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Transforming Diabetes Supplies in the Prison System: An Example of Environmental Social Innovation

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Abstract: Background: The disposal of plastic material has been gaining negative attention due to its impact on the environment and people's health. Insulin pens used by people living with diabetes are disposed of through landfills or incineration, negatively impacting the environment and generating costs for the state. Methods: In an attempt to reduce the disposal of plastic in the environment and reduce disposal costs, the "Insulinadiamor" project was created, which uses handicrafts as a means of re-socializing women deprived of their liberty. In this project, female inmates in the state of Sergipe turn insulin pens into ballpoint pens. Results: During the year 2022, 2000 insulin pens were transformed into ballpoint pens. We estimate a loss of around USD 37,150.28 for the state due to the inappropriate use of medicines, which was reflected in the return of complete insulins. In addition, by avoiding landfill or incineration of the plastic content collected, we contributed to an estimated saving of almost USD 603.91 for the state and more than 80 kg of CO_2-equivalent emissions. Conclusions: This project brings a sustainable and transformative approach involving financial savings, rehabilitation of inmates, and contribution to the environment. It also raises the importance of creating more sustainable initiatives to reduce plastic waste in the health sector and other areas.

Keywords: recycling; insulin pens; ballpoint pens; diabetes mellitus; prison system; resocialization

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1. Introduction

Diabetes Mellitus (DM) is one of the most prevalent chronic diseases in the world [1]. The condition consists of the lack of, inability to produce, and/or inadequate action of insulin, which can lead to persistent hyperglycemia or hypoglycemia, exacerbating the complications of the condition [2,3]. According to the World Health Organization (WHO), it is estimated that by 2025, there will be more than 463 million people living with DM [4], which will have a direct impact on healthcare costs and the use of hospital supplies to maintain these treatments. The most prevalent subtypes of DM are type 1 and type 2. For patients with DM1, the condition is characterized by insufficient insulin production by the beta islets due to autoimmune action, and the Brazilian Diabetes Society (SBD) recommends that this condition be managed with insulin therapy as the first choice [5]. Patients with DM2, on the other hand, are initially started on pharmacotherapy with oral antidiabetics and then, if there is no glycemic control, treatment is maintained with insulin therapy, either in the form of ampoules or pens [4,6]. Both diabetes types are characterized by an increase in blood glucose levels but with different pathophysiological causes and treatments [2,7].

The emergence of new pharmaceutical technologies, such as injection pens, occurred in 1980 and is considered a breakthrough in treatment [8]. There are currently two types of pens available: disposable and reusable, the latter being less commonly used [9]. They are made up of an initial compartment that fits the needle for application, a central compartment that houses the insulin cartridge, and a rear part for dosage control. In the reusable pen, whenever the cartridge is empty, the central compartment is opened to insert a new insulin refill [6,10]. This pharmaceutical form has enabled desirable metabolic control, with greater adherence to treatment and improved quality of life for patients, compared to ampoule-type insulin [10,11]. The vast majority of people who use insulin prefer injection pens because they are easier to use [9].

According to the resolution in force in Brazil, all sharps and contaminants generated in the treatment of diabetes, including insulin injector pens, must be disposed of in the same type of waste as the materials used in health services [12]. However, this waste ends up being discarded among hospital waste, posing potential risks to public health and the environment [13,14]. This pharmaceutical technology becomes a public expense when it is disposed of, as this procedure requires a controlled landfill for the material, which can also be sent for incineration, which becomes a major source of gases and toxic substances affecting human health [15,16]. The emission of carbon dioxide, a gas generated in this incineration process, has been gaining prominence due to its important role in promoting global warming. According to NASA, 2022 is tied for the fifth hottest year on record [17]. The years 2013–2022 were the hottest years on record, and in 2023, the world will break the record for the hottest months on record [18,19].

