


Article

Systems Thinking and Solid Waste Management in Puerto Rico: Feedback Loops over Time

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Abstract: This article uses a systems-thinking framework to analyze Puerto Rico's solid waste system. Our findings were based on 36 semi-structured interviews from stakeholders that work within the solid waste system. Interviewees represented businesses, advocacy organizations, a university, and government agencies, including municipal, central, and federal government. This research is unique because it focuses on a case study using a historical lens to explore the policies and stakeholder dynamics that shape a system's behavior, where the behavior is in reference to the flows of discarded materials either entering the circular economy or the island's waste disposal facilities. Through our research, we found that Puerto Rico's overall solid waste system is stalled within a balancing feedback loop where policies and dynamics have taken place that have created resistance to efforts to improve the current situation. In our discussion, we reflect on the policies and stakeholder dynamics that have caused this balancing feedback loop and make recommendations to better support a reinforcing feedback loop that will lead to changes to achieve Puerto Rico's solid waste disposal and recycling plans and goals required to foster a circular economy. This study can inform future policy making and institutional coordination efforts within Puerto Rico and abroad.

Keywords: systems thinking; history; solid waste management; Puerto Rico; feedback loops; stakeholder dynamics



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1. Introduction

Puerto Rico is an archipelago in the Caribbean that became an unincorporated territory of the U.S. in 1898. The human-populated islands have 28 active waste disposal facilities, including 11 Environmental Protection Agency (EPA)-compliant landfills and 17 open dumpsites, seen in Figure 1, where “waste is in direct contact with soil and other natural resources” [1]. Many of these waste disposal facilities have reached capacity and the rest are predicted to be at capacity within a few years [1,2]. This is an important moment for solid waste management in Puerto Rico because the central government is receiving a large grant, discussed in Section 1.1.1, that can be used to invest in improved practices.

In this study, we apply a systems-thinking framework and use a historical approach to analyze Puerto Rico's solid waste system. Meadows (2008) defines a system as “A set of things—people, cells, molecules, or whatever—interconnected in such a way that they produce their own pattern of behavior over time” [3] (p. 2). A systems-thinking approach studies how a system behaves using feedback mechanisms that are either reinforcing feedback loops or balancing feedback loops. According to Meadows (2008), a reinforcing feedback loop “reinforces the direction of change. These are vicious cycles and virtuous circles,” and a balancing feedback loop is a stabilizing mechanism that “opposes, or reverses, whatever direction of change that is imposed on the system” [3] (p. 187). In this study, the

solid waste system behavior is in reference to the flows of disposed materials that either enter the global circular economy and are generally exported off the island or sent to the island's landfills and dumpsites. A circular economy will be defined in this study as “the reprocessing of goods and materials [that] generates jobs and saves energy while reducing resource consumption and waste” [4] (p. 436). Within this overall behavior of a system, there are underlying stakeholder interactions and dynamics, the structures of the system, that drive this system behavior. Therefore, this study aims to explore these explanatory feedback mechanisms with a historical lens to understand impacts on the system's overall behavior and to provide a holistic perspective to better inform future decision-making processes.

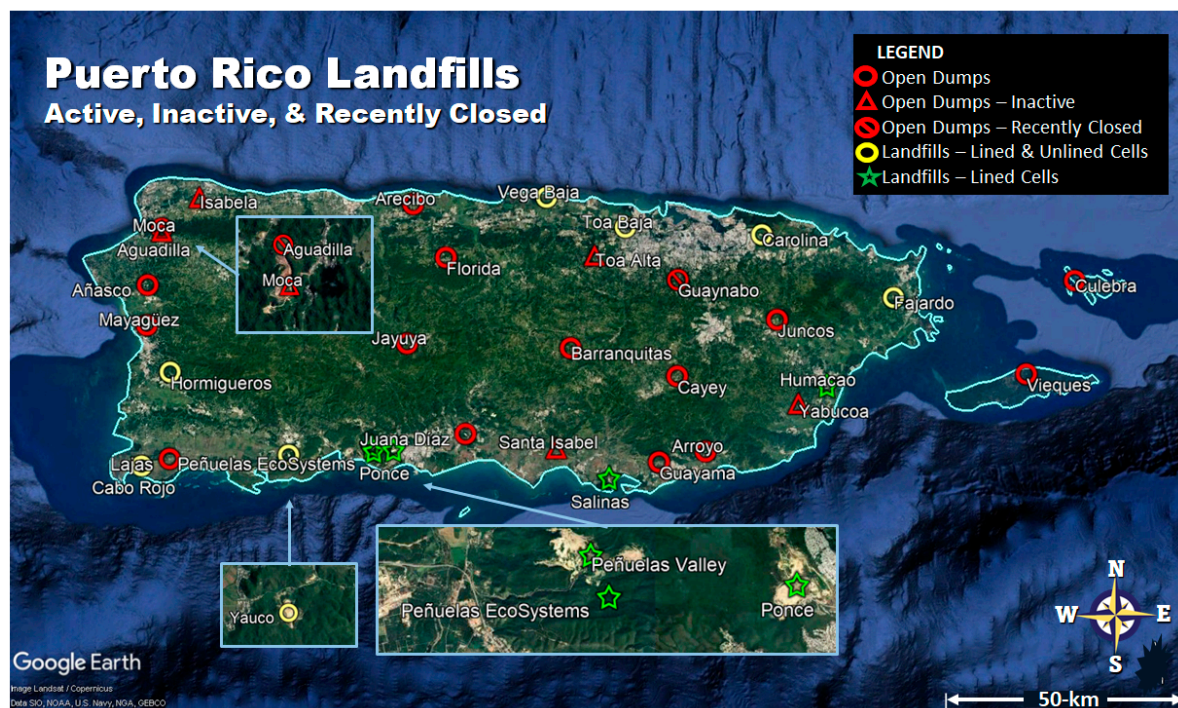


Figure 1. “Puerto Rico Landfills”. Note: Plössl, C. Puerto Rico Landfills. 2022.

Though some academic literature explores solid waste management using systems thinking, case studies often do not analyze systems with a historical lens. According to Meadows, “long-term behavior provides clues to the underlying system structure. And structure is the key to understanding not just what is happening, but why” (2008, p. 89). By studies excluding a historical context and evolution over time of stakeholder dynamics within systems thinking, not only is the holistic perspective lost relating to understanding how the system's behavior has developed up to the point that the study is framed within, but it also gives decision makers little understanding and context of why the system is behaving the way it is. As Meadows discusses, understanding the history of a system can provide explanatory mechanisms that are lacking without this holistic perspective. Additionally, current studies on stakeholder dynamics discuss the feedback loops that occur within a short period of time within a system. This study aims to discuss and highlight the feedback loops that have been occurring over several years within Puerto Rico. In addition, few studies explore systems thinking within solid waste management by studying stakeholder dynamics.

