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Reducing Volume to Increase Capacity—Measures to Reduce Transport Energy for Recyclable Waste Collection

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Abstract: The production of municipal waste is increasing all over the world. Although a significant part of the waste is collected as commingled waste, much of it is recyclable if disposed of properly. Thus, separate deposition and collection plays an extremely important role today, more than ever, not only in terms of preventing pollution but also from the point of view of recycling as a driver of circular economy and of efficient use of resources. This work is focused on the development of compaction equipment to be applied to containers, which allows a more efficient approach to the process of collecting waste for recycling. As a management option, recycling depends on collective behavior which is based on individual acts. Therefore, individual use of plastic/metal compaction systems can help meet recycling targets, even as a complement to conventional bins. Thus, herein a proposal is presented for a plastic/metal collection station with a built-in compaction element that allows for the compacting of the separated waste, individually, in an easily accessible drawer. Sorting and compacting waste before collection will result in a reduction of the number of collection/transport stops, which will also translate into higher energy efficiency, cost savings, optimization of the transported tons/km ratio, and profitability.

Keywords: compaction; Cyclea container; *Ecopoint*; metal and plastic packaging; optimization; recycling; routes

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1. Introduction

We live in a consumerist society that is avid for new products, often disposable, that accompany the latest developments in technologies as well as other offers in terms of food and clothing, among others. This tendency of mankind, perhaps a need to keep up with "fashion", is contributing to the levels of pollution that currently exist, not only by their disposal but also in the corresponding act of acquisition, boxes, paper, plastic, tapes, etc., that are commonly deposited in unsorted urban waste. On the other hand, in a pandemic situation such as COVID-19, and recently "Monkeypox", the use of means of protection, such as disposable masks or medical treatment products, has intensified, considerably increasing the production of waste. This recorded increase is due to the COVID-19 pandemic which caused the suspension or cancellation of all measures and actions that were being taken by the various institutions and organizations [1]. "It is true that, with the confinement and the use of disposable protective masks, the production of waste has increased considerably" [2]; however, the increase was not due solely to confinement, but may also be linked to the new labor policies such as teleworking. This has been the trend because in 2020 during COVID-19, European countries registered growth in the number of people working primarily from home, reaching values above 25%. Countries such as Finland, Luxembourg, and Ireland had very high growth rates of remote work; however, in Portugal in the last year, it rose to 14.5% compared with 6.5% in the previous year [3]. Figure 1 shows the data for 2021 and the EU27 average. It should be noted that there was considerable growth both in the percentage of people working from home in Europe and in the new positioning of the countries considered [4]. In the countries marked with (a), values are from the previous year as updated values are not yet available.

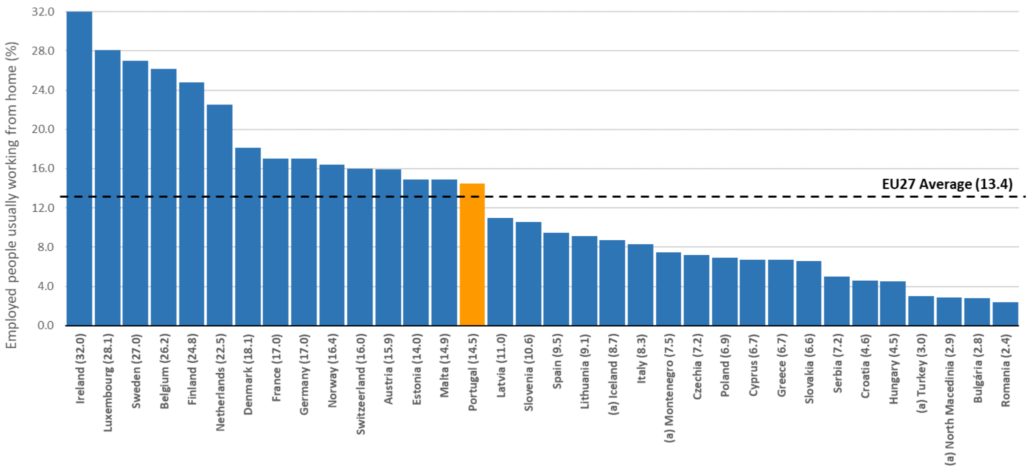

Figure 1. Employed people primarily working from home in Europe 2021 (%) [5].

These changes in working habits have contributed to transferring industrially produced waste (paper, ink cartridges, organic waste, etc.) to a residential context, since work activity at home will also generate waste. On the other hand, working from home can trigger the need to obtain packaged food products for daily consumption, contributing to the increase in plastic and metallic packaging that can be discarded in unsorted urban waste or in separate deposition bins [2]. The combination of teleworking with confinement and the use of personal protective equipment during the COVID-19 pandemic, with an "*estimated monthly use of 129 billion face masks and 65 billion gloves worldwide*" [6], contributed to a general increase of the environmental contamination, an increase of 13.6 million tons (20.5%) from 2009 to 2019 [7]. There was an increase in plastic waste, likely resulting from the use of single-use plastics, personal protective equipment (COVID-19 and other hospital equipment [8]), and online shopping and home delivery in plastic packaging, becoming a serious threat to ecosystems and human health, both in terms of nano- and microplastics. Thus, there is an expected growth of 40% in packaging and 17% in other applications [9], and an increase in metallic packaging, resulting from *take-away* deliveries of drinks and meals.

With this rampant growth of waste, one must ask oneself what to do with the waste that is generated daily [10], but the scenario we face leads us to another question that materializes: what to do to properly manage the waste that grows exponentially and how to mitigate its impacts. We must remember that inadequate management results in widespread environmental contamination and loss of valuable resources, which will harm not only public health but also environmental health as well as the means to address the challenges posed to the waste sector during and after the pandemic [11].

