



THE SUSTAINABLE LANDFILL: AN INTEGRATED SERVICE FOR THE ENVIRONMENT AND ITS POSSIBLE IMPACT ON THE SME'S SECTOR

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Abstract

Purpose. This paper aims to contribute to the debate on waste management with the intention of considering the waste cycle as a network of environmental services, which are vital and necessary to the industry. At the same time, it wants to emphasize the concept of the sustainable landfill, that finds a new role whenever it is collocated at the end of the cycle.

Design/methodology/approach. A simple model shows that the lifespan of a landfill, in the absence of economic constraints, depends on the actions put in place upstream of the final storage phase, which will have to be all the more incisive the greater the community's aversion to the creation of landfills. The various phases of the waste cycle are detailed, together with an economic exploration of the economic dimension of the waste sector, also outlining organization and ownership structures.

Findings. The sustainable landfill, a necessary building block that cleanly closes the material cycle, imposes the constraint that produces backward effects throughout the supply chain, even to the point of changing the structure of the entire network. Within a circular economy framework, the potential for SMEs, in terms of new market space, turnover and economic profits is enormous.

Practical and Social implications. The waste sector, extremely relevant for its economic dimension, is very parcelled out, characterized by the presence of a large number of SMEs and exhibits very interesting margins of profitability whenever a sustainable landfill is taken into consideration.

Originality of the study. It intends to fill a gap in the literature, emphasizing the concept of sustainable landscape and presenting the waste cycle as a network of services for the environment, that is a specific management model (Integrated Waste Management As A Service or IWaMAAS)

1. Introduction

Waste management is one of the most controversial aspects, in relation to human activity, because of the impact generated socially and environmentally. Globally, only 19 percent of waste becomes recovered material through recycling and composting, while 11 percent is treated by incineration. The growth forecast, made for 2050, is 3.4 billion tons, considering movements in urban areas (Kaza et al., 2018). Separate waste collection and disposal-related services make a substantial contribution to reducing environmental pollution (Castillo-Giménez et al., 2019), but the containment of negative impacts, on society and the environment, depends on a multiplicity of factors (Cervantes et al., 2018), such as the involvement of individuals, institutions, and companies that offer various waste management services (Agovino et al., 2016; Soltani et al., 2015). The responsibility for waste management is in the hands, at least for some stages of the cycle, of local authorities that generally have limited resources, with negative effects in the capacity for planning, procurement, operational monitoring, and so on. The absence of cooperation among municipalities contributes to a fragmented picture at different geographic levels, both local and global.

The concept of circular economy (Korhonen et al., 2018) dovetails perfectly with waste management (Kirchherr et al., 2017), especially in Europe (Bogner, 2005). On the one hand, the transition to the circular economy must take place at multiple levels (micro, meso, and macro) (Cerquetti et al., 2021); on the other hand, achieving the goals requires the involvement of a plurality of actors ranging from institutions to businesses, from consumers to governments, as agents of a single network (Merli et al., 2018). Also business models are affected by this concept, with strong impacts also on small and medium enterprises (SMEs) (Trequattrini et al., 2021). A systematic literature review (Ahmadov et al., 2025) focuses on the different factors (macro, meso, and micro) and mechanisms influencing the transition process, contributing to develop a conceptual model about the dynamics of the circular transition process within SMEs.

However, the realization of the circular economy through prevention, reuse, and recycling is far from the goal of “zero waste,” and faces a somewhat generalized unpreparedness to manage the waste stream that recycling generates. Wise waste management cannot ignore a balanced use of different treatment and disposal methods (Cossu, 2009). The landfill, at this point, makes it possible to complete the disposal service, close the material cycle and control the spread of contaminants. It can no longer be considered “a dustbin,” nor be abandoned to obsolete and inadequate quality standards.

Within this framework, the “sustainable” landfill stands as a necessary building block to cleanly close the material cycle. It is an approach that

has not been much analyzed in the literature, hence the paper is giving a contribution in filling the gap in this direction. Some authors address the opportunity of reducing environmental parameters to acceptable risk level in order to prevent damage to humans and the environment (Osazee, 2021), whereas some others advise the necessity of planning in advance operations and monitoring, closure and post-closure care (Townsend et al., 2015). The choice of a sustainable site of location is made on parameters which are identified and categorized into three groups including environmental, economic, and social criteria (Rahimi et al., 2020). Once the landfill has been closed, there are significant international experiences about the various types of landfill use destination¹.

To fully play the role of sink, it must be designed and implemented in accordance with the principles of environmental sustainability, that is, with all technical measures that can ensure the stability of waste and immobilization of pollutants after the closure of the landfill. The time considered is that of one generation (30 years), within which to achieve environmental balance (Cossu et al., 2020). However, it is important to underline that the financial guarantee to be observed in Italy (30 years) does not seem to be the right instrument to obtain the final quality of the landfill. If technical interventions are not made (regardless of low or high recycling rates), at the end of the financial guarantee, the result will be a contaminated land rather than a depleted landfill site.

SMEs are fully involved in the ecological transition and as it will be shown in the paper, the economic interests related to this sector have now assumed very important dimensions. The decision to build sustainable landfills as the final element of the integrated waste management cycle undoubtedly has effects that reverberate backward throughout the supply chain and impact the mainly medium-small businesses that are part of it. In this paper, an attempt will be made to give substance to this claim. To understand the impact of sustainable landfill on the ownership regimes of management companies, reference will be made to the notion of control. We will speak of private ownership when the entity or entities that control the company operating any waste management facility are private, while we will speak of a public company when control is in the hands of public capital. However, the debate about privatization in public service provision is still open: expected results in terms of higher efficiency and investments have not been achieved, so supporting a growing re-municipalization trend (Petersen et al., 2018). In particular, in the waste sector, contextual factors and the role of policymakers that influence governance models, need further investigation (Gradus et al., 2019; Romano et al., 2023).

¹ See Cossu (2020). Many examples come from Europe (Germany, France, Malta, Great Britain) but also from China, Usa, Japan, Israel and South Africa.

The reference to the ownership regime is relevant in the context of the waste chain because it reintroduces a classic reflection on the different time horizons of public and private interests. When one moves away from a company's break-even point to pursue the interest of future generations by minimizing the negative externalities associated with the final storage phase, it inevitably affects its ownership regime. Indeed, the interests of public or private investors are clearly different. A sustainable landfill has, by its nature, particularly long-time horizons that are perhaps ill-suited to private ownership. High initial investment costs, often compounded by a lengthy administrative and socio-political process to locate a site, can only discourage a private investor.

But while sustainable landfills seem to reduce the space for the private sector, the choice to promote them can trigger very interesting prospects throughout the upstream supply chain. In fact, as already pointed out, these kinds of facilities need a special waste management chain, in all stages of collection, recycling and treatment, which offer great entrepreneurial opportunities. Here the space for private and investee companies is enormous (Preite et al., 2024; Del Bo et al., 2025).

The integrated waste management service also plays a strategic role for the entire SME system, located in a given territorial basin, for two main reasons. The first is that businesses need to manage the amount of waste, especially special waste, they produce in a cost-effective manner. Both by reducing its quantity, maximizing recycling opportunities, and reducing the costs associated with the inevitable final storage. The second reason is that SMEs can become from a business and industry perspective active participants in the waste management chain. So, the decision to build sustainable landfills, seemingly penalizing as they are subject to more stringent environmental constraints and devoted to the defence of future generations, presents an extraordinary form of incentive to build a real industrial waste supply chain with significant investment and employment opportunities.

This paper aims to contribute to the debate on waste management and its possible impact on the net of SMEs with the intention of considering the waste cycle as an integrated service using the logical scheme proper to network analysis. Its optimization involves the identification of critical nodes and bottlenecks that prevent the system from achieving balances in line with circularity and sustainability, a matter to which also SMEs are called to carefully report (Roberto et al., 2024). At the same time, it wants to emphasize the concept of the sustainable landfill, that has been deeply investigated by Cossu et al. (2020), but that finds a new role whenever it is collocated at the end of the cycle: the entire upstream system changes and adapts to achieve high quality in final storage. Section two details the various phases of the waste cycle and proposes a classification of waste,

introducing a simple model in which the lifetime of a landfill, in a closed administrative unit, in the absence of economic constraints, depends on the actions put in place upstream of the final storage phase, which will have to be all the more incisive the greater the community's aversion to the creation of landfills. The model deliberately does not present an empirical application, due to the lack of Italian data on the specific subject of sustainable landfills, but rather emphasises the relationships between the relevant variables in determining the break-even point.

