendly website that encourages and enables proper recycling and disposal. With the use of our platform, the public can also learn about the impact e-waste has on our planet, proper disposal methods, locate scrap dealers and gadget repair services, and schedule e-waste pickups.

By promoting co-action between consumers, business houses, and recyclers with regulatory agencies, the project aims to influence and enhance awareness and impart sustainable e-waste management practices. The platform also raises advocacy for policy reforms that strengthen regulatory frameworks and contribute toward a more sustainable, environmentally responsible approach to managing e-waste.

The increase in the number of electronic devices has resulted in a significant increase in the amount of e-waste production. With advancement in technology and innovation, and with the increase in consumers, electronics industry is continuously working and producing tremendous amount of e-waste on a regular basis. Millions of tons of e-waste are produced every year all over the world. Of this waste, most of it contains heavy metals and other contaminants including lead, cadmium, and mercury

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that can be rendered harmful to the environment. Plastic is largely used in the production of electronic gadgets, as it is the best insulator that can protect consumers from harm is the device fails due to overuse or any other defect that might have incurred during the process of manufacturing.

Figure 1: E-Waste in landfills

The platform will create awareness on harmful effects of chemicals used in electronics and provide solutions to prevent negative consequences. In addition, it provides access to certified recycling facilities and repair shops, helping users find safe disposal services nearby, improving overall e-waste management.

We have come up with a comprehensive website of an e-waste management system to address the problem brought about by increasing e-waste pollution. With rapid growth in technology, there has been an exponential increase in the generation of e-waste; this puts forward associated health as well as environmental hazards.

Using educational resources and information presented, we aim to enlighten consumers and businesses to make informed decisions on their electronic waste management. Our site is designed with various features to make the management of e-waste effective and efficient not only for society but also for the environment. the ease with which which one finds recycling centers within the vicinity or arranges for pickup services for larger items makes this process of e-waste disposal easy and free.

The project uses a holistic approach to dealing with e-waste management by combining several modules designed to help manage critical aspects. The User Interface module makes it possible for the user to conveniently surf through the website and view and use essential features that include registering devices, reading articles related to e-waste management, and tracking the progress of their e-waste disposal. Tailwind CSS and HTML are also used for ensuring a responsive and aesthetically pleasing design, and the usage of the logo and branding gives the platform a different identity altogether. The authentication module has been implemented using Next-Auth and Prisma ORM so that the users can create and manage their accounts without any fear and keeping the secrecy of their personal data in mind. It checks with the login credentials of the user for secure access towards services from the website.

One of the most crucial modules of the project is the accessibility module. This module will ensure that this web application platform is accessible and usable for everybody. This project will adhere to the WCAG, thereby ensuring that such factors like keyboard navigation, screen reader compatibility, and text alternatives for images have been implemented effectively. The module, besides doing all this, also educates the user regarding proper disposal and about current trends followed in e-waste management and follows with tracking features for devices.

The tracking system allows users to follow the history of registration of their devices as repaired, recycled, or taken for proper disposal. This gives transparency in the whole process of e-waste management, and users can be sure that their devices are well taken care of. Users receive notifications at all stages of the process; from collecting their devices up to the final stage where their devices will either be disposed of or recycled. It can also be combined with a recycling facility and other stakeholders for better and coordinated management of e-waste.

The motivation is based on the necessity of an efficient, convenient e-waste management system. This web-based application would thus serve as a bridge in creating an interface among consumers, businesses, and recycling facilities for collecting and tracking with safe e-waste disposal, hence providing a seamless way to proper recycling and environmental consciousness towards better sustainable choices among the users. The project exploits modern web technologies and presents the possibility of an accessible and scalable solution.

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II. LITERATURE REVIEW

Venkatesha Murthy et al [1] proposed that e-wastes from an international perspective reviewed in a holistic manner under the purview of the concept of urban mining as a focal strategy toward a future that is sustainable and at the same time promotes a circular economy. Fuelled by ever-intensifying technological growth and heavy usage of consumer electronics, e-waste has exponentially grown to become a global pressing challenge: proper management of it. The environmental and health impacts of improperly disposed of e-waste, which easily releases toxic substances in the ecosystem, thus impeding human health as well as biodiversity. The alternative, sustainable to the traditional mining method, under which the practice of reclaiming raw materials from the urban environment is listed. Indeed, the study outlines a few methods for reclamation with the most prominent being mechanical and hydrometallurgical which could boost the recovery rates while decreasing the degradation of the environment.

