

# Recycling Bin Based on the Internet of Things for Santa Elena Province

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**Abstract.** As municipal solid waste keeps growing, waste management becomes a more complex issue for developing and developed nations. Latin America has fast population growth and low recovery rates. In Ecuador, Santa Elena is one of the few provinces which have not initiated segregated waste collection. Internet of Things has great potential to improve waste management systems at various points. The research objective was to analyze the current municipal solid waste management system and to propose a solution that incorporates Internet of Things technology to achieve segregated waste collection in an efficient way tailored for the municipalities of Santa Elena province. First, the current waste management system of the three municipalities of Santa Elena province was identified using literature review and interviews to municipal workers and recyclers. Analyzing similar waste management applications and considering local conditions, an improved waste management system was designed incorporating Internet of Things. The proposed solution includes solar-powered recycling bins which incorporate filling-level sensors and smoke sensors. Data is sent using a Wi-Fi module to a web server so real-time monitoring can be performed and updated efficient collection routes generated.

**Keywords:** waste management · Internet of Things · recycling bin · waste collection · Santa Elena province

## 1 Introduction

As cities continue to grow and industrialize, municipal solid waste (MSW) management has become a more complex issue worldwide [1]. Urban waste management represents a great challenge for modern societies, and it is an important pillar for sustainable development [2]. This matter requires urgent attention as the waste managed improperly affects people and the environment mainly in developing economies where this topic may be overlooked [3]. Municipal waste management can be expensive, as it represents around 4 to 20% of local budgets [4]. Traditional practices need to be improved with smart technologies to increase waste management systems' efficiency and to migrate to a circular economy towards sustainability [5].

Around 80% of Latin America's population dwells in urban areas [6]. Despite significant breakthroughs, municipal solid waste management in Latin America has not developed as fast as population growth. This region still has low recovery rates and open

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dumps which affect sanitation and may be a threat to human health and the environment [7]. Waste usually has a high percentage of organic materials, which is common in developing countries [8]. Sorting and recycling have not yet been widely implemented around this region in comparison to similar economies in different parts of the world [6].

Despite that Ecuador is one of the first countries to create a national program on integrated solid waste management and to incorporate into its constitution nature's rights, current waste management systems need to be improved [9, 10]. Only 52% of municipalities operate landfills as the final disposal stage. The Ministry of Environment intended to close open dumps and temporary cells before 2018, however, it has not been done yet [11]. Household waste represents a great amount of urban solid waste [12]. Municipalities are responsible for collecting, treating, and disposing waste under a figure called decentralized autonomous governments [13]. Ministry of Environment Agreement 161 establishes extended producer responsibility principles for different products like mobile phones, batteries, pesticide containers, and used tires [11].

Not every Ecuadorian municipality has implemented mechanized waste collection in the cities. It is not uncommon to see piles of garbage bags on street corners. There are municipalities like Ambato, which installed waste bins more than 15 years ago. On the other hand, in municipalities like Salinas, you can see waste collectors loading by hand waste bags into waste collection trucks. Cities like Ambato, Cuenca, Riobamba, Quito, Guayaquil, among others have a mechanized residential solid waste collection. On average, 13,653 tons of waste are collected per day in Ecuador. Although differentiated collection is in place, only 34% of municipalities have implemented formal segregation; therefore, only 15% of waste is collected separately [14, 15].

Smart cities use information and communication technology (ICT) to improve cities' operations toward sustainability [16]. Frequent areas managed smartly include energy, transportation, green building, water supply, waste management, and land management [17]. Internet of Things (IoT) technology has brought attention to a wide range of applications in the science and engineering world where wired and wireless networks can be used [18]. IoT connects citizens, activities, data, and things converting information into actions that have generated exceptional possibilities to reshape assets and services [19]. IoT combines various technologies to create an interconnected network of small and large devices with sensors and actuators. Devices can communicate and exchange information through the internet so autonomous decisions can be made [20]. Developed and developing countries use Internet of Things applications to grow sustainably. As developing nations face financial and technical restrictions towards implementing smart city concepts, it is important to create an adequate environment to launch IoT initiatives [21].

Waste management supported by Internet of Things technology has become an important subject for research [22]. IoT has great potential to improve waste management systems at various points so circular economy and sustainability can be achieved. IoT devices can be installed in landfills [23, 24], energy conversion facilities [25], recycling centers [26], waste collection vehicles [20], dustbins [27], among others. Bins and containers integrated with filling sensors may be able to reduce overfilled or unnecessary collected bins through platforms that update waste collection routes in real-time [28].