The third section explores the economic dimension of the waste sectors, outlining also organization and ownership structures. Characteristics, limitations and aims of the sustainable landfill are explained in section four. Finally, the waste cycle is presented as a network of services for the environment, assuming a specific management model (Integrated Waste Management As A Service or IWaMAAS). In the end, remarks and references close the paper.

2. The waste cycle and the role of landfills for the chain of small and medium-sized enterprises

Waste management is the set of policies, procedures or methodologies aimed at managing the entire waste process, from its generation to its final destination thus involving the phase of collection, transportation, treatment (recovery or disposal) until the reuse/recycling of waste materials, usually produced by human activity, in an attempt to reduce their effects on human health and impact on the environment. The proper management of hazardous and non-hazardous waste, whether of urban or special origin, is the basis of the principles that the European Union has set forth in specific Regulations and Directives².

Based on the principle of the hierarchy of waste treatment, the European Commission has established that the proper management of Waste must adhere to a precise hierarchy of actions.

According to this principle, prevention should be implemented by encouraging the reduction of waste generation and hazardousness and facilitating its reuse, recycling and other recovery operations. At the bottom of the hierarchical ladder is landfilling, conceived as a residual option to be zeroed out over time.

² Each Member State, including Italy, has implemented the principles enshrined by the European Union with specific legislation: single text of Legislative Decree 152/2006 as amended and supplemented. See Clini (2024) "La gestione dei rifiuti urbani", in Eugenio Picozza and Annalisa Di Giovanni, *La disciplina dei servizi pubblici locali di rilevanza economica*, Giappichelli, 2024.

Waste can be distinguished firstly into non-hazardous and hazardous waste. Then they can also be classified into two other main macrocategories: municipal waste and special waste. The distinction relates to their origin and how they are managed³. Each category of waste creates a network that in fact forms a system of interdependent networks composed of operators of various natures; these include companies both that are part of the network and that must interface with it for production reasons.

As for the origin of municipal waste, this is produced by commercial and public household activities in urban areas. Paper, plastic, glass (recyclables), organic waste such as food scraps, non-recyclable waste, bulky waste, etc. also fall into this category. Municipal waste is usually collected, treated and disposed of by public waste collection services, which often sort it according to its type in order to facilitate recycling. Special waste, on the other hand, comes from industrial, artisan, agricultural, hospital and other specific production activities. These wastes do not fall into the municipal waste categories and require special management⁴. While municipal wastes are often destined for recycling facilities or landfills, special wastes may require specific facilities for treatment and disposal, depending on their hazardous or non-hazardous nature.

A not insignificant distinction between the two categories of waste also concerns their economic management at the time they are sent to landfills, in fact the price of delivery in the case of municipal waste is often regulated while in the case of special industrial waste it is subject to market mechanisms and therefore this price is significantly affected by the differences between demand for storage and availability of suitable space or landfills willing to accept them.

The waste business cycle is the process that describes all stages of waste management, with the goal of minimizing environmental impact and maximizing resource recovery.

3 Inert wastes are solid wastes that by their nature do not undergo any physical, chemical or biological transformation, that is, they do not dissolve, burn, degrade naturally and are not subject to physical or chemical reactions.

4 Examples of special wastes are industrial wastes, medical wastes (such as hospital wastes), processing wastes, hazardous wastes (such as solvents, paints, used oils), and materials contaminated with toxic or hazardous substances with specialized facilities and procedures for treatment and disposal, such as incinerators or licensed landfills. They are regulated by special waste legislation. Testo Unico Ambientale (TUA), DLgs. 152/2006 and subsequent amendments.

It is a complex system (in a mathematical sense)⁵. In line with circular economy policies, the waste economic cycle aims to close the life “circuit” of materials by reducing waste, reusing resources and, when possible, recycling materials for other uses. The waste economic cycle is divided into several stages, which include production, collection, transportation, treatment, recycling, energy recovery and, finally, disposal. Each stage involves economic and management activities that can involve both the public and private sectors.

In this paper we will deal in a privileged way with waste disposal in a particular type of landfill, the sustainable landfill, and then make a reflection on the impact that this landfill can have on the network of SMEs. The landfill is sustainable only if all (industrial) necessary pre-treatment and in-situ treatment of the waste is carried out in order to achieve optimal target values, to be verified in the post management phase. The most relevant treatments to environmental sustainability are pretreatment prior to landfilling and in situ treatment⁶.

The aim is to contribute to the debate on waste management and its possible impact on the SME network with the intention of considering the waste cycle as an integrated service using the logical framework of network analysis. Providing for a sustainable landfill at the end of the cycle affects the entire upstream system generating a backward effect throughout the supply chain, changing the structure of the entire network. Its optimisation involves identifying critical nodes and bottlenecks that prevent the system from achieving a balance in line with circularity and sustainability, an issue that directly involves SMEs as both waste generators and users of secondary products created within the waste cycle presented as a network of services for the environment, adopting a specific management model.

The concept of the Integrated Waste Management As A Service understood as a network of firms with an environmental service function will be used (Seadon, 2006).

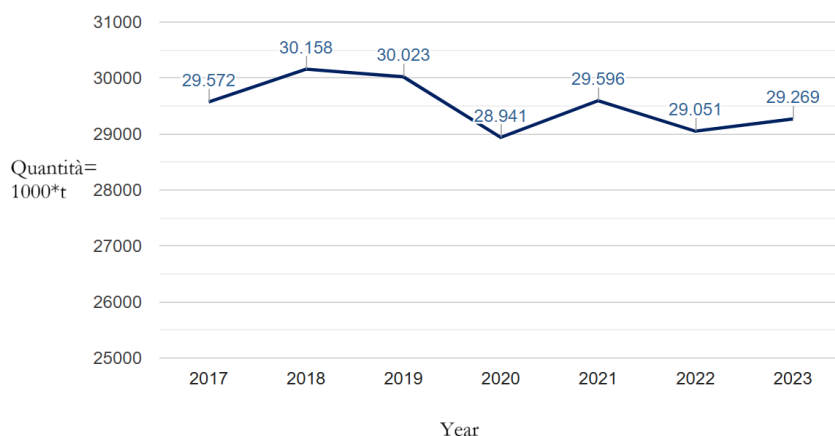
⁵ Although there is no unanimous formal definition of it, it can be said that a complex system has certain basic characteristics: it is composed of a considerable number of interacting subsystems; it exhibits emergent characteristics, that is, ordered behaviors resulting from interactions among subsystems when the subsystems themselves or their connections exceed a certain number; it is highly structured; it exhibits feedback mechanisms (whereby an output response also becomes an input stimulus); and it is characterized by nonlinear dynamics that are sensitive to initial conditions (chaos). Thus, a complex system is characterized by a large number of variables, and observable behaviors depend to a large extent on how subsystems organize and interact with each other. https://www.treccani.it/enciclopedia/sistema-complesso_%28Enciclopedia-della-Matematica%29/.

⁶ Among the pretreatments prior to landfilling we have mechanical biological, thermal and leaching treatment. Among those in situ we find leachate reticulation, forced aeration, natural convective aeration and leaching (Cossu et al., 2020).

3. The economic dimension of the waste sector and the role of SMEs

The objective of this section is to frame the sector that deals with waste management, in all its phases, to highlight its relevance from an economic point of view, and the opportunities for companies in terms of profitability. Nonetheless, the strategic role it takes on, as a provider of a whole range of environmental services, organized in networks, used by the entire industrial sector, should be highlighted. An initial survey of municipal waste production shows that at the national level, from 2017 to 2023, the trend is slightly downward, with values that seem to settle around 29 million tons (Fig. 1).