Therefore, this research is unique because it studies the system behavior of Puerto Rico's solid waste sector through qualitative interviews using a historical approach to understand past and present stakeholder dynamics and policies to make future recommendations for improved practices that support a circular economy. Additionally, though there are a few publications describing the historical context regarding Puerto Rico's solid waste

system, this paper takes a holistic approach and shows through feedback loops that past policies and stakeholder dynamics have led to counteractive interactions, stalling progress. Though this research specifically focuses on Puerto Rico, the study has applications to understanding how other locations, such as islands and different contexts that struggle with solid waste management, can analyze and make changes towards sustainable practices.

Specifically, the paper's objective is to explore two questions relating to the underlying explanatory mechanisms in the system structure: 1. What are the perceived policies and stakeholder dynamics that have occurred over time that have caused materials to be sent to EPA-compliant landfills compared to open dumpsites? 2. What are the perceived policies and stakeholder dynamics that have occurred over time that have caused materials to be sent to the circular economy?

1.1. Literature Review

1.1.1. Background of Puerto Rico's Solid Waste Sector

Beginning in the 1960s, Puerto Rico started to recognize the issue of solid waste on the island through the creation and focus of public agencies [5]. In 1978, Puerto Rico began to focus more strongly on solid waste management by creating the Solid Waste Management Authority (SWMA), which would be the primary entity responsible for solid waste tracking and planning initiatives. Between 1988 and 1994, Puerto Rico established and implemented a regional landfill plan that reduced the number of small informal dumpsites operating on the island [5]. For example, 32 open dumpsites were closed in 1994 [5]. In 1992, Law 70 was established, which created the goal that the island would reduce its daily waste production in three years by setting a 35% recycling goal and mandating that each municipality have a recycling coordinator [5]. This same law gave the SWMA the responsibility for coordinating the Program for the Reduction and the Recycling of Solid Waste [5].

In 1995, the SWMA revised the 1991 and 1993 island-wide solid waste infrastructure regional plan, which proposed greatly expanding the number of solid waste management facilities to 74 units [5,6]. Over \$140 million was allocated for the construction and implementation of the solid waste infrastructure. However, as of 2006, only 29 facilities had been constructed and not all of these units were being used [5]. The central government's 1992 proposed goal of a 35% recycling rate by 1995 was postponed until the year 2000, when, once again, it was moved to the year 2006 [5]. In 2006, the SWMA estimated the recycling diversion rate to be at 15.3% [7]. However, today, the recycling rate is below 10% [1]. In 1997, the Environmental Quality Board (EQB), responsible for permitting and regulating solid waste facilities, approved Regulation 5717. This regulation amended the solid waste regulation of 1993, affecting issues such as the operation and management of facilities overseeing non-hazardous material and creating rules surrounding used tires [5]. This 1997 amendment was inconsistent with the federal standard regulation and will be discussed further in this paper. In 2021, the 1997 amendment was changed to once again be consistent with federal regulations [8,9]. In 2003, the SWMA produced the "Strategic Plan for Solid Waste Management in Puerto Rico" document and conducted a waste characterization study [5]. Moreover, in 2003, the program Operation Compliance was created, where the EQB aimed to support the remaining open dumpsites in closing, discussed in the following sections [5]. In 2008, the SWMA produced another plan, titled the "Dynamic Itinerary for Infrastructure Projects" [7]. The document had the primary objective to "develop and implement infrastructure strategies to manage Puerto Rico's solid waste in a safe and efficient manner for the next 25 years in compliance with regulations" and proposed \$2.5 billion in infrastructure costs [7] (p. 1). Both the 2003 and 2008 solid waste plans were never implemented and will be discussed further in this paper.

One reason for Puerto Rico's increase in focus within the solid waste sector during the 1990s was Governor Pedro Rosselló's administration between 1993 and 2001. His administration was one of the first in Puerto Rico to fully implement policies that prioritized privatization, entrepreneurship initiatives, deregulation, and outsourcing within the public sectors [10,11]. Rosselló's administration also invested in large infrastructure projects, and,

according to Atilas-Osoria (2018), although “these neoliberal policies and mobilizations gave the false impression of growth and economic stability, they increased the Puerto Rican public debt” [10] (p. 832).

In 2018, the EQB and SWMA were reorganized to become part of the Puerto Rico Department of Natural and Environmental Resources (DNER), where solid waste management falls under this Puerto Rican central government agency. In the fall of 2019, the U.S. Congress approved a \$40 million EPA Community Development Block Grant related to disaster mitigation to be given to the Puerto Rico DNER to support the solid waste sector. As of September 2022, roughly \$6.5 million had been designated for staffing purposes to hire new staff under temporary contracts and provide salary adjustments to existing personnel [12]. Additionally, roughly \$4 million had been designated to conduct a waste characterization study and to develop an integrated solid waste management plan, with another \$2.5 million designated to other miscellaneous funds. The plan will partly be dependent on the findings of the waste characterization study and Governor Pierluisi’s 2021 waste disposal facility closure plan, which assigns \$31 million to dumpsite closure [12,13]. From the integrated solid waste management plan, the remaining \$27 million will be spent to implement the outlined strategies and practices by the end of the grant period, in September of 2026 [12].

1.1.2. Systems Thinking in Solid Waste Management

Systems thinking, described in Section 1, is a conceptual framework that aims to understand the behavior operating within finite boundaries using loops of causality over time [3]. Though much of the literature dealing with solid waste management and systems thinking relates to the operational mechanisms and technologies of material processing, few sources discuss the complexity of stakeholder dynamics and policies. Gutberlet et al. (2017) [14] used systems thinking and other theoretical approaches to explore findings and recommendations for a city’s solid waste management system in Kenya. The authors asserted that links between actors need to be strengthened, such as improved relationships between the formal and informal waste collection system operating in the city to increase collection services and decrease environmental pollution from solid waste. The article also recommended that increased participation from various stakeholder groups will also increase recycling efforts, causing less waste and possible pollution from waste disposal sites. Tong et al. (2021) [15] used a systems-thinking approach to analyze the impact on the informal recycling sector, such as independent waste pickers, within Vietnam. The authors found that, contrary to other reports, stakeholders in the informal recycling sector greatly support formal stakeholder recycling efforts. Guibrunet et al. (2017) [16] also studied the involvement of the informal sector within recycling systems in Mexico and Chile. The authors highlighted that factors such as the informal sector’s contributions to recycling systems are not analyzed using traditional waste flow quantification processes. Therefore, some of the most important stakeholders stay hidden in traditional methodologies. Additionally, Prasetyanti et al. (2014) [17] concluded, using a systems-thinking approach, that community-driven solid waste management is key to successful engagement and programming. Within this community-based approach, the authors describe that specifically women acting as environmental leaders can best empower other community actors. The authors described that communities can become empowered and work to become independent of government in managing solid waste systems. Similar to the articles described above, the authors also discuss the importance of independent waste pickers and how these individuals can assist government officials as well as women to oversee waste management programs. Therefore, the authors also conclude that government needs to play a collaborative role in community efforts. Serge Kubanza and Simatele (2018) [18] highlighted the importance of using systems thinking as frameworks to understand solid waste management systems, especially when analyzing global regions. The authors focused their study within the city of Kinshasa in the Democratic Republic of Congo and discussed, using a systems-thinking approach, the societal complexities that lead to poor solid waste management.