Hence, we have to take an active role, knowing that environmental problems cannot be solved by themselves [10]. Thus, urban waste, among others, must be properly treated to avoid problems of generalized environmental contamination and to contribute to an effective behavioral change which translates into an improvement in climatic conditions.

Therefore, it is necessary to take actions that contribute to an increase in waste recycling rates aimed at the transformation of waste products into raw materials, the reduction of the use of new raw material, and the production of non-treatable waste [12], that is, promoting the Circular Economy Recycling (CER). In this sense, and given the fact that the average calorific value of urban solid waste is approximately 10 MJ/kg, in the context of CER, there will be interest in using waste as a source of energy [13]. Thus, waste is no longer seen as a cost but as a valuable resource [14]. Consequently, municipal solid waste plays a key role in the context of the circular economy since population growth and the increase in the standard of living favor the consumption of goods and the production of higher amounts of waste.

Concerning municipal waste management, Ferraz de Campos et al. [15] analyzed the waste generated all over the world; they focused their attention in more detail on the situations of Brazil and Portugal and concluded that Portugal is following the European goals of elimination of disposal in landfills and developing circular economy as well as energy recovery. In this respect, Ferraz de Campos et al. [15], citing the data available from the Portuguese Environmental Agency [16], observed that the direct destination of MSW from Portugal mainland varied in the period from 2013 to 2018, with an increase in the destination to mechanical and biological treatment (from 17% to 25%) and a constant share of approximately 20% of waste destined to energy valorization. Concerning the selective collection, in 2018 it represented 20.4% of the total, and the remaining 79.6% were collected as commingled waste [17]. However, as noted by Costa et al. [18], Portugal has seen a strong investment in the infrastructures for the collection, treatment, and destination of waste as a result of the political willingness to achieve the goals defined by the European Union (EU). This has been accompanied by a considerable commitment to waste separation, with approximately 89% of the population separating waste. Interestingly, younger people also recycle less (which seems contradictory to their activism against climate changes). Costa et al. [18] also observed that knowledge regarding smart waste management is very low in Portugal in spite of the great attractiveness of the existing projects. Costa et al. [18] concluded that the European legislation and targets will put pressure on the Portuguese authorities to implement a fairer tariff payment system. The tariff must account for all the waste management activities, and therefore, the costs associated with the selective collection and transportation represent an important share of the tariff [19].

Thus, in this context, plastic packaging occupies the largest share of production for industrial applications (36%) in a context of worldwide plastic production of approximately 400 million tons per year [20]. With a tendency to increase from 300 million tons in 2015 to 1,800 million tons in 2050 [21], its recycling will translate into considerable economic return and provide overall benefits of 167 EUR/ton [22] as well as a reduction in CO_2 emissions. Similarly, through recycling, we can obtain pure metals that can later be transformed into metallic products such as nickel, cadmium, copper, zinc, and iron, which can be used in homes or industry [23,24]. On the other hand, in addition to the products obtained from recycling, other value-added substances, such as hydrogen, can be obtained, contributing in the short term to the National Hydrogen Plan [22]. In this sense, curbing the use of disposable products, reducing their use, recycling, and reusing them are the first steps toward waste elimination (3R policy), focusing on converting waste into raw material that can be reused to form other valuable products [25]. Renewal or reuse is used to rationalize energy use, reduce the need for large undifferentiated waste treatment (such as mechanical biological treatment, MBT) facilities, and to avoid harmful effects on society and for environmental protection by reducing greenhouse gas emissions [26].

Recycling, in addition to being a collective "intention", is above all an individual act that begins in the mind of each human when one decides to separate certain wastes into classes instead of simply discarding them with undifferentiated waste [2]. Then, following the selective collection and transport to the transformation units, it assumes a leading role as it allows, from the outset, the classification of waste material to be purified, as well as the recovery of waste (recycling revenue that may result in 167.2 EUR/t or 31.7 EUR/hab year [27]), while the residual fraction not recovered (tailings) will be disposed of in sanitary landfills or incinerated. The selective collection of packaging waste is an entrenched practice in Europe [28], with a great impact on the costs of managing recyclable waste [29] and with effective repercussions on the Portuguese circular economy [22] as well as on the global one. In India, at the Municipal Corporation of Delhi, for example, it is expected that between 2017 and 2020, the total value added to the waste trade operations will be approximately 46.6 million USD, with recycling saving the municipal budget approximately 2.3 million USD per year [30].

Portugal has an urban packaging waste recycling rate close to that of the European average (62.8%) and in line with a substantial part of the 27. Although this rate is close to the average (EU27), it will be necessary to increase and develop new strategies and actions, whether private or governmental, such as the taxation (30 cents) of disposable plastic or aluminum packaging (Ordinance No. 331-E/2021, of 31 December, among others). The government action, paying for packaging, will act as a deterrent; however, we must continue to increase our contribution to a more sustainable development. There was an improvement compared with the 57.6% rate of the previous year, reflected by an increase of six positions to currently occupy the 16th position in the EU27 ranking (Figure 2) [31,32].

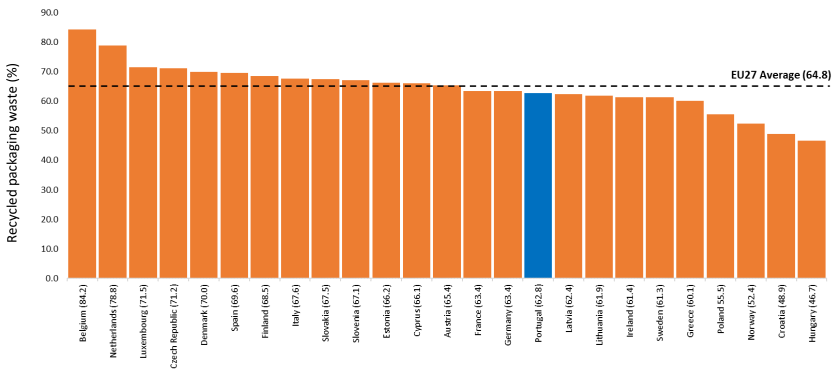

Figure 2. Recycling rate of packaging waste for 2019 [31].