Fig 1. National municipal waste generation trend, years 2017-2023.



Source: <https://www.catasto-rifiuti.isprambiente.it/index.php?pg=ru>

At the per capita level in 2022 each Italian citizen produced 494 kilograms, a decrease of 1.6% compared to 2021⁷.

According to the 2024 Green Book edited by Fondazione Utilitatis and Utilitalia, Federazione Utilities, the municipal waste sector shows high dispersion, both horizontally and vertically: there is a very large number of operators that coexist with specialized operators in the upstream or downstream stages of the supply chain and a few large operators that close the management cycle. The sample considered⁸ includes companies that deal exclusively with municipal solid waste management (thus single-utility, about 80 %), but also operators active in other sectors, such as energy, wa-

⁷ These are always Ispra's data.

⁸ The sample considered within the Green Book 2024 (Fondazione Utilitatis and Utilitalia, Federazione Utilities), consists of 552 companies.

ter and transportation (multi-utility, about 20%). The turnover generated in 2022 turns out to be 13 billion euros, corresponding to about 0.7% of GDP. The level of employment stands at 86000, accounting for 1.47% of those employed in the industrial sector.

The 2023 Althesys report shows that the waste management sector is strongly driven by technological innovation. Small and medium-sized companies remain, but the number of operators and the ability to generate value is growing over time⁹.

Confirming the picture outlined by the Green Book mentioned above, the Althesys report shows a picture favorable to the entry of new players into the market, also from other sectors. While in 2013 only operators from the waste sector were noted, in 2023 in addition to these there are also technological, financial, energy companies and utilities from other sectors. In the municipal waste sector, a large contribution comes from multi-utilities, which make 52.6 % of investments. Large groups consolidate and expand their position by acquiring other companies and expanding their activities¹⁰. The spatial distribution of managers, employees and turnover shows a higher concentration of companies and workers employed in the South (34% and 33 % respectively), while the highest percentage share in terms of turnover belongs to the Northwest, with 34%. More details are illustrated in Table 1.

Table 1. Sector estimates

Turnover Environment sector (mln/€) 13.056.711		Impact on Italy's GDP 0,73%	Coverage of the population (of the considered sample of 216 companies) 62%	
Employees 86.430		Employees Italy 0,34%	Employees industry 1,47%	
Territorial Distribution				
Nord-Ovest		Nord-Est	Centro	Sud
Companies	151	107	107	187
Turnover	4.395.478	3.729.432	2.227.775	2.704.024
Employees	26.577	17.943	13.264	28.645

Source: GreenBook, 2024.

9 The report also suggests that there is also an emerging gradual convergence in terms of objectives and results between the municipal and special waste sectors, and also some evolution of extended producer responsibility systems, leading to strategic alliances based on research and innovation. This makes it possible to optimize the recovery processes of complex materials, (such as some metals of great strategic value) and the production of energy sources (e.g., biomethane).

10 Data come from Althesys Report, 2023.

Very relevant information on the economic balance of management comes from the analysis of the income statement. Single-utility companies record, in 2022, 10.8 billion euros in total revenues with employment of 72000 people. The EBIT and EBITDA¹¹ indicators are positive and indicate that companies manage to adequately meet operating, financial, extraordinary and tax costs, with an aggregate profit of 612 million euros. Small companies are the most numerous in the sample (accounting for 51%), followed by medium-sized companies (24% of the total) and large, medium-large and top companies, which jointly occupy 26%. And it is the latter category that performs best with EBIT of 26 million, value added of 106 million versus a sample average of 1.8 million and 11 million respectively. The overall picture thus shows that indicators improve as firm size increases.

Current legislation, in order to maximize service efficiency and achieve economies of scale and scope, dictates certain obligations at the national level that lie in the identification of an administrative ambit, called ATO, within which networked local public services of general economic interest must be organized, and the establishment, for each ATO, of a governing body, the so-called EGATO¹². In Italy, there appear to be 76, with some regions not yet having complied with the obligation to identify the ambit government¹³.

When considering the distribution of population and the municipalities by mode of entrustment, in-house management affects 30% of municipalities and 40% of the population: it is clear that this type of management affects relatively large municipalities. In contrast, in-house management on a population basis shows half the value (1%) of that of municipalities (2%), so it can be inferred that this mode involves predominantly small municipalities¹⁴.

11 EBIT (Earnings Before Interest and Taxes) represents operating income, taking into account depreciation and amortization, but not interest and taxes. EBITDA (Earnings Before Interest, Taxes, Depreciation and Amortization), on the other hand, considers operating income before interest, taxes, depreciation and amortization.

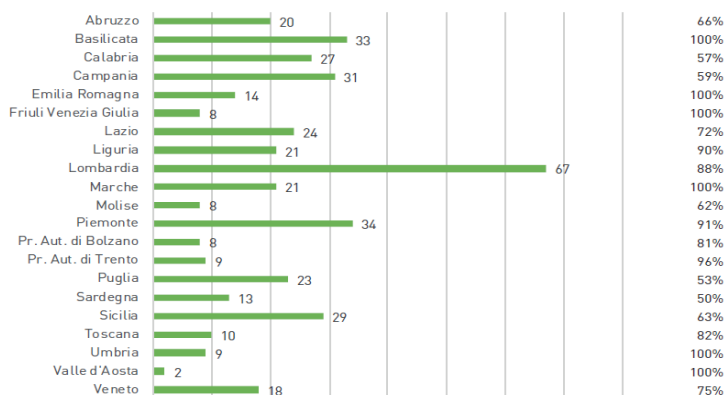
12 ATO stands for Ambito territoriale ottimale (Optimal territorial ambit), a geographic area defined by the region that is considered optimal for the management of a given local public service. EGATO stands for Ente di Governo dell'Ambito Territoriale Ottimale (Governing body of the Optimal territorial ambit) and represents the entity that organizes and manages the service in that ATO, ensuring that municipalities within the area participate and cooperate.

13 Figures reported by the 2019 Monitor-SPL National Report "Organizational and management structures of municipal waste service."

14 As part of the analysis of service entrustment, relating to the activities of collection, sweeping, transport, treatment and disposal of municipal waste, with a population coverage of 76% and 60% of municipalities, the 2019 Monitor-SPL National Report indicates that 803 active managements were identified, within which we find the entrustments arranged according to the regulations in force, the managements subject to direct entrustment, and the cases of service managed directly in economy by local authorities. At the national level, competitive bidding generally prevails (58%), followed then by in-house entrustments, to joint ventures, and management in economy.

It is extremely relevant to analyse the characteristics of corporate governance and the economic and financial performance of the sector¹⁵. Figure 2 shows the number of companies by region and the coverage of the population served. In terms of legal form, at the national level, corporations, S.R.L. and S.P.A. are predominant with shares of 41% and 30%, respectively, followed by single-member S.R.L. and single-member S.P.A., both with a value of 9%. This is followed by S.C.A.R.L.P.A. with 4% and a residual share that includes various types of companies¹⁶.

Fig. 2. Number of firms by region and coverage of population served.



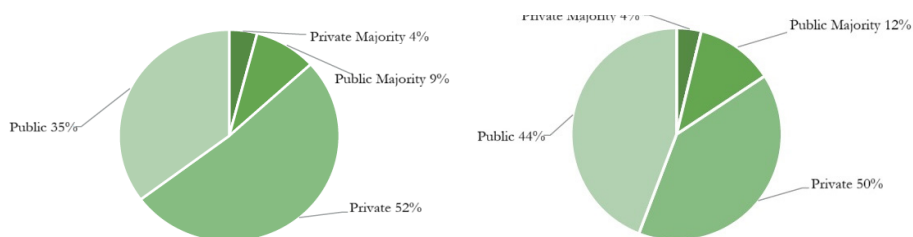
Source: 2019 Monitor-SPL National Report "Organizational and management structures of municipal waste service."

Ownership structures are assessed from the perspective of direct and indirect shareholdings (Figures 3A and 3B). The analysis shows a prevalence of private firms (52%), followed by public firms (35%), and then public-majority firms and private-majority firms. When we turn to second-tier ownership structures, we see a decrease in private enterprises (40%), with an increase in public enterprises instead (accounting for 44% of the total).

