Cleaner Waste Systems 4 (2023) 100073

Contents lists available at ScienceDirect

Cleaner Waste Systems

journal homepage: www.journals.elsevier.com/cleaner-waste-systems

An assessment of the illegal dumping of construction and demolition waste

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ARTICLE INFO

Keywords:
Construction and demolition waste (CDW)
Dumpsite
Illegal dumping
Municipality

ABSTRACT

Addressing the illegal dumping of construction and demolition waste (CDW) is challenging because there are significant costs associated with clean-up actions but, for many local authorities, no data is available to describe this reality and to support the decision-making process. This research is focused on how to study the dynamic of CDW dumpsites, characterising these occurrences in order to understand the factors that influence them and to raise awareness to the problem with the results obtained. It involved the municipalities of a rural region, with scant infrastructure for CDW treatment, in monthly observations of the aforementioned sites. In total, 136 dumpsites were observed, with 65% of them located on public-owned land. For these dumpsites, 18 thousand tonnes of CDW were estimated, of which 59% correspond to the mineral fraction. The cost of removing the abandoned CDW was estimated at between €84 and €99 per tonne, with the component directly associated with municipal resources estimated at around 28% of the total. During the one-year monitoring period, 26 new dumpsites were observed, and 156 tonnes per month of CDW were recorded. Performance indicators demonstrated that the municipalities with some type of local solution for CDW management report less illegal dumping. These findings are relevant for filling the gaps in data about the illegal dumping of CDW on local scales and in less developed countries, supporting decision-making processes. In terms of research, the results address gaps in the literature since there is scarce data about these occurrences.

1. Introduction

Illegal dumping, or the intentional abandonment of waste in unauthorized areas (Liu et al., 2021; Lu, 2019), has been extensively studied from the point of view of its various effects. Indeed, the interaction between these effects may be key to fully understanding the problem (Du et al., 2021). For instance, research has been conducted pondering essentially the following factors: territorial and environmental conditions (Limoli et al., 2019; Vaverková et al., 2019; Seror and Portnov, 2018; Sharma et al., 2018); law enforcement and supervision (Seror and Portnov, 2020); the need for cooperation among stakeholders (Santos et al., 2019; Sahramäki and Kankaanranta, 2017); social circumstances (Wright et al., 2018); and individual characteristics (Lu, 2019; Comerford et al., 2018). However, most studies have focused on analysing illegal dumping as a whole, rarely presenting a detailed analysis by type of waste. In the context of those studies, the focus was on municipal waste (Jiang et al., 2020; Nagpure, 2019; Yang et al., 2019; Sharma et al., 2018), but where different fractions are presented as mixtures.

The construction sector is an important economic activity in terms of circular economy (Zhang et al., 2022; European Commission, 2020), and because illegal dumping is a problem frequently associated with this sector, the abandonment of construction and demolition waste (CDW) could be more researched (Yang et al., 2019). While illegal CDW dumping is frequently mentioned in some studies (Chen et al., 2019; Hao et al., 2019; Islam et al., 2019; Ding et al., 2018; Yuan et al., 2011; Webb et al., 2006), the reality and reasons for it are not sufficiently explored. Several studies mention the occurrence of illegal CDW dumping, but only as part of the whole illegal dumping problem (Otwong et al., 2021; Hidalgo et al., 2019; Nagpure, 2019, Ichinose and Yamamoto, 2011).

This is also the case in Portugal, where there is no data available that is collected through a systematic and supervised process, with pre-established research criteria, namely considering municipal records, about the illegal dumping of CDW (APA, 2018). This lack of data makes it difficult for municipalities to be aware of the costs of clean-up actions of abandoned CDW and how to intervene, to create solutions to the problem.

From this perspective, it is relevant to study occurrences of the illegal dumping of CDW on a local scale dynamic, comprehending causes and consequences. This research project aims to respond to the lack of

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https://doi.org/10.1016/j.clwas.2022.100073
Received 7 November 2022; Received in revised form 9 December 2022; Accepted 29 December 2022

data about this subject on a local scale. Furthermore, it intends to raise awareness of the constraints and, simultaneously, to encourage the implementation of solutions, in terms of political and operational decisions, but also in addressing gaps in the literature about these occurrences in rural areas or less developed countries with similar characteristics.

2. Literature review

2.1. Determinants of illegal dumping

According to Du et al. (2021), illegal waste dumping has generally been studied from four perspectives: environmental science and ecotoxicology; decision-making of stakeholders regarding the economic perspective; evaluation of factors from a management standpoint; and the use of emerging technologies to retrieve and manage occurrences.

In this context, contributions have been added to specific subjects. For example, geographical attributes are a common factor observed in research (Jordá-Borrell et al., 2014). In most cases, illegal dumping is related to low population density, peripheral inhabited areas (Vaverková et al., 2019), the percentage of forest cover, the distance to the edge of forest areas (Seror and Portnov, 2018), topographical features, and the characteristics of road networks (Matos et al., 2012).

Specifically for municipal waste, households with easier access to waste collection services are less likely to act illegally (Sotamenou et al., 2019). This conclusion is corroborated by Yang et al. (2019), pointing out that low accessibility to waste treatment is associated with illegal dumping, and that the mismanagement of spatial characteristics leads to illegal behaviour. Moreover, as a way to avoid abandonment, He et al. (2022) affirm the necessity of evaluating cross-regional alternatives for waste management. Other circumstances have, however, also been examined, for instance in Thailand, where Otwong et al. (2021) indicated the possible causes for recyclable industrial waste dumping: lack of a market, the absence of efficient monitoring processes, poor regulations, inadequate penalties, and non-engagement of the private sector.

