How far are we from closing the loop of sewage resource recovery? A real picture of municipal wastewater treatment plants in Italy

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ABSTRACT

This paper presents the results of a broad-scale survey of resource recovery implementation in Italian wastewater treatment plants (WWTPs). To the best of our knowledge, this is the first survey comprising a large number of WWTPs done in Europe: more than 600 plants were investigated, representing a treated load of around 20 million population equivalent (≈25% of the total in Italy). Conventional and innovative options for both material and energy recovery along the water and sludge line were surveyed, in order to i) offer a real and complete picture of the current state of resource recovery in WWTPs, and ii) underline key aspects and potential areas for improvements, as a baseline for future developments in the direction of more sustainable plants.

Survey outcomes showed that resource recovery is just in its infancy in sewage treatment: only 40% of plants perform at least one option for material/energy recovery. The action most often implemented is recovery of material from surplus sludge for agricultural purposes and the internal reuse of treated effluent as water for various types of plant maintenance. The production of energy from biogas also occurs frequently but only in large plants. On the other hand, some well-known options, such as external reuse of treated effluent or nutrients recovery, were implemented only in a minority of plants: this is likely due to limitations resulting either from strict regulation or difficulty placing recovered products on the market. In conclusion, an overall explanation of these driving forces within the system is explored.

Keywords: wastewater treatment plants; material recovery, energy recovery; Italian survey; sustainability.

1. Introduction

Urban wastewater treatment with secondary processes is now an extremely mature technology able to produce a safe effluent from the points of view of both human health and environmental impact (Batstone et al., 2015). However, the current demands from a rapidly growing human population and the consequent need for a more sustainable society are spurring new developments in sewage handling (van Loosdrecht and Brdjanovic, 2014). These developments have two main drivers: general process improvements/optimization, and treatment plants' contribution to the recycling of resources (Grant et al., 2012). Such goals can be achieved if all the resources available in wastewater are recovered, i.e., water itself, nutrients and energy, or in other words, as described by Verstraete et al. (2016), if a NEWEL nexus (Nutrients-Energy-Water-Environment-Land) is established. Sewage treatment can be designed with "flexible" technologies that theoretically allow for closing cycles and recovery of resources if plants are properly conceived. For this reason, the wastewater industry is facing a paradigm shift: wastewater treatment plants (WWTPs) are no longer designed merely as systems to remove pollution (end-of-pipe approach), but instead as factories where various value-added products can be recovered (resources-oriented approach). This means that, next to the production of a purified effluent, which remains an essential pillar of treatment, WWTPs can become (pro)active resource producers: from WWTP to WRRF (water resource recovery facility).

In the last few years, alternatives for resource recovery in WWTPs have been touted mainly for: (a) recovery of thermal, electrical and mechanical energy, to be consumed either inside or outside the plant, and (b) recovery of materials to be sold on the market. While renewable energy recovery (through biogas production and utilization, hydropower or heat from wastewater) is quite practicable, at least when energy is used immediately on-site in plant operations (also with the aim of a net energy balance: McCarty et al., 2011), conversely, recovery of materials presents some barriers due to their intrinsic properties: difficulties in handling and storage, contamination, constraints in commercialisation, and low public acceptance, because many residuals are still perceived as wastes (Verstraete et al., 2016). But even if the recovery and production of energy at sewage works is currently getting the most attention (also achieving energy self-sufficiency: see, for instance, Nowak et al., 2011), material recovery from wastewater and sludge (as phosphate and bioplastic production, etc.: see van Loosdrecht and Brdjanovic, 2014) should not be overlooked as they can play an important role in developing more sustainable services.

Therefore, assembling a detailed picture of the extent these actions are currently implemented in WWTPs is a fundamental starting point in boosting sustainability. However, this is difficult information to acquire, because comprehensive data about resource recovery applications in full-scale plants are rare on a broad scale (e.g., the national level) or incomplete in terms of surveyed options. For instance, surveys performed by NRC (2012) and WEF (2013) were restricted to effluent reuse and biogas production (and consequent energy recovery), respectively. Similarly, a broad survey covering the majority of European countries has been described by Kelessidis and Stasinakis (2012) but was limited to sludge reuse options. In summary, complete surveys of large geographical areas including all the potential options for energy and materials recovery at different stages of WWTP have not been investigated, so far.

