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Analysis of the variation of costs for sewage sludge transport, recovery and disposal in Northern Italy: a recent survey (2015–2021)

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ABSTRACT

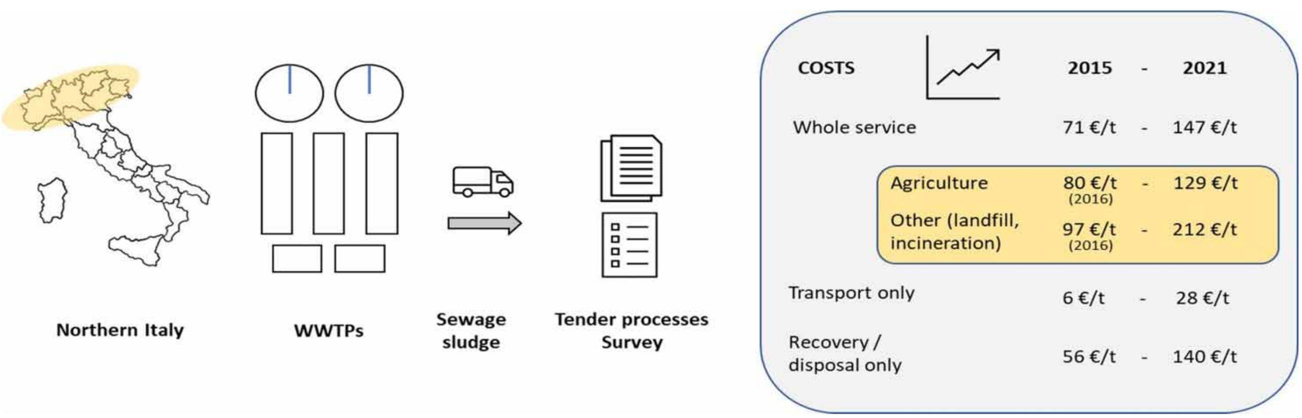
The cost for the recovery/disposal of residues produced by wastewater treatment plants (WWTPs) represents a relevant aspect in the economics of WWTP management. We elaborated and applied a desk-based methodology to analyze tender processes and to investigate quantitatively and qualitatively the variability of unit costs for sewage sludge (EWC 190805) management in Northern Italy from 2015 to 2021. We conducted a qualitative survey for operators of the sector. Unit costs for sludge management increased over time. The unit cost was mostly affected by the type of sludge recovery/disposal being the cost for recovery in agriculture (direct or by composting) lower than incineration and landfilling. Other variables influencing the cost were the distance and discount offered by the contractor. Regulatory and judiciary events determined a sudden increase of sludge disposal costs in Italy between 2017 and 2019. Recovery in agriculture, when practicable, remains the preferable option. Results can orient and support the optimization of sludge management costs and be of interest for future studies at national or European level.

Key words: biosolids, management cost, recovery/disposal routes, tender process, wastewater treatment plant

HIGHLIGHTS

- A systematic methodology based on the analysis of tender processes to investigate trends in sewage sludge disposal costs was developed.
- The cost of sludge recovery/disposal increased over time in Northern Italy in 2015–2021.
- Variables most influencing the cost were sludge quality type of recovery/disposal.
- Recovery/disposal only influenced costs more than transport.

GRAPHICAL ABSTRACT



INTRODUCTION

The generation of sewage sludge is an unavoidable consequence of wastewater treatment. Wastewater treatment plants (WWTPs) produce on average 0.3 kg of dry matter (DM) per kg of chemical oxygen demand (COD) removed, with 75–85% water content (Ginestet & Camacho 2007; Canziani 2016), and approximately 20–25 kg DM per person per year in Europe (EU-27) (EUREAU 2021).

Sewage sludge derived from urban WWTPs is a waste labelled under the European Waste Catalogue (EWC) with the code 190805. Once treated, sludge is managed mainly by recovery and reuse in agriculture or for energy production by means of incineration, or disposed of by landfilling (Cieślik *et al.* 2015; Shaddel *et al.* 2019). The most practiced route for sludge management in Europe is the reuse on land (Eurostat 2021), regulated by the Sewage Sludge Directive 86/278/EEC (Bianchini *et al.* 2016; Collivignarelli *et al.* 2020; Campo *et al.* 2021). The flexibility in national implementation provided by the Directive resulted in a variety of approaches and limit values adopted by each member State (Hudcová *et al.* 2019; Gianico *et al.* 2021). In 2018, countries mainly recovering sewage sludge in agriculture, directly or by composting, were Ireland, Lithuania, Hungary, Spain, Czech Republic and Norway, while in northern countries such as Netherlands, Belgium Germany and Switzerland incineration was predominant, and landfilling was mainly practiced in Malta, Bosnia Herzegovina and Romania (Eurostat 2021).