One peculiar remark is that it is common for pre-existing dumpsites to reappear, even after clean-up actions (Niyobuhungiro and Schenck, 2021). This may be because the geography of these sites favours illegal behaviour, or because the generation of waste is greater than the authority's ability to handle it legally (Šedová, 2016). When illegal dumpsites are an unresolved problem for several years, a decision whether to restore such sites must be made. In most cases, however, this involves high investment (Hidalgo et al., 2019).

Yang et al. (2019) observed that higher levels of territorial monitoring and supervision are necessary. This is more relevant in cases where waste management policies and law enforcement are declared ineffective (D'Amato et al., 2018). Engagement at the corporation level is a necessity, and the relationship between illegal behaviour and public awareness and participation must be explored (Sahramäki and Kankaanranta, 2017).

Analysing the reality of illegal dumping is challenging and hindered further by the lack of consistent data. From this perspective, there are limitations to the characteristics and the spatial distribution of illegal occurrences (Jordá-Borrell et al., 2014). This being so, some recommendations made by Webb et al. (2006) deserve reflection, for instance increasing the difficulty and risk, reducing rewards and incentives, but excluding the possibility of excusing offenders.

2.2. Construction and demolition waste illegal dumping

Research on illegal dumping has mainly concerned solid waste (Du et al., 2021). Although several studies have considered the CDW value chain, illegal dumping has not been one of the primary subjects (Yang et al. 2019). Though scarce, some studies have presented certain results for the illegal dumping problem, where CDW is considered in terms of its general characterization (Nagpure, 2019; Rahim et al., 2017; De Melo et al., 2011; Ichinose and Yamamoto, 2011). Although each of these cases has its own context, the mineral fraction is predominant.

For CDW, geographical factors, such as the distance to the nearest main road, the depth of a ravine, and the proximity of a forest are good predictors for CDW illegal dumping, as well as for illegal dumping in general. However, the large size of some of these areas in the territory make them more difficult to monitor (Seror and Portnov, 2018). All these problems can result from inadequate planning and construction site management and supervision, as well as from the prevalence of micro and small construction companies with a lack of workforce expertise (Ramos and Martinho, 2022, 2021).

Blaisi (2019) observes that CDW illegal dumping occurs mainly because of transportation costs. This is in line with data presented by Mihai (2019), where CDW abandonment is encouraged in middle-sized and smaller cities because there are not enough waste recovery facilities. Ichinose and Yamamoto (2011) add that the number of illegal dumpsites declines if the number of intermediate waste management facilities rises. However, De Melo et al. (2011) studied CDW management in the Lisbon Metropolitan Area, where the facility identified is about 23 km from Lisbon, and even in this context, CDW dumpsites still occur.

Regarding CDW management, law enforcement is a topic that is frequently raised in the field (Duan et al., 2019; Mihai, 2019; Menegaki and Damigos, 2018). Additionally, researchers have analysed the effect of penalties on illegal dumping, demonstrating that they can effectively control it (Chen and Lu, 2017; Tam et al., 2014). However, while penalties and incentives might bear positive results, excessive values may not create the expected effects (Liu and Teng, 2022; Du et al., 2020). Along the same lines, Chen et al. (2019) concluded that raising a penalty without maintaining the probability of supervision could be unproductive. Liu et al. (2021) report that law enforcement policies might have low efficiency depending on the fines inflicted, or even on the low probability of being caught (Seror and Portnov, 2020). It is also relevant to consider that a waste producer can always try to find ways to avoid being caught acting illegally, reducing the efficacy of policies (Liu et al., 2022). Or even that although supervision could reduce illegal dumping, the subsequent effect on landfill disposal and recycling might be unclear (Liu et al., 2020).

However, You et al. (2020), through a case study focused on a waste transportation supervision system, also state that unauthorized vehicles continue to abandon CDW. This adds to the complex reality of CDW management challenges, where the absence of environmental awareness is often a major problem to overcome (Hao et al., 2022; Liu et al., 2022).

In Portugal, Santos et al. (2019) observed that CDW is illegally disposed of in public and private areas, with cleaning actions often supported by municipalities at a high cost. Despite this being a frequent problem, there is an evident lack of cooperation to resolve it. De Melo et al. (2011) state that data regarding illegal CDW dumping are not consistent at a municipal level, which is a constant problem in Portugal (APA, 2018; European Commission, 2015). In turn, Seror and Portnov (2020) observed that although local legislation exists, limited budgets and the scant human resources of local authorities make it largely ineffective at tackling CDW illegal dumping behaviour (validated by APA, 2018). These conclusions are supported by Rahim et al. (2017), who also indicated the need for more cooperation between construction companies and government.

Gálvez-Martos et al. (2018) identified best practices for the local scale, which involved clear guidance for small waste producers, minimum waste sorting conditions, reinforcement of municipal collection service, and communication mechanisms. In fact, public involvement and government action can impact the behaviour of waste producers, as they might feel obliged to comply with norms (Du et al., 2020; Chen et al., 2019), or even want to feel integrated within the solutions (Al-Otaibi et al., 2022; Mahajan et al., 2022; Vasconcelos

