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Driving Municipal Recycling by Connecting Digital Value Endpoints in Smart Cities

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Abstract: Uncontrolled global economic growth at any cost is having palpable and general consequences for SC (smart cities) environments and sustainability worldwide. The current economic growth model is, according to experts, decidedly unsustainable, and if urgent measures are not taken, the quality of life for future citizens will decline. In the search for solutions that would make cities sustainable, the deployment of the ICT factor is playing a decisive role. However, in its role as a driver, the ICT factor needs to increase the numbers of value endpoint connectors by incorporating citizens, corporations and institutions into city decision-making, thereby becoming a real integrative tool that achieves sustainability and is more than merely a tech flag. In this sense, the present paper proposes that the digital and programmable economy as an ecosystem should become a sustainability city driver because it facilitates the integration of different value endpoints in order to work in the same purpose, allowing, for example, increased sustainability levels in cities such as improving municipal recycling. This paper will apply ICT and digital concepts, the environment-social-economy model and fuzzy logic methodology.

Keywords: IoT; digital assets; programmable economy; blockchain; value; sustainability; smart cities; recycling

1. Introduction

In recent years, starting with the Kyoto Protocol [1] and including the Paris Agreement COP21 [2], there has been an increasing awareness of issues related to climate change and the sustainability of the planet. To put the dimension and scope of these phenomena into a global context, it is estimated that the cost and risk of inaction towards the global economy could reach 5% of the planetary GDP each year, reaching up to 20% total. This situation could be reversed if only 1% of the global GDP were invested in activities that mitigated climate change each year [3]. Moreover, the effects of globalization in all its extremes have spread. The Western way of life and set of socialized needs have spread throughout the five continents, encouraging developing countries to imitate the lifestyles of the developed nations. As a consequence, according to experts, if the effect of technology on development is maintained constantly, between 1.5 to 8 planets similar to Earth would be needed to offer the same level of quality of life and to supply all the new consumers at the same pace as that which exists in developed countries [4].

These developments are forcing different social and economic agents to reconsider the need to make drastic changes in productive processes and in citizens' consumption habits due to the ecological and physical limitations that these developments impose both globally and locally, thereby inviting the questioning of the current and future welfare model. In this sense, SCs (smart cities) are not alien to this transformation, and their future will require measures to strengthen the sustainability of cities.

If the current trend continues, there is a strong possibility that these cities will be unable to support a minimum level of well-being for their future citizens [5].

To try to reduce this imbalance, cities will no doubt become increasingly unique players in promoting sustainability, since they constitute an important center of origin and a destination for many of the negative externalities that are affecting the sustainability of the planet. In searching for solutions, it should be noted that countries and SCs themselves cannot focus their efforts on a single discipline or address the new challenges solely and exclusively from a technological point of view. Promoting sustainability requires an interdisciplinary approach to help understand the problem of sustainability for the subsequent formulation of solutions because there are important interconnections between elements that exist beyond the technological ones that need to be put into context to achieve a truly sustainable transformation. These solutions must include the design of holistic and integrated policies, taking a step beyond pure coordination with more transversal approaches [6]. Undoubtedly, the deployment of technology and digital transformation will play a key role in SCs as a backbone of multidisciplinary integration.

Although there is no definitive consensus on the idea of SC, there seems to be approval regarding the relevance of this term and the use of technology in cities. This deployment of technology is noted because there is growing pressure to improve the efficiency of cities and reduce negative spillover effects, while promoting aspects related to human capital [7,8]. It seems clear that the impact of ICT on better city management is having a transversal impact on all agents [9]; however, there is a set of "soft" factors, such as citizen participation, collaboration and reward, that are associated with the objectives of managing resources better, improving services offered and encouraging innovation, and all of these factors result in an improvement of well-being [10,11]. In this way, SCs are moving forward from phase 1.0 (ecosystem connectivity) to phase 2.0 by intensifying the decision-making process through the involvement of all actors (government, corporations and residents) that have a role in it, with the aim of improving quality of life, increasing competitiveness, promoting sustainability and creating open and inclusive platforms [12–14].

Despite the expansion of technology in society, it is worth wondering if the development of the SC is a sustainable pattern. The answer is directly related to the existence of a delicate balance between the concept of a citizen's standard of living, understood as an acceptable minimum level of well-being, and the set of distortions that maintaining this level causes in the form of negative spillover effects. Formulas for maintaining this sustainable balance involve great concepts, such as citizen education, corporate initiatives, government intervention, stakeholder involvement, finances and their potential to solve negative spillovers [5].

The consequences of reaching a citizen's standard of living are varied. One of them has its origin in the failures of the market and of policies that determine the prices of products and services in SCs without incorporating the spillover effects that the consumption of these products and services have on sustainability. It is in these urban spaces or in their peripheries where most of the said products and services are generated, exchanged or consumed and where the negative externalities that these consumptions imply take place. Therefore, to achieve a balance between the citizens' standard of living and the consequences of maintaining that standard, it is necessary to minimize these market failures by incorporating new approaches in urban management that take into account the most negative consequences of decisions on the sustainability of the urban ecosystem (negative spillovers) and that reward those decisions that benefit sustainability (positive spillovers).

Technology and digitization are playing a decisive role in alleviating these failures and increasing urban sustainability. This impact can be accelerated if the deployment of technology is combined with other key factors, such as those related to urban political decision-making aimed at sustainability, with measures that reinforce citizens' behavior and the activism of corporations towards a sustainable strategy, among others. This is when technology achieves its maximum potential as a true integrator vehicle for connecting all these value endpoints (institutions, citizens and corporations) in the same direction more agilely and efficiently. This new combination of technology and key factors seeks to alleviate or solve the different unsustainable facets that occur in an SC, with one of these facets being the municipal recycling issue.

The first objective of this paper is to highlight the importance of the digital and programmable economy (PE) as a tool, an integrator, and an efficient vehicle for managing externalities and improving cities' sustainability by connecting endpoints. This concept opens up new SC management possibilities and is becoming a key element in formulating future SC sustainable strategies, more so if one considers the vertiginous acceleration of negative spillover that occurs in them, for instance, household waste recycling.

The second objective of this paper is to emphasize the need to focus on the treatment of current and new threats to SCs from a more holistic and inclusive point of view, considering the vital importance of the role that institutions, citizens and corporations will play in the search for new sustainability solutions. To face the great challenges ahead, the SC of the future will need to reinforce and promote the active participation of the citizen and of corporations by using the aforementioned opportunity offered by ICT in its different aspects.

To elucidate this subject, an exploratory approach to urban recycling is proposed using the environment-social-economy (ESE) framework and fuzzy logic to present a new waste recycling model that uses an inference algorithm that makes it possible to simulate the level of expected municipal recycling in a city based on the combination of the aggregate factors that are developed in this study. These aggregate factors include the city recycling policy, citizens' recycling reinforcement, corporate sustainability activism and the digital economy. The goal is to find a balance between these inputs in such a way that the municipal recycling rate can be increased by deploying the programmable economy (PE) as a value endpoints backbone integrator.

In this article, the aim is to go deeper into the PE as an alternative means to addressing the problems arising from municipal recycling from a holistic point of view, integrating the concepts related to brand activism, environment policy factors, and citizens' behaviors, all managed by a digital and programmable economy allowing for sustainability value exchange among participants and the city's agents.

In this case, the methodology offered by the fuzzy set theory is used to visualize, based on the opinion of multidisciplinary experts and an inference algorithm that estimates how the recycling rate fluctuates for a set of SC, a better combination of SC inputs considering sustainability as a digital value that can be captured for social agents in order to make better decisions in the cities contributing to achieving more sustainable spaces

This paper is organized as follows. In Section 2, the theoretical background is described. In Section 3, the methodology is presented, followed by the results. Finally, Section 4 summarizes the most important conclusions of this paper.

2. Theoretical Background

2.1. Sustainability and Environmental Policy

The relationship between industrialization and its effects on the environment has captured the attention of economies and organizations throughout recent history. However, all the measures applied by the various online actors to alleviate these effects have been more reactive than proactive. It was not until the recent financial crisis of 2008 that we tried to offer another approach to alleviating these effects by balancing the various solutions, while considering the effects derived from resolving the crisis at any cost.

Historically, in searching for solutions, the side effects that increasing production and consumption create for the environment have been underestimated [5]. In other words, the economy and its agents have been living in a production and consumption bubble [15], without considering the negative spillover effects that this "modus vivendi" generates in the ecosystem. SCs are not strangers to this bubble, and it is necessary to take measures to contain and reduce it by incorporating solutions to the problems that result from the most sustainable SC strategies, bearing in mind that there are many disciplines that include development, globalization and economy or social justice. The concept of sustainability must include other interdisciplinary vectors, such as technological, organizational, institutional and innovation, and its treatment requires both top-down approaches through the intervention from governments with large-scale actions and bottom-up measures through intervention from society with smaller-scale, but more effective, actions [5]. The problem of sustainability is the result of individual and collective human behavior; therefore, this problem cannot be exclusively treated as an economic or technological problem without considering the set of mechanisms that intervene in these behaviors [16].

