

Internet of Things for Plastic Bottle Recycling: A Case Study for Salinas

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Abstract. Waste generation is growing worldwide because of urbanization and population growth. Plastic bottles are being discarded incorrectly polluting the environment and wasting resources. Reverse vending machines that work with the Internet of Things offer a great possibility to promote plastic bottle recycling at locations where recycling is not compulsory. For the first phase, the current plastic bottle waste management system was determined for the municipality of Salinas using a literature review, interviews, and field visits. An improved model was suggested to address the main concerns and promote plastic recycling among other materials. An important part of the model is reverse vending machines for plastic bottles. Phase two relates to the design of the reverse vending machine. The researchers performed a literature review to determine the features of different reverse vending machines with IoT technology. A process flow chart was elaborated to establish the different systems for the machine. Once the characteristics of the machine were determined it was drawn using Autocad 3D. The machine designed detects, collects, compresses, and storages empty plastic bottles up to 1 L. The electronic circuit includes the Internet of Things technology to award economic compensation for recycling and alert when the storage bin needs to be emptied to avoid overload, using Wi-Fi communication. These machines should be implemented in central locations like supermarkets, restaurants, and schools around the municipality of Salinas and evaluated for other municipalities of the province of Santa Elena and Ecuador.

Keywords: Waste management · Internet of Things · bottle compacting · recycling · reverse vending machine

1 Introduction

Waste is rising because of urbanization and population growth worldwide [1]. The World Bank estimated that waste generation will reach 2.59 billion tons by 2030. In some developing countries, waste disposal is not correctly performed as landfills are unavailable, which can be health and environmental hazards [2]. Plastic production has continuously increased since the 1950s, and its global annual generation reached 330 million metric tons in 2016 [3]. Plastic accounted for 12 percent of global waste [2].

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Plastics are a fundamental part of society; however, their incorrect disposal may raise concerns as human and animal health can be affected. As most petroleum-based plastics are non-biodegradable, plastic waste has become a threat to the environment. Plastic pollution is spread worldwide and can produce climate destabilization. Plastics are accumulated across the environment along many landscapes. Around 400 million tons of plastic are produced for different applications [4]. Plastics discarded on land may reach oceans downstream. Around 14 million tons of plastic waste go to the ocean. Plastics can harm animals or be eaten by them. These plastics unproperly managed can endanger food security, diminish food quality, affect animal and human health, affect tourism, and contribute to climate change [5].

The main problem of plastic pollution is the current linear economy which involves single use of plastics before final disposal. There must be a shift to a circular economy where plastics are driven to new uses. Recycling transforms waste into new materials allowing us to save raw materials and reduce energy consumption and greenhouse emissions. Advances in manufacturing processes have increased the percentage of recycled plastic; however, it remains small even in Europe which has strong policies to protect the environment [6]. Discarded plastic bottles pose a threat to the environment as consumption of bottled drinks has kept growing in the last decade [7].

Even though there have been important investments in the recycling industry, plastic recycling faces barriers such as the complexity of identifying which plastics are recyclable, not prioritizing recycling, and believing that plastic recycling is complex [8]. Policies to reduce the plastic problem include an upstream approach as reducing and replacing and a downstream approach as collecting, reusing, and recycling [9]. In addition to the downstream approach, reverse vending machines have been implemented worldwide to ease and increase waste collection.

To manage population growth, rapid urbanization, and lifestyle changes, it is necessary to develop smart sustainable cities. A fundamental pillar of green smart cities is waste management [10]. Municipalities in developing and developed countries have the challenge of implementing efficient waste management systems to collect, transport, recycle, and dispose of waste by health and environmental standards. Efficient waste collection may be hindered by problems with bin collection, overloaded bins, inefficient picking routes, limited resources, and other aspects [11].

Smart cities are urban zones that use information and communication technologies with sensors, and interconnected devices to generate information that is analyzed to improve operational efficiency, public transportation, daily activities, and life quality [10–12]. A smart city is environmentally friendly, socially inclusive, and sustainable [13]. Technology with data analytics will reshape lives when citizens access personalized and improved aspects like economy, mobility, governance, and awareness [14]. Important features of a smart city are environmental conservation and citizens' health which can be achieved by implementing an adequate smart waste management system [13]. Smart cities rely on the Internet of Things (IoT) technology to provide the feature of smartness to different services.

