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Regional demolition waste treatment capacity: a case study based on the identification of building selective deconstruction value chain's stakeholders

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Abstract

The construction and demolition sector is a major contributor to waste generation, prompting European and national public authorities to adopt a waste management strategy based on circular economy (CE) principles. This strategy aims to promote the reuse and recycling of construction materials. A key prerequisite for this strategy is selective deconstruction, which allows for more efficient waste recovery by separating materials based on their treatment, reuse, recycling and landfill potential. Selective deconstruction involves a value chain that includes a range of stakeholders. This paper proposes a methodology for identifying the stakeholders involved in this value chain, from project owners to waste reclamation and recycling companies. This methodology is applied to the Lille European Metropolis (France – LEM) to estimate the Deconstruction Resources Treatment Capacity of this Region (DRTCR). Finally, this capacity is analysed in relation to the volume of resources generated by deconstruction, and to the objectives set by the circular economy strategy. Results demonstrate the importance of developing selective deconstruction at a local scale, and highlight the need for investment in this sector and potential of sustainable business.

Keywords: circular economy; construction and demolition waste; selective deconstruction; stakeholders; resources management; regional capacity.

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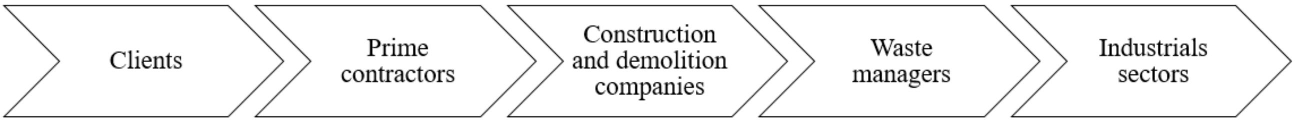
1. Introduction

The transition from a linear to a circular economic model aims to optimize resource use to preserve natural capital (Ellen MacArthur Foundation, 2015). Throughout the 20th century, the increasing mechanization of the demolition industry and declining profitability of building materials' reusing operations led to significant growth in construction and demolition waste (C&DW) production (Ghyoot et al., 2018). In 2018, the construction and demolition (C&D) sector accounted for 35.9% (2.337 million tonnes) of the waste generated in the EU, making it the primary source of waste production (Eurostat). In France, 47.3 million tonnes of C&DW were produced in that year. In response to this problem, the concept of a circular economy (CE) emerged in the academic literature in the early 2000s, becoming a key category of public policy in countries such as Germany[1], Japan[2], China[3] or the Netherlands[4]. The European Waste Framework Directive 2008/98/EC sets a target of 70% for non-hazardous C&D waste reuse, recycling, and material recovery by 2020 (European Parliament, 2008). In line with this goal, the French Parliament passed a "No-Waste for a Circular Economy" law in 2020 (Parliament, 2020).

In the C&D sector, selective deconstruction is a way to implement CE principles by replacing building demolition with a process that separates materials according to different treatment, reuse, and recycling sectors (Roussat et al., 2009; Assefa and Ambler, 2017; Ghyoot et al., 2018). Although private companies and public authorities increasingly use selective deconstruction, little academic literature specifically addresses this issue. Some research focuses on new deconstruction methods and programming (Sanchez et al., 2019, 2020). However, the development of selective deconstruction involves a value chain consisting of actors not only directly involved in the building site but also upstream and downstream (Tirado et al., 2021). The full commitment of owners, prime contractors, and project management assistance specialized in CE issues is required during the earliest phase of deconstruction to coordinate the various stages and actors of the worksite. Moreover, once materials are deconstructed, their treatment, reuse, or recycling may involve a range of different sectors. Therefore, the development of selective deconstruction potentially concerns many different stakeholders and jobs (Gálvez-Martos et al., 2018).

This study focuses on estimating the stakeholders and employment potential involved in an advanced selective deconstruction value chain, specifically in the Lille European Metropolis (LEM)[5] and its 95 municipalities. Through building an exhaustive database of potential stakeholders, from clients and contractors to waste reclamation and recycling companies (figure 1), this article aims to provide an overview of the CE development potential. This database is utilized to estimate the capacity of actors located in this area to treat resources generated by selective deconstruction. More specifically, the Deconstruction Resources Treatment Capacity of a Region or area (DRTCR) refers to two parameters of the construction and demolition waste management (C&DW-M): (1) the volume of products, equipment, materials, and waste resulting from selective deconstruction and generated per year from one region. For CE concept, having been removed selectively, those materials correspond with potential resources that can be recycled, recovered or re-used into building construction or rehabilitation. Then (2) the ability of workers employed by companies in the value chain and established in the area to process these resources define this capacity. The goal is to determine the ability of one Region/area to generate C&DW and its capacity to close loops in the building industry. The focus is placed on the labour force that directly handles these resources, by working on building sites, removing construction elements, transporting them to a treatment center, sorting them and preparing them for theirs recycling, recovery or re-use. Therefore, the DRTCR highly relies on the size of the workforce of the value chain, which is precisely the focus of the proposed methodology. The interest could be to help decision makers in regional communities to orientate and facilitate the implementation of public and/or private infrastructures optimizing the DRTCR of the C&DW-M.

Figure 1. Actors in the selective deconstruction value chain



Source: Author's elaboration, adapted from (Lofti, 2016)

The article first describes the multiscale regulatory framework that makes CE the main waste management strategy in the C&D sector, at the European, French and sub-national levels. The study then moves to literature review section, followed by a section describing the methodology used to create the database and estimate the DRTCR. The last section is dedicated to the main results and their discussion. Firstly, it determines the DRTCR of the LEM, and compares it with the estimated volume of

[1] Waste management law in a "closed-cycle substances" ("Kreislaufwirtschaftsgesetz") adopted in 1994.
[2] "Basic Act for Establishing a Sound Material-Cycle Society" adopted in 2000.
[3] Framework law to promote circular economy adopted in 2008.
[4] National waste management plan 2009–2021 entitled "towards a material chain policy".
[5] This article and the results it presents are the fruit of a research project carried out within an industrial chair called « RECONVERT » and financed by Lille European Metropolis and I-Site. Url : https://reconvert.wp.imt.fr/

waste generated in this area. Then, it examines the objectives fixed by public authorities in their CE strategies, showing that their achievement requires an increased DRTCR that could address gaps in the selective deconstruction value chain.