In urban areas, the disposal and collection of recyclable waste is usually carried out in community recycling containers, *Ecopoints*, (Figure 3a, left—*cyclea* container yellow, green, and blue) or door-to-door (Figure 3b, right—small domestic container), separated into individual containers of smaller capacity per household, depending on the geographic area. Regarding collection carried out at surface recycling points, *Cyclea* is one of the most used drop-off containers in Portugal. These are configured for vertical loading with a capacity of 1500 liters for plastic and metal packaging (yellow container) or glass (green container) and 2500 liters for collecting paper and cardboard (blue container) [33].

Figure 3. Example of drop-off containers (*Ecopoint*), *Cyclea*, currently used in most municipalities in Portugal [33] and selective collection door-to-door [34].

Likely, the growth registered in the year 2019 and the rise in the packaging recycling rate to 63% of recycled waste is due not only to the awareness of the need to recycle it (placement of recyclable waste at collection points) but also to the possibility of doing it right at the source after the consumption of the goods in our home (promoted by door-to-door collection), and perhaps because of the greater availability to do so in times of confinement. This change of behavior with regard to the daily selective collections (interspersing the commingled waste collection with the collection of packaging, paper, and glass), triggered the need to create a very careful planning of the logistics systems of collection, storage, and processing. It should also be noted that the entire responsibility for the waste management methods and strategies [35] ("*control, collection, transfer, processing, and disposal waste, with a target to minimize the reduction on landfills, along with material recovery/recycling–target set by the European Green Deal and Circular Economy Strategy*" [36]) falls on the municipalities or inter-municipalities; therefore, all investments and costs of the recycling process are centralized. On the other hand, as processing costs are fixed, it will be in the logistics system of waste collection that most of the gains or losses may fall. Thus, an improvement, a reduction in the costs associated with the activity, will involve changing and optimizing the routes, making them more comprehensive, changing the carrying capacity of the vehicles, or reducing the number of weekly collections per ton of waste collected.

The literature review on the subject presented in this work, in the most diverse databases, returned few references related to compaction and compaction devices for small waste containers. These include a study presented by Xevgenos et al. [37] who proposed an innovative project: a portable device for a miniature separator/compactor, developed for the household separation of urban solid waste based on a hydraulic piston system. Although this approach can result in a substantial reduction in the volume of domestic solid waste deposited, with compression rates between 7 and 22% [20], the acquisition of the proposed hydraulic compaction equipment for individual use at home would result in a high investment which is inaccessible to a large part of domestic producers.

Another study by Pace et al. [38] analyzed a heat melting compaction device developed by NASA to melt the plastics in the waste collected and encapsulate the waste in it. However, this kind of device does not allow for easy recycling of the waste collected as the plastics are melted and combined in an undistinguishable material. Furthermore, it cannot be applied to compact metals, due to the higher pressure needed to compact this material. The use of compaction devices has been advocated only in the collection or in the transportation vehicles [39]. Therefore, an intermediate and proximity solution, where the compaction device is installed in a container for collecting community waste, i.e., in the *Ecopoint*, would result in a reduction in costs for domestic waste producers and, at the same time, in transport costs as it would allow for an increase in the mass of products to be transported by the municipal waste collectors in a single pass.

Hence, in the present work we present a technological solution developed to reduce the frequency of collections of recyclable materials. This approach, supported by a manual compression system for plastic and metallic packaging, aims to increase the storage capacity of the yellow container, thus contributing to the fulfillment of the national goals established in the various guidelines such as the Strategic Plan for Municipal Solid Waste (DL 152-D, 2017) [40], the General Waste Management Regime (DL 178, 2006) [41], and the orientations from the European Union to Portugal [42].

The objective of this article is to analyze the feasibility of using a small vehicle for the collection of metallic packaging and to determine the gains not only in terms of diesel consumption but also in the overall costs per journey. To this purpose, the national framework of the problem of selection and collection of urban solid waste was considered. On the other hand, to respond to these problems, an innovative model of manual compactor was developed intended to be coupled to traditional waste collection containers. In addition, a comprehensive comparison of a weekly collection route was performed considering two different types of vehicles, a micro and a tri-flow type.

2. Management of Municipal Solid Waste in Portugal

In Portugal, the production of urban or municipal solid waste (MSW) has registered a downward trend since 2009, reaching a minimum of 4.36 Mt in 2013. In this year, and because the production of waste is associated with the economic level of each country, we can say that in 2013 there was a serious economic crisis. This resulted from the global financial crisis of 2007-2008 and developed in the context of the Eurozone public debt crisis which mainly affected peripheral countries, including Portugal. After this year, MSW production grew slowly, reaching values in the year 2020 that were close to those observed in 2010, and having a daily production of waste that remained constant in the years from 2018 to 2020, with the daily capitation returning to values previously seen from 2008 to 2010, that is, reaching 1.4 kg/capita · day (Figure 4) [43].