Marshall and Farahbakhsh (2013) [19] used a systems-thinking approach to compare the development of solid waste management systems in “industrialized” versus “developing” countries and explored how this history has led to current practices. In their paper, the authors discussed major contributing factors that have led to existing solid waste management practices in these two general contexts. The authors have built on Wilson (2007) [20] to emphasize history in the article and restate Wilson’s (2007) views that “building an understanding about what has driven SWM [Solid Waste Management] in the past can provide much-needed context and insight for how best to move forward in the future” (2013, p. 989). The authors also discussed reinforcing feedback loops and the self-organizing behavior around a point of equilibrium. According to Kay et al. (1999) [21], the equilibrium of a system can be degraded if a significant source of energy is applied that can push the system in a far enough direction to disrupt its point of equilibrium. The system, however, will create new structures to retain this point of equilibrium. Meadows (2008) supported this idea when she discussed balancing feedback loops, saying they “are both sources of stability and sources of resistance to change” [3] (p. 30). In the following sections, the behavior of the feedback loops occurring over time within Puerto Rico’s solid waste system will be explored.

1.1.3. Governance Strategies for Societal Challenges

Solid waste management challenges are faced around the world. According to Rodić and Wilson (2017) [22], solid waste management directly relates to 12 of the 17 United Nations’ Sustainable Development Goals. Even though solid waste management is directly related to sustainable development, it remains a significant issue in many countries and territories. According to Phillips and Thorne (2013) [23], “Waste management is one of the least recognized public policy issues in the Caribbean,” where it remains unprioritized compared to other societal problems (p. 5).

Waste management may not be prioritized in many contexts because it may be perceived as a wicked problem. Rittel and Webber (1973) [24] created this psychological construct, defined through 10 key characteristics that discuss the complexities of resolving social and ecological system challenges. The authors discuss that, as these challenges evolve with a human population that is also changing, the definition and solution of these challenges also continues to remain dynamic. Levin et al. (2012) [25] have defined super wicked problems as including issues where time is limited; “those who cause the problem also seek to provide a solution; the central authority needed to address them is weak or non-existent; and irrational discounting occurs that pushes responses into the future” (p. 124).

Termeer et al. (2012) [26] stated that wicked problems need specific governance capabilities. These capabilities include “(a) reflexivity, or the capability to deal with multiple frames; (b) resilience, or the capability to adjust actions to uncertain changes; (c) responsiveness, or the capability to respond to changing agendas and expectations; (d) revitalization, or the capability to unblock stagnations” (p. 680). The authors discussed the importance of government institutions in revitalizing and moving forward from stagnation, stating:

Revitalization refers to the capability of actors in a governance system to recognize and unblock counterproductive patterns in policy processes, and thus to reanimate actors and to enhance processes of innovation needed to cope with wicked problems. Without revitalization, there is the risk of regression, or of undertaking futile attempts to apply ‘more of the same’ solutions, and of escalating arguments between people who stick to their own routines (p. 686).

Termeer et al. (2012) [26] also emphasized the accompanying dimensions of these capabilities, including acting, observing, and enabling. These dimensions need to be in place so that governments creating policies can reflect on the complex issue, act to manage the issue, and be allowed to take action and see what is transpiring. One tool that could be used with these capabilities is a multi-criteria decision analysis, discussed by Gadaleta et al. (2022) [27], which gives decision makers the ability to compare different waste management options.

Acemoglu and Robinson (2012) [28] studied reinforcing feedback loops by exploring the dynamics within institutions, understanding how nations can become successful or fail in sustaining societies rich in democracy and wealth. The authors theorized that the more inclusive political and economic institutions become, supported by a strong central government capable of enforcing regulations promoting this inclusivity, the more likely a nation will obtain sustainable democracy and wealth. The authors explained how institutions can transition from a “vicious” to a “virtuous” reinforcing feedback loop, or vice versa, through unique moments in time when events or individuals change the direction of a country’s institutions, referred to as critical junctures. These moments are when institutions can diverge from previous paths and disrupt balancing feedback loops or change the direction of reinforcing cycles. This institutional change of direction over time is referred to as institutional drift. The authors explained that changes in feedback loops are created from “institutional drift punctuated by critical junctures” in time [28] (audiobook timestamp 16:41:20).

2. Materials and Methods

The primary researcher initially conducted semi-structured interviews to study vegetative disaster debris management after Hurricanes Irma and Maria [29] and impacts from the Puerto Rican central government reorganization that occurred in 2018 [30]. However, during the conversations, many interviewees discussed much broader topics and often reflected on past historical moments to describe how the solid waste management system had evolved into its current state. Realizing the interviewees were including relevant information regarding broader issues including perceptions and experiences relating to the island’s waste disposal facilities and the efforts to invest in a circular economy, the primary researcher integrated interview questions regarding the following topics.

- A. Waste management policies’ impacts on personal/organizational role or waste management sector
- B. Roles and relationships of different stakeholder groups at different points in time
- C. Challenges within the solid waste sector

This Institutional Review Board-approved study used 36 interviews to inform the findings. Interviewees worked in sectors related to solid waste management within Puerto Rico. They included 16 interviewees from businesses, comprising consulting firms, compost companies, recycling companies, and general solid waste companies, seven from municipal governments, one from the central government, four from advocacy organizations including non-profits and an association, two from an academic institution, and six from the federal government, including the EPA and the U.S. Forest Service. Interviewees were limited to Puerto Rico’s mainland due to limited access to interviewees on the municipal islands of Vieques and Culebra.