15 The sample taken for analysis in the Monitor-SPL national report consists of 326 companies whose balance sheet data are available in the Aida - BureauVanDijk database.

16 Such types of companies include: S.C.A.R.L., simplified S.R.L., consortium limited liability company, consortium cooperative companies, consortium limited liability companies.

Figures 3A and 3B. Ownership structures, direct shareholdings and indirect shareholdings.



Source: Monitor-SPL National Report "Organizational and management structures of municipal waste service," 2019

The nature of the entities holding public shareholdings shows the absolute predominance of municipal administrations (97%). The remainder is divided, in descending order, between mountain communities/unions, unions of municipalities, consortia, provinces, municipal pharmacies, metropolitan cities, and regions.

The dominant class in the direct shareholding of private companies is individual or family type shareholding, with a 63% share, followed by entrepreneurial type shareholding (32%) and mixed type shareholding (14%), which includes companies held by individuals or families and corporations¹⁷.

Generally, an enterprise defined as public, or majority public (always in indirect ownership structures) is considered to be in public control, and similarly, an enterprise defined as private or majority private is defined as being in private control. In Italy, most managers are in public control (56%) regardless of first-tier ownership structures. In addition, little shareholding (between 2 and 10 shareholders) seems to predominate, with an interesting presence of individual shareholding as well, both in publicly and privately controlled companies¹⁸.

Considering both aspects of contracts and ownership structures, it can be observed that in-house contracts and public ownership are predomi-

17 The analysis conducted on a geographic basis also shows some interesting aspects: in the Northwest, individual or family-type shareholding weighs about the same as entrepreneurial and mixed-type shareholding, and a similar situation is found for the Northeast. In the centre, on the other hand, individual or family-type shareholding clearly dominates (with about 82%), and similarly occurs in the south and islands, albeit at a lower value (65%).

18 It is important to point out that within governance there are also dynamics of corporate control, direct and indirect types. While in the first case it refers to the ownership of more than 50 % of the units or shares with which voting rights are associated, in the second case the individual has the majority of votes to appoint the board of directors and control body, so the parent company is in a position to direct the subsidiary's activities according to precise economic planning lines.

nantly found in larger companies located more frequently in the centre-north, while contracts awarded through tenders to private companies, which are more widespread in the south, are more fragmented and often concern individual segments of the service chain.

Some empirical examples regarding ownership structures are particularly interesting. Among these is the Contarina case¹⁹: this is a wholly publicly owned company currently responsible for waste management in 49 municipalities in the province of Treviso²⁰. Today's Bacino Priula Board of Directors was formed through the merger of the two consortia, Priula and TV3, into a single legal entity. The strong institutional preference for proceeding with separate waste collection has enabled Contarina to improve its economic, environmental, and social performance, becoming a benchmark in Italy and worldwide for sustainable waste management, through a circular approach that respects the waste hierarchy: minimize, reuse, and recycle. The success of the business model—in which ownership structure and governance have played a decisive role—is clearly demonstrated by the excellent economic, environmental, and social results reported in the latest financial statements, with significant growth in revenue and investments²¹.

Further interesting empirical evidence is provided by Cinquegrana et al. (2016), who analyze the performance of public and private companies in the water and sanitation sectors (as recorded in Istat's ASIA database) over the three-year period from 2008 to 2010²². The results show that public com-

19 In 2025, it received the prestigious Green Leaf Award from the European Commission as a model of the circular economy, with low rates of landfill disposal (4.2%) and incineration (8.7%) and a high recycling rate (86.8%). Detailed information about the Contarina case is given in the book edited by Romano (2024) relating to the effective management and good governance of local public service companies, with distinctive features and critical success factors of wholly publicly owned companies.

20 Initially, in 1989, the company had mixed public-private ownership, albeit with a public majority. The private sector had been brought in to finance the plant investment, with the investment's amortization funded through user fees. The Priula intermunicipal consortium significantly expanded the number of participating municipalities over time, with a strong and shared preference for separate waste collection, a policy not supported by the private partner's management. This led to remunicipalization, with the Priula consortium purchasing the private partner's shares: the conviction of mayors and administrators was rooted in the need for a company capable of prioritizing environmental and economic considerations in its decisions, with a clear understanding of the region's needs to minimize the reliance on landfills and incinerators. This choice prevailed over the private sector's objective, which was instead focused on maximizing profit margins and the distribution of dividends.

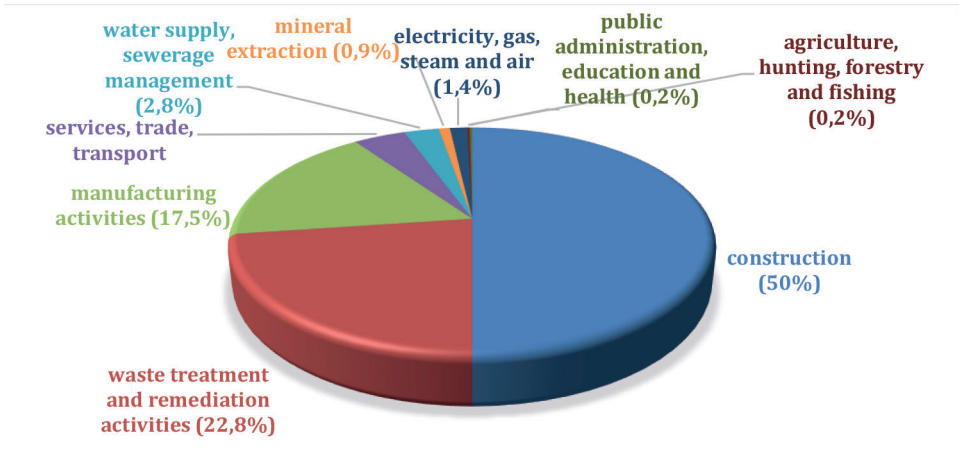
21 Please refer to Romano's book (2024), "Good Management and Good Governance of Local Public Service Companies", specifically Chapter 5, which analyzes the Contarina case. The data show an increase in revenue from 79 million to 97 million euros between 2017 and 2023, an EBITDA margin rising from 15.2% to 18.5%, and investments increasing by approximately 30%, from 15 million in 2017 to 21 million in 2023.

22 Specifically, the study is based on estimating a cost frontier and measuring the distance between

panies are slightly less efficient than private ones and that the differences are most pronounced in the case of large companies, while mixed public-private companies perform substantially similarly to those that are wholly publicly owned. The analysis also focuses on various economic and financial performance indicators²³: overall, public companies are less profitable than private companies. However, labor productivity in public companies is not lower than that of private companies, and value added per worker is often higher in public companies than in private companies. The authors attribute the higher profitability of private companies to greater control over labor costs.

The special waste sector has a significantly higher output than municipal waste with a value in 2022 of 161 million tons²⁴. The largest contribution comes from the building and construction sector, which with a production of about 80.8 million tons reaches half of the total production (Fig. 4). The production of special non-hazardous waste follows exactly the same breakdown, making up as much as 94% of total production.

Figure 4. Breakdown in % of total special waste production, by economic activity, year 2022



Source: ISPRA

en each firm's cost function and the frontier. The analysis uses firm size, the technological intensity of production (measured by the labour cost share) and regional location (North, South and Islands) as control variables.

23 The considered indicators are the following: 6 for productivity, 3 for profitability, 10 for cost structure, 3 relating to liquidity indicators, and 4 for growth.

24 The reference data are again ISPRA (Report 2024). This value also includes the amount of special waste from the treatment of municipal waste.

The distribution of such waste across the country reveals a strong concentration in northern Italy, compared with a more developed industrial fabric (92.7 million tons or 57.4%), followed by the centre (28.1 million tons, 17.4 % of the total) and then southern Italy (with 40.6 million tons or 25.2 %).

The parcelization of service that exists for municipal waste is also found for special waste. The considered companies²⁵ generate a production value of 4.7 billion euros. Large operators absorb 72% of the value of the supply chain, but in all stages (collection, treatment, recovery and disposal) small and medium-sized operators are active, accounting for 83% of the total. Investments reach 218 billion euros and are a sign of a rapidly evolving sector.