According to the OECD, in 2019, more than 6.1 million tons of plastic were improperly disposed of in the aquatic environment. These plastics generate an impact of 3.4% of global carbon emissions, impacting the environment [20]. It is estimated that hospitals generate more than 5 million tons, generating a negative impact on health and the environment, accounting for 4.4% of greenhouse gas emissions [21]. In recent years, the presence of microplastics in the environment has been investigated and found to be more prevalent than expected [22]. These residues have already been linked to deaths from asphyxiation and have also been found in human blood [23]. Concerned about this emerging environmental issue, medical centers have been creating strategies to reduce waste generation, from waste reduction and recycling to responsible purchasing and conscious use [24].

Around 400 million tons of plastic waste are generated worldwide every year [25]. Recycling still needs more government investment and social awareness, given its importance in minimizing the social problem of waste. Only 9% of the 9 billion tons of plastic produced by humanity over the years has been successfully recycled [26]. Recycling is beneficial to the global crisis by limiting the amount of waste that goes to landfills and the use of raw materials [27]. In landfills, where insulin pens can be disposed of, anaerobic decomposition takes place which leads to methane, which affects the environment 28 times more in terms of heat retention in the atmosphere compared to carbon dioxide [28].

As a method of minimizing the amount of environmental waste generated by empty insulin pens, they can be used as raw material for handicrafts [6]. This can play a significant role in protecting and preserving nature, especially when done sustainably and consciously. Furthermore, in Brazil, it is common for inmates to be encouraged to engage in resocialization activities as well as to develop independence and entrepreneurship once they have served their sentence [29,30]. Therefore, insulin pen recycling can be used as a tool for social reintegration and reducing criminal recidivism among individuals serving time in prison, allowing them to learn and develop skills, ultimately culminating in personal transformation [13,29]. Despite bringing benefits to the economy, the environment, and the resocialization of inmates, projects like this are rarely carried out in Brazil, and no reports were found of actions to transform hospital waste in this way.

With this in mind, a strategy was developed to reduce the amount of insulin pen waste that is discarded in nature by reusing this material and turning it into a ballpoint pen. The process of making, dismantling, and assembling the pens is carried out in craft workshops by individuals deprived of their liberty. The participation of people deprived of their liberty in society is important because it is to these people that art and crafts are presented as a form of resocialization and humanization. We are therefore investing in three areas: resocialization, savings, and reuse, in order to reduce the impact of insulin pen disposal on the environment.

2. Materials and Methods

2.1. Study Design

The study took place from January to December 2022 in the state of Sergipe, located in northeastern Brazil. It was developed at the Federal University of Sergipe, in conjunction with the State Department of Justice and Consumer Protection (SEJUC) and the Sergipe Health Care Center (CASE). To carry out this project, a mapping exercise was carried out to quantify the number of insulin pens distributed by CASE, as well as to analyze the number of pens returned by patients to the public agency. In 2019, the management of the public agency established a protocol for the return of insulin pens used by patients when they were empty so that they could be collected and stored in cardboard boxes in the pharmacy department [31]. These insulins were sent to the sorting process, where they were separated by type and content and then sanitized. All the steps of the methodology are shown in Figure 1.