In Italy, a decrease of disposal of sewage sludge in landfills was observed, from 40% in 2010 (Eurostat 2021) to 7% in 2019 (ISPRA 2021). In 2019, in Italy, 56% of sewage sludge was disposed of (of which 13.2% was in landfills and 7.7% by incineration) and 41% was recovered, of which 67.9% was by activities of recovery/reuse of organic substances (ISPRA 2021).

There is a great variability in the cost of alternatives for sludge disposal in European countries and the costs can vary according to local conditions (Foladori *et al.* 2010). The costs for sludge management and disposal may reach 40–60% of the total costs for managing the entire WWTP, including personnel, maintenance, energy and sludge treatment and disposal (Foladori *et al.* 2010). A publication from the EU (EC 2002) confirmed lower cost for sludge addressed to landspreading of solid and semi-solid sludge (160–210 €/t DM), whilst landfilling, mono-incineration and co-incineration of sludge with other wastes entail the highest costs (210–330 €/t DM) considering operational and investment costs. Foladori *et al.* (2010) reported the average cost of wet sludge disposal in Europe as 63.4 €/t (in the range of 0–120 €/t), including transport, being data from 2003 to 2007. It corresponded to an average cost of 317 €/t DM, with 80% water content, varying from 359 €/t DM for landfilling and 139 €/t DM for recovery in agriculture, with higher cost associated with landfill and incineration. Kacprzak *et al.* (2017) estimated an average cost for sewage sludge disposal in selected countries in EU (data up to 2013) varying between 160 and 310 €/t DM, with variation among countries and type of recovery/disposal.

At the European level, main factors influencing sludge management and leading to very different costs for disposal were: climatic conditions, land resources, transport, local regulations and fertilizer limits, amount of sludge production, disposal options and ethical factors (values and priorities) related to the acceptability of specific practices or technologies (Foladori *et al.* 2010; Collivignarelli *et al.* 2020). Also, increased consideration to climate changes and mitigation of greenhouse gas emissions focus attention on additional benefits of sludge applications to soils and resource recovery from sludge as phosphates (Kacprzak *et al.* 2017).

In Italy, the management of sludge, considering loading, transport, analysis and recovery or disposal, was estimated to impact between 15 and 40% of the costs of a WWTP (ATIA ISWA Italia 2019). In Lombardy region, the unit cost for sewage sludge recovery in agriculture decreased from 90 €/t to about 50–70 €/t in 2015 due to the increasing competitiveness of the business in the recovery market (Canziani 2016). In 2016, the cost for sewage sludge recovery by incineration was in the range of 80–90 €/t (Canziani 2016). Visigalli *et al.* (2019) reported typical unit cost for sludge disposal as 70–250 €/t, while transport counted for 15–20 €/t. Some utilities of Integrated Water Service (IWS) carried out an estimation of unit costs for sludge disposal for the Investment plans of Optimal Territorial Basins (OTB) ('Piano d'Ambito')[1]. One utility, which manages several WWTPs in the Milan province, observed an increase of costs from 2015 to 2019 from 55 €/t to 103 €/t for sludge suitable for recovery in agriculture, from 81 to 120 €/t for incineration and from 104 to 202 €/t for landfilling. Another one, managing the two large plants serving the city of Milan, registered an increase (2015–2020) from 68 to

[1] In Italy, the water services are organized in Optimal Territorial Basins (OTB), defined by the Regions and individualized through the territorial and functional integration of the different activities of the integrated cycle. A single utility is in charge of the whole water cycle, from catchment and distributing domestic water to collecting and treating wastewater (Integrated Water Service).