The Internet of Things relates to a network of interconnected objects that incorporate sensors, software, and technology to communicate with each other and with the cloud. People, things, and processes are connected anywhere and anytime to reshape existing services and create innovative ones in the context of smart cities [12]. The IoT technology is currently used to improve waste management worldwide and has continuously been studied to create new solutions related to waste [15]. IoT has been studied to create dynamic routing and scheduling of garbage trucks, smart waste bins, waste segregation, recycling, waste reduction, waste disposal, and environmental monitoring and for decision-making [16].

In the waste segregation field, waste bins have been equipped with sensors, IoT technology, and in some cases, computer vision and machine learning to distinguish the different materials waste is made of and classify them into different categories [17, 18]. The IoT technology has been implemented in reverse-vending machines to aid waste segregation and further recycling.

Vending machines are machines that give merchandise automatically in exchange for money. Reverse vending machines work oppositely by receiving used containers and returning rewards or monetary benefits [19]. These devices have different systems which include container deposit, material recognition, compaction (in some cases), storage, and incentives [20]. Reverse-vending machines can be an effective way of collecting plastic waste for recycling in exchange for incentives or money [21]. In countries where recycling is compulsory, reverse vending machines collect around 70% of beverage containers [22]. Reverse vending machine technology is migrating from old-time systems to digital systems that use IoT technology and return rewards related to the weight processed [23].

While reverse vending machines have been widely used in some parts of the world, in some countries, where recycling is not mandatory, they are barely used. In Ecuador, reverse vending machines have been studied in bachelor's thesis for Quito [24, 25] and Riobamba [26, 27]. In the municipality of Salinas, reverse vending machines have not been investigated before; therefore, it is necessary to study this type of machine which works with the IoT technology to promote the collection of plastic bottles for recycling.

2 Materials and Methods

2.1 Study Area

The study area is the municipality of Salinas, located in the province of Santa Elena of Ecuador. Santa Elena Province has three municipalities, Santa Elena, Salinas, and La Libertad. The main productive activities include fishery, aquaculture, tourism, and agriculture, among others [28, 29]. For the year 2022, Ecuador had almost 17 million inhabitants and Salinas municipality has 86 801 inhabitants in 37 490 dwellings. Salinas is located on the coast of the Santa Elena Peninsula [30] (see Fig. 1).



Fig. 1. Location of Salinas [31]

2.2 Methodology

This methodology describes the two phases performed for this study (see Fig. 2). Phase one intends to establish the current plastic bottle waste management model. A literature review was performed to establish the different elements a waste management system has and gather information about the current practices of waste management at the Municipality of Salinas. Interviews and field visits were performed to determine the streams plastic bottles follow. Municipal workers, private workers, formal recyclers, and informal recyclers were approached with semi-structured interviews. Field visits were performed to plastic bottle collection sites. Once the current model was established, an improved model was created using recommendations gathered during interviews and concepts of circular economy considering the current local situation. This study analyzed plastic bottles discarded in the city of Salinas and did not extend to rural areas. Few informal recyclers were approached because of high crime rates (study limitations).

Phase two relates to the design of the plastic bottle reverse vending machine for Santa Elena province. The researchers performed a literature review to determine the features of different reverse vending machines with IoT technology that have been implemented and studied before. A list and a process flow chart were elaborated to establish the different systems the machine will use. It was necessary to define a compaction method to establish the different elements of the machine. This study was limited to plastic bottles up to 1 L. The machine capacity was determined by comparing the capacity of machines designed for other provinces of Ecuador and their inhabitants. The elements of the electronic circuit of the machine were selected to comply with the requirements established for the machine. Once the characteristics of the machine were determined it was drawn using Autocad 3D. Economic feasibility was determined under the considerations of national law for plastic bottle recycling and according to the machine design capacity.