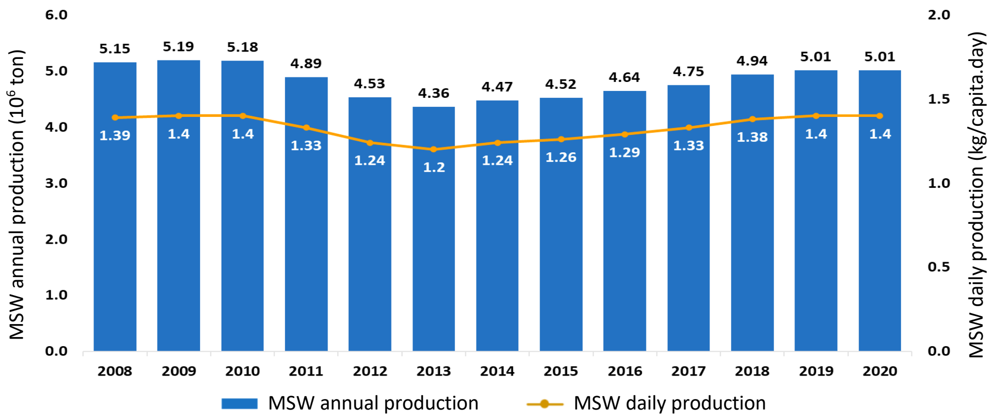

Figure 4. Production and capitation of municipal solid waste in mainland Portugal [43].

However, considering these stable conditions and the slight improvement in the volume of recycled waste (Figure 2), the amount of recyclable waste did not follow the European trend. The amount of recyclable waste produced per inhabitant continues to be lower than the European average, with a total amount of recycling of approximately 41%; however, it showed a slight increase in 2019. Therefore, according to Santos et al. [2] "the increase in urban solid waste is associated with an improvement in the economic situation, which leads us to believe that the decoupling of waste production from economic growth has not been achieved".

On the order hand, according to data available from the Portuguese Environment Agency (APA) conveyed through the Environmental Status Report [44], the amount of municipal solid waste collected in Portugal since 2014 has been increasing, with a stabilization of the value from 2019 to 2020 (see Figure 4). On the other hand, we can observe that the MSW production in 2020 is similar to the production between 2008 and 2010 (approximately 5 million tons of waste), and between 2011 and 2013/2014 there was a significant drop in production, largely associated with the economic crisis. The economic recovery has driven a notable increase in municipal solid waste production values; this trend can be observed in Figure 4. In the period from 2013 to 2019, there was an increase in production rates, reaching 5 million tons of waste, which corresponds to a capitation of 511 kg/(capita · year) and a daily production of 1.40 kg per inhabitant in 2019. In 2020, the total production of urban waste in Portugal was approximately 5.01 million tons (+0.1% compared with 2019), which corresponds to a daily production of 1.40 kg per inhabitant (same as in 2019) which corresponds to an annual capitation of 512 kg/(capita · year), a value above the European average [43]. If the amounts of the Autonomous Regions are included in the referred value, the capitation rises to 513 kg/(capita · year), with the value of daily production per inhabitant remaining unchanged [45]. Although the recycling rate of packaging waste in 2019 was 63% and the recovery rate was 72%, both with an upward trend, the recycling of plastics and metal stood at only 36 and 46%, respectively [44] (Figure 5), i.e., 129,553 tons.

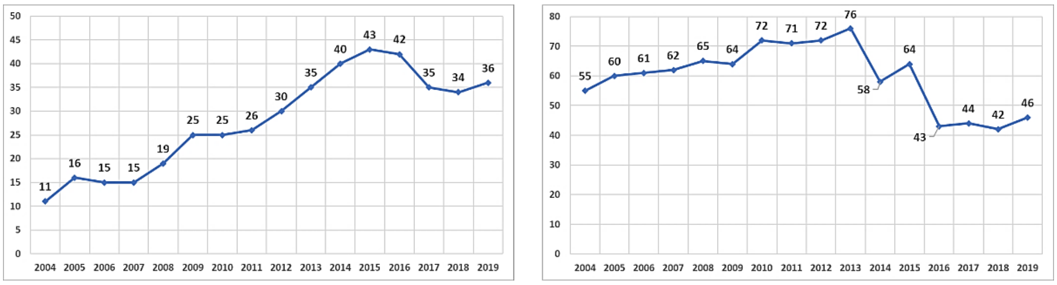

Figure 5. Plastic (**left**) and metal (**right**) packaging recycling rates (%) in Portugal [44].

However, only 13.38% of the MSW produced is recyclable plastic and metal, as shown in Figure 6, which seems to be a good characteristic of the waste produced, due to waste prevention policy [43].

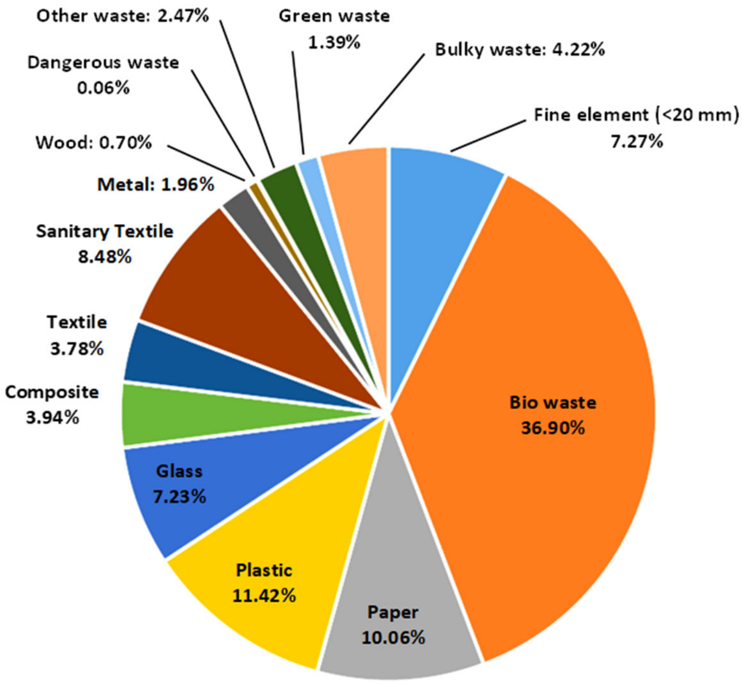

Figure 6. Physical characterization of municipal solid waste in the year 2020 (%) [43].