Sathish Kumar et al. and Joshi et al. are some of the first researchers to be published on using IoT for smart waste management with wireless sensor networks together with cloud computing to optimize dustbin picking [29, 30]. Sathish Kumar et al. paired ultrasonic sensors with Arduino UNO to monitor filling levels to alert when bins require to be emptied. RFDI tags were included, and a system was created to monitor in real-time bins. An Android application was programmed and related to a web server for sending alerts and remote monitoring [30]. Waste management using Internet of Things for India was proposed using a solar-powered compacting dustbin with a wireless connection to transmit filling-level data to a cloud server to generate optimized collection routes. Operational waste collection costs were calculated to be reduced by 80% [31]. Monitoring systems applied to smart bins integrated with wireless filling sensors to update collection routes have also been studied in South Korea [27]. Shyam et al. proposed an algorithm to update and optimize daily routes for picking smart dustbins. The innovation relies on that not only daily data sent by sensors is analyzed but historical data which aids to predict future conditions relating to factors such as traffic and cost-efficiency [20].

IoT has been studied under different scopes and applications to improve waste management, not only to optimize collection routes but to aid waste segregation towards circular economy. Deep-learning convolution neural networks were created to classify waste in the initial collection stage into six categories. IoT devices allowed information exchange between dustbins and waste management centers to improve routes and maintenance [32]. Rahman et al. also used deep learning together with IoT for waste classification. IoT was used for controlling in real-time from anywhere and Bluetooth allowed data monitoring in the short-range trough a mobile application [33]. Internet of Things technology was used to improve accountability in household waste segregation in China [34].

In the Ecuadorian context, a smart waste monitoring system was developed for Riobamba city. An existing waste container was retrofitted with a solar panel and a device to send data collected by level, temperature, humidity, and pH sensors. The scope included database, web page, and server implementation [35]. For Cuenca city, a smart recycling container was designed and built. Through capacitive sensors, it identifies if it is a plastic bottle or a can so it can be sent by a rotary tray to the right part of the container. An ultrasonic filling sensor was also used to monitor the filling level of the bin to optimize collection routes [36]. Even though IoT has been studied before in Ecuador, it was only analyzed for Riobamba and Cuenca cities where mechanized collection is in place and have implemented waste classification. The research objective was to analyze the current municipal solid waste management system and to propose a solution that incorporates IoT technology to achieve segregated waste collection in an efficient way for the municipalities of Santa Elena province.

## 2 Materials and Methods

### 2.1 Study Area

Santa Elena province is in the southwestern part of the coastal region of Ecuador (Fig. 1). This province has an area of 3691 km$^2$ and an altitude from 0 to 800 m.a.s.l. Almost 45% of the land is rural. It is dived into three cantons: Santa Elena, La Libertad, and Salinas [37].

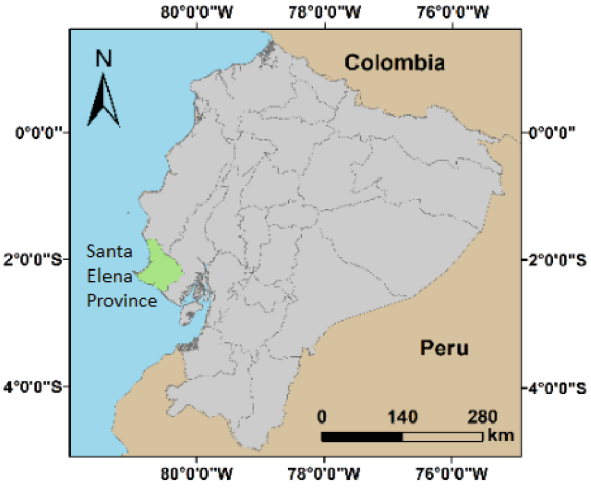


**Fig. 1.** Location of Santa Elena province [38]

Ecuador's average waste composition for 2021 was: 55% organic, 11% plastic, 6.5% non-hazardous sanitary, 5.1% cardboard, and 4.6% paper. No current information is available for Santa Elena province. In Ecuador, only 34% of municipalities have initiated or operated waste segregation process. Santa Elana is one of the few provinces which have non-existing waste classification programs executed by municipalities. Average waste generation for Santa Elena province is around 0.8 kg per day [14]. Waste pickers, which may be part of an association or not, perform urban mining. There are few private recycling initiatives and recyclers associations.