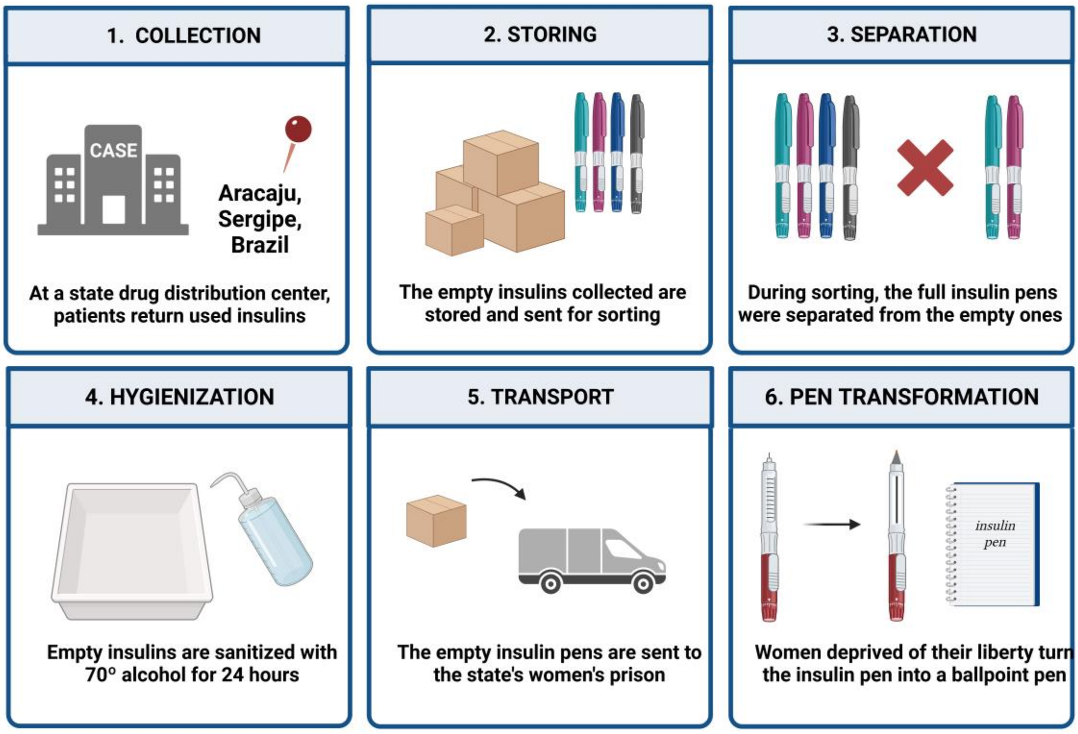

Figure 1. Step-by-step methodology from collecting the pens to transforming them into ballpoint pens.

2.2. Sorting the Collected Insulin Pens

After being packaged, the insulin pens are sent to the Federal University of Sergipe (UFS), where they go through the sorting process which consists of categorizing, separating, and sanitizing the material received. In addition, the insulin pens are inspected and removed from the plastic bags, followed by the removal of needles and/or any other materials still attached to them. Insulin pens that were returned with the medicine still in them were sent back to CASE for proper disposal. After this inspection, empty insulin pens are separated into categories according to the type of insulin, so the model can vary according to the class of insulin and the manufacturer of the product. Reusable pens are not widely distributed in these health centers due to their high cost, so the pens used in this study were all disposable. When the categorization process is complete, the pens are properly sanitized to remove dirt and/or bacteria, since insulin pens have direct contact with the patient's skin and various surfaces. To do this, the material is left in trays with 70% alcohol for 24 h. Once the sanitizing stage is over, they are removed from the tray and dried with flannels to be organized again in new, clean cardboard boxes, from where they will be transported to the Women's Prison (PREFEM) for disassembly in order for the recycling process to begin.

2.3. Insulin Pen Recycling Process

At PREFEM, the inmates begin the handicraft process by dismantling the insulin pen and transforming it into a ballpoint pen. For this stage to take place, workshops were planned and held to teach the inmates step-by-step how to structure and assemble the pens, as well as the correct use of the necessary materials, such as pliers, to make the expected product. The parts that make up the insulin pen are described in Figure 2.

