# Paving the Way for Smart Community Composting

## A Design Science Research Project in Estrela UNESCO Global Geopark

**J. Monteiro, J. Barata, H. Gomes and E. Castro**

**Abstract.** Community composting is an essential facet of circular economy and sustainable food production. Our contribution based on design science research presents the development of a regional composting network in Estrela UNESCO Global Geopark. The community composting model uses mobile technologies and geographic information systems. This paper details the instantiation of the mobile solution layer and proposes a plan to scale-up the model to the entire region. The theoretical contribution of this paper is the concept of smart community composting inspired by the 5.0 movement expanding in societies, cities, and industries. For practice, our work presents a mobile information system customized for UNESCO Geoparks and their recently created GEOfood brand to promote sustainable production practices.

**Keywords:** Smart Region · Smart Community Composting · Geopark · Circular Economy

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# 1 Introduction

Circular economy (CE) is becoming a popular research area in information systems (IS) [37]. The interest is justified by the critical role of information to achieve transparency in material flows, since “*isolated windows of data availability only lead to local optimization of process efficiency for individual actors but fail at realising CE’s full potential*” [37]. New digital platforms connecting different stakeholders of sustainable supply chains will be a priority [7].

Sustainable food supply chains will need to implement circular practices. Over 30% of the food is lost, and food production will need to increase by 60% in 2050 [16]. Composting is a possible solution to reduce waste while simultaneously improving the soil and society’s response to climate changes [3, 10]. This circular practice can be adopted at homes but also in specific communities [23].

Digital transformation is shifting to the “5.0” era in cities [27] and industry. For example, the priorities established by the European Commission in 2021 include sustainability, human-centric development, and resilience with a “*focus from shareholder to stakeholder value, with benefits for all concerned*” [13]. This vision is inspired in the Society 5.0 proposed by Japan, and also aligned with the recent City 5.0 concept defined by [27] as “*a liveable city that is (re)modelled with the aim of eliminating restriction for its citizens by using digitalization for the provision of public goods and services*”. The traditional agriculture sector is also shifting to digitalization for sustainability, as detailed in the report presented by the Food and Agriculture of Organization of the United Nations [29]. Technologies like the Internet of Things (IoT), cloud, and mobile solutions may be adopted in individual smart composting systems [2, 6, 22]. However, there is a lack of research in smart composting at a regional scale. Therefore, smart community composting is the challenge addressed in this paper.

Our Design Science Research (DSR) [15, 19] started in cooperation with Estrela UNESCO Global Geopark (Estrela Geopark) [34]. UNESCO recognized this region’s geological relevance in 2020, and their association’s strategy puts sustainability at the top of the priorities. They aim to incorporate a circular economy in local food production supported by information technologies (IT). Accordingly, the following research objective was formulated: (RO1) *deploy a smart community composting platform to support Estrela Geopark’s circular economy*. Additionally, inspired by the concept of projectability presented by [1], “*to understand how design theories and design principles, as prescriptive constructs, imply intentionality for operation in other places or time*s”, an additional research objective (RO2) is to “*project smart community composting at the regional scale of Estrela Geopark*”.

The remainder of this paper is organized as follows. Section 2 presents the research approach. Next, a review of relevant literature on CE, IS, and smart composting is offered. Section 4 details the design, development, evaluation, and projection of the smart community composting platform. Subsequently, we state the conclusions, limitations, and future work opportunities.