The sustainability problem is addressed from the SC point of view, because although cities are generators of positive externalities in that they have played a key role in the development of humanity throughout history as centers for the exchange of information and collaboration, they are also generators of abundant negative externalities such as urban congestion, pollution and the associated environmental impacts [17] due to cities' consumption of 2/3 of the world's energy. In addition, cities are responsible for 70% of greenhouse gas emissions [18] and are generators of 12% of total global waste—the large volume of waste is generated in the so-called primary waste produced by various sectors of economic activity (agriculture, mining, quarrying, manufacturing, energy production, water purification and distribution, and construction)—77% of this waste originates in households [19]. Thus, there is no doubt that the importance of SC in the generation of negative spillovers is enormous. Following the trend, given that 55% of the world's population currently live in urban areas, the forecast for 2050 suggests that this percentage will reach 68% [20] and that all these negatives spillovers will only increase.

In the conceptualization of an SC, the vision of sustainability is also included as an important aspect of its development [21]; the term "smart environment" has even been coined as a necessary ingredient of an SC [22]. The concept of a sustainable city should be understood as a nonstop process in which the exploitation of resources, investments, technological development and institutional initiatives are consistent with the current and future needs of citizens [23]. These needs must be linked closely to the premise that it is the administrations themselves that have the responsibility to envision that future and establish what are the tolerable limits for their city. This responsibility implies the reformulation of sustainability in terms of knowing its effects on the ecosystem at a global level and not only in a particular situation, and with a long-term time horizon that goes beyond only satisfying the interests of current citizens. In other words, an SC needs to determine the levels of support or the tipping point (a point beyond which it is extremely difficult if not impossible to reverse the current trend of a city, regarding such issues as climate change and its effects on health) to which it is subject, so that it does not overshoot points or create situations in which the limits of the system are inadvertently exceeded and that are practically impossible to reverse [24].

The term "sustainability" establishes the need for a balance between aspects related to economy, citizenship and the environment in an SC [25]. Placing a particular focus on the environment, a smart and sustainable city has goals, such as addressing climate change and environmental issues, to be achieved in an adaptable, reliable, scalable, accessible and resilient way by providing an effective regulatory and local governance mechanism that ensures equitable policies that include the four attributes of the smart and sustainable city: sustainability, quality of life, urban aspects, and intelligence [26]. Alternatively, some scholars develop a similar concept, the smart-eco city, which proposes that the city should be ecologically healthy (by using advanced technologies and having economically productive and environmentally efficient industries), have a responsible and harmonious systematic culture and have a functionally living landscape [22].

To carry out this sustainable development, developing and developed countries and cities try to find new formulas for managing their negative externalities. For example, it is known that waste generation is closely related to population and urbanization, and there is a correlation between waste generation and GDP per capita or per capita energy consumption [27]. Therefore, in most developed and developing countries, because of increasing population, prosperity and urbanization, it remains a major challenge for municipalities to collect, recycle, treat and dispose of increasing quantities of solid waste. For example, we can see in Figure 1 that since 1990 (base 100), OECD (Organization for Economic Cooperation and Development municipal waste has continued to increase; the chart shows a stagnation that coincides with the recent crisis between 2008 and 2012, again registering an increase from 2013 [19].

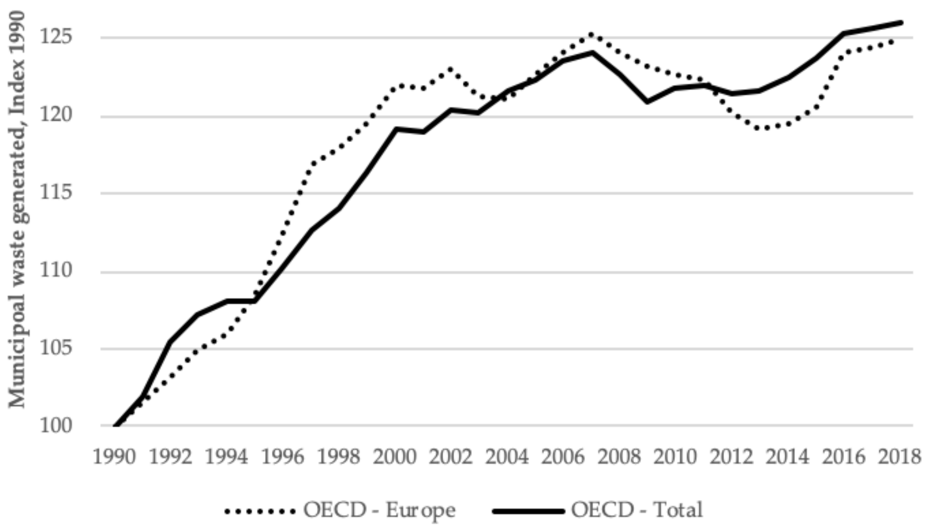

Figure 1. Municipal waste generated OECD [19].

In relation to waste generated, the United Nations draws attention to the basic concept of waste hierarchy. This concept has undergone several transformations, although it has always emphasized the set of strategies developed by countries and cities to minimize the amount of waste generated [28], as represented by an ordered pyramid. The basic premise is to avoid and reduce the generation of garbage by applying the 3R concept. The 3Rs (reduce, reuse, recycle) are meant to be a hierarchy, in ascending order of importance [29]. The aim of the waste hierarchy is to extract the maximum practical benefits from products and to generate the minimum amount of waste. The impression of minimizing waste in terms of extent or environmental effects, by reducing the quantity of waste, reusing waste products with simple treatments and recycling waste by using it to produce products is usually referred to as the "3Rs". Again, to put this into context, Figure 2 shows the behavior of OECD countries regarding municipal waste recovery and recycling for the year 2018 [19].

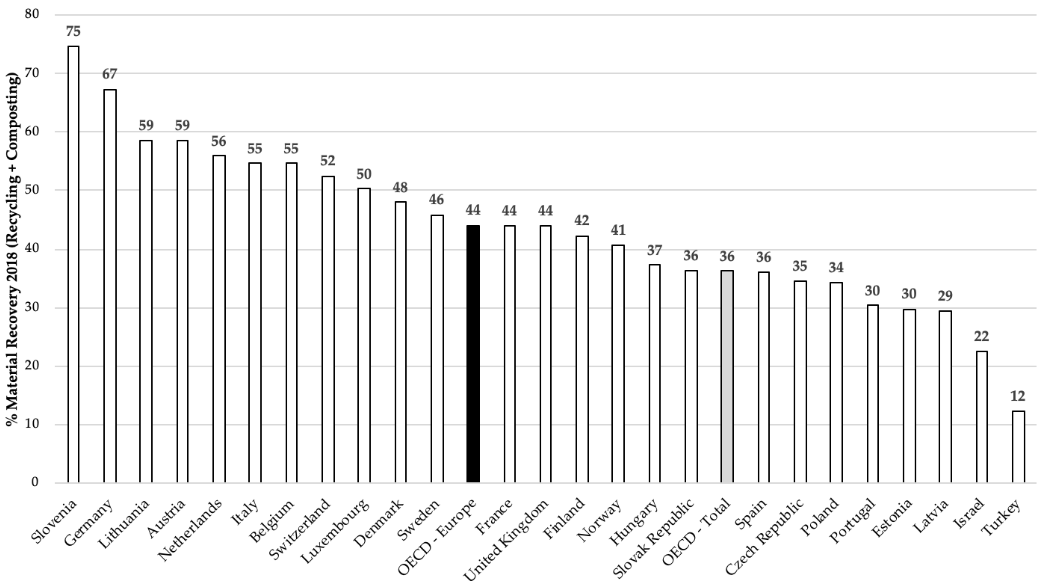

Figure 2. Percentage of municipal waste recovery OECD, 2018 [19].

As seen in Figure 2, although governments and local administrations have tightened policies towards greater sustainability by promoting the measures included in the 3Rs in cities, the average percentage of municipal recycling for OECD countries is a scant 36%. Therefore, the situation is far from satisfactory, since more than half of the waste generated in households is still outside of one of the key vectors of the 3Rs established by the UN, and there are great opportunities to improve the levels of the reuse and recycling of materials discarded by households.

2.2. Sustainable by Citizen Reinforcement and Corporate Brand Activism

Apart from the municipal sustainability policies, there are two big key players in the effort to improve SC daily base sustainability: citizens (consumers) and corporations. Focusing on human behavior, learning theory [30] and human reinforcement theory refer to the idea that stimuli can be used to produce desired behaviors. B.F. Skinner argues that the administrator only needs to understand the relationship between behaviors and their consequences to create conditions that encourage desirable behaviors and discourage undesirable ones. This appreciation could be used in recycling by city management to motivate citizens and corporations to support good recycling conduct and dissuade bad recycling conduct through positive incentives.

