Digital solution for sustainable e-waste management

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***Abstract*— The problem of electronic waste is increasing at a rapid pace every year. In today's time, people often buy a lot of electronic items like power banks, mobiles, laptops, TV etc. The old devices are thrown away without thinking what it would cause to the environment, also harm the aquatic life when thrown in the river. These electronic items contain harmful chemicals which can pollute the soil, water and air. To address this critical problem in a effective manner, we introduce a platform named E-collector which is a digital platform. This platform solves this problem for both the user and institutions, by facilitating them to dispose e-waste in a safe manner. To solve this problem we introduced the feature of educational popups which educate the user regarding the harmful feature present in their device. The platform through the map shows the nearest e-waste centers in their area. Users can enter their location & search for authorized e-waste centers. we have introduced reward system based on the precious metal retrieved from the device in this way we build an end to end process to tackle the problem of electronic waste.**

***Index Terms*—E-waste, Electronic collector, electronic waste disposal, credit value estimation, pickup scheduling, institutional recycling educat-, ional pop-ups, hazardous materials, device histories, behavioural experiments, predictive governance, survival curves, lifecycle tracking.**

I. INTRODUCTION

The issue of disposal, collection and proper recycling of electronic waste is a big problem, every year lots of e-waste is directly thrown into the river, which pollutes rivers and harms the aquatic life, due to this waste gets deposited near riverbanks and corners. To address this problem, we have to understand what the e-waste is, meaning of electronic waste is old, unused or broken electronic items like computers, mobile phones, televisions and batteries. In today's world technology is growing at a rapid pace, and the lifecycle of product is getting reduced, people want to buy new devices, due to this the world of e-waste has become one of the fastest growing problem, because people simply throw their devices without thinking how it would affect the environment. This problem is dangerous for both environment and human health. The reason why e-waste is becoming a problem because it contain toxic chemicals.

like lead, mercury, cadmium and other harmful chemicals, if these e-waste are not properly recycled or dumped, then it can cause both land and water pollution, other reasons are e-waste contain non-biodegradable item like plastic and metals, they don't degrade for years, due to which waste management becomes difficult in cities, another reason can be open burning of e-waste which causes air pollution.

The problem does not only involve how it will be collected, but also how the whole process of disposing it should be made user friendly, so that people can dispose their e-waste properly.

most of the time people are not aware where to take their retired gadgets, or they do not think what will happen when their device will be disposed, they do not even check whether they are giving it to an authorized center. People keep their old, retired gadgets at their home for years without any use, or they handover it to scavengers who use harmful ways like open burning and acid extraction.

Numerous studies have shown problem of electronic waste is increasing every year. According to global E-waste Monitor 2024, in the year 2022 around 62 million tonnes of e-waste got generated over the world, this amount is increasing every year by 2.6 million tonnes, it's main reason is increasing

consumption [1]. The gap between e-waste getting generated and e-waste getting recycled is increasing. According to E-waste Monitor's research e-waste contains valuable materials like gold, copper and palladium, but only 17.4% of total e-waste get's collection. The main reason for this is complexity in the collection and processing systems. Researchers have confirmed that consumer behavior and weak infrastructure has been the main reasons of this in the process of electronic waste disposal. If users do not have easy tools and incentives, then they follow unsafe disposal practices, which is harmful for the environment.

Various researches show that increasing volume of e-waste which contains both hazardous and valuable materials, can cause serious health risk for the human, especially when the disposal system and recycling systems are informal and weak. Therefore there is an urgent need for public awareness and strong recycling systems, coordinated systems which support the e-waste disposal, this creates an opportunity for a practical solution in this space, which is proposed in this research paper. A major portion of e-waste does not reach the right recycling facilities, this is the main reason of this problem. According to a review of e-waste management in India, only 20–25% of e-waste is officially recorded and registered, rest of e-waste goes in the landfills which pollute the environment [3]. According to a study on e-waste and its impacts it is a small portion of the total solid waste, still since it contains lead, cadmium and chromium like elements, it is responsible for the 70% of the toxicity [5].