## 2 Research Approach

DSR [15, 19] is the selected research approach. The resulting IT artifact aims to assist Estrela UNESCO Global Geopark in adopting circular economy practices at a regional level. Fig. 1 summarizes the research according to the DSR grid [4].

| **Problem** | **Research process** | **Solution description** |
|---|---|---|
| A digital platform is necessary to deploy community composting.<br>Existing proposals were not made for regional scale. | Steps of problem formulation, design and development, evaluation, and communication [26]. Future orientation of the artifact [1]. | IT artifact with web/mobile interface. |
| **Input knowledge** | **Concepts** | **Output knowledge** |
| GEOfood;<br>Smart Regions;<br>Smart composting systems. | Information systems;<br>Circular economy;<br>Composting;<br>Geographic Information Systems. | Design requirements and a guiding model for community composting in smart regions;<br>Roadmap. |

**Fig. 1.** DSR Grid for the Development of Smart Community Composting

The work presented in this paper corresponds to DSR-cycle encompassing the phases from the idea conception to the design, development, and deployment of the smart community composting prototype in a natural environment but still under supervised conditions. Additionally, we followed the concept of projectability in DSR [1] to create a possible roadmap for expanding community composting to the entire Geopark region.

### 2.1 Regional Setting for DSR

Estrela Geopark is a territory in the Iberian central region with geological heritage, "*a rich biodiversity and long history of human presence with strong cultural and economic links to the mountain*" [34]. Geoparks recently launched the GEOfood brand worldwide to distinguish and help producers in protected regions [33]. The

GEOfood manifesto fosters sustainability (maximizing local materials; minimizing transport impact), cooperation, and preservation of regional food heritage.

Estrela Geopark's territory is vast: 2216 km² and nine municipalities. Their association intends to include community composting as part of their overall strategy for sustainable local food production.

Composting organic material (e.g., food scrap, weeds, dry leaves, or fruits) is not yet disseminated in the Estrela Geopark community. The transformation of food waste compost can reduce their footprint while informing the population about this critical priority for the coming years. Estrela Geopark also wishes to strengthen the links between different zones in the territory. Notably, they plan to create a network of (1) urban food waste producers and (2) rural food waste recyclers (the local food producers).

At this research stage, Estrela Geopark is interested in modelling the circular economy network for smart composting, deploying the IT solution that supports their circular economy strategy, and draft a regional scale-up of smart community composting. The following section reviews relevant literature on the circular economy, information systems, and smart composting.

# 3 Literature Review

The selection of papers included in this section was made in Web of Science (WoS) and Scopus. Using specific keywords, we started with a bibliometric analysis and identified crucial clusters and concepts with the VOSviewer tool [11]. Subsequently, we have assessed related work to identify trends in this line of research.

## 3.1 Information Systems for Circular Economy

Fig. 2 presents the results of a search in WoS (all records: 41 results) and Scopus (title, abstract, and keywords: 88 results) using the keyword combination “information systems” + “circular economy”.

