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Novel ICT System for Recycling and Eco-Shopping

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Abstract: Recently, there has been a growing effort to reduce the environmental impact of products throughout their life cycle, particularly during the end-of-life (EoL) stage. To incentivise consumers' recycling/reusing behaviours and enhance their environmental awareness, a novel ICT-based system for recycling and eco-shopping has been developed in this paper. The recycling of EoL products is conducted based on information-communication technologies to remotely monitor and manage the recycled products (such as electronics or household bio-wastes), enabling consumers' recycling process over the Internet. Consumers are awarded the eco-credits, which can be used for various forms of eco-incentives, such as shopping discounts, tree planting donations, and exchanges for theatre and museum tickets. The eco-costs reflect the environmental impact of a product throughout its life cycle. The consumer is informed about the eco-costs through eco-shopping, which are displayed on a payment receipt. Both eco-costs and eco-credits are recorded in the consumer's eco-account. To develop the recycling and eco-shopping system, multiple information-communication technologies are utilised, such as hardware digital monitoring/control, Internet-based communication services, traceability media (bar-code and QR code), user identity recognition and privacy protection, and multi-language supports. A case study is conducted, including online tracking of the recycling process and then implementing incentive activities with the eco-credits and eco-costs. The system has been successfully validated via illustrating recycling, eco-shopping, and eco-incentives in public places (e.g., schools, urban cultural centres), as well as promoting the consumer's participation in recycling and enhancing their environmental awareness, which proved the successful implementation of the novel contribution of this research.

Keywords: recycling; eco-shopping; eco-incentive; eco-credit; eco-cost; eco-account; barcode; online tracking; web services; QR code; sustainability

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1. Introduction

In the EU, electronic waste (e-waste) is the fastest growing waste stream, with an annual growth rate of 3–5%, three times faster than general waste. About 90% of the waste is still landfilled or incinerated without any pre-treatment. This allows the substances contained in the products (such as heavy metals and brominated flame retardants) to enter into the soil, water, and air, which in turn poses a threat to human health and causes damage to the environment [1].

Today, around 700 million electrical and electronic devices are idle in households in Europe; if all these devices are collected and recycled, approximately 14,920 tons of gold, silver, copper, palladium, cobalt, and lithium would be recovered, worth more than 1 billion euros, which will make a large amount of secondary materials available for use [2]. However, only 35% of electronic wastes are collected and recycled per year, where 12–15% of mobile phones and tablets are properly recycled, lower than the recycling rate of general e-waste [2]. According to the findings of the European Commission DG Environmental Organization [3], most people did not attempt to recycle their end-of-life (EoL) electronic devices due to a lack of responsibility and awareness. According to the survey conducted

by the European Erasmus student project, more than 50% of consumers were concerned about electronic waste recycling, while they do not commit to recycling electronics because there is insufficient information on access to the e-waste collection point and a concomitant lack of awareness of the environmental problems related to the product [3].

It is critical to reduce the environmental impacts of WEEE at all stages of the equipment's lifecycle, and particularly in the EoL stage. Currently, Directive 2002/96/EC on waste electrical and electronic equipment (WEEE) and the Supplementary Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment have been introduced into UK law to promote the product EoL management, eco-design, life-cycle thinking, and ex-tended producer responsibility [1].

To increase people's awareness of recycling EoL products, there have been some incentive schemes, such as the Scotland reward scheme for recycling plastic bottles and the Apple reward scheme for recycling the electronic products developed by the own company (like iPhone), which are used to award end-users when they recycle/reuse the products. However, those schemes are applied for limited end-users who recycle a specific type of product (e.g., light bulb, bottle, or mobile phone). At present, there is no generalised solution to collect and recycle different types of products, which is still a challenge. In addition, the product's residue-quality is considered in the incentive scheme; however, the ecological impact through the product's life cycle has not been covered, which is presumably not conducive to raising the consumer's environmental awareness [1,2].

Few recycling bins provide the function for consumers to recycle products without human assistance/interference to optimise the schedule and efficiency of waste collection. For example, the intelligent bin developed by ReciclaGana (www.reciclaygana.org (accessed on 8 June 2022)) employs the electronic bar-code to track the product recycled [4]. However, the recycling operation is unable to be conducted through the Internet, and hence, consumers are required to go to a designated location where they might be not aware in order to retrieve their rewards. Further, due to the lack of sufficient ICT (information and communication technologies) supports, the rewards cannot be recorded into the consumer's account (such as instant display of their coupons/points spent), which greatly affects consumer's experience and restricts their participation in recycling activities. Therefore, it is demanded to develop an ICT-based recycling system, effectively incentivising consumers to recycle their waste products.

In addition, a number of studies have tested/verified the use of ICT, showing possible ways to improve the consumer's experience in a smart city setting [5,6]. Sobnath et al. proposed the application of modern smart technologies to improve the mobility of visually impaired people by making use of the IoT and sensors [7]. Some IoT-based smart detection mechanisms were introduced to detect potential threats in the wireless network to alleviate data security issues [8].

To overcome the above problems, the innovative online recycling and eco-shopping system have been developed, which has the following novel features that the existing systems cannot achieve (see Table 1):

Table 1. The novel features of the system developed in this research.

Limitation of Existing Schemes/Systems	Solutions Presented in This Paper
Although recycling reward schemes are available to consumers, the rewards are not able to be recorded in the consumer's account.	Consumer eco-account consists of eco-credits and eco-costs. The eco-credits reflect consumer's positive behaviour through recycling, while the eco-costs represent the consumer's negative behaviour generated by shopping.

Table 1. *Cont.*

The ecological impact through product's life cycle has not been considered in the existing reward schemes, which restricts the improvement of consumer environmental awareness.	The eco-credits are used to award the consumer for positive behaviour in their recycling/reusing. The eco-credits derived from the eco-costs that reflect the impact of the product on the environment. Consumers can use the eco-credits in different ways, such as discount at a shop, exchange for theatre tickets, tree planting, etc.
Recycling process is not conducted via the Internet. Consumers are instructed to go to a designated location to physically get their rewards back.	The ICT-based system for recycling and eco-shopping has been developed to make the recycling process online. Multiple information communication technologies are utilised, such as digital simulation and monitoring, Web-based communication services, traceability with use of bar-code and QR code, user identity recognition, user privacy protection, multi-language supports.
Existing recycling systems are limited to a specific type of product, not various products.	The system and method developed in this research can be applied to recycle different products. Although the paper focus on the electronic product, the approach developed in this paper can also be used for recycling other products, such as household bio-wastes, as presented in Section 2.

(1) When consumers recycle EoL products, they will receive the eco-credits, which are used to award customers for their positive behaviour in recycling/reusing. Consumers can use the eco-credits in different forms, such as discounts at a shop, exchanges for theatre tickets, tree planting, etc. The eco-credits are calculated based on product environmental impacts derived from the eco-costs, residual value, and long-time use. The eco-costs are aggregation of the impact on the environment through the product's life cycle. The eco-credits and eco-costs are recorded in the consumers' eco-account, which are the outcome of the CIRC4Life project supported by European Commission's H2020 programme [9,10].

(2) The recycling and eco-shopping system developed in this paper can be applicable to collect different products, not limited to a designated type of product operated by existing systems, thereby expanding the application scope of waste treatment and helping promote consumer's sustainable behaviour. In this paper, the developed system has been demonstrated via recycling/collecting electronic products, but it is also equally applicable to recycle other products, such as household bio-wastes.

(3) The recycling of EoL products is conducted online to track and monitor the whole recycling process, enabling consumers to collect and recycle their products (such as electronic devices or household bio-wastes) through the Internet, which is a novel application in this area. The recycling system utilises the intelligent bin based on a range of information and communication technologies, achieving online tracking, recycling, and management of EoL products.

In the following sections, the overall architecture and related concepts of the system are introduced, and the technologies and methods used for system development are reported, followed by the presentation of a case study to demonstrate the functions and operation of the system and the implementation of the eco-shopping and eco-incentives, and the conclusions given at the end of the paper. The intelligent bin system is demonstrated in public places for real application and related eco-shopping schemes are implemented, which verifies the success of the system.

2. Overview of the Intelligent Recycling System with Eco-Incentives

The ICT system for recycling and eco-shopping is developed, promoting consumers to recycle products that reach their EoL stage (e.g., electronic waste [4] and household bio-waste [11]) and allowing consumers to conduct eco-incentive and eco-shopping activities, as shown in Figure 1.

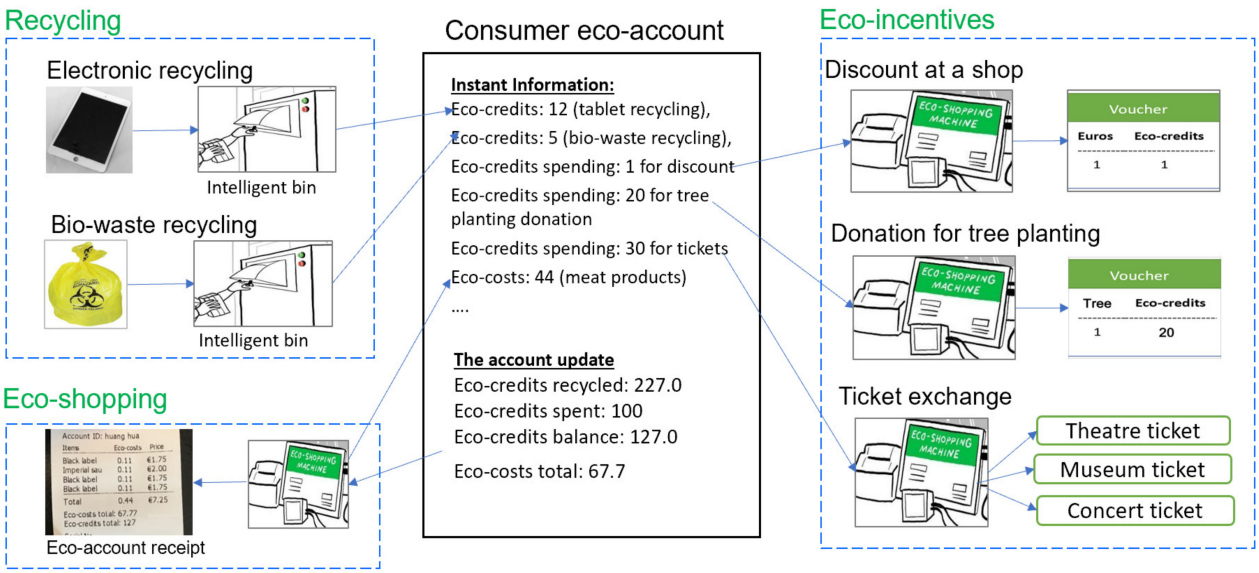


Figure 1. Overview of the ICT-based recycling and eco-shopping system.