It is interesting to note that the heterogeneity of economic and management structures is accompanied by a strong differentiation in plant engineering as well, detectable both at the sectoral and geographic levels. Specifically, waste-to-energy plants are prevalent in northern Italian regions, as are plants for organic waste. For this last type of waste, an estimate of the needs for 2035 shows a surplus for northern regions and a more or less marked deficit for southern regions depending on the scenario considered of high or low waste production²⁶.

4. Landfills are necessary: a simplified model

According to Legislative Decree No. 36 of January 13, 2003, which implements European Directive 99/31/EC, it is possible to distinguish landfills into 3 categories: for inert waste; for non-hazardous waste; and for hazardous waste. These facilities must meet certain technical and construction requirements and comply with specific standards because different wastes have different effects on the environment.

In Italy, according to the most recent data, there are 261 total landfills in operation²⁷. Of these, 118 are landfills for inert waste, 132 for non-hazardous waste and 11 for hazardous waste. Municipal waste landfills fall mainly into the non-hazardous waste category. Special waste, both hazardous and non-hazardous, can be delivered to specific or mixed landfills, depending on permits and the type of treatment required. These facilities are distributed throughout the country, with a greater concentration in the North, which hosts about 45 percent of the total facilities.

The acronym NIMBY (Not In My Backyard) is well known and has un-

²⁵ Althesys report of 2023 takes into consideration 59 companies.

²⁶ Ibidem.

²⁷ The source is ISPRA, Rapporto Rifiuti Speciali, Edizione 2024, dati di sintesi.

doubtedly been at the centre of debate whenever a community has found itself deciding whether or not to approve the siting on its territory of a facility intended to treat waste, be it a biodigester, incinerator, or landfill²⁸. Everyone produces waste and the amount of waste produced is often positively correlated with the level of consumption.

There is a need to return to thinking about the waste management cycle by trying to obtain a model that allows for the pursuit of two distinct objectives: that of efficient technical management of waste along with that of adequate economic efficiency by highlighting all the constraints, of a technical, regulatory and economic-financial nature, that are part of the problem. In this perspective, the issue of landfill creation and management within the organization of the entire waste cycle remains central as well as the construction of an integrated waste management model that takes into account the physical, administrative, social and economic specificities of the territories.

Assume the existence of a closed democratic administrative reality A , where closed means located in a territory that has no trade with the outside world at least as far as waste management is concerned. This administration has within it consumers (C), generating enterprises of different nature (I_p), trade and service sectors (S_c) each of which produces as a result of its activity a certain waste stream distinguished into municipal waste (R_u) and special waste (R_s) which, as mentioned above, must be managed internally in A . The R_u produced will be mainly a function of the activities of C and S_c while R_s will be a function of S_c and I_p . For now, the classic distinction between hazardous and non-hazardous waste is left out. C , I_p , S_c , R_u , and R_s can be considered carriers, that is, they can be composed of elements or agents with different characteristics. Therefore:

$$R_u = f(C, S_c) \text{ and } R_s = g(S_c, I_p)$$

The waste will have to be stored, in the simplest scenario, within a dedicated site i.e. a landfill (D). Since the landfill is a place not desired by the administrative reality in question, or rather not wanted by the community living there, the process of identifying the location in which to locate the landfill is tortuous and the level of social cost will be proportional to the population density of A or rather to some relationship between the numerosity of the community living in A and the availability of physical space in A suitable for hosting a landfill.

If the siting of the landfill is a costly process in terms of social consensus,

²⁸ For the definition and origin of the acronym Nimby, see <https://www.britannica.com/topic/NIMBY>.

the creation and management of the landfill become a critical step. Indeed, since the landfill is nothing more than a container that can accommodate waste, a relevant issue is to decide what the physical life of the landfill should be, i.e., its saturation time. Obviously, the mode of delivery is related to economic, environmental and social costs that are a major part of the problem under analysis. At this first stage, the public or private mode of landfill management is left out. The problem thus formulated unequivocally defines, given the capacity of the landfill (C_D) and the flow of the various wastes produced in A , the time by which the landfill will reach saturation, and a new storage site will therefore need to be identified.

Given C_D and the waste stream $F(R_u; R_s)$, the physical lifetime of the landfill (Tvf) in the absence of intervention is determined:

Sub C_D and $F(R_u; R_s)$, Tvf is determined

Once the Tvf interval is exhausted, a new landfill must be available that can accommodate the waste stream produced within A . Since implanting and operating a landfill also has financial costs ($Cost$) the problem also takes on an economic dimension. These costs must be borne by the community inhabiting A either through a general taxation (T) or through a form of pricing t that affects R_u and R_s delivered to the landfill. So, it must at least be:

$$Cost = t_{R_u} + t_{R_s} + T \text{ with } t \text{ and } T \geq 0$$

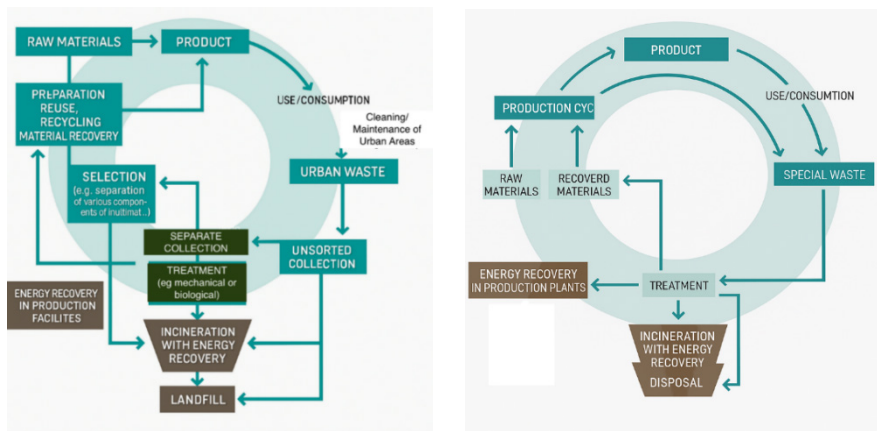
Note that any social costs (environmental, health, etc.) associated with the presence of D are not taken into account for the time being. Note also that we do not go into the question of whether D is public or private in nature: in fact, in a completely private context, the coverage of $Cost$ could be left to market rules as is partly the case today for R_s .

To lengthen the Tvf interval, the only option is to put in place interventions between the production and storage phases. These may be reduction in the production of R_u and R_s streams, treatment, recycling and reuse as seen above. Only if the final flow is reduced to zero will it be possible to dispense with landfilling otherwise it will remain necessary. The diagrams in Figs. 5 and 6 show a classic representation of the possible interventions that can be put in place to try to lengthen the Tvf value²⁹. It should be pointed out at the outset that the municipal waste cycle in the figure does not break down, at the stage referred to as "sorting," the components of

29 The source of the two figures is authoritative: it is, in fact, the Ispra Database on Municipal and Special Waste; <https://www.catasto-rifiuti.isprambiente.it/index.php?pg=&width=1352&height=878>.

wet, plastic, paper and glass. These types of materials are subject to very different industrial treatment processes. The location and management of some of these facilities present problems comparable to those of a landfill, increasing the degree of complexity of the system. Consider, for example, biodigesters used to treat the wet part of municipal waste³⁰. Figures 5 and 6 essentially illustrate the entire supply chain of small and medium-sized enterprises involved in the waste management cycle. This includes companies directly engaged in the treatment and processing of raw waste, as well as those that generate it (the I_p 's in the simplified model), which need to store the residues from their production activities in some way.