The primary researcher used a snowball sample where she started with a few interviewee contacts and, at the end of each interview, participants were asked for additional potential interviewee contacts [31]. The interviewees were contacted by email, text, or phone before the interview to be introduced to the topic. Due to the COVID-19 pandemic, almost all semi-structured interviews were conducted over the phone or through an online platform with the video turned off. Two interviewees elected to be given the interview questions in a word document that was emailed. Interviewees were given the option to have the interview conducted in English or Spanish. Interviewees agreed to participate in the interview and to be audio recorded before questions began. Those recordings were then transcribed using the software Sonix.ai. For those interviews given in Spanish, native Spanish speakers corrected the transcriptions of the conversations that were then translated into English using Google Translate and manually corrected again. The primary researcher used the computer software ATLAS.ti 8.0 to create thematic coding schemes to understand how the narratives were tied to one another [32]. Analytical memos were used by the primary researcher to track and align internal dialogue with discussion development. The primary researcher conducted interviews from June 2020 until May 2021 and completed a

five-day exploratory site visit in the San Juan metropolitan area in January 2020 and August 2021. Four stakeholders from the federal government, the central government, a private business, and an advocacy organization reviewed the final manuscript to provide feedback on the document.

3. Results

The findings below correspond to the study's research questions, where Section 3.1 addresses question one, stated in Section 1, regarding the policies and stakeholder dynamics that have occurred over time that have caused discarded material flows to be sent to waste disposal facilities in Puerto Rico. Section 3.2 addresses question two, stated in Section 1, discussing the policies and stakeholder dynamics that have occurred over time which have caused the material flows entering the circular economy. These sections focus on two main outcomes for materials on the island, where discarded materials are sent to either waste disposal facilities or are sent to compost companies and recycling collection businesses, where the materials are generally shipped off-island to be processed. Additionally, the findings are organized starting with the U. S. federal government level, where policies and procedures can flow both through central and municipal levels of government. Though we have separated findings by stakeholder group to clarify outcomes, there is overlap of impacts between the groups due to these complex interactions.

3.1. Policies and Stakeholder Dynamics Causing Materials to Be Sent to Landfill or Dumpsite Facilities

The following sections are organized by different stakeholder groups, and findings are discussed chronologically within each group.

3.1.1. Federal Government Stakeholders' Interventions and Challenges

Some interviewees explained the current issues with EPA enforcing open dumpsites on the island. A few interviewees indicated that specific EPA personnel have stopped past efforts by other EPA personnel to enforce compliance regulations on the remaining open dumpsites on the island. Other changes such as the transition of priorities of incoming EPA regional administrators were also reported as having impacts on levels of federal landfill enforcement within Puerto Rico.

3.1.2. Central and Municipal Government Stakeholders' Interventions and Challenges

The Puerto Rican central government has, at times, played a key role in landfill compliance on the island. Some interviewees who had been involved with solid waste management over several decades discussed the central government's efforts in the 1970s to stop open burning and dumping waste in the ocean. One interviewee representing the EPA stated,

At that time there was a lot of, you know, dumping into the sea or burning waste every evening so the EQB, at that time, stepped in very aggressively and put an end to the open burning of municipal wastes, to their credit. And then they required every municipality to establish a landfill.

As explained in Section 1.1.1, the EQB began enforcing the modified EPA Resource Conservation and Recovery Act (RCRA) Subtitle D regulations for compliant landfills in the early 1990s. One EPA interviewee stated,

Governor Pedro Roselló [. . .] gave out funds for landfills to close [. . .]. What RCRA said was ok you will close down the landfills' and the requirements were very lax in the beginning. But as time passed by, the requirements, the law requirements became more stringent.

In the early to mid 1990s, Puerto Rico had pushed the closure of open dumpsites, however, between 1996 and 1997, interviewees discussed how there were two key regulations that the EQB changed. One regulation dealt with financial assurance relating to

landfill closures, described as a financial backing structure where, before the change in the regulation, municipalities were required to set aside a certain amount of money to close municipal landfills properly. According to one federal government employee,

This meant municipalities no longer had to show financial assurance, and since most landfills were owned by municipalities, they were exempted from it. And then you got a race to the bottom because they're competing with even private landfills and such. The money that they had put aside for closure got used for other purposes.

According to interviewees, the other changed regulation dealt with allowing landfills to expand (lateral expansion) without a liner on the bottom, which would prevent contamination from the landfill leachate.

Interviewees shared that by 2006, Operation Compliance, discussed in Section 1.1.1, had ceased to exist. According to one EPA employee, "Regulations had not been fixed by the Commonwealth. Operation Compliance had failed completely by that point in the Commonwealth and the conditions had continued to deteriorate in Puerto Rico." A few interviewees expressed that tensions arose between municipalities, the EQB, and the EPA after Operation Compliance. One interviewee expressed their perceptions of the history leading to tensions by discussing that in the early 1970s, the EQB had enforced rules that created one central dumpsite within each of the majority of the municipalities. However, after this rule, municipalities pushed back on the EQB for any further landfill enforcement. The interviewee stated,

I think after that, any enforcement action against a municipality was like acting government against government [. . .]. 'You don't dare put a fine on a municipality. You can give them technical assistance. You can give them a compliance plan. But don't you dare impose a fine or don't you dare close up a dump.' I think that was all happening behind the scenes and that's why at the end, you know, EPA had no choice but to step in.

The interviewee went on to describe the tensions between the EPA and the EQB at the time, where the EQB seemed unable to enforce compliance on the remaining open dumpsites that were violating the RCRA regulations. Therefore, the EPA had to intervene over the territory's central government to ensure enforcement measures by issuing closure orders to four select dumpsite facilities that were not in compliance (though originally five dumpsites, the fifth closed on schedule) [33]. The interviewee explained, "The Puerto Rican government was embarrassed, not only the municipalities, but the Puerto Rican government, because obviously EQB had not done their job [. . .]. I think it was like a shock because EPA had never taken enforcement action against landfills." However, due to leadership changes within the EPA, once those orders were issued, EPA personnel were told to no longer pursue those closure orders. In terms of current issues, interviewees discussed that the DNER does not have enough staff or resources to enforce current landfill regulations. Interviewees described that this is because of the decreased presence of the central government caused by defunding and the central government reorganization in 2018.

Some interviewees believed that the central government wasted valuable financial resources by investing in recycling programs when EPA non-compliant landfills still exist on the island. According to one waste consultant, Puerto Rico has not prioritized its budget to operate compliant landfills compared to other infrastructure projects. Another interviewee representing the EPA explained issues with supporting recycling initiatives by the agency. The interviewee stated,

We put a lot of effort into recycling, but we never dealt with the issue of recycling not working in Puerto Rico [. . .]. Since there are discount holes in the ground, open dumps, where the true cost of disposal is somewhere along the lines of 18 dollars a ton; then 50 to 100 dollars a ton of recycling was doomed to fail even if there were markets for all of this, which there weren't. And that we had polled

landfill operators, recyclers and such and it was all in agreement that unless you raise the price of landfill disposal by, among others, requiring a compliant operation of landfills, then recycling just couldn't take hold.