2. Contextualisation : an evolving regulatory framework

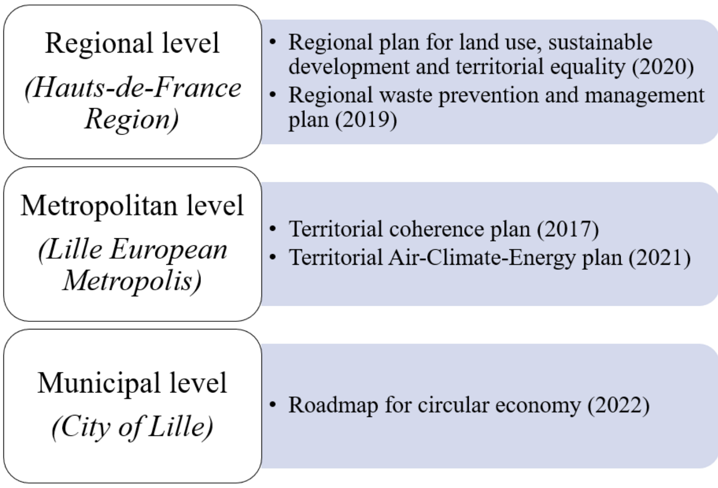
The legislative and regulatory framework at European, national, and sub-national levels demonstrates a clear and increasingly ambitious path towards the implementation of a CE in the C&D sector. Beginning in 2008, the European Union established a directive with the aim of achieving a 70% re-use, recycling, and material recovery rate for non-hazardous C&D waste. According to a 2020 report of the European Environment Information and Observation Network, most of European countries have already reach this 70% target, but “despite [these] high recycling rates, the recycling of C&DW is largely downcycling” (EIONET, 2020, p. 12). Moreover, this global rate masks substantial variations in material flows. While inert waste represents the largest volume and is relatively easy to recover, there is now a need for a more detailed waste management strategy, by adopting more precise objectives for each material. In 2015, the European Commission adopted a Circular Economy Package aimed at pushing forward the transition towards a circular economy. This package notably promotes the recycling of waste materials and sets targets for reducing landfilling. The European Commission reaffirmed its commitment to the CE strategy five years later, as part of the European Green Deal. This broader plan sets more ambitious objectives, and notably aims to achieve a climate-neutral Europe by 2050.

Similarly, France government established the *Grenelle* Law 2 in 2010, which outlined a waste planning strategy that ultimately led to the implementation of waste diagnostics for building demolition in the 2014-2020 national waste prevention program. In 2015, the "NOTRe" law (territorial organization reform) transferred waste planning jurisdiction to the regions, while the Law for Energy Transition and Green Growth established the circular economy concept as a guiding principle for the first time. By 2018, the French government had made CE a cornerstone of its waste management strategy through the Circular Economy Roadmap, which aimed to increase sorting, re-use, and recovery of demolition waste. Two years later, the "No-Waste for a Circular Economy" law further solidified this commitment by introducing an Extended Producer Responsibility (EPR) for construction material manufacturers and setting specific objectives for recovery rates for various materials. The EPR establishes an eco-contribution on the sales of construction products and materials, which is collected by sellers and transferred to Producer Responsibility Organizations (PROs). The PROs are responsible for organizing the collection, treatment, and recovery of building waste and material. The "No-Waste for a Circular Economy" law aims for a recovery rate of 88% for mineral waste and 57% for non-mineral waste by 2027. Precise objectives related to particular materials flows are also set, and their implications in terms of volume will be explored at the LEM level in section 5.

At the sub-national level in France, which refers to governance and decision-making below the national level, public actors have taken significant steps towards promoting circular economy practices. Since 2015, regions, which are the administrative level beneath the State, have taken over jurisdiction of waste planning, which is carried out through regional waste prevention and management plans. These plans outline strategies to prevent waste generation and promote circular economy practices, and are specific to each region in France. For example, the Hauts-de-France Region, which includes the LEM area, established a waste prevention and management plan in 2019, outlining its key objectives and an action plan for circular economy, with a particular focus on C&D materials. Regions also have to draw up a regional plan for land use, sustainable developmtent and territorial equality. That of Hauts-de-France, adopted in 2020, gives a prominent place to the implementation of CE in the C&D sectors, with specific objectives such as landfilling reduction, development of on-site sorting, and expansion of a territorial grid of recovery sites. Although these objectives address specific issues, their lack of precision and quantification makes it difficult to evaluate progress towards a more sustainable C&DW-M. Instead of setting specific targets, these planning documents outline the general ambitions of local authorities regarding urban planning, transportation, waste management, and energy. As shown in Figure 2, this kind of strategic documents is also implemented at the metropolitan and municipal levels. In particular, LEM adopted a territorial coherence plan in 2017, and a territorial Air-Climate-Energy plan four years later, with each setting CE objectives such as encouraging C&D waste re-use and recovery, promoting the develoment of recycling channels, or land using for waste recovery. Finally, in this multiscale regulatory framework, municipalities have also make CE a key strategy for resources management in the C&D sector. Lille for instance, the main city of the LEM, has notably adopted a roadmap for circular economy in 2022, with the ambition of creating a local platform for exchange and treatment of construction materials.

A these different scales, public authorities draw a clear path towards the implementation of CE in the C&D sector, establishing more and more precise and ambitious objectives related to resources recovery.

Figure 2. Local authorities' planning documents promoting CE in the C&D sector



Source: Author's elaboration[6]

3. Literature review

While the concept of selective deconstruction itself still requires further exploration, there has been extensive research dedicated to the application of circular economy principles in the C&D sector. These studies can be broadly classified into two categories. The first focuses on the technical and organizational challenges associated with managing C&DW. The second group of studies takes the C&D sector as a case study to inform research on circular economy more broadly. In this context, employment is among the social aspects impacted by the adoption of circular economy practices.