Figs. 5 and Fig. 6. The cycle of municipal (left) and special (right) waste reduction and treatment



Source: Ispra

Some observations can be made in keeping with the proposed simplified model:

- (a) the activity of using and consuming goods always generates both municipal waste and special waste;
- (b) business activity (production cycle) generates special waste;
- (c) the design of environmentally friendly products can reduce the

30 The treatment of municipal waste can also generate special waste. Municipal waste, once collected, is often subjected to sorting, treatment and disposal processes that can produce waste or residues classified as special waste. These may include: (a) sorting waste, in fact during the sorting stage of municipal waste, materials such as metals, non-recyclable plastics or other components may be separated and classified as special waste; (b) ash and slag because if municipal waste is incinerated, the slag resulting from the combustion process becomes special waste, often hazardous due to the presence of toxic substances; (c) sewage sludge from the wastewater treatment processes of waste disposal plants; (d) chemical wastes; and (e) wastes from treatment plants related to maintenance operations or simple operation (such as contaminated filters, waste oil or contaminated materials).

amount of waste sent to landfills in accordance with the principles of the circular economy, as it simplifies the sorting and treatment stages;

(d) waste treatment allows on the one hand to recover materials but on the other hand inevitably produces special waste because a treatment process is very unlikely to have 100 percent efficiency, and the level of efficiency takes different degrees depending on whether we are talking about plastics, paper, or glass;

(e) waste treatment that ends in energy recovery stages in production plants (e.g., Solid Secondary Fuel, CSS, used to generate energy in cement plants) or incineration for the sole purpose of producing energy also has a final stage that requires the disposal and storage of special waste, specifically ash³¹;

(f) the landfill remains the indispensable final step in any intermediate process created for the purpose of reducing the amount of residue produced in the simplified model in order to lengthen its physical life, i.e., the variable T_{vf} .

All production activities generate special waste including treatment actions resulting from separate waste collection. This is often not made clear in the most common presentations of the waste cycle since in the information given to the public the focus is placed on municipal waste and the techniques that enable its reduction. The landfilling phase of which disposal is also a part is represented, even in visual terms, as residual although always present and indispensable.

According to this simplified model that sees a closed administrative unit in the absence of economic constraints, waste cycle management is transformed into a technical problem that can be summarized as follows.

Proposition 1

The lifetime of a landfill is a function of the actions that a closed administrative unit takes upstream of the final storage phase. These actions will be more incisive the greater the community's aversion to the creation of landfills and the less space available suitable for the placement of a landfill.

This is clearly a simplified model, which could be enriched by loosening

31 CSS stands for Secondary Solid Fuel, which is the solid fuel produced from waste that meets the classification and speciation characteristics identified in the technical standards UNI CEN/TS 15359 as amended and supplemented. CSS finds application in various industrial sectors, including cement factories, incinerators, and thermal power plants. The acronym RDF stands for Refuse Derived Fuel while CSS stands for Secondary Solid Fuel. While CSS is specifically produced for use as a fuel in industrial plants with specific energy needs, RDF can have a wider range of applications, including the production of electricity and heat (<https://www.valli-ambiente.it/news/classificazione-dei-rifiuti-una-semplificazione-guida-alluso>). Valli Ambiente).

some constraints. The first is that administrative unit A is not closed but open to exchange with the outside world, specifically with other administrative units that may be domestic or foreign. The second lies in the fact that the management of the waste cycle has economic constraints, that is, there is the issue of its cost-effectiveness, which reflects the choice of possible ownership models within the cycle. In this paper we will follow this last.

5. The relationship between the physical and economic life of a landfill site

The economic life of a landfill refers to the period during which the facility is able to operate in a financially sustainable manner within technical and regulatory constraints. This concept includes several aspects:

(a) the assessment of investment and operating costs: plant and operating expenses for waste treatment, environmental monitoring, personnel, maintenance and safety;

(b) revenues from waste delivery (fees paid by municipalities or companies) and, in some cases, from energy production (e.g., through biogas capture) plus any subsidies;

(c) environmental regulations, such as, for example, those for compliance with waste, emissions, and remediation regulations, which directly affect the duration of the landfill's operations as they affect both costs and revenues;

(d) the post-management phase. Indeed, even after closure, a landfill has costs associated with environmental monitoring and maintenance to avoid negative impacts on soil, air, and groundwater. This period can last for decades.

The simplified model introduced in Section 4 established that landfill (D) is a necessary element of the waste cycle, acting as a "container" whose physical life (T_{vf}) is determined by its defined capacity (CD) and the incoming waste stream $F(R_u; R_s)$. To extend the T_{vf} interval, the only option is to implement effective actions upstream of the final storage phase, such as production reduction, treatment, recycling and reuse. The model shows that, in a context without explicit initial economic constraints, T_{vf} depends on the effectiveness of these actions and the extent to which the administrative community is averse to the creation of new landfills. However, to analyse the real need for landfills, the model must be integrated with the financial dimension, as the construction and operation of the landfill generate financial costs ($Cost$). The economic life of a landfill refers specifically to the period during which the facility can operate in a financially sustainable manner, taking into account investment and operating costs, revenues from landfill fees (t) and any subsidies (T). The break-even point (BEP) is

the key metric for assessing economic life.

The relationship between physical life and economic life is not always direct: financial sustainability depends not only on fixed costs (FC) and variable costs (VC), but also on the necessary inclusion of external costs (EC), whether environmental or social, in order to obtain a comprehensive economic analysis. The ownership structure and economic objectives of the operator (profit maximisation for private individuals versus potential Tvf maximisation for public bodies) become decisive here. A private operator, for example, could reach break-even point before physical saturation, and then maximise profits, removing the incentive to extend the Tvf because this would mean postponing profit flow; he could also have an incentive to externalise environmental costs to anticipate the break-even. Therefore, optimal waste cycle management, with the landfill as the binding end node, must balance physical life (technical capacity and social imperative of waste reduction) with economic life (financial sustainability and internalisation of costs, influenced by the ownership regime), as the ownership structure can reduce physical life if the objective is profit maximisation, allowing the externalisation of social and environmental costs.

The BEP of any investment is obtained from the application of a formula, which in its simplest version can be stated as follows:

$$BEP = CF / (PV - CVU)$$

where CF are the fixed costs, PV the selling price of the good or service, and CVU the variable cost per unit, i.e., the variable cost input to a single unit of product. The analysis for calculating BPE is effective only if one is aware of the firm's fixed costs and variable costs. The value in parentheses, $(PV - CVU)$, indicates the contribution margin, i.e., how much the fixed costs affect the final selling price, while the sum of fixed and variable costs represents total costs: $CT = CF + CV$ previously referred to, in the case of the landfill, as $Cost$. The selling price is actually the waste delivery fee t (which can be different for municipal or special waste: t_{Ru} and t_{Rs}). Simple application of the formula tells us how many units are produced, in the case of the landfill, how many tons of waste, leading to the break-even point of the investment made. Then profits will begin to be made.

As it has been guessed from the presentation of the simplified model, tariffs can also be such that cost coverage can be through external financial support. That is, given the formula $Cost = t_{Ru} + t_{Rs} + T$, if $T > 0$ then it means that the public entity breaks even on the plant i.e. provides financial coverage, since it was assumed that T are amounts from general taxation. If $T = 0$ then the landfill is breaking even while if $Cost < t_{Ru} + t_{Rs}$, a profit is being generated, and its destination may be different in the case of public, private

or mixed ownership of the plant.

It is important to note that if there are external costs (C_{est}) associated with the operation of the landfill in order to have a comprehensive economic analysis these will have to be considered as a component of $Cost$:

$$Cost = CF + CV + C_{est}$$

The nature of external costs can be either environmental or social. The break-even point of the landfill will therefore have to be the following:

$$BEP = (CF + C_{est}) / (PV - CVU).$$

Without the evaluation of external costs any consideration of whether to lengthen T_{vf} or to build landfills with very low environmental impact (the sustainable landfills discussed in the next section), is of little interest since the decision to build a landfill takes on the same characteristics as any financial investment. It is the environmental component and the need to use precautionary approaches that make the issue of sustainable landfill construction and management peculiar.

As mentioned before, if the landfill were private, the break-even point could occur before the landfill is fully saturated. In this case, profits could be generated. Indeed, this is the condition for having an investment by a private party, which will obviously have an incentive to minimize the $Cost$ variable by acting as much as possible on its CF , CV and C_{est} components. This can lead both to greater efficiency and to an attempt to disregard any external costs, that is, to externalize the environmental damage that the landfill may produce.