2.1. ICT-Based Recycling System

The recycling system applies the Internet and smart technologies to monitor and manage the recycled products (such as electronics and bio-waste) and make consumers recycle online. As the core of the system, the existing electronic control unit is applied to monitor and control the recycling process, such as scanning the user's two-dimensional QR (quick response) code, switching on/off the electronic lid of the bin, generating and printing the barcode of the product, and information communication with the central database. In addition to the electronic control unit, the system also includes a scanner, a printer, a bin, and a sensor. The scanner is used to scan the QR code of the consumer, obtain their information and pass it to the control unit for the consumer to log in; the printer is to print a receipt of the product recycled, which is then attached to the product package for tracking. The bin is used to contain the recycled products and is equipped with the electronic control unit, scanner, and printer. The sensor is used to measure the storage (filling) level of the bin. Once the bin is full, an e-mail is sent to the recycling company; then the recycled products are collected and classified, and relevant recycling data are transmitted to the cloud data centre in time.

Consumers recycle EoL products (e.g., electronic tablets) with the recycling system, and then receive eco-credits that are used to credit their positive behaviour generated from their recycling activities. The eco-credit is associated with the eco-cost, which is a cumulative value accounting for the product's ecological impact through the whole supply chain. Based on the eco-cost, the eco-credit is calculated, taking into account the product's residual quality, longer-time usage, and materials [12].

The eco-credits are recorded to the eco-account of the individual consumer, including recycled and spent eco-credits and their balance, which are shown in Figure 1. The recycling company assesses the product via a traceability system and then calculates eco-credits (for the information about traceability and assessment, please refer to the relevant report developed by H2020 CIRC4Life project [13]). In addition, consumers can view the eco-credits in their eco-accounts and also obtain the information of recycling procedure using their mobile phone (for the information about consumer mobile app please refer to the authors' related paper [14]).

2.2. Eco-Shopping System

The eco-shopping system allows the consumer to purchase products (such as meat products) in the shop and to access the information of the consumer eco-account. The system

generates the eco-account receipt with information of eco-costs of the products purchased, eco-credits balance, and cash payment, as shown in Figure 1.

In the shop where the eco-shopping takes place, there are two independent parts: one is the existing shop's accounting system, and the other is the eco-shopping system developed in this paper. The two systems are not to interfere with each other, ensuring the integrity and safety of the shop's accounting system.

Eco-shopping is implemented through the following steps: (i) At the check-out point, the consumer scans the QR code shown on the identity (ID) card (or mobile phone [6]) though the card reader, which allows the consumer to gain access to the eco-account. (ii) The shop assistant scans the barcode attached to the product with the reader, to obtain the product eco-costs. (iii) The system prints the receipt that contains the information of cash payment, the eco-costs, and the eco-credits. (iv) Then the system records the products into the consumer's eco-account.

2.3. Eco-Incentives with Eco-Credits in Eco-Shopping

- Shopping discount

The eco-credits obtained from recycling EoL products can be used to pay for the discount of new products to encourage consumer's participation, thereby increasing recycling rate. For example, the shop offers a discount with eco-credits for a keyboard: the price of the keyboard is 10 euros, and the 5% discount is 0.5 euro which is to be paid by the eco-credits; and the remaining 9.5 euros are to be paid by cash.

The eco-shopping system contains a computer, scanner, and a printer. First, the shop staff calculates the discount amount of the products to be purchased in euros. Second, the shop staff inputs the discount amount (euros) to the eco-incentive computer, which converts the euros into eco-credits and prints out voucher with the exact amount of euros converted from the eco-credits. The eco-credits that are equivalent to the discount amount will be deducted from the consumer's eco-account. Third, the shop staff completes the purchase in the shop's existing accounting computer. The shop staff inputs the amount (euros) of the voucher as the discount value of the purchase, and keep the voucher as an evidence of payment. The customer pays the remaining amount of the price with cash.

- Donation for tree planting

In addition to the discount presented in above sub-section, the eco-credits obtained through the recycling activity can also be used to donate/exchange tree planting, which is implemented through e-mail communication between the consumer and the manager. For ease of operation, consumers do not need to go to the office physically; instead, they send an e-mail to the manager, with the following information: QR code (consumer ID) and eco-credits spent for further processing. The operation procedure includes the following two parts:

(a) Operation at the consumer side: The consumer opens the mobile App, which is developed by the CIRC4Life project supported by EU H2020 program [14], and checks whether the eco-credits are enough for planting trees. Then the consumer captures a screenshot picture of the QR code for the eco-incentive from the mobile App [14], and utilises the built-in e-mail application of the mobile phone to send an e-mail to the manager. In the email, the consumer is to include the following information: the intention (i.e., donation for tree planting), QR code picture, and the amount of trees to be converted by the eco-credits (20 eco-credits per tree). The QR code for tree planting is different to the one that is used for recycling presented in Section 2.1, which ensures the security of user data.

With regard to the user's privacy and security, the QR code is produced with a dynamic protection method, which can be updated by the mobile App every time the user logs in, as presented in [14]. The QR code is to expire after using it for planting trees, which means that each code can only be used once. For other donations, the consumer has to send a new code.

(b) Operation at the manager side: The manager checks the email and scans the QR code to ensure that the QR code is not used. Through the eco-incentive computer, the

manager enters the amount of the trees and converts trees to the equivalent eco-credits, which are then deducted from the eco-account. Finally, the manager prints out a receipt as a form of evidence (the QR code expires), and e-mail the consumer to confirm the operation.

- Exchange for theatre/museum tickets

Similar to electronics recycling, consumers can recycle household bio-wastes through the intelligent bin and acquire eco-credits. The system developed for recycling electronics is also adapted to recycling bio-waste [11]. The eco-credits obtained can be converted to various types of tickets, e.g., theatre, museum, or concert tickets.

Through the eco-incentive computer, the administrator inputs the eco-credits converted from tickets, which are deducted from the consumer's eco-account. Then the computer prints out the ticket, which contains the exact amount of the eco-credits converted.

2.4. Consumer Eco-Account

The eco-account is used to record eco-credits and eco-costs. The eco-costs reflect consumer's negative behaviour generated from purchasing activity, while the eco-credits represent consumer's positive behaviour obtained from recycling activity. As illustrated in Figure 1, the eco-credits from recycling electronics or household bio-waste products are added to the eco-account, and these can be spent in different eco-incentive activities. The information of the eco-account is updated in real time to record consumers' footprints through their recycling and purchasing.

The technologies applied in the development of the intelligent recycling system and eco-incentives are presented in Section 3.

3. Technologies and Methods Applied

3.1. Online Recycling EoL Products with the Intelligent Bin

Figure 2 shows the overview of the recycling system with the intelligent bin, which consists of an electronic control unit with a microcomputer, a scanner, a reader, a printer, a sensor, and a bin (container), which are detailed in the following:

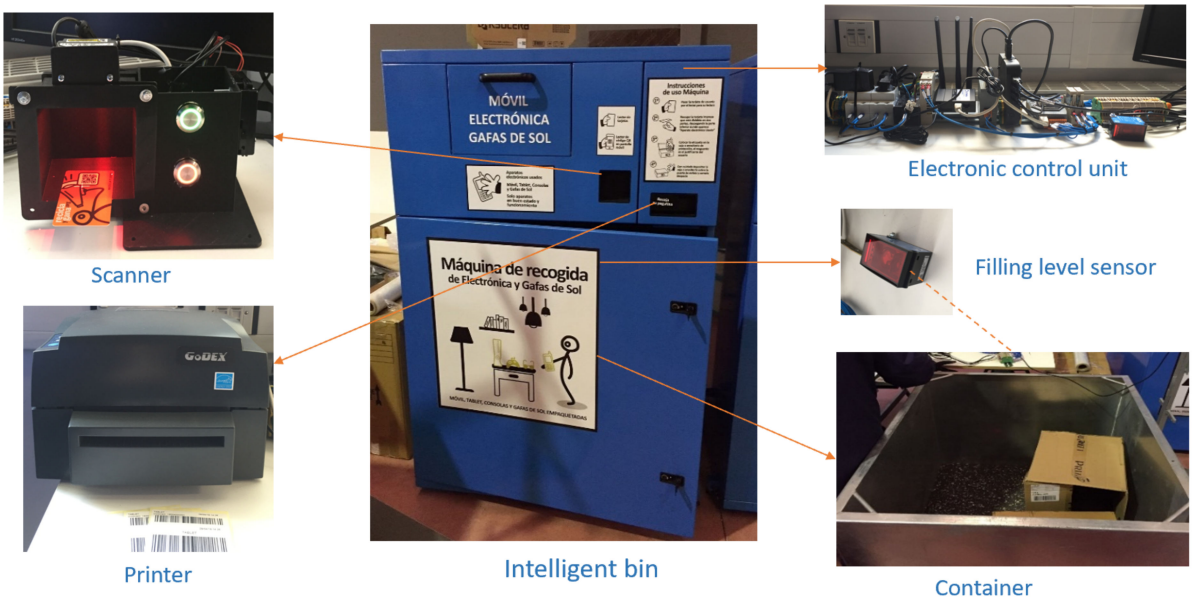


Figure 2. Intelligent bin used in the recycling system.