3.1 The construction and demolition waste management

An important part of the literature dealing with CE in the C&D sector comprises engineering science works that focus on technical and organizational processes related to C&DW-M. These works study the recovery of specific types of materials, such as concrete, metal, timber, plaster, plastic, and glass (Gorgolewski et al., 2008; Jung et al., 2015; Wijayasundara et al., 2016; Campbell, 2018; Mazzarano, 2021), or look at a particular type of building (Minunno et al., 2018). These studies suggest strategies for CE development in the sector, such as on-site recycling, manufacturing recycled aggregate, use of mass timber, but point out the fact that those strategies require improvements in organizational structures, technical knowledge, and investment in infrastructures. One of the main method used in the field is the life cycle analysis (Coelho and De Brito, 2012; Bovea and Powell, 2016; Wang et al., 2018; Brambilla et al., 2019; L. Eberhardt et al., 2019), which allows authors to highlight the environmental impact of waste demolition, and to investigate potential benefits of CE practices, which could concern the waste management as well as the building process and the type of components used in the construction. Moreover, the effectiveness of C&DW-M at the country or region scale were evaluated in the aims of improving it (Yeheyis et al., 2013; Lockrey et al., 2016; Nasir et al., 2017; Yuan, 2017; Zheng et al., 2017; Huang et al., 2018; Christmann, 2018). Those works aim at pushing policy-makers towards improvement in C&D waste management, by proposing CE strategies and objectives such as increasing recycling rate and reducing lanfill rate, adopting targeted economic incentives, or encouraging innovative

[6] All the documents mentionned are available online, on the websites of the Hauts-de-France Region: https://www.hautsdefrance.fr/ ; the LEM: https://www.lillemetropole.fr/ ; and the city of Lille: https://www.lille.fr/

technologies and market models. Other works examine waste treatment capacities in terms of the types of facilities (Mihai, 2019) or technologies used (Di Maria et al., 2018). Those studies are completed by the approach taken here, that aims to cover this issue of treatment capacities, in regard to the stakeholders of an region or area and their available labour force, as stated above in the definition of DRTCR. Indeed, although those works are of great interest for estimating generation and flows of C&D waste, especially through material flow analysis, and for exploring ways to reduce them, few of them aim to investigate stakeholders that are likely to take charge of these waste. That is why the next subsection deals with approaches in terms of CE social aspects that are, in this regard, complementary.

3.2 Circular economy in the construction and demolition sector and its social aspects

The methods for measuring and quantifying the circular economy have stimulated significant reflection and research. As results, the identification of a set of indicators that could reflect the circularity of a sector or a region has been extensively studied and discussed (Iacovidou et al., 2017; Nuñez-Cacho et al., 2018; Scarpellini et al., 2019; Fusco Girard and Nocca, 2019). Employment is often included as one of these indicators and considered in the social aspects of CE (International Labour Organization, 2011; Moreau et al., 2017, 2017; Laurenti et al., 2018; Jabbour et al., 2019; Padilla-Rivera et al., 2020; Scarpellini, 2021). These studies highlight the socioeconomic embeddedness of the CE and investigate its implementation's impacts, which extend beyond environmental considerations and affect the organization of work and employment within society. Furthermore, substantial research has focused on the CE's job creation potential (Horbach et al., 2015; Mitchell and Morgan, 2015; EHORE, 2017; Aranda-Usón et al., 2018), as well as employment structure and distribution (Repp et al., 2021), while some studies specifically address skills development (Consoli et al., 2016; Burger et al., 2019). This article follows the approach of Llorente-González and Vence (2020), who studied the repair, reuse, and recycling sectors using the second revision of the statistical classification of economic activities in the European Union (NACE Rev. 2). The authors' goal was to investigate the labour intensity of those activities defined as circular, on a European scale and using Eurostat statistical aggregates. The present article shares a similar objective, at a smaller scale corresponding with a metropolitan area, which allows for a comprehensive identification of stakeholders in a specific value chain: that of building selective deconstruction.

The academic interest in CE applied to the C&D sector is increasing, as evidenced by the growing number of systematic literature reviews (Ghisellini et al., 2018a, 2018b; Hossain et al., 2020; Ruiz et al., 2020; Superti et al., 2021). These studies aim to identity factors that could influence the adoption of CE in the sector, and their results suggest that a comprehensive framework and methodology for CE integration and evaluation are yet to be developed. To progress down this path, many studies focus on CE practices implemented by C&D companies (Chau et al., 2017; Leising et al., 2018; Chang and Hsieh, 2019; Rehman et al., 2020; Guerra et al., 2021; Guerra and Leite, 2021; Doussoulin and Bittencourt, 2022), and some provide analysis in terms of "best practices" (Jiménez-Rivero and García-Navarro, 2017; Gálvez-Martos et al., 2018). Other works explore the potential development of CE in the sector (Schultmann and Sunke, 2007; Sassi, 2008; L. C. M. Eberhardt et al., 2019; Romnée et al., 2019), and the indicators that could reflect this development (Nuñez-Cacho et al., 2018). On the scale of a company, those indicators refer in particular to waste generation, energy management, emissions and other negative externalities, materials management or the 3R principles – reduce, recycle, and reuse. However, only a few studies examine the social aspects of the sector's transformations due to CE implementation (Wuyts et al., 2019; Tomić and Schneider, 2020), or its consequences in terms of work practices (Ann et al., 2013). This latter study, with the case of Hong Kong, showed that a charge on C&DW disposal to landfills may not be sufficient to encourage actors of the C&D sector to change their building practices so as to reduce waste. This litarature suggests that CE implementation in the building sector relies not only on changes in the regulatory framework, but also on stakeholders' capacity to adapt their practices and organization to these challenges.

As no specific academic works identify stakeholders of the selective deconstruction value chain exhaustively, the following method is here proposed.

4. Methodology

4.1 Database construction

The method developed is applied to the specific area of LEM, in order to demonstrate its usefulness through a concrete case study. The metropolis covers an area of 671 km² and includes 95 municipalities, with a total population of approximately 1.1 million inhabitants. The metropolitan scale is particularly relevant to the issue of C&D waste management as it provides a consistent framework for optimizing material and waste streams, while also considering the environmental impact of transport.

In order to create an inventory of all the companies that could potentially be involved in the deconstruction value chain and are located in LEM, the database of the French National Identification System and Directory of Enterprises and their Establishments (*SIRENE*)[7] was used. This database is administered by the French national statistical institute (*INSEE*)[8], that provides data on a wide range of economic and social indicators. It contains information on every registered establishment in France and identifies each of them with a code that is related to their main activity. The codes used in this database are based on the French statistical classification of economic activities (*NAF*)[9], which operates on a similar principle as the European NACE Rev. 2. This approach builds on previous research, particularly in the field of industrial ecology (Kasmi, 2018) and repair, reuse, and recycling activities (Llorente-González and Vence, 2020).