Whether the landfill would be publicly or mixed ownership and the ownership has profit distribution as its goal is relevant. In the case of public ownership, one might expect a greater focus on minimizing external costs but this is not a given. It also appears, as one of the most relevant issues, both the amount of fees that are paid for waste delivery and the economic regime, market and nonmarket, to which they are subjected. It should be recalled that special waste falls under the free market so that the transfer prices respond to the dynamics of supply and demand for storage while the transfer fees for municipal waste are regulated³².

Paradoxically, in a situation where in administrative area A the demand for special waste storage was greater than the supply of storage, a private special waste landfill could define its T_{vf} variable solely by maximizing

32 References on how the municipal waste tariff regulation system works can be found in ARERA's consultation document, Definition of the waste tariff method for the second regulatory period (MTR-2), July 2, 2021.

its profits. Once the permit to build the facility is obtained, the social component of *Cest* is nullified as is the incentive to stretch *T_{vf}*. In light of the considerations so far, the previous proposition can be supplemented as follows.

Proposition 2

The lifetime of a landfill is a function of the actions that a closed administrative unit takes upstream of the final storage phase. These actions will be more incisive the greater the community's aversion to landfill creation and the less space available suitable for the placement of a landfill. Ownership structure reduces the physical lifespan of a landfill to the extent that ownership can afford to externalize environmental and social costs and operates with the intent of maximizing its profits.

If we were in the presence of a public operator running the plant with the aim of maximizing *T_{vf}* then all actions would be aimed at extending the life of the landfill. The actions would be quite different from a profit-maximizing perspective. The landfill, as the final collector of the residue that cannot be otherwise managed except through storage, is the stringent constraint from which to start in an attempt to describe all upstream actions aimed at reducing the waste delivered to it. So, the waste cycle, in fact, depends on the capacity and characteristics of landfills and the regulatory constraints that govern them.

The picture sees its degree of complexity increase if one seeks to achieve the goal of reducing the waste stream to be stored through intermediate facilities such as biodigesters, incinerators, separation and treatment plants, and recycling facilities, which, created with the aim of reducing storage needs, replicate in whole or in part the problems that have been highlighted for landfills. That is, they will have their own well-defined physical capacity, their own need for cost-effectiveness and their own BEP, their management depends on the ownership regime, they may generate external costs that must be minimized and internalized in the production process, and they are subject to a problem of acceptability by the communities that must host them. In a way they are born to reduce the economic-social-environmental problems of landfills but end up replicating them although with different characteristics.

Hence the need to conceive of the waste cycle as an integrated system that ultimately provides a social and environmental service, as in the case of integrated mobility systems. What is the best management model for the entire integrated system depends on the set of factors previously described. Can it be left to spontaneous organization? Can optimal administrative areas be defined? How much of the process needs to be regulated? The landfill appears as the final collector of the entire process, which de-

pend, in a backward optimization perspective, on the choices made about its technical and economic characteristics. The “sustainable landfill” represents the most modern and ecological vision that a final waste storage system should have in an economy that actually wants to call itself circular.

6. The waste cycle as a network of enterprises and services for the environment: the IWaMAAS network

Network Analysis (NA) is an interdisciplinary methodological approach that studies the relationships between entities (called nodes) within a network. These entities can be individuals, organizations, computers, genes, or any other unit that can be connected to others. The connections between nodes are called links or arcs, and the overall structure of the network is represented as a graph, composed of nodes and links³³.

NA can also be applied to the waste cycle to analyze and optimize material flows, relationships among the numerous enterprises involved, and the overall structure of the waste management system. This approach can help identify inefficiencies in the system, improve its sustainability and also its environmental sustainability, and support strategic decisions. It can be used for modelling the waste management system understood as a network. Nodes represent the actors or stages in the waste cycle, such as waste producers (e.g., households, businesses); collection centres (e.g., ecological islands, drop-off points); treatment facilities (e.g., incinerators, biodigesters, recycling plants, landfills); and markets for recycled materials. Links, on the other hand, represent the flows of waste or materials between nodes (e.g., transportation of waste from a residential area to a recycling plant). A network can show how waste is collected, transported, processed, and

³³ NA uses a number of key concepts. Nodes (Vertices) are the basic units of the network, representing actors or entities. Links (Arcs) are the connections between nodes, which can be direct or indirect, weighted or unweighted. Degrees, on the other hand, are the number of connections a node has. A node with many links is often considered “central” within the network under analysis. Thus, Centrality is defined as a measure that identifies the importance of a node in the network (e.g., degree, betweenness, closeness). References to recent scientific literature are: Barabási (2016). *Network Science*. Cambridge University Press. This book provides a comprehensive overview of network science, with practical and theoretical examples. Newman (2018). *Networks*. Oxford University Press. A text covering both the theoretical foundations and practical applications of network analysis. Borgatti et al. (2009). *Network analysis in the social sciences*. An article exploring the use of network analysis in the social sciences. Lusher et al. (2013). *Exponential Random Graph Models for Social Networks: Theory, Methods, and Applications*. Cambridge University Press. An advanced text that focuses on statistical models for the analysis of social networks. Cinelli et al. (2021). The echo chamber effect on social media. A recent article using network analysis to study the echo chamber effect on social media. Bardoscia et al. (2021). The physics of financial networks. A review of applications of network analysis in the context of financial networks.

returned to the production cycle³⁴.

NA can be used to track and quantify waste flows through the system (material flow analysis). This would help identify bottlenecks (e.g., overloaded plants), optimize transport routes to reduce costs and environmental impact, and also assess the efficiency of recycling and material recovery. Through network models, alternative scenarios can be simulated, such as the introduction of new treatment plants or increased separate collection. Then NA can reveal which actors are most central in the waste management system, and for example, identify the most critical treatment plants or major waste generators (Centrality) or group (in Community) actors with similar functions (e.g., municipalities sharing a treatment plant). If a recycling plant were highly central, its closure could have a significant impact on the entire system. Through network analysis, one can try to optimize logistics or costs. In fact, by applying optimization algorithms to networks, it is possible to reduce waste transport distances, minimize operating costs, and improve overall system efficiency (e.g., minimum route algorithms can be used to plan waste collection routes).

From the above, we can see how NA can be combined with tools for life cycle assessment of various facilities (Life Cycle Analysis or LCA) to quantify the environmental impact of waste streams, identify the stages of the cycle with the greatest impact (e.g., CO₂ emissions from transport), and propose more sustainable solutions (e.g., increasing recycling or reducing landfilling). It allows studying the resilience of the collection and storage system with respect to potential facility failures, sudden increases in waste generation (e.g., during special events or emergencies), regulatory changes. NA can support the transition to a circular economy by both mapping recycled and reusable material flows and identifying opportunities to close material loops (e.g., linking waste producers with recycled material users)³⁵.

Considering integrated waste cycle management as a network that can perform an environmental service function offers a reading perspective underlying which there are a number of issues that deserve to be explored (Integrated Waste Management As A Service). First and foremost, it is a service that should be aimed at reducing the impact of human activities on the environment and therefore managed with its sustainability in mind given that its purpose should be to reduce landfilling and also the impact that landfills will have on future generations (the importance of the sustainable landfill concept returns). However, it cannot be ruled out that the

34 For an application see Cerqueti et al. (2021). Municipal waste management. A complex network approach with an application to Italy.

35 For some examples see: Liao et al. (2023); Chertow (2000); Brunner and Rechberger (2016); Ghisellini et al. (2016).

service can be provided with other objectives such as profit maximization.

The scientifically and technically relevant issue is that it is not just one network but a series of overlapping industrial networks that can be analyzed, and even managed, each in isolation or as a structure of connected and interdependent networks. For example, the waste collection cycle can be viewed as a network of nodes and links that include waste generation points, sorting points, treatment points, recovery facilities for processing, reuse or recycling, and disposal nodes for non-recoverable residues that may be incinerators or landfills. In this example, the network can be broken down into sub-networks because plastic, glass, paper, aluminium do not necessarily always follow the same routes but may be part of different structures. Each of these networks produces, at some stage, special waste destined to enter as input into a dedicated network (the special waste network, for example) composed of its nodes and links. The same reasoning can be made for municipal waste. This is another network with its nodes and links such as households, municipalities, sorting and pretreatment centres, biodigesters, and landfills.