Several approaches have been made to promote recycling and prevent garbage generation [31,32]. The use of incentives in the form of reward or recognition to influence recycling differs depending on the type of reward, the target group in question and the value of the reward [33]. Thus, attitudes towards recycling vary according to whether individuals are recyclers or non-recyclers; low-medium recyclers perceive rewards more favorably than existing recyclers [34]. Furthermore, studies have revealed that the use of incentives to encourage recycling requires strong advertising campaigns that include a guide to recycling by local councils, public services announcements, and feedback cards [33]. Additionally, these types of initiatives require good planning and a well-developed and interconnected waste infrastructure to be successful [35].

Currently, corporations, to alleviate the growing problems of sustainability, are undergoing a transformation from engaging in cause marketing (corporate social responsibility) to engaging in brand activism (seeking to have an impact on the biggest societal problems) because the measures taken by governments and online institutions to reverse unsustainability are insufficient and because consumers demand greater involvement by corporations [36]. The definition of the term “brand activism” is presented by Kotler and Sarkar and includes “the set of efforts made by corporations online to promote, impede or direct social, political, economic and environmental reform with the desire to promote improvements in society” [36].

As society becomes aware of the environmental impact of the products and services it consumes, consumers and citizens are taking responsibility for their purchases and lifestyles. This tendency must be considered by companies to understand to what extent these behaviors affect their brands and the profiles of their consumers, reinforcing the sustainability attributes of their products [37]. Consumers increasingly expect not only the company but also the whole supply chain to be sustainable [38], and this constitutes a good opportunity for companies. Since transparency and authenticity are key in the digital age, corporations need to increase their sustainability responsibility, ensuring sustainability throughout their value chain from start to finish, including the consumer packaging journey and the household waste materials (recycling and reuse) with which they pack their products. This is a good example of how corporations operate responsibly.

According to Sheffi [39], there are four reasons why companies should embrace sustainability: (1) consumers and investors consider it important, and doing nothing could imply losing value; (2) in some cases, it can reduce costs (for example energy costs); (3) reasons of the cultural change type whereby younger people are more aware of the aspects of sustainability; (4) the potential problems that will be caused by the reduction of the resources available to companies because of global warming. Recent studies confirm that consumers increasingly demand more sustainability in the products they buy, with millennials, Generation Z and Generation X demonstrating more support for sustainability, and corporations are increasingly reaching agreements with manufacturing industries and governments online to reduce waste [40]. Thus, corporations must be increasingly proactive to make a better world because consumers expect their brands, which are increasingly authentic, thereby establishing a strong line of trust, to contribute to solving the major problems facing the planet. Corporations that implement a progressive policy of brand activism will also experience a significant impact on their sales [36]. Therefore, corporations can play a big sustainability role in the focus of SCs on daily base citizen routines. Corporations provide products and services to the citizens living in SCs, and corporate involvement in sustainable SCs must be proactive, embracing the entire value chain that their goods or services produce, including negative spillover effects, such as packaging recycling. In addition, the sustainability as a value and as a source of competitiveness for companies and organizations, is having substantial increase in the academic and business fields such as marketing, financial, management, economics, innovation, technology, or social corporate responsibility and so on, and is shared by many individuals, organizations and institutions who demonstrate the importance of this value including it in their present and future strategic plans [36,38,41,42].

The conjunction of these two measures, the sustainable corporation brand activism together with citizens' recycling reinforcement and institutional recycling policy, can decisively contribute to increasing the level of municipal recycling in the cities. However, these measures must find a facilitator and integrator route that unites endpoints; this is the technological vector. Currently, ICT measures, in some way, are contributing greatly to municipal waste management and increasing municipal recycling. However, considering institutional policy, citizen habits and proactive corporate activism as a basis, these ICT measures are not sufficient alone. In searching for a better resource combination, a municipal recycling solution could be accelerated through better endpoints management by digital technology and programmable economy (PE) as a backbone connecting citizens, corporations and institutions.

2.3. The Programmable Economy as an Integrator Backbone

There are two interesting approaches to the role of technology in economics and sustainability. One is anchored in the concept of substitutability [43] and the other in the idea of the Steady-State Economy (SSE) [44]. Solow's idea of sustainability is founded on the fact that technology can create high degrees of substitutability between one resource and another and implicitly indicates that nature and human-made capital are somehow fungible, arguing that essentially any kind of natural capital can be replaced by the hand of man. What is telling is that if resources are fungible, society has no obligation to protect those resources for future generations, and society is obliged to leave only the ability to create well-being without having to take resources into account. In contrast, Daly defends the idea that many of the resources that nature provides cannot be replaced by products or services made by human beings, arguing the first principle of thermodynamics, which is included in the SSE model, whose objective is to keep the throughput of a raw material (low entropy) and waste (high entropy) at levels within the regenerative and assimilative capacity of the ecosystem. Therefore, the neoclassical economic view sees growth as a continuous expansion, while the SSE model believes that the economy must be in permanent equilibrium with the ecosystem in which it operates [5]. Regarding these two approaches, it is important to say that the revolution of ICT technologies has the capacity to facilitate sustainable innovations by reducing the amount of materials and energy needed while stimulating the economy so that sustainability becomes a "chosen direction" by the agents; therefore, sustainability should not be considered as posing a dilemma between growth and sustainability itself but rather as an opportunity that needs to be taken into account [45]. In this way, the future of SCs requires facing this dilemma, regarding whether the natural goods that affect an SC in a broad sense can be substituted with goods made by the human hand through technology or if said technology can become a complement to promote the balance of the ecosystem.

Keeping the need to maintain the balance of the ecosystem included in SSE strongly in mind, we want to argue how the PE can contribute to improving this balance in the SC ecosystem by reducing the entropy that negative externalities generate, for example, a low rate of municipal recycling, increasing the connection and integration of the endpoint institutions, corporations and citizens that operate in them. However, in what way can SCs combine technological advances with citizen reinforcement, corporate activism and institutional policy to increase the municipal recycling rate efficiently, rapidly and transparently?

The PE will be the answer. The PE concept was introduced by Gartner in 2014 to refer to an intelligent economic system that supports and manages the production and consumption of goods and services, making possible new exchanges of value (monetary and nonmonetary) [46]. This exchange of value can be among some physical or virtual endpoints that fit to an edge. According to graph theory, the concept of endpoints is defined as nodes (things or humans with some value) belonging to an edge or relationship of some sort between two or more nodes and it may be tangible or intangible [47]. Thus, connecting valuable endpoints in the digital age means to join nodes or entities with some value (virtual or physical) using digital tools. The programmable economy looks forward, allowing that these endpoints can exchange this value between them by monetizing it in a trusted way.

The PE is supported through blockchain or DLT (distributed ledger technology), IoT (internet of things), monetization, a token economy, smart contracts, artificial intelligence and cryptography, thereby supporting new forms of value exchange, new types of markets and new forms of the economy. In this programmable economy, it will be the individuals and the smart machines that will define value and determine how exchanges will be determined through peer-to-peer transactions involving organizations and even smart machines and agents [48].

The PE permits the creation of new business models by combining the physical world with the digital one, allowing predictions regarding behavior to be made while changing the ways in which value is exchanged. The PE's implications include removing the middleman, imagining new ways of exchanging the value of the tangible and intangible between people and institutions, rethinking new forms of governance relationships, allowing greater automation by minimizing external oversight and decentralizing the economy, and managing information better. However, perhaps one of the greatest characteristics of the PE is the possibility of monetizing things and services by redefining the economy and the way in which value is exchanged between intelligent physical or intangible things between several actors, including corporations, citizens, and institutions [49], enabled by the second generation of the Internet, Web 2.0. The transformation of the web from an "internet of information" to an "internet of value" radically changed the operation of the economy and of institutions [50].

PE technology drastically reduces the cost of trust, allows us to imagine new business models and opens the possibility of deploying new forms of collaboration. As a source of trust, PE can expand corporations', institutions' and citizens' degree of digital transformation, whereby processes and objectives can be shared among all actors. All this is possible because this technology makes the information contained within it immutable, safe, shared and consensual [51].

On the other side, a PE by smart contracts or intelligent contracts, a concept attributed to Nick Szabo [52] in 1996, facilitates the agreement of individuals, organizations and institutions in such contracts over how they want their business or public services to be carried out consistently and automatically, keeping participant interactions recorded transparently at all times. This technology allows better decision-making between people and between machines without human intervention.

In addition, one of the most important characteristics of PE technology is that it allows the reduction, very consistently, of the so-called "transaction costs" defined in Coase's work, "The Nature of the Firm" [53]. These costs include the cost of organization, negotiation, information monitoring and coordination [54]; digital technologies can clearly reduce many of these costs. PE technology tends to reduce decisions and many coordination functions could be replaced by software, opening new institutional and corporation possibilities to reduce transactions, control, and monitoring costs and to provide the possibility of achieving more efficient data coordination.