122 €/t for sludge recovery in agriculture and from 43 to 115 €/t for dried sludge recovered by cement factories. These increases were attributed mainly to market externalities and regulatory uncertainty that occurred between 2015 and 2018, and to the increase in sludge production due to improved performance of treatment plants. In Italy, over time, regulations posed more restrictive limits for the reuse of sludge in agriculture – such as the recent Law 109/2018 (Italian Parliament 2018) that introduced new limits for hydrocarbons, some organic micropollutants and restricted limit values for some heavy metals. However, improved technologies related to digestion, dewatering and thickening in the sludge line of WWTPs enhanced the potential of its recovery such as for energy production, together with higher competition and increased demand which affected the cost of sludge management (Campo *et al.* 2021).

As for many public services, the entrusting of services for the management of sludge produced by WWTPs in Italy is administered through tender processes. This study proposes a methodology and shows results on the variation of costs for sludge management in the last six years in Northern Italy, with the aim of supporting the sector in the optimization of costs and sludge management. Systematic and comprehensive studies and published data on sludge disposal costs for European countries, specifically Italy, are scarce. In this study, we contribute to the sector by researching sludge disposal costs and the variables affecting their variation in the North of Italy. This area, with seven regions representing about 30% of its territory, hosts most Italian treatment plants: 56% of landfills for special waste, 57% of co-incineration plants, 57% of composting plants (ISPRA), with Lombardy being one of the Italian regions with the highest reuse of fertilizer in agriculture derived by sludge (Ref Ricerche 2018).

The understanding and investigation of unit costs for sludge recovery/disposal and their variability are of great relevance due to their incidence on WWTP management costs and their relationship with waste destination, from the perspective of a circular economy, both at national and European level.

METHODS

A desk review of publicly available tender processes for the management (collection, transport, and recovery/disposal) of sewage sludge (European Waste Code EWC 190805) treated by urban wastewater treatment plants (WWTPs) in Northern Italy was conducted. In Italy, water and wastewater treatment plants are mostly managed by public bodies (97%) which can outsource services, such as waste management, through public tender processes. The study covered the following seven regions in the North of Italy: Piedmont, Lombardy, Liguria, Aosta Valley, Veneto, Trentino Alto Adige and Friuli Venezia Giulia, and a time frame of about seven years (Jan 2015–Sept 2021). Tender documents were collected from websites of contracting authorities and water management companies in the regions. Additionally, a combination of keywords was searched on Italian tendering websites 'smaltimento', 'fanghi', 'rifiuti speciali', '190805' (recovery/disposal, sludge, special waste, 190805). Inclusion criteria were: the date (2015–2021), the EWC (190805), the location (selected regions), the indication of the tender base price and/or the awarded price (or the data to calculate it) for at least one of the management activities for sludge produced by WWTPs (collection, transport, reuse/recovery/disposal, analysis).

Collected data for each tender process were: company name, year, region and province, tender base price and/or awarded price, raw sludge amount (tons), number of WWTPs served, type of recovery/disposal, document source, discount offered, total value of the bid, duration of the service requested. Data were collected, summarized and analysed by using Microsoft Excel (2010).

We conducted a quantitative and a qualitative analysis.

For the quantitative analysis, data were grouped by tender processes that reported (or for which was possible to calculate) the base unit costs (€/t) and the awarded unit cost (€/t), intended for the dewatered sludge exiting the WWTP raw. For each group, data on costs were divided in three subcategories based on the following sludge management activities: (1) whole service (loading, transport, recovery/disposal and analysis), (2) transport only, (3) recovery/disposal only. In tender processes not indicating the unit cost, it was calculated by dividing the total cost by the tons of sludge to be managed. The awarded price, when not indicated, was calculated by applying the discount offered by the awarded company to the base tender price. When bids were divided into lots, meaning that the total amount of the bid was divided into small segments independent from each other, the cost indicated for each lot was extracted separately.

For the unit costs, we calculated the mean, median, minimum and maximum, 1st and 3rd quartile and the standard deviation. Results were summarized and compared over time.

A qualitative analysis of the variation of costs of sludge management was conducted by a desk review and a survey. For the desk review, we carried out: (1) identification and selection of the variables that may influence the price, (2) identification and grouping of tender processes with information on selected variables, (3) qualitative analysis of data identified variables influencing the price variability.