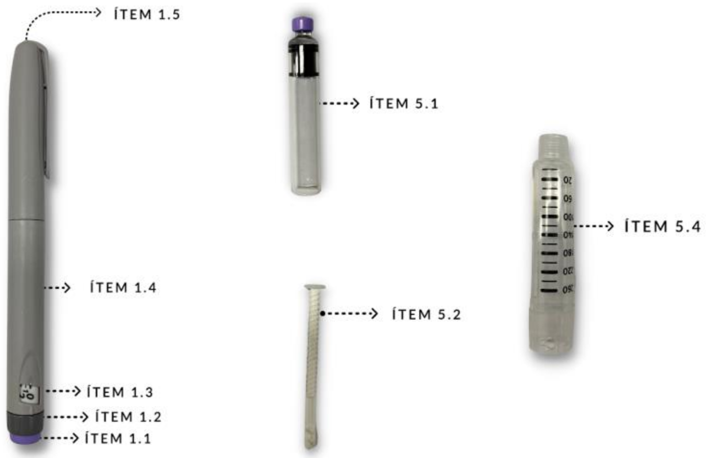

Figure 2. Parts of the insulin pen. Graphic representation of the parts of insulin pens that need to be reassembled for transformation into a ballpoint pen. Item 1.5 refers to the insulin pen cap. Item 1.1 refers to the applicator button. Item 1.2 refers to the rotary knob for selecting the units to be applied. Item 1.3 is the display where the selected units can be observed. Item 1.4 refers to the body of the insulin pen, where the central insulin stem is located. Item 5.1 refers to the carpule, the glass region where insulin is contained. Item 5.2 refers to the stem of the pen. Item 5.4 refers to the pule wrap, where the marker of the insulin pen units can be observed.

To begin disassembling the insulin pen, the cap is first removed, as shown in Figure 3 (item 1.5), followed by the insulin carpule holder (Item 5.4) and the carpule (Item 5.1), which is disposed of in a sharps container. After this procedure, the central stem of the pen (Item 5.2) is removed with the assistance of pliers. When all the parts have been removed, the assembly process begins. During the pen assembly stage, the insulin cartridge holder is inserted and checked that it is securely attached to the pen. Next, a ballpoint pen refill is inserted and hot glued around the tip of the pen, completing the manufacturing process of the final product and making it ready for use (Figure 3).

2.4. Statistical Analysis and Data Visualization

To help visualize the amount of material that was collected and reused during the project, as well as the amount categorized by type of insulin, a figure was created on the

Circos® website (http://circos.ca/, accessed on 11 March 2023) [32,33]. The data were tabulated and statistically analyzed using Microsoft Excel® software (Microsoft 365 for Windows). The percentages were calculated. The conversion rate used from the real (BRL) to the dollar (USD) was determined based on the exchange rate values in Brazil on 15 December 2023 (USD 1.00 equals BRL 4.9391).

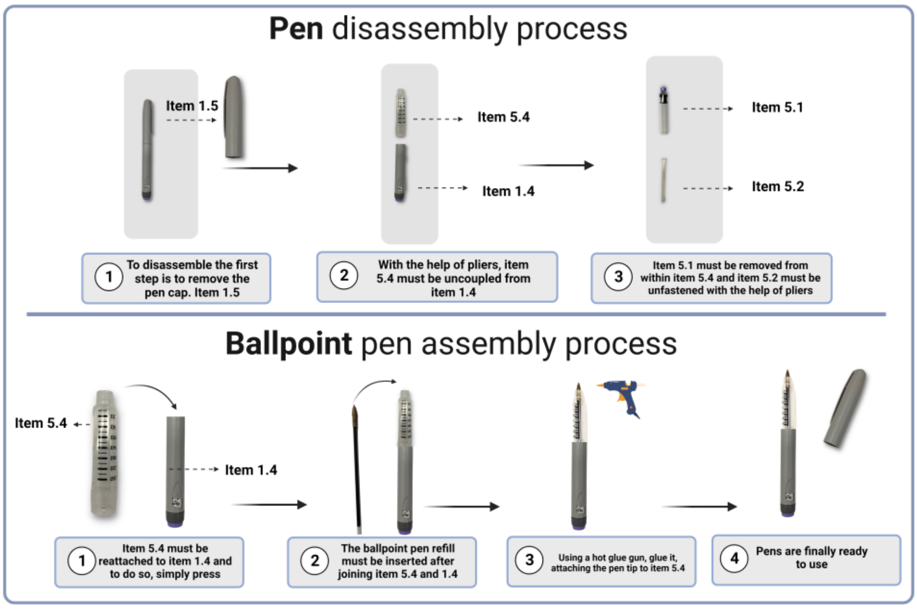

Figure 3. Insulin pen disassembly and reassembly process. This graphic representation details the crucial steps to ensure the proper manufacture and functionality of the device. In this diagram, you can see the processes involved in disassembling the insulin pen, transforming it into a stereographic pen that is ready for use. All the items mentioned were described earlier in Figure 2.