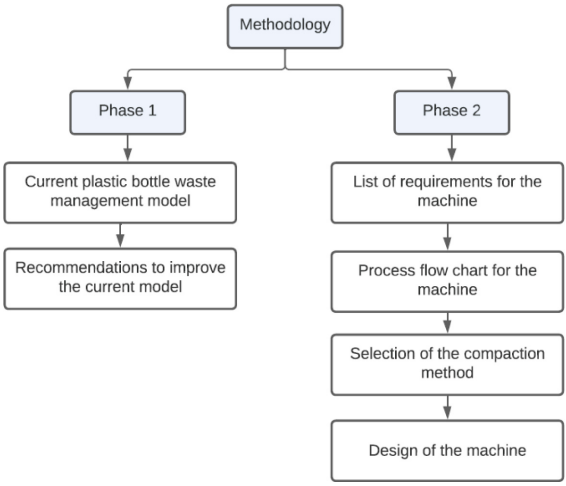

Fig. 2. Methodology

3 Results and Discussion

First, the current plastic bottle waste management model was determined for Salinas Municipality (see Fig. 3). The municipality operates as final disposal an open dump site. This practice poses a threat to the environment and health. Waste collection and disposal is a service offered by the municipality which is charged to citizens in electricity bills. The current waste collection is performed by waste trucks which pick up garbage bags. Bins or differentiated collection is not compulsory and has not yet been implemented by the municipality of Salinas. However, this does not imply that all plastic bottles are not collected for recycling. Formal and informal recyclers collect recyclables which include plastic bottles by opening plastic bags. Formal recyclers are pickers who are part of associations legally established. In addition, some citizens place recyclables in different bags or aside from normal waste bags to ease the collection of them. In some cases, recyclers even purchase recyclables from houses and institutions. Most recyclers drive load tricycles; however, there are also pickups and trucks. Another method that has been implemented, is drop-off recycling. Large bins have been installed at some central locations like supermarkets, schools, restaurants, and beaches, however, users do not receive any kind of compensation for taking waste to these containers. All the plastic bottles collected are transported by truck to Guayaquil City (which is in another province) where they are sold to recycling facilities. Despite the efforts made by recyclers, there remain plastic bottles inside waste bags that are collected by waste trucks and sent to final disposal in the municipality dump site. Other plastic bottles end up polluting the beaches around the province. There are some groups of young people who perform campaigns to collect waste from beaches; however, there are still some plastic bottles that remain on beaches and in the ocean. The amount of waste generated from plastic bottles and the amount of each stream has not been determined. Salinas faces specific challenges regarding plastic collection as it is one of the few municipalities in the country that does not report the weight of recyclable materials collected as equipment for this purpose has

not been implemented at the dumping sites. As tourism is a main productive activity for the county, an important number of plastic bottles is generated during holidays.