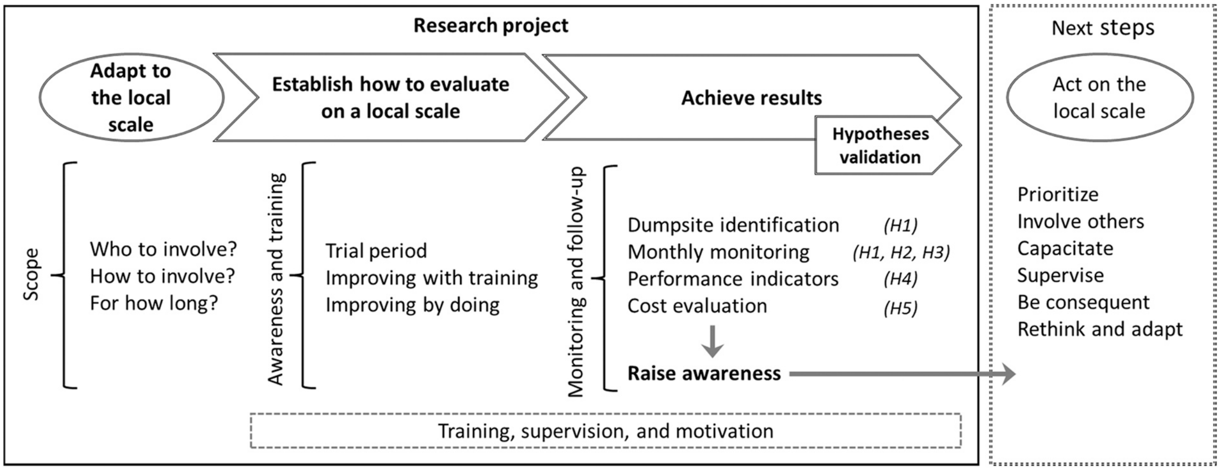

Fig. 1. Methodological approach to the monitoring process in the local scale context.
Legend: H - Hypothesis.

et al., 2020). However, important gaps in knowledge have been identified over time that are transversal to the construction sector (Ramos and Martinho, 2021; Gangolells et al., 2014; Saez et al., 2013; Begum et al., 2009).

As Yuan et al. (2011) state, the cost of CDW must include a component related to construction site waste management, and the environmental cost of illegal dumping. The second component, regarding the cost of clean-up actions is often overlooked, as is the indirect income loss from this material not being reincorporated into the construction sector, under controlled conditions. And which, by not complying with circular economy principles, does not add value.

3. Method

3.1. The methodological approach used in the study

The methodological approach was developed to help close gaps in the current research and to meet the need to consider the reality of the local scale (Fig. 1). This research was carried out in a region of Portugal called *Baixo Alentejo* – European Nomenclature of Territorial Units for Statistics, level 3 (NUTS 3) – an area of 8,543 km^2, comprising 13 municipalities. It is a rural region, where the area of municipalities varies between 168 km^2 and 1,293 km^2, with a median of 648 km^2. It is a region with low population density, averaging 14 inhabitants per km^2. For contextualization, the average population density for Portugal is 112 inhabitants per km^2 (adapted from INE, 2020). Additionally, it is a flat territory, with sparse vegetation, and few main roads.

The lack of infrastructure and solutions for CDW management is identified as a challenge in Portugal (European Commission, 2015). This problem is particularly relevant in the *Baixo Alentejo* region, where the main solutions are far from most of the municipalities and construction sites. Other important constraints are the lack of human resources available to municipal services, and knowledge gaps recognized by stakeholders (APA, 2018). Moreover, the reality of the construction sector, which makes up over 95% of micro and small construction companies, is pertinent (IMPIC, 2020).

3.2. Hypotheses

In this research project, five hypotheses (H) were framed to acknowledge the reality of illegal CDW dumping (Fig. 1): H1 – illegal CDW dumping occurs equally on publicly and privately owned land; H2 – illegal CDW dumping is a more recurrent situation at pre-existent dumpsites than at new dumpsites; H3 – the physical composition of CDW differs according to the size of the dumpsite; H4 – Proximity solutions for CDW management avoid illegal dumping; H5 – Municipalities contribute with an important portion of the total cost of CDW abandoned cleaning actions.

3.3. Monitoring criteria

3.3.1. Trial monitoring period

After deciding on the scope of the research project, a municipal representative was selected in each municipality to be responsible for internally coordinating the monitoring process, which was carried out monthly for 15 months. The first three-months was a trial period, during which technicians received instruction in monitoring. Dedicated sessions were held with a few municipalities at a time, mostly by videoconference because this took place in 2021, during the Covid-19 pandemic.

In May 2021, it was possible to travel to the study area to oversee the CDW dumpsites with the municipal representatives, and adjustments were made to certain procedures to ensure the harmonization of criteria. The capacitation approach was maintained during the entire monitoring period.

3.3.2. Dumpsite characterization and monitoring reporting

Each municipal representative received instructions concerning the identification and evaluation of CDW dumpsites: a) to register as a dumpsite any site where CDW was abandoned; b) to identify and register all known CDW dumpsites within the municipal boundary; c) to visit all known CDW dumpsites every month; d) to register new dumpsites; e) to visit the new dumpsites monthly; f) to photograph the dumpsites; g) to identify each different type of CDW present; and h) to estimate the respective quantity.

Every month, each municipal representative sent a *Microsoft Excel* file with their results for the dumpsites and for estimating CDW. They were also asked to gather information from existing data on illegal CDW dumping in the past, and on construction sector dynamics.

For each dumpsite, the following was required: a) an ID, and b) site ownership status (*i.e.,* public or private). For technical reasons, it was not possible to carry out local georeferencing of each dumpsite. With regard to estimating CDW dumping, the following data was required: a) date of the visit; b) types of CDW in each dumpsite, in accordance with the six-digit codes of the European List of Waste (ELW) (European Commission, 2014); c) estimation of the volume of CDW (cumulative approach); d) a calculation of the weight of CDW, using a pre-established dataset on the density of materials; and e) whether a cleaning action overseen by the municipal services or other entities has occurred. In the last case, the action date was requested, as well as the destination for the CDW and respective cost.

The quantity of CDW present at each dumpsite was estimated by volume. To harmonise the estimation criteria among municipalities, it was explained during training that a unit of volume familiar to each technician, depending on their experience, should be used for reference. For instance, a 1 m^3 big-bag or a 6 m^3 multibenne container. With regard to the types of CDW present, this was assessed considering only the surface of each CDW dumpsite.

3.4. Criteria for performance indicators

The first group of indicators was aggregated into two main subgroups. The first relates to the total amount of CDW currently accumulated in the area under study. The second considers only CDW accumulated during the monitoring period of one year.