In order to bridge this gap, we looked inside about 600 Italian WWTPs (corresponding to approximately a quarter of the national load of treated sewage). We showed the current status of implementation of resource recovery options: both conventional and emerging alternatives, for a total of 20 options corresponding to all phases of treatments in plants, were considered. Finally, we outlined the main driving forces playing a role in the implementation of recovery actions, either in favor or against: in this way, future efforts toward the development of more sustainable WWTPs could be easily identified.

2. Materials and methods

A 1-page, easy-to-fill-out questionnaire (Figure 1) was elaborated for data collection; creating a clear, user-friendly form was essential to obtain a significant amount of responses: as a result, more than 600 WWTPs provided their data.

In brief, after a preliminary section related to general information on some of the main features of WWTP (such as plant configuration, treated load, etc.), the questionnaire lists a large variety of resource recovery options, both conventional and innovative. They were divided by type of resource (material *vs.* energy) and grouped by plant stage (water *vs.* sludge treatment lines): 20 options were considered, including the recovery of materials from screening, de-gritting and de-oiling; nutrients and biopolymers; treated effluent and sludge; heat and electricity from biogas; finally, the last section, called "Other Recovery Forms," accounts for recoveries taking place inside the WWTP but not involving wastewater directly (e.g., photovoltaic systems). They represent proper indicators of the current scenario, although the scientific literature is proposing some promising alternatives. For instance, the authors are currently carrying out a study aimed at recovering nutrients from sludge (Collivignarelli et al., 2015a) by running a thermophilic membrane reactor; this process has led to promising results indeed in liquid wastes treatment (Bertanza et al., 2010a; Collivignarelli et al., 2015b).

With respect to data processing, the survey outcomes were parameterized according to WWTP size; three classes were established: SMALL WWTPs, with a sewage treated load lower than 10,000 PE

(Person Equivalent), MEDIUM (10,000 ≤ PE ≤ 100,000) and LARGE (PE >100,000).

3. Results

3.1. Surveyed WWTPs

The questionnaire was very successful in eliciting feedback from plant managers. Twenty-nine water authorities provided their 2014 data, for a total of 627 WWTPs assayed. They correspond to around 5% of municipal WWTPs in Italy, approximately 16,000 in number (but this includes micro-plants with only primary treatment, e.g., Imhoff tanks). But, even more important, they represent a treated load of about 20 million PE, around 25% of the total load of municipal wastewater treated in Italy, according to the Italian National Institute of Statistics (ISTAT, 2011). This result was a fundamental achievement for this research, and ensures the statistical representativeness of our survey.

A wide range of WWTPs was included, varying from a minimum of 50 PE to a maximum of 4 million PE. Size distribution is presented in Table 1, showing how all the classes were represented, while the geographical distribution of surveyed plants in the Italian context (Northern, Central and Southern Italy) is reported in Figure S1 of Supplementary Information.

3.2. Resource recovery implementation: a general overview

As a first and general outcome, the survey indicated that the level of implementation of resource recovery in Italian WWTPs is quite low. Indeed, fewer than half of surveyed plants (245 out of 627) perform as much as one type of resource recovery; the majority of Italian plants do not apply even one recovery option. Detailed information for each WWTP class is reported in Table 2: it demonstrates that recovery is performed mainly in large plants, with about 85% performing at least one action. This is an expected outcome, considering constraints in investments for small plants due to economies of scale.

The same data, presented in terms of treated load (data not shown) indicate a higher percentage of recovery (i.e., ≈ 75%, 15 out of 20 million PE), due to the predominance of large plants in the total treated load.

3.3. Resource recovery implementation: specific actions

This section analyzes the extent of diffusion of each recovery action. Percentage values are expressed in two ways:

i) first, out of all the surveyed plants (i.e., 627), in order to understand the overall extent to which each recovery option is practiced in Italy (Figure 2A);
ii) then, a zoom-in was performed on the sub-group that implements at least one type of recovery option, in order to focus only on the "virtuous" plants: Figure 2B reports such a ratio split up for plant size.