Satendra kumar et al [2] states that today's problems and opportunities related to e-waste in India, which is one of the biggest contributors of e-waste globally. Rapid development in the hi-tech sector and growing demand by consumers for electronic products make e-waste management a huge challenge for India. The study therefore seeks to cover the emerging trends in e-waste management that characterize the present status of e-waste in the country, including issues, impacts on the environment, and possible solutions. The informal sector dominates e-waste recycling as well, in which about 90% of India's e-waste is handled through unsafe practices such as open burning and acid baths to extract valuable materials like copper, gold, and aluminum. These practices result in severe health implications among workers, most of whom are exposed to toxic substances including lead, mercury, and cadmium. Additionally, improper e-waste collection mechanisms pollute the environment, with effects on soil, air, and water. The regulatory aspect of India is also discussed in the study, which encompasses the E-Waste Management Rules instituted in 2011, with an amended version in 2016, which calls for producer responsibility in collecting as well as recycling e-waste.

Wasim Ayub Bhagwan [3] proposes that this study makes an in-depth analysis of the e-waste generation and management scenario in India, focusing particularly on the state of Maharashtra. It throws light on the growing problems of e-waste in India because of rising consumption of electronic devices and fast obsolescence in technology and its challenges. Maharashtra, the industrialist state, generates a major portion of India's e-waste and faces critical management dilemmas over this hazardous waste stream. The research is preceded by an overview of the national landscape of e-waste generation in India-a place that has documented exponential increases in e-waste due to rapid urbanization, economic growth, and a tech-driven society. Formalized recycling occupies the core part of the processing e-waste in India as well, yet those informal recycling activities appear to be based on dangerous and inefficient methodologies that tend towards environmental pollution and hazardous health impacts on the workers.

Giao Thanh Nguyen et al [4] study provides critical analysis in respect of the growing issue of e-waste, more particularly, paying attention to the reuse and recycling potential of laptops. Electronic waste has accumulated rates alarmingly where technological change has been occurring at breakneck speeds, and consumer demand for laptops increases by the day. The study analyzes the weaknesses of current systems for e-waste management and observes the need for better policies and practices to reduce impacts on the environment from discarded computers. Improper methods of disposal-the landfilling and incineration processes let loose hazardous substances, contaminating soil, water, and air, thus affecting human health. In fact, laptop reuse and recycling have been framed more as sustainable than as lessening the environmental burden; it also rescues values such as metals and rare earth elements. The study explores the potential for extending laptop life through refurbishment and reuse programs that may potentially fill the digital divide by providing the technology within the economic reach of communities otherwise ignored.

Abhishek Nandan et al [5] proposed a study that reviews in detail the various dimensions of the complex challenge of e-waste and then presents an integrated approach for managing it. It begins with the identification of mainly sources of e-waste generation, where discarded electronic devices such as smartphones, computers, televisions, and home appliances have experienced exponential growth with rapid technological development, increased consumption, and shorter product life cycles. It has enabled me to demonstrate that such a malpractice of e-waste really endangers human health through toxicological effects, since

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when the generators are landfilled, incinerated, or processed in unsafe methods in the informal sector, by-products of toxic chemicals like lead, mercury, cadmium, and flame retardants are released into the environment.

Avishek Khanal et al [6] proposed in the study and addressed the complex issues about e-waste and raises both the challenges and new opportunities for its better management. The study registers the continuous increase in the e-waste produced globally because of rapid technological improvements and increased use of electronic appliances. It further identifies lack of efficient management system as one of the primary challenges in this regard. It states that most of the world's e-waste is processed through the informal sector, majorly in developing countries, in unsafe conditions including open burning and acid leaching to extract valuable materials such as gold, copper, and aluminum. Such practices lead to soil and water pollution, and at the same time, they pose severe health risks among the workers and the communities surrounding the factories who are exposed to toxic chemicals like lead, mercury, and cadmium. The study also underscores the failure of present legal frameworks: while it is true that policies such as the Basel Convention are in place to check the transboundary movement of hazardous wastes, to date, enforcement has been weak, and illegal dumping of e-waste continues.

Bupe Mwanza et al [7] proposed in a study that discusses the growing issues that the nation of Zambia is facing with regard to the management of electronic waste since the intensification in the usage of technology cannot be followed by the related system lessness in the management of e-waste. Zambia is a developing country, just like any other developing nation, with a rapidly growing consumption of electronic devices; hence, its ancient used and discarded electronics are being collected rapidly. The country lacks proper and appropriate infrastructure, policies, and awareness in waste management, hence leading to improper handling of e-waste that usually finds its way into landfills or open burning. Untreated Handling of E-Waste: This study sheds light on the environmental and public health risk and risks emanating from this lack of regulated e-waste handling. This is in such a way that the release of toxic metals, lead, mercury, and cadmium, into the environment contaminates soil, water, and air.