Considering the characteristics of the region, together with the geographical determinants identified in the literature (Vaverková et al., 2019; Seror and Portnov, 2018), the municipalities were aggregated into three categories according to area size: area inferior to 500 km^2 (5 municipalities), area equal or superior to 500 km^2 but inferior to 1,000 km^2 (5 municipalities), and area equal or superior to 1,000 km^2 (3 municipalities).

Because waste management facilities have been shown to have an impact on CDW illegal dumping (Mihai, 2019; Ichinose and Yamamoto, 2011), this assessment included whether the municipalities provided local solutions for CDW management. Among these solutions is the provision of big-bags to individuals or micro and small construction companies, the rental of multibenne containers, or making available municipal controlled spaces for preliminary storage of CDW.

The second group of indicators attempts to understand the relationship between CDW illegal dumping and the construction sector dynamics. Data on construction sector activity for the period between 2017 and 2020 were provided by the municipalities, and municipal average values were calculated.

3.5. Cost evaluation for construction and demolition waste illegal dumping

For raising awareness purposes, this evaluation consisted of calculating an indicator of cost, for the amount of CDW abandoned. However, a lack of organized operational information at a municipal level (also stated by De Melo et al., 2011) makes that challenging. For this study, one difficulty arose from the different unit values recorded by the municipalities for vehicles (*e.g.,* vehicles for transportation of personnel and equipment *versus* vehicles for transportation of waste). Nevertheless, effort was taken to maintain the estimation as close as possible to the reality under study, and to the defined objectives. In any case, the municipal technicians involved were asked to provide a validation of the unit costs used, as well as the methodological approach taken.

To calculate the indicator of cost (C), by unit of mass (€ per tonne), two components were assumed. First, the municipal component (CM), where CDW is removed from dumpsites using their resources, and delivered to municipality controlled spaces for preliminary storage, before gaining scale to optimize the cost of transportation. It was decided to use an intermediate point for preliminary storage because the majority of dumpsites consist of small amounts of CDW. The second part involved the transportation of the CDW to an intermediary or final waste management operator (CF) (Eq. 1).

$$C = CM + CF \tag{1}$$

Each component of cost considers the sum of the cost calculated individually for different CDW groups since they have significant physical characteristics and different treatment costs. For estimation purposes, the following CDW groups (g) were established: mineral fraction, bituminous mixtures, CDW mixtures, and hazardous CDW.

To calculate the first component (CM), the variables concerning the CDW cleaning action at the dumpsite and transportation to the municipal controlled site were used (Eq. 2). The calculation specifically for the cleaning action involved: the total quantity of CDW in each CDW group (Q); the working time required to remove a unit of mass (T); the human resources income per unit of time, taking into account the number of workers assigned to the cleaning action (W); and the cost for the equipment allocated to the service, per unit of time, but excluding the vehicle for CDW transportation (E). For the transportation of CDW to a municipal site for preliminary storage, the calculation involved: the quantity of CDW transported each time, in reference to the vehicle capacity used for CDW transportation (q1); the distance to each dumpsite, bearing in mind a round trip (d1); and the cost of transportation to the vehicle responsible for this service, per unit of distance (c1).

$$CM = \sum_{g=1}^{n} (Q_g \times T_g \times W_g \times E_g) + \sum_{g=1}^{n} (q1_g \times d1_g \times c1_g) \tag{2}$$

Regarding the second component of cost (CF) (Eq. 3), the calculation involved: the quantity of CDW transported each time, considering the vehicle capacity used (q2); the distance to the waste management operator (d2); the transportation cost to the vehicle responsible for this service, per unit of distance (c2); and the environmental fee for each group of CDW, per unit of mass (F).

$$CF = \sum_{g=1}^{n} (q2_g \times d2_g \times c2_g \times F_g) \tag{3}$$

4. Results and discussion

4.1. General considerations

For the monitoring work, 12 out of the 13 municipalities of the *Baixo Alentejo* region participated consistently and in accordance with the monitoring criteria defined. Given that the municipality that did not participate corresponds to only 2% of the total regional area, it was deemed to be of scarce relevance, so the assessment was made considering the entire region.

Another reason for this decision was because it is important to be aware that is not possible to distinguish whether the CDW dumpsites observed in a municipality area result from that same territory, or from illegal behaviours by individuals or construction companies from nearby municipalities.

4.2. Construction and demolition waste dumpsite identification

With regard to the characterisation of CDW dumpsites, Fig. 2 presents the evolution of those currently in existence. For the trial period, between March and May of 2021, 110 dumpsites were registered. The data collected are more variable because the municipal technicians responsible for this monitoring work were learning the reality of CDW illegal dumping in the territory.

Within the monitoring period, 136 dumpsites, mainly small-sized in terms of estimated volume, were observed (subsection 4.4, Fig. 4). Of these, 26 were dumpsites discovered between June 2021 and May 2022, which represents an average of 2.2 new dumpsites per month. That number remained stable after the trial period, which denotes a tendency for the reoccurrence of CDW dumping at existing dumpsites (noted by Niyobuhungiro and Schenck, 2021).

In general, CDW dumpsites are located strategically, in more isolated zones and near roads (corroborated by Vaverková et al., 2019; Matos et al., 2012), and sometimes just outside the controlled sites for preliminary storage of CDW because the area is fenced. This might be due to a lack of environmental awareness (Hao et al., 2022). In addition, oversight actions are limited and penalties are rarely applied (APA, 2018). While it might be easier for municipal services to pay more attention to those locations, scant human resources does not facilitate this type of intervention (Seror and Portnov, 2020; APA, 2018).