- The electronic control unit utilises a micro-computer with flash memory, to monitor and control the recycling operation and store daily data of consumer operation. The control unit is equipped with a digital control module, which collects and processes digital signal data from the reader, and then transmits analogue signal data to the

control components to open the lid of the bin and print the receipt (bar-code label). The ICT software developed by this research applies a common communication protocol, i.e., standard Hyper Text Transfer Protocol, which is adapted to the communication interface of the data centre.

- The electronic reader is used to obtain the identity of the consumer by scanning the QR code. Each consumer has an account with a unique QR code, which is shown on a consumer ID card [15,16]. For example, if the QR code is not recognised by the control unit (e.g., it does not match the data recorded in the control unit), then the bin will not be allowed for further operation.
- The printer generates two bar-code labels, allowing the consumer to attach the label to the product recycled. The bar-code label ensures that the product can be tracked throughout recycling process, and the recycler is able to evaluate the product based on the information provided by the bar-code.
- The electronic control unit is connected with a capacity sensor, which measures the storage status (filling level) of the bin. The e-mail server has been deployed in the microcomputer of the control unit to pass the bin information to the recycling company for collection and maintenance.
- The bin contains a green button and a red button for the consumer to enter the product status (i.e., working or damage). The bin will not check the working status of the product, and hence, the recycling company will assess and verify the product information (such as status, model/brand, life time, etc).

The ICT software for the electronic control unit has been developed to transmit the user's recycling information data to the data centre over the Internet, which is a novel application. Because the electronic control unit of the intelligent bin produces a number of data every day, it is essential to transmit the consumer's recycling data to the remote data centre, so as to monitor activity online and track all recycling processes.

As the core data sent by the control unit, the product's bar-code plays an important role in tracking the product and transmitting eco-credit values [17]. The bar-code is custom developed with the following five parts: user ID, date, bin ID, product status, and product ID, which are presented as follows:

(1) User ID is an 11-digit code, which is formed by 5-digit postal code and 6-digit sequentially generated user-code (e.g., 000001, 000002, 000003 . . .).
(2) Date of the recycling operation, composed by 6 digits (from number 12 to number 17) in the format of year, month, and day, such as 181122.
(3) Bin ID is 5 digits (from number 18 to number 22). Each bin has a unique number that is generated in the sequential format (e.g., 000001, 000002, 000003 . . .) to identify the place where the disposal takes place.
(4) Check digit represents the product status, either 0 (if the product doesn't work) or 1 (if it works).
(5) Product ID is the last 5 digits standing for the product, e.g., 00001, 00002.

Figure 3 shows an example of barcode '16004000001190429000010000 59', which consists of the following five parts: (1) 16004000001: user ID (11 digits); (2) 190429: date (6 digits); (3) 00001: bin ID (5 digits); (4) 0: status (1 digit, not working); (5) 00059: product ID (5 digits).

Figure 3. Barcode of the product recycled.

3.2. Internet-Based Information Interaction Using Web Service Technology

As the most widely used application programming interface, the REST-based Web service (Representational State Transfer), is applied to create the online connection between the microcomputer of the electronic control unit (client side) and the cloud computer of the data centre (server side). The Web service enables the client side to transmit the information data to the server side, and hence, the data of the products recycled are able to be uploaded to the remote database instantly (whenever the client-side computer triggers the request). The Web service ensures the communication between the server side and the client side, and the compatibility of different computer languages/platforms.

The implementation of the REST-based Web service starts by processing the raw data to JSON (JavaScript Object Notation) form [17], including the bar-code attached to the product, date/time, and the filling level of the bin, which are encoded in JSON with the following programming syntax:

```
{
        "barcodeByBin":
                {"string":"160040000061904260000110009"},
          "dateTime":
                {"string":"01/01/2022 18:37:37"},
          "fillingLevel":
                {"double":10}
}
```

The above code is utilised to transmit the consumer's recycling operation data to the Web server, where '160040000061904260000110009' is the product's barcode, '01/01/2022 18:37:37' is the date and time of recycling, and '10' is the storage level of the bin. The tags 'string' and 'double' are used to specify the formats of the above records. The start bracket and the end bracket are used to define a complete code including all the records.

With the above code, the information data are parsed as the JSON form, and then pass with a target response code to the data buffer in the computer memory, using the Response module/function of G computing language based on the NET development environment. When the client-side computer in the control unit invokes a data transmission request through the REST (representational state transfer) based Web service provided by the Web server, the response with the recycling data, which remains in the data buffer, is transmitted to the server computer.

The related ICT software (user interface and programme code) has been compiled and installed, which allows the electronic control unit of the intelligent bin to transmit the intelligent bin data to the database. The independent server deployed at the Cloud computer in the Nottingham Trent University has been used to develop and test the programmes and interfaces of the electronic control unit and validate the effectiveness of the Internet communication, e.g., retrieving and sending recycling data and response results via the electronic control unit, as shown in Figure 4. The recycling data are also passed to the traceability module developed by the CIRC4Life project for use by the company [15].

Figure 4a,b shows G language codes for hardware interface and communication used in the LabVIEW programming environment, which are used to develop the user-interface and programme for the control unit computer, based on Figure 4c, which shows the real-time processing of the data by online sending intelligent bin data to the server, with the following inputs and results:

(1) URL (uniform resource locator) containing the network address and port of the independent server): http://circ4lifebin:8002/RESTservice/PostData (accessed on 8 June 2022).

(2) The data related to the recycling activity are sent to the server online:

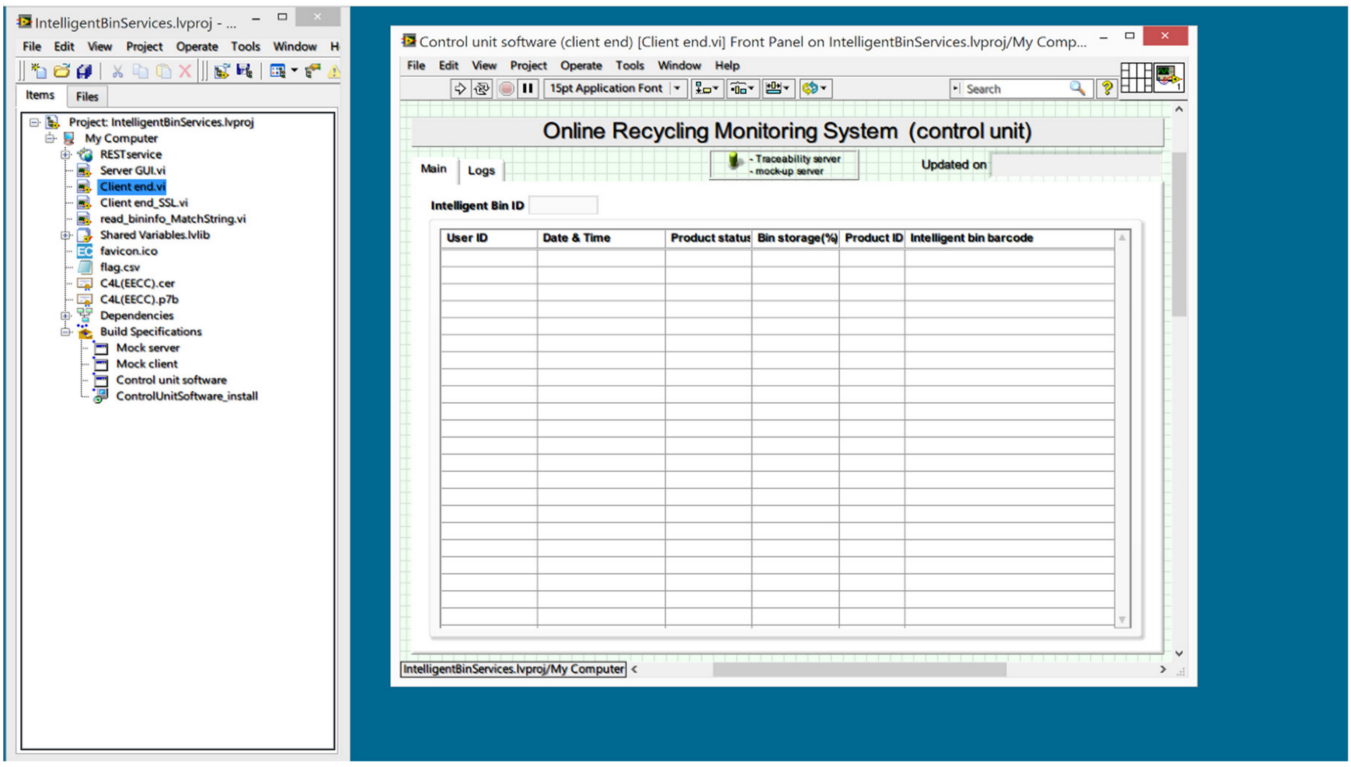
```
{
   "barcodeByBin":"160040000031909120000100058",
   "dateTime":"2019-04-26T15:49:08+00:00",
   "fillingLevel":65
}
```

(3) Then the results are obtained from the server, including:
(a) Header of response:

HTTP/1.1 200
Server: nginx/1.16.0
Date: Thu, 26 Apr 2019 14:49:43 GMT
Content-Type: application/json; charset=UTF-8
Transfer-Encoding: chunked
Connection: keep-alive