3. Results

During the year of the research (2022), more than twenty-five thousand insulin pens were collected. Four types of insulin pens were used in this study: Glargine/Lantus®, Glulisin/Apidra®, Detemir/Levemir®, and Asparte/NovoRapid®. The pen that was most used and returned by patients was Glargine/Lantus®, a slow-acting insulin. This may have been because, as it is a slow-acting pen, a larger dose is needed to supply the treatment during the day, so more pens are required to fulfill the monthly treatment in some cases. The second most commonly used and returned insulin pen by CASE patients was the rapid-acting Asparte/NovoRapid®. This type of insulin, along with the slow-acting Glargine, is the most widely available at the health center where the study was conducted. Not all insulin pens collected were recycled, for reasons such as damaged integrity and the pens not being empty. Figure 4 shows the exact number of pens that were collected and recycled, separated by type of insulin. In 2022, two thousand (2000) collected insulin pens were successfully recycled and then distributed to the population. It is worth mentioning that all individuals who received the recycled pens were instructed to bring them back when finished, to simply change the refill and avoid discarding this material. In this way, the unnecessary disposal of plastic material into the environment and the purchase of new ballpoint pens, also made of plastic, are avoided.

In Table 1, the filled insulins that were returned among the insulins collected were also counted. In other words, patients did not use the complete treatment offered by the government due to a lack of adherence or purchase from private drugstores. As a result, the insulins they collected every month for use were returned partially or completely filled. It is worth mentioning that for safety reasons, even if they are full, these pens cannot under any circumstances be transferred to other patients and must be discarded. We found that the insulin pen most frequently returned, either partially or completely full, was Glargine/Lantus®, with almost two thousand pens wasted. This was followed by Glulisin/Apidra®, which was the second most frequently inappropriately discarded insulin type, with one thousand pens wasted.

