

Article

Novel Mobile Application System for Implementation of an Eco-Incentive Scheme

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Abstract: In order to incentivise consumers to engage in sustainable consumption, a mobile application system is developed to implement an eco-incentive scheme, in which eco-credits are awarded to consumers who recycle and reuse end-of-life products and in which they can use the eco-credits for discounts in shopping, exchange the eco-credits for museum/theatre tickets, or make donations for tree planting. In this paper, the related concept and eco-incentive scheme are introduced first; the infrastructure of the mobile application system is presented; and the process of system development is detailed. The mobile system infrastructure consists of three layers: a database server; communication and integration; and four functional modules including user registration and login, obtaining eco-credits, spending/donating eco-credits, and viewing eco-credit history. Multiple mobile development techniques are utilised to implement the mobile application system. A case study was conducted, demonstrating that the mobile application for eco-incentive can efficiently support consumers in recycling products and managing their reward records. The literature review and user survey revealed that there has not been a mobile application system with the eco-incentive functions of the mobile app presented in this paper, which indicates the novelty of this research.

Keywords: eco-incentive scheme; eco-cost; eco-credit; mobile infrastructure; sustainable consumption



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1. Introduction

Currently, circular economy (CE) is a popular concept promoted by the European Commission, several national governments, and many businesses around the world [1]. As a sustainable development strategy, CE has been used to tackle the urgent problems of environmental deterioration and resource scarcity [2]. More and more consumers are interested in sustainable products and services, and the emergent field of sustainable product development has been rapidly evolving, as shown in the literature [3]. For instance, a qualitative method for sustainable product development was presented [4], and the life-cycle-based method for sustainable product development was proposed [5]. To effectively solve the problems encountered by enterprises and organizations in the process of sustainable development, eco-accounting was proposed [6,7] in order to measure the consumer's sustainable consumption behaviour through major environmental impact categories along the product supply chain, sharing the eco-accounting results among stakeholders. Obviously, eco-accounting would be one step further than supporting sustainable development in circular economy. However, most existing eco-accounts have not given enough attention to reward mechanisms that further incentivize consumers to engage in recycling activities.

To address the above issue, this research developed a novel mobile application system for the implementation of an eco-incentive scheme based on the mobile eco-accounting framework, which is part of the CIRC4Life project supported by the European Commission Horizon 2020 program [8].

2. Literature Review

To enhance consumers' awareness and implementation of sustainability, a reward mechanism or incentive scheme that encourages recycling end-of-life products (EoL) should be incorporated into eco-accounting. At present, some existing incentive schemes, such as the Scotland reward scheme [9] for reusing plastic bottles and the Apple reward scheme for recycling electronic products developed by some companies, e.g., Apple iPhone [10], are utilised to award consumers after they recycle/reuse products. In addition, Reward Green Travel Choices [11] offers rewards and incentives for schools, businesses, and communities to encourage residents and students to choose greener travel alternatives and healthier lifestyle options and to reduce their carbon footprint. However, those schemes are limited to consumers who recycle a specified kind of product with residue quality or choose green services. So far, there is no generalized scheme that can incentivize a consumer to recycle different types of products or services. A dynamic incentive–penalty mechanism used to guide consumers in buying eco-labelled products was proposed in [12,13], but this solution was based on an eco-label, not an eco-point or eco-point-related index. It cannot evaluate consumers' environmental impacts in a precise way. EcoRewards [14,15] can provide services that link communities and organizations to their Waste Service Providers and Ethical tour operators and award users with EcoPoints as a reward for positive “EcoActions”, but the eco-reward scheme is not integrated into eco-accounting and cannot record consumers' eco-footprints. Ouvrard and Stenger discussed incentives and environmental policies dealing with the role of the economy in protecting the environment by revisiting traditional economic instruments and by pursuing an advanced consideration of the role of new forms of incentive, and suggested that policymakers should take into account combinations of socially acceptable incentives [16]; however, no available system architecture has been proposed to implement such an incentive scheme.

Currently, there are some mobile application systems targeting sustainable consumption. The mobile app presented in [17] provided users with estimations of the users' greenhouse gas emissions using paired bank transactions data, and the mobile app in [18] encouraged car drivers to reduce traffic and its consequential impacts on the environment, such as climate change. In order to reduce environmental burdens and to provide eco-feedback information, e.g., energy consumption, for householders, a mobile app was presented in [19]. In addition, the mobile app presented in [20] provided the product information (e.g., price, expiry date, and quality indicators) to consumers for grocery shopping, and the reGAIN app reported in [21] was developed for eco-accounting. However, these mobile apps focus on providing users with ecological information about products and services, “Internet + Recycling”, or grocery shopping, but none of them are related to the eco-incentive. Although the systems reported in [11–16] tackled eco-incentives, they were developed for website-based applications and not for mobile application. According to the literature search, the mobile application system developed in this research is the first attempt at applying the mobile app technique for eco-incentives.

Based on the mobile eco-accounting framework, a novel mobile application for eco-incentive is developed by this research and reported in this paper. To overcome the challenges stated above, this mobile application using an eco-incentive scheme awards eco-credits to consumers who recycle EoL products, and consumers can be incentivized with these eco-credits in ways such as offering discounts for shopping. In the calculation of the eco-credits, a product's impact on the environment is taken into account via the product eco-cost. Thus, the eco-incentive scheme connects the consumer's footprints to their eco-accounts and reflects the products' environmental impacts.

With the mobile application for an eco-incentive scheme, a smart mobile phone user can manage their eco-account, receive and spend eco-credits, view the eco-credit balance, trace the history of eco-credits, and utilise other functions such as finding the locations of recycle points and eco-incentive shops/enterprises. To develop and operate the mobile application, various ICT techniques have been applied, including traceability and QR codes, APIs and web service, security and reliable network transmission. The rest of this

paper is organized as follows: Section 2 introduces the eco-incentive scheme, including the related concepts and the system infrastructure; the system design and implementation is elaborated in Section 3; a case study is conducted to show the procedure of applying the mobile application in Section 4; the evaluation and discussion of the eco-incentive system are presented in Section 5; and Section 6 concludes the paper.

3. Overview of the Mobile Application System

As stated in Section 1, eco-accounting is an important instrument to measure the consumer's sustainable consumption behaviour. Within the eco-accounting infrastructure of this research, products' negative impact on the environment is indicated by eco-cost, the consumer's positive behaviour for the environment by recycling EoL products is credited with eco-credits, and the eco-incentive scheme is implemented with the eco-credits, which are further presented below.

3.1. The Related Concepts

3.1.1. Eco-Cost

The eco-cost reflects the negative impact of products on the environment, and it is adopted to record consumer's footprints resulting from the purchase and consumption of the products. A higher eco-cost value indicates a more negative environmental impact of the product, and vice versa. The eco-cost is a single value, which is calculated with a method derived from the lifecycle impact assessment method [22]. Details of the eco-cost calculation method are available in [6].

3.1.2. Eco-Credit

The eco-credit is used to record consumer's recycling activities and to credit the consumer's positive behaviour of recycling EoL products to avoid 'use and then throw away' situations. When consumers recycle EoL products, they receive corresponding eco-credits, which are recorded in the consumer eco-accounts. The eco-credit is calculated based on the recycled product's life span in service, impact on the environment represented by eco-cost, and residual value. The eco-credit calculation method is detailed in [22].

3.1.3. Eco-Incentive

In order to encourage consumers to recycle EoL products, in addition to awarding eco-credits to consumers, the eco-incentive scheme is developed and implemented by this study. Within this scheme, the eco-credits can be used as cash or equivalent to spend. So far, as part of CIRC4Life project [8], the eco-credits can be used for discounts on shopping in local shops and online stores, exchanging the eco-credits for theatre or museum tickets, and the donation of the eco-credits to the local authority to plant trees, as illustrated in Figure 1.