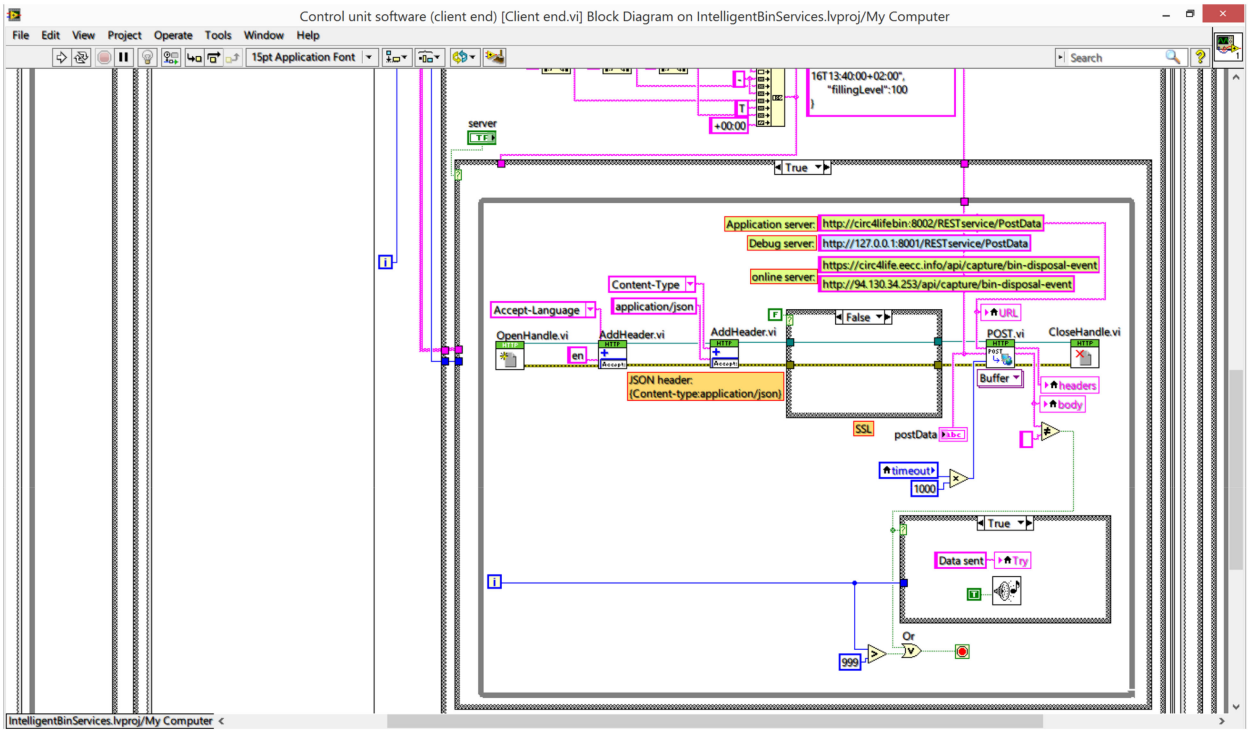
(b) Body of response:

{"timestamp":"2019-04-26T14:49:43.19473","status":200,"message":"<?xml version=\"1.0\"encoding=\"UTF-8\" standalone=\"yes\"?><result><duration>18</duration><startTime>2019-04-26T14:49:43.173</startTime><endTime>2019-04-26T14:49:43.192</endTime><eventIds><eventId>c33aeba1-162b-4140-a815-b0702df0387f</eventId></eventIds></result>":"success"}

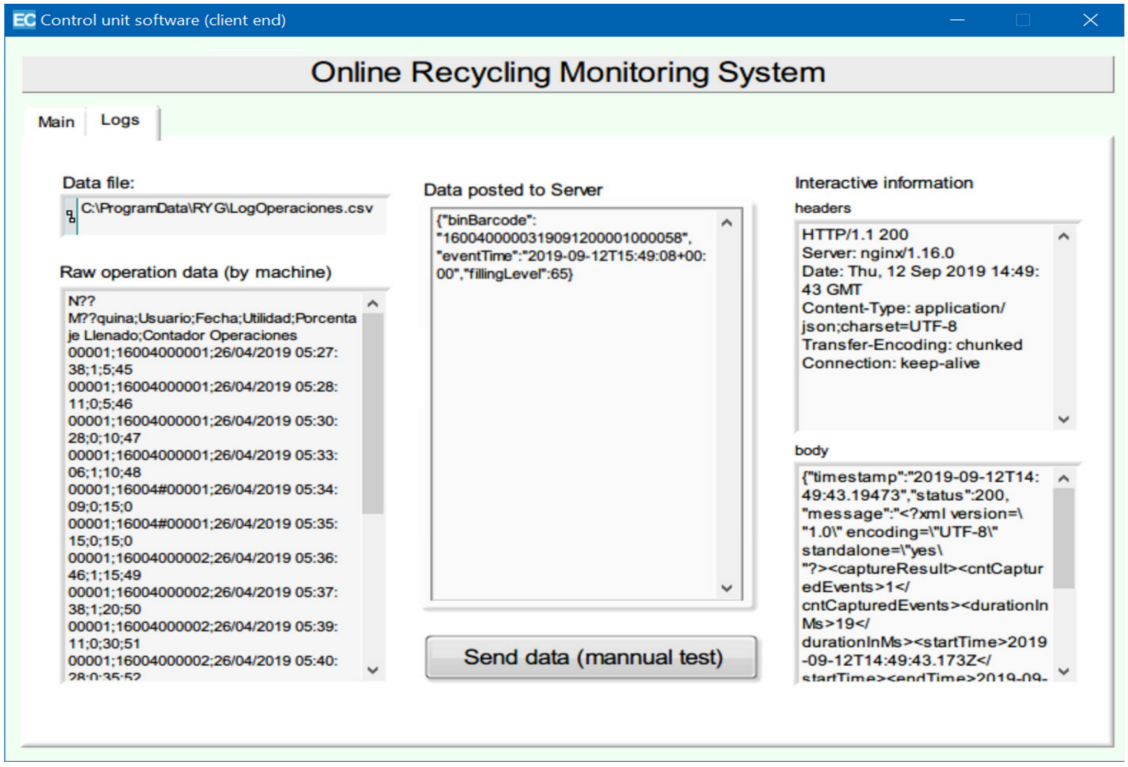


(**a**)

Figure 4. *Cont.*



(**b**)



(**c**)

Figure 4. Development of the user interface and programme code for online transmitting the intelligent bin data to the data centre. (**a**) Development of user-interface (UI) for monitoring recycling process; (**b**) Development of online recycling monitoring programme code; (**c**) Programme debugging and testing.

3.3. SMTP-Based Secure Email Communication

The electronic control unit of the intelligent bin automatically sends an e-mail to the recycling company everyday, informing the recycling company about the filling level of the bin and reminding them of the schedule to plan waste collection. To achieve this function, the electronic control unit is coded in Extensible mark-up language (XML), including IP address and computer port of the control unit, SMTP (Simple Mail Transfer) protocol, schedule of sending e-mail, etc. The SMTP protocol provides the method to create and send the email to the recycling company, which is based on the following rule:

- Email address: circ4lifebin@hotmail.com
- SMTP (e-mail transfer) Server: smtp.office365.com

  Port: 587
  user name: circ4lifebin@hotmail.com
  Password: ********
  Security: STARTTLS

- POP (e-mail receiving) server: outlook.office365.com

1. Password: ********
2. Security: SSL/TLS

Figure 5 shows the code of communication interface of the electronic control unit, which includes the setup of user information, e-mail address, IP address, port, and relevant networking data. At the end of the day, an email with the status of the filling level is scheduled to be sent to the email address of the recycling company.

```
  <ICPCON>
    <IP>192.168.250.2</IP>
    <Puerto>502</Puerto>
  </ICPCON>
  <Etiquetadora>
    <NombreImpresora>Godex G500</NombreImpresora>
  </Etiquetadora>
  <EMail>
    <emailOrigen>CIRC4LifeBin@gmail.com</emailOrigen>
    <emailDestinatarios>CIRC4LifeBin@gmail.com;egarcia@recyclia.es</emailDestinatarios>
    <ServidorSMTP>smtp.gmail.com</ServidorSMTP>
    <Usuario>CIRC4LifeBinInfo</Usuario>
    <Contraseña>circ4life</Contraseña>
    <PuertoSMTP>587</PuertoSMTP>
    <SSL>true</SSL>
    <AsuntoNotificaciones>Tablet Control %M</AsuntoNotificaciones>
    <CuerpoNotificaciones>Registration List</CuerpoNotificaciones>
  </EMail>
  <HorasNotificacionesEmail>
    <Hora>PT12H</Hora>
  </HorasNotificacionesEmail>
  <HorasNotificacionesEmail>
    <Hora>PT0H</Hora>
  </HorasNotificacionesEmail>
</dsDatosLocales>
```

Figure 5. XML code for configuring the e-mail server for waste collection notification.

The commonly used e-mail receiving tools (e.g., Microsoft Outlook, Outlook Express, and Fox-mail [18]) can be used to receive the e-mail notification from the intelligent bin system. To this end, the server information related to SMTP (Simple Mail Transfer Protocol) and POP (Post Office Protocol) protocols are to be pre-configured within the e-mail receiving tools, to ensure that the e-mails from the intelligent bin are retrieved properly.

Figure 6 shows the messages received from the intelligent bin regarding the filling level. When the bin is full (i.e., more than 90 percent of the storage space is occupied by the products recycled), the recycling company will be reminded to schedule the collection.