Based on results of the qualitative analysis from the desk review, we prepared a survey to be submitted to utilities involved in sludge management tendering process (Supplementary Material S1). The questionnaire, to be filled online, was sent to utilities in the area of study of which we had a direct contact. The questionnaire was composed of 15 questions about variables which can affect the cost of sludge recovery and disposal. The questionnaire was aimed at confirming the desk review findings and clarify aspects that were not easily emerging from the desk review. The questionnaire was prepared by Google Modules (Google LLC) and answers were collected and analysed by Microsoft Excel (2010).

Results were summarized and compared.

RESULTS

We analysed 131 websites and identified 49 reporting tender processes meeting inclusion criteria. The desk review resulted in the identification of 194 tender processes; for 100 of them it was possible to extract both the base and awarded unit costs, for 22 the awarded unit cost only, and for 72 the base unit cost only. The most represented region was Lombardy with 42% of bids, followed by Veneto and Piedmont. Fifty-nine per cent of tender processes referred to the period 2019–2021. A summary of extracted data is presented in Table 1. Each tender process could report one or more base and/or awarded unit cost, as an example, when the service to be contracted was divided into lots (intended as parts in which the bid can be divided into that maintain their functionality and feasibility): the same tender process can indicate a base price for lot n. 1 and a different price for lot n. 2.

Quantitative analysis

In Northern Italy, the tender base unit cost for the whole service (loading, transport, recovery/disposal and analysis) (n=208) increased by 125% on average over the studied period, with the median value starting at 78.6 €/t in 2015 up to 176.9 €/t in 2021 (Figure 1). The median values of tender base unit costs for transport only (n=25) ranged from 13 €/t in 2015 to 30 €/t in 2021; the median value for recovery/disposal only (n=21) ranged from 59 €/t in 2015 to 120 €/t in 2021. See Table S2 and Figure S2.1 in the Supplementary Material for detailed results.

The awarded unit costs for the whole service (loading, transport, recovery/disposal and analysis) (n=179) increased by 95% over the last seven years, with the median value starting at 62.4 €/t in 2015 up to 122.2 €/t in 2021 (Figure 2). The median values for awarded unit costs for transport only (n=26), ranged from 5.7 €/t in 2015 to 22.8 €/t in 2021; the median value for awarded unit costs for recovery/disposal only (n=21) ranged from 55.7 €/t in 2015 to 145.0 €/t in 2021. See Table S2 and Figure S2.2 in the Supplementary Material for detailed results.

Even if the components of the price by service, i.e. transport vs recovery/disposal, were indicated (or were possible to be calculated) in few tender processes, results showed that the activity with more influence on the total price is the recovery/disposal more than the transport (Figure 3). The unit cost for transport represented on average 16 and 18% (awarded and

Table 1 | Summary of tender processes analyzed per year and data extracted from tender processes

		Number of data extracted in tender processes					
		Tender base price			Awarded price		
Year	Number of tender processes	Whole service	Transport only	Recovery/disposal only	Whole service	Transport only	Recovery/disposal only
2015	14	12	4	3	9	2	2
2016	16	22	3	0	13	0	1
2017	22	19	2	2	23	1	1
2018	27	25	0	4	18	1	3
2019	41	35	4	5	28	5	0
2020	52	63	6	6	68	11	7
2021	22	32	6	1	20	6	7
Total	**194**	**208**	**25**	**21**	**179**	**26**	**21**