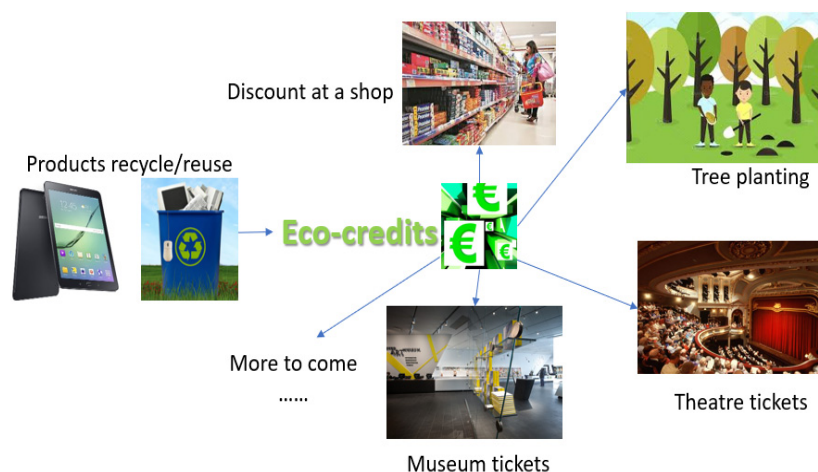


Figure 1. The eco-incentive scheme.

An individual consumer's awarded eco-credits, eco-credits spent for the eco-incentive, and remaining eco-credits (eco-credits balance), together with the eco-costs, are recorded in the consumer's eco-account, forming a comprehensive record of the consumer's environmental footprint.

3.2. System Infrastructure of the Mobile Application System

The system infrastructure to implement the eco-incentive scheme is shown in Figure 2, which consists of three layers: database server, communication and integration, and mobile applications.

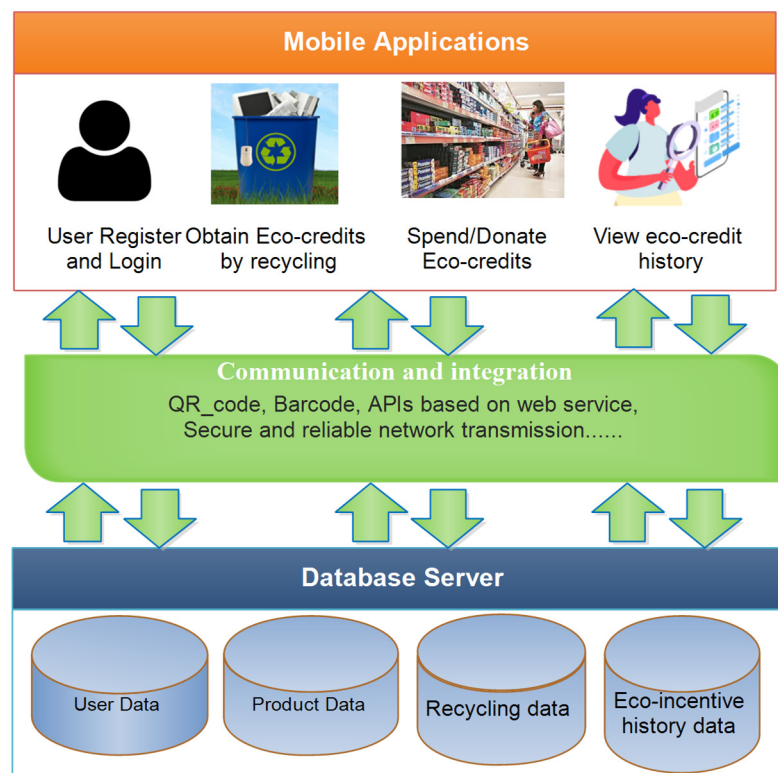


Figure 2. The system infrastructure of the eco-incentive scheme.

The bottom layer is the database server that runs and manages the database of the eco-incentive system. The data include user data, product data, recycling data and eco-incentive history data. Details of the data scheme can be found in Section 4.1.

The middle layer is responsible for the communication and interaction based on multiple ICT technologies, such as QR code, barcode, Internet communication technologies, and APIs based on web services. The QR code is used to identify a consumer account when the consumer spends/donates their eco-credits, and the barcode is utilised in the communication with the intelligent bin which stores the recycled EoL products. The APIs based on web services are used to facilitate the data exchange between the database server and the mobile application. To assure the trustworthiness among value networks, the technology of secure and reliable network transmission is also adopted in the middle layer.

The top layer deals with the consumer mobile application, which consists of four function modules: user registration and login, obtain eco-credits by recycling, spend/donate eco-credits and view eco-credit history. A detailed description of the above four function modules is shown below.

3.2.1. User Registration and Login

To use the eco-incentive system, the consumer must register an account in the eco-incentive system. Thus, the user register module provides the function for consumers

to create a new user account. Meanwhile, the user login module is used to validate the consumer's ID (namely user account) and allow the authorized consumer to enter the eco-incentive system. The consumer's ID is identified by the individual identification code, which is obtained in the consumer's registration process. After submitting the user account and password, the individual identification code and password string are sent to the remote server over the Internet for validation. Once the authentication is successful, the customer is enabled to log into the eco-incentive system for further communication.

3.2.2. Obtain Eco-Credits by Recycling

When consumers' products (such as mobile phone, tablets and other electronic products) come to their end of life, they can recycle the products through the intelligent bin system developed by the CIRC4Life project team [23]. After the assessment of the recycled products, the eco-credits are calculated as part of the intelligent bin system. Details on how to calculate the eco-credit value of a recycled product can be found in [24]. Then, utilising the module of obtaining eco-credits by recycling, the value of the calculated eco-credit related to the recycled products is sent to the remote database centre for storing in the consumer's account. This means that the more products the customers recycle, the more eco-credits the consumers will gain. After recycling the products, the eco-credits of the products are saved into the customer's account. The eco-credits available in the customer's account can be viewed in this module with the consumer's mobile phone.

3.2.3. Spend/Donate Eco-Credits

The eco-credits obtained by recycling products can be paid in cash or the equivalent to the consumers, which will be used for purchasing new products. In addition, consumers can donate their eco-credits for tree planting. The module of spending/donating eco-credits consists of the following parts: spend eco-credits to receive discounts on purchasing products, spend eco-credits to receive cinema/museum/theatre tickets, and donate eco-credits for tree planting, which are detailed below and illustrated in Figure 1.

(1) Spend eco-credits for discount of products purchased

With the eco-credits, consumers can receive discounts when purchasing the products in a store. Firstly, the consumer logs into the eco-incentive system via their mobile phone, and then scans the product barcode to obtain the serial number of the product that will be purchased. The serial number of the product (product ID) is sent to the data processing centre for calculating how many eco-credits are required to pay the corresponding discount on purchasing the product, and the eco-credits are then deducted from the customer's eco-account by scanning their QR code.

(2) Spend eco-credits for museum/theatre tickets

Consumers can also spend their eco-credits receive free tickets (cinema tickets, museum tickets, theatre tickets and so on). With this function of spending eco-credits to receive tickets, the stakeholder accepting the eco-credits for incentives, such as local authorities and intermedia organizations, can scan the consumer's QR_code, which is used for identifying consumer's account, to retrieve and deduct the eco-credits from consumer's account for the corresponding tickets.

(3) Donate eco-credits for tree planting

In order to encourage consumers to contribute to the improvement of the environment by planting trees, this function is developed for consumers to donate their eco-credits to local authorities who then convert the eco-credits for tree planting. With the eco-incentive system, the consumer captures a screenshot of their user QR codes (QR code pictures), and then sends an email to the authority agent with the donation information, including the purpose (donation for tree planting), QR code picture to indicate the ownership of the donation, and the amount of eco-credits donated to plant the trees. After receiving the donation e-mail, a confirmation email from the authority agent is then sent to the consumer

for confirming the operation. Finally, the donated eco-credits for tree planting are deducted from the consumer's account. The consumer can check the account to view the eco-credits spent in the donation.