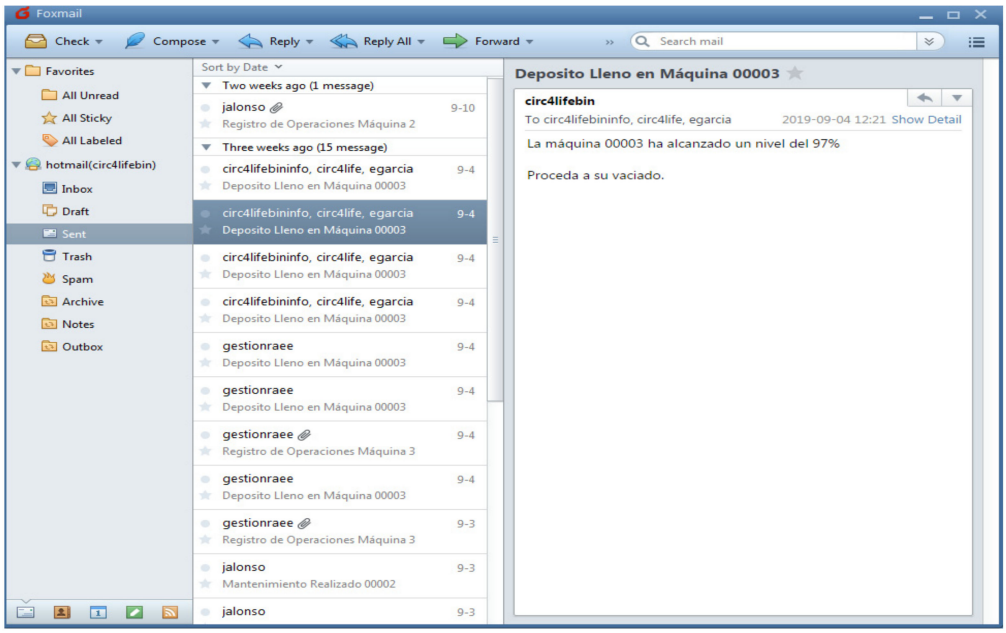


Figure 6. Notification email of bin's storage status.

3.4. Shopping with the Eco-Credits through Interaction with Scanning/Printing Equipment

To implement the eco-shopping discount with the eco-credits, the two systems are utilised in the shop: the eco-shopping system developed and the shop's existing accounting system, which are separate and will not affect each other (see Figure 7). The shop staff works on the two systems at the same time.

Figure 7. The eco-shopping system developed by this paper and the existing shop's accounting system.

The eco-shopping system includes a computer, a reader, and a printer. The reader is utilised to scan the QR code shown on a consumer ID card [15,16], enabling the shop staff to gain access to the consumer's account. The computer enables the shop staff to input the euros to pay the discount with the eco-credits and obtain the information of the consumer account (such as total existing eco-credits).

Through the eco-shopping computer, the eco-credits are calculated with the discount amount (euros) of the products to be purchased and then are deducted from the consumer's account. The printer is used to generate the receipt showing both the eco-credits converted

by the discount euros and the consumer's account information (see Figure 8). The shop staff is to complete the purchase using the discount value of the receipt through the existing shop's accounting computer.

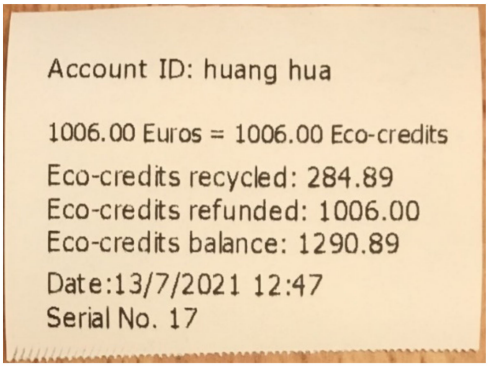


Figure 8. The eco-credit receipt.

When the consumer wants to return the product, he/she is allowed to bring the product back to the shop. With the eco-shopping computer, the shop staff can add the eco-credits converted from purchased amount (euros) of the product to the consumer's account, to complete the refund.

3.5. Tree Planting Donation Based on Dynamic QR-Code Verification

The eco-credits earned can also be used to donate for planting trees. In this incentive scheme, the consumer sends the QR code to the administrator via e-mail, in order to perform the donation of tree planting with the eco-credits [19].

Figure 9 shows the human-machine interactive interface of the administrator, which is used to scan the QR code, check consumer's identity, and input the amount of the trees that are converted to the eco-credits and recorded in the data centre. Figure 10 shows the interface which records the eco-credits spent for tree planting by individual consumers.

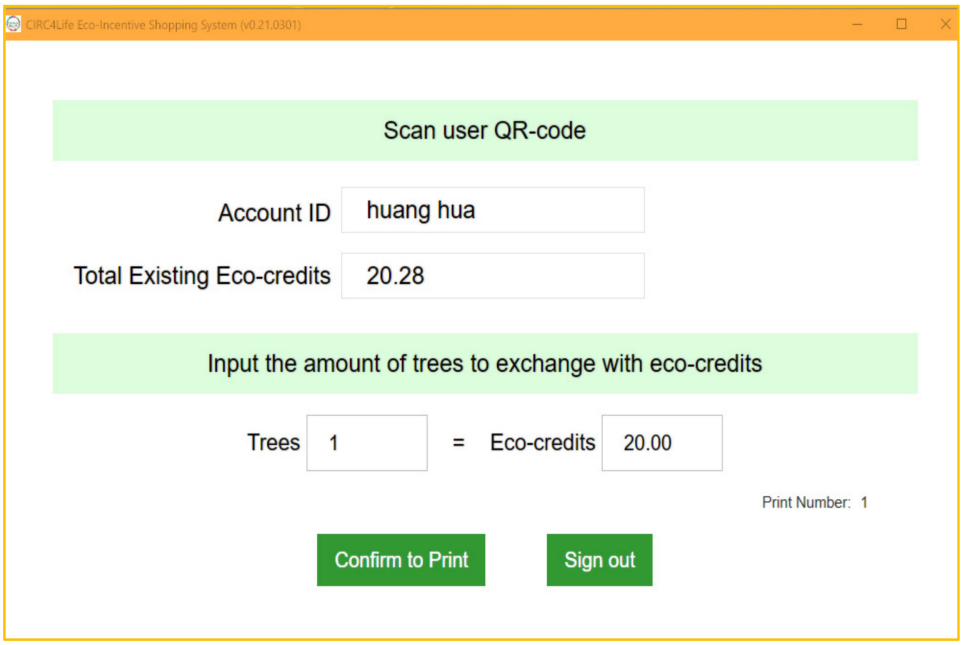


Figure 9. Development of the interactive interface for exchanging eco-credits with tree planting.

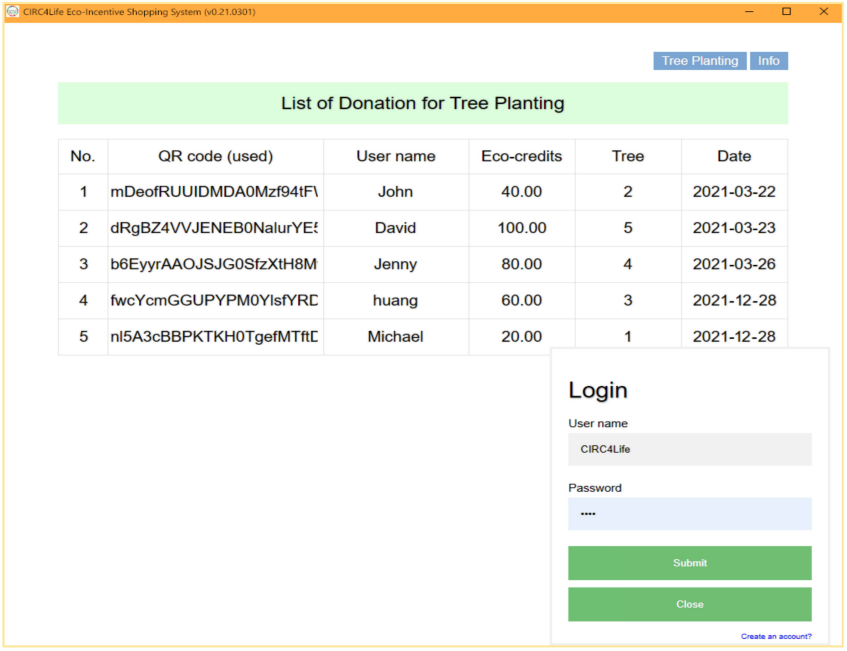


Figure 10. Development of the management interface (e.g., administrator register, login, and history records of tree planting donations).

The interface contains a list that dynamically records eco-credits spent when the consumer donates for planting trees (Figure 10). The information of individual consumers is to be in real time inserted and added to the list, including user name, QR code, eco-credits used, number of trees, and donation date. The related database has been developed to record consumer data and authorise the administrator to manage the data (such as register and log in).

In order to mitigate the consumer's security risk (e.g., the QR code could be reused or hacked), each QR code that the consumer sends for tree planting is only used once. Different from the existing static two-dimensional code [19], the QR code developed in this paper is a dynamic and temporary code containing the encrypted user information, which is to immediately expire on the completion of the tree planting (Figure 11).

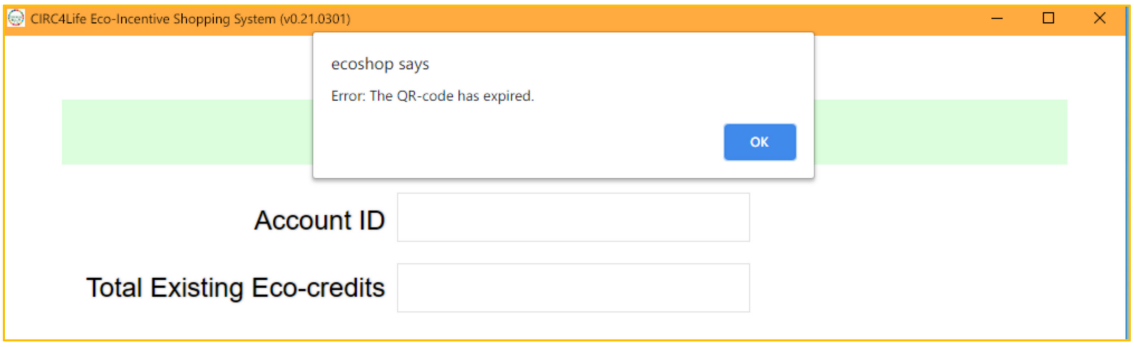


Figure 11. Invalid QR code detected to prevent fraud.