Thus, PE allows a strong boost to municipal recycling by using IoT, DLT, smart contracts, tokens and digital wallets. If increasing the household recycling rate is desired, governments, by having a sustainable policy focus, can force corporations to monetize the potentially recyclable materials that they use in their products. Thus, they can add value to their token packs by incorporating virtually passive tokens in them. These pack tokens can be active after the human household recycling operation so that when citizens recycle their household bag into street recycling containers, a proof of work (PoW) is produced, and these tokens are activated, converting the potential intrinsic value of the recycled packaging into real value that is automatically transferred to the active subject's (citizen) wallet. The entire process can be produced in a decentralized way by the PE's supporting various elements, such as the blockchain or DLT, the wallets, and the signing of smart contracts between citizens, corporations and the administration, as shown in Figure 3.

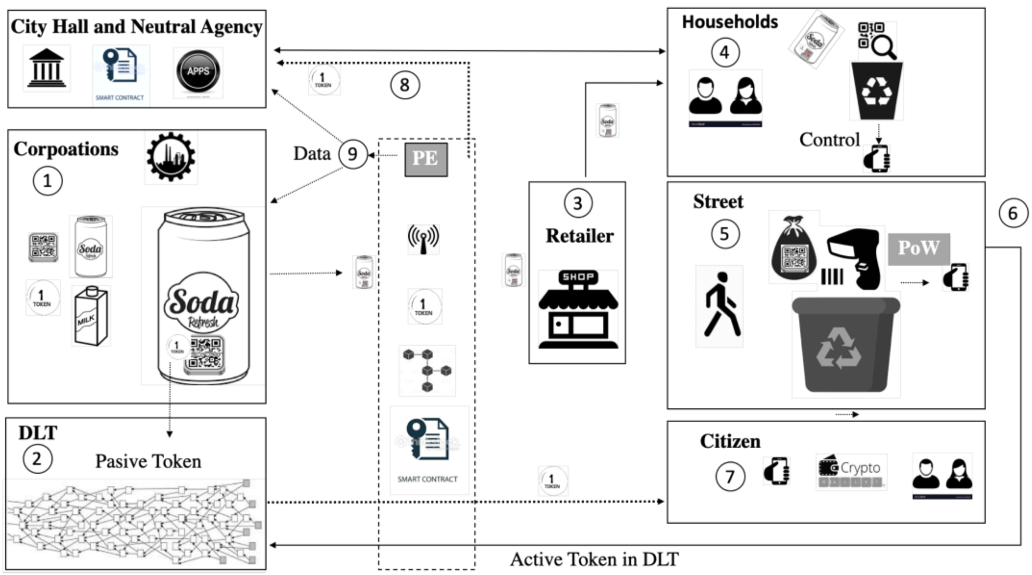

Figure 3. Waste recycling proof of work (PoW) (the authors).

In other words, the mechanism would be composed of the following steps. Step 1: Corporations, to increase municipal recycling, can integrate a passive recycling token into their packs in their production process. Step 2: This token is automatically registered in the DLT remaining in passive mode or stand by. Step 3: Product arrives at the retailer making the sale as usual. Step 4: Consumers in their home after the act of consumption, deposit the empty package in the household recycling container, previously scanning it in such a way that the deposit of the various recycled packaging is accumulated in their household container scan. Step 5: Once the household packaging is accumulated, the citizen deposits the bag of packaging to be recycled through the recycled packaging bag, in the street special recycling container (paper, glass, plastic), which contains a summary of all packaging by type that consumers have recycled separately. Here, the PoW is produced, converting the passive tokens to active tokens by transferring individualized package passive tokens into active tokens through the citizen wallet through the PE (steps 6 and 7). Step 8: City hall (or independent administrator) receives a fraction of each activated token to deal with the necessary infrastructures required by the total system. Step 9: Finally, corporations and municipalities receive aggregate information on recycled products through street containers, maintaining citizens' privacy at all times. These data become the core. In this process, corporations advance the economic value of the final data that they will obtain by recovering the cost in the form of aggregate consumer information while maintaining the households' privacy. This information can be very valuable to corporations because it constitutes a reliable proof of work of recycling and household consumption, allowing them to direct promotion activity towards selling and recycling. After that, citizen token income can be exchanged for public transportation discounts, payment of local taxes, or sustainable commerce coupons, or users can exchange the income for fiat money with minimal human interaction. Additionally, city hall income can be reinvested directly in maintaining and constructing new city infrastructure.

Therefore, PE by externality monetization enables the possibility of deploying the digital asset concept (a digital asset market representing physical assets, such as recycling packages in cities). In other words, through PE technologies, it is possible to create a new city household recycling strategy that motivates citizens through positive incentives and motivates corporations in recycling brand activism by allowing them to exchange tokens for data. Additionally, the PE, as applied to institutional administration, becomes an excellent technology for governance, decentralization and information systems. All of the above can have an impact on productivity and organizations' efficiency and will be extremely beneficial for organizations [55].

In view of the above explanation and to put all the concepts in order (sustainability policy, citizen reinforcement, and corporation activism), a new approach to urban recycling is presented using the environment-social-economy (ESE) framework formulated by Ashford and Hall [5]. This triangle of sustainability is frequently represented by the economy, the environment and social concerns and explains that all policies that affect the economy and the environment have social impacts. In addition, long-run flows of environmental services are provided at a level sufficient to maintain a stable ecosystem.

Taking the ESE model as reference, it is proposed that the solutions to the municipal recycling problem become more holistic and include, in addition to the different functions of Batty's Smart City [9], the combination of the aspect of the economy related to corporate activism; the environment policy factors encouraged by institutions; and the aspects related to citizens' behavior, such as human reinforcement, with the technological factors generated by digitization and the programmable economy. All of this is contemplated in the ECCPE (Environment-Corporations-Citizens-Programmable Economy) model, as presented in Figure 4, to improve municipal recycling.

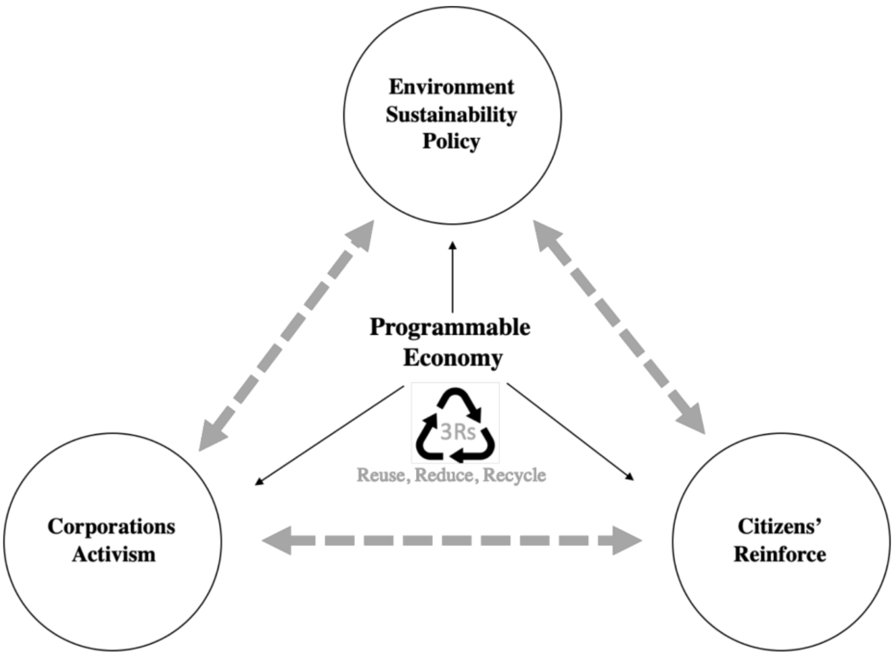

Figure 4. Environment-Corporations-Citizens-Programmable Economy (ECCPE) Model (the authors).

The problem that is to be solved revolves around knowing to what extent the modification of the recycling factor by citizens' incentives, city policy and corporate recycling activism strategy combined through PE technology increases the municipal recycling rate. Specifically, and as a first phase, it is necessary to know whether the implementation of recycling incentives, a city recycling policy focus and corporate recycling activism, all integrated by the programmable economy, as described in Figure 4, can alter municipal recycling rates (3Rs) more than the implementation of citizen incentives and corporate activism without a PE to maintain a city policy fix. This new exchange of value (monetary and nonmonetary) that municipal recycling could deliver would be made between the city´s agents (consumers/citizens, corporations, institutions) thanks to PE because it allows to manage some physical or virtual endpoints as digital nodes [47,48] that could be fit to a sustainability edge as the ECCPE model suggests.

In the search for such results, there are no simple solutions since inaccuracy and uncertainty exist within cities. In addition, certain parts of the proposed municipal recycling system are unknown and cannot be measured reliably without clear limits on the concepts of sustainability policy, corporate activism and citizen behavior. For this reason, making use of fuzzy systems methodology to reproduce reality more faithfully and to relax restrictions is proposed because there are concepts that have no clear limits. On the other hand, fuzzy set techniques are used, allowing the development of models to manage information problems when it is vague, imprecise or incomplete [56]. The reason why these methodologies have been used is that they contribute to solving decision-making processes and they allow to manage an information database when it is scarce or imprecise. Therefore, fuzzy science is used to find an algorithm for understanding what the better way would be to deploy the ECCPE model.