3.2.4. View Eco-Credit History

To track the consumer's eco-footprints and environmental impacts, it is necessary to show the eco-credit records received in eco-recycling and spent in eco-incentive activities. Thus, the mobile application provides the function to view eco-credit history. With this function, the user can view their eco-credit balance, eco-credits received, eco-credits spent, and the related history information of eco-recycling and eco-incentive activities.

4. Development of the Mobile Application System

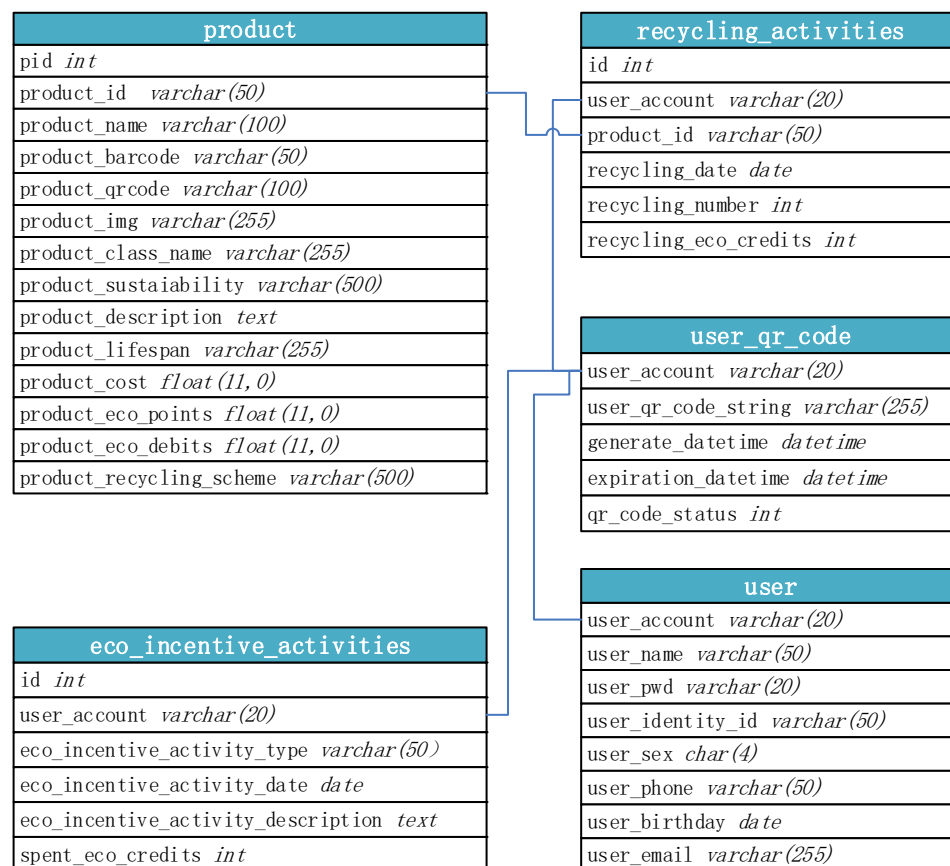
4.1. Data Scheme of the Mobile Application System

In order to implement the above function modules, it is necessary to design a data scheme related to the eco-incentive system. In the eco-incentive system, there are various kinds of data, such as dynamic data for recycling activities, eco-incentive history, and other information related to consumers and products. Those data are managed by utilising the so-called Navicat Premium, a data management tool [25]. Based on the Navicat Premium platform, we design the data scheme for the eco-incentive system, and create relevant data tables in the MySQL server. In the eco-incentive system, there are five main databases: user database, userQR code database, product database, recycling activities database and eco-incentive activities database. The user database is used to store the consumer's name, account, password, eco-cost total, eco-credit total and other personal information, such as email, gender, birthday, phone, head_img (portrait image), the string of QR code and so on. The relation information between the consumers' user account and user QR code is stored in the userQR code database. The product database is for storing product ID, product name, product barcode, product image, product category and other eco-information, such as product' eco-cost values, product sustainability, product recycling scheme, product lifespan, etc. The information related to consumers' recycling activities (such as user account, recycled product ID, recycling date, recycling number, recycling eco-credits, etc.) are stored in the recycling activities database. As for the eco-incentive history, the information related to consumers' eco-incentive activities (such as user account, eco-incentive's activity type, activity date, activity description, spent eco-credits, etc.) are stored in the eco-incentive activities database. To better understand and describe the interaction between five data models, the relationship among them is shown in Figure 3.

In Figure 3, the data models *recycling_activities*, *eco_incentive_activities*, *user* and *user_qr_code* are linked by the key data field *user_account*. In addition, the data field *product_id* is used to link the two data models: *recycling_activities* and *product*.

4.2. APIs Based on RESTful Web Service

In the eco-incentive system based on the proposed mobile infrastructure, all resources and data related to consumers, products, and the history of eco-activities, such as user account information, product information, recycling activity data, eco-incentive activity data and so on, are stored in the database of the remote server. To access or update the resources and data stored in the remote server, a set of common application programming interfaces (APIs) are utilised to enable the client application to connect with the remote server over the Internet. In this paper, Representational State Transfer web service APIs (i.e., APIs based on the RESTful web service), which can enable the service's request and response transmission over a well-known transport protocol—the Hypertext Transfer Protocol (HTTP)—are adopted, and the format of transmitted resources and data using a REST-based web service is JavaScript Object Notation (JSON) and text information. In this research, to implement the functions of the proposed eco-incentive mobile application, a number of APIs are developed based on RESTful web service, which are utilised for



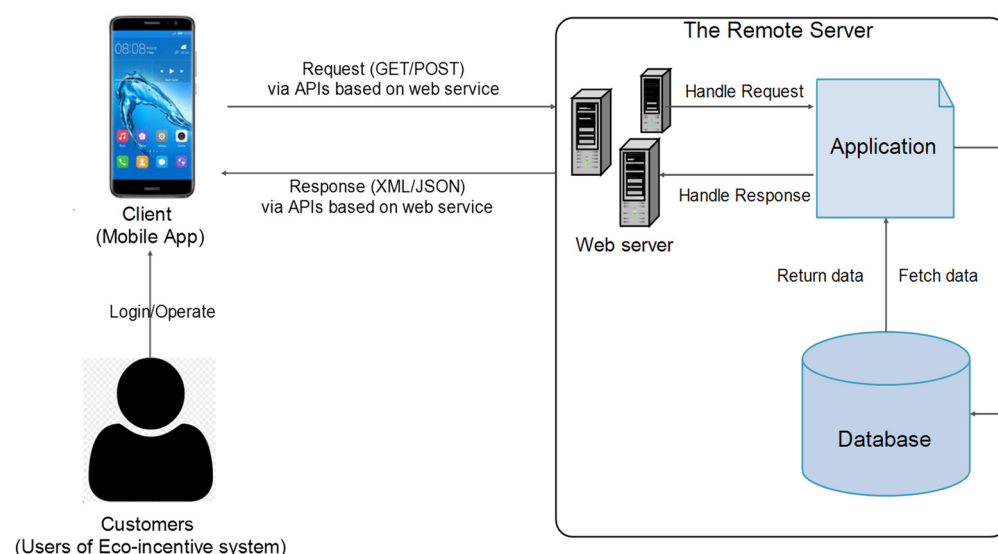


Figure 4. Communication between mobile application and remote server.

As shown in Figure 4, when consumers log in or operate the mobile client, the mobile application initializes a remote connection to the remote server by sending a GET/POST request, via calling the API based on the web service provided by the web server. Then, the web server analyses and handles the request through the application services to access/fetch/update data from the central database. After completing the request, the application services transform the data returned from the central database into XML/JSON messages, then the web server sends the XML/JSON messages in response to the mobile client.