Interviewees discussed the influence that municipalities can have over the enforcement of landfill compliance regulations. One waste consultant interviewee stated that municipalities have a lot of direct access to the governor's office and elected officials and, therefore, can also control levels of enforcement pursued by central solid waste agencies through higher central government authority offices.

3.2. Policies and Stakeholder Dynamics Causing Materials to Be Sent to the Circular Economy

The following sections are organized by different stakeholder groups, and findings are explored chronologically within each group. Unlike the previous section, interviewees also described the importance of non-governmental stakeholders within the circular economy, reflected below.

3.2.1. Federal Government Stakeholders' Interventions and Challenges

Interviewees reported that personnel within the EPA office located in Puerto Rico have also played a role in supporting efforts on the island regarding the promotion of education related to recycling and compost. Interviews described the efforts of personnel to support advocacy and consulting firm organizations' efforts around these types of programs. Additionally, interviewees also reported that the island's EPA office is easy to communicate with and provides funding opportunities to local organizations.

3.2.2. Central and Municipal Government Stakeholders' Interventions and Challenges

As stated in Section 1.1.1, the island invested a large amount of planning and financial resources in the recycling sector in the early to mid 1990s, including creating a 35% recycling goal that was set to be achieved by 1995. Some interviewees discussed the central government's support after setting the 35% recycling goal. One interviewee from a waste business perceived that, after the recycling law was in place, there was initially an increase in support from the central government. The interviewee stated, "For a couple of years people started thinking about recycling and there was a big push in education and training, but it went out with the years." Another interviewee representing the EPA described the decline in the vision and motivation behind the 35% recycling goal by stating,

Recycling became 'make sure you have somebody in the [municipal] office to answer the questions when the Solid Waste Authority [. . .] in Puerto Rico came by and checked on compliance with it, make sure you have the office staffed, you've got some recycling bins around and then you can throw your arms up and say it's not working, but we are trying'. It just became one more, well, arguably unfunded mandate from an out of touch government.

Another one of these initiatives during that time, which played an essential role in the recycling and compost sector today, was the business creation and development within the circular economy through central government funding initiatives, including grant money to start recycling and compost businesses. One recycling business interviewee described that, in 1996, through the central government's recycling assistance program, the SWMA financed recycling businesses, especially if they were worker-owned and community-based businesses. According to the interviewee, only one of the nine businesses funded by the grant still exists. According to another waste business interviewee, in 1998, under the Aqueduct and Sewer Authority, the central government opened a bid to begin a public-private compost facility within Puerto Rico, where, among the four companies that entered a bid, the business that won still exists today.

Interviewees explained that the central government is currently not supporting recycling efforts. One interviewee from a waste business said, "the government does not help or does not promote, the citizen is not encouraged." Another interviewee from an advocacy

organization stated, “I think they just see the recycling as an expensive program where they just need to pay for the transportation and provide the pickup service rather than seeing a return on investment socially, environmentally, and economically.”

Interviewees described that the central government also used financial and planning resources that were inadequately utilized. Interviewees reported that, between the mid 1990s and early 2000s, the SWMA constructed its own facilities, including recycling facilities, composting facilities, and transfer stations, where waste is transferred from smaller to larger trucks to be taken to landfills. According to one federal government employee, “There was investment in its property acquisition in building the equipment and building the buildings themselves. And they were never operated [. . .] they were developed but never used.” As described by interviewees, in 2003 and 2008, the SWMA created solid waste plans; however, due to political turnover and the debt crisis, neither plan was successfully implemented.

The Puerto Rican central government has also attempted to create financing mechanisms to fund solid waste programs. Interviewees explained how a fund was designated to support practices to recycle tires. Interviewees described that, in Puerto Rico, there is a tax placed on both the customers buying the tires and the businesses distributing the tires. Once the material is at the end of being used, there should be money under the EQB, now DNER, to export the tires off the island since there are no facilities on the island capable of processing the material. However, interviewees expressed concerns that there are no funds available regardless of the tax and that tires have become a significant problem on the island. One advocacy interviewee stated, “right now we’re seeing a really big tire problem. Now we’re seeing tires stacked up to the roof at tire changing places, clandestine landfills and municipalities are starting to have to pick up tires because the problem is getting big.”

In terms of support, some interviewees expressed that, up until the early 2000s, the SWMA gave municipalities material resources and supported municipal recycling programs. Interviewees discussed that municipal governments are required to have a recycling coordinator. Some interviewees expressed that training by the municipalities for the coordinators is minimal. According to one waste business interviewee,

They don’t even know what they’re doing most of them, and we tend to keep giving them some feedback and training on what they should concentrate on and what they should do because they’re usually like the political price. ‘You help me in the campaign, so I’ll put you as a coordinator.’ But they don’t really, most of them, they don’t really know what they’re doing.

However, interviewees referenced the support of the non-profit, Coalición Coordinadores de Reciclaje Municipal (CCOREM), which acts as a unifying and training organization for the municipal recycling coordinators. According to interviewees, this group has held regular seminars to train coordinators and acts as a support group to improve their programs and identify new markets for recycled products.

Interviewees explained that recycling behavior and education in the municipalities at the residential level is a significant issue. Interviewees pointed out that there is a high level of contamination, where people do not segregate their household recyclables. One waste consultant interviewee highlighted that Puerto Rico has an aging population and that many of Puerto Rico’s residents were alive during Puerto Rico’s industrial push between the 1950s and 1970s. During this time, cultural norms and products shifted from a reuse culture to a non-reuse culture and consumption levels increased, but residents’ education related to waste disposal habits never changed.

Interviewees also expressed that, currently, only a handful of municipalities on the island have strong recycling programs at the residential level. One interviewee representing a waste business said, “I do not see much enthusiasm either in doing new things or in educating. There is no promotion and education and communication plan aimed at anything.” Interviewees discussed that many municipalities do not have the money to invest in recycling programs or choose to invest in higher priority areas. Due to the lack of personnel and resources at the central government level, some interviewees expressed that municipal governments are the only entity supporting recycling programs on the island.

A waste consultant interviewee added that central government bureaucracy dealing with permits can discourage and stop new initiatives from developing at the municipal level.

3.2.3. Non-Governmental Stakeholders' Interventions and Challenges

Stakeholder groups that work outside of government, such as advocacy groups and businesses, have played an important role in diverting recyclable materials away from the island's limited landfills and dumpsites. Some interviewees explained that private recycling companies are the entities that pushed recycling in the beginning and that have kept the existing programs going. A waste business interviewee added,

The private companies were the ones that were pushing the issue because recycling is a good business if you do it well, if you do it the right way. Private companies [. . .] started pushing the issue and went into the municipalities to start programs.