Yet, the recycling rates had an average of 21% for the past 20 years, a trend that goes in the opposite direction to the community and national strategy for the MSW. However, there has been a marked increase in recycling values of approximately 1% since 2002. Although this growth is verified, this data places Portugal far from achieving the goals established by the European Union, which is strongly attributed to insufficient selective domestic collection of recyclable materials.

Furthermore, it should be noted that the management of all municipal solid waste to be treated involves not only its collection but also its transport before processing. Regarding solid waste collection, there are two procedural steps: disposal in containers (either at selective collection points or at home, selective or undifferentiated collection) and collection with a transport vehicle (and transport to the municipal processing unit's centers). Note, however, that the collected fraction of packaging waste is mostly a very light fraction (a low density leads to volume restriction [m^3] rather than tonnage restriction in transport [kg]) with a larger volume than weight, due to huge voids associated with lack of compaction. The work that will be presented below focuses on the phases of collection, disposal, removal, and transport, based on a proposal to improve the packaging collection container. This proposed modification of the yellow *Cyclea* allows the separation and compaction of plastics/metal deposited in a single container during the collection phase. Compaction will allow the reduction of the volume deposited by increasing the density of waste to be transported. This action will reduce the energy consumption spent on transport, while allowing the reduction of the need for large intercity mechanical/physical treatment units for the separation of plastic/metal in processing.

3. Container Model Proposed for Packaging

The proposed model that is presented here has as its final objective the optimization of the selective collection rounds that involves the complementarity of the current plastic and metallic packaging containers. It is intended to take advantage of the current configuration of *Cyclea* containers, presenting a proposal to change the deposition nozzle and the waste collection container, providing not only the deposition of packaging but also the separation of these two recyclable waste flows (plastic and metal). This change aims to reconfigure the traditional collection holes present on the front face of *Cyclea*, to a new and innovative manual compaction system, capable of substantially reducing the volumes of packaging, including metal cans, bottles, and others (Figure 7).

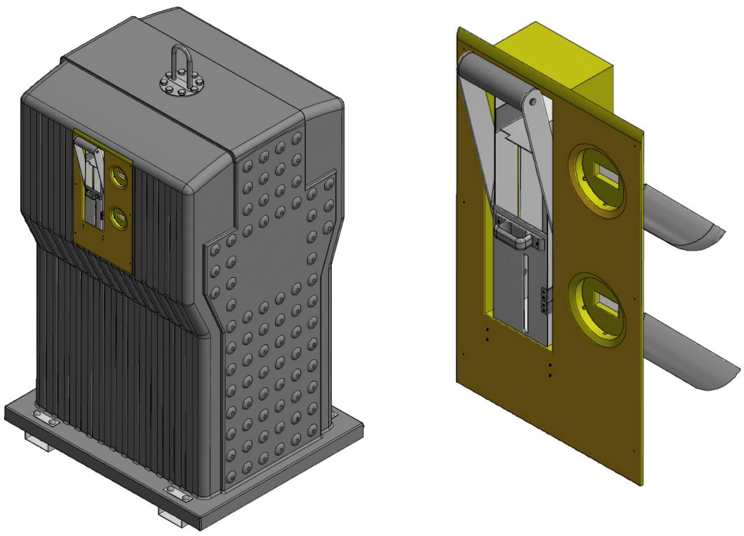

Figure 7. Proposal of a new *Cyclea* model with a compaction system for selective collection of metals and plastics in one single container [1,46].

The compaction model developed and placed on one of the sides of the container has a compaction capacity of up to 345 mm. This height provides a capacity for compacting plastic bottles from 0.33 L to 2 L as well as beverages cans and others with a maximum diameter of 100 mm (Figure 8).

Figure 8. One of the recycling parts of household packaging: metal and plastic.

Additionally, the compacting element has moving parts. Although they are manual, additional safety measures have been taken to prevent the users from keeping their hands inside the equipment while compressing the packages. The safety measures implemented—essential for safely operating the compactor—were achieved by placing a door to access the chamber that, when not fully closed, prevents the downward movement of the compaction lever. The degree of compaction obtained can be visualized by means of an indicator that, depending on the final position of the compaction lever, shows the compression rate and the final volume of the compacted object. Note, however, that during operation, the packages must be open, not only to avoid explosions of the pressed object, but also because it allows less effort and a more adequate compaction; therefore, it is expected that the user removes the lids prior to compaction to get better results (see Figure 9).

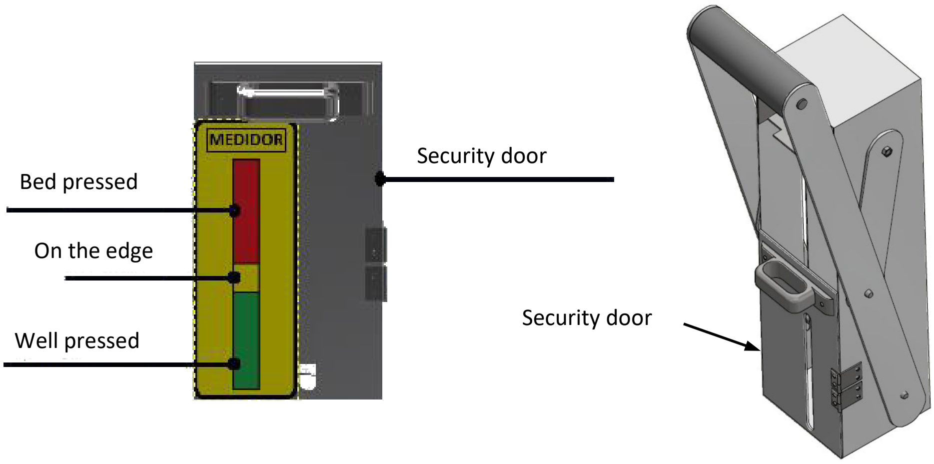

Figure 9. Compression level and security door [46].