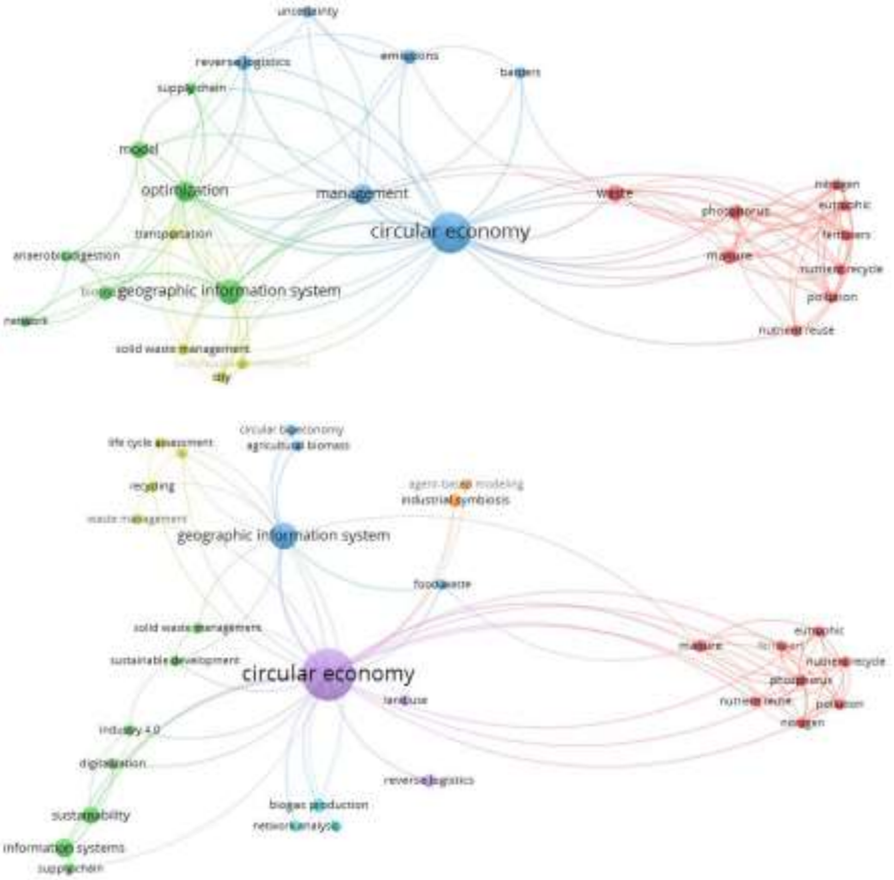

**Fig. 2.** Information Systems and Circular Economy: Bibliometric Analysis

WoS (at the top) presents four main clusters: the red cluster (on the right) associated with specific products (e.g., nitrogen, fertilizers, nutrients); the central blue cluster for circular economy and the close relation with managerial aspects, reverse logistics, barriers, uncertainty, and emissions; the more “IS-related” green cluster (e.g., model, network, supply chain); and the yellow cluster including transportation and urban development (e.g., solid waste, city). Scopus reveals more clusters, with the red (products, nutrients) and green (IS-related) aligned with WoS, but also included specific clusters of papers about agriculture (blue cluster, aggregating geographic information systems, food waste, biomass). In both cases, it is clear (1) the important role of geographic information systems in circular economy development, (2) the need to create networks within the supply chain, and (3) the significance of food systems in circular economy developments.

The circular economy has entered in IS agenda. The recent papers published by [37] with the purpose to mobilize the IS community for this "grand challenge" reveals two important lines for future research: "[f]*irst, in consideration of recent advances in tracking technologies, we invite discussions on the issue of representational faithfulness of complex product systems in circular material flows. Second, in acknowledgement of the dynamic and often unpredictable nature of circular material flows, we invite discussions on issues of data sharing in large and complex social systems*". An example of a study in this area is [35] for industrial parks' perspective. The main IS elements are (1) the information about companies in the network, (2) material flow, (3) key flow traces, (4) regulations and standards, and (5) industrial symbiosis [35]. Another recent example using geographic information systems is the web-based interface developed for solid waste management in England [25].

Real-time monitoring of supply chains as a whole will enable a clearer understanding of material flows [37], leading to more efficient control, reducing costs and waste, and, where possible re-introducing them back into the chain. Product traceability is currently a significant challenge that can be addressed through information systems and blockchain [14, 31]. In addition to improving communication between stakeholders [36], information systems bring the links of circularity and the ability to balance the supply-demand relation [30].

Some authors have focused on agriculture and food supply chains. The study conducted by [28] in Spain concludes that it is viable to use food waste (collected in distribution and retail) for animal feed. Different organic wastes can be used for producing compost that is important for fertilization, such as wineries [18]. Blockchain is a possible solution to test in the creation of circular economy networks [31]. However, digitalization in general, using different technologies (e.g., IoT, big data, data analytics) can create a more innovative circular economy [17]. Information is crucial to (1) monitor the production of waste, (2) support the creation of networks of stakeholders to reuse waste, as happens in the case of compost, and (3) explore the potential of data to optimize the process.

The following section details the potential of digital transformation for the issue of food waste and smart composting systems.

### 3.2 Smart Composting

Geographic information systems have an essential role in composting digitalization, but there are other opportunities, as shown in Fig. 3.