Another interviewee from another waste company stated, "who has driven recycling in Puerto Rico has been small and medium-sized recycling companies".

One recycling incentive program implemented by the solid waste company ConWaste was conducted in the municipality of San Germán, where residents were charged for regular waste collection, but not for the collection of recycling, to promote a higher recycling rate. According to an interviewee, this program had a high success rate of between a 43 and 44% recycling rate; however, incoming Puerto Rican politicians who ran on a platform to stop waste collection fees terminated this program when they took office. Another interviewee, in a follow-up response, highlighted that this program created an economic disadvantage for larger families who produced more food waste since this organic matter was not being separated from general landfill waste.

Interviewees identified glass as one significant problematic material on the island. Though Puerto Rico once had a glass recycling facility, according to interviewees, that facility had to close due to financial problems, especially since recycled glass received a lower profit compared to #1 (PET-Polyethylene Terephthalate) and #2 (HDPE-High density polyethylene) plastics. Though a few plants on the island use glass as an additive to produce concrete, most of the glass is not recycled and is sent to the island's waste disposal facilities [6]. According to one interviewee representing the EPA, when the glass factory indicated it would be closing, the director of the SWMA went to the governor's office to ask for subsidies to keep the facility open. Unable to receive government funding, the glass recycling facility closed. The same interviewee also discussed that Puerto Rico used to have a scrap metal recycler on the island that recycled metals into construction materials. Additionally, there was a tire recycling center that used to shred the tires and resell the recycled material on the island. However, all of those facilities have since closed. According to a waste consultant interviewee,

If the government will establish an incentive for different factories to come to Puerto Rico, we will be able to recycle more, and for our landfills not to suffer so much. But the government doesn't give any kind of incentive to companies and industries that will establish themselves here and help us recycle glass or recycle other types of plastic, like we only recycle #1 [PET-Polyethylene Terephthalate] and #2 [HDPE-High density polyethylene], which are the main ones, but, you know, there are many plastics that can be recycled and can produce different kind of products that can be used in Puerto Rico and if the government will give incentives to those companies or factories, we will be able to recycle much more.

Interviewees also described solid waste advocacy groups as pushing circular economy initiatives such as efforts to unify stakeholders across sectors or hosting events that promote recycling and compost education. However, some interviewees perceived a decreased physical presence of these organizations' activities in the last few years. Though some interviewees perceived a strong online presence by these groups, advocacy organization personnel such as employees or volunteer activities were perceived as decreasing. Advo-

cacy organization interviewees also perceived a decrease in support of human and material resources from the central government in the last few years. A few waste consultant interviewees also described efforts to promote a circular economy, such as through assisting in compost initiatives and working with Puerto Rican politicians to promote recycling efforts in the Puerto Rican Congress. However, some of these interviewees also described a decrease in program initiatives.

Interviewees also identified the current challenges regarding the recycling and compost sectors. One advocacy organization interviewee discussing infrastructure challenges related to collection stated,

I recycle in my house and sometimes I have up to a month's worth, because before I had a recycling center near me and they took it, so now I don't have any recycling center here. The biggest challenge is to have a recycling infrastructure that works so that citizens and companies can carry out effective recycling.

Another major challenge discussed was the lack of businesses within Puerto Rico supporting the circular economy. One interviewee from the University of Puerto Rico stated that one issue is,

In Puerto Rico, we have the law, etc., but really, we don't have the market for that. We pick up the material and we send them to China, 90 percent of the material that we collect in Puerto Rico, was delivered to the United States and from there to China.

Another waste consultant interviewee explained the high costs of running a recycling plant, such as costs for electricity, and added that another challenge is the "lack of incentives from the government at a central level. Incentives to stimulate the development of the recycling industry." Interviewees also described the numerous barriers of entry that currently exist for recycling and compost businesses, including problems dealing with legislation and permitting. A waste consultant discussed the issues with policy implementation, saying,

Last year they entered Law Number 60, Puerto Rico's incentive code and included partial and total recycling activities for the granting of incentives from the Department of Economic and Commercial Development. That is to encourage the creation of new industries, but we have one problem, that's that we have a lot of regulations, a lot of things, but they're not being implemented. We must create a culture of recycling in the country [Puerto Rico]. And of course, a government policy that is proactive. That is an urgent matter.

Another waste business interviewee described how the lack of enforcement behind recycling policies is restraining the recycling sector's growth due to the lack of demand for recycling businesses. The interviewee stated, "there is no enforcement. Since there is no supervision, for so much, there is no fine, nor punishment. Whether you do it right or wrong, nothing happens. And that's been the main constraint on growth."

4. Discussion

The findings above show that stakeholders within Puerto Rico attempted to create reinforcing feedback loops within policies and stakeholder dynamics in the 1990s regarding sending less material to the island's waste disposal facilities along with decreasing the number of open dumpsites on the island. In the following discussion, we reflect upon our findings to observe why and how these feedback loops have transitioned from reinforcing to balancing feedback loops, defined in Section 1. According to Meadows (2008), "When one loop dominates another, it has a stronger impact on behavior. Because systems often have several competing feedback loops operating simultaneously, those loops that dominate the system will determine the behavior" [3] (p. 44). Our discussion will explore these counteractive and competing feedback loops that have occurred over many years within the solid waste system in Puerto Rico. Recommendations are made on how reinforcing feedback loops can be retained to accomplish Puerto Rico's waste management goals.

4.1. Feedback Loops Relating to Enforcement at EPA-Compliant Landfills

Meadows (2008, p. 34) discusses that feedback loops and systems thinking use a holistic perspective, saying, “You’ll stop looking for who’s to blame; instead you’ll start asking, ‘What’s the system?’” The concept of feedback opens up the idea that a system can cause its own behavior.” In the case of Puerto Rico, the central government began trying to influence the behavior of the solid waste system in the 1970s, starting with efforts to stop open burning and dumping into waterways. This began a complex history between island residents, municipal governments, the territorial central government, and the federal EPA. As Meadows (2008) says, this system has continued to cause its own behavior where every piece has a part to play.

“Vicious” reinforcing loops that stall the progress of closing open dumpsites within Puerto Rico are seen at different government levels occurring over several years. As discussed, the federal government has struggled with pushing enforcement of landfill regulations within Puerto Rico due to different factors over many years. This reinforces the unsustainable economic structures and incentives that dumpsites promote on the island. A major balancing feedback loop caused by the central government took place over multiple years, where, initially, central government funds were given to municipal dumpsites to close, however, a few years later, the central government changed landfill regulations on the island, which promoted the use of dumpsites.