The activities were categorized based on the four main steps of the deconstruction value chain, namely, clients and general contractors, C&D companies, waste collection and treatment companies, and outlet industries. Economic activity codes were selected through several methods. First, all codes that directly refer to the deconstruction value chain were selected. To ensure comprehensive coverage of the waste collection and treatment part, all C&DW collection points were identified using the tool provided by the French Construction Federation[10] and added any missing codes. Additionally, professional literature, particularly the Démoclès project[11], was consulted to match each type of waste with its potential forms of reusing and recycling.

However, the potential missing part of the value chain is the non-profit organizations and social businesses sector. They may intervene in the deconstruction phase through job integration workshops, and in the recovery phase via resale and recycled goods shops[12]. Although these activities are an integral part of the value chain, the associations carrying them out are generally registered under a code that refers specifically to their social aim, rather than an economic sector. To integrate them into the analysis, a census of these actors located in LEM was conducted, using professional organizations' directories[13]. As a result, 10 establishments operating in the building sector were added to the value chain.

The database was subsequently refined by removing closed establishments and liquidated companies, and classifying each actor based on the type of materials they potentially handle. Table 1 presents a comprehensive list of economic activities included in the database, along with the number of actors operating in the metropolitan area. Although they are accountable for it, clients (real estate managers) and prime contractors are not directly involved in resources treatment, in the sense that their workforce do not directly handles them. In total, the database includes 802 actors across 35 activities.

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[7] "*Système national d'Identification et du Répertoire des ENtreprises et de leurs Etablissements*". Available online: https://www.sirene.fr/

[8] "*Institut national de la statistique et des études économiques*". URL: https://www.insee.fr/

[9] "*Nomenclature d'Activités Française*". Available online on the website of the *INSEE*.

[10] Source: www.dechets-chantier.ffbatiment.fr

[11] Source: www.democles.org/

[12] In France those actors are known as "*ateliers chantiers d'insertion*" (ACI), "*ressourceries*" and "*recycleries*".

[13] Those directories are available online : https://ressourceries.info/?FfF ; http://www.lesentreprisesdinsertion.org/france/annuaire-entreprises

Table 1. Overview of metropolitan actors potentially involved in the deconstruction value chain

Actors in the value chain	Economic activities	Number of establishments located in LEM
Construction and demolition companies	43.11Z – Demolition	12
	43.12A – Levelling and grading of construction sites	58
	43.12B – Site preparation	11
	43.99C – General masonry and structural work	329
	43.99D – Other specialised construction activities	38
Waste collection and treatment companies	38.11Z – Collection of non-hazardous waste	15
	38.12Z – Collection of hazardous waste	3
	38.21Z – Treatment and disposal of non-hazardous waste	8
	38.22Z – Treatment and disposal of hazardous waste	2
	38.31Z – Dismantling of wrecks	4
	38.32Z – Recovery of sorted materials	27
	39.00Z – Remediation activities and other waste management services	14
	08.12Z – Operation of gravel and sand pits; mining of clays and kaolin	5
	46.72Z – Wholesale of metals and metal ores	25
	46.73A – Wholesale of wood and construction materials	149
	46.77Z – Wholesale of waste and scrap	2
Outlet industries	13.93Z – Manufacture of carpets and rugs	6
	20.16Z – Manufacture of plastics in primary forms	2
	20.30Z – Manufacture of paints, varnishes and similar coatings, printing ink and mastics	6
	22.21Z – Manufacture of plastic plates, sheets, tubes and profiles	
	22.22Z – Manufacture of plastic packing goods	5
	22.23Z – Manufacture of builders' ware of plastic	5
	22.29A – Manufacture of plastic technical components	9
	22.29B – Manufacture of plastic consumer goods	11
	23.51Z – Manufacture of cement	8
	23.99Z – Manufacture of other non-metallic mineral products	1
	24.42Z – Aluminium production	3
	24.45Z – Other non-ferrous metal production	1
	42.11Z – Construction of roads and motorways	1
	42.99Z – Construction of other civil engineering projects	21
		11
Social and solidarity economy	82.99Z – Other business support service activities n.e.c.	1
	85.59A – Adult continuing education	2
	88.10C – Work-based social support	1
	88.99A – Other social work activities without accommodation n.e.c.	1
	88.99B – Social work activities without accommodation	5

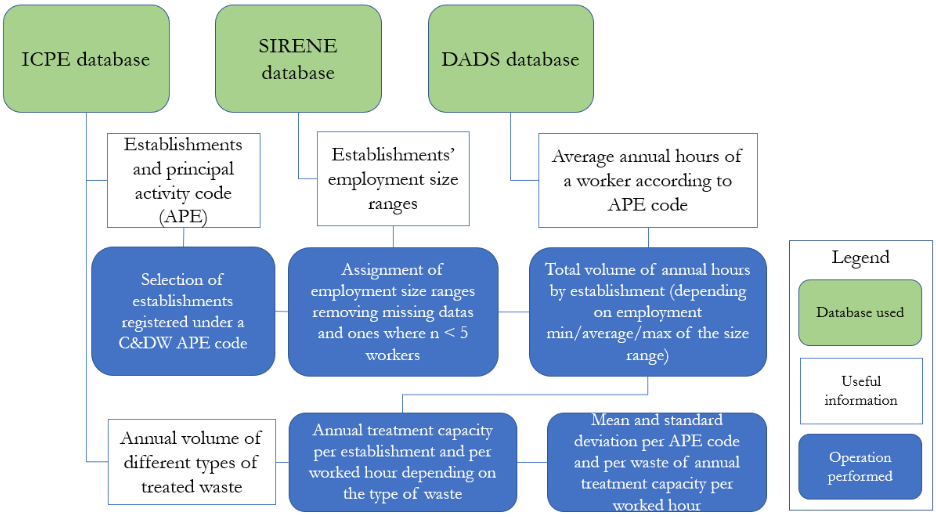
Source: Author's elaboration, codes refer to the Nomenclature d'Activités Française (NAF) and were translated using the Statistical classification of economic activities in the European Community headings (NACE).