4.4. Data Retrieval via Barcode

In this mobile application for eco-incentives, we apply the Java programming language within Android Studio to implement the function of barcode scanning. The implementation consists of three steps: the image of the product barcode (e.g., GS1-128 barcode [26]) is obtained via the Camera API of the mobile device, and the obtained image is pre-processed as a grayscale image. The grayscale image is then decoded through the decode analysis. Finally, the related information contained in the barcode, such as the product ID, the number or the text, is retrieved from the network or the remote database server with the results obtained in the second step.

4.5. Implementation of Eco-Incentive Activities with Consumer's QR Code

As described in Section 3.2, when consumers spend their eco-credits to receive a discount on purchasing products, to receive tickets, or to donate their eco-credits for tree planting, the QR code of consumers must be shown, scanned and verified by the scanner of the machine to realise the communication with the remote server. It means that the QR code, which is linked to consumer's user account, is an essential factor for implementing the eco-incentive activities. To ensure the security and reliability of eco-incentive activities data, a dynamic QR code will be generated and utilised in the transaction process of an eco-incentive activity. To better understand how to create and use the dynamic QR code, the detailed process of implementing an eco-incentive activity is presented in Figure 5. When the QR code is verified as invalid (e.g., it has been used before), then the mobile app sends a message informing the consumer to use a valid QR code.

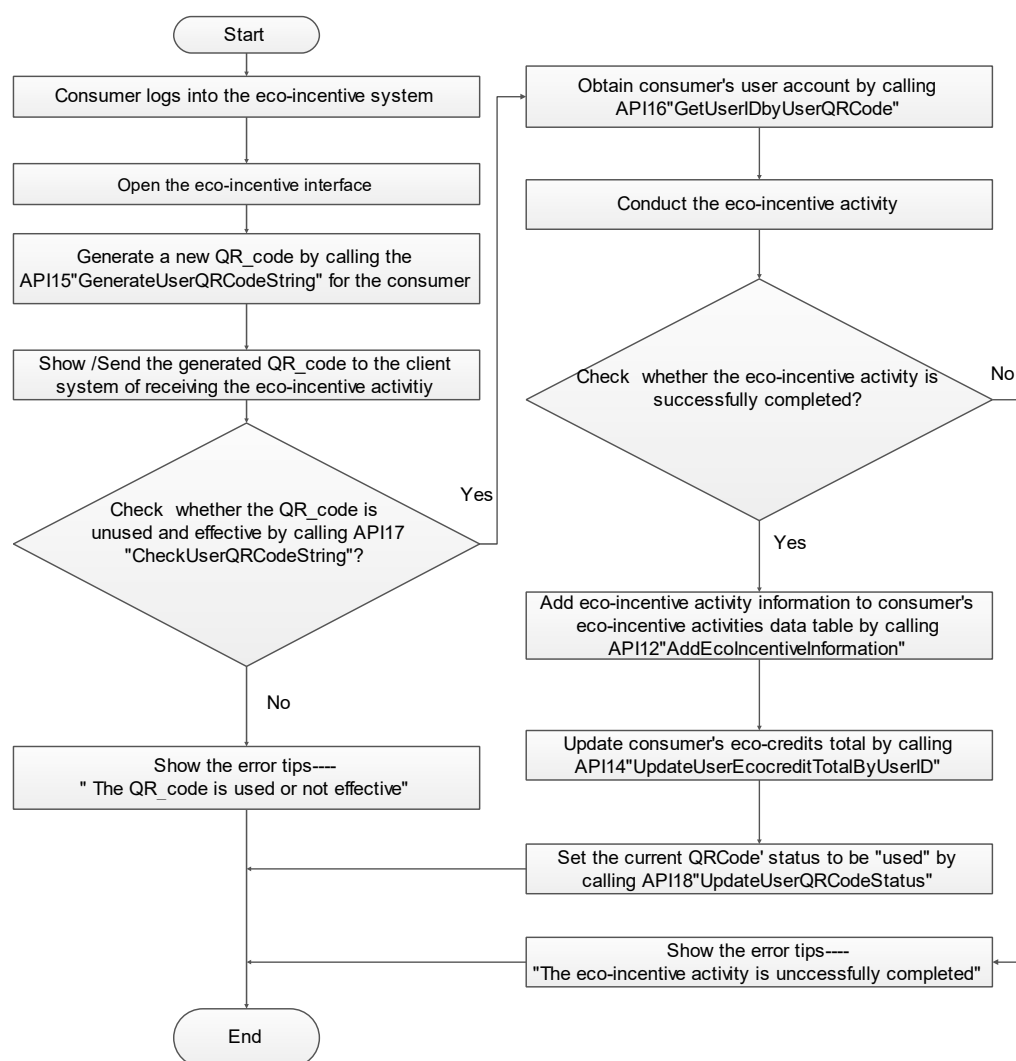


Figure 5. The process of implementing an eco-incentive activity.

As shown in Figure 5, when a consumer logs into the eco-incentive system and opens the eco-incentive interface, the system will generate a new QR code by calling the API15 “GenerateUserQRCodeString” for the consumer. Then, the generated QR code is to be shown or sent to the client system receiving the eco-incentive activity. The client system, such an eco-incentive machine, calls the API17 “CheckUserQR CodeString” to check whether the received QR code is unused and effective. If the QR code is not used and is not beyond the period of validity, the system obtains the consumer’s user account by calling API16 “GetUserIDbyUserQRCode” to complete the eco-incentive activity. Then, the information related to the eco-incentive activity is added into the eco-incentive activities database by calling API12 “AddEcoIncentiveInformation”, and the consumer’s eco-credit total is reduced and updated by calling API14 “UpdateUserEcocredit_TotalByUserID”. Finally, the current QRCode’ status is set as “used” by calling API18 “UpdateUserQRCodeStatus”.

In order to spend eco-credits in the eco-incentive activity, there are two systems used in the shop or ticket agency: one is the eco-incentive client system developed by the CIRC4Life project, supported by the EU H2020 programme (see Figure 6), and the other is the shop or ticket agency’s existing accounting system. The two systems are separate and do not affect each other, and, hence, the shop or ticket agency staff is to work on the two systems at the same time. The eco-incentive client system consists of a scanner, a printer, a computer and related software. The scanner is utilised to capture the QR code shown on the mobile application for eco-incentive though the reader, allowing for the shop or ticket agency staff

to gain access to the consumer's user account. The computer of the eco-incentive client system is connected to the scanner and the printer, and is able to control their actions and operation (such as passing the QR code or barcode to the computer, and passing printing commands to the printer). The computer is to display the eco-cost values through the API2 and record the eco-costs obtained from the purchase, and then reduce the eco-credits spent in the consumer's user account.