Municipal technicians were asked to register whether the dumpsites were located on public or private land, in order to determine who might

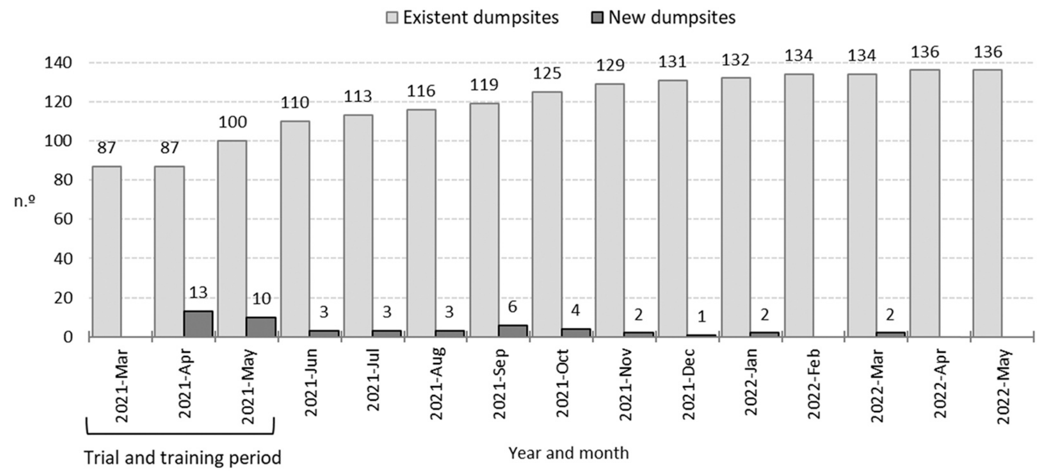

Fig. 2. Evolution of the number of existent construction and demolition waste dumpsites.

be responsible for the cleaning action. In May 2022, it was observed that 65% of the dumpsites were located on public land and the remaining 35% on private land.

4.3. Estimation of dumped construction and demolition waste

To estimate overall CDW it was first necessary to know the existing situation in the region and then add to that the CDW accumulated over one year. Municipal representatives were asked to register data about CDW cleaning actions that occurred during the monitoring period. There were, however, few actions and those that did occur dealt with small amounts of CDW, and municipal representatives were unable to register data from the operational staff. Thus, it was decided to perform the analysis without discounting these portions, since the estimated CDW would not differ significantly from the reported situation.

Although data were collected every month for each municipality, Fig. 3 presents the analysis by quarter, allowing a general perception of the tendency. This assessment excludes the trial period. Thus, the estimation performed in volume, for the existing situation in May of 2022, represents 10,401 m^3, corresponding in the present case study to 18,603 tonnes of CDW.

There is a specific CDW dumpsite to report that has different characteristics from the others. It is a consolidated site for CDW illegal dumping that remained unchanged for a long period. This is a reality of illegal dumping (*e.g.,* Hidalgo et al., 2019), that is sometimes overlooked in the territories. The estimate for this dumpsite was 6,300 m^3, corresponding to 11,340 tonnes of CDW.

However, if considering only the accumulated abandoned CDW for one year, it represents 1,263 m^3, equivalent to 1,867 tonnes. On average, this works out at 105 m^3 per month in the region, equivalent to 156 tonnes.

Excluding the specific CDW dumpsite mentioned before as an outlier, 61% of the total amount of CDW, in weight, is present on public land. For the accumulated CDW for one year, from June 2021 to May 2022, the equivalent proportion rises to 90%.

4.4. Physical composition of dumped construction and demolition waste

The physical composition of the CDW observed is presented in Fig. 4, in accordance with data registered in May of 2022, and excluding the consolidated dumpsite mentioned in subsection 4.3, which in that specific case, comprises the mineral fraction of CDW.

Although the estimates were reached considering the surface area of the CDW piles, around 1.5% corresponds to hazardous waste, being a mixture of CDW containing hazardous substances, contaminated soil and stones, or construction materials with asbestos. It is plausible, however, that more mixtures of CDW with hazardous substances exist. This is corroborated by the fact that, in smaller dumpsites where it is easier to identify and detail the different types, more hazardous CDW is discerned.

Around 59% of the estimated CDW corresponds to the mineral fraction (ELW 17 01 07), particularly comprising mixtures of concrete, bricks, tiles, and ceramics. This type of CDW has a high potential for recycling (data on the physical composition of CDW in illegal dumpsites corroborated by Nagpure, 2019; Rahim et al., 2017; Ichinose and Yamamoto, 2011). These mixtures may contain some lightweight materials, for instance little pieces of plastic, insulation materials, and wood. These results express the current reality in the construction sector, where the mineral fraction is predominant (Sormunen and Kärki, 2019; Coelho and De Brito, 2010). Furthermore, they reflect that the reality of illegal dumping is a huge constraint given the loss of material that could otherwise be reincorporated into the construction sector.

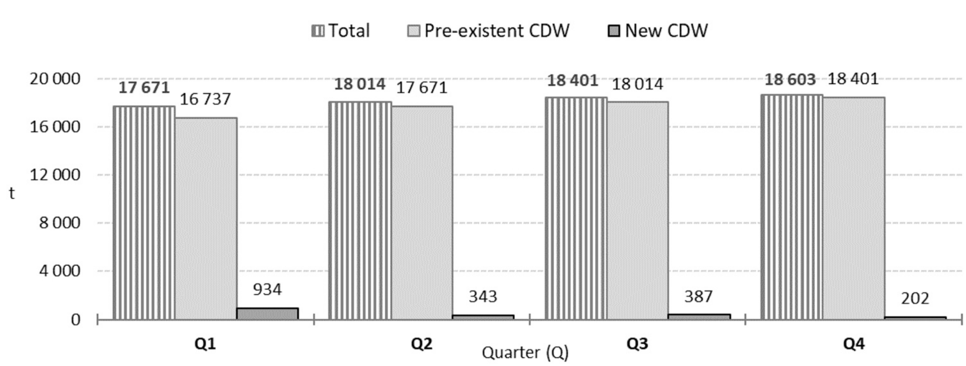

Fig. 3. Evolution of estimated construction and demolition waste accumulated in dumpsites, by quarter, between June 2021 and May 2022.