When devices are burned, or through dangerous chemical process are broken, so these materials get mixed in the air, water and soil, which creates long term health problems. Our platform introduces a chatbot which assists the user in knowing about this topic, its consequences and benefits they can receive by submitting their e-waste. The problem with e-waste, in this case, involves not only how it will be collected but also how the whole process of disposing it should be made easy and user-friendly, so as to ensure that people are able to dispose of it in the right way. This is where, most of the time, users are not aware of where to take their retired gadgets whether it is an authorized place for disposing of at a recycling center, or what will eventually happen to their garbage when it has been disposed of.

Below is table 1 which shows about the categorization of e-waste sources and system interventions.

TABLE I

CATEGORIZATION OF E-WASTE SOURCES AND SYSTEM INTERVENTIONS

Group	Source	Intervention
1	Institutional e-waste	Dashboard for bulk tracking
2	Household stored devices	Awareness notes and credit option
3	Rapid replacement cycles	Easy steps to submit old devices
4	Informal processing sector	Routing waste to authorized centers
5	Disposal forecasting	Using past data for future estimates
6	Awareness gaps	Showing harmful materials in devices
7	Predictive modelling	Estimating recoverable materials
8	Policy requirements	Supporting EPR-based recycling

II LITERATURE SURVEY

Several existing approaches and interventions highlight that e-waste management is a complex and multi-dimensional problem, especially in countries like India and also all over the world [2, 4], where there is no well developed collection, recycling and disposal system which is efficient and customer friendly. Currently the e-waste management is mostly depends on the informal sector [6], in these sectors safety rules and environment guidelines are not followed in a proper manner, which causes harm to the environment [7]. One of the biggest problems is that there is no digital record available for the lifecycle of the e-waste like where the product is manufactured, who is using the product, at last where it got disposed, the data of above mentioned processes is not tracked, therefore it is difficult to confirm that e-waste has been disposed and recycled in a safe and authorized way, due to this rules like Extended Producer Responsibility (EPR) had also became difficult to implement.

There is a lack of awareness on the customer side regarding the disposal of the e-waste [8]. In today's time there are lots of mobile app and cloud platforms, IoT and data analytics like tools are available in the market, using these tools we can make more transparent the e-waste management process. Today there is a huge need of proper centralized e-waste management system, also there is lack in coordination between stakeholders, consumers, producers and recyclers, therefore there is a need of platform to connect the stakeholders which track the whole lifecycle of the e-waste in real time, such type of platform helps in sustainable e-waste management, resource recovery and environmental protection, such type of solution is

needed to solve the problem of e-waste in the long run. Researches indicates that institutional participation like startups and educational institutions can submit e-waste in bulk for recycling and disposal purpose. Educational institutions or startups can send disposal request to authorized e-waste centers, and once their request has been accepted by the center, they can submit their e-waste.

The workflow of the website is user can submit the type of e-waste they want to submit, quantity of e-waste, photo and tell the working condition of the device, then the request will be forwarded to the nearest e-waste recycling centers, after the authorized center accept the user's request for e-waste submission then the pickup is scheduled at the appropriate specified time, after the disposal of electronic items, depending on the amount of precious metal retrieved from the device, based on these credit point is generated which will be further converted into cash or coupons.

Through awareness, we also want to draw Government attention so that it stop the open burning and acid leaching practices to prevent environmental contamination. Public education campaigns can promote responsible disposal, highlight environmental and health risks and also encourage the principle of Reduce, Reduce and Recycle [10].

Previous have explored technological interventions, the concept of micro recycling hubs has been explored. These uses low energy mechanical separation and using chemical process, extraction of valuable metals is done. These small urban centered recycling facilities reduce the cost of transportation and it also discourage the improper disposal. Through these hubs the recovered metals like copper, gold, cobalt and rare earth elements can be further integrated in the manufacturing chain. This increases the reuse recovery of raw material and also utilizes the natural resources efficiently.

Studies have also suggested that incentive-based digital platforms increases the customer participation .Reward points, cashback and certificates motivate the end users to submit their e-waste to the authorized recycling centers. It also highlight that centralized dashboards helps government institutions and organizations to sustainably monitor the performance and the coordination between government, private sector and citizens helps in responsible and sustainable disposal of the e-waste. Talking about the behavior change of the end user can be done through the incentive based system, when the user will get reward for the work in form of cash coupons and certificates and mention on our website, then they will feel good and more responsible, the whole process increases engagement also increases the participation in formal e-waste recycling systems.