4. Case Study

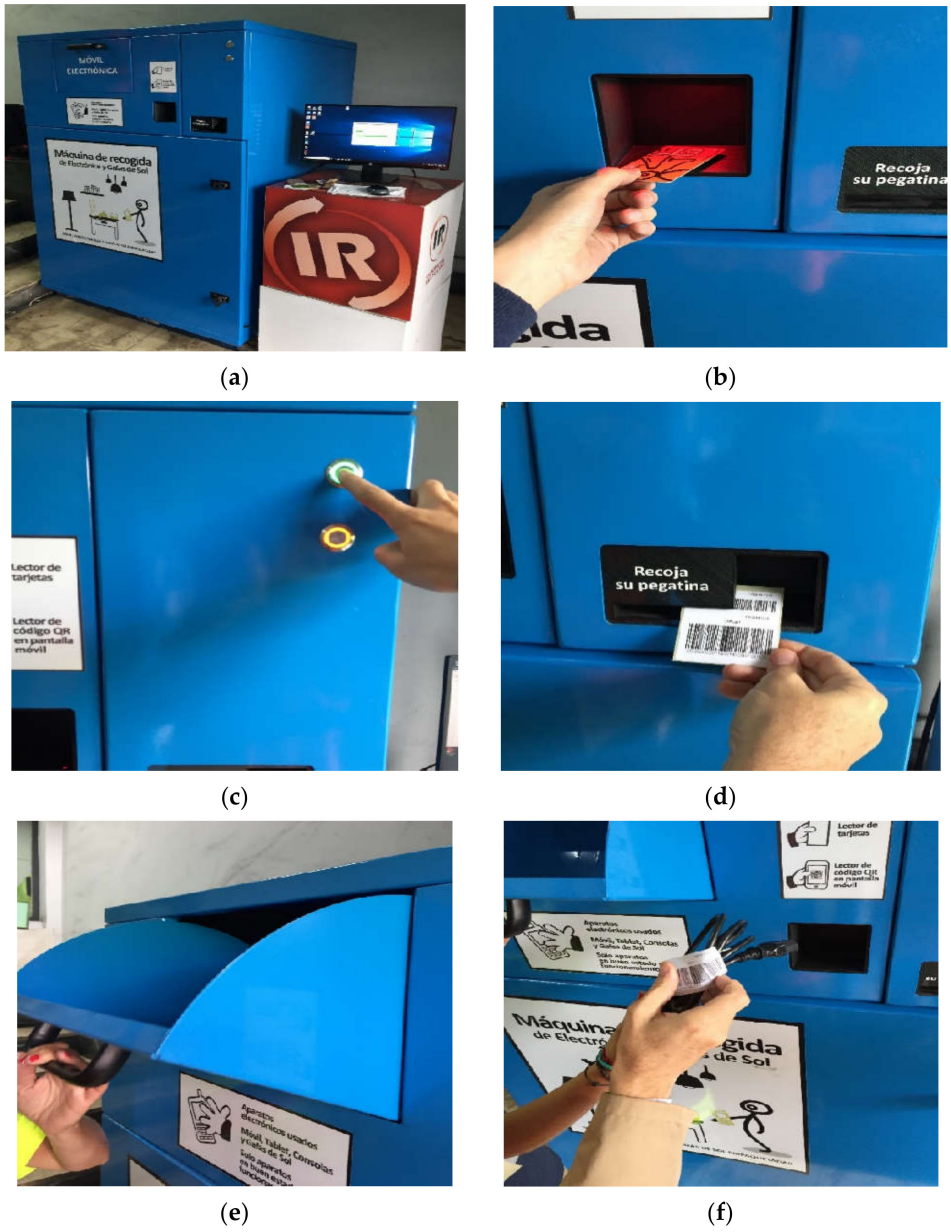
The case study has been conducted to demonstrate the recycling and eco-shopping system developed, which is detailed in the following sub-sections:

4.1. Online Recycling and Monitoring with the Intelligent Bin

The intelligent bin was installed with related software at a factory of Indumetal company in Erandio, who is a partner of H2020 CIRC4Life project. Then the intelligent

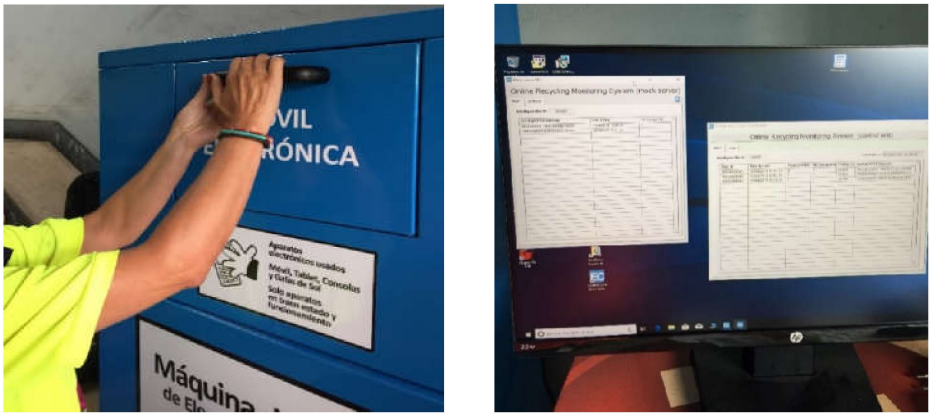
bin was utilised in Gexto's city council, cultural centres, and schools for demonstrating the system's functionality (via teaching and training) [18].

To monitor and manage recycled products online, the ICT software has been developed and deployed on the microcomputer in the electronic control unit of the intelligent bin, with assistance of the external devices (such as monitor, computer mouse, keyboard) connected to the computer of the electronic control unit (see Figure 12h), which ensures the success of installation. When the intelligent bin was demonstrated in schools and other public places, the external devices were dismantled.



(**a**) (**b**) (**c**) (**d**) (**e**) (**f**)

Figure 12. *Cont.*



(**g**) (**h**)

Figure 12. Operation procedure of the intelligent bin system. (**a**) Set up the intelligent bin with the external devices. (**b**) Consumer logs in via scanning the QR code shown on a consumer ID card or a mobile phone. (**c**) Select a button to input the product status (i.e., working or damaged). (**d**) Print the two barcode labels: one is attached to the waste, and the other is used as a receipt. (**e**) Bin lid/door is unlocked and opened. (**f**) Attach the barcode label to the e-waste. (**g**) Place the waste in the bin and close the lid. (**h**) The system records and tracks the recycling information online.

The intelligent bin was installed in schools and cultural centres in Gexto, and electronic devices were used to illustrate the recycling procedure. Recycling of EoL products started by scanning the QR code that was shown on a consumer's ID card or a mobile phone. The QR code is a unique identifier, which represents the identity of consumer. (The consumer can get the QR code by registering an account through the mobile app developed by the CIRC4Life project [9]). The QR code is displayed on a card (or a smartphone), as shown in Figure 13. The consumer scanned the code through the code reader in the intelligent bin. When the QR code matches with the interior coding standard of the reader, the consumer can proceed to operate the intelligent bin.

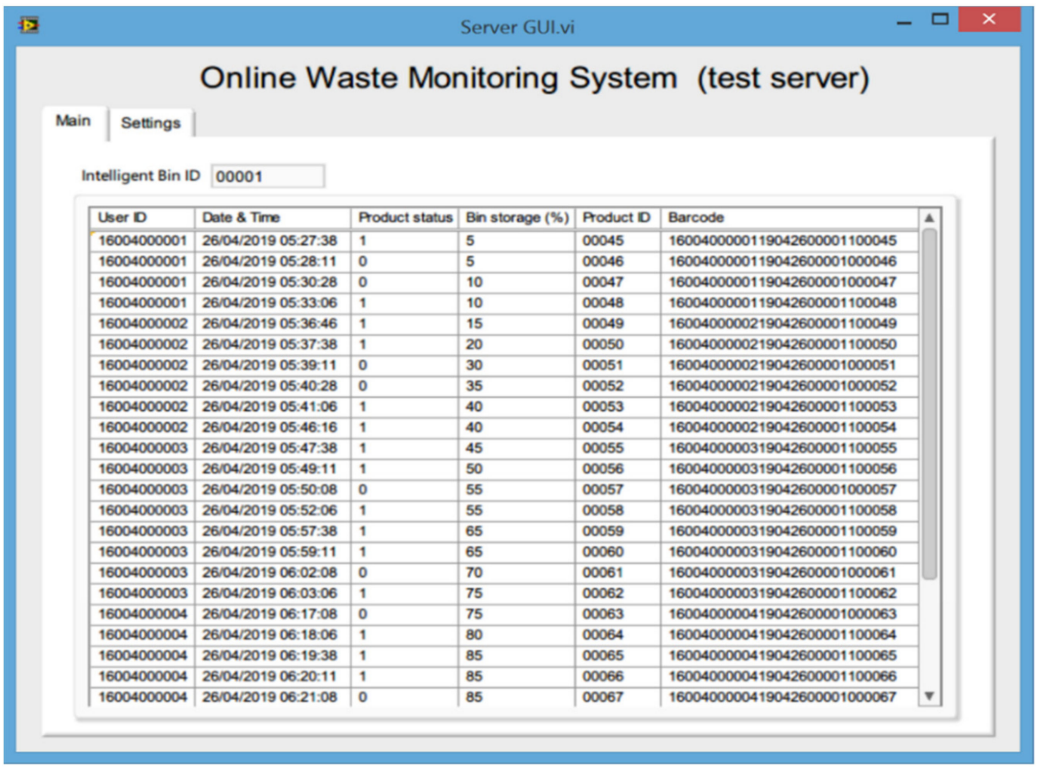
Figure 13. Consumer ID card.