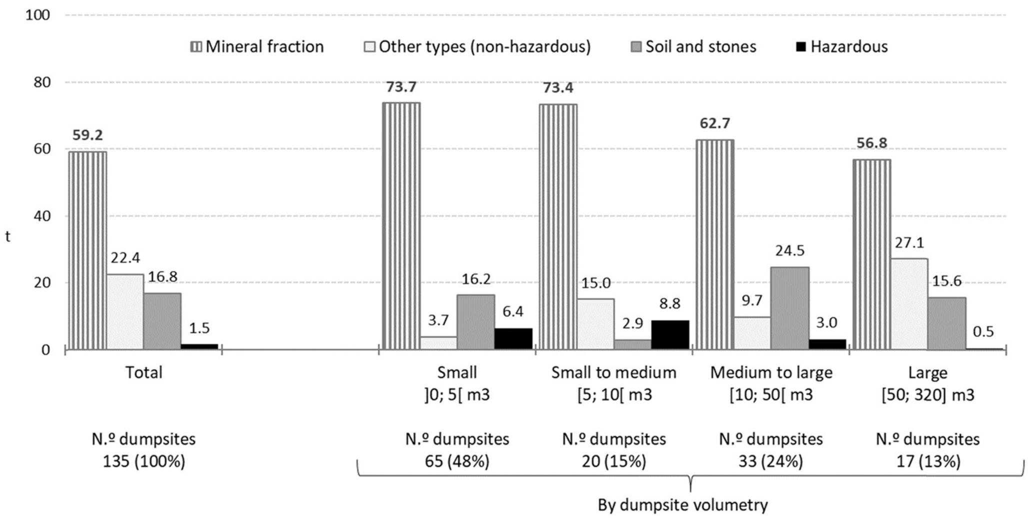

Fig. 4. Estimated physical composition for dumped construction and demolition waste, total and by dumpsite volumetry.

Less significantly, other types of CDW (*e.g.,* parcels of mixed CDW, bituminous mixtures, and wood) represent 22.4% of the total. Soil and stones, on the other hand, represent 16.8% of the total, and it is this category that has a high potential for reuse as long as it complies with specific regulations to determine whether it can be considered waste or a by-product.

Concerning the categories relating to the volume estimated for each dumpsite, it was observed that while the physical composition varies according to the size of the dumpsite, the mineral fraction predominates. Nevertheless, this fraction is more prevalent in smaller dumpsites, which may be due to CDW arising from small repairs and minor do-it-yourself construction and demolition activities. In medium-large and large dumpsites, other types appear, which can be related to the CDW accumulated over time from different sources.

4.5. Performance indicators for illegal construction and demolition waste dumping

The performance indicators of illegal CDW dumping in the *Baixo Alentejo* region (described in subsection 3.4) are presented in Table 1. First, the indicators were calculated for the existing CDW, excluding the dumpsite that was considered an outlier (subsection 4.3). Second, they reflect the CDW accumulated for a year. An analysis was performed for the volume, since the results may be useful for other sites where the physical composition may differ, and the weight was also analysed for this case study.

On examining the analysis of existing CDW up to May 2022, the number of dumpsites, as well as the amount estimated per unit area, is higher in smaller sized municipalities. This may be because of the dilution factor of larger areas, since smaller areas favour the discovery of sites which, in turn, could result in a more accurate assessment (supported by Seror and Portnov, 2018). Also, in the municipalities with a larger area, the amount of existing CDW in each dumpsite is higher, denoting existing dumpsites with more significant amounts of waste. With regard to indicators calculating CDW accumulation for one year, it appears that, in general, there is no clear evidence associated with the area range. However, the amount of CDW abandoned in each new dumpsite is less significant in larger areas, which could be because it takes more than one year for occurrences to become more significant.

On the other hand, municipalities with local solutions for CDW management achieve better results in terms of less illegal dumping (also supported by Gálvez-Martos et al., 2018; Ichinose and Yamamoto, 2011). This is true even if municipalities perceive the well-known constraints associated with the management of CDW on a local scale, and the attendant high costs (Blaisi, 2019; APA, 2018), or even problems with onsite sorting by construction companies (Gálvez-Martos et al., 2018).

Indicators regarding the construction sector dynamics were also calculated from the perspective of the number of construction works completed (Table 2). This calculation took into consideration the accumulation of CDW abandoned over the one-year period. Only private construction works subjected to a municipal process of licensing or prior notification were studied. It was not possible to obtain consistent data for public construction works at the municipal level. In any case, such interventions are usually carried out by medium and large construction companies, with more established procedures in terms of CDW good practice and compliance with legal requirements (Ramos and Martinho, 2022, 2021). Moreover, data on construction works carried out by the municipalities were not consistent. They were also not considered in this case because the perception is that small amounts of CDW are generated, which are sent to municipal controlled sites.

Municipalities executing fewer construction works appear to face more problems regarding illegal CDW dumping per completed construction. These municipalities are categorized in the lower area range (Table 1), which might help to justify the results. However, the analysis of municipalities with local solutions to CDW management shows they have better outcomes which, in this case, translate as less significant CDW abandonment in relation to each private construction work completed.

4.6. Cost evaluation for illegal construction and demolition waste dumping

This cost evaluation (Table 3) is intended to raise awareness about one major challenge that municipalities frequently face, which is the cleaning of CDW from dumpsites with its attendant high costs (Santos et al., 2019, APA, 2018; European Commission, 2015). At this level of analysis, no distinction was made between land ownership status (public or private), although this matters with regard to legal responsibility for the cleaning action and the respective cost of removing the dumped CDW.