However, all the survey rough data are reported in Table S1 and S2 of Supplementary Material.
Overall, Figure 2 clearly highlights how material recovery is definitely implemented more than energy recovery -with sludge reuse being the most common recovery action- and how a lot of options remained almost blank. Hereinafter, each section of the plant is analyzed in detail.

3.3.1. Material recovery in water treatment line

Percentages shown in Figure 2 demonstrate both strengths and weaknesses.
Reuse of treated effluent turns out to be widely applied for internal uses: it is performed by 98 WWTPs (16% of total plants), or 40% of 245 plants with at least one recovery, and ranging from 22% for small plants up to 57-63% for the medium-large classes (Figure 2B). The detailed picture of the destination of internal reuse of effluent shows a large variety of solutions for internal purposes (Figure 3), and the most common were equipment washing (e.g., screens, centrifuges …), sprinkling on final clarifiers for foaming control, and polyelectrolyte production.
Another strength is that pre-treatment stages do promote material recovery, in particular screenings (recovered by 26% of small plants) and grit (26% of large plants). Screened material is, in the majority of the cases, washed out and reject water then recirculated in the anoxic reactor, as an additional

source of organic matter for denitrification enhancement. In rarer cases (2 WWTPs only), the separated material is then triturated and conveyed to the anaerobic digestion (AD) process. Surprisingly, the recovery of screens is mostly applied in small to medium WWTPs, while nearly absent in the largest. Recovery of grit separated in degritting units is aimed at producing a secondary raw material, which may be beneficially reused in various civil applications (mainly manufacturing and landfill coverage). While grit recovery is feasible in some medium and large centralized plants (8 and 9 WWTPs, respectively), no small plant recovers grit, likely because it is not economically feasible.

Conversely, some critical points clearly stand out. The recovery of treated effluent for external uses is extremely rare: only 9 WWTPs (4 of the plants with at least one recovery) perform such recovery, either for direct agricultural use, industrial use or for sewer cleaning. This finding can be attributed mainly to a number of barriers (most of all, lack of social acceptance and conservative legislation) that still prevent the widespread implementation of wastewater reuse not only in Italy but also throughout Europe and beyond on a global scale (Alcalde Sanz and Gawlik, 2014). For instance, irrigation of crops or fresh vegetables for human consumption demands extremely stringent compliance with regulations (e.g., < 100 CFU/100 mL of *Escherichia coli* according to both the Spanish - R.D. 1620/2007 - and Italian - DM 185/2003 - reuse law), thus implying the need of post treatment stages: among others, it is noteworthy to mention constructed wetlands, which could play a strategic role in wastewater reclamation, representing a low cost and environmental friendly option, that has been demonstrated to meet the law limits and provide water for ornamental green or crops (Cirelli et al. 2007). Similar limitations in effluent reuse characterize the majority of European Countries (see for instance the manual AQUAREC - Bixio and Wintgens, 2006): indeed, only Cyprus and Malta exceed 10% effluent reuse of the total amount of treated wastewater. Furthermore, the presence of trace pollutants in the effluents could be an additional criticism, expensive tertiary treatments being required for their abatement (e.g., ozonation: Bertanza et al., 2010b).However, a more compelling discussion would require mention of indirect reuse (effluent discharged in a river then used for agricultural purposes downstream): this survey did not ask about it because it's not directly quantifiable by WWTP managers. However, we are aware that this is a common practice in several areas of Italy; especially in water-scarce locations of Southern Italy, the geographical area less well-represented in the survey (see Figure S1 of Supplementary Information). Therefore, a negative judgment on the lack of effluent reuse should be partially mitigated.

Moreover, only 6 WWTPs (2% of the plants with at least one action) recover oil after the de-oiling stage, then conveyed to AD; this is likely due to regulatory constraints, again: oil is defined as a waste as soon as it is separated in pre-treatments, thus implying the respect of several legal thresholds before its (re)use (e.g., Directive 2008/98/EC), even if it takes place inside the WWTP itself.

Finally, no plants perform cellulose fibers recovery, indicating that the technology is not yet mature on a full-scale perspective, as also affirmed by Ruiken et al. (2013).