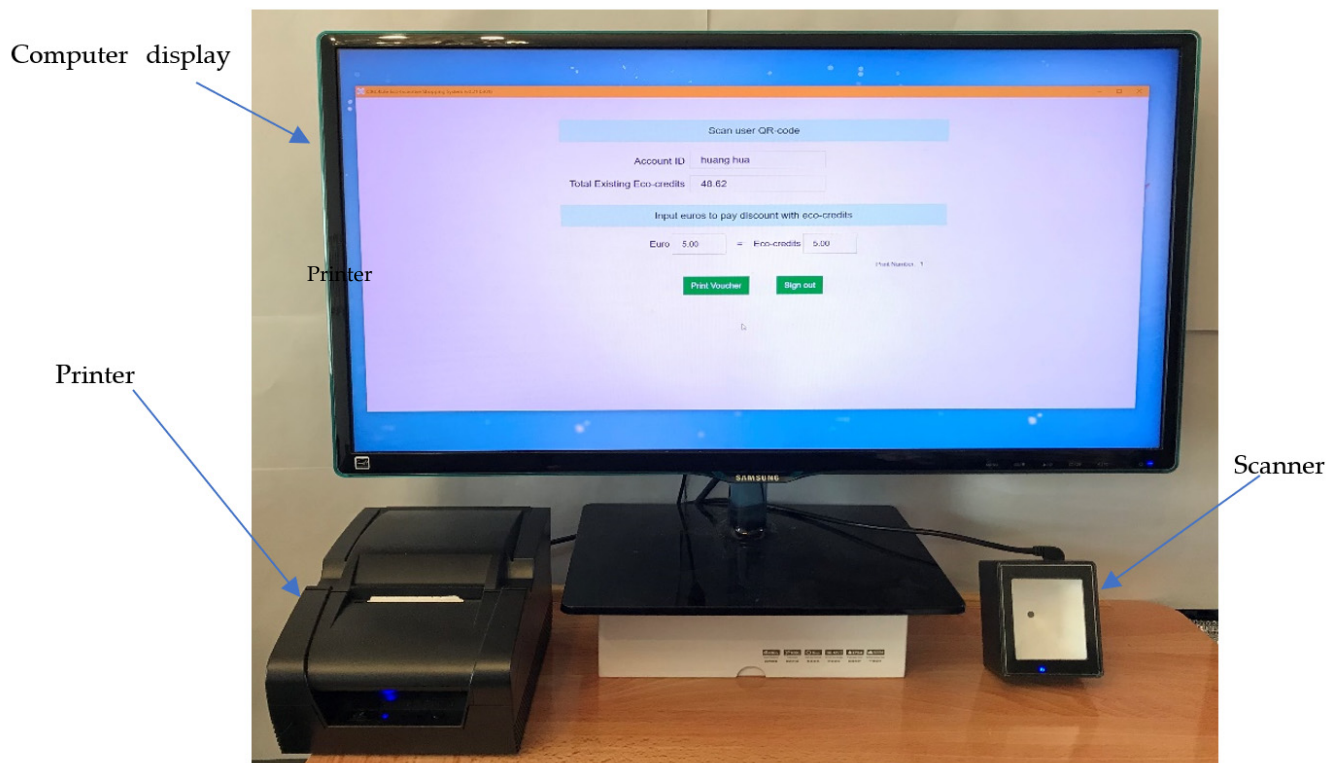


Figure 6. The eco-incentive client system.

5. Case Study

The demonstration of the circular economy business model developed by the CIRC4Life project took place in Basque Country, Spain [27]. The demonstration includes recycling EoL electronic products, such as computer tablets and mobile phones, and eco-incentives for the recycling activities. The mobile application for the eco-incentive presented above was applied in the demonstration, which is presented in this section to illustrate the mobile application.

5.1. User Register and Login

To use the eco-incentive mobile application for the first time, the consumer has to complete the user registration form to create an account. To do so, the user needs to provide personal information, such as their email and password. After the completion of registration, the consumer can sign in the eco-incentive system by inputting their user account and password with the user login interface, and then access the information related to the eco-cost total, eco-credit total and the recycling/eco-incentive history. The interfaces of the eco-incentive system support multiple languages, which are currently English, Spanish, and Basque.

5.2. Obtain Eco-Credits via Recycling Activities

The procedure of obtaining eco-credits by recycling products is shown in Figure 7. To recycle products, with the information shown on the mobile application, the consumer can find the location of an intelligent bin, in which the consumer can place the product to be

recycled and view the types of products that can be accepted by the intelligent bin. If the product is still in a working condition, but the user wants to put it in the recycle system, the user has to pack the product with proper packaging materials such plastic bubbles to avoid damaging the product before putting it into the container of the intelligent bin. Step-by-step instructions are attached to the intelligent bin for the consumer to conduct the operation. Figure 8 shows the operation procedure of the intelligent bin with the mobile application. After collecting the recycled products from the intelligent bin, the recycle centre evaluates the recycled products and calculates the corresponding eco-credits of each recycled items. Then, eco-credits related to the recycled products are added to the consumers' eco-credit total. Afterwards, the consumers can scan the barcode labels, which were received from the intelligent bin when recycling the product, to view the information of the recycled product and check the earned eco-credits. The history of their eco-recycling activities can also be viewed.

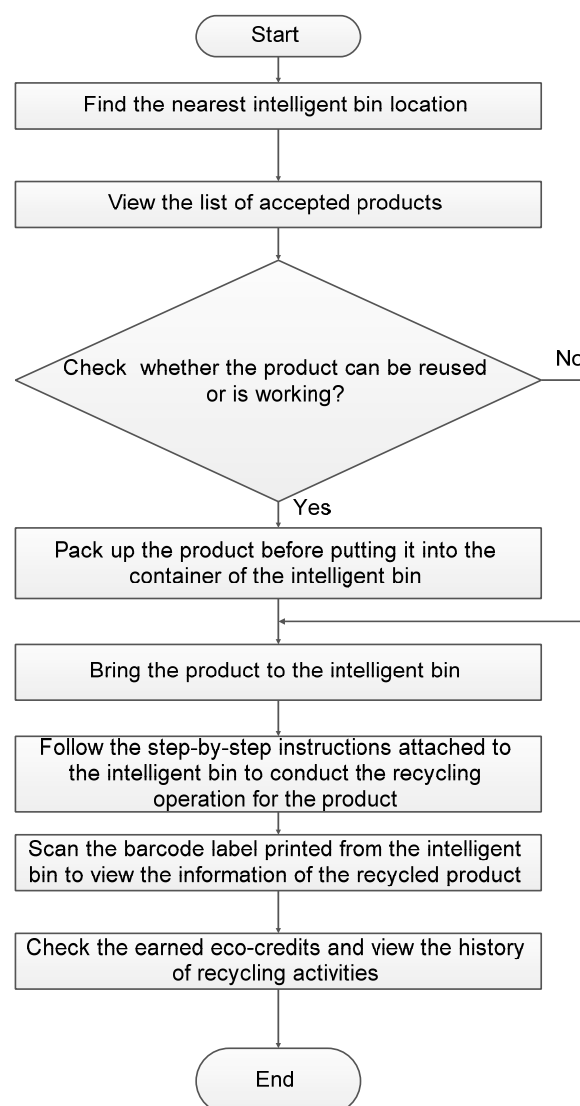


Figure 7. The process of obtaining eco-credits via recycling products.



Figure 8. The recycling operation with the intelligent bin.

5.3. Spend Eco-Credits for Eco-Incentive Shopping and Cinema/Theatre/Museum Tickets

As described in Section 3.2, with the mobile application, consumers can conduct eco-incentive activity by spending their eco-credits to receive discounts on purchasing products in the shop or receive free cinema/theatre/museum tickets from the ticket agency, where the staff operates the software–user interface of the eco-incentive system and prints the incentive receipts for the consumers. The detailed process of receiving incentives can be found in the mobile application, as shown in Figure 9.

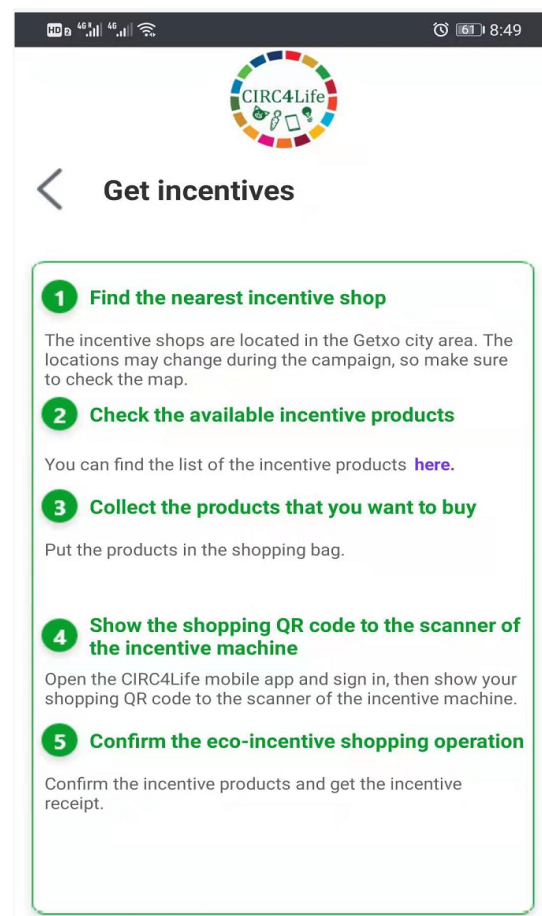


Figure 9. The process of receiving incentives.