With regard to cleaning actions carried out by the municipality, it takes three men 15 min to clean-up 1 tonne of CDW, with each man earning €7 per hour. A vehicle to transport the workforce to the dumpsites, and the use a medium-sized backhoe was considered necessary, giving unit values of €10 and €35 per hour, respectively. The estimated cost of transport between the dumpsites and municipal preliminary storage sites was based on average distances that reflected the size of the area covered by each municipality. This led to an average of around 9 km (considering 5 km for municipalities with a smaller area, 10 km for medium, and 15 km for the rest). A medium-sized vehicle

Table 1
Indicators for construction and demolition waste illegal dumping, considering the area size of each municipality.

Group of indicators		Indicator	Area range, for each municipality considered (km^2)	Total	CDW local solutions (Municipalities)	
					Without	With
Existing CDW abandoned	By unit area	Existing dumpsites (n.º/100 km^2)	[1000; 1300]	1.2	2.0	0.7
			[500; 1000]	1.8	2.1	1.5
			[160; 500]	2.2	1.0	3.1
			Total	**1.6**	**1.9**	**1.4**
		Volume of CDW (m^3/km^2)	[1000; 1300]	0.4	0.7	0.2
			[500; 1000]	0.5	0.9	0.1
			[160; 500]	0.7	1.3	0.3
			Total	**0.5**	**0.9**	**0.2**
		Weight of CDW (t/km^2)	[1000; 1300]	0.6	1.2	0.3
			[500; 1000]	0.9	1.8	0.2
			[160; 500]	1.2	2.1	0.5
			Total	**0.9**	**1.6**	**0.3**
	By existing dumpsite	Volume of CDW (m^3/site)	[1000; 1300]	33.8	36.6	28.8
			[500; 1000]	27.3	44.5	8.8
			[160; 500]	0.7	128.7	8.3
			Total	**30.4**	**49.1**	**14.2**
		Weight of CDW (t/site)	[1000; 1300]	56.2	59.5	50.4
			[500; 1000]	0.9	86.8	15.9
			[160; 500]	1.2	209.0	14.6
			Total	**53.8**	**87.1**	**25.0**
CDW illegally accumulated during 1 year	By unit area	New dumpsites (n.º/100 km^2)	[1000; 1300]	0.5	1.1	0.1
			[500; 1000]	0.1	0.1	0.1
			[160; 500]	0.5	N.D.	0.9
			Total	**0.3**	**0.4**	**0.2**
		Volume of CDW (m^3/Km^2)	[1000; 1300]	0.1	0.2	0.1
			[500; 1000]	0.1	0.1	0.1
			[160; 500]	0.4	0.7	0.1
			Total	**0.1**	**0.2**	**0.1**
		Weight of CDW (t/Km^2)	[1000; 1300]	0.2	0.1	0.2
			[500; 1000]	0.1	0.2	0.1
			[160; 500]	0.6	1.0	0.2
			Total	**0.2**	**0.3**	**0.2**
	By new dumpsite	Volume of CDW (m^3/site)	[1000; 1300]	13.3	15.0	1.5
			[500; 1000]	16.7	30.0	10.0
			[160; 500]	3.9	N.A.	3.9
			Total	**11.2**	**16.0**	**4.5**
		Weight of CDW (t/site)	[1000; 1300]	11.5	12.7	2.7
			[500; 1000]	28.5	48.0	18.8
			[160; 500]	6.3	N.D.	6.3
			Total	**12.1**	**15.1**	**7.9**

Legend: N.D. – No Data

Table 2
Indicators for construction and demolition waste illegal dumping, considering the number of private construction works for one year.

Group of indicators		Indicator	Private construction works completed (n.º)	Total	CDW local solutions (Municipalities)	
					Without	With
CDW illegally accumulated during 1 year	By private construction work completed	Volume of CDW (m^3/work)	[60; 85]	2.7	N.D.	2.7
			[40; 60]	1.0	1.4	0.5
			[20; 40]	2.5	3.5	1.9
			[0; 20]	27.6	25.5	N.D.
			Total	**2.8**	**4.3**	**1.8**
		Weight of CDW (t/work)	[60; 85]	4.6	N.D.	4.6
			[40; 60]	1.7	2.4	1.0
			[20; 40]	3.1	3.0	3.2
			[0; 20]	42.2	38.4	N.D.
			Total	**4.2**	**6.0**	**3.1**

Legend: Considering the average for 1 year, to each municipality evaluated, from 2017 until 2020; N.D. – No Data.

Table 3
Estimation of cost for construction and demolition waste cleaning actions on dumpsites.

Estimated CDW (%)		Estimated cost range (%)						Indicator (€/t)
		Municipality		Final destination (Waste operator)			Total	
		Cleaning	Transport	Transport	Treatment	Fee		
Including the large scale consolidated CDW dumpsite								
Mineral fraction	90.6	17.9	8.0	19.6	37.9	0	83.3	77
Bituminous mixtures	3.9	0.8	0.3	0.8	3.5	0	5.4	117
CDW mixtures	4.9	1.0	0.4	1.1	5.3	1.3	9.0	154
Hazardous CDW	0.6	0.1	0.1	0.4	1.5	0.2	2.2	300
Total	**100.0**	**19.7**	**8.8**	**21.9**	**48.1**	**1.5**	**100.0**	**84**
Excluding the large scale consolidated CDW dumpsite								
Mineral fraction	72.6	13.9	5.4	13.2	25.7	0	58.3	79
Bituminous mixtures	11.2	2.2	0.8	2.1	8.5	0	13.6	119
CDW mixtures	14.3	2.7	1.1	2.6	13.0	3.2	22.6	156
Hazardous CDW	1.8	0.3	0.1	1.0	3.7	0.4	5.6	303
Total	**100.0**	**19.2**	**7.5**	**18.9**	**50.9**	**3.6**	**100.0**	**99**

costing €2 per km was considered for CDW transportation, since that is the reality of most municipalities in the region.