There are two LED buttons mounted on the intelligent bin: the green button represents that the product is working, while the red button indicates that the product is damaged. The consumer selected one button to enter the working status of the product.

Then the lid/door of the bin was unlocked, and two barcode labels (identical stickers) were printed: one label was placed on the waste product for further tracking and processing, and the other label was kept by the consumer as a receipt.

The detailed information of the barcode label consists of the following five groups of parameters: user ID, date and time of disposal, disposal location, product status, and product ID (serial number). Then the consumer attached the barcode label to the product packaged and put it into the bin through the unlocked lid/door. The product must be packaged (e.g., in a box or bag) in order to ensure that the item is not damaged before it is thrown into the bin.

The online tracking software has been developed to transmit the recycling data from the intelligent bin to the data centre. For software development and testing purpose, an independent Web server has been developed, as stated in Section 3 and shown in Figures 12h and 14. In the meantime, the intelligent bin data were also transmitted to the traceability server developed by WP5 team of the CIRC4Life project [11].



User ID	Date & Time	Product status	Bin storage (%)	Product ID	Barcode
16004000001	26/04/2019 05:27:38	1	5	00045	160040000011904260000100045
16004000001	26/04/2019 05:28:11	0	5	00046	160040000011904260000100046
16004000001	26/04/2019 05:30:28	0	10	00047	160040000011904260000100047
16004000001	26/04/2019 05:33:06	1	10	00048	160040000011904260000100048
16004000002	26/04/2019 05:36:46	1	15	00049	160040000021904260000100049
16004000002	26/04/2019 05:37:38	1	20	00050	160040000021904260000100050
16004000002	26/04/2019 05:39:11	0	30	00051	160040000021904260000100051
16004000002	26/04/2019 05:40:28	0	35	00052	160040000021904260000100052
16004000002	26/04/2019 05:41:06	1	40	00053	160040000021904260000100053
16004000002	26/04/2019 05:46:16	1	40	00054	160040000021904260000100054
16004000003	26/04/2019 05:47:38	1	45	00055	160040000031904260000100055
16004000003	26/04/2019 05:49:11	1	50	00056	160040000031904260000100056
16004000003	26/04/2019 05:50:08	0	55	00057	160040000031904260000100057
16004000003	26/04/2019 05:52:06	1	55	00058	160040000031904260000100058
16004000003	26/04/2019 05:57:38	1	65	00059	160040000031904260000100059
16004000003	26/04/2019 05:59:11	1	65	00060	160040000031904260000100060
16004000003	26/04/2019 06:02:08	0	70	00061	160040000031904260000100061
16004000003	26/04/2019 06:03:06	1	75	00062	160040000031904260000100062
16004000004	26/04/2019 06:17:08	0	75	00063	160040000041904260000100063
16004000004	26/04/2019 06:18:06	1	80	00064	160040000041904260000100064
16004000004	26/04/2019 06:19:38	1	85	00065	160040000041904260000100065
16004000004	26/04/2019 06:20:11	1	85	00066	160040000041904260000100066
16004000004	26/04/2019 06:21:08	0	85	00067	160040000041904260000100067

Figure 14. Online monitoring and management of EoL product recycling.

The recycling company was informed of the filling level of the intelligent bin via email at 23:00 every day. Then the products were collected and further processed with classification and quality assessment, and the assessment result were uploaded to generate the eco-credits. For more information about eco-credit calculation and product assessment, please see the technical deliverables and reports developed by the CIRC4Life project [10,15].

4.2. Shopping Discount in a Shop with the Eco-Credits

The eco-credits obtained from recycling activities were used to pay for the discount of products purchased, incentivising consumer's participation.

The developed eco-shopping system has been demonstrated at the Expert Mancia shop in Gexto [19], where a consumer purchased an electronic router with the eco-credits. The eco-shopping system was separate from the existing shop's accounting system, and the both systems were used at the same time but not to interfere with each other, which ensures the data security of the shop's accounting system. The eco-shopping system contains a computer, a scanner, and a printer.

The related software was installed on a computer in the shop, which is shown in Figure 15. The shop staff inputted the discount amount of the products to be purchased via the user-interface developed. For instance, if the price of an electronic router was 320 euros, then the 5% discount was 16 euros, which were converted to 16 eco-credits (see Figure 15). Then the system printed out the voucher with the exact amount of discounts converted from the eco-credits (see Figure 16), and deducted the eco-credits from the consumer's eco-account.

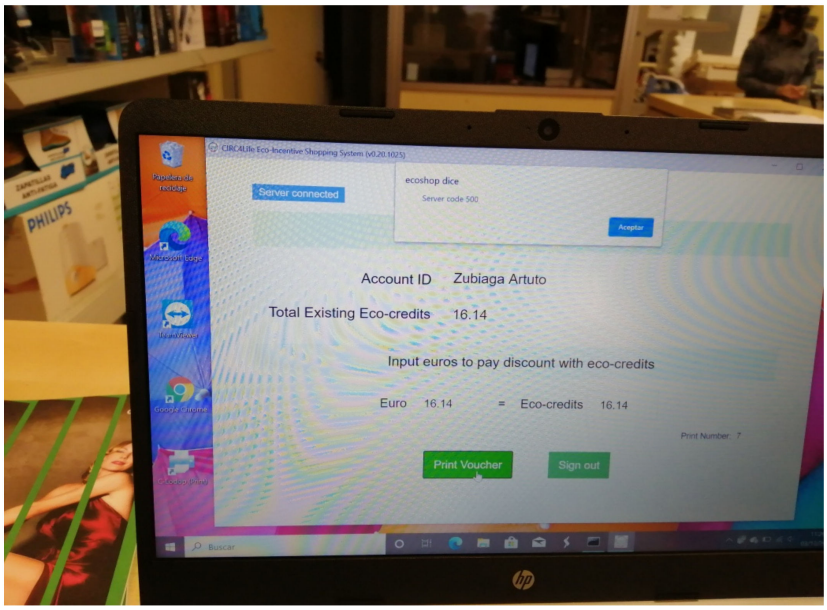


Figure 15. The shop staff input euros to pay discounts with the eco-credits.

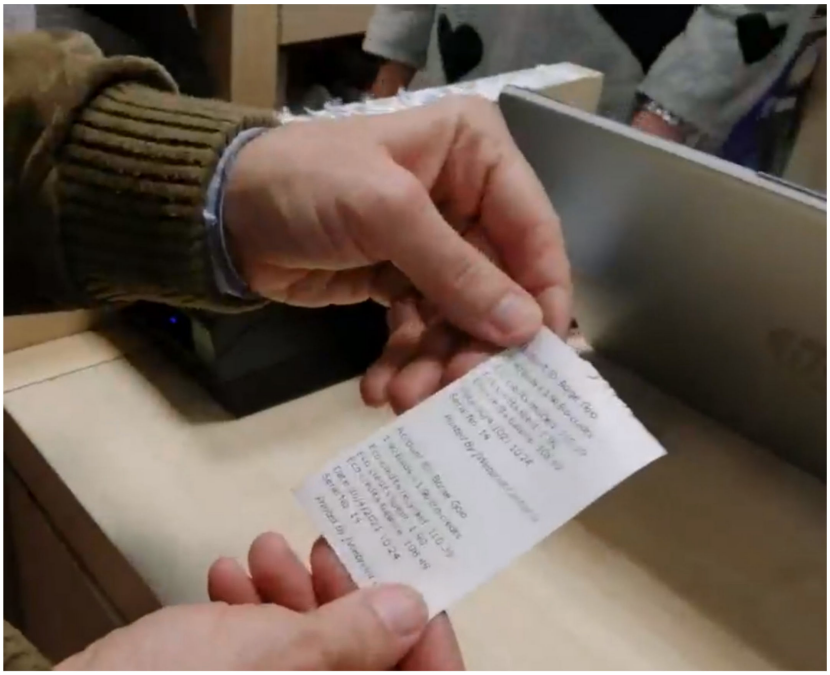


Figure 16. The receipt with the exact amount of discounts converted by the eco-credits credits (Reprinted/adapted with permission from Ref. [18]).

Multiple computer languages and development methods were utilised to develop the user interface and associated incentive program code, including: (1) PHP (Hypertext Preprocessor) for the web communication development; (2) Javascript for barcode scanning and receipt development; (3) MySQL for database management; (4) CSS (Cascading Style Sheets) for web style and user interface.

Figure 17 shows the Javascript programme which is used for converting the discount amount (euros) to the eco-credits when the shop staff inputs the discounts amount via the user interface.

```
function changeEuro(){

  var getUserMoney = document.getElementById("userMoney").value;
  getUserMoney = parseFloat(getUserMoney).toFixed(2);
  var changeEuro = document.getElementById("changeEuro").value;
  var changeCredits = document.getElementById("changeCredits").value;
  var changeResult = document.getElementById("changeResult").value;

  if(!changeEuro){
     changeEuro = (0).toFixed(2);
     changeCredits = changeEuro;
     changeResult = getUserMoney;
  }else{
     changeEuro = parseFloat(changeEuro).toFixed(2);
     changeCredits = changeEuro;
     changeResult = getUserMoney - changeCredits;
  }
  if(changeEuro-getUserMoney>0){
     changeEuro=getUserMoney;
     changeCredits = changeEuro;
  }

  if (changeEuro<0) {
     changeEuro = (0).toFixed(2);
     changeCredits = changeEuro;
  }
```

Figure 17. Javascript programme for converting the amount of discount (in Euros) to the eco-credits in real time.

The programme was created with the 'changeEuro function' to implement the Euros to eco-credits conversion, based on the following criteria which is shown in the code of Figure 17: When the amount is entered, the programme responds immediately and displays the eco-credits converted without delay. If the amount is empty, the programme does not perform any operation until the shop staff inputs a value. If the amount is more than the limit that the total eco-credits can be used, then the programme works out the value according to the existing total eco-credits.