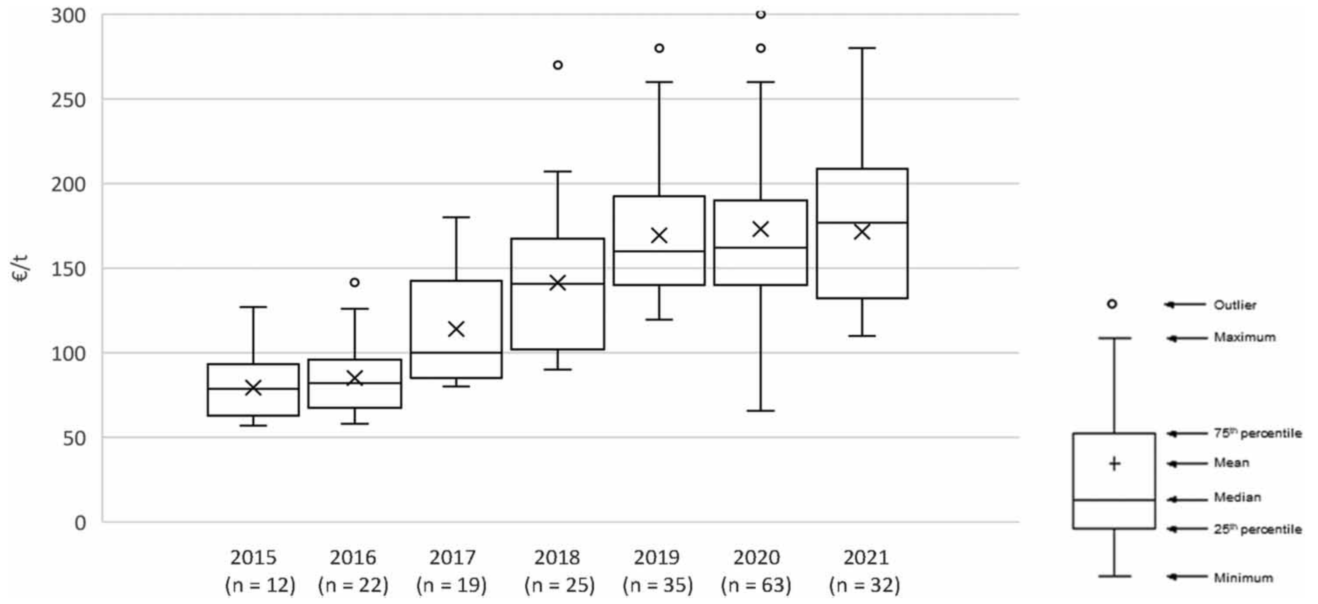


Figure 1 | Results of elaborations for tender base unit costs for sludge management activities (loading, transport, recovery/disposal and analysis) in Northern Italy (2015–2021). The amount of data (base unit cost) per year *n* is indicated in parenthesis.

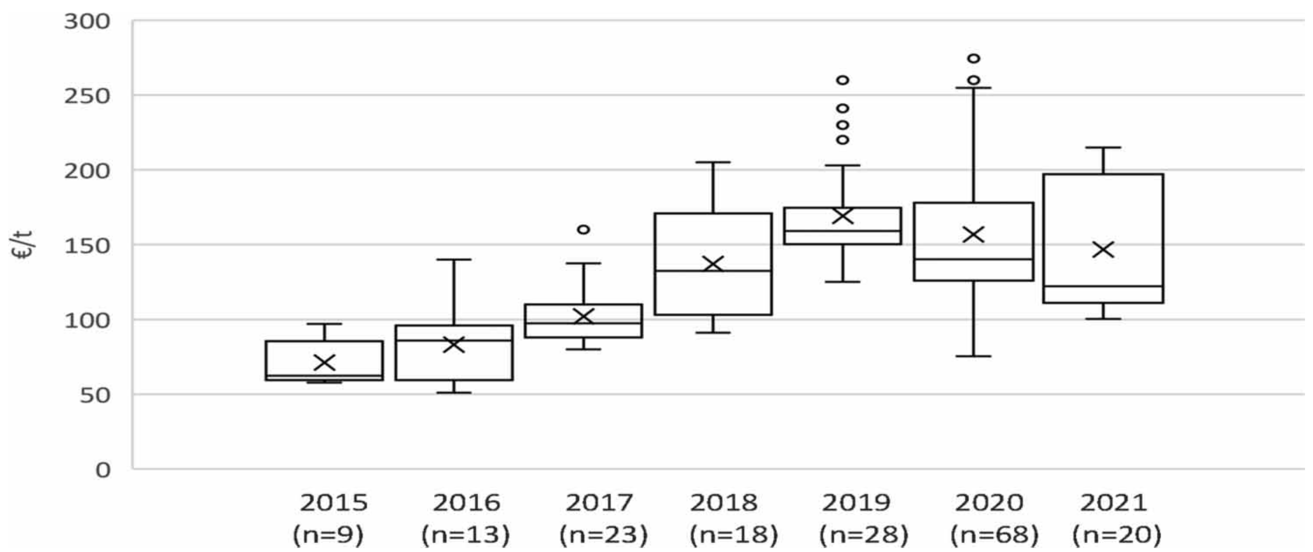


Figure 2 | Results of elaborations for awarded unit costs for sludge management activities (loading, transport, recovery/disposal and analysis) in Northern Italy (2015–2021). The amount of data (awarded unit cost) per year *n* is indicated in parenthesis.

tender base price respectively) of the total cost, and was not observed to have a relevant effect over time on the overall cost of the management of sludge exiting the WWTPs (Table S2, Figures S2.1 and 2.2 in Supplementary Material).