III.METHODLOGY

The focus of the methodology used to develop E-collector is to create a simple, transparent, and digital solution that enables both individuals and institutions to submit and dispose of e-waste in a safe and responsible manner. The website approach is designed in such a way that every individual user can clearly understand what is happening at each step of the process. Users also receive clear guidance throughout the steps, which helps them make easy and informed decisions, it also ensures that authorized recycling centers receive accurate information regarding the type of waste, quantity, and other relevant details. This clarity and accuracy make the recycling process more efficient and well organized.

Fig. 1 displays the home interface of the E-collector platform, which consists of the home page along with links to various pages such as the Blog page, Startup Support page, and Credit page. The complete methodology includes multiple stages such as awareness creation, device evaluation, credit justification, structured pickup scheduling, tracking and monitoring, and an institution dashboard, all of which work together to provide a smooth and accountable e-waste management process.

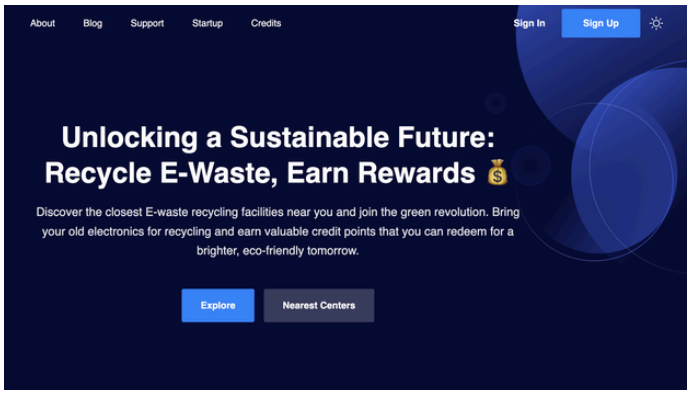

Fig. 1. Homepage interface of the E-Collector platform displaying the core objective and user navigation options.

Below in the fig 2 is a flow chart which explain the flow of application

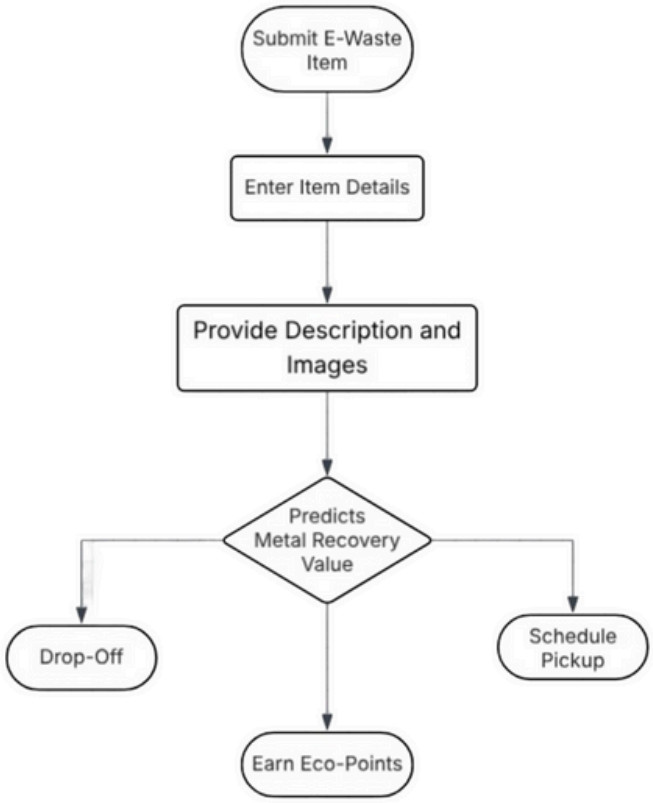

Fig. 2 Flowchart of e-waste management in the proposed application

A. Awareness Through Device-Specific Educational Pop-ups

The first step in the methodology involves building awareness at the user level, most people are not aware about the harmful materials their device contain, therefore they don't think about before throwing them or storing them unnecessarily. This step involves initiating the user to perform the required step. To solve this problem our platform introduces customized educational popups based on the category of the device user select, for example when some person selects smartphone in the option the system instantly shows a small popup explaining that the device contain lithium in the battery, lead in the circuit, brominated retardants in the casing. These popups are not random or generic, it appears based on the device, this makes the user aware at the exact moment when he is deciding to dispose of the device .The unique thing in this feature is awareness become specific, personal instead of long random warnings that people often ignore.
Below is a fig 3 explaining the user features supporting awareness.