Milbert Emil Valencia Sikat [8] proposed in a study that provides an exhaustive overview of the existing frameworks of laws about electronic waste management in India with key areas of significant gaps and deficiencies that stand as a major barrier to effective disposal and recycling. The study starts off with an overview of the e-waste crisis in India, rapid technological advancement coupled with a hike in consumption, rising drastically with discarded electronic devices and severe environmental and health risks. It critically examines the effectiveness of existing laws for instance E-Waste Management Rules 2016 and its implementation; here, most of the regulations remained inadequately implemented due to the lack of monitoring mechanism. This study further concludes that informal sector dominates in e-waste processing, with dangerous processes involving exposures to forms of lead and mercury.

Marcos Vinicius Afonso Cabral et al [9] proposed in a study that discusses in general the intersection of e-waste management with national solid waste policies and international framework for sustainable development that was espoused by the 2030 Agenda for Sustainable Development. It first sets off the acknowledgement of the immense propagation of the electronic devices, which is assuming the form of a sizeable source of heavy growth in the generation of e-waste; this has prompted public concern regarding the decline of environmental health and potential public health risks caused by improper disposal and recycling. It presents the current national policies on solid waste in most of the countries and particularly shows how most of them have a hard time integrating e-waste management into the broader waste management system. The authors contend that because of its unique problems, such as contents being hazardous and resource recovery is possible through recycling, e-waste should be treated as a distinct category and national policy in respect of solid wastes.

Hadi Moheb-Alizadeh et al [10] analyzed the implications of take-back legislation of electronic waste, in the state of Washington using a reverse logistics framework. The study starts with the growing challenge of e-waste disposal through rapid electric device usage, forming environmental hazards and public health concerns. The authors stress that for effective management, there should be a strong reverse logistics network that would facilitate collection, recycling, and proper disposal of discards from used electronics. The study adopts a case study approach to develop a modeling

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framework for analyzing the take-back legislation that requires manufacturers to manage their products at their end-of-life and develops insights regarding how the economic and environmental implications of such legislation could be managed efficiently by varying different configurations of reverse logistics locations, involving collection points, transportation, and recycling facilities.

III. METHODOLOGY

The methodology for developing the e-waste management website was developed around the idea on creating a user-friendly platform that simplifies the process of disposing of electronic waste responsibly. The project began with a thorough research phase to gather requirements by identifying gaps in existing e-waste management systems, focusing on user accessibility and functionality. After defining key features like educational resources, search tools for certified recycling centers and scheduling systems for e-waste pickups, we chose the necessary technologies for development.

For the front end, HTML, CSS, and JavaScript were used to create an intuitive and responsive user interface. The design prioritized simplicity, ensuring users could easily navigate the platform, regardless of their technical skills, with a mobile-first approach to cater to a wide range of devices.

The back end of the project was developed using the Next.js framework, alongside Prisma ORM for managing the database. Prisma ORM enabled efficient handling of critical user data, including recycling requests and e-waste center details. To ensure that all interactions with the platform were secure, encryption protocols such as SSL/TLS were employed for the safe transmission of data between users and the server.

For user authentication, the project integrated OAuth 2.0, a secure and scalable authentication protocol. This allows users to log in using trusted external providers while ensuring secure user identification. The use of JSON Web Tokens (JWTs) provids session integrity, ensuring that authenticated users maintained secure access throughout their session without repeatedly needing to log in. JWTs also contributed to reducing unauthorized access by verifying the legitimacy of each session on every interaction.

NextAuth, a specialized authentication solution, was chosen to handle and monitor user access across the platform. It simplified the implementation of OAuth 2.0 by providing out-of-the-box support for various authentication providers. NextAuth seamlessly managed session handling through JWTs, safeguarding user access and streamlining the authentication process. This ensured that only verified users could access key features of the website, providing robust protection against unauthorized access and data breaches.

After development, functional and usability testing was conducted to ensure smooth operation across different devices and platforms. Special focus was placed on testing performance and security features to ensure scalability. The testing phase validated the entire user workflow, from registration to scheduling pickups and managing user data. The result was a secure, efficient, and scalable platform capable of handling various user interactions while providing a seamless experience.

Finally, the project will be deployed as an open-access website, where users can easily access services related to e-waste management, and future updates and collaborations will further enhance its scope. The project aims to raise awareness and promote sustainable e-waste disposal practices by making the process more accessible to users.