4.3. Donation of Tree Planting with the Eco-Credits

In addition to paying the purchase discount, the consumer can also donate their eco-credits to tree planting [14]. To do so, an interactive test was carried out, starting with the consumer who sent a QR code (consumer identity for eco-incentive) to the manager via e-mail. Further, the manager scanned the consumer's QR code via a scanner, and checked the eco-credits and whether they are correct for planting trees. Then the manager inputted the amount of trees into the developed operation interface, which converted the trees into eco-credits and were deducted from the consumer's eco-account. Figure 18 shows the receipt containing the eco-credits converted by the trees as well as the consumer's eco-account information.

To ensure the consumer's privacy and security, the QR code was protected by the dynamic encryption method developed in this research, so each QR code can only be used once. Figure 19 shows the code for dynamically encrypting/decrypting the QR code in order to protect the code from being copied and exploited by hackers.

To record and manage the tree planting data of each consumer, a meta-database structure was built based on the MySQL database management system, which is shown in Figure 20.

The meta-database model contains massive data search, database modelling, and creating descriptive meta-data that enable exploration of related informative data, with major concerns of managing digital resources, legacy data integration, and electronic identification [12]. Figure 20 shows the database developed for tree planting, including the records of consumer's QR code, user name, amount of trees, the date of tree planting.

Figure 18. Receipt of tree planting with the eco-credits.

```
if (qrcodeLength > 92) {
      var messageRaw=message;
      var key=message.substr(92,2);
      message=message.substr(6,10)+message.substr(26,15)+message.substr(48,11)+message.substr(68,16);
      //alert('QR.length='+message.length+'\nQR='+message+'\nkey='+key);
         var str1=new Array(message.length);
         var c;
         for(i=0;i<message.length;i++)
         {
            c=message.charAt(i);  //alert('c='+c);
            if(c>='a'&&c<='z')
            {
               ....
            }
```

Figure 19. Javascript programme for QR code verification and protection.

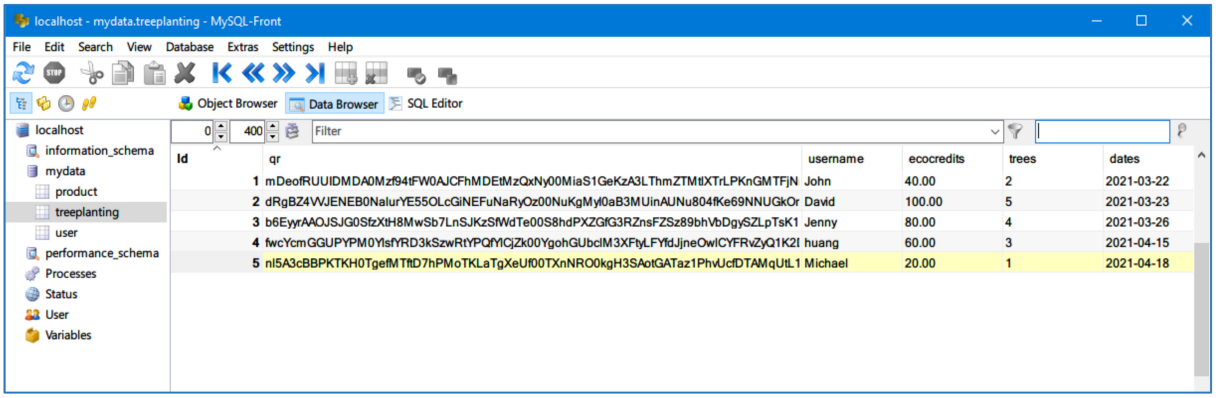


Figure 20. The database development.

4.4. Exchange the Eco-Credits for Tickets with Multi-Language Support

The intelligent bin that was developed for recycling electronics was also used to recycle household bio-waste [9,11]. Similar to electronic waste recycling, consumers can recycle household bio-waste through the intelligent bin and earn eco-credits which are then converted to vouchers, such as theatre, museum, and concert tickets.

The related eco-shopping/eco-incentive system (a computer, a printer, and a scanner) has been developed. Figure 21 shows that the administrator scanned the consumer's QR code, and then inputted the eco-credits converted from tickets utilising the eco-incentive computer. Subsequently, the eco-credits were subtracted from the consumer's eco-account, and the ticket was printed out with the exact amount of the eco-credits consumed.

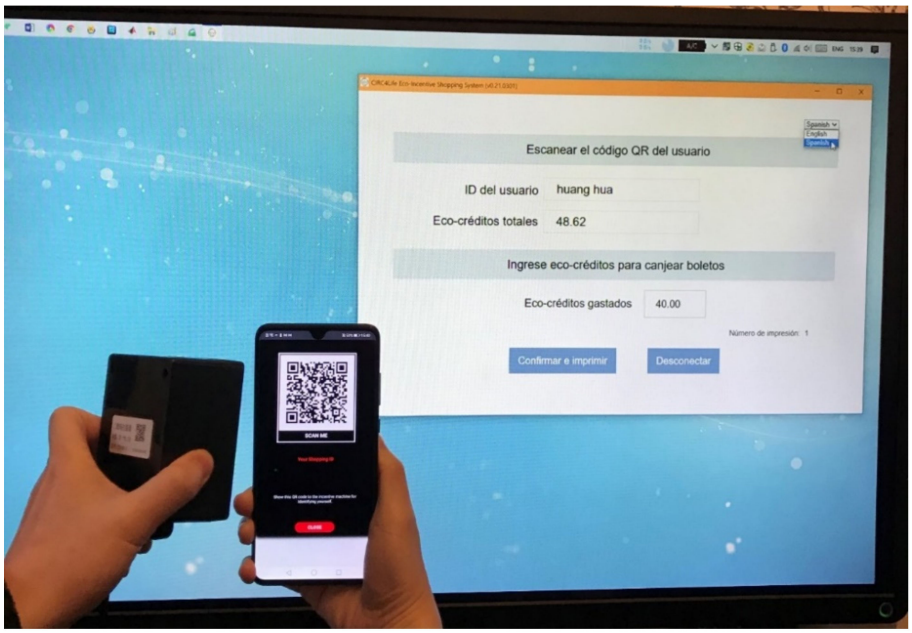


Figure 21. Multi-language version of eco-incentive software is developed to exchange the eco-credits with the theatre, museum, or concert ticket.

Both English and Spanish versions of user interfaces have been developed to meet the needs of the application. To this end, the database for the multilingual management was developed by creating language models, searching and matching information data, and conversion of characters and text in uniform types and formats to ensure compatibility between different languages. The database can be extended to accommodate and adapt more languages.

The different languages can be freely switched through the drop-down menu at the top right corner of the user interface, which are shown in Figure 21. The administrator selected a language and then performed the operation within the corresponding selected language environment, including scanning QR code and inputting eco-credits converted from tickets. The ticket voucher was then printed according to the language selected.

4.5. Eco-Shopping with Consumer Eco-Account Receipt

The developed system was also installed at a shop to demonstrate the eco-shopping functionality. When the consumer purchased products (such as sausages) in the store, they could access the information of the consumer eco-account (eco-credits and eco-costs) through the receipt. In the check-out point, the consumer scanned the barcode of the product, and then the computer showed the product's eco-costs, details, and price. With selecting the "Confirm to Print" button, the system calculated the total amount of eco-costs and then printed out the receipt.

Figure 22 shows the receipt which contains the following information: (a) Eco-costs and eco-credits total; (b) Eco-costs of each item purchased; (c) Cash payment information.

Figure 22. Receipt showing the eco-credits, eco-costs, and payment information.

5. Conclusions

The ICT-based recycling and eco-shopping system has been successfully developed, and was validated through the case studies via promoting consumers to recycle EoL products, retrieve eco-costs in eco-shopping, and spend eco-credits in the eco-incentives, which effectively improve consumer's environmental awareness.

This research has made the following contributions to knowledge:

(1) It made a contribution to online recycling and eco-account management. Existing smart recycling systems are limited to recycling EoL products in an 'off-line' form without the support of Internet technology. Hence, consumers do not have their own electronic account to record their rewards. The consumer needs to be physically present at the designated place to get the rewards, which affects user's experience and reduces their enthusiasm of recycling. To address this issue, the ICT system for recycling and eco-shopping has been established based on a range of information and communication technologies. With this system, the consumer can set up an individual eco-account and access the information within the account, such as eco-credits obtained from recycling activities. The developed system successfully achieves the online tracking and management of recycling and eco-incentives.

(2) It made a contribution to eco-shopping and eco-incentives to promote consumer participation in recycling. When recycling EoL products, the consumer retrieves the eco-credits which can be used to spend in a variety of forms, such as discounts on products, donations of tree planting, and exchanges for theatre/museum/concert tickets. The more products the consumer recycles, the more eco-credits they will receive. In the future, the eco-credits could also be used for utility bills, council tax, or transaction of goods in electronic money form, which is a novel application in this subject area.

(3) It made a contribution to reducing the environmental impact of products throughout their life cycle, especially during the EoL stage. Currently, some recycling schemes can provide rewards (e.g., coupon or points) on the completion of recycling in order to improve the recycling rate [2]. However, the existing schemes only consider the product's residual quality, which could lead to short-time use and frequent purchases of products. Because the ecological impacts of products are not considered, the consumer's environmental awareness might be undermined. To overcome this problem, the concept of the eco-credits is introduced, which is to credit the consumer's positive behaviour through recycling/reusing activities. The eco-credits are based on the environmental impact throughout the product's lifecycle, longer time use, and other

related factors (such as energy consumption), which will help consumers select more sustainable products and improve their environmental awareness.

Future efforts will focus on the application of remote sensing and data security to the smart online recycling, which is developed in this research. In addition, due to the small amount of electricity required, it is anticipated that the recycling system can be driven using renewable energy sources, such as solar energy. The relevant technology has not been fully investigated and further research is needed.

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