3. Methodology

3.1. Fuzzy Logic

The theory of fuzzy sets was introduced in 1965 by Lofti A. Zadeh. The idea resides in the fact that the elements that make up human thought are not numbers but linguistic labels. According to the principle of incompatibility as the complexity of a system increases, the ability to be precise decreases to the point that precision and meaning are exclusive characteristics [56]. From this idea, fuzzy logic allows us to represent common thought in a mathematical language based on the theory of fuzzy sets and their characteristic functions. Fuzzy logic's applications have increased to the point of being considered a real revolution, developing a large number of extensions, such as soft computing that covers the fuzzy sets and fuzzy logic for approximate reasoning and the theory of possibility [57].

According to this theory, what is being considered is a referential set or universe of discourse, U, and an ordinary subset, A ⊂ U, of those elements that fulfil a specific characteristic. For ordinary subsets there are only 2 possibilities, ∀ x ∈ U: "x" satisfies the characteristic (x∈A) or "x" does not comply (x∉A). Therefore, the membership function of A is defined as:

$$\forall \mathrm{x} \in \mathrm{U}\ \mu_A(x) = \begin{cases} 1\, if\ x \in A \\ 0\, if\ x \notin A \end{cases}$$

An ordinary subset of A ⊂ U is symbolized by the pair (U, $\mu_A(x)$).

Now, if the elements of A can take any value in a range [0, 1], it could be said that there are elements of U that fulfil the characteristics defined in subset A, but only to a certain degree. In this sense, the membership function of A will be defined as

$$\forall \mathrm{x} \in \mathrm{U}:$$

$$\mu_A(x):\ \mathrm{U} \rightarrow\ [0,1]$$

$$\mathrm{X} \rightarrow\ \mu_A(x) = \alpha \in [0,1]$$

In this way, it is possible to construct a fuzzy subset (U, $\mu_A(x)$) symbolized by $A \subset \mathrm{U}$.

$$A = \{(x,\ \mu_A(x))/x\ \in \mathrm{U}\}. \tag{1}$$

On the other hand, fuzzy logic allows the assignment of linguistic values to the variables of a problem, similar to the evaluation of a parameter usually conducted by people, whether they are experts or not [58,59].

In this sense, the universe of discourse is the range of possible values for an input to a fuzzy system. A fuzzy set is any set that allows its members to have different grades of membership (membership function) in the interval [0,1]. Linguistic variables are the input or output variables of the system whose values are words or sentences from a natural language, instead of numerical values. A linguistic variable is generally decomposed into a set of linguistic terms.

3.2. Mamdani Fuzzy Inference Systems

There are two well-known rule-based fuzzy inference systems (FIS), the Mandami fuzzy method [60] and the Tagaki Sugeno (T–S) fuzzy method [61]. The main idea of the Mandami method is to describe process states by means of linguistic variables and to use these variables as inputs to control rules. The Mandami fuzzy model involves developing membership functions and defining the subsequent rules. The rules connect the input variables with the output variables and are based on the fuzzy state description that is obtained by the definition of the linguistic variables.

The basic components of a Mandami Fuzzy System [62] are the following: fuzzification, a'knowledge base with an inference system and defuzzification. Meanwhile, the general structure of a fuzzy model includes the input variables, the development of rules and the output variables.

i. Fuzzification, understood as the introduction of input values and their interpretation as linguistic values, determines the membership functions of the system variables in the fuzzy sets. The universe of discourse of each variable was determined by the linguistic components for input and for output. A fuzzy set is defined by the expression below:

$$A = \{(x,\ \mu_A(x))\ /\ x\, \epsilon\, \mathrm{U},\ \mu_A(x)\, \epsilon [0,1]\}. \tag{2}$$

where U represents the universal set, x is an element of U, A is a fuzzy subset in U and $\mu_A(x)$ is the membership function of fuzzy set A.

ii. The knowledge base consists of fuzzy rules defined with the help of experts. A single fuzzy if-then rule assumes the form: If x is A Then y is B where A and B are linguistic values defined by fuzzy sets in the range (universe of discourse) x and y, respectively. The "x is A" part of the if-then rule is called the antecedent or premise, while the "y is B" part of the rule is called the consequent or conclusion [63]. During data processing, a fuzzy system fuzzifies the crisp data and applies the Mandami inference system using the fuzzy rules (by experts). In this study, the fuzzy control rules are of the form

$$R_i : If\ X_1\ is\ A_i^1\ and \ldots and\ X_r\ is\ A_i^r\ Then\ Y\ is\ C_i$$

where the variables X_j, $j \in \{1, 2, \ldots, r\}$, and Y have the domains U_j and V, respectively. The firing levels of the rules, denoted by $\{\propto_i\}$ are computed by

$$\propto_i = T\left(\propto_i^1, \ldots, \propto_i^r\right)$$

where T is a t-norm and $\propto_i^j$ is the firing level for A_i^j, $j\epsilon\{1, 2, \ldots, r\}$. The causal link from $X_1, \ldots, X_r$ to Y is represented using an implication operator, I. This results in the conclusion $C\prime_i$ inferred from the rule R_i being

$$\mu_{C\prime_i}(x) = I\left(\alpha_i, \mu_{C_i}(x)\right),\ \forall x\, \epsilon\, U \tag{3}$$

and using Mandami implication I, the formula is

$$\mu_{C\prime_i}(x) = I_M(\alpha_i, \mu_C(x)) = \min\{\alpha, \mu_C(x)\}. \tag{4}$$

The final output of the model is the aggregation of outputs from all rules using the max operator:

$$\mu_{C\prime}(x) = \vee_{i=1}^{n}\left[\alpha_i \wedge \mu_{c_i}(x)\right] = \vee_{i=1}^{n}\mu_{c\prime_i}(x). \tag{5}$$

iii. Defuzzification is used to obtain an output from the previous fuzzy set. A centroid method is usually used. Subsequent defuzzification produces a crisp value output. Defuzzification uses some methods, such as center of gravity or centroid (COG), mean of maximum (MOM), and first of maximum (FOM). Centre of gravity is the most popular and the most precise method used for defuzzification. The center of gravity method is a grade weighted by the areas under the aggregated output functions. The formula for the centroid is given as

$$\text{COG} = \frac{\int \mu_c(x)xdx}{\int \mu_c(x)dx}. \tag{6}$$

where $\int \mu_c(x)dx \neq 0 \; for \; all \; \mu_i$.

3.3. Fuzzy Inference System to Estimate Municipal Recycling

This section introduces a fuzzy inference system to estimate municipal recycling (FISMUR) by algorithm. The objective of the proposed algorithm is to provide the municipal recycling rate based on the input given as recycling policy focus (relationship between country environment sustainability policy and municipal recycling rate), recycling-oriented (corporations recycling activism and positives incentives for citizens' recycling) and a technological factor (programmable economy). The linguistics variables, fuzzy set and universe of discourse are given in Tables 1 and 2:

Figure 5 shows a block diagram of the proposed FISMUR algorithm (fuzzy inference simulation municipal recycling), which includes a fuzzification block, a knowledge base, a fuzzy inference engine and a defuzzification block.

The proposed algorithm consists of three steps: fuzzification, fuzzy rules, and defuzzification.

Step 1—Fuzzification: in order to keep the number of fuzzy rules at a reasonable level, input can be defined as fuzzy set levels with three membership functions known as "Low", "Medium" and "High". For the output, the municipal recycling fuzzy set has three membership functions, "Low", "Medium", and "High".

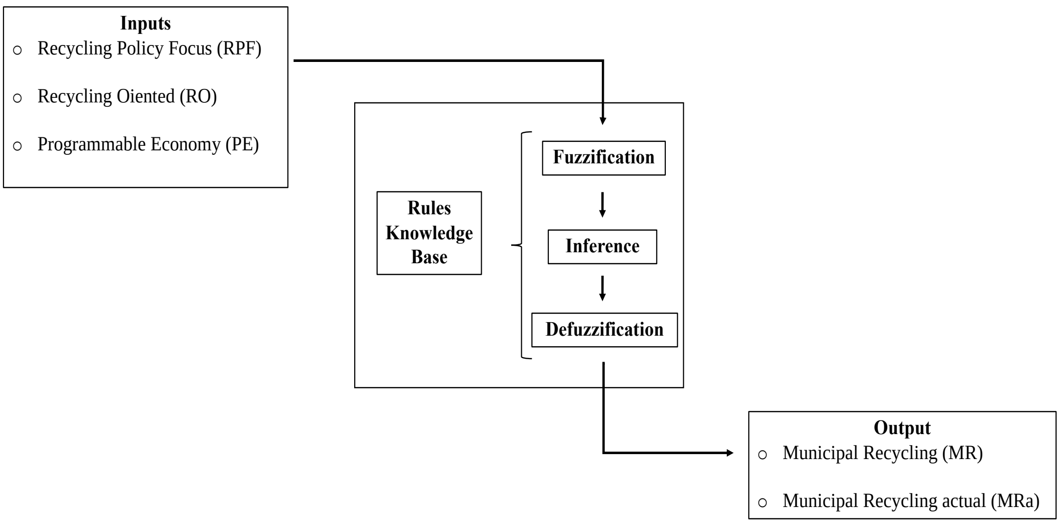

Figure 5. Fuzzy inference simulation municipal recycling (FISMUR) algorithm (the authors).