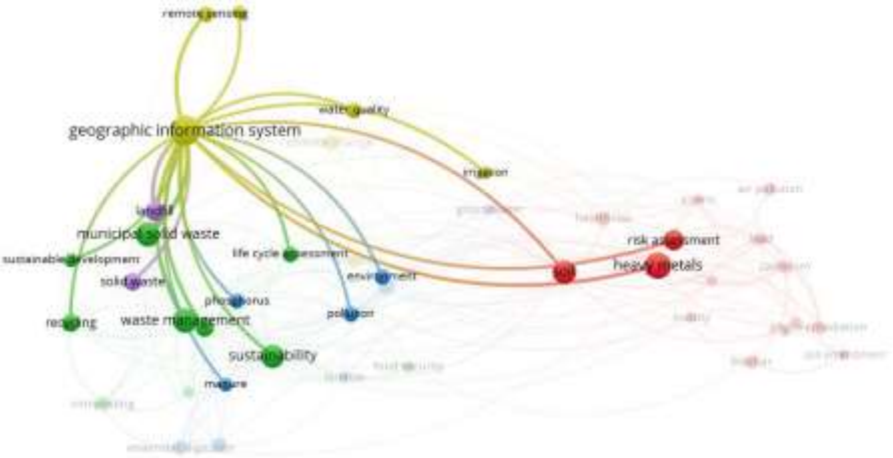

**Fig. 3.** Information Systems and Composting: Bibliometric Analysis in Scopus

Only 20 papers were found in Scopus using the keyword “smart compost”, and one in WoS. The latter is presented by [24], creating an Arduino-based prototype to monitor temperature, humidity, moisture, and gases. Therefore, we searched all fields in Scopus using the keyword (compost OR composting) AND “information system”, returning 1724 hits represented in Fig. 3. The yellow cluster highlighted in the figure reveals the importance of remote sensing. An interesting example using wireless sensor networks is presented by [6], illustrating the details of sensing temperature and moisture, and communication infrastructure.

Sensing devices can be used for on-farm composting [8], and several studies present prototypes for smart composting systems. For example, the smart composting systems built by [2] using an Arduino or the IoT-based solution created by [32]. Another example of a smart composting machine is presented by [12], including a mobile app for real-time management of the system parameters. However, these studies are for a single composting unit, and when multiple composting units exist, it is necessary to add the potential of the cloud [22].

Composting is also evolving to a community scale, aiming at more sustainable consumption. New technologies can contribute to this goal, as presented by the study of [9]. Community composting can be implemented in urban areas [10], and its benefits are already reported in the literature, for example, the study made in Chicago [23]. Rural composting is also possible [21]. However, information systems development of urban and regional areas (e.g., UNESCO Global Geoparks) with multiple composting sites is still understudied.

# 4 Results

This section details the DSR phases of design, development and instantiation, evaluation made by researchers and practitioners, and projectability of system scale-up.

## 4.1 Smart Community Composting Design

Fig. 4 presents a C4 model [5], which systematizes the actors and components involved in the digital twin for community composting in the Estrela Geopark region. C4 modelling includes creating a hierarchical collection of diagrams with four levels of increasing abstraction, namely, *context, container, component, and code* [5]. Fig. 4 presents the level 2 diagram (container) summarizing the IT artifact.