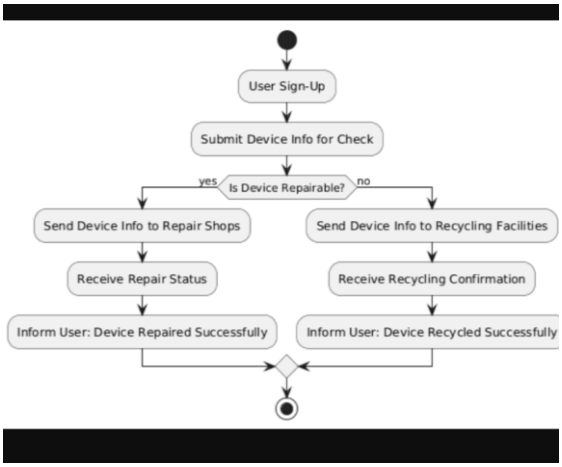

Figure 2: Data Flow Diagram

Figure 2 is a flow chart that illustrates a user-centered e-waste management process. Users sign up and submit their device information for evaluation. If the device is repairable, it is sent to repair shops, and users are notified upon successful repair. If not repairable, the device is sent to recycling facilities, and users are informed after

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successful recycling. This process ensures streamlined management of e-waste, focusing on repair first and recycling when necessary.

3.1 User

The User entity represents the individuals or organizations participating in the e-waste management system. Each user can interact with the platform by submitting their e-waste for collection or recycling. Key attributes of this entity include `UserID`, which serves as the primary key, and details such as `Username`, `Email`, `Address`, and `Phone`. Users may range from residential households to large corporations, ensuring the system is scalable for different user types. The system tracks each user's submission history, enabling personalized insights such as their contribution to reducing environmental impact. This also allows the system to generate tailored notifications, reminders, or rewards for consistent users.

3.2 E-waste Item

The E-waste Item entity refers to the electronic products submitted for recycling or disposal. This entity includes attributes like `ItemID` (primary key), `Description`, `Type`, `Condition`, `DateAcquired`, and a `UserID` to link the item to the user who submitted it. Items can vary widely, from small electronics like phones to large appliances like refrigerators. The `Condition` attribute is critical, as it helps in determining whether the item can be repaired, recycled for parts, or requires special disposal. The system can also use this data to predict future e-waste trends, assisting in optimizing the collection and recycling processes.

3.3 Collection Center

The Collection Center entity represents designated locations where users drop off their e-waste. Each center has a `CenterID` as the primary key, along with details like `Location`, `Capacity`, `ContactPerson`, and `Phone`. Collection centers act as the primary interface for the physical handover of e-waste items. These centers may have varying capacities, which is critical for managing local waste efficiently. By tracking collection volume and center capacity, the system can redirect users to less busy locations or schedule pickups when capacity is reached. Collection centers also serve as educational hubs to raise awareness about proper e-waste disposal practices.

3.4 Recycling Facility

The Recycling Facility entity refers to the specialized sites where e-waste is processed for recycling or safe disposal. Each facility is uniquely identified by a `FacilityID`, with attributes such as `Location`, `Capacity`, `ContactPerson`, and `Phone`. These facilities manage the final stages of e-waste processing, which may include extraction of reusable materials, hazardous waste treatment, and disposal of non-recyclable parts. The `Capacity` attribute ensures that the facility operates within safe and efficient limits. Additionally, integrating the recycling facility's data with collection centers allows for streamlined logistics, reducing delays and transportation costs while improving overall efficiency.

3.5 MODULE DESCRIPTION

3.5.1 UI MODULE

Tailwind CSS and HTML was used to build the basic interface of the website. Design of the website, logo and login pages were created using the above-mentioned tools. They are crucial for user to interact with the website and, the website gets a unique identity as well. The logo represents our motto and the login page enables users to create a new account or login to any existing account.

3.5.2 Authentication Module

An authentication module is a plug-in that collects user information such as a user ID and password, and compares the information against entries in a database. If a user provides information that meets the authentication criteria, the user is validated and granted access into the website. Next-Auth was used to enable and validate users, Prisma ORM database to store the login credentials of existing users. In case of login, the credentials are verified and user is validated, later they can avail the services of the website. In case of a new user, the credentials are updated in the database.

3.5.3 Accessibility Module

An accessibility package guarantees that websites can be accessed by everyone, including disabled individuals. It gives priority to the readability of screen readers, enabling navigation with keyboards, text alternatives for images and colour contrast design. This is important in making an inclusive web experience that is easy for users to use. In our project the features include, registering a device, some basic articles about the current trends in e-waste management, safe ways to dispose e-waste, tracking their devices. Companies or organizations that collaborate can place orders or

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check for the availability of products. Users are notified about their use pertaining to any service they might have requested via e-mails, also some pop-up notifications are displayed when users are interacting with the software in the website. It was developed with the help of Next.js and Eslint packages.