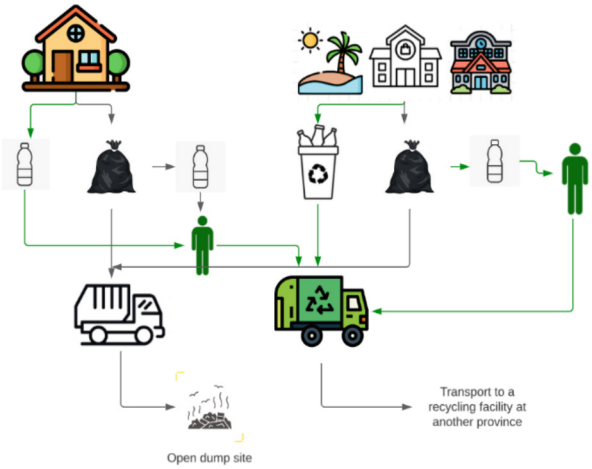

Fig. 3. Current plastic bottle waste management system

Figure 4 summarizes an improved waste management system for any municipality of Santa Elena province. A major concern of the current waste management is the open dump sites; therefore, it is suggested to build a landfill. A study performed in 2023 [32], established the approximate cost and the feasibility of a landfill for Santa Elena province as it is compulsory for municipalities to close technically open dump sites and build landfills. Waste bags should be replaced by containers and special waste trucks for containers acquired. It should be analyzed if filling level sensors should be installed in the bins [33]. Other municipalities in Ecuador, like Riobamba, Ambato, and Cuenca have in place waste containers for more than a decade, showing it is feasible to implement this technology in the country. There is the opportunity to implement initiatives related to smart cities like smart bins, smart waste trucks, and efficient collecting routes created through machine learning. Curbside bins for recyclables should be placed and more bins for collecting recyclables should be installed in supermarkets, schools, churches, restaurants, and other central locations. Recyclers would no longer be able to collect the same quantity of recyclable materials as with the previous model, however, some of these people could be employed in the transfer station where recyclables will be separated. Awareness campaigns should be performed by municipalities to introduce the appropriate use of bins for recyclables to citizens. Incentives should be considered to motivate waste segregation. Regarding incentives, this study proposes implementing reverse vending machines for plastic bottles with IoT in central locations that will be explained in detail.

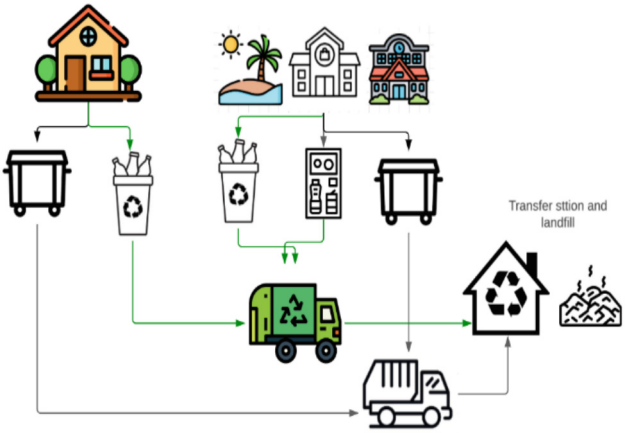

Fig. 4. Proposed waste management system

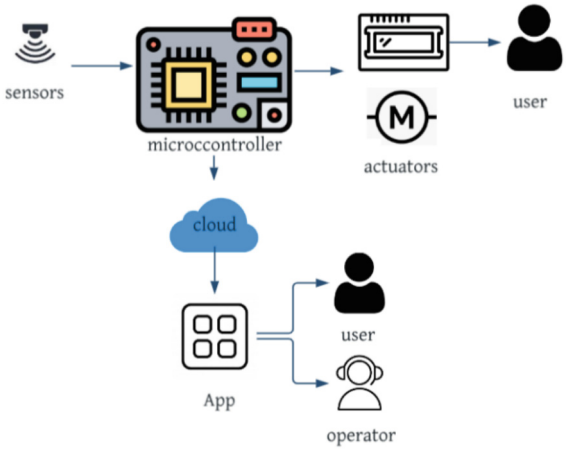

Fig. 5. Proposed IoT layers

The IoT infrastructure is organized into three layers. On the first one, sensors are located (see Fig. 5), they gather information like a rejection of an item, the weight of an accepted bottle, storage filling level, and data of bottles to be redeemed according to the identification number. This layer also includes actuators like servo motors and the LCD. Sensors and actuators have wired communication with the chip microcontroller ESP32. The next layer is the communication layer. The gathered information is transferred through this layer using the Wi-Fi technology to the cloud so it can be processed and analyzed. The machine requires an electric supply and as it is designed to be installed in central locations, electricity and Wi-Fi are available in this kind of location. The last layer is the processing and application layer. An application alerts the operator when the bin is 80%, 90%, and full so it can be emptied on time to prevent the machine to not being able to process more plastic bottles. The central system processes the received

data of weights according to each identification number to update users' balance so it can later be redeemed. This layer involves backend processing and cloud computing.

The machine can process empty plastic bottles up to 1000 ml and has a storage capacity of 500 compressed bottles. Its dimensions are $80 \times 80 \times 180$ cm. The user places an empty plastic bottle into the entry compartment which has a rounded shape to prevent big objects from being introduced into the machine (see Fig. 6). The keypad is located next to the entry compartment. The door to remove the rejected items is placed down the handle to open and empty the bin.