4.2 Treatment capacities estimate

The goal is to estimate the demolition waste treatment capacity of the stakeholders in the value chain, specifically focusing on C&D companies, waste collection and treatment companies, who are primarily responsible for managing waste generated by demolitions. The estimate of their waste treatment capacity is based on the database of the Classified Installations for

Environmental Protection (*ICPE*)[14]. It is the French regulatory system for industrial facilities that have a potential impact on the environment and public health, and it contains information on every waste treatment facility in France. Data concerning the principal activity code of each establishment, the types of waste treated, and the annual volumes treated for each type were extracted. As summarized in Figure 3, using this information, an average treatment capacity per activity code per type of waste was determined, for the selected activity codes and materials that are part of demolition waste. To express the average capacities in tons per worked hour, the annual declaration of social data (*DADS*)[15] was utilized to obtain the average annual hours worked per worker per activity code. This database, which is not open-source, is established by the French national statistical institute (*INSEE*), and contains annual declarations of social data related to the employment of workers, such as wages, hours worked, social security contributions, and taxes, that French employers are required to submit to the public authorities. In addition to the information concerning the average annual worked hours, data about the distribution between workers, intermediate professions and managerial staff were also used. Indeed, as the DRTCR was defined in the introduction, it depends on the labour force that directly and concretely handles resources, and it therefore concerns annual hours worked by workers.

Figure 3. Methodology for treatment capacities estimate per activity code and per material



Source: Author's elaboration

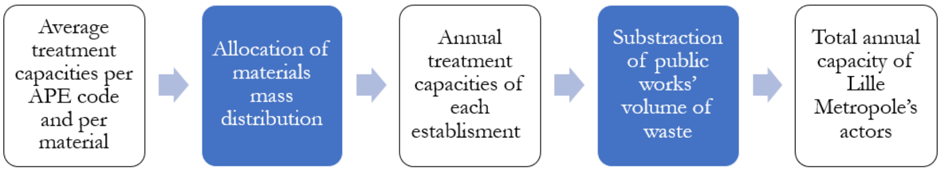
Using the average capacities per worked hour, the capacity of each establishment located in the LEM area was estimated by referencing the employment size ranges. However, because not all workers treat every type of waste, a materials mass distribution of demolition waste was first applied to these capacities: two types of distributions were used (Appendix 1), one that concerns ratios of C&DW estimated for the French EPR implementation[16] ("EPR distribution"), the other corresponds with the study of legal declarations in France for demolition sites larger than 1000 square meters[17] ("OPTIGEDE distribution"). Both were obtained from works conducted by the French Environment and Energy Management Agency (*ADEME*)[18], a public organization that operates under the supervision of the Ministry for the Ecological Transition and Solidarity, and aims to

[14] "*Installations Classées pour la Protection de l'Environnement*". Available online: https://www.georisques.gouv.fr/
[15] "*Déclarations Annuelles de Données Sociales*".
[16] ADEME, TERRA, TBC Innovactions, ELCIMAI Environnement, Au-Dev-Ant, E. PAROLA. 2021. Etude de préfiguration de la filière REP Produits et Matériaux de Construction du secteur du Bâtiment. 29 pages. Available online : https://librairie.ademe.fr/dechets-economie-circulaire/4573-etude-de-prefiguration-de-la-filiere-rep-produits-et-materiaux-de-construction-du-secteur-du-batiment.html
[17] ADEME, OPTIGEDE, Estimation de la production de déchets de bâtiment. 5 pages. Available online : https://optigede.ademe.fr/outils-pour-les-entreprises.
[18] "*Agence de l'Environnement et de la Maîtrise de l'Energie*". URL: https://www.ademe.fr/

promote the transition towards a sustainable and low-carbon society. These distributions allow to estimate the annual treatment capacity of each establishment for each type of waste.

Some of the construction and waste collection and treatment activities involve actors that not only treat C&DW, but also public works waste (roads). The building sector generates 19% of the waste generated by building and public works, according to the French Ministry of Ecological Transition[19]. To account for this volume of waste, 81% of the total volume treated were deducted for activities related to public works waste. Figure 4 provides an overview of the different steps took to estimate the total treatment capacity of demolition waste by actors of the LEM.

Figure 4. Overall methodology for total treatment capacity estimate



Source: Author's elaboration

5. Results

This methodology allows to examine the data pertaining to the selective deconstruction value chain in LEM. Table 2 presents an overview of the value chain's scope in terms of the number of establishments, employment figures, annual worked hours, and total net payroll, which surpasses 218 million euros. Total gross payroll was calculated using the conversion ratio provided by the French Ministry of Labour, Full Employment and Inclusion[20].

Table 2. General data on the selective deconstruction value chain in Lille European Metropolis

Actors in the value chain	Number of establishments (LEM)	Number of employees (mean of employment size ranges)	Total annual worked hours	Total net payroll (€)	Total gross payroll (€)
Construction and demolition companies	448	2 485	3 278 215	47 312 909	80 431 945
Waste collection and treatment companies	254	4 162	6 124 887	87 274 754	148 367 081
Outlet industries	90	2 990	4 335 500	73 311 810	124 630 077
Social and solidarity economy	10	489	709 050	10 101 793	17 173 048
Total	**802**	**10 126**	**14 447 651**	**218 001 266**	**370 602 152**

Source: Author's elaboration, based on data of SIRENE and DADS databases established by the French Institut National de la Statistique et des Etudes Economiques (INSEE)

As a basis of comparison, Eurostat data are referred to, and more specifically the wages and salaries by NACE Rev. 2 activity data. It provides data concerning the mean wages and salaries annually earned by a full-time employee, per activity. As shown

[19] Source: https://www.ecologie.gouv.fr/dechets-du-batiment
[20] This ratio is 1.7. Source: https://code.travail.gouv.fr/

in Table 3, NACE Rev. 2 activities corresponding with the four groups of actors in the value chain were selected. The number of employees working in LEM establishments (Table 2) was then used to calculate the total gross payroll, which is in total very similar with the one calculated with *INSEE* data, with only 1.5% of variation. This similarity demonstrates the reproducibility of this method, and this finding suggests that it can be applied to other European regions as well.