Complex stakeholder dynamics at different government levels causing balancing feedback loops relating to landfill closure enforcement were also described. Tensions between the central government and municipal governments led to a lack of enforcement by the central government, which led to the federal government enforcing regulations at the municipal level. This is where the “vicious” reinforcing feedback loop can be seen as starting again at the federal level, where interviewees reported the federal government not having the ability to enforce those closure orders within Puerto Rico. These complex stakeholder dynamics and policies can therefore create a balancing feedback loop over several years, where counteractive feedback loops ultimately stall progress within the solid waste system.

Interviewees also described “vicious” reinforcing feedback loops related to economic structures for landfills and dumpsites. Meadows (2008) discussed limiting factors within a system. One limiting factor described by interviewees is the amount of money needed to pay for tipping fees at EPA-regulated landfills and the finances needed to pay for municipal recycling programs. A tipping fee is the general term used to describe the fee that is paid to a facility to accept discarded material in order to pay the operating costs to manage it. Another issue related to money was that dumpsites charge cheaper fees than their competitors to gain business, creating a “race to the bottom”, as stated by one interviewee. The island’s finances and disposal costs lead to complex feedback loops. For example, the cheaper landfill tipping fees are, the fewer recyclable materials are sent to recycling businesses that are more expensive. The less business recycling companies receive and, in turn, suffer financially, the less those services exist, and more waste is sent to landfills and dumpsites. This chain of events reinforces more disposal and less recycling, recreating the problem indefinitely. While, from an economic standpoint, municipalities see cheaper dumpsites as the best financial option, those dumpsites quickly fill up, creating less space and remaining time for Puerto Rico’s waste disposal facilities. Once waste disposal capacity has run out, this could cause municipalities to have to pay for very expensive waste management options. Therefore, as will be discussed in Section 4.3, the central government needs to increase enforcement power to close dumpsites while simultaneously supporting the circular economy, such as through incentive programs to decrease costs for all stakeholder groups.

4.2. Feedback Loops Relating to Stakeholders and Financing in the Circular Economy

Interviewees described that, during the 1990s, the central government attempted to create a reinforcing feedback loop for the recycling and compost sectors by creating

more businesses to support the sector. During this time, the central government gave grants that fostered the growth of different waste management businesses that exist today. The central government also gave material resources and support to municipal recycling programs and advocacy organizations. Therefore, the central government was focused on creating strength within the circular economy through pluralism by engaging and supporting new and existing stakeholders within the circular economy to act as a curtailing mechanism to reduce waste going to landfills. According to Acemoglu and Robinson (2012), pluralism is where a broad coalition of stakeholders becomes empowered and can push reform. However, at that same time, policy changes were being made to cheapen dumpsite facility tipping fees, described in Section 4.1. These decreased dumpsite tipping fees directly incentivized disposal in waste facilities instead of materials being given to the businesses that the government spent money on trying to create. As reported in the findings, according to an interviewee, of the nine recycling businesses that were funded by the central government, only one of those still exists. This speaks to the counteractive interactions of these policies and initiatives being implemented around the same time.

As described in the findings, the central government has stopped focusing on pluralism in the solid waste sector over recent years. Due to Puerto Rico's economic situation, the central government has faced significant budget cuts, which have decreased the number of personnel and programs. However, by the central government decreasing support to stakeholders within the circular economy, it has created a "vicious" reinforcing feedback loop that has caused the past investment of planning and financial resources to be in vain, ultimately causing a balancing feedback loop over several years. The findings also provide evidence of the barriers to entry, such as permitting regulations for new and existing businesses, that have curtailed pluralism and created a stifled circular economy sector.

As will be discussed further in Section 4.3, as in the 1990s, the ability of the central government to support stakeholders in the circular economy through human and financial resources creates a "virtuous" reinforcing feedback loop that facilitates stakeholder involvement, such as recycling businesses. By the central government empowering and supporting more stakeholders, it will create an inclusive political and economic institution where,

inclusive economic institutions are [. . .] supported by and support inclusive political institutions, that is those that distribute political power widely in a pluralistic manner and are able to achieve some amount of political centralization so as to establish law and order, the foundations of secure property rights, and an inclusive market economy [28] (audiobook timestamp 16:30:45).

As discussed in the findings, private businesses began to push recycling practices at the municipal level in the absence of government support. In the last few years, the waste business ConWaste, in one of the municipalities, began a residential program based on incentives to promote household recycling. This program created a "virtuous" reinforcing feedback loop and pushed the residential recycling rates above the island-wide 35% goal. However, with a lack of compost programs or organic waste recycling incentives, the program caused economic disadvantages to large families and was completely stopped by incoming politicians. In doing so, counteractive interactions took place, stopping a reinforcing feedback loop and creating further stagnation of policies and practices in the solid waste sector. This shows the impacts of the lack of pluralism in Puerto Rico within the solid waste sector. Because there were not enough stakeholders supporting organic recycling efforts such as compost businesses or programs supporting these businesses, the abundance of food waste ultimately harmed non-organic recycling efforts, stopping a pilot program aimed to attain higher recycling rates.

One reinforcing feedback loop that was observed in the findings dealt with institutional financing mechanisms. As explained, policies were in place in the case of the tax fund for tires to empower institutions that could regulate and support an inclusive "virtuous" reinforcing feedback loop and send less waste to the island's waste disposal facilities. However, these funds were used differently and never went to the institutions supporting

sustainable waste management. In addition, there were funds that could have been spent in other productive ways, including the spending on the construction of central government-managed facilities. As interviewees reported, the Solid Waste Management Authority invested in physical infrastructure that was built and never used. Additionally, planning and financial resources were used to create a solid waste plan for the island in 2003 and 2008, yet these plans were ultimately never implemented. Money in these efforts is part of the reinforcing feedback loop that has occurred over many years that limits the central government's current capacity and available resources to support other programs that could have been more sustainable.

4.3. Recommendations for Drifting towards a “Virtuous” Reinforcing Feedback Loop

Acemoglu and Robinson (2012) use the word “drift” to symbolize the time component of an institution's transition to a new direction and that these new directions could take many years to become fully implemented. Puerto Rico has implemented measures that have started its drift towards sustainable solid waste management. However, within the past few decades, initial efforts have decreased or been stopped by counteractive measures that have led Puerto Rico's solid waste system behavior to become stuck in a balancing feedback loop. The system is now stagnating, as can be a tendency of system behavior [21]. Many efforts by stakeholders to push Puerto Rico in the direction of a circular economy by taking advantage of critical junctures, described in Section 1.1.3 as important moments in time that directional change can occur, have been undermined, not allowing Puerto Rico to “drift” as quickly or as successfully into a “virtuous” reinforcing feedback loop. Critical junctures have been described above, such as the closure of dumpsites to meet EPA-compliant landfill regulations in 1994, as well as the 1992 recycling goal and initiatives that followed. The DNER \$40 million grant is another potential critical juncture, where the solid waste system and the institutions operating within it can use this opportunity to drift again in a progressive direction. However, this time, stakeholders have the opportunity to create “virtuous” reinforcing feedback loops within stakeholder dynamics and policies that could keep Puerto Rico on track to obtain its goals.