Fig. 6. Proposed reverse vending machine

The proximity infrared reflective sensor TCRT5000 detects if the item is made of plastic (see Figs. 7 and 8). If not, it is rejected, sent back to the user and a message is shown on the LCD. When an inserted item needs to be rejected a step servomotor 1 is activated and rotates 90° so the item can fall into a canal where the user can pick it up, later the motor returns to its original position. At the entry, a load scale (capacity of 5 kg) helps to determine if the item needs to be returned because it is not empty or is not a plastic bottle. After the bottle is accepted, the LCD shows a message asking the user to introduce his identification number so his bottles can be redeemed. Each bottle accounts for 2 American cents, in compliance with an Ecuadorian law for plastic bottles. After the bottle is accepted, servomotor number two activates a linear conveyor until the bottle reaches a normally closed limit switch sensor at the beginning of the compression system. This system is operated by a 0.5 HP alternating current motor which is coupled to grooved rollers. The rollers are grooved so the air that is inside the bottle can escape. The compressed bottle goes to the storage compartment where the ultrasound distance sensor HC-S0R04 senses the filling level alerting the operator when the bin is 80%, 90%, and 100% full.

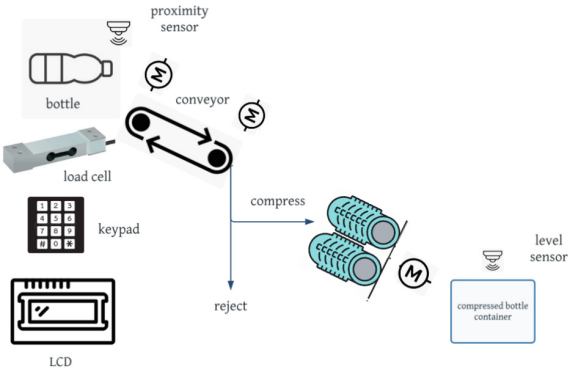

Fig. 7. Components scheme of the proposed reverse vending machine

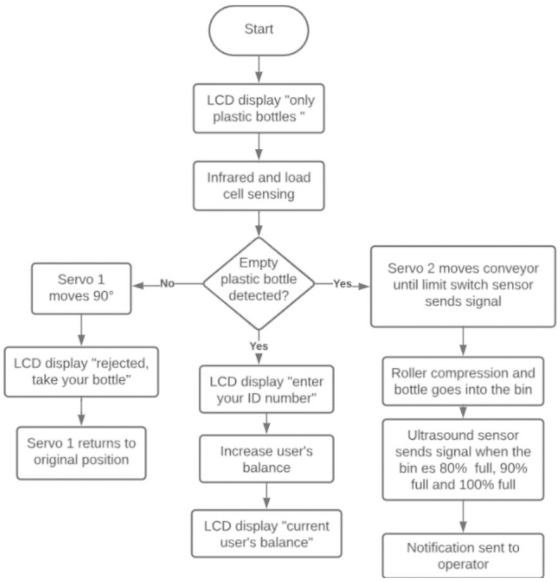

Fig. 8. Flow diagram for the reverse vending machine

The economic feasibility considered a capacity of 1000 bottles per day. The initial investment for setting up the RVMs amounts to $1,500. The investment is projected to be recovered by the fifth year of operation. Calculations yield an NPV of $1,200, indicating positive profitability. The calculations adhere to Ecuadorian legislation, which sets a bottle sale price of 2 cents per bottle. Long-term maintenance and operational costs were considered.

4 Conclusions

The current plastic waste management system of the three municipalities of the province was studied and detected that although plastic bottles are being collected by recyclers, this activity could be improved using reverse vending machines at central locations like supermarkets, restaurants, and schools. A model of a plastic bottle reverse machine which includes IoT technology was proposed. The IoT is used to allocate the economic compensation for recycling and alerting when the bin needs to be emptied. To increase the machine capacity, rollers compress the bottles. Users introduce their identification number so two cents per bottle can be later redeemed. The technical and economic feasibility are positive under Ecuadorian law considerations. The implementation of reverse vending machines should be performed in the province of Santa Elena with campaigns to raise awareness of the importance of recycling. Further research should include image recognition, and machine learning algorithms to improve rejected items detection.