Table 3. Comparison between total payrolls calculated with Eurostat and INSEE data

Actors in the value chain	NACE Rev. 2 activities	Corresponding NAF activities	Mean wages and salaries, per employee in full-time equivalents, per year	Total gross payroll in € (Eurostat)	Total gross payroll in € (*INSEE*)
Construction and demolition companies	[F41] Construction of buildings [F43] Specialised construction activities	43.11Z 43.99C 43.12A 43.99D 43.12B	38 323	95 233 897	80 431 945
Waste collection and treatment companies	[E38] Waste collection, treatment and disposal activities; materials recovery	38.11Z 39.00Z 38.12Z 08.12Z 38.21Z 46.72Z 38.22Z 46.73A 38.31Z 46.77Z 38.32Z	34 688	144 371 456	148 367 081
Outlet industries	[C] Manufacturing	13.93Z 22.29B 20.16Z 23.51Z 20.30Z 23.99Z 22.21Z 24.42Z 22.22Z 24.45Z 22.23Z 42.11Z 22.29A 42.99Z	41 727	124 763 730	124 630 077
Social and solidarity economy	[Q88] Social work activities without accommodation	82.99Z 88.99A 85.59A 88.99B 88.10C	24 129	11 799 081	17 173 048
Total				**376 168 164**	**370 602 152**

Source: Eurostat, Labour cost, wages and salaries (including apprentices) by NACE Rev. 2 activity, online data code: LC_NCOSTOT_R2

The methodology described in the previous section allows to estimate the DRTCR of the LEM's value chain. It must be taken into consideration that the same resources can be handled by different stakeholders. three groups have been defined and correspond to the main stages of C&DW-M: after having been removed from a building by workers of a first company, workers of a second one can transport them to a treatment center ran by a third one. To avoid counting operations concerning the same resources multiple times, value chain's stakeholders are divided into three different groups. As shown in Table 4, Group A consists of stakeholders whose labour force works directly on building sites, Group B includes stakeholders involved in resource collection and treatment, and Group C comprises stakeholders engaged in resource reselling (46.72Z, 46.73A, 46.77Z), mineral waste recovery (08.12Z), and public works and construction activities that are not primarily focused on waste management and treatment but may involve it as part of the construction process (43.12A, 43.12B, 43.99C, 43.99D). These stakeholders (group C) are integrated in the selective deconstruction value chain because, even if they generally use new or "virgin" products, equipment and materials, they might be able to reintroduce resources generated, collected and treated by the two other groups, in a complete circular economy which closes a large number of loops into the building industry. Thus, they are here considered as "stakeholders closing loops for building industry".

Table 4. Stakeholders' distribution according to the order of resources' handling

Group A Resources generation from selective deconstruction	Group B Resources collection and treatment	Group C Stakeholders closing loops for building industry
43.11Z – Demolition 38.12Z – Collection of hazardous waste 38.31Z – Dismantling of wrecks 39.00Z – Remediation activities and other waste management services	38.11Z – Collection of non-hazardous waste 38.21Z – Treatment and disposal of non-hazardous waste 38.22Z – Treatment and disposal of hazardous waste 38.32Z – Recovery of sorted materials	43.12A – Levelling and grading of construction sites 43.12B – Site preparation 43.99C – General masonry and structural work 43.99D – Other specialised construction activities 08.12Z – Operation of gravel and sand pits; mining of clays and kaolin 46.72Z – Wholesale of metals and metal ores 46.73A – Wholesale of wood and construction materials 46.77Z – Wholesale of waste and scrap

Source: Author's elaboration

The results are presented in Figure 5, according to the two types of mass distribution that were used: the "EPR distribution" that concerns all waste of the building sector, and the "OPTIGEDE distribution" that is specific to demolition waste. While estimating average capacities per worked hour, based on the employment size ranges of ICPE establishments, the minimum, the average and the maximum of the size ranges were used, leading to a maximum, an average, and a minimum capacity. Those capacities were then applied to the employment size ranges of the actors established in LEM. The minimum, the average and the maximum of the size ranges were used. The results present the mean and the standard deviation of the metropolitan actors, for the minimum (Min), the average (Ave) and the maximum (Max) capacities.

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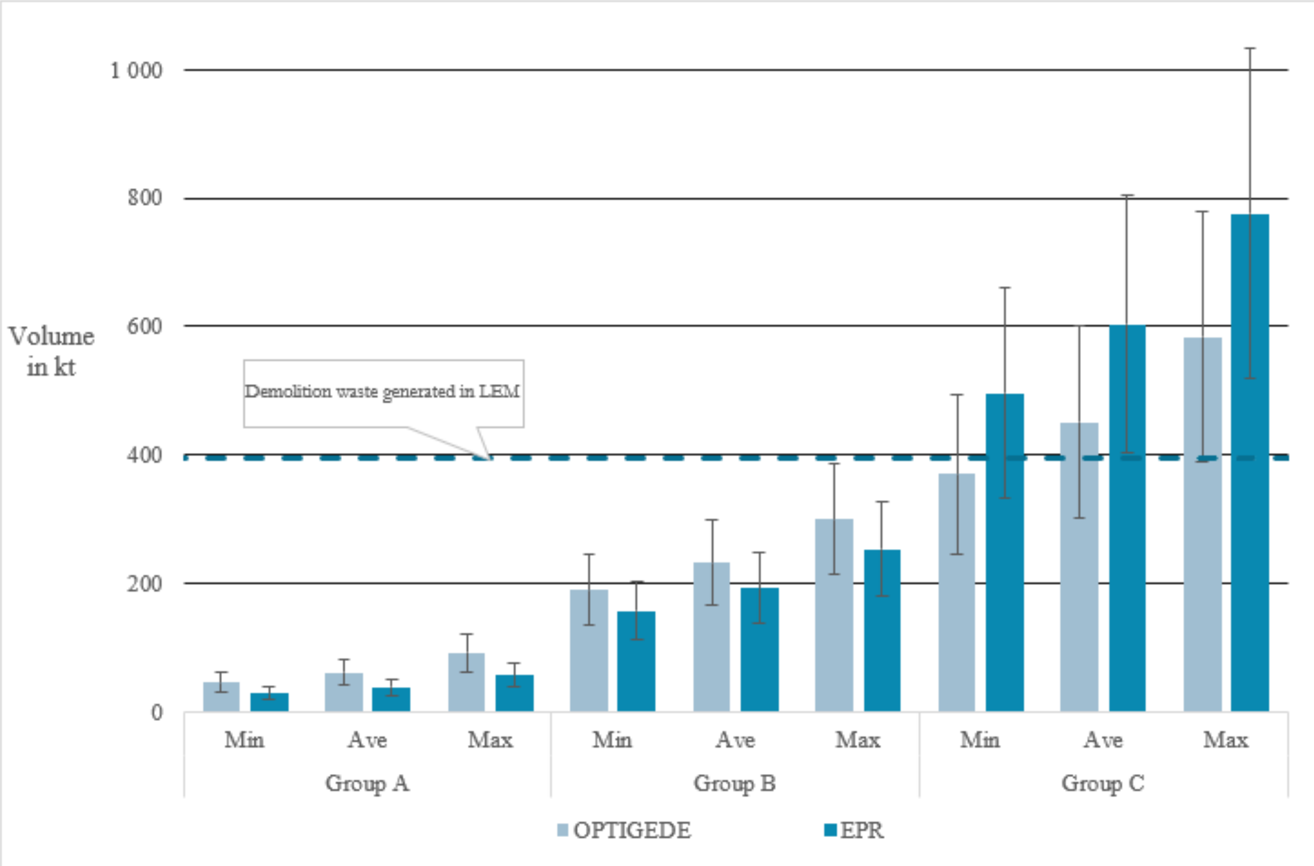
Figure 5. Annual DRTCR of LEM's actors