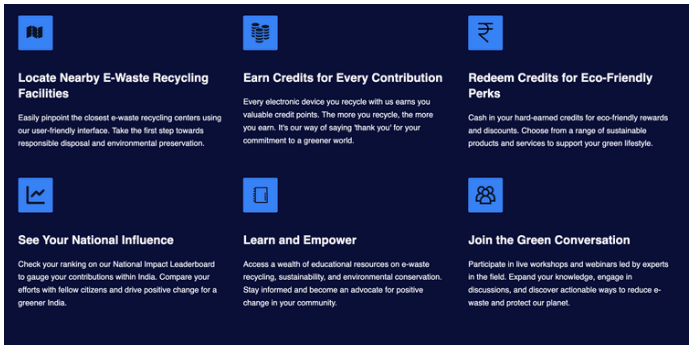

Fig. 3. Key user features supporting awareness,

B. Device Model Input and Estimated Credit Calculation

After the awareness section, next stage involves determining estimated credit points based on the user's old device. The system asks the user to submit the model name of the device, type of the e-waste, quantity, working condition and image of it. based on all these points the system generates the credit value dynamically. To achieve this we are using a large dataset which contains data of various devices, amount of precious and valuable materials they contain and other key points. When user selects it's device like power bank for disposal and recycling the credit points are shown instantly how much they will receive after the device disposed off properly, but they are not transferred to their wallet at the exact moment, when device get's disposed off then it is transferred to the wallet. behind the scene our website communicates with the authorized centers to check whether the work is done and how much precious metal is retrieved from the device, later on the credit point is converted into cash or coupon which motivates the users to participate more actively. The whole idea of this section is to create a connection between digital rewards and real environment action.
fig 4 show the credit estimation workflow showing submission, reward, calculation and user options. It also shows how the reward system works.

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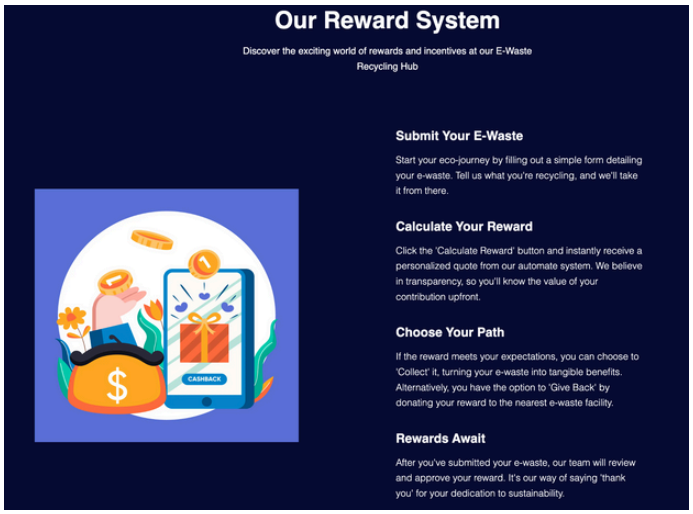

Fig. 4. Credit estimation workflow showing submission, reward calculation, and user options.

C. Structured Pickup Scheduling System

once the user understands the harmful components in their device and estimates credit value, the next step is the pickup scheduling feature. The platform provides a proper form where the user selects the type of e-waste from a predefined accepted list, they also fill the details like working condition, quantity, address and preferred pickup slot. This creates a standardized format for collecting information, so that the recycling centers do not receive incomplete or confusing request.

The system automatically routes this pickup request to the nearest collection or recycling facility. The routing works based on the backend logic which checks availability of the recycling centers, access to user's location and the type of item being submitted.

Fig 5 shows the option to submit your e-waste step by step user disposal journey, including form submission, pickup process and reward confirmation.