Qualitative analysis

Qualitatively, we identified and analysed, by the desk review, the following variables that could influence the unit cost of sludge management: type of recovery/disposal (agriculture, incineration, landfill), distance to be covered for transport to recovery/disposal facilities, area (region or province), type of sludge (dewatered/dried), discount offered by the contractor, number of plants included in the bid, and quantity of sludge to be managed.

The unit cost was influenced by the type of recovery/disposal the sludge could undergo. The cost for recovery or reuse was lower than the cost for disposal, with the recovery in agriculture being lower and the disposal in landfill the highest. We could identify 22 tender procedures explicitly indicating the possible destination for the sludge: we extracted the unit prices for

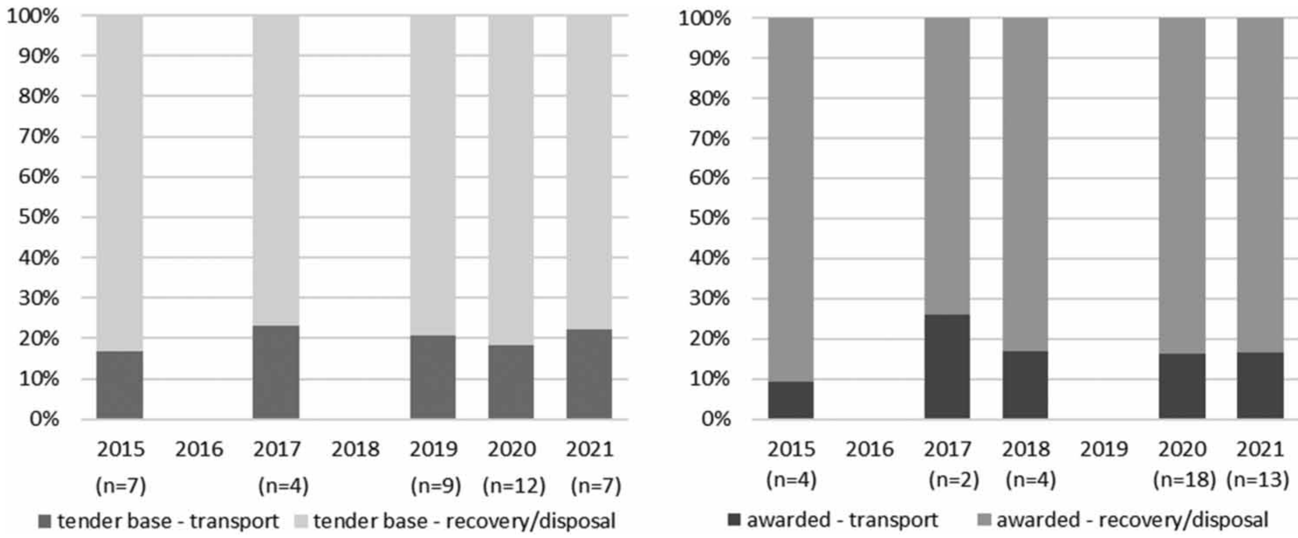


Figure 3 | Weight, in percentage, calculated on the average of tender-base and awarded unit costs for transport only and recovery/disposal only over time (2015–2021) in Northern Italy. The amount of data per year *n* is indicated in parenthesis.

managing the sludge to be recovered in agriculture and to undergo other types of recovery/disposal, e.g. incineration, landfill. On average the price for the recovery of sludge in agriculture is lower than other recovery or disposal (Figure 4).

The distance of WWTPs from recipients also emerged as having an influence on the unit cost: in a few calls for tender, a slightly higher unit cost was indicated for collecting sludge from WWTPs further from recipients.