### 2.2 Methodology

This research was divided into two phases (Fig. 2). The purpose of phase one was to identify the current waste management system of the three municipalities of Santa Elena province. First, literature review was performed to analyze current waste management practices in the municipalities. Scarce research was available; therefore, it was necessary to obtain more information through field visits and interviews in the three municipalities. Municipal workers in charge of waste management were interviewed using semi-structured questionnaires to establish the current urban waste management

system and the willingness to accept IoT implementation. Formal and informal recyclers were interviewed too to establish where they perform their activities and what kind of materials they work with. Their willingness to perform formal recycling aided with IoT was assessed too. The purpose of phase two was to propose an improvement for the current system incorporating IoT using the information gathered in phase one towards implementing differentiated waste collection. For the second phase, exploratory research was performed using scientific articles on similar IoT solutions to choose the best options for Santa Elena province reality. The main stages of the province waste management system were evaluated and improved incorporation IoT smart recycling bins and considering recycling streams. The recycling bin was designed using Autocad 3D and the circuit to be implemented inside the waste bins was designed using Proteus Professional 8. Route planning mechanisms were not included in the scope of the research.

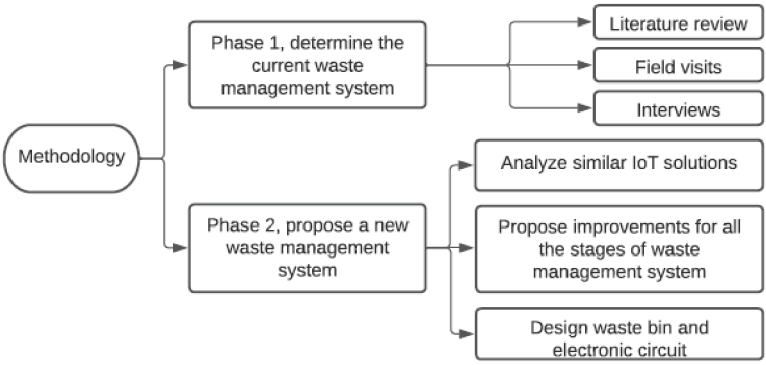


**Fig. 2.** Methodology used for the research.

## 3 Results and Discussion

The three municipalities of Santa Elena province were visited to assess the current municipal solid waste management system. Salinas and La Libertad municipalities have a municipal solid waste department while Santa Elena municipality has created a public company for managing waste called EMASA-EP. It is considered a better practice to create public companies for urban waste. None of the municipalities have implemented landfills and final disposal is performed at open dumpsites (Fig. 3). During field visits, it was noticed that in general MSW is placed into plastic bags at street corners, and in a few cases, it is placed into closed bins or containers. Recyclers open the bags to get valuable materials like plastic, paper, cardboard, metal, or electronic waste. During interviews with recyclers, it was mentioned that some of them are part of associations and others are informal recyclers. Municipalities have not implemented a segregated collection of MSW. Waste trucks transport the load to the open dumpsite of each municipality. At the dumpsites, there are also recyclers who collect materials. Formal and informal recyclers sell and transport the materials to Guayaquil city, which is located in another province.

When interviewed, stakeholders showed interest in participating in projects to increase the efficiency of waste management where recyclable materials are recovered in a formal way.