As previously mentioned, the selection and deposition of the pressed material in the correct container is always the responsibility of the user/owner/producer, as the choice of insertion opening—upper hole for plastic, lower hole for metal (Figure 7)—will depend on the user's ecological awareness. To guide the depositor, so that there are no doubts, the information necessary for the correct separation of recyclable plastic and metallic waste is placed next to each deposition hole. In addition, given the configuration of the deposition holes, the possibility of removal of the inserted residues by third parties is also safeguarded. This position of ours, transferring responsibility for the selection of waste to the producer, aims to simplify the compaction system by excluding the need for sensors which, in addition to the possibility of detecting the deposited waste and accounting for it, would make the system more expensive. The use of sensors, at this point of development, would be a fallible situation since it would be possible to deposit plastics in the metal container and vice versa.

3.1. Selective Waste Drawer

Conventionally, the separation of urban waste from plastic and metallic packaging will only be carried out in the processing unit and in the waste treatment phase. It is true that, although there is a pre-separation of waste (recyclable and non-recyclable) in the packaging collection, there is still a mixture of plastic and metal in the conventional containers. Therefore, and in the model developed and presented here, the selection of plastic and metal is carried out in the receptacle; that is, it is carried out in the act of deposition of the residue. Thus, the selection, which is entirely the responsibility of the depositor, is made through a selective collection drawer that will store plastic and metallic waste in different compartments with a capacity of approximately 320 liters. The allocation of each of the waste depends on the choice of insertion mouth (plastic or metal) that will guide the deposition to one side or the other of the drawer, that is, direct deposit in containers (removable bags) designated for each type, which will allow selective removal by the drawer method by a non-specialized operator (Figure 10) or by mechanical means, normally by a hydraulic arm (crane), in accordance with the current collection procedure.

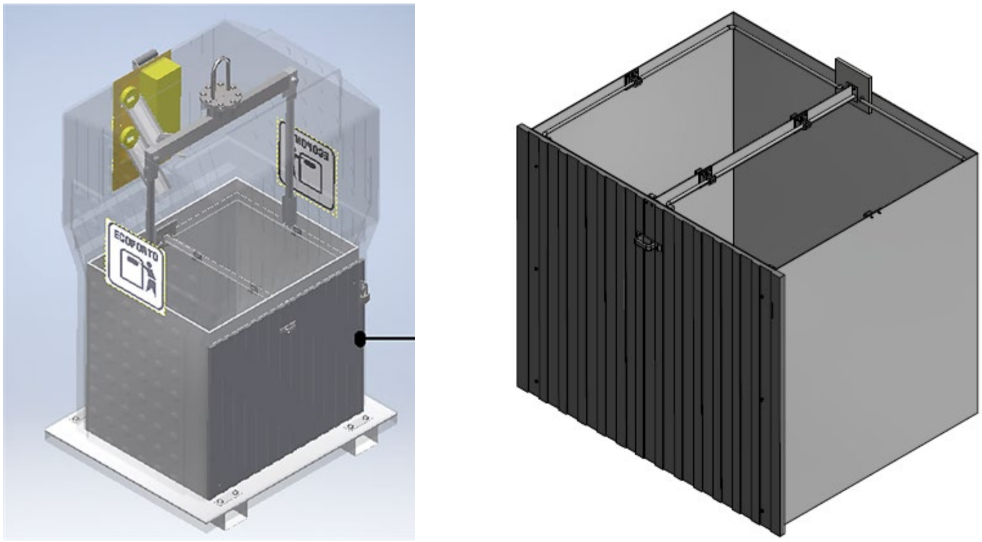

Figure 10. Selective waste collection drawer [46].

It should also be noted that these recycling approaches partially transfer waste separation problems to producers at the disposal stage. As such, they depend on raising the awareness of the depositors, awakening them to the need for effective recycling of MSW in the phase of selective waste disposal. These actions translate into indirect benefits for the municipality because, by anticipating the separation phase normally carried out in the treatment unit of most of the solid waste to be collected, we act as facilitators of the separation process and, consequently, of recycling.

It should be noted that by adopting the collection of selected waste in a drawer, it is easier to extract it and properly bag it in different envelopes, enhancing the use of transport vehicles with smaller dimensions. This potential reduction in the dimensions of the volume of the collection vehicle facilitates access to urban areas with restricted access and to historic centers with narrow streets, where the entry of larger vehicles is usually difficult. Whether using reduced or conventional vehicles, the reduction of transport costs is achieved by reducing the number of trips (with the consequent decrease in fuel consumption) and greater quantity transported per unit of volume from the vehicle collection park to the collection points and vice versa.

3.2. Storage Capacity

The use of a waste collection drawer divided into sections for plastic and metallic packaging led us to reduce the initial volume of the *cyclea* from 1500 liters to a quantity of approximately 320 liters. It is certain that this significant reduction, a ratio close to 4.7 lower than the initial volume of the container, will have to be compensated for by the increase in the amount of material to be received.