The consumers can find the nearest incentive shop by looking at the Google map embedded in the mobile application. In the incentive shop, the consumer can check the available incentive products and choose the products to buy; then at the checkout point, the consumer shows their QR code, which is linked to the consumer's eco-account, to the scanner of the incentive machine. With the consumer's confirmation of the purchase, the eco-credits are deducted from the consumer's eco-account, and the eco-incentive shopping operation is completed, with the printed receipt showing the purchase details, including the eco-credits spent for the product purchased.

In a procedure similar to the eco-incentive shopping, the consumer can spend eco-credits for cinema/theatre/museum tickets: the consumer looks at the map embedded in the mobile application to find the location of the agent dealing with the eco-credits for the tickets, scans their QR code with the incentive machine, and receives the tickets, with a printed receipt showing the eco-credits spent for the tickets.

5.4. Donate Eco-Credits for Tree Planting

To contribute towards the improvement of the environment, consumers can use the eco-incentive mobile application to donate their earned eco-credits for tree planting. To guide consumers as to how to donate eco-credits to plant a tree in a green area of specific cities, such as Getxo in Basque Country, Spain, the process of donating eco-credits for tree planting (see Appendix B) can be found in the mobile application. Following the step-by-step instructions given, consumers can complete the eco-incentive activity of donating their eco-credits to plant a tree in a tree planting area of Getxo.

5.5. View Eco-Incentive History

After consumers complete the eco-incentive activities, such as spending eco-credits for discounts to purchase products, to exchange for cinema/theatre/museum tickets, or for donating eco-credits for tree planting, the mobile application system for eco-incentives enables the consumers to view the history of the above eco-incentive activities. As an example, the screen capture of viewing eco-incentive history is shown in Figure 10.

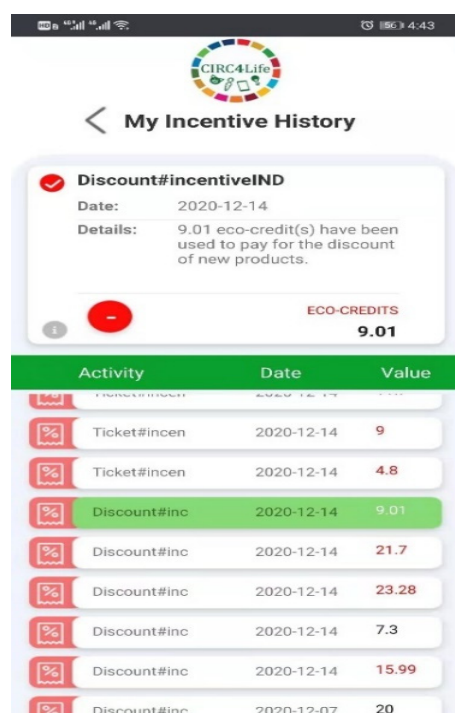


Figure 10. Eco-incentive history of spending eco-credits for discount.

6. Validation of the Mobile Application System

6.1. Analysis of the Survey Results

To validate the mobile application for eco-incentives (namely the mobile app), a survey was conducted with a questionnaire of eight questions, and a total of 39 replies were received. The survey results are shown in Appendix C.

According to the survey results, it can be concluded that most of the participants of the survey were satisfied with the mobile app and agreed with the usefulness of this mobile application for their sustainable consumption.

The survey indicates that the participants did not have a crash issue caused by the mobile app, and the overall satisfaction was rated 4.2 out of 5, which is a relatively high score, although there is still room for further improvement (see the survey results of Questions 1 and 8 for further information).

In answering the question ‘Do you know a similar app?’, five participants of the survey answered with ‘yes’, but only one of the apps mentioned by them is relevant to mobile applications for eco-incentives; however, it was based on self-reporting and the number of items recycled, without assessment of the recycled item and no eco-accounting function to track footprints, unlike that which our mobile app can do for eco-incentives. These survey results, together with the literature review presented in the introduction section of this paper, prove that the mobile app developed by this research is novel for eco-incentives.

As shown in the survey results of Question 2, approximately 20% of participants encountered a problem to create their accounts with the mobile app. However, there was no reason given and this might be related to various unknown issues, such as lacking experience in using mobile apps, further investigation should be carried out to avoid such a problem.

The major negative comments are about the design of the user interfaces, which need to be more user friendly, and the instructions, which need to be easier to follow, as indicated in the survey results of Questions 3 and 4. Therefore, as part of future work, we shall improve the interface design in terms of aesthetic, typography and readability.

The suggestions provided by the participants in answering Question 7 help us in the future improvement of the mobile application for eco-incentives, through approaches such as the creation of an iPhone version, resolving the issue with the registration, making the instructions clearer and more understandable to everyone, removing the printing option, further improving the aesthetics of the mobile app, and making it more user friendly [28–30].

6.2. Performance of the Mobile App

The mobile app was published in the Google Play store a year ago; so far, more than 1500 users have downloaded it without complaint.

To evaluate the processing speed and stability of the mobile app, multiple techniques and methods have been utilised, such as monitoring the speed of processors across cores and the physical memory in use by the active processes of the mobile app, and handling errors/breakpoints via feed loop tracking, etc., which achieves the effective allocation of resources used in the mobile app. Figure 11 shows the overview of the performance testing with the Google play console.

As shown in Figure 11, the mobile app has been installed and tested in various mobile phones, such as Huawei Mate, Sony Xperia, Google Pixel, Samsung Galaxy S9, Nokia 1, LGE K3 and so on, covering a range of mobile operation systems from the earlier version (v5) to the latest version (v12), which ensure the efficiency and performance of the mobile app. So far, no issues have been found. Through analysis and comparison, the average CPU usage and average memory usage of the mobile app is low. In the meantime, the average amount of data sent/received by the network is very small, which means the response speed of the mobile app is very quick. Obviously, the overall performance of the mobile app is good, and the efficiency of the mobile application system for eco-incentives is high.

The mobile app can therefore efficiently support the implementation of the eco-incentive scheme proposed in this paper.

Performance

rendering is slow ⓘ
○
device has problems

cold start time ⓘ
○
device has problems

equipment	Average CPU usage	Average amount of data sent by the network	Average amount of data received by the network	Average memory usage	cold start time	
✔ Test equipment with no issues found						
Huawei Mate 9	8.30%	3.78 B	0 B	140MB	333 ms	→
Motorola Moto Z Droid	9.11%	3.87 B	1.17B	140MB	744 ms	→
Sony Xperia XZ1 Compact	5.43%	6.5B	2.42 B	65.4MB	-	→
Google Pixel	9.43%	2.4B	106 B	101MB	519 ms	→
Google Pixel 2	5.19%	28.4B	133 B	67.6MB	-	→
Motorola Moto G4 Play	14.05%	16.6B	38.6 B	64.8MB	788 ms	→
Samsung Galaxy S9	4.53%	22.8 B	37.9 B	148MB	139 ms	→
Google Pixel 2	5.18%	18.5B	39.3B	110MB	309 ms	→
Google Pixel 3	5.13%	5.01 B	19.8 B	77.6MB	-	→
Nokia Nokia 1	12.45%	39.3B	113 B	44.6MB	1710 ms	→
Huawei P8 Youth Edition	0.00%	0 B	0 B	1.28MB	-	→
LGE K3 2017	12.71%	40.8 B	69.1 B	59.2MB	2760 ms	→

Figure 11. The overview of performance testing for the mobile app.

7. Conclusions

To incentivize the reuse and recycling of consumer products, this study developed an eco-incentive scheme, based on which a mobile application system for eco-incentives was developed. Within the system, there are four main function modules: user register and login, view products' eco-information, obtain eco-credits by recycling and spend/donate eco-credits. The mobile application was successfully illustrated with a case study and validated by user survey results.