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Disclosure of Interests. The author(s) have no conflict of interest to declare.

References

1. Moya, D., Aldás, C., López, G., Kaparaju, P.: Municipal solid waste as a valuable renewable energy resource: a worldwide opportunity of energy recovery by using waste-to-energy technologies. Energy Procedia **134**, 286–295 (2017). https://doi.org/10.1016/j.egypro.2017.09.618
2. Kaza, S., Yao, L., Bhada-Tata, P., Van Woerden, F.: What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. World Bank Publications (2018)
3. Lebreton, L., Andrady, A.: Future scenarios of global plastic waste generation and disposal. Palgrave Commun. **5**, 6 (2019). https://doi.org/10.1057/s41599-018-0212-7
4. Fletcher, S., et al.: Turning off the Tap: How the world can end plastic pollution and create a circular economy (2023)
5. International Union for Conservation of Nature: Marine Plastic Pollution (2021)
6. Cruz Sanchez, F.A., Boudaoud, H., Camargo, M., Pearce, J.M.: Plastic recycling in additive manufacturing: a systematic literature review and opportunities for the circular economy. J. Clean. Prod. **264**, 121602 (2020). https://doi.org/10.1016/j.jclepro.2020.121602
7. Zia, H., et al.: Plastic waste management through the development of a low cost and light weight deep learning based reverse vending machine. Recycling **7**, 70 (2022)
8. Roy, D., Berry, E., Dempster, M.: "If it is not made easy for me, I will just not bother". A qualitative exploration of the barriers and facilitators to recycling plastics. PLoS One. **17**, e0267284 (2022)
9. Lau, W.W.Y., et al.: Evaluating scenarios toward zero plastic pollution. Science (1979). **369**, 1455–1461 (2020). https://doi.org/10.1126/science.aba9475
10. Mingaleva, Z., Vukovic, N., Volkova, I., Salimova, T.: Waste management in green and smart cities: a case study of Russia. Sustainability. **12**, 94 (2019)