Source: Author's elaboration

Although the results obtained using the two mass distributions are similar in magnitude, there are still noticeable differences, especially for group C. On average, the estimated DRTCR for this group ranges from 450kt when using OPTIGEDE to 600kt when using EPR. The reason for this is the difference in the methodology underlying those distributions. The OPTIGEDE distribution relies on legal declarations of waste and materials generated specifically by demolition sites. On the other hand, the EPR distribution considers both C&DW, and is based on macro-estimates at the national level. Group C comprises stakeholders whose activities are not directly related to demolition waste management, but rather to public works and construction. Therefore, it is not surprising that their capacity, as estimated from OPTIGEDE, is significantly lower than the one estimated from EPR.

6. Discussion

To contextualise the results, the volume of demolition waste generated in the LEM area can be estimated using national data on a per capita basis, since there are no official data at the metropolitan level. The waste produced by the construction industry is divided into two main sectors: the building sector and public works. In France, according to the French Ministry of Ecological Transition[21], public works represents 80% of the total waste volume, which amounts to 224 million tons. Within the building sector, waste generation is divided between demolition (49%), building renovation (38%), and new construction (13%).

[21] Source: https://www.ecologie.gouv.fr/dechets-du-batiment

However, it's important to note that these values may not include preliminary demolition, which is often part of construction sites. In France, construction sites can be declared without including this preliminary deconstruction. Therefore, a detailed analysis of each site can provide a more accurate view of waste distribution in the sector. Nevertheless, those figures allow to estimate the volume of demolition waste generated in LEM. The French building sector produces a yearly total of 46 million tons of waste, out of which 49% is generated by demolition, amounting to 22.5 million tons. The population of LEM was 1.17 million according to the 2018 census, which represents 1.75% of the total French population of 67.16 million in the same year. Applying this percentage to the national volume of demolition waste yields an estimate of 394,105 tons of waste at the metropolitan level, as shown in Figure 5.

The average DRTCR of the group B, which comprises stakeholders involved in resource collection and treatment, is approximately 200kt. According to the methodology proposed here, metropolitan waste collection and treatment actors (group B), even under the assumption of a maximum capacity, are unable to provide the LEM area a sufficient capacity to manage this volume of resources. This result is even clearer for group A, that comprises demolition companies, collection of hazardous waste and remediation activities. With an average DRTCR of 38kt (EPR distribution) to 61kt (OPTIGEDE distribution), the study shows that stakeholders established in LEM have not a sufficient capacity to take charge of all deconstruction works of the area. Thus, results showed that most of deconstruction sites, as well as transport and treatment of generated waste, are taken into charge by actors operating in LEM but established outside its geographical area (activities related to Group A and Group B).

Group C presents a much higher DRTCR, with an average of 450kt to 600kt depending on the distribution used. The stakeholders it comprises have the potential to reintroduce the resources processed by the two other groups in the building industry. Indeed, resources management and treatment may already be part of their activities. For example, levelling and grading of construction sites may involve the removal and disposal of soil and other resources, and masonry and structural work may involve the handling and disposal of construction debris. That is why, without any new infrastructures dedicated to C&DW-M, they might help closing the gap identified between the estimated volume of demolition waste and the DRTCR of the group B. Otherwise, the gap pointed out here suggests that a large proportion of deconstruction resources – about half of them according to the estimates of this study – is treated by actors established outside the LEM area. Based on these findings, the DRTCR could be a relevant indicator to help decision makers in regional communities supporting the implementation of new relevant activities of C&DW-M.

The results presented above apply to all materials, and it is proposed to analyse if the DRTCR remains relevant when focussing on each material individually. This is especially significant given that France's establishment of the EPR system has already set objectives for specific materials. The decree of 10 June 2022, which relates to the No-Waste for a Circular Economy law and concerns the extended producer responsibility for construction materials, states that the recycling rates for wood, plaster, plastic, and glass should be raised by 2027 to 45%, 37%, 24%, and 18%, respectively (while they are currently at 41%, 16%, 17% and 3%, respectively). Group B capacities mainly concerns treatment and recycling of these materials. To achieve these recycling objectives, the hypothesis is that these materials are selectively deconstructed, collected, and processed individually before being recycled. Since the legislation focuses on these specific materials, let's examine the DRTCR of the LEM for these flows.

Using both EPR and OPTIGEDE distributions, the respective shares of wood, plaster, plastic and glass were imputed to the estimate built above of 394,105 tons of demolition waste generated in the LEM area. The resulting volumes are compared, in Table 5, with the DRTCR of groups B, for each considered material flow. The capacity rates presented in these tables represent this DRTCR, in comparison with the estimated volumes of materials generated in LEM.

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Table 5. DRTCR for specific material flows focused by French legislation

Distribution	Material	Share in the material mass distribution[22]	Estimated volume generated in LEM (in tons)	Volumes to be recycled according to fixed objectives	Annual DRTCR (in tons)	Capacity rate (± standard deviation)
EPR	Wood	4.9%	19 311	8 690	2 586	30% ±9%
	Plaster	0.3%	1 182	437	69	16% ±4.7%
	Plastic	0.4%	1 576	378	65	17% ±5%
	Glass	0.4%	1 576	284	14	4.8% ±1.5%
OPTIGEDE	Wood	1.11%	4 375	1 969	497	25% ±7.6%
	Plaster	0.24%	946	350	5.7	1.6% ±0.5%
	Plastic	0.04%	79	19	7.7	40% ±12%
	Glass	0.02%	158	28	0.5	2% ±0.6%

Source: Author's elaboration

Since this pertains to specific materials flows, the differences between the results obtained are more noticeable, primarily due to the weight discrepancy provided based on the mass distributions. Table 5 shows that this discrepancy ranges from 1 to 10 for plastic and 1 to 20 for glass. Beyond these differences, it was found that the DRTCR of LEM's actors does not match any of the volumes to be recycled according to the objectives set by legislation. Using the EPR distribution, the capacity rate ranges from 4.8% for glass, to 30% for wood. With the OPTIGEDE distribution, this rate ranges from 1.6% for plaster, to 40% for plastic. Those results highlight significant gaps in comparison to the volumes that need to be treated, indicating the need for a substantial additional capacity. But since there are large differences in the volumes and capacity rates between EPR and OPTIGEDE distributions, those results for specific flows should be viewed with caution and shall not be considered as a truthfully representation of the actual capacity of LEM's actors.