Table 1. Linguistic Variable.

Recycling Policy Focus (RPF)	Recycling Oriented (RO)	Programmable Economy (PE)	Municipal Recycling (MR)	Municipal Recycling actual (MRa)
-Actual Municipal Recycling/ Environmental Sustainability Policy Index.	-Customer waste recycling incentives. -Corporations recycling activism.	-Programmable economy (IoT, blockchain, DLT, smart contracts, monetization and token economy).	-%Material recovery (recycling + composting).	-%Material recovery (recycling + composting) actual.

Table 2. Fuzzy set and universe of discourse.

Linguistic Variable	Fuzzy Set	Universe of Discourse
-Recycling policy focus (RPF)	$A_{RF} = \{x, \mu_s(x)\ /\ x\epsilon[0, 100]\}$	$U = [0, 100]$
-Recycling-oriented (RO)	$A_{RO} = \{x, \mu_C(x)\ /\ x\epsilon[0, 100]\}$	$U = [0, 100]$
-Programmable economy (PE)	$A_{PE} = \{x, \mu_E(x)\ /\ x\epsilon[0, 100]\}$	$U = [0, 100]$
-Municipal recycling (MR)	$A_{MR} = \{x, \mu_T(x)\ /\ x\epsilon[0, 100]\}$	$U = [0, 100]$
-Municipal recycling actual (MRa)	$A_{MRa} = \{x, \mu_T(x)\ /\ x\epsilon[0, 100]\}$	$U = [0, 100]$

To define the recycling policy focus, recycling-oriented and programmable economy membership functions, what is used is the environmental sustainability index [64] and municipal recycling index [19], degree of customer orientation index [65] and digital adoption index [66] approach, respectively, behind a universe of discourse valued between 0 and 100. The data used for this study [19,64–66], have been taken at the country level, taking into account that there are no specific, homogeneous and consistent data related to them on SC at the global level with enough temporal amplitude. On the other hand, the ECCPE model proposed from the ESE framework will use the data aggregated at the national level as inputs to subsequently extrapolate them generally to the SC included in the same national territory.

To obtain the output municipal recycling membership functions, the municipal waste generation and treatment (% material recovery recycling + composted) [19] approach is used as a close reference in a universe of discourse valued between 0 and 100 and for municipal recycling actual situation a universe of discourse valued between 0 to 80. The reason that these indexes are used is that there is a positive correlation between the municipal recycling index by OECD countries with the degree of customer orientation index, the digital adoption index and the environment sustainability index with $R^2 = 0.453,\ 0.518$ and 0.536, respectively.

The initial linguistic variables are divided where each has their own appropriated linguistic values defining the fuzzy set membership function, as explained in Tables 3–7.

Step 2—Fuzzy Rules: in this step, linguistic quantification is used to specify a set of rules that captures the experts' knowledge about how to control the output.

To be able to determine which rules to apply to the model, two SC experts (Public Administration and Private Enterprise) were asked through personal interviews to carry out the rules.

It is important to mention that this project was divided into two phases: in the first phase, the model is tested with five SC experts to later introduce their acquired learning, then go to phase two and extend the number of experts to 14 in the fields of: institutional, technology, blockchain, management planning, private sector, waste management industry and academics. The interview methodology started by explaining the model, then experts completed some matrix in order to establish the importance of a recycling policy focus, citizens' recycling-oriented and corporations recycling activism and digital and programmable economy in municipal recycling, thereby establishing the rules given in Table 8.

Table 3. Recycling policy focus membership function (RPF).

Linguistic V	Functions
Low (L)	L Function: $1-\mu_x = \begin{cases} 0 & if\ x \le 20 \\ \frac{x-20}{45-20} & if\ x \in (20,45) \\ 1 & if\ x \ge 45 \end{cases}$
Medium (M)	Triangular Function: $\mu_x = \begin{cases} 0 & if\ x \le 20 \\ \frac{x-20}{45-20} & if\ x \in (20,45) \\ \frac{70-x}{70-45} & if\ x \in (45,70) \\ 0 & if\ x \ge 70 \end{cases}$
High (H)	L Function: $1-\mu_x = \begin{cases} 0 & if\ x \le 55 \\ \frac{x-97}{97-55} & if\ x \in (55,97) \\ 1 & if\ x \ge 97 \end{cases}$

Table 4. Recycling-oriented membership function (RO).

Linguistic V.	Functions
Low (L)	L Function: $1-\mu_x = \begin{cases} 0 & if\ x \le 55 \\ \frac{x-55}{70-55} & if\ x \in (55,70) \\ 1 & if\ x \ge 70 \end{cases}$
Medium (M)	Triangular Function: $\mu_x = \begin{cases} 0 & if\ x \le 65 \\ \frac{x-65}{75-65} & if\ x \in (65,75) \\ \frac{85-x}{85-75} & if\ x \in (75,85) \\ 0 & if\ x \ge 85 \end{cases}$
High (H)	L Function: $1-\mu_x = \begin{cases} 0 & if\ x \le 80 \\ \frac{x-80}{99-80} & if\ x \in (80,99) \\ 1 & if\ x \ge 99 \end{cases}$

Table 5. Programmable economy membership function (PE).

Linguistic V.	Functions
Low (L)	L Function: $1-\mu_x = \begin{cases} 0 & if\ x \le 15 \\ \frac{x-15}{70-15} & if\ x \in (15,70) \\ 1 & if\ x \ge 70 \end{cases}$
Medium (M)	Triangular Function: $\mu_x = \begin{cases} 0 & if\ x \le 60 \\ \frac{x-60}{70-60} & if\ x \in (60,70) \\ \frac{70-x}{80-70} & if\ x \in (70,80) \\ 0 & if\ x \ge 80 \end{cases}$
High (H)	L Function: $1-\mu_x = \begin{cases} 0 & if\ x \le 75 \\ \frac{x-75}{80-75} & if\ x \in (75,80) \\ 1 & if\ x \ge 80 \end{cases}$

Table 6. Municipal recycling actual membership function (MRactual).

Linguistic V.	Functions
Low (L)	L Function: $1-\mu_x = \begin{cases} 0 & if\ x \le 5 \\ \frac{x-5}{15-5} & if\ x \in (5,15) \\ 1 & if\ x \ge 15 \end{cases}$
Medium (M)	Triangular Function: $\mu_x = \begin{cases} 0 & if\ x \le 8 \\ \frac{x-8}{24-8} & if\ x \in (8,24) \\ \frac{24-x}{40-24} & if\ x \in (24,40) \\ 0 & if\ x \ge 40 \end{cases}$
High (H)	L Function: $1-\mu_x = \begin{cases} 0 & if\ x \le 32 \\ \frac{x-32}{77-32} & if\ x \in (32,77) \\ 1 & if\ x \ge 77 \end{cases}$

Table 7. Municipal recycling membership function (MR).

Linguistic V.	Functions
Low (L)	L Function: $1-\mu_x = \begin{cases} 0 & if\ x \le 10 \\ \frac{x-10}{20-10} & if\ x \in (10,20) \\ 1 & if\ x \ge 20 \end{cases}$
Medium (M)	Triangular Function: $\mu_x = \begin{cases} 0 & if\ x \le 16 \\ \frac{x-16}{36-16} & if\ x \in (16,36) \\ \frac{36-x}{56-36} & if\ x \in (36,56) \\ 0 & if\ x \ge 56 \end{cases}$
High (H)	L Function: $1-\mu_x = \begin{cases} 0 & if\ x \le 40 \\ \frac{x-40}{96-40} & if\ x \in (40,96) \\ 1 & if\ x \ge 96 \end{cases}$

Step 3—Defuzzification: the inputs for the fuzzy system introduced in this study were recycling policy focus, recycling-oriented and programmable economy, all of which are crisp. Initially, the fuzzy system fuzzifies the crisp data and then, with the Mandami inference system, applies the fuzzy rules. Finally, using COG, the municipal recycling is determined (MR and MRactual).

Table 8. Rules (knowledge base).