11. Aazam, M., St-Hilaire, M., Lung, C.-H., Lambadaris, I.: Cloud-based smart waste management for smart cities. In: 2016 IEEE 21st International Workshop on Computer Aided Modelling and Design of Communication Links and Networks (CAMAD), pp. 188–193 (2016). https://doi.org/10.1109/CAMAD.2016.7790356
12. Medvedev, A., Fedchenkov, P., Zaslavsky, A., Anagnostopoulos, T., Khoruzhnikov, S.: Waste management as an IoT-enabled service in smart cities. In: Balandin, S., Andreev, S., Koucheryavy, Y. (eds.) Internet of Things, Smart Spaces, and Next Generation Networks and Systems, pp. 104–115. Springer International Publishing, Cham (2015)
13. Anagnostopoulos, T., et al.: Challenges and opportunities of waste management in IoT-enabled smart cities: a survey. IEEE Trans. Sustain. Comput. **2**, 275–289 (2017)
14. Gracias, J.S., Parnell, G.S., Specking, E., Pohl, E.A., Buchanan, R.: Smart Cities—A structured literature review. Smart Cities **6**, 1719–1743 (2023). https://doi.org/10.3390/smartcities6040080
15. Fallavi, K.N., Kumar, V.R., Chaithra, B.M.: Smart waste management using Internet of Things: a survey. In: 2017 International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC), pp. 60–64 (2017). https://doi.org/10.1109/I-SMAC.2017.8058247
16. Sosunova, I., Porras, J.: IoT-enabled smart waste management systems for smart cities: a systematic review. IEEE Access. **10**, 73326–73363 (2022). https://doi.org/10.1109/ACCESS.2022.3188308
17. Shamin, N., Fathimal, P.M., Raghavendran, R., Prakash, K.: Smart garbage segregation & management system using Internet of Things (IoT) & Machine Learning (ML). In: 2019 1st International Conference on Innovations in Information and Communication Technology (ICIICT), pp. 1–6 (2019). https://doi.org/10.1109/ICIICT1.2019.8741443
18. Mohammed Aarif, K.O., Mohamed Yousuff, C., Mohammed Hashim, B.A., Mohamed Hashim, C., Sivakumar, P.: Smart bin: waste segregation system using deep learning-Internet of Things for sustainable smart cities. Concurr. Comput. **34**, e7378 (2022). https://doi.org/10.1002/cpe.7378
19. Sambhi, S., Dahiya, P.: Reverse vending machine for managing plastic waste. Int. J. Syst. Assur. Eng. Manag. **11**, 635–640 (2020). https://doi.org/10.1007/s13198-020-00967-y
20. Schneider, D.R., Tomić, T., Raal, R.: Economic viability of the deposit refund system for beverage packaging waste–identification of economic drivers and system modelling. J. Sustain. Develop. Energy Water Environ. Syst. **9**, 1–33 (2021)
21. Zia, H., et al.: Plastic waste management through the development of a low cost and light weight deep learning based reverse vending machine. Recycling **7**(5), 70 (2022). https://doi.org/10.3390/recycling7050070
22. Tur, A.I., Kokoulin, A.N., Yuzhakov, A.A., Polygalov, S.V., Troegubov, A.S., Korotaev, V.N.: Beverage container collecting machine project. IOP Conf. Ser. Earth Environ. Sci. **317**, 12006 (2019). https://doi.org/10.1088/1755-1315/317/1/012006
23. Rana, M.E., Shanmugam, K., Yi, K.Q.: IoT based reverse vending machine to identify aluminium material and allocate point reward. In: 2022 International Conference on Decision Aid Sciences and Applications (DASA), pp. 645–649. IEEE (2022)
24. Villacís Astudillo, P.G., Suárez Lafaurie, D.A.: Plan de negocios para la creación de una compañía de acopio de botellas de vidrio y plástico post-consumo, por medio de máquinas expendedoras a la inversa, y la exposición de publicidad estática en las mismas, en la ciudad de Quito (2016)
25. Llive Bastidas, F.A., Mejía Mena, D.A.: Diseño, simulación y estudio de la factibilidad de implementar una máquina de reciclaje de botellas plásticas en la Escuela Politécnica Nacional (2016)

26. Castillo Herrera, W.P., Daquilema Guaraca, R.: Diseño y construcción de un modelo de máquina expendedora inversa (RVM) automatizada, orientada al reciclaje de botellas plásticas PET para la facultad de Mecánica-ESPOCH (2014)
27. Pino Pilco, V.K.: Diseño y construcción de una máquina de canje automático con verificación electrónica, para botellas plásticas tipo pet de 500 ml a 1.2 (2020)
28. INEC. VIII Censo de Población y VII de Vivienda, Quito (2023)
29. González, L.C.: Análisis de la demanda turística desde el punto de vista de la motivación y satisfacción de su gastronomía El caso Salinas (Ecuador). HOLOPRAXIS. Rev. Cien. Tecnol. Innov. **2**, 225–249 (2018)
30. León-Valle, W., Núñez-Guale, L., Valencia, A., Cedeño, J.: La Pesca Artesanal un legado del saber ancestral, provincia de Santa Elena. Rev. Investig. Soc. **3**, 51–63 (2017)
31. Campuzano, M.G., Crisanto, T.: E-waste management: a case study of municipalities of Santa Elena Province - Ecuador. In: Rodriguez Morales, G., et al. (eds.) Information and Communication Technologies, pp. 587–598. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-62833-8_43
32. Campuzano, M., Bayas, M., Rovira, R.: Recycling bin based on the Internet of Things for Santa Elena Province. In: Gervasi, O., et al. (eds.) Computational Science and Its Applications – ICCSA 2023 Workshops, pp. 32–43. Springer, Cham (2023)