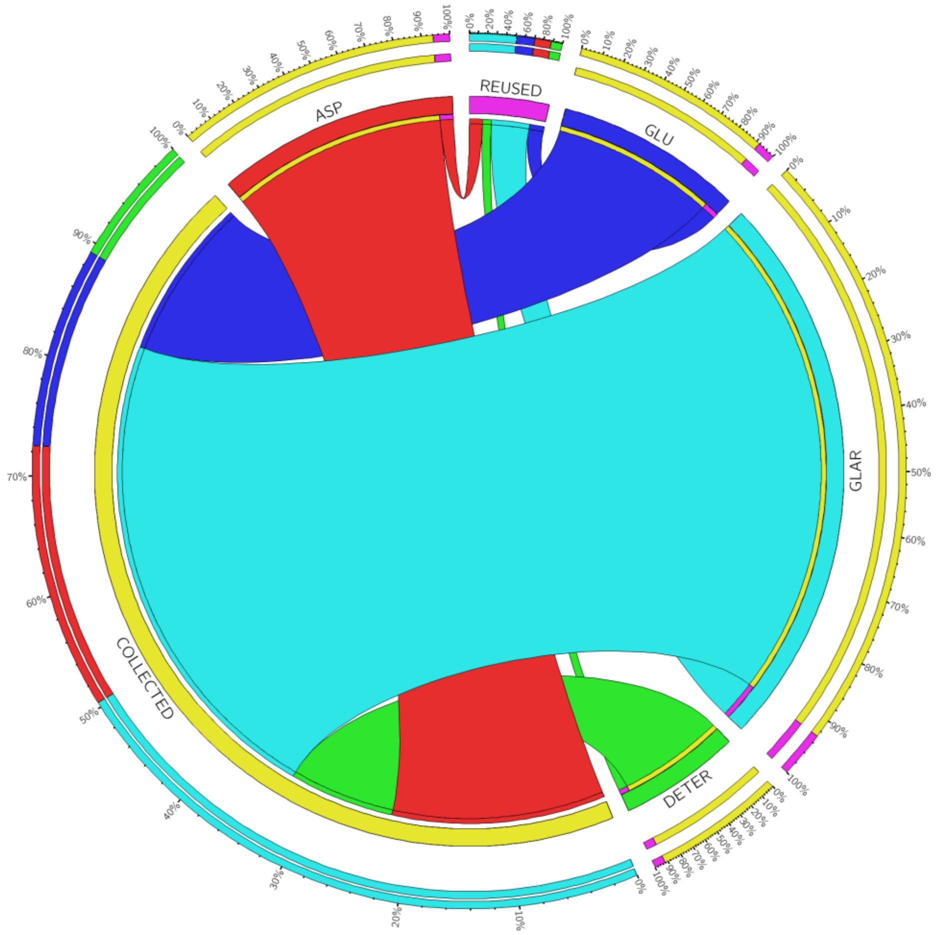

Figure 4. Specification flow of the types and quantities of insulins recycled. Figure 4, which shows a circus graph, displays the proportion of pens that were reused and collected for each type of insulin: Glar = Glargine/Lantus® (Reused = 1012; Collected = 13,090), Glu = Glulisin/Apidra® (Reused = 394; Collected = 4397), ASP = Asparte/NovoRapid® (Reused = 354; Collected = 3870), Deter = Detemir/Levemir® (Reused = 240; Collected = 2808).

Table 1. Quantification and cost of insulin pens. In this table, it is possible to see the amount of insulin collected during 2022. We separated the amount that each filled pen costs the state and then evaluated the annual amount spent on the incineration of these collected inputs.

Type of Insulin	Collected Quantity	Number of Pens Filled	Value per Unit (USD)	Wasted Value per Year (USD)
Glargine/Lantus®	13,090	1900	5.87	11,194.34
Glulisin/Apidra®	4397	1002	21.44	21,488.10
Glulisin/Apidra®	2808	153	10.87	1663.48
Asparte/NovoRapid®	3870	486	5.77	2804.36
Total	24,165	3541	-	37,150.28

Of these, we verified the cost of each insulin per unit, as available on the Secretaria do Estado de Saúde de Sergipe site [34]. As a result, we carried out an analysis and discovered that the health system wasted more than USD 37,150.28 on insulin that was inappropriately used in 2022 (Supplementary Table S1). This is in addition to the amount spent by the state on disposal by incineration of more than USD 1450.13. Moreover, it would cost almost

USD 603.91 to incinerate all the empty insulin pens that were collected during the year. We made this calculation based on the price that the state spends to incinerate 1 kg of hospital supplies, which corresponds to USD 1.80 (Supplementary Table S1). However, in addition to the financial loss to the country's public health system, it is worth highlighting that more than three thousand pens were improperly discarded, also generating a large environmental impact due to the disposal of a large amount of plastic.

It is worth noting that the values shown in Table 1 refer only to state cost and waste. The state where the study took place is the smallest in the country, thus raising great concern about the impact that this pharmaceutical form and its inappropriate use can have on the environment and society as a whole.

We weighed the pens without the carpule (glass part), therefore only weighing the plastic part, and found that each empty Glargine/Lantus® pen weighs 17 g, Novorapid/aspart® 15 g, Detemir/Levemir® 16 g, and Glulisin/Apidra® 17 g (Table 2). Converting all these grams to the total number of pens we managed to recycle (2000 pens), we arrived at a total of 33,052 kg of recycled plastic from insulin pens. It is estimated that for every kilogram of recycled/bio-based plastic, around 2.5 to 3 kg of CO_2-equivalent emissions (CO_2-eq) are reduced [35]. In this work, we reused 33,052 kg of insulin pens, creating an innovative way to reduce hospital plastic waste. As a result, we can estimate that we have avoided emissions of between 82,630 and 99,156 kilos of CO_2-eq.

Table 2. Amount of insulin recycled and kilograms (kg) of reused plastic material. In this table, we demonstrate the amount recycled per type of insulin, equating the weight of the plastic content of each pen to kg of reused plastic.