A few calls for tender fractioned the total amount of the bid into lots to facilitate the participation of small and medium enterprises. Among criteria for the partition into lots, we identified the partition by zone, which grouped plants in a nearby area, and the partition by quality of sludge which consequently involved their possible destination. The difference among unit costs related to lots can be traced back to variables such as distance or type of sludge or type of recovery/disposal. Moreover, the awarded price was influenced by the discount offered by the contractor and can vary within the same tender process by lots when they were assigned to different contractors.

The analysis also suggested that the price can be influenced by the type of sludge (dewatered/dried) but available information was not sufficient to determine the extent of impact on the price.

Finally, there were three cases in which tender documents specified different base prices related to the need for special means of transports due to the access or the structure of WWTPs; and one tender process indicated a higher price in relation with or to the urgency of sludge collection (within 24 hours being more expensive than within 3 days).

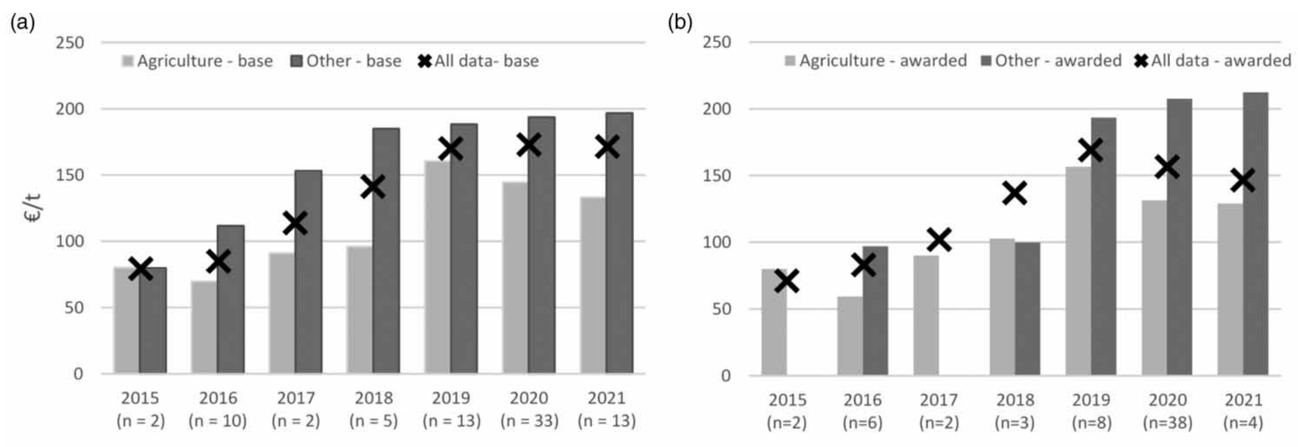


Figure 4 | Average values for the unit cost per year of sludge recovery in agriculture, other recovery/disposal of sludge, all data, base (a) and awarded (b) price. The amount of data per year (*n*) is indicated in parenthesis.

Qualitatively, no relation was observed between the unit cost and the number of plants to be served, or the quantity of sludge to manage, or the area (region or province).

The survey was submitted to 31 utilities of IWS, 11 of which responded. Sludge management activities covered the whole service, whilst it was pointed out that in some plants analysis or loading could be not included in the bid. Respondents estimated that sludge management costs impacted on the overall WWTPs management cost of a percentage comprised of between 11 and 40% in 2020.

The main variable affecting sludge management cost resulted in the sludge quality and type of recovery/disposal, followed by the distance from the destination plan. The quantity of sludge (three respondents), the discount applied by the contractor (two respondents), the loading/transport, the area, the number of plants (one respondent) were less mentioned as relevant in the definition of the price. All respondents affirmed to have noticed an increase of sludge costs over the last six years, the increase being mostly related to the activity of recovery/disposal. Respondents confirmed that recovery of sludge for agricultural reuse is less expensive than energy recovery, and that the most expensive destination is the disposal of in landfill, which could be up to twice the cost of recovery ('*landfilling costs up to twice than other destinations*', ' *disposal in other plants costs about twice than agriculture recovery*'), some affirming '*The possibility of recovery in agriculture lower considerably the cost*', '*The sludge managing cost is mainly linked to the possibility of recovery in agriculture*', '*Incineration and landfill are more expensive*'.