Thus, the initial objectives of this proposed collection model will only be achieved as the waste is compacted and stored in the drawer, since, for example, a tinplate can of 118 × 100 × 0.25 mm will occupy a volume of approximately 0.927 liters before compaction. With compression, considering a force of approximately 2500 N, it will undergo a displacement of about 80 mm, now occupying a volume of 0.298 liters [35]. In addition, in their initial state before compression, the cans do not occupy all the inner space of the container. Thus, if we consider that 10% of the space between the cans is "empty", the space occupied by the cans would be only 675 liters (considering only half 1500 liters containers), so the amount collected would be approximately 728 cans, while in the half drawer (320 liters and 2.5% of empty spaces), approximately 1054 compressed cans would be collected, which is equivalent to additional 326 cans. The compaction of plastic/metal packaging translates into a sharp decrease in the volume of the product to be recycled and, consequently, there will be a significant increase in the amount stored in a smaller volume. Therefore, the implementation of such compaction units in the packaging waste *Ecopoints* would contribute to a reduction of approximately 30-45% in collection and transportation costs, with the corresponding reduction in energy consumption and greenhouse gases emissions (GHG), while also contributing to an increase in the population involvement in their MSW production management through selective disposal and preprocessing of recyclable fractions.

The reduction in volume and the increase in the loading capacity of the collection vehicles translate into a significant reduction in rounds which will then translate into a substantial reduction in transport costs (Figure 11). Compare the collection capacity of a large tri-flow vehicle of 15 m^3 (collection of 3 types of waste at the same stop: 5 m^3 + 5 m^3 + 5 m^3) without compaction, with a micro (mono-flew) vehicle of 5.5 m^3 (suitable for selective collection in areas of difficult access). Based on the previous data, it can be seen (Figure 11) that the proportion of vehicles will be approximately 2.5 times less with 6.5 collections (tri-flow) and 17 collections (micro) per round, respectively. In the first case, three vehicles and six people would be needed for the collection, while in the second case, only two people would be needed in a larger round.

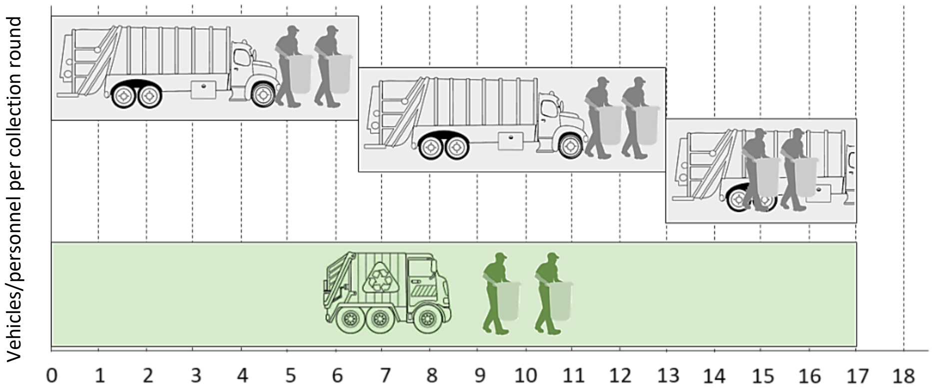

Figure 11. Number of rounds of collection of uncompacted and compacted waste.

Therefore, this cost reduction is not a unique benefit, as it will always be associated with the reduction of associated emissions in addition to the vehicle's life cycle costs, personnel, and fuel costs, as well as in the compaction that will be avoided in the installations of MSW processing [47,48]. Thus, if the previous statement is more detailed, it will be necessary to start from certain premises that we will consider as fixed. In this sense, the cost of the two vehicles (CV)—initial investment, maintenance, insurance, consumption, and periodic inspections—was considered equal and, consequently, all their associated costs. For personnel costs, a monthly remuneration amount of €893 was defined, working 8 hours/day, 22 days a month, over 11 months. The defined collection route corresponds to 30 km with a maximum number of 17 containers (plastic/metal). The "Micro" vehicle (5.5 m^3) carries out a single round per week while the "Tri-flow" vehicle (15 m^3) carries out the same round as the "Micro" with three different routes. Mileage difference is based on different route restart points (Table 1).

Table 1. Collection and transport cost for the Micro and the tri-flow vehicle (route/vehicle).

Vehicle Type	Vehicle Cost	Team Cost	Cost of the Last Route	Round Trip Cost for Unloading	No. of Contain. Collect.	Freq. (Week)	km	Total Cost
5.5 m^3	€25,580	€15	€1,279	€6	17	1	30[a]	€326
15.0 m^3	€21,317	€15	€8,527	€5	6	3	25[b]	€362
	€17,053	€10	€4,263	€5	6		20[c]	€259
	€21,317	€12	€1,291	€5	5		25[d]	€275

Thus, the different distances covered by the "Tri-flow", identified in Table 1, correspond to the initial route (Figure 12b), represented in red (±5 km), and the respective route to the deposition point, defined in gray (± 10 km). In Figure 12c, for a second route of the same vehicle (±5 km), the collection starts at the stop point of the previous collection, following the same route of the "Micro", see Figure 12a. The route to the deposition point is now ±5 km. Figure 12d represents the third route of collection of metallic packages which corresponds to the last part of the route.