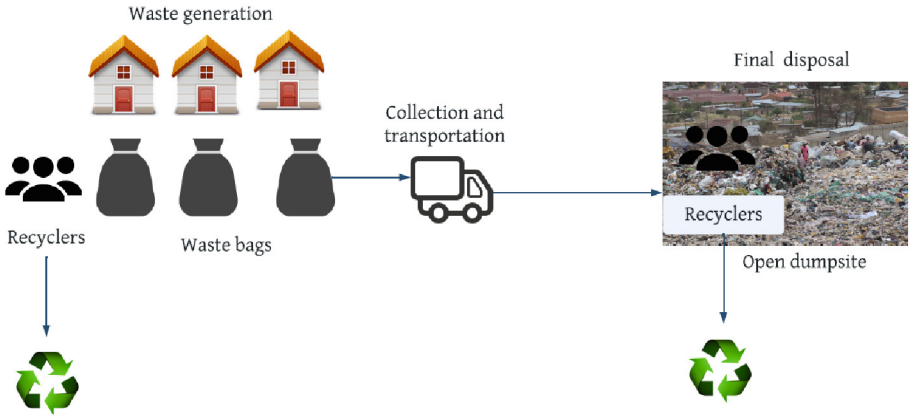


**Fig. 3.** Current municipal solid waste management system of municipalities of Santa Elena province

Since citizens are not used to separate waste, it would be useful to start a differentiated collection with smart recycling bins, first in Santa Elena municipality since they have a more advanced waste management system. It also should be considered that recycling bins should be gradually introduced so people may be more familiar with separating waste. The proposed improved system includes a bin for recyclable materials and another for common solid waste (Fig. 4). The recycling container will be for plastic, paper, and cardboard which are the main recycling materials. Since there is no electricity supply at the streets where waste is collected, solar panels and rechargeable batteries were considered for the bins. Containers have a capacity of 120 L, each one. Low-cost technologies have been selected to implement IoT inside the waste bins. Filling levels and smoke alarms are sent wirelessly to the cloud through internet. Collection routes are updated based on filling levels to avoid static routs and static schedules which may result in picking empty bins. Waste truck workers have access to mobile devices so they can perform collection as planned and inform of any inconvenience they may find during their work. IoT will improve efficiency and save money and time. Because the current system does not have a recycling center, it is proposed to merge a transfer station and the IoT monitoring center. It is considered that is better for recyclers to pick recyclable materials from general waste at the transfer station to avoid health hazards at the final disposal stage. It is advisable for the municipalities' authorities to consider landfills instead of open dumpsites to reduce environmental and health hazards (Fig. 5). Later, organic waste should be converted into compost or to produce energy using biogas or landfill gas.

IoT components and photovoltaic power system are shown in Fig. 6 and Fig. 7. The type of solar panels chosen for this research was polycrystalline (p-Si) since they are less expensive than monocrystalline ones; however, they have 5% less efficiency. If a waste

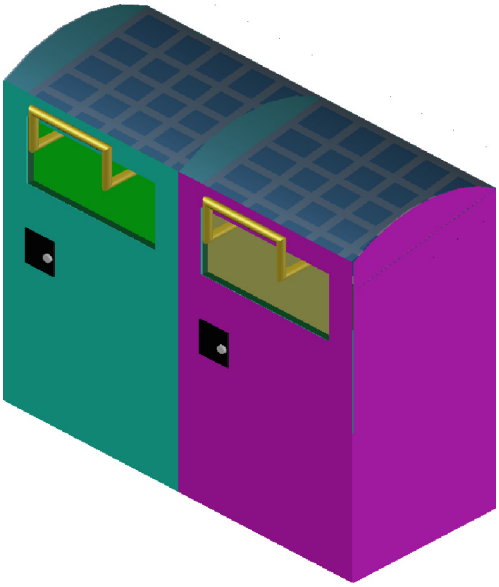

**Fig. 4.** Proposed solar-powered smart bins

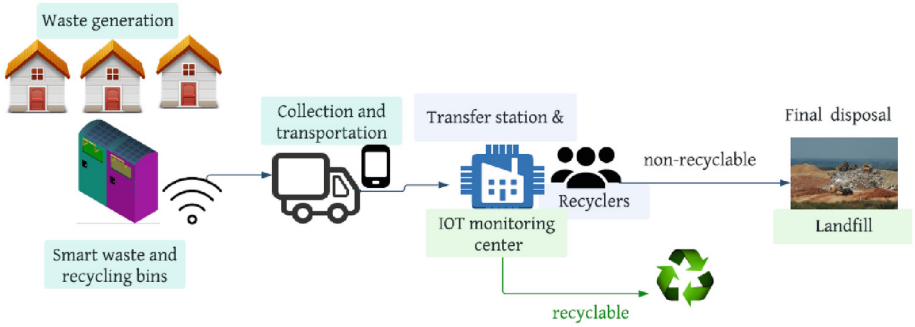


**Fig. 5.** Proposed waste management system

collector detects dust on the solar panel glass, he can clean it to increase the energy the system receives. The rechargeable module and battery will allow stored energy to be supplied when there is not enough solar radiation. The microcontroller board Arduino UNO was selected because it has a small size that fits into the bin, has an average price, and fulfills the needs to process data from the two sensors. Further research should consider using an ultra-low-power and highly-integrated microcontroller that may have better performance concerning battery life [39]. The HC-SR04 ultrasonic distance sensor measures the filling level by sending an ultrasound that bounces back when it finds an obstacle. The distance is calculated using speed and time. An ultrasonic sensor was chosen because it measures levels for liquid and solid materials and does not need to be in contact with the measured material. This type of sensor was selected because IR