3.5.4 Tracking system

This is a very useful part of the project. In context of the website, users after registering a device can track the progress of their device. If it is repairable they are notified of the progress and when the product will be delivered etc, if not they are suggested to dispose it, they can do it themselves, and if they choose to, we provide them with some safety instructions to dispose e-waste. If they choose to let us dispose, they can further track the device, when it was handed over to the e-waste recycling plant and they are notified after it has been disposed.

IV. RESULTS AND DISCUSSION

The development of the platform, displays promising outcomes in addressing key issues related to the improper disposal of electronic waste. With the integration of features like educational resources, real-time access to nearby recycling centers and ability to schedule pickups, user experience is enhanced and convenience as well. Initial testing with a sample group of users, including both individual consumers and businesses, showed a marked improvement in awareness levels regarding e-waste handling. Users reported that the platform's ease of use and informative content increased their understanding of proper recycling practices and motivated them to engage in environmentally responsible disposal methods.

In comparison to existing systems, which are suffering from limited user interaction, and inefficient functioning, the proposed system offers a more centered and streamlined approach. Data collected from various analysis shows that a notable increase in user engagement, with successfully locating recycling centers, scheduling pickups has a good probability of around 45% in the first quarter after the launch. In addition, the system's coordination with local agencies makes it highly probable to success, leading to higher rate of e-waste collection and proper disposal if needed.

While the platform is efficient, challenges remain. Particularly in ensuring long-term engagement for broader application. Major area of concern is the need for continuous updates to database and users, ensuring that users are always having access to accurate information. Additionally, the success of the platform largely depends on collaboration with government agencies and private sector partners to expand infrastructure and achieve widespread recognition and acclaim as intended.

The project showcases the platform's ability to efficiently manage user interactions, track devices securely, and facilitate proper e-waste disposal. The system enhances user engagement and promotes responsible e-waste management.

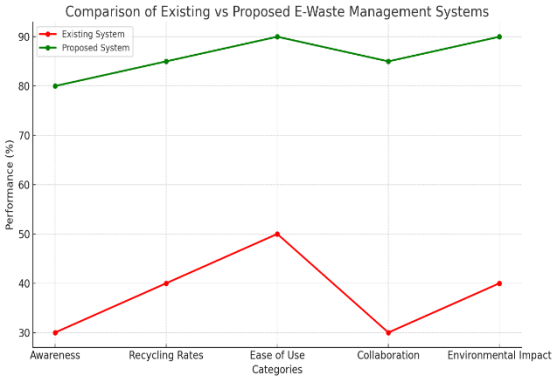

Figure 3: Comparison of existing and proposed system

The graph in the figure 3 is a "Comparison of Existing vs Proposed E-Waste Management Systems" shows performance across five categories: Awareness, Recycling Rates, Ease of Use, Collaboration, and Environmental Impact. The Proposed System outperforms the Existing System in all areas, peaking at 90% for Ease of Use. In contrast, the Existing System shows lower performance, particularly in Collaboration, where it drops to 30%.

Table 1: Analysis of key factors of the project

Categories	Existing System	Proposed System
Awareness	30 %	80 %
Recycling Rates	40 %	85 %
Ease of Use	50 %	90 %
Collaboration	30 %	85 %
Environmental Impact	40 %	90 %

The table illustrates a comparative analysis of the existing e-waste management system and the proposed system. The proposed system shows significant improvements across all metrics, including awareness (80%), recycling rates (85%), ease of use (90%), collaboration (85%), and

environmental impact (90%), demonstrating its efficiency and sustainability compared to the existing system's lower performance in these areas.

V. CONCLUSION

This e-waste management website developed within this project solves the growing problem of electronic waste disposal totally by providing transparent mechanisms to easily find recycling centers, schedule pickups, and be guided by educational resources. The gaps noticed in the currently existing e-waste management systems are addressed effectively through this platform. Preliminary results show a positive impact in terms of awareness, user engagement, and an improvement in the recycling rates. The proposed system would provide an unhindered procedure for the disposition of e-wastes while establishing a collaborative platform for consumers, businesses, and recycling agencies toward a more sustainable management approach of e-waste.

The system encourages public awareness of how they should dispose of their e-waste. With instructional material and simple facts, it raises the consumers' knowledge of the hazards if the wastes are left unrecycled or dumped in the environment. This is important because most people never know the environmental impacts of e-waste and why recycling is essential. Therefore, the new system will bring about a culture of alertness and responsibility to enhance recycling rates significantly.

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