3.3.2. Material recovery in sludge treatment line

As shown in Figure 2B, the recovery of surplus sludge includes almost all WWTPs performing at least one recovery action (231 out of 245), and more than one third of all plants. In particular, possible destinations for sludge reuse are summarized in Figure 4: in the large majority of cases, sludge is used for the recovery of organic matter and nutrients in agriculture, either directly via land-spread or through composting, while only to a lesser extent as fuel for energy production through incineration. In the latter case, plants were asked about the further recovery of materials (e.g., phosphorus) from incinerated sewage sludge ashes (ISSA), but none indicated this option.

The comparison with liquid effluent, reuse of which for irrigation purposes is far less prevalent, indicates once again how regulation plays a driving role. Indeed, wider reuse of sludge in agriculture is likely a consequence of the uncertainty in European regulation, where the 20-year-old Directive 1986/278/EEC (CEC, 1986) is still the reference for many countries (as in Italy, where it is implemented with the LD 99/1992). Indeed, the Italian trend agrees with that exhibited by other European countries: more than half of sludge is reused for agricultural purposes in EU-27 (Kalessidis and Stasinakis, 2012), while incineration is much more prevalent only in those countries (Germany, Netherlands and Belgium) where national requirements for sludge disposal on soil are much more stringent than EU provisions. For this reason, the current Italian situation might change if a new legislative framework is established: for example, the European draft "Working Document on Sludge and Biowaste" (EC, 2010) suggests more stringent limits on heavy metals and new limits on several organic contaminants (such as dioxins and polycyclic aromatic hydrocarbons) and pathogens (such as *Salmonella* spp. and *Escherichia coli*), thus likely making sludge reuse more difficult in the future. The other investigated options are almost absent. Only 1 WWTP is producing biofuel used for cars/trucks through the conversion of biogas into methane: the high costs of biogas cleaning, ranging between 0.25-0.50 €/Nm^3, works against its diffusion. Nutrients recovery aimed at the production of fertilizers from reject water streams is never applied, mainly because of the present difficulties in finding a place for the recovered products (such as struvite from phosphorus or ammonium sulphate from nitrogen), which are not always valuable or marketable, or because of the scarce economic sustainability of these options compared to feedstock (Shu et al., 2006). Finally, production of biopolymers (e.g., polyhydroxyalkanoates, PHA) faces the same fate, as technologies are not yet mature from a full-scale perspective (STOWA, 2014).

3.3.3. Energy recovery in water/sludge lines

Energy recovery takes place mostly in the sludge line, as expected considering that the main source for this kind of action is represented by the exploitation of biogas from anaerobic digestion of sewage sludge. This option is quite common in large WWTPs (almost half: see Figure 2B), while scarce attention is given to exploitation of biogas in medium (12%) and small (not even one) plants: the latter either are not provided with AD or it is provided but does not generate power. With respect to the type of energy, Figure 5 (left) shows that heat is the main product (by means of heat exchangers, cooling processes of either exhausted gas from biogas combustion or biogas engines), but there is also room for electricity production through co-generation systems (biogas engines/microturbines).

Another interesting issue is related to the widespread presence of strategies to enhance biogas production: as displayed in Figure 5 (right), 80% of WWTPs exploiting biogas also implement some actions for increasing its production. Treating sludge before AD with mechanical (trituration and thickening systems) or chemical (ozonolysis) trains are the most common strategies, but co-digestion with other organic substrates (e.g., the organic fraction of municipal solid waste) and the use of flocculants in primary clarifiers are also implemented in the Italian scenario.

On the other hand, actions for energy recovery in water line are much rarer: hydropower and heat recovery from wastewater streams were indicated in 3 and 1 WWTPs, respectively. No plant currently uses Microbial Fuel Cells technology for electricity production.

3.3.4 Other recovery forms

Finally, we investigated other alternatives aimed at recovering resources not directly connected to wastewater (and its constituents), in order to complete the picture on the level of environmental sustainability in Italian WWTPs.