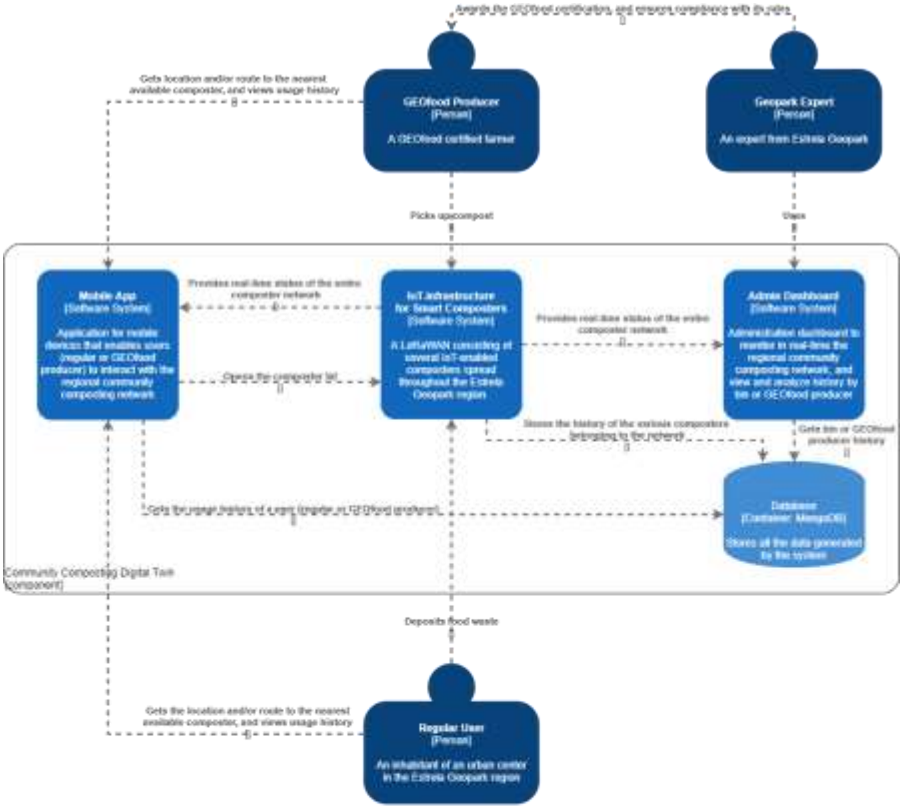

**Fig. 4.** Container Diagram for Smart Community Composting Digital Twin

The system consists of three essential software elements: (1) a mobile application that will allow the entire community (i.e., GEOfood producers and local population) to interact with the regional community composting network, (2) a network of IoT-enabled composters strategically placed in specific locations of the Estrela Geopark region, and (3) a web platform where Geopark experts will be able to monitor in real-time the status of each of the composters in the network, as well as consult their or GEOfood producers' usage history. All these components are described in detail in the next section. The system also includes a non-relational database (MongoDB) that will store all the data generated by the system. This data will be essential to the future adoption of intelligent data analysis and artificial intelligence techniques that provide simulation and prediction capabilities to the digital twin.

Three types of users will interact with the initial version of the system: (1) Geopark experts, (2) GEOfood producers, and (3) local population. GEOfood producers (certified farmers) will use the system to obtain free natural fertilizer to integrate into their agricultural production. GEOfood producers need to comply to different regulations to maintain their GEOfood label. For example, the preference for natural fertilizer on their crops. The local population wants to "recycle" part of their food waste and contribute to regional sustainability. It will be necessary for this type of user to carry out awareness-raising action to make them aware of the importance and impact of adopting circular economy practices for the environment and the local economy. Additionally, municipal policies may provide incentives for community composting. Finally, the Geopark experts will use the system to manage the regional community composting network and verify that the GEOfood producers meet the guidelines for GEOfood certification.

Information systems can enable circular economy practices with the deployment of smart community composting. The next section details the development and instantiation of the mobile components of the system.

### 4.2 Artifact Development and Instantiation

The smart community composting system has three main components: (1) IoT infrastructure for smart composters; (2) web platform for Estrela Geopark supervision; and (3) application for mobile devices.

The IoT infrastructure consists of an extended network of smart composters placed at various points in the Estrela Geopark territory's urban centers. Each smart composter is IoT-enabled, allowing monitoring the compost heap size and the main parameters characterizing the composting process's state (namely, temperature, humidity, and methane) and access control to the bin content (through an electromagnetic lock attacked to the bin lid). The various smart composters are connected via a Low Power Wide Area Network (LPWAN) [20] to communicate with the application server.