The analysis of the survey results presented in Section 6 and the literature review presented in Section 2 revealed that although there have been mobile applications for recycling and eco-shopping and Web-based applications for incentives, there has not been a mobile application system with the eco-incentive functions of the mobile app presented in this paper, indicating the novelty of this research.

In comparison with the existing incentive systems, the mobile application system developed by this research enables eco-incentives with the following novel features:

- Implementation of the eco-incentive scheme, which uses eco-credits to award consumers who recycle EoL products.
- The mobile infrastructure is developed based on the eco-accounting framework to enable the eco-incentive scheme and to track consumer's eco-footprints.
- Effective application of multiple mobile development technologies, including Internet communication technologies, QR code, barcode and APIs based on web services, to achieve the required functions of the mobile application for the eco-incentive scheme.

In summary, the mobile application system efficiently supports consumers in recycling EoL products and managing their reward records, and enhances consumer's awareness and implementation of recycling activities. The current version of the mobile application for eco-incentive only supports Android phones. In the future work, the mobile application for iOS phones will be developed, together with other improvements suggested by the user

survey results. In addition, the new version of the mobile application will be developed to support more languages.

As another future work, how to apply the approach resulting from this research in wide practice will be further investigated.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. The Detail of APIs Based on RESTful Web Service.

ID	API Name	Request Method	Request URL	Description
API1	GetProductByProductID	GET	API_URL/Product/GetProductByProductID	Obtain product information including eco-cost, and other eco-information by product ID
API2	GetProductByBarcode	GET	API_URL/Product/GetProductByBarcode	Obtain product information including eco-cost, and other eco-information by barcode
API3	GetUserInformationByUserID	GET	API_URL/User/GetUserInformationByUserID	Obtain consumer's personal information by user account
API4	GetTotalEcoCreditByUserID	GET	API_URL/User/GetTotalEcoCreditByUserID	Obtain consumer's eco-credit total by user account
API5	GetTotalEcoCreditByUserQRCode	GET	API_URL/User/GetTotalEcoCreditByUserQRCode	Obtain consumer's eco-credit total by user QRCode
API6	GetRecycleInformationByUserID	GET	API_URL/Recycle/GetRecycleInformationByUserID	Obtain consumer's recycling activities record information by user account
API7	GetEcoIncentiveInformationByUserID	GET	API_URL/EcoIncentive/GetEcoIncentiveInformationByUserID	Obtain consumer's eco-incentive history by user account
API8	UserLogin	GET	API_URL/User/UserLogin	User login authentication with user account and password
API9	UserRegister	POST	API_URL/User/UserRegister	Add consumer's user account, password and other personal information
API10	UpdateUserInformation	POST	API_URL/User/UpdateUserInformation	Update consumer's user personal information by user account
API11	AddRecycleInformation	POST	API_URL/Recycle/AddRecycleInformationByUserID	Add consumer's recycling activities record information
API12	AddEcoIncentiveInformation	POST	API_URL/EcoIncentive/AddEcoIncentiveInformation	Add consumer's eco-incentive activities record information
API13	UpdateUserEcoCostTotalByUserID	POST	API_URL/User/UpdateUserEcoCostTotalByUserID	Update consumer's eco-cost total by user account
API14	UpdateUserEcoCreditTotalByUserID	POST	API_URL/User/UpdateUserEcoCreditTotalByUserID	Update consumer's eco-credit total by user account
API15	GenerateUserQRCodeString	POST	API_URL/User/GenerateUserQRCodeString	Insert a QRCode random string into the consumer's user_Qrcode data table by user account
API16	GetUserIDbyUserQRCode	GET	API_URL/User/GetUserIDbyUserQRCode	Obtain consumer's user account by UserQRCode
API17	CheckUserQRCode	GET	API_URL/User/CheckUserQRCode	Check whether consumer's QRCode is unused and effective
API18	UpdateUserQRCodeStatus	POST	API_URL/User/UpdateUserQRCodeStatus	Update the status of a consumer's QRCode by setting its value to 1 (0—unused, 1—used)

Appendix B

Donate your eco-credits for planting a tree on your behalf!



Now, through CIRC4Life App you can use the eco-credits you have obtained by recycling your electrical and electronic devices for a sustainable environmental action. Thus, in addition to the benefits of recycling, you can contribute even more to the improvement of the environment by planting a native tree in a green area of Getxo.

Instructions:

- ☐ Open CIRC4Life App in your mobile phone.
- ☐ Check your eco-credits available in "My balance" section
- ☐ If you have 20 eco-credits (or more), then you can donate them for tree planting (20 eco-credits = 1 tree planted on your behalf, 40 eco-credits = 2 trees, etc).
- ☐ Capture a screenshot picture of the QR code from the mobile app:
 - ✓ Open the screen that contains the QR code (shopping ID).
 - ✓ Take a screenshot picture of your phone screen. For example, press and hold the Power and Volume-down buttons at the same time for a few seconds.
 - ✓ Then go to the Gallery (picture library) of the phone and find the screenshot of the QR code
- ☐ Send an e-mail to circ4life@indumetal.com and circ4life@recyclia.es including the purpose (donation for tree planting), QR code picture captured before, and the amount of trees to be donated with your eco-credits.
- ☐ Wait for the reply email confirming the operation.
- ☐ Check your eco-account (My Balance) to see the eco-credits spent in the donation.
- ☐ Check our webpage <https://www.circ4life.eu/demo2> to know more and news about the tree planting action in Gexto.

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Figure A1. The process of donating eco-credits for tree planting.

Appendix C. Survey Results

The survey was conducted with a questionnaire of eight questions and a total of 39 replies were received. The survey results are shown below.

(1) Question 1

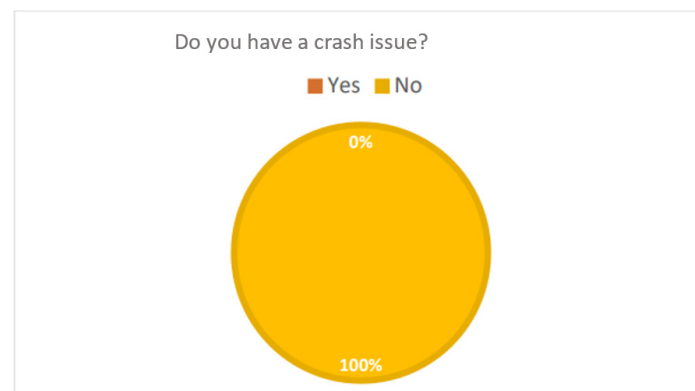


Figure A2. The survey results of Question 1.

As shown in Figure A2, the mobile app did not cause a crash issue.

(2) Question 2

Did you manage to create an account without any problems in the mobile App?

Answered: 37 Skipped: 2

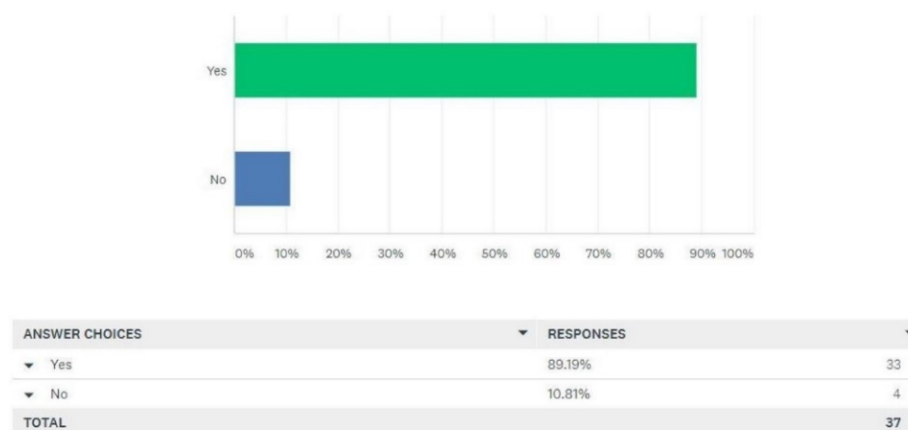


Figure A3. The survey results of Question 2.