Figure 2 shows that the most common practice is the recovery of engine/machine waste oil: indeed, it is collected and conveyed to appropriate facilities in one third of the plants (with at least one recovery action: 80 out of 245), with a homogenous size distribution. Another relatively diffused option is the use of recovered materials to enhance nutrients removal: around 10% perform P precipitation with recovered chemicals, and around 5% employ denitrification with external recovered substrates (e.g., whey) as a source of organic matter. These options are strongly size-sensitive, being diffused almost exclusively in large WWTPs; this is likely due to the stricter limits on concentration of nutrients in effluent with which they must comply (compared with the small to medium categories).

Finally, with respect to energy, 7% of plants with at least one recovery (17 WWTPs) produce energy from renewable sources (other than biogas), specifically from solar power by means of photovoltaic systems, and a small number (4 WWTPs) apply heat recovery from blowers/pumping systems.

3.4. Overall discussion: lessons learned and future perspective

Beyond the extent of implementation of resource recovery options in Italy, interpretation of the survey results supplied critical information about the driving forces characterizing this system: technical reliability, economical feasibility and socio-legislative acceptance. These forces can facilitate the spread of a resource recovery option or work against it. We qualitatively analysed these factors in the diagrammatic representation of Figure 6, where four illustrative examples are presented. 1) Direct external reuse of treated effluent is extremely rare in Italy (ranging from 1% up to 15% for large WWTPs), likely because the strict thresholds set by legislation result in the need for rigorous polishing treatments. Even if technically reliable, it is not always cost effective for WWTPs (additionally, based on the authors' other research, broader discussion should be promoted on the environmental sustainability of tertiary treatments: Papa et al., 2013, and Papa et al., 2016). 2) No plants recover nutrients from supernatants of sludge treatment lines. Even if the technologies are quite mature (e.g., P precipitation as struvite), it is still cheaper to produce fertilizers from raw material (phosphate ore). 3) No cases of cellulose fiber recovery are reported. Even though no regulation currently hampers recycling of toilet paper, this technology is not yet mature for full-scale implementation. 4) Conversely, sludge reuse in agriculture is widely practiced due to older and less stringent legislation that doesn't push toward more advanced and expensive treatment technologies. In fact, based on the evidence showing that, where land application of sludge has been used for many years, neither severe human health consequences nor environmental damage have been observed, it has helped increase social acceptance, even if some problems (mostly odor) persist.

Moreover, insight into these driving forces can also be used to foresee system evolution, as modifications in their pressure can easily alter the scenario. For example, it is well known that phosphate is a finite resource, and it is estimated that only 50–100 years of phosphate reserves remain (Donatello and Cheeseman, 2013). This implies a predictable increase of phosphate ore prices in the near future, making phosphorus recovery from sludge supernatants (or ISSA) economically competitive with feedstock: as a consequence, its implementation should be expected to increase. However, it is the authors' belief that any new process/technology or management strategy should be carefully evaluated before its implementation by considering as many factors as possible; examples of such an approach are reported in Gianico et al. (2015), Bertanza et al. (2016) and Tomei et al. (2016).

4. Conclusions

For the first time in Italy, and in Europe to the best of our knowledge, we now have a real picture of the actual implementation of resource recovery options in WWTPs. Thus, the survey itself represents the core new finding of this work. More than 600 plants were surveyed, corresponding to a quarter of the national load of treated wastewater: therefore, this data can be considered a useful baseline, for all the actors involved in wastewater treatment (managers, researchers and policymakers), of the current status of sewage resource recovery and the forces driving it, simultaneously highlighting the areas where potential enhancements might occur. Improvements that, indeed, are urgently needed: the survey demonstrated, as first scientific outcome of the work, that resource recovery is still in its infancy, as more than 60% of plants do not perform any kind of recovery. Noticeable differences were recorded depending on plant size: small WWTPs were much less virtuous than large ones.

The second part of data processing was devoted to show the diffusion of specific options: the recovery of material resources is definitively more common than energy recovery, and sludge reuse is the most diffused option: around 40% of surveyed plants (up to 70% of large WWTPs) recover surplus sludge. Its most diffused destination is to agriculture (either direct land-spread or post-composting). Another option widely practiced is the recovery of treated effluent for internal reuses, applied by ≈ 15% of surveyed plants (up to 50% of large WWTPs) and typically used for equipment washing or sprinkling on clarifiers.