Type of Insulin	Number of Recycled Pens	Weight per Unit (g)	Total Recycled Weight (Kg)
Glargine/Lantus®	1012	17.0	17,204
Glulisin/Apidra®	394	17.0	6698
Detemir/Levemir®	240	16.0	3840
Asparte/NovoRapid®	354	15.0	5310
Total	2000	-	33,052

4. Discussion

Numerous benefits have been made possible for public bodies in the state of Sergipe. CASE, the institution responsible for distributing insulin therapy to patients with diabetes, has seen a significant reduction in infectious waste that would otherwise have been disposed of in landfills or incinerated [36,37], contributing to a reduction in the emission of pollutants into the atmosphere, as well as a significant reduction in public spending [34]. Implementing recycling projects such as "insulinadiamor" in prisons has several significant benefits. Firstly, it contributes to environmental sustainability, so that many materials used during DM treatment, such as insulin pen packaging, can be recycled or reused responsibly, reducing the amount of waste sent to landfill or incinerated, which reduces the negative environmental impact associated with these disposal methods [13]. In addition, overproduction, improper disposal of plastic in the environment, and the influence of external factors such as high temperatures, sunlight, friction, or slow decomposition contribute to its fragmentation, leading to the formation of plastic microparticles, which have a devastating impact on ecosystems [38].

Landfills, where much of the plastic is disposed of, are great accumulators of toxic substances such as microplastics. These substances are formed by the aging of landfilled plastic and are carried by the air, generating environmental and health impacts [39,40]. When ingested, these particles can cause physical damage, block the digestive tract, and lead to the accumulation of toxins found in the lungs, hearts, and even blood of humans [41]. Materials such as plastics contain elements that are potentially harmful to the environment if disposed of improperly. That is why recycling these items can help prevent contamination of the soil, water, and air, contributing to the preservation of natural ecosystems [36]. By reusing these materials, there is a reduction in the demand for virgin raw materials, which implies less extraction of natural resources and, consequently, less environmental impact associated with these processes [36,37]. According to the OECD, plastic waste is responsible for around 4% of the world's total greenhouse gas (GHG) emissions. The majority (93%) of plastics are produced using fossil fuels [42].

The incineration of plastics is also proving to be an ineffective alternative since the microplastics and toxic substances generated in practice during incineration will spread throughout the environment [43]. The incineration of plastics at the end of their useful life has a major impact on the environment, causing 70% of total emissions [42]. A study carried out in China showed that per metric ton of plastic waste incinerated, around 360,000 to 102,000 microplastic particles are generated [44]. This finding shows that incineration is not an effective alternative for reducing the environmental impact of plastic waste. In addition, the process of incinerating plastic can be risky as the fire can spread if not properly controlled, causing an even greater environmental impact [45].

A Brazilian resolution, created in 2004 by the National Health Surveillance Agency (ANVISA) [46], states that all sharps and contaminants, including insulin pens, should be disposed of in the same waste stream as sharps, such as those used in health services. However, it has been scientifically proven that this waste ends up being discarded among common waste, posing potential risks to public health and the environment [47]. The difficulty in obtaining an adequate plan or project to receive and treat infectious waste, as well as the lack of information and educational strategies on recycling, reducing, and reusing materials from agencies and institutions, characterizes the handling of health service waste as deficient and costly to public health in Brazil [47]. The study by CUNHA et al., 2017 [47] shows that more than half of patients do not receive instructions on the packaging and disposal of household waste resulting from DM treatment or disposing of sharps in common waste. In this scenario, by complying with the protocol established by CASE, the patient contributes directly to the reuse of the pen, supporting the process of re-socialization of individuals deprived of their liberty in Sergipe and a lower incidence of environmental waste.

In addition to the environmental and economic advantages, the integration of inmates into these projects is of social benefit as it offers them the chance to learn and develop in specific areas, such as waste management, material separation, and reuse. These skills can be of great value to individuals when they leave the prison system, offering them employment opportunities and facilitating their social reintegration [48]. It can also have a positive impact on prison dynamics, helping to create a sense of contribution to society and an opportunity for participants to feel useful [29,48,49]. Education through art and crafts is seen as an unconventional activity in the reality of prisons and should be provided as an educational activity to promote humanizing education within the prison system [48–50]. Therefore, offering educational, vocational, and psychosocial rehabilitation projects inside prisons is fundamental to preparing individuals for life outside prison, increasing their chances of finding a job and reintegrating into the community. This also helps to reduce the burden on the prison system, as it reduces the number of repeat offenders, relieving overcrowding and the associated costs [51].