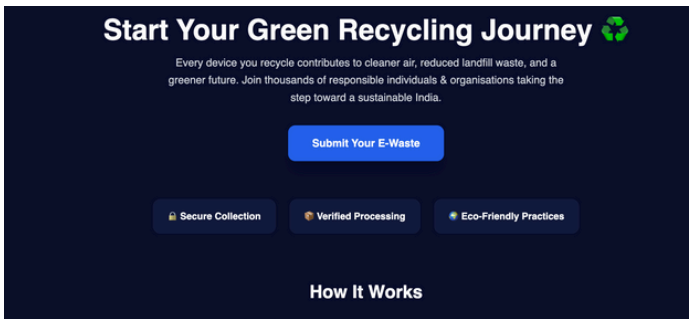

Fig. 5. Step-by-step user disposal journey including form submission, pickup process, and reward confirmation.

D. Backend Routing and Verification Workflow

This part of methodology involves the user to submit their location to get the nearest e-waste recycling facility, when user enter their location through the map, we show the government authorized e-waste centers near them where user can pick to submit their e-waste based on their convenience, once the request reaches the recycling center, the backend workflow begins, the recycling center receives details about the device including category, model, condition, and the estimated credit points that were calculated earlier, After receiving the device the centers match the device with the form they received from the end user, This verification is done to avoid reward fraud and also to maintain the trust between the platform and its users, once the item is disposed off correctly, the backend updates the system and releases the credit points into the user's profile, This ensures transparency, user can clearly see when and why they received the reward.

E. Institutional Recycling and Centralized Dashboard

Apart from individual users, the methodology also includes a structured system for institutions like schools, colleges, offices and startups, These organizations generate e-waste in bulk, and they often don't have a proper way to monitor how much they are disposing every month or year. To solve this problem, our platform provides a centralized dashboard where they can submit their e-waste and also track their total contributions. This feature is unique from other platforms because they focus only on the existing users individual users By allowing institutions to participate easily, the entire recycling chain becomes stronger. Institutions can also use this dashboard to showcase their sustainability performance and meet government based environmental goals.

F. Personal Environmental Impact Report for Every User

A unique feature added to this platform is about a personal environment report that gets updated every time a user disposes of an electronic device through the system. The main idea of this feature is to showcase the user their impact of work, and end the feeling that work is getting unnoticed. Many of the users does not realize how much impact they have

made through one disposal, So the report gives them a simple summary of the positive impact they have created. The report consist of details like how much e-waste they have successfully submitted, and what harmful materials they prevented from entering the environment and how much of the natural resource is saved because their device was recycled quickly. Everything is shown in an easy and understandable format, so that user can clearly connect their action with a real environment benefit. This feature also helps the user to feel motivated and more involved in the sustainability effort, because they can track their personal progress over time. The goal of the process is not just to complete the disposal process but to build a long term habit of responsible e-waste management among users.

G. Tools and technologies

This platform is developed using the MERN stack which stands for MongoDB, Express.js, React and Node.js. MongoDB here acts as a database for the platform. Express.js is a framework of Node backend used to handle user requests, store pickup details and manage communication between recycling centers. React is a frontend library used to build UI interfaces and the whole UI of user interface of the web site is built using this technology. Node.js is also used in the backend. On the front end React is combined with Next.js to give faster loading speeds, server side rendering and clear clean user experience that works well even on the slower networks. The interface is kept responsive using responsive CSS which adapts as per different screen sizes. Overall MERN stack is combined with Next.js and which support quick development, clear data flow, and a stable structure for the entire e-waste management platform.

IV. ANALYSIS

when we compare e-collector with other existing platforms we can see differences can clearly be seen most of the existing platforms explains and deals with process of recycling at the broad level, but they do not provide step by step guidance to the user our system bridges this gap [2, 4], it works at various stages first of all it awares the user, pushes the user to submit their e-waste and contribute to the sustainability. It offers educational popups at the same moment when user interact with the platform, the popups offers general instructions like instruction why do you need to dispose of e-waste correctly, it also tells the user about the harmful components present in various devices, this makes the awareness personal and meaningful.

The another feature which is the root cause why the platform stand out is the credit estimation feature, other e-waste platform does not offer reward or offer fixed reward, but our platform offer rewards based on the precious metal retrieved from the device, this makes the solution transparent and honest, credit is rewarded or transferred to the user's wallet, only when the device is disposed of properly, pickup scheduling process is also a big problem in other existing systems, our platform offers end to end pickup scheduling [10].