With regard to transporting CDW to a waste management operator, a larger vehicle with greater handling capacity was contemplated at a cost of €3 per km. For estimation purposes, calculations were based on an average of 45 km being the distance from the city hall of each municipality to the waste management operator specified by municipal representatives. For the cost for CDW treatment, a market consultation was carried out in the region. The values used are indicative but intended only to represent an order of magnitude of the regional standards and are dependent on the contracted conditions. The following values were applied: €35 per tonne for the mineral fraction (with some lightweight material incorporated); €75 per tonne for bituminous mixtures; €90 per tonne for non-hazardous CDW mixtures; and €200 per tonne for hazardous CDW. Soil and stones were excluded from the calculation because, in general, they can be reused. Wood was also excluded since there were few observations of this material at dumpsites and it often disappears, possibly because it can be useful in other contexts. The environmental fee respects what is stipulated in Portugal to reduce landfilling of materials with recovery potential, and was set at €22 per tonne for 2021 and 2022.

Considering these assumptions, a cost indicator was calculated for two scenarios: including or excluding the consolidated CDW dumpsite referred to in subsection 4.3. Including this dumpsite led to a cost of €84 per tonne. However, if that dumpsite was excluded, the cost rises to €99 per tonne, since it mainly comprises the mineral fraction. This cost differs from municipality to municipality, depending essentially on the distances involved, the operational conditions, and on the physical composition of CDW.

The results concerning the evaluation of each portion of costs are expressed in percentages since the objective is to raise awareness of the different components that make up the municipalities' contribution to overall costs. In this context, the municipal component directly involving their equipment and human resources, corresponds to 27–29% of the total cost. This component is often diluted in other municipal costs, and so does not raise awareness about the problem of illegal CDW dumping. Also, it does not contribute to the shift in the vision of policymakers, encouraging them to recognise that the current cost burden for clean-up actions of abandoned CDW may be more effectively spent investing in local solutions to promote effective CDW management. For now, in the *Baixo Alentejo* region there are neither consistent initiatives nor is there data available at a municipal level which would allow an estimation of the benefit of implementing local solutions for CDW management instead of dealing with the illegal dumping of CDW. In this instance, it was not possible to proceed with in-depth analysis, simply opting to raise awareness of the problem through the results obtained.

5. Conclusions

The main objective of this research was to study the dynamic of CDW dumpsites on a local scale, and also to increase awareness of this issue through performance indicators and cost evaluation. The monitoring work was performed in a rural region, characterized by larger distances between most of the municipalities and the final CDW management waste operators. To achieve this objective, data were collected to evaluate the situation at the start of research and its evolution over one year.

In total, 136 CDW dumpsites participated in the study, of which 65% are located on public land. The estimate overall of abandoned CDW at these sites is approximately 18 thousand tonnes, with 59% corresponding to the mineral fraction. This portion, which has great potential for recycling, is always predominant regardless of the dumpsite size, which is an indication of how much circularity potential is lost because of illegal CDW dumping. With regard to the existing dumpsites, the perception is that there is a considerable recurrence of CDW abandonment. Between June 2021 and May 2022, 26 new CDW dumpsites were recorded, with an estimated 72 tonnes per new dumpsite.

CDW illegal dumping usually implies considerable costs for municipal services. Despite the many constraints resulting from gaps in information, it was estimated that a value between €84 and €99 per tonne would be needed to resolve CDW abandonment into the region, with the component directly associated with municipal equipment and human resources estimated at between 27% and 29% of the total. Municipalities are not aware of these costs, because they are not registered independently. So, this component is often neglected by municipal services since it is diluted in other costs.

When performance indicators were calculated to understand the dynamics of dumpsites, the conclusion was that municipalities with local solutions for CDW management have a less severe CDW abandonment problem. This statement is valid even though the municipalities are not satisfied with their alternatives. These solutions should be encouraged on a local scale, and awareness should be raised about the relationship with the aforementioned cost that is often borne by municipal services.

In this context, the findings of this research are useful in terms of filling gaps in the literature about data on the illegal dumping of CDW, in this specific case is addressing the problem in a rural area. The results are also important for tackling gaps in less developed countries characterised by facing similar challenges. Furthermore, the results are relevant for decision-makers in the areas mentioned, since one of the main purposes was to raise awareness and provide technical knowledge that did not previously exist. This is important to better understand what vision should be addressed, and how to tackle the main problems, specifically promoting local solutions to allow CDW waste to be properly collected and stored until it is sent to its final authorised destination.

However, it will be essential in further research to test intervention strategies and policies on a local scale, to comprehend which initiatives might contribute to better and more effective CDW management in this context, namely: CDW preliminary storage under municipal responsibility; awareness and oversight actions; and procedural control on licensing processes, assessing whether CDW was transported to authorised final destinations in the quantities expected. It will also be important to understand how local scales can contribute to the more general goal of achieving the circular economy principles in the construction sector, where all types of scales of intervention must contribute towards a common goal.

Moreover, since frequent and systematic monitoring work is time-consuming and demanding in terms of resources, future research needs to explore alternative ways to study illegal CDW dumpsites. This could perhaps be achieved using new technologies, or even with the involvement of those closest to the problem, such as local stakeholders and citizens, to identify occurrences and locate the sources.

Data Availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors would like to thank the municipal technicians and the representatives of the construction companies who collaborated on this research project.

The authors acknowledge financial support from the "(De)construct for Circular Economy" project, financed by the EEA Grants Environment Program (08_Call#2_(Des)construir_Economia_Circular). This work was also supported by the Portuguese Fundação para a Ciência e a Tecnologia (FCT) under the project LA/P/0069/2020 granted to the Associate Laboratory ARNET, and the strategic project UIDB/04292/2020 granted to MARE - Marine and Environmental Sciences Centre.

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