This study has some limitations. Not all patients adhered to returning the insulin pens, and some pens had to be discarded from the study because their structure was damaged. In addition, insulin pens that still contain the drug must be disposed of according to the protocols and sent to other agencies, which makes it impossible to add them to the reuse project. In addition, the recycling of the pens depended on the main workforce, the inmates, which made it possible to process only a portion of the pens collected during the year. This is a limitation, especially when it comes to assessing the annual impact on reducing CO_2 emissions, as we have only analyzed the pens that have been successfully recycled so far. The purchase of raw materials, such as sanitizing items, was also a limitation, as this is a reintegration and sustainability project with no financial return. To overcome these limitations, it is necessary to carry out actions to explain the importance of returning the pen in an intact state to patients using insulin, as well as demonstrating the importance of our project to government bodies, so that we can expand the workforce at the state and national level. In this way, transforming a discarded pen into a usable one will have a greater impact on the environment and the economy as a whole.

Projects to recycle and transform plastic materials have been carried out in innovative and environmentally friendly ways [52–55]. However, the world still lacks initiatives to help combat the negative impact caused by the overconsumption of plastic on our planet. Initiatives, from the home to the workplace, can be very useful if propagated and carried out to protect the Earth. Furthermore, investing in resocialization is a way of promoting restorative justice, which focuses on repairing the damage caused by crime. By providing opportunities for learning, therapy, and rehabilitation, a favorable environment is created for inmates to reflect on their actions, take responsibility, and become productive and responsible members of society after serving their sentences [49]. Linked to this process, the project also reduces the amount of waste that is incinerated or dumped in landfills and could stimulate similar initiatives or be applied elsewhere.

5. Conclusions

This study demonstrates the significant role of the waste generated by the inputs used in the treatment of diabetes mellitus, not only as a factor in increasing public spending but also as a potential source of environmental damage when poorly managed. The correct management of these materials provides a notable reduction in CO_2-eq emissions. In addition, we have identified a considerable waste of public resources due to the inappropriate use and disposal of insulin pens. There is a pressing need to promote changes in behavior and sustainable practices in waste management among managers, employees, and users of the Unified Health System (SUS). This requires a focus on ethical and environmental responsibility, emphasizing the importance of a conscious approach to consumption and waste generation, replacing landfill and incineration practices with transformation and recycling wherever possible. Therefore, there is an urgent need to develop additional strategies to minimize the negative impact of this waste on public health and the environment. To this end, it is necessary to raise awareness and educate patients to promote a more rational use of available resources, contributing to a more efficient management of waste related to the treatment of diabetes mellitus. In short, the collective action of health professionals and patients is essential to reduce the impact of this waste on the environment and to improve the effectiveness of the resources used to treat diabetes mellitus. In this way, it is possible to reduce the negative impact that hospital waste has on the environment and promote more rational treatment by patients.

6. Patents

The innovative product entitled: recyclable insulin pen, was patented in 2020, as a utility model, under the number BR 202020007003-2 U2 [30].

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su16010452/s1, Table S1: Quantification of insulins collected in 2022 and calculation of expenditure generated for the state.

Author Contributions: Conceptualization, L.P.B. and P.H.M.M.; methodology, P.H.M.M., D.M.R.R.S., E.E.D.S., P.C.d.J., J.B.d.S., M.d.S.B., R.S.S., L.M.M.d.S., A.G.G., L.A.d.M.S. and L.P.B.; formal analysis, P.H.M.M., M.d.S.B. and D.M.R.R.S.; investigation, P.H.M.M., E.E.D.S., M.d.S.B., R.S.S., L.M.M.d.S., J.B.d.S., P.C.d.J., A.G.G. and L.A.d.M.S.; data curation, P.H.M.M.; writing—original draft preparation, P.H.M.M., D.M.R.R.S., M.d.S.B., E.E.D.S., R.S.S., P.C.d.J., J.B.d.S. and L.M.M.d.S.; writing—review and editing, L.P.B., A.G.G. and L.A.d.M.S.; supervision, L.P.B. All authors have read and agreed to the published version of the manuscript.

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