Fig. 5 displays the real-scale prototype of the smart composter currently being tested.

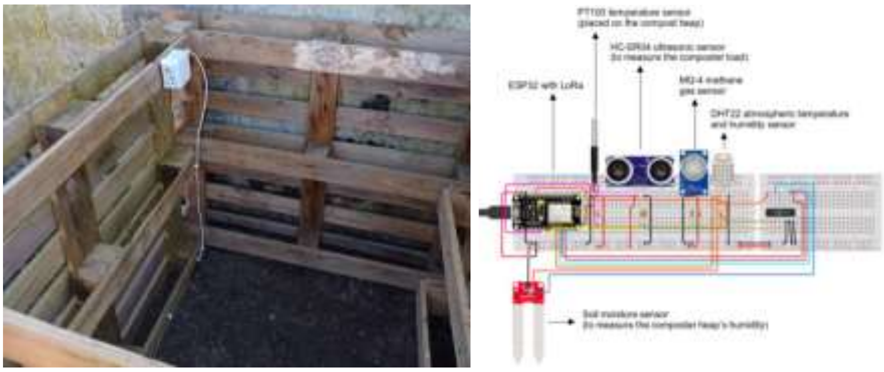

**Fig. 5.** Smart Community Composter Unit and IoT Diagram

The physical twin of each composter (the cover was removed to show the interior) maximizes the use of local materials (e.g., wood) and is equipped with an LPWAN device using LoRa [20] and sensors to monitor the most relevant composting process parameters - circuit represented on the right.

The digital twin web platform will allow Estrela Geopark's team to monitor the smart composter network's real-time status. Fig. 6 presents the administration dashboard graphical user interface (GUI).

**Fig. 6.** Administration Dashboard of the Digital Twin

On the left side of Fig. 6, the three-dimensional replica of the composting unit shows the amount of fertilizer. It is also possible to identify the smart composting network devices' location (on the top-right), the parameters, warnings (e.g., composter waiting for picking), and activity log on the bottom of the screen.

The mobile application is used by GEOfood producers and end-consumers of the food supply chain to connect with the community composting system. The mobile app is optional for the general local population - may assist in locating composting bins but is unnecessary for depositing food waste because that part will be unlocked for improved accessibility. Fig. 7 depicts the mobile app GUIs.


(a) (b) (c) (d) (e)

(f) (g) (h) (i)

**Fig. 7.** Mobile application GUI's high-fidelity prototypes

The first image (Fig. 7a) presents the system access and registration. The mobile app integrates Google and Facebook authorization mechanisms to facilitate both tasks. Personal data will be required from the users: name, date of birth, the municipality where they live, and their role in the system (Fig. 7b). The producer's database (network of companies adopting the GEOfood brand) is restricted and managed by Estrela Geopark.

The mobile app identifies the nearest available composter according to the user's location and suggests the route to take (Fig 7c-7e). Identifying the nearest available composter will depend on the user's role. On the end-consumer side, the suggested route points to the nearest composter that is not yet a few weeks) (Fig. 7g). On the producer side, the app will point to the composter containing natural fertilizer resulting from the composting process, ready for pick up (Fig. 7f). We assume that the user will only play one of the application roles. According to the association experts, end-consumers are more associated with urban areas since local farmers usually recycle their food waste.

To ensure the integrity of the compost heap during the composting process and consequently the quality of the compost produced, we have equipped the system with mechanisms that prevent users from disturbing the process (by not allowing the lid of the bin to be opened after detecting that it is full) and redirecting them to the nearest available composter (Fig. 7h).

The mobile app also enables users to view metrics related to their interactions with the community composting system. On the one hand, the end-consumer will see how much food waste is reintroduced into the food supply chain and to what extent this contributes to reducing their carbon footprint (Fig. 7i). On the other hand, the GEOfood producer will see the amount of fertilizer introduced into his production and check if they meet the environmental standards to keep GEOfood's certification.