sensors have shorter ranges and sunlight, hardness and colors may affect their accuracy [40]. However, further research might be necessary to increase accuracy as creating tailored caps to reduce detection angles that may avoid lateral surfaces detection [41] or installing two ultrasonic sensors in the waste bin [42] or using different type of sensors to triangulate data. HC-SR04 sensor is not expensive and has a measurement range from 2 cm to 400 cm with a resolution of 0.3 cm, which is adequate considering that the height of the bin is no more than 150 cm. The MQ2 gas sensor is used to detect gas and smoke, it is used to alert if there is smoke produced by a fire inside the bin. The NRF 905 module connects the sensor node and the gateway sensor. This device has a communication range of up to 1000 m. The Wi-Fi module ESP8266 is a system on chip (SoC) that includes a TCP/IP protocol stack that gives Arduino UNO access to the Wi-Fi network and it is widely used for IoT applications. Communication through Wi-Fi was selected for this work under the scenario that the government program of Santa Elena of becoming a digital province is fulfilled. However, other communication technologies such as Narrowband IoT and LoRa should be also considered to transfer data [43]. The generated data is stored and processed for real-time monitoring and waste collection improvement. Based on the amount of waste stored inside the bin, collection routes will be generated.

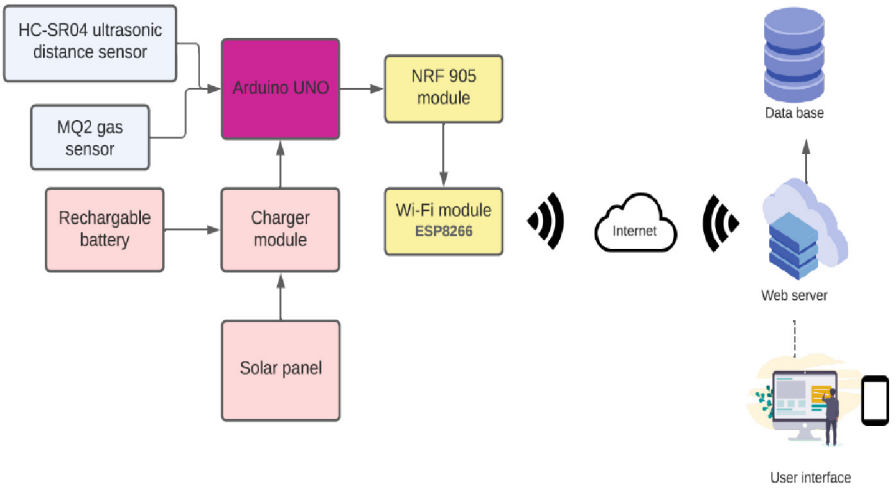


**Fig. 6.** Block diagram for the proposed system

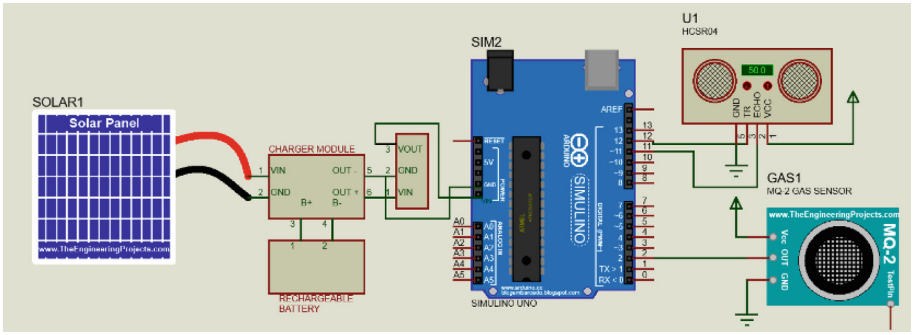


**Fig. 7.** Solar-powered circuit to be integrated into the waste bins

## 4 Conclusions

The current municipal solid waste management system of the three municipalities of Santa Elena province does not include waste bins; therefore, waste is placed in plastic bags that sometimes can be broken prior to collection. Waste classification has not been formally implemented by the municipalities. However, it does not mean that all recyclable materials go to open dumpsites because formal and informal recyclers perform the task of picking recyclable materials. This situation may be improved by implementing smart solar-powered recycling bins integrated with Internet of Things technology. Data from filling-level sensors will allow the generation of efficient dynamic collection routes. The current waste management system should be improved not only at the collection stage but also at the final disposal as landfills have not been implemented yet. The next stage for the research should validate the proposed bin from an operational and financial point of view. Other communication technologies such as Narrowband IoT and LoRa should be also considered to transfer data. Further research should include machine learning algorithms to predict waste generation and generate more efficient picking routes.

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