As far as energy is concerned, the exploitation of biogas is the most common action but diffused only in large WWTPs, while in small-medium plants it is almost absent. Another interesting finding came out on this side: when present, this recovery is frequently preceded by a strategy to enhance biogas production.

A strong outcome is also related to unimplemented actions. Indeed, we found that a lot of options on the questionnaire were left almost blank: not only the most innovative (e.g., cellulose fibers recovery), but also some of the most conventional (e.g., external reuse of effluent). This means that further efforts must address reducing the existing barriers against resource recovery in WWTPs; these hurdles can be resolved into three main driving forces: technical reliability, economic feasibility and socio-legislative acceptance.

In conclusion, the answer to the initial question in the title of this paper is that we are quite far from closing the loop of resource recovery and creating environmentally sustainable WWTPs in Italy. However, a more green perspective could catch on in the near future, as the influence of these driving forces is correctly exerted.

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Table and Figure captions

Figure 1. The Questionnaire: list of resource recovery options enclosed in the survey, split up by treatment stage and type (material *vs.* energy).

Figure 2. Implementation of resource recovery options in Italian WWTPs. Percentages refer either to (A) the total number of surveyed plants (627) or (B) only the sub-group of 245 WWTPs that perform at least one option, split up by class (transparent blue bars = material; full red bars = energy).

Figure 3. Internal effluent reuse: most common destinations.

Figure 4. Sludge reuse: most common destinations.

Figure 5. (left) Energy recovery forms from biogas exploitation and (right) most common strategies for the enhancement of biogas production.

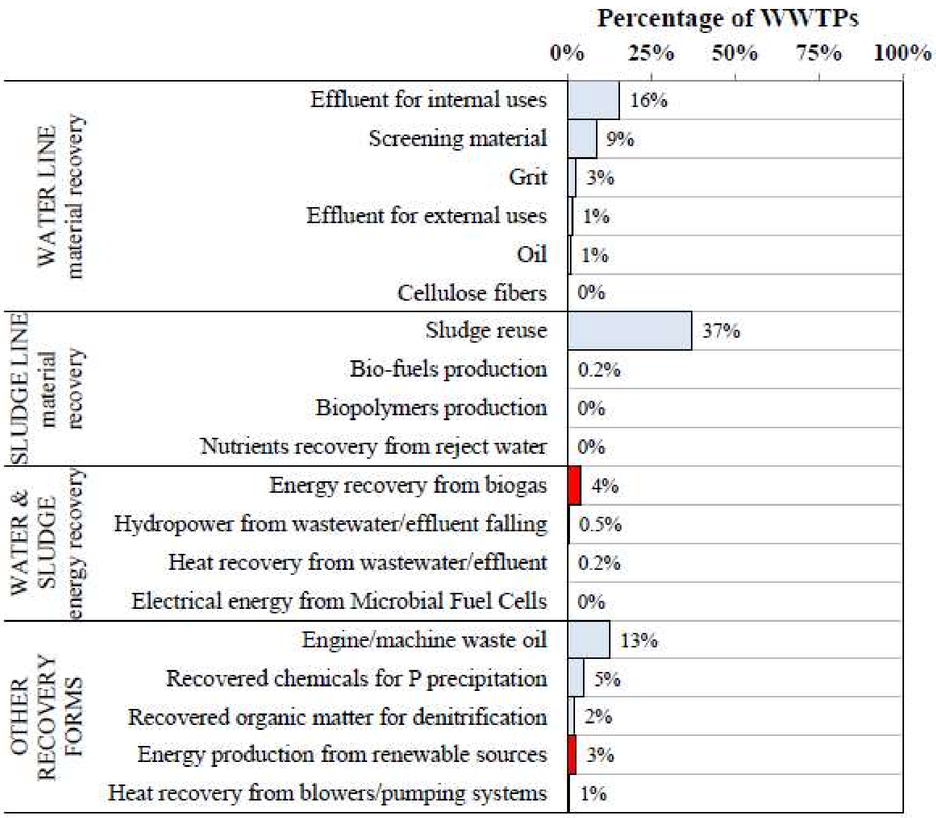
Figure 6. Conceptual framework of key factors driving the implementation of resources recovery options in wastewater treatment, and qualitative representation of some case studies.