As shown in Figure A3, most of the participants of the survey (89.19%) managed to create an account without any problems in the mobile app. The others did not state the reasons why they encountered a problem.

(3) Question 3

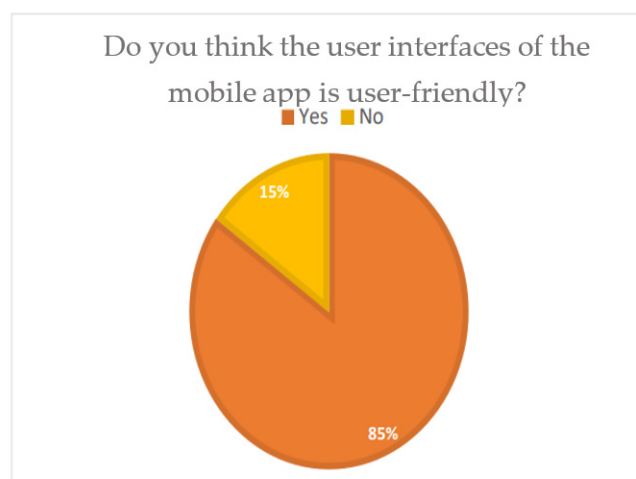


Figure A4. The survey results of Question 3.

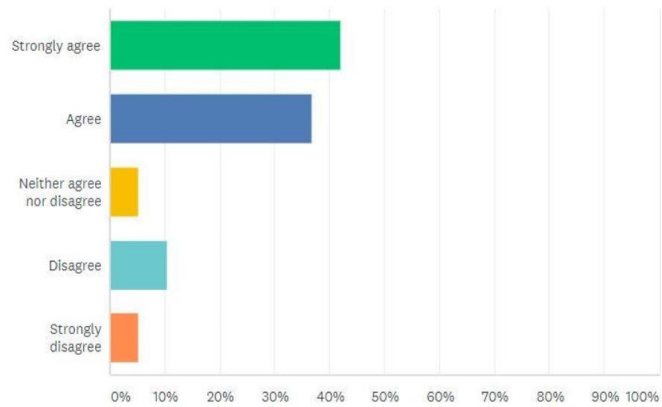
As shown in Figure A4, the majority of the users (85%) found the interface user-friendly, but others (15%) made the following suggestions for improvements:

- The same logo shown on different screens is not consistent in thickness and typography, so work has to be conducted to improve the logo's readability.
- It is rather user-friendly, but I do not want to print because it is not environmentally friendly and it is not necessary to have a printed ticket. I would prefer to delete this option from my phone.

(4) Question 4

Are the instructions given in the mobile App easy to follow?

Answered: 38 Skipped: 1



ANSWER CHOICES	RESPONSES	
Strongly agree	42.11%	16
Agree	36.84%	14
Neither agree nor disagree	5.26%	2
Disagree	10.53%	4
Strongly disagree	5.26%	2
TOTAL		38

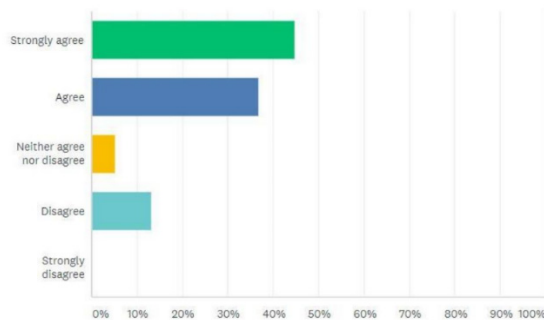
Figure A5. The survey results of Question 4.

As shown in Figure A5, 15–20% of the participants considered the instructions or technical descriptions given in the mobile app to not be clear enough.

(5) Question 5

Do you think the mobile App' functions are useful for your sustainable consumption?

Answered: 38 Skipped: 1



ANSWER CHOICES	RESPONSES	
Strongly agree	44.74%	17
Agree	36.84%	14
Neither agree nor disagree	5.26%	2
Disagree	13.16%	5
Strongly disagree	0.00%	0
TOTAL		38

Figure A6. The survey results of Question 5.

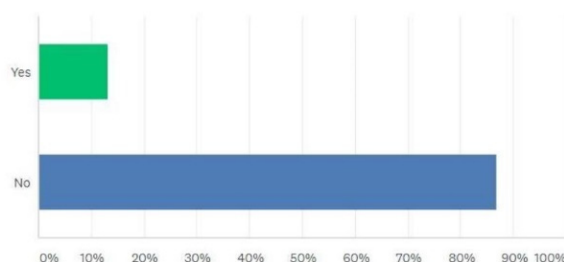
As shown in Figure A6, most of the participants agreed that the mobile app's functions are useful for their sustainable consumption: 44% strongly agreed and 36% agreed. The following comments received reveal the reasons:

- 'After recycling my damaged iPad, I received the eco-credits. I think this is a good way to encourage recycling and reuse'.
- 'I like to receive the eco-credits and would like to receive more by recycling'.
- 'The functions to show balances and history of eco-credits are helpful for me to trace my footprints'.

(6) Question 6

Do you know a similar app?

Answered: 38 Skipped: 1



ANSWER CHOICES	RESPONSES	
Yes	13.16%	5
No	86.84%	33
TOTAL		38

Figure A7. The survey results of Question 6.

As shown in Figure A7, five participants replied with 'yes' and they stated the following examples:

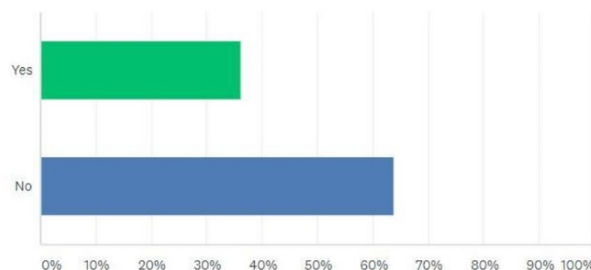
- App for encouraging healthy lifestyles such as giving up smoking.
- App for accounting daily sports activities such as running, walking, etc.
- Recycling app to find local recycling opportunities and to provide access to the ways to recycle different materials.
- App for people to self-report their recycling activities, such as depositing coffee cups in recycling bins, and then receive credits based on number of items recycled.
- A machine for recycling bottles and awarding gift vouchers based on the number of bottles recycled.

Amongst the above five examples, the last one is not a mobile app but a machine, the first two are about healthy lifestyles but not related to recycling activities, and the third is more about providing recycling information. Only the fourth one is related to providing an incentive for recycling activities, but it is far too simple, only based on self-reporting and the number of items recycled, without assessment of the recycled item and eco-accounting to track footprints, unlike that which our mobile app can do for eco-incentive.

(7) Question 7

Do you have any suggestions for further improvement of the mobile App?

Answered: 36 Skipped: 3



ANSWER CHOICES	RESPONSES
Yes	36.11% 13
No	63.89% 23
TOTAL	36

Figure A8. The survey results of Question 7.

As shown in Figure A8, 13 participants provided suggestions for further improvements of the mobile app. Below are the most interesting and relevant comments:

- Have more instructions on how to use the scanner.
- The pictures could be smaller, the instructions are not clear, and the back button is more of a menu button.
- The current app is of the Android operation system. It should also have an iPhone version.
- To improve the authentication process/ID creation and remove the task to print the stickers.
- To focus more on the colors and typography, and to add a mascot to make it more user-friendly.

(8) Question 8

How would you rate this mobile App in general?

Answered: 38 Skipped: 1



	1	2	3	4	5	TOTAL	WEIGHTED AVERAGE
★	2.63% 1	10.53% 4	13.16% 5	15.79% 6	57.89% 22	38	4.16

Figure A9. The survey results of Question 8.

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