The results obtained for these flows, as well as those for all material flows, indicate that there is still a significant gap in comparison to the volumes generated in LEM, indicating the need for a substantial additional capacity to meet the circular economy (CE) targets. This suggests once again that a large portion of the demolition waste generated in the metropolis might have to be treated outside its geographical area, which could result in increased transport emissions. In this regard, developing a selective deconstruction value chain sustainably and at a local scale seems crucial. Coordination between value chain stakeholders is essential, but it may not be enough to address the significant challenges of CE. Public actors and private stakeholders might need to invest in new waste treatment infrastructures to meet the targets set by the regulatory framework. While this investment may seem like a constraint due to the climate emergency, it presents an economic opportunity for the metropolitan area to create thousands of new jobs that are unlikely to be relocated.

7. Conclusion

The focus of this article has been on the role of selective deconstruction, a key but not yet automatic lever for implementing CE in the C&D sector. This method has the potential to significantly increase waste treatment, reuse, and recycling ratios, thanks to its ability to better divide material flows. However, to achieve this, it requires the involvement of multiple stakeholders across the selective deconstruction value chain, and not just the method itself. The first goal of this article was to provide a replicable and comprehensive methodology for identifying these stakeholders, which relies on the statistical classification of economic activities. The reproducibility of this method makes it a promising tool for future research in other French regions and, with sufficient time and resources, in other European areas as well. In fact, the comparison with Eurostat data revealed very similar results, indicating that the method can be effectively applied to other regions.

[22] The share of plaste ris the sum of "Gypsum plasterboards and planks", "Inert matrix with plaster" and "Insulation composite with plaster". The share os wood is the sum of "Untreated wood" and "Slightly adjuvanted wood".

This methodology was applied to the area of LEM, allowing to identify the stakeholders involved in the selective deconstruction value chain and to assess their capacity to treat materials and waste from deconstruction. The analysis conducted in this study showed that LEM, with approximately 10 000 employees in the sector, has a significant potential for CE development. It was found that the three groups of stakeholders comprising the selective deconstruction value chain, has an average DRTCR of around 50kt for group A (resources generation from selective deconstruction), 200kt for group B (resources collection and treatment), and 450kt to 600kt for group C (stakeholders closing loops for building industry). Taking into consideration that LEM has an estimated volume of demolition waste of 400kt, the highlights the need to develop the value chain, especially by involving stakeholders of group C. Similarly, looking at specific materials flows that have been focused by legislation, the results show that the current capacity may not be sufficient to achieve the CE strategy and its objectives.

However, the DRTCR's reliability at this level of granularity is questionable, as the results showed significant differences depending on the mass distribution used. Although the DRTCR built in this paper is a good indicator at the scale of all material flows, there is still some work to be done to make it truly relevant at a finer level of granularity, flow by flow. This work could benefit greatly from improved waste traceability, that could provide more precise and accurate data to support the DRTCR's calculations. In this regard, the implementation of the EPR for construction materials may help. Indeed, producer responsibility organizations responsible for this implementation are obligated to ensure an effective traceability of the waste they process.

The findings of this study have significant implications for the economic and environmental sustainability of LEM, and by extension, other urban areas that face similar challenges in managing C&D waste. By adopting CE strategies, LEM can reduce its dependence on virgin materials, create new jobs that cannot be outsourced, and reduce greenhouse gas emissions. Nonetheless, the development of local waste recovery economic sectors and infrastructures still requires a great deal of effort. The methodology presented in this article aimed to steer public policy towards more sustainable resource use and management, by highlighting what still need to be done. The implementation of CE and the attainment of objectives hinge indeed on the involvement of all actors in the value chain, as well as the support of public authorities.

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Appendices

Appendix 1. Detailed materials mass distributions used

Materials	EPR distribution	OPTIGEDE distribution
Bituminous mixtures	-	0.79%
Unpolluted soil	7.6%	0.19%
Concrete and stones	37.2%	70.9%
Tiles and bricks	7.6%	1.81%
Ceramic	-	0.26%
Glass without joinery	0.4%	0.02%
Mixed inert waste	22.9%	16.7%
Others inert waste	-	1.22%
Gypsum plasterboards and planks	1.3%	0.06%
Inert matrix with plaster	-	0.13%
Insulation composite with plaster	-	0.05%
Untreated wood	4.9%	0.72%
Slightly adjuvanted wood	-	0.39%
Windows and other glazed openings	-	0.01%
Metals	6.6%	2.87%
Plastics	0.5%	0.04%
Minerals wools	0.5%	0.06%
Biosourced insulation	-	0.01%
Other insulating materials	-	0.42%
Waterproofing complex not containing tar	-	0.02%
Floor coverings	-	0.04%
Non-hazardous waste electrical and electronic equipment	-	0.01%
Mixed non-hazardous waste	7.4%	1.27%
Plants	-	0.03%
Topsoil	-	0.05%
Other non-hazardous non-inert waste	0.2%	0.4%
Asbestos bound to inert materials	1.2%	0.44%
Other types of bound asbestos	-	0.05%
Friable asbestos	-	0.1%
Bituminous mixtures containing tar	-	0.05%
Waterproofing complex not containing tar	-	0.001%
Paints containing dangerous substances	-	0.001%
Wood treated with dangerous substances	0.03%	0.04%
Equipment containing dangerous refrigerant fluids	-	0.001%
Lights	-	0.003%
Other waste electrical and electronic equipment containing dangerous substances	0.4%	0.01%
Soil containing dangerous substances	-	0.57%
Other hazardous waste	1.1%	0.31%

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