Table 1. Size distribution of surveyed WWTPs.

Table 2. Summary of “virtuous” WWTPs, i.e., plants performing at least one type of resource recovery action, together with size distribution.

Material Recovery	*Energy Recovery*
WATER TREATMENT LINE	
☐ Screening material (specify destination: ________) ☐ Cellulose fibers (specify destination: ________) ☐ Grit (specify destination: ________) ☐ Oil (specify destination: ________) ☐ Effluent for external uses (specify destination: ________) ☐ Effluent for internal uses (specify destination: ________) ☐ Other ________________	☐ Hydropower from wastewater/effluent fall (specify how: ________) ☐ Heat recovery from wastewater/effluent (specify how: ________) ☐ Electrical energy from Microbial Fuel Cells ☐ Other ________________
SLUDGE TREATMENT LINE	
☐ Sludge reuse o direct land-spreading o composting o incineration o other: ________ ☐ Biopolymers production (specify what/how: ________) ☐ Nutrients recovery from reject water (specify what/how: ________) ☐ Bio-fuels production (specify what/how: ________) ☐ Other ________________	☐ Energy recovery from biogas o thermal, how: ________ o electrical, how: ________ o biogas production enhancement, how: ________ ☐ Other ________________
OTHER RECOVERY FORMS	
☐ Engine/machine waste oil (specify destination: ________) ☐ Recovered chemicals for P precipitation (specify what: ________) ☐ Recovered organic matter for denitrification enhancement (specify what: ________) ☐ Other ________________	☐ Energy production from other renewable sources o photovoltaic systems o wind turbines o other: ________ ☐ Recovery of heat produced by blowers/pumping systems (specify how: ________) ☐ Other ________________

Figure 1. The Questionnaire: list of resource recovery options enclosed in the survey, split up by treatment stage and type (material *vs.* energy).



A)

B)