One respondent pointed out that recovery at cement factories is still the cheapest destination for dried sludge, even compared to recovery in agriculture (dewatered sludge). Respondents declared to be aware of the possible destination of sludge according to its quality when preparing the bid and to consider it for the definition of the tender process base price.

When asked about reasons for the increasing trend of the unit cost for sludge management, respondents attributed it to more restrictive regulations and normative uncertainty, one mentioning the lowered acceptability limits for sludge to be recovered in agriculture; the diminished and limited availability of sites receiving or treating sludge; the limited competition among operators of the recovery/disposal sector; and, the increase of sludge quantities and the demand for recovery/disposal sites.

DISCUSSION

Study results showed that in the North of Italy, in the last seven years, average unit prices for sludge management increased. The increase affected tender base prices more than awarded unit prices. The increase was mainly due to the component of the price representing the recovery/disposal of sludge than the transport. Variables affecting the price were principally the type of recovery/disposal, then the distance, the discount offered, while the influence of the area or number of plants in the bid was not noticeable. Our study confirmed the trend of costs as well variables influencing it already identified in previous studies and reports at regional and European level.

The type of recovery/disposal of sludge represents an interesting variable because, in its turn, it is influenced by other factors such as the availability of sites as lands or treatment plants, the number and type of operators in the market, the competitiveness, and the regulatory framework, in particular for sludge recovery in agriculture.

We observed an increase of prices especially between 2016 and 2019, followed by a stabilization or even a little decrease. It is to be noted that in Lombardy, since 2015, the introduction of the regional regulation 'DGR 2031/X/2014' (Lombardy Region 2014), distinguishing limits for suitable and high-quality sludge to be recovered in agriculture, had a crucial impact on the regulatory framework. In the following years (2017–2019) continuous normative changes and judiciary issues, especially on parameters and limits for agriculture recovery, led to a great uncertainty (Ricerche 2018). The situation resulted in a slowdown of sludge recovery as fertilizer, especially in Lombardy, and a strong public opposition, and consequent cost increase (Utilitalia 2017). This generated in parallel an increase request for cross-border disposal, or disposal from other regions (ARERA 2019). At the same time, technological improvements and process optimizations resulted internationally to an improvement of WWTPs performance with a consequent increase of sludge production, and an increased demand for recovery and disposal options. These events, as underlined by utilities representatives responding to the survey, were the main aspects causing the abrupt increase of sludge disposal costs from 2016 to 2019. Also, since 2017, we observed an increased variability of prices, especially of tender base prices.

Sludge recovery in agriculture, when practicable, emerged to be economically advantageous and preferable.

As the variable area intended as the geographical location (region or province) did not emerge as relevant in directly influencing the price from the qualitative analysis of bids, we can hypothesize that other variables, mentioned in the survey, were affecting the cost, such as WWTPs being located in areas with less availability of land for sludge recovery, or treatment plants as incinerators, cement factories, or landfills for special waste.

Moreover, strategies implemented by utilities of IWS, such as the possibility and balance of sludge quantities to dewatering or dry, affected sludge type of recovery/disposal and their management costs. It was not possible to determine the extent of this influence from our results.

The developed methodology, based on public data from tender processes, has the potential to be applied to investigate price trends of activities related to WWTPs undergoing public tender processes, such as waste management and procurement, as an example, of reagents, or services.

Limitations of the study were: tender processes analyzed were limited to those accessible and available online; information and data of interest for the study were reported inconsistently in tender documents; disaggregated data per activity (transport and recovery/disposal) were limited. Despite these limitations, we consider that the study shows a reliable picture of the economics related to activities for the recovery or final disposal of sludge from WWTPs in Northern Italy.

CONCLUSIONS

This study clearly shows an increase of the costs for the management of sludge that occurred in Northern Italy in the last seven years (2015–2021). This is mainly related to the recovery/disposal services rather than transport. The study also evidences as the recovery in agriculture is less expensive than other forms of recovery or disposal. Moreover, regulatory framework changes also affected the variation of costs. It emerges that, from an economic point of view, and despite the increasing trend of costs over time, agricultural recovery of sludge should be prioritized when possible.

We consider the methodology applied was simple and useful and it was successful to investigate the trend of costs of activities related to WWTPs that undergo public tender processes. Results can orient and support the optimisation of sludge management costs.

This systematic analysis could be of interest for studies or analysis at national or European level in future.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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