This networked system, which we might call “multi-layered,” sees the presence of actors managed under private, public, or mixed ownership with economic objectives that may differ depending on the objective functions of the property. Given the fragmented nature of the sector, characterised by a large number of SMEs (Small and Medium-sized Enterprises), network analysis (NA) plays a crucial role in integration, providing the analytical lens needed to effectively map and coordinate the huge number of operators. SMEs, being active in all stages of the chain, particularly in special waste (representing 83% of operators), are themselves the vital nodes of these industrial networks. Improving integration through NA means not only optimising the flow of materials but also identifying how individual SMEs can maximise the business opportunities and profitability offered by the transition to a circular economy, acting as providers of environmental services. The system could be optimized according to its physical, economic, or hybrid sustainability.

The complexity of the system is apparent but, as mentioned above, if the aim were to conceive of the entire waste cycle as a service for environmental sustainability, it should be studied as a single system trying to identify the best ownership, economic and spatial management according to its environmental sustainability. This would be the first best.

Proposition 3

The integrated waste cycle is a system of integrated and overlapping networks with the landfill as its final storage node.

Proposition 4

If the landfill is a sustainable landfill its technical-economic characteristics serve as a constraint in the construction of the entire waste cycle management network.

7. Final Considerations

This paper has explored the waste management cycle taking into account the concepts of sustainability, economic efficiency, and systemic integration, proposing a novel conceptual and analytical framework to understand the role of the sustainable landfill within a broader industrial network of environmental services. The major idea developed throughout the work is that landfilling, often considered the least desirable solution in the waste hierarchy, must be rethought, not eliminated, as a crucial infrastructural and functional component of a circular economy. In this context, the sustainable landfill is not merely an endpoint, but a decisive node that influences upstream processes, reshaping the operational and strategic dynamics of the entire waste cycle. The choice to build sustainable landfills can have relevant impacts on the entire supply chain of small and medium-sized enterprises that are part of the waste management chain and offer profitable opportunities for those that want to enter in this sector.

The simplified model proposed in the paper tries to link the physical lifetime of a landfill (T_{vf}) to the collective capacity of a community or administrative unit to implement upstream interventions—such as waste reduction, pre-treatment, and reuse. Whenever the model is integrated within an economic perspective, it further reveals how ownership regimes (public, private, or mixed) significantly affect both the physical and economic longevity of landfills. More specifically, it shows that when ownership structures allow for the externalization of environmental and social costs, the incentives to maximize the operational life and environmental performance of landfills are weakened.

Moreover, the analysis presented highlights the growing economic weight of the waste management sector, characterized by increasing investments and a trend toward technological and organizational innovation. In this fragmented yet evolving landscape, SMEs play a pivotal role, not only as waste producers but as active participants and service providers within the circular economy paradigm. The involvement of businesses in waste cycle management, with a view to creating a sustainable landfill site, could have significant implications in terms of incentives to develop technological innovation projects for waste reduction, implement alternative production processes that use waste that cannot be disposed of, and invest in industrial design to improve recycling opportunities and thus minimise waste.

The introduction of network analysis as a methodological tool has allowed us to reinterpret the waste cycle as a complex, multilayered system of interconnected nodes and flows, what we have termed the IWaMAAS model. Through this model it is possible to acknowledge the complexity of managing differentiated waste streams (municipal, special, hazardous) but also to emphasise the need for strategic coordination across actors, sectors, and territories. It identifies central nodes, critical bottlenecks, and structural inefficiencies, so providing a robust foundation for decision-making processes, with the aim of maximizing system resilience and minimizing environmental impact.

In this vision, the sustainable landfill becomes both a constraint and a driver of innovation: a constraint, in the sense that it imposes rigorous environmental standards and long-time horizons; a driver, because it stimulates the development of upstream infrastructure, services, and governance models aligned with sustainability goals. Its implementation - technically sophisticated, socially negotiated, and economically evaluated - should be considered not as an unfortunate necessity but as a civic infrastructure of public interest, on par with transportation networks or energy grids.

In our vision sustainable landfills, far from being a residual or obsolete solution, are essential in constructing an effective and environmentally sound waste management system. Their integration into a broader circular economy strategy must be carefully planned, regulated, and supported by public policies that should be based on transparency, long-term investment, and active participation from all stakeholders. SMEs are strongly called upon to take part in this process.

Ultimately, the debate on the sustainability of the waste cycle and the integration of the IWaMAAS model provide the basis for clearly distinguishing the functions of the sector and the related optimal ownership structures. The management of the waste cycle as an integrated and interconnected service, of which SMEs are a fundamental part, reveals that the ownership regime has a significant impact on both the physical life (*Tvf*) and the environmental performance of final disposal facilities. With regard to the final node, sustainable landfill, public ownership is strongly recommended. This preference stems from the very nature of the facility, which requires particularly long-time horizons and aims to minimise negative externalities and defend the interests of future generations. These objectives are ill-suited to private interests, which, operating to maximise profit, have an incentive to reduce *Tvf* if they can afford to externalise environmental and social costs (*Cest*).

The high initial cost and the tortuous administrative and socio-political process involved in locating a site, although discouraging for private investors, are costs that a public body is better placed to manage with a view to maximising sustainability. On the contrary, for the upstream stages of the

supply chain (treatment, recycling, recovery and reuse), there is enormous scope for private ownership and affiliated companies. These activities are those that require the most innovation and efficiency and offer great business and profit opportunities for SMEs, which are active in all stages of the chain, particularly in special waste. The decision to build sustainable landfills, although it seems to limit the space for private operators in the management of the final node, actually acts as an extraordinary incentive to build a real upstream industrial chain managed by private operators, focused on reducing the flow of waste entering the landfill. In conclusion, the sustainability of the entire system requires binding, long-term public management of the final stage (the sustainable landfill), which acts as both a constraint and a driver, and dynamic, market-oriented private management of all intermediate reduction and recovery services, where efficiency and value generation are maximised.

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Legend of Symbols and Acronyms		
Symbol/ Acronym	Definition (English)	Source Context
A	Closed administrative reality/ unit	Simplified model setting
IWaMAAS	Integrated Waste Management As A Service	Management model based on network analysis
NA	Network Analysis	Interdisciplinary methodological approach
LCA	Life Cycle Analysis (or Life Cycle Assessment)	Tool used to quantify environmental impact
D	Landfill (Dedicated storage site)	Final collection site for waste
C	Consumers	Source of waste stream R_u
I_p	Generating enterprises of different nature (Industry/ Production)	Source of waste stream R_s
S_c	Trade Sector	Source of waste stream R_u and R_s
R_u	Municipal waste	Waste stream
R_s	Special waste	Waste stream
C_D	Capacity of the landfill	Physical limit of the landfill container
$F(R_u; R_s)$	Waste stream (Flow of Municipal and Special waste)	Total incoming waste volume
T_{vf}	Physical lifetime of the landfill	Saturation time of the landfill
Cost	Financial costs of implanting and operating a landfill	Total costs, $CT = C_F + C_V$
t	Form of pricing / fee	Fee affecting R_u and R_s delivered to the landfill
T	General taxation (or financial support)	Amounts from general taxation used for cost coverage
t_{Ru}, t_{Rs}	Transfer fees for Municipal and Special waste	Specific delivery prices (derived from t)
C_{est}	External costs (Environmental or Social)	Costs associated with landfill operation that must be internalized for comprehensive analysis

C_F	Fixed costs	Costs independent of the quantity produced
C_V	Variable costs	Costs that vary with the volume of activity
C_{vu}	Variable cost per unit	Variable cost input to a single unit of product
P_v	Selling price of the good or service	Equivalent to the waste delivery fee t in the landfill context
ATO	Administrative Ambit (Ambito Territoriale Ottimale)	Administrative area defined for organizing public services
EGATO	Governing body of the ATO	Body responsible for the governance of the administrative ambit