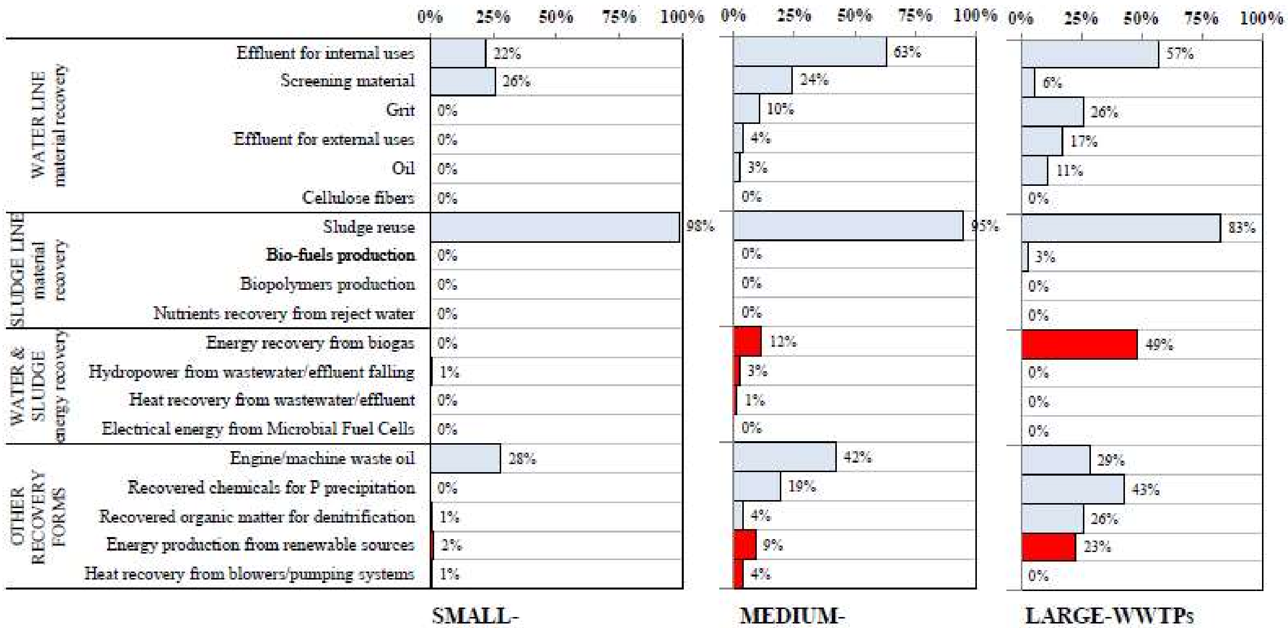


Figure 2. Implementation of resource recovery options in Italian WWTPs. Percentages refer either to (A) the total number of surveyed plants (627) or (B) only the sub-group of 245 WWTPs that perform at least one option, split up by class (transparent blue bars = material; full red bars = energy).

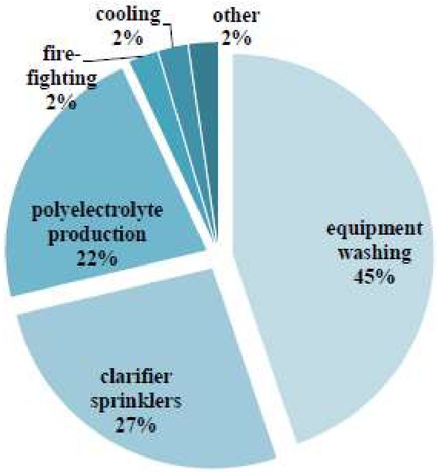


Figure 3. Internal effluent reuse: most common destinations.

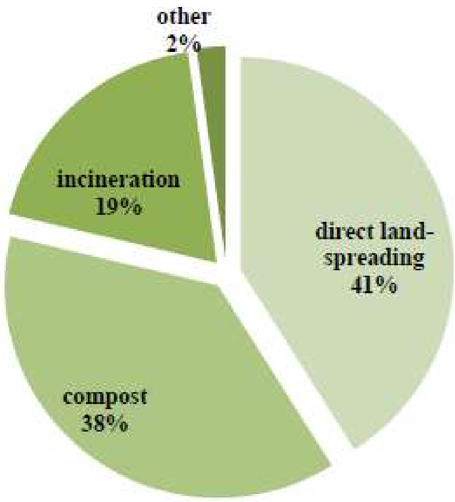


Figure 4. Sludge reuse: most common destinations.

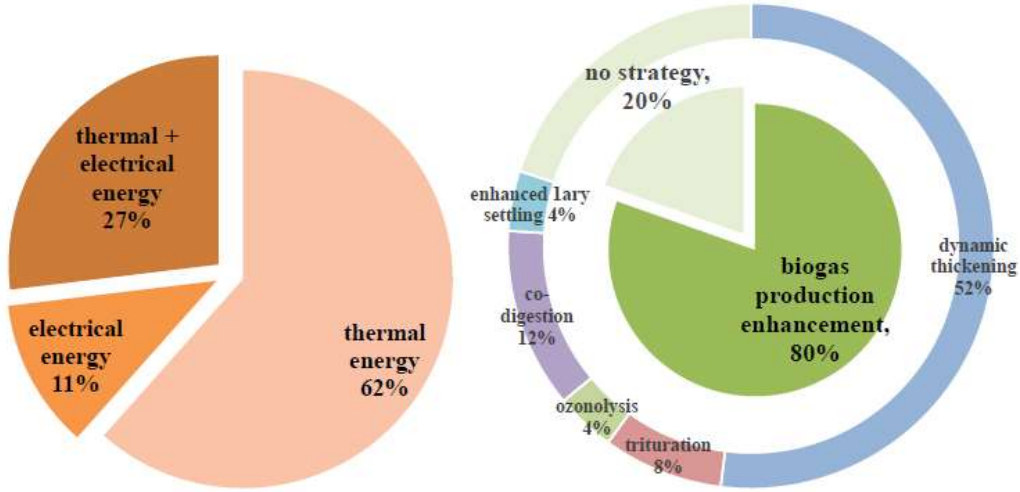


Figure 5. (left) Energy recovery forms from biogas exploitation and (right) most common strategies for the enhancement of biogas production.