Rule	If RPF	And RO	And PE	Then MR	Then MRactual
1	H	H	L	M	-
2	H	M	L	M	-
3	H	L	L	L	-
4	H	H	M	H	-
5	H	M	M	H	-
6	H	L	M	H	-
7	H	H	H	H	-
8	H	M	H	H	-
9	H	L	H	H	-
10	M	H	L	M	-
11	M	M	L	M	-
12	M	L	L	L	-

Table 8. *Cont.*

Rule	If RPF	And RO	And PE	Then MR	Then MRactual
13	M	H	M	H	-
14	M	M	M	M	-
15	M	L	M	M	-
16	M	H	H	H	-
17	M	M	H	H	-
18	M	L	H	M	-
19	L	H	L	L	-
20	L	M	L	L	-
21	L	L	L	L	-
22	L	H	M	M	-
23	L	M	M	L	-
24	L	L	M	L	-
25	L	H	H	H	-
26	L	M	H	M	-
27	L	L	H	M	-
28	H	H	None	H	-
29	H	M	None	H	-
30	H	L	None	L	-
31	M	H	None	H	-
32	M	M	None	M	-
33	M	L	None	M	-
34	L	H	None	M	-
35	L	M	None	L	-
36	L	L	None	L	-
37	L	None	None	-	L
38	M	None	None	-	M
39	H	None	None	-	H

4. Results

Figures 6 and 7 show the output of the fuzzy inference system in MATLAB (Toolbox Fuzzy Logic MATLAB) [67], the software used for predicting municipal recycling. For example, if the values of input variables for a particular country (i.e., recycling policy focus—RPF, recycling-oriented citizen incentives and corporate activism—RO, and the digital and programmable economy—PE) are 83, 80 and 80 on the scale 0–100, respectively, then the membership functions profile is shown in Figure 6. The values of output variables municipal recycling (MR), belonging to the high language variable, and actual municipal recycling (MRactual) would be 78.4 and 62.7, respectively, observing better performance in MR simulation than MRactual after RO and PE variables have been used.

Control levels between input structure variables with IF-THEN are presented in Figure 7 (dark, grey and white areas represent low, medium and high municipal recycling, respectively). As shown, municipal recycling increases as the recycling policy focus (horizontal axis) and the PE (vertical axis) increases always from the minimal level of the recycling policy focus variable, its effects being more noticeable if the recycling policy focus is larger (1). Thus, the intensive use of the PE from a certain level of recycling policy focus has a greater impact on the increase in municipal recycling levels. On the other side, actions carried out through initiatives for the recycling oriented, RO (positive citizen incentives and corporate activism), shown on the vertical axis, alone to increase the level of municipal recycling are more limited to certain levels of city recycling policy focus (horizontal axis) (2). In other words, at the same level of recycling policy focus, the expected results are greater if the two inputs (RO plus PE) are combined. Thus, it is clear that the joint effect of the recycling-oriented focus (RO) through the deployment of the PE in increasing municipal recycling is greater (3).

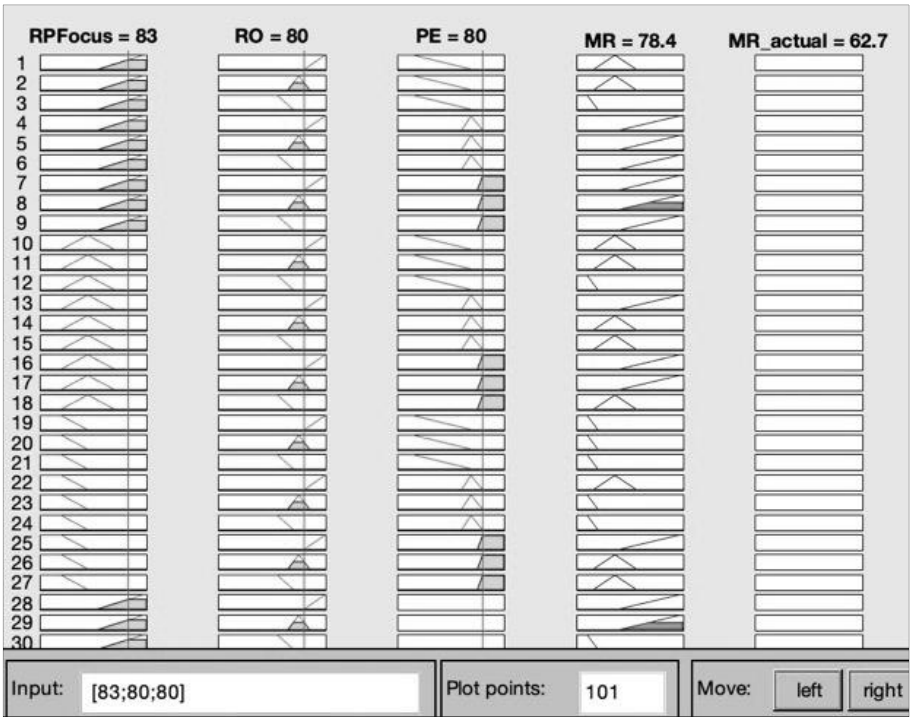

Figure 6. Membership function example from MATLAB (Source: the authors).

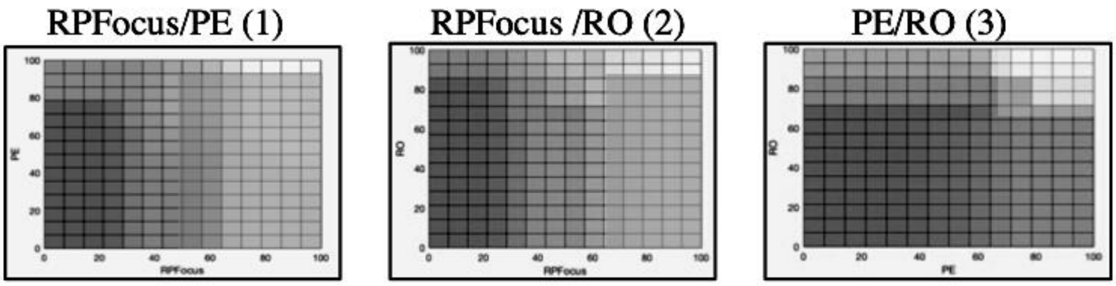

Figure 7. Control levels between inputs and outputs MATLAB (Source: the authors).

Empirical data from the recycling policy focus (RPF) vs. predicted values by the fuzzy inference system municipal recycling (FISMUR) simulation in several OECD and non-OECD cities are revealed in Table 9 with different levels of inputs.

As seen in Table 9, there is a good correlation between the municipal recycling and the recycling simulation FISMUR (1), with $R^2 = 0.896$, which is notably high. On the other hand, Figure 8 also shows that the greatest potential for municipal recycling was obtained from the variable recycling-oriented (RO) and when PE was carried out at the same time—FISMUR (3)—and not oriented recycling in isolation—FISMUR (2)—keeping the recycling policy focus constant, producing a significant "level change" effect in the variable on municipal recycling, this being greater when the two factors are combined (change in level "b"), which is done only through the recycling oriented (change in level "a") on the trends registered during the last years (1990–2018) for each set of countries.

Table 9. Fuzzy inference system municipal recycling (FISMUR), scale 0–100.

Country	Recycling Policy Focus RPF Actual	% Municipal Recycling + Composting, 2018, MR	FISMUR (1) RPF = Actual RO = 0, PE = 0 MRactual	FISMUR (2) RPF = Actual RO = 80 P = 0	FISMUR (3) RPF = Actual RO = 80 PE = 80
Germany	89	66	64	65	80
Slovenia	83	60	62	64	78
Austria	73	59	60	60	76
Belgium	83	54	62	64	78
Netherland	73	53	60	60	76
Switzerland	63	52	43	56	65
Italy	79	50	62	62	77
Lithuania	79	50	62	59	77
Sweden	64	49	45	59	65
Denmark	65	48	47	49	66
Luxemburg	60	47	37	59	65
UK	66	44	49	59	68
Poland	67	44	52	59	70
Norway	59	43	34	47	65
Finland	59	42	34	47	65
France	62	42	41	54	65
Ireland	61	41	40	51	65
Hungary	58	34	33	44	65
Czech R	48	33	24	36	62
Iceland	48	33	24	36	62
Estonia	44	31	24	36	62
Spain	46	30	24	36	62
Latvia	40	28	24	30	59
Slovak R	34	23	22	30	52
Portugal.	31	19	19	25	49
Greece	27	17	17	22	43
Turkey	19	9	14	8	23
Europe	**59**	**41**	**40**	**47.3**	**64.4**
Korea	99	59	64	67	80
Australia	61	42	40	51	65
China	67	30	52	59	70
Japan	34	21	19	30	52
Thailand	22	11	10	13	29
Indonesia	14	6	6	8	23
Philippines	10	5	5	8	23
Asia + P	**44**	**25**	**28**	**33.7**	**48.8**
United States	67	35	52	59	70
Canada	40	27	22	30	59
NAmerica + C	**53**	**31**	**37**	**44.5**	**65.5**
Colombia	34	20	19	30	52
Mexico	6	4	5	8	23
Brazil	2	1	5	8	23
Chile	1	0.5	5	8	23
S. America	**11**	**7**	**8**	**13.5**	**30.2**
Israel	38	21	21	28	56
Iran	12	6	6	8	23
Egypt	11	6	6	8	23
Niger	8	4	5	8	23
Morocco	7	4	5	8	23
Africa	**15**	**8**	**8**	**12**	**29.6**