One of the ways this can be done is through pluralism. From a systems perspective, the creation of pluralism is done through the promotion of a broad coalition of stakeholders participating in a sector or institution, which causes sustainable reinforcing feedback loops [14–16,28]. Therefore, it is critical that the central government gives opportunities to business start-ups in the recycling and compost sectors, decreases present barriers of entry, and supports existing initiatives by stakeholders through human, material, or financial resource support. Pluralism will also make the solid waste system less vulnerable to external events such as natural disasters or financial crises. According to Meadows, “A diverse system with multiple pathways and redundancies is more stable and less vulnerable to external shock than a uniform system with little diversity” [3] (p. 3).

Hence, if the Puerto Rican government can strategically invest in a broad coalition of stakeholders with human and material resources, the behavior of Puerto Rico's solid waste system can move past its stagnation, lift out of its balancing feedback loop, and once again begin to “drift” toward a “virtuous” reinforcing feedback loop within the solid waste sector. According to Acemoglu and Robinson (2012), “History is not destiny” [28] (audiobook timestamp 16:25:27). If Puerto Rico can take advantage of the large grant given to the DNER, it can empower stakeholders in the circular economy and decrease the burden on its limited landfills and dumpsites.

A central government needs to have a sufficient amount of presence to hold enforcement power to implement regulations and direct economic activities, defined as centrality [28]. According to Wilson (2007), within the solid waste management sector, “there seems to be general consensus that weak institutions are a major issue [. . .] so that institutional strengthening and capacity building becomes a major driver” [20] (p. 203). Therefore, it is vital that DNER employees feel empowered, united, and motivated to conduct job responsibilities properly. Additionally, all government employees, including at

the federal, central, and municipal levels, should invest in initiatives to increase these enforcement capabilities. For the central government to use this money to stop the stagnation of the solid waste sector, both pluralism of stakeholders within the circular economy and the strengthening of the centralization of the central government need to be created and supported.

Solid waste management within Puerto Rico can be seen as a wicked problem, forever evolving due to internal and external pressures. In terms of governance strategies, in order for the DNER employees to assist Puerto Rico's transition out of the solid waste system's stalled balancing feedback loop, the agency needs to implement the governance practices, especially revitalization, discussed in Section 1.1.3. Revitalization will allow the central government employees to change the policies and practices in place that create the island's "vicious" reinforcing feedback loops that have ultimately caused the system to be stalled in a balancing feedback loop.

Wilson (2007) [20] stated how countries attempting to improve solid waste management, especially with facility development, need to gradually improve policies and requirements. Therefore, it is recommended that the DNER also invest in pilot studies with infrastructure or programs so as to give time for reflection of improvements and not to use resources inadequately. Similarly, just as Termeer et al. (2015) [26] described observation as an essential dimension, Meadows (2008) [3] also has recommended reflection and observation of past system behavior to make improvements. She states,

That calming down may provide the opportunity to look more closely at the feedbacks within the system, to understand the bounded rationality behind them, and to find a way to meet the goals of the participants in the system while moving the state of the system in a better direction (p. 114).

Therefore, the DNER needs to conduct in-depth research on what has already been attempted and find out what did not work and why. It is recommended that the DNER conduct quantitative research, such as through economic analysis, and qualitative research, such as focus groups, to learn how to avoid past missed opportunities. For example, if the DNER plans to construct more facilities, as was done with previous grant money, then the agency's employees need to recognize why those facilities were never operated so as not to repeat the wasting of planning and financial resources. With the remaining \$27 million of grant money, the DNER has an extraordinary opportunity to implement practices to change the balancing feedback loop of the solid waste system, but only if the DNER does the research to understand past efforts and attempts. Future research regarding potential pathways for solid waste management in Puerto Rico could also include interview and survey work with the public or waste generators to gauge feedback and experiences of consumer perspectives. It is critical that the DNER does not repeat history with wasted money or time, which the island's disposal facilities no longer have.

5. Conclusions

This paper explores the policies and stakeholder dynamics that impact the behavior of the solid waste system within Puerto Rico. The paper finds that, through the interactions of reinforcing "virtuous" and "vicious" cycles, progress in Puerto Rico's solid waste system has become stagnant. This paper makes a unique contribution to the academic literature by integrating a historical approach into a case study focused on stakeholder dynamics and policies within solid waste management that have created the current system's behavior. By highlighting the historical context of stakeholder dynamics and policies within the solid waste system in Puerto Rico, we are able to analyze the explanatory mechanisms and understand why the system's behavior is stalled within a balancing feedback loop. Unlike other sources, we use a holistic perspective to understand how feedback loops interact over several years to cause these larger system outcomes. The findings also show that, to push the solid waste system out of stagnation, the central government can reflect and make changes with the money from the EPA Community Development Block Grant. We recommend that, in order for the system's behavior to transition from a balancing

feedback loop to a “virtuous” reinforcing feedback loop, both pluralism of stakeholders in the circular economy and the centrality of the DNER, defined as the strength to conduct its responsibilities, need to be supported.

Creating opportunities for circular economy business growth and development will add diversification and a broader coalition of stakeholders. This will make the solid waste sector less vulnerable to system shocks and will create reinforcing feedback loops within the circular economy by allowing stakeholders to become engaged and empowered. We recommend that the central government uses the \$40 million grant to support the growth of a broad coalition of stakeholders in the waste management sector through incentivizing the creation of new organizations while supporting existing stakeholders. We also recommend that the central government increases its own centrality by improving its ability to enforce solid waste management regulations. Lastly, we recommend that the central government researches and reflects on past efforts to improve Puerto Rico’s solid waste system before deciding how to spend the grant money.

As the DNER has already done, outlining plans for employing more DNER staff and providing better support to existing employees is key to improving the agency’s centrality and enforcement capabilities. However, it is important that the agency finds long-term sustainable solutions to its current centrality challenges so that the money designated to hire and invest in new employees is not a wasted resource, as has been the case with other funding opportunities. As islands and other contexts struggle to change the behavior of solid waste management systems, it is important that research is used that explores feedback loops using a historical lens to better understand what has already happened to improve future practices.

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