### 4.3 Evaluation

The real-scale prototype received positive feedback from Estrela Geopark. According to the association experts, the system will be able to generate valuable data to quantify the amount of fertilizer each GEOfood producer picks up to support Estrela Geopark goals. Moreover, the data could be used to conduct quantitative studies to represent the users' behaviors regarding community composting and, finally, understand how community composting can nurture territorial cohesion between urban and rural spaces. Data will be handed in compliance with European Commission directives relating to data protection and privacy.

Estrela Geopark will be able to monitor the real-time status of the smart composters spread throughout the region. Additionally, the dashboard allows the analysis of the usage records per composter, producer, food supply chain (e.g., farmers, cheese producers), and municipality. Remote supervision is necessary to enable the smart composters network (e.g., best location) and promote awareness-raising actions in cities less aware of environmentally friendly practices. Incorporating food waste in regional supply chains can improve soil productivity and quality, and avoid chemical and toxic fertilizers and pesticides.

There are also challenges in the smart community composting that must be addressed in the subsequent DSR cycles. First, the mobile application opens the composter when a user is near (i.e., ~1 to 2 meters to allow some error in the measurement). The mobile device requires GPS location and Internet access for proper operation, which is a current system limitation. Second, the structure is made of endogenous materials like wood, which is an advantage but is also more vulnerable to vandalism. Future work is necessary to improve the locking system when the compost unit is full and waiting for pick up - unlocked by authorized GEOfood producers. Third, the system needs maintenance that needs to be made by municipality staff. This is not problematic because the municipalities are the main associates of Estrela

Geopark, but specific training (e.g., replacing a damaged sensor) and procedures (e.g., routinely checking if the composter is used correctly) will be required.

This DSR cycle was an essential step toward developing smart community composting in the region, supported by digital twins. However, "*projectability is a quality that one can find in design theories, principles, and artifacts*" [1], as we explore in the next section (RO2).

### 4.4 Projecting an Iterative Deployment of the Regional Community Composting Network

After evaluating the smart community composting system, preparing a comprehensive process to deploy the IT artifact (i.e., the digital twin) in the entire Estrela Geopark region is vital. However, notwithstanding the interest revealed by local entities, awareness campaigns are crucial to promote adherence of end-consumers to the system. Moreover, younger generations should be included in this process because they (1) will be the future end-consumers and (2) may have a positive influence on the circular economy practices of their family.

The potential of DSR projectability [1] is explored in this section. To do so, we envisioned a "best world": the deployment of composting digital twins covering several sites in all urban centers of the Estrela Geopark region with a significant adhesion by the whole community (i.e., GEOfood producers and local population), starting with the younger population. Therefore, the path to a more circular food supply chain will require a multidisciplinary approach and a sociotechnical strategy involving the younger generations in the region, more familiar with mobile technologies.

Fig. 8 presents a roadmap for deploying the regional community composting network with the collaboration of secondary and vocational schools. On the one hand, reaching the younger population will promote circular economy awareness. On the other hand, the school network will validate all the system's functionalities before it is extended to the entire community.