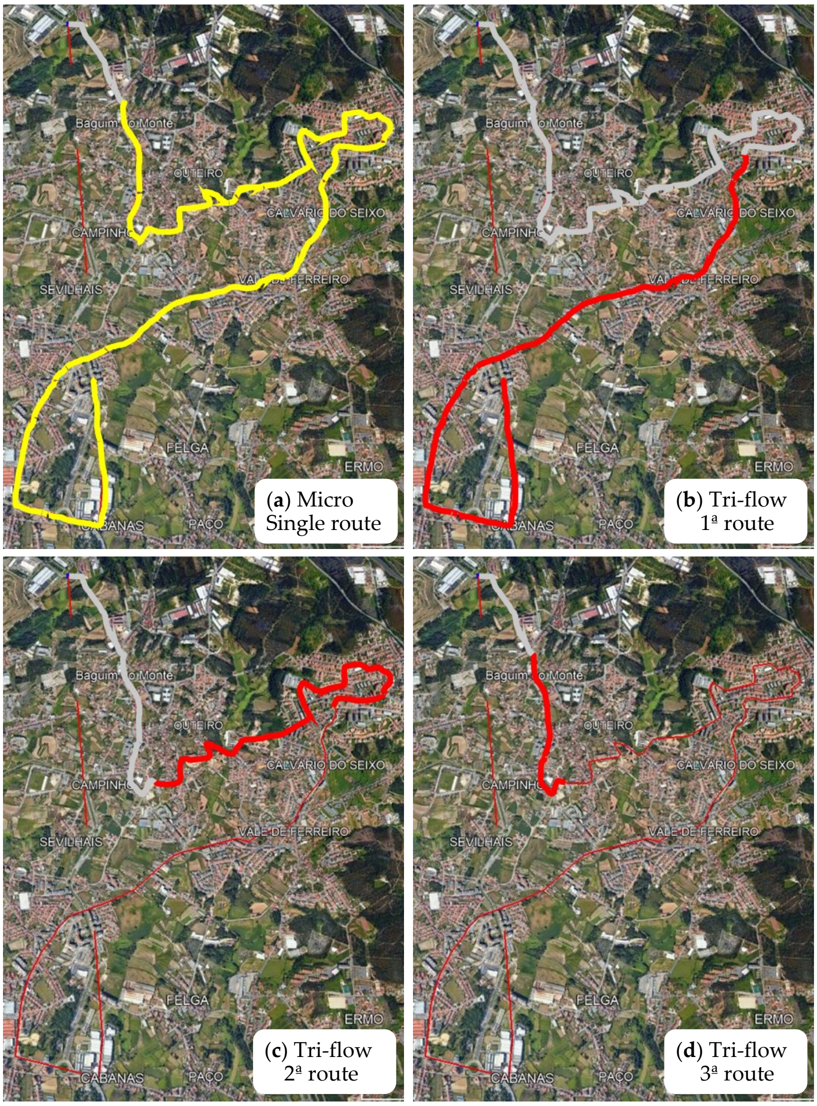

Figure 12. Collection and transport routes for: (**a**) Micro; (**b**–**d**) Tri-flow vehicle.

After deposition in the processing unit, the vehicle returns to the starting point, at the beginning of the first route, and travels the same route as the "Micro" vehicle (±15 km). Therefore, the costs (see Table 1) in the situation of collection carried out with a single tri-flow vehicle, for the same route, will correspond to approximately €900, which is roughly three times more. Note that these costs relate only to the collection of packaging; although the vehicle can collect glass and paper, the costs associated with glass and paper were not included in this analysis.

Among the gains already mentioned and explained above, it should also be considered that the reduction of energy consumed begins in the first stage of waste processing, since the first stage of compaction is carried out by the depositor. In this sense, the depositors transfers their muscular energy to the compaction process, converted into mechanical energy through the activation of the lever. Thus, contrary to the domestic model proposed by Xevgenos et al. [35], the project herein presented does not require the use of electrical energy and is based solely and simply on the mechanical (muscular) energy provided by the user of the municipal waste collection container. This contribution, even though small, is the beginning of a process of reducing the energy spent on compaction which begins at the collection point, that is, at the *Ecopoint*. These contributions are very important to bring us closer to fulfilling the goals stipulated by PERSU2020 [49].

In future works, other approaches to the route under study may be analyzed. In this analysis, the efficiency of the route can be studied, considering, for example, the use of a tri-flow vehicle with a capacity of 5 m^3 and a compression ratio of three to one. Additionally, from the point of view of the problem studied above, a study that will be very important to carry out concerns multiplying (by three) the number of vehicles in transit on the same route instead of just one carrying three materials. In this situation, the collection to be carried out by each of the vehicles would start at the three points defined in Figure 12b–d, and can examine the fuel gains resulting from this solution. In other words, it can examine what global gains could be made.

4. Conclusions

The use of plastic and metallic packaging collection units equipped with a compacting unit will optimize the load capacity, lower the packaging volume, and allow for a greater quantity of packages collected in *Cyclea* containers and collection points. With the proposed remodeling of *Cyclea*, in addition to the considerable increase in the amount (weight) of solid waste collected (30-45% increase), it is also intended to contribute to raising citizens' awareness to the need for recycling. Citizens, as participants in the separation and recycling process, carry out, in the initial phase of the recycling process, a sorting process that leads to the selective disposal of waste. It is essential that, for a good use of all waste, this cycle coexists with the conventional one, thus allowing for the collection of all types of packaging.

This is an innovative project that, combined with *Cyclea*, allows volume reduction due to packaging compaction. Consequently, it enables the collection of a greater number of packages per *Cyclea*, which can be considered an act of optimizing the management, which is intended to be profitable and, consequently, will essentially translate into a reduction in the number of weekly rounds or the number of daily rounds, that is, in energy gains. Thus, in addition to the economic return, compaction at the collection point can contribute to the reorganization of routes, not only in terms of collection routes, but also in terms of route times. An expected reduction on fuel consumption for transportation, ranging from 30-45%, will also contribute to the corresponding GHG emissions reduction, not only for transportation but also for waste compaction in large municipal waste compaction systems.

In addition, in an information society where data collection and processing are essential for an efficient management of resources and assets, sensing is essential. In a Smart City, these systems can be equipped with data acquisition sensors that, connected online to the city's global network, provide information on the amount of product processed or volume collected and can estimate the best day for collection. This interaction is an improvement for sustainability and planning, as it allows for the scheduling of collection in advance, optimizing route management, and anticipating the process itself, making it more efficient and profitable for all the stakeholders involved.

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