The next unique feature is ability of the platform to handle routing efficiently, user has to apply no extra effort from the UI the ease of use makes our platform more practical and user friendly, in the case of big institutions participation our platform stands out, most of the existing platforms focuses on the individual user, not on big institutions, through our platform institutions can submit e-waste in bulk and get rewards which will be further converted into cash or coupon, our platform also offer standardized and centralized dashboard for them, this increases transparency between organizations, recycling center and our platform which act as a bridge between them. The overall user interface and interactivity is another feature why our platform stands out, it also is designed in a simple and easy to use manner, every step is thought and made in such a way that normal user does not feel confusion during the process.

Other existing platforms consists of too many steps which confuse the user, due to this user loose their interest in the mid way, if we properly see and observe our platform is not only a technical tool, but is a complete experience which guides, teaches and rewards them for their action. Our solution creates ecosystem for end to end pickup delivery. Another unique feature of our application is that every user gets a personal environment report, this is not just a fancy feature it shows the user the differences they are creating by disposing of their e-waste in a proper and responsible manner. The other feature of our application is that it shows nearest authorized recycling centers which government recognized all over India, user can enter their location, it will show all centers nearest to their area. Our platform offers both reward, it gives the feeling the accountability to the end user which makes it unique.

V. RESULTS

The result section of e-collector platform shows that it is a simple and well structured digital platform which can help people in the process of handling electronic waste in a effective manner. The biggest achievement in this is knowing about the harmful components present in the device, this awareness is given at the same moment when user things to dispose their electronic device. When user came to know about the estimated credit point calculation then they should throw there anywhere rather than recycle it through authorized centers to get the reward. The process involves verification based credit release which increased trust among the users. The process of structured pickup scheduling has made the whole process quite easier, user can dispose of their e-waste without any confusion. The system of automatic routing to nearest e-waste authorized recycling center is done through our platform which reduces the time in device pickup. For big institutions this platform is also quite beneficial, they can contribute in the sustainability goal and also can submit e-waste in bulk, and also track the amount of e-waste they have submitted. Overall platform includes awareness to dispose section, through all above process user does not have to struggle with the technical process. The workflow supports the extended producer Responsibility, because it encourages verified collection and authorized recycling. In simple language we can say that when user gets the right guidance & process is simplified, then they participate in sustainable e-waste management.

Fig 6 explain the correlation between GDP per capita and E-waste generation.

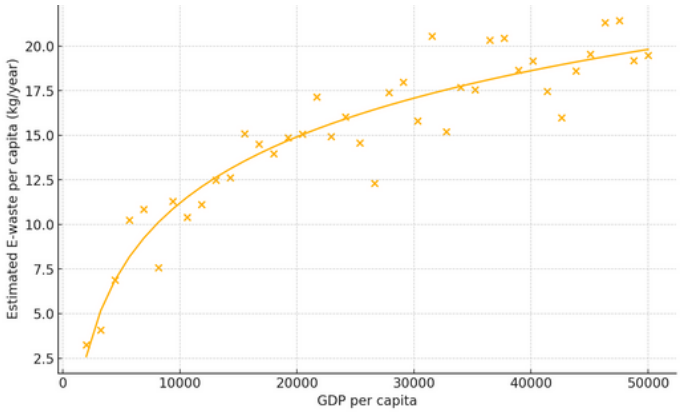

Fig. 6. Correlation between GDP per capita and E-waste generation.

VI. CONCLUSION

Overall research have shown that when people get simple and guided system, then the process of handling e-waste become quite easy, creating platform which instead of confusing users guides them, increases participation. E-collector platform have combined awareness, convenience and accountability in a natural way, this approach is suitable for both users and institutions. Providing device specific information regarding harmful components and also giving the clear path of disposal makes the overall system efficient. Structured pickup and verified credit system which has made the process trustworthy and practical, user gets the assurance their given devices is handled properly and rewards are genuinely linked with it. The personal environment impact report or by it given by the platform has shown the user's impact in real world, this feature motivated the user for future also. In simple words this platform has created a smooth and meaningful experience, through this experience this habit shifted the user's habit from careless habit to sustainable and responsible e-waste management. Research clearly show that when process is simple, transparent and user friendly, then user's willing participate in them, such systems help people in adopting ethical e-waste handling practices and long term sustainability.

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