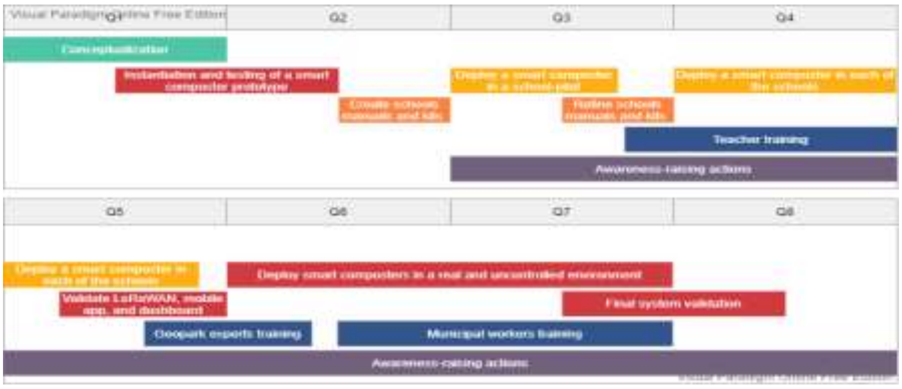

**Fig. 8.** Smart Community Composting Roadmap for Estrela Geopark

Fig. 8 suggests a sequence of steps to involve educational institutions, in all municipalities in the region, in the digital twin scale-up. After deploying an individual unit, the scale-up of the composting network needs to evolve gradually, and its success will be heavily dependent on population adherence.

Estrela Geopark already has an educational program (EstrelaEduca) that could be extended to support this roadmap. Training is required to key entities in the "best world", including the students and their parents, producers (via GEOFood certification), and municipalities responsible for the infrastructure. The teachers (e.g., informatics, environment, citizenship) may also receive training to assist the students in assembling and maintaining the smart composter. After the final system validation, the scale-up to the whole community may be more manageable. During this stage, training will be given to municipal workers to maintain the IoT-enabled bins and compost heap and to Geopark experts to manage the system. Several awareness-raising actions should be carried out throughout this process to show how community composting can be relevant for the environment and the regional economy.

Projecting the smart community composting at a regional scale is a complex endeavor, and this is only the first step. However, we found benefits in extending the DSR evaluation, envisioning an opportunity to align technology innovation with sustainability awareness, and the creation of the necessary conditions for a widespread circular economy with physical and digital components.

## 5 Conclusion

This paper presented the development and projectability of smart community composting in Estrela Geopark. The research process adopted the design science research paradigm [15, 19] and aimed to incorporate circular economy practices in a UNESCO territory with geological significance. In addition, the technology layers explored the potential of IoT and mobile systems to deploy an infrastructure connection (1) urban areas producing food waste, (2) rural areas incorporating compost in food production, and (3) the recently created GEOfood brand [33] for sustainable food and agriculture. A roadmap for digital-twin-enabled community composting is suggested for the context of the local food supply chain.

Some limitations must be stated. First, although Estrela Geopark association confirmed the suitability of the developed artifacts for their community composting strategy, the system is not yet deployed in the entire region. A real-scale prototype is under evaluation before replicating the composting devices in the nine municipalities. Therefore, a roadmap is proposed. Second, transferability to other Geoparks adopting the GEOfood brand is also unconfirmed at this stage. Moreover, each Geopark presents a different combination of urban and rural areas. Only some of them may perhaps share the exact characteristics of Estrela Geopark, with a wide area of urban users and the production of endogenous food products able to incorporate compost in their local supply chain. Currently, there are 161 Geoparks in 44 countries, and 24 are integrating the GEOfood initiative. Third, producers' adherence to the smart composting system can be ensured via GEOfood requirements for using the brand and economic incentives for using compost. However, urban users composting practices are only now beginning in some regions like Estrela Geopark. Some municipalities already support home composting (which may streamline the transition to community composting), but many end-users will need more time to adhere to a circular economy. Nevertheless, the experts participating in this project believe that the system may contribute to this goal, showing the importance of circular economy to the entire region and simplifying compost pick up even in cases where home composting is not common practice.

Substantial opportunities for future work are also identified. First, departing from the DSR limitations found, it will be necessary to scale-up the municipality level platform. A gradual deployment to increase region awareness for circular economy, simultaneously supporting their endogenous food production and external image, is considered the best approach by Estrela Geopark. Second, data analytics and artificial intelligence capabilities are still immature. The data collected can be used to create a circular economy index for the region and identify patterns of compost production in each area of the Geopark. Third, smart community composting is only a part of the circular economy potential. Information systems will be essential to improve sustainability in smart regions, increasing cohesion between urban and rural areas while contributing to the competitiveness of the local economy. DRR projectability [1] is a good starting point to envisioning more sustainable futures.

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