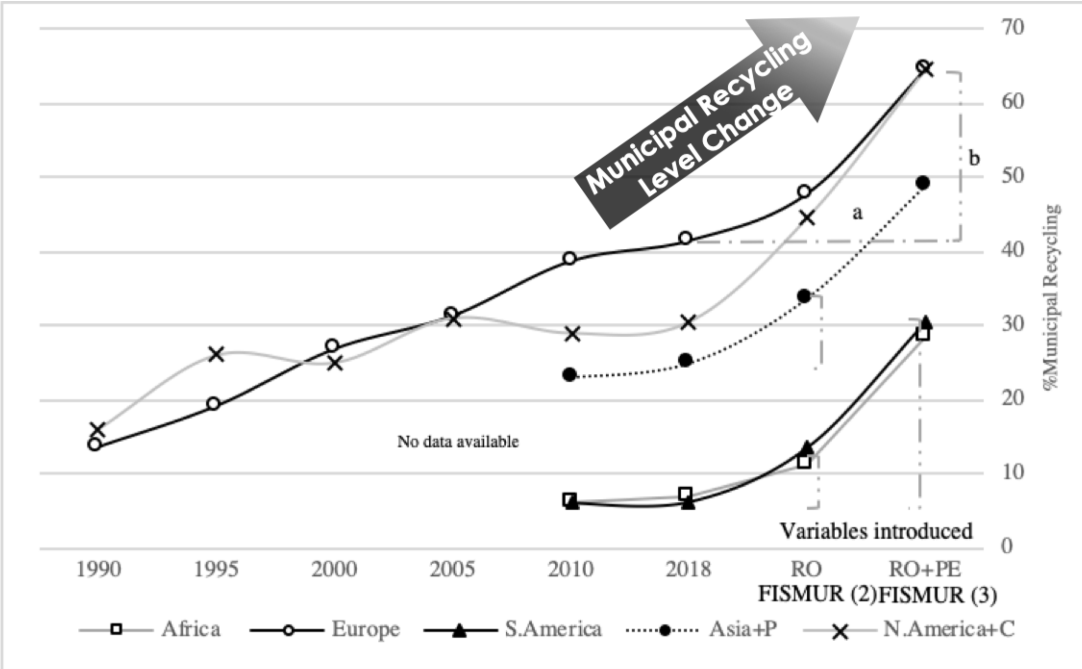

Figure 8. Percentage of municipal recycling trends by country set, Recycling Oriented (RO), Recycling Oriented + Programmable Economy (RO + PE) introduced (1990–2018).

In spite of that, for developing countries, it is better to improve their recycling policy focus as a priority because although they increase RO and PE variables at the same time or isolated, they cannot achieve more than 30% of municipal recycling rates from 9%, compared with developed countries that have achieved rates of more than 60%. Alternatively, for developing countries, it will be very expensive to obtain high levels of PE and RO (i.e., 80) if they have poor values of them too.

5. Conclusions

The only way to guarantee future cities' survival is to decisively face the challenges of a sustainable SC path by, for example, managing their negative externalities, capitalizing on their extraordinary positive ones and extending their time horizon responsibility. For this, the SC must involve all agents without exception, excluding partial visions and interests, since multidisciplinary points of view are needed to address highly complex problems such as sustainability. Undoubtedly, to accelerate this process, technology will play an increasingly important role, its use being more decision-making intensive by intensifying, integrating, facilitating and connecting SC value endpoints rather than being only a tech milestone. As already mentioned, beyond the different theories about the role of technology in sustainability strategy, the revolution of ICT technologies has the capacity to facilitate sustainable innovations by reducing the amount of materials and energy needed while stimulating the economy so that sustainability becomes a "chosen direction" by the agents [45] and so the potential of sustainability can accelerate if it is converted into an SC integrator backbone.

The results presented by this exploratory study would allow institutions and corporations to take more effective measures to progress aspects related to SC sustainability and, in particular, to improve municipal recycling rates from a broader point of view that includes the programmable economy, corporate brand activism and human capital elements. To achieve these objectives, a knowledge base was acquired through a group of SC experts, and representative organization indicators were used to calibrate the membership functions of the input and output variables. Through this knowledge, it was possible to extract the linguistic variables and their rules, making it possible to build a fuzzy inference system. The system was tested with real and hypothetical data on OECD and non-OECD cities using the Fuzzy Logic Toolbox from MATLAB.

In this research, the objective is to reduce the negative externalities generated by household unrecycled waste using fuzzy systems (Mamdani inference) for diagnosing the problems of municipal recycling, considering some inputs (recycling policy focus, recycling orientation and programmable economy) and regarding the ECCPE (Environment-Corporations-Citizens-Programmable Economy) model, which is inspired by the ESE framework formulated by Ashford and Hall [5] and reinforcement theory, all of which deploying exchange value endpoints backbone (physical or virtual) that fit to recycling edge in SC.

These inputs are not exhaustive of the complex urban waste-recycling framework, but they have a large impact on it. It has been observed that by using the FISMUR algorithm and keeping the urban policy recycling focus variable constant for each country, the impact of deploying corporate recycling activism with a citizens' recycling incentive strategy base that rewards sustainable recycling through PE technology is greater than if recycling was done in isolation; presenting both options has a high impact in terms of increasing municipal recycling.

The benefits of applying the proposed fuzzy inference system may vary, depending on the initial level of policy recycling focus (sustainability policy index and municipal recycling relationship). Regarding this point, it is observed that there are limitations in a country's "sustainability policy", which affect the ability to take advantage of the benefits of the other inputs. In this sense, deploying recycling-oriented initiatives requires at least a medium-level-of-sustainability policy to be effective. Therefore, cities without a minimum-level-of-sustainability policy should prioritize investing in one first to subsequently reach a certain level of environment policy that allows them to capitalize on other initiatives. Likewise, from a certain level of country recycling focus (medium-high), the best initiatives to increase recycling levels apply both recycling-oriented initiatives (corporate activism and incentives that influence citizen behavior) and PE initiatives and do not focus so much on only improving environment policy. The initial country recycling focus level is a key aspect of assessing the application of more advanced initiatives. Therefore, developed smart cities can start deploying RO and PE initiatives because they have great levels of digital adoption and customer focus; meanwhile, early city developers first need to invest in and improve their environment policy to achieve a recycling policy focus tipping point that permits them to take off, and, second, early city developers need to combine RO and PE initiatives with the expansion of digital adoption and customer-oriented initiatives. Thus, it cannot be affirmed that the same level of recycling focus corresponds to the same level of municipal recycling because there are specific variables for each city that are very important, such as population density; cultural aspect; and economic variables, such as GDP per capita and the Gini index.

This article also highlights the possibility of exploring the treatment of other negative externalities generated in cities through the programmable economy as a facilitator and integrator tool. The set of concepts that this technology includes will all be of vital importance in the future. This article promotes citizens' participation in city decision-making and promotes transparent, reliable, monetized, peer-to-peer and decentralized corporate recycling activism to open a new way for urban managers to explore negative externalities or other issues. In no way is this study intended to minimize the role of institutions; in contrast, it seeks to provide them with technological capabilities to find new modes of fairer management efficiency and dissuade citizens and corporations from generating negative footprints and encouraging them to contribute to generating a more sustainable city.

This article has some limitations. It should be noted that this approach is in its first stage. At this moment, this research has only attempted to test the feasibility of the model to move on to the next phase. As for other limitations, this paper does not address the important technologies needed to implement the PE, such as 5G, artificial intelligence, big data, the machine-to-machine economy and cryptography. Consequently, a very important point about the latter is that this article does not discuss the importance of the impact on sustainability that the deployment of this technologies could have, leaving it for future research. Additionally, this article does not include other variables of great relevance and very high impact included in the environment-social-economy (ESE) framework paradigm formulated by Ashford and Hall, such as legal aspects, taxes, user profiles, government policies and many more.

As part of future research, it is planned to add new variables to the proposed system such as type of reward, the target group in question and the value of the reward because, as it has been seen in the theoretical background section, all of them are being testing in some cities and data could be available for their study. On the other hand, other results derived from this work could be analyzed, such as the impact of increased recycling and data collected on SC management or the effects of this impact on corporate marketing campaigns, and to consider the possibility of applying PE and diffuse systems to the treatment of other urban externalities. Moreover, the proposed system in this paper could provide a new research to the Financial Technology (FinTech) field exploring the knowledge on robo-advisors as a sub-topic under FinTech. Previous findings indicate that the participants from digital and real asset management have serious concerns on how FinTech would disrupt their businesses; meanwhile, PE could improve this processes by proposing technology solutions according to different business situations and these ideas could also lead to new business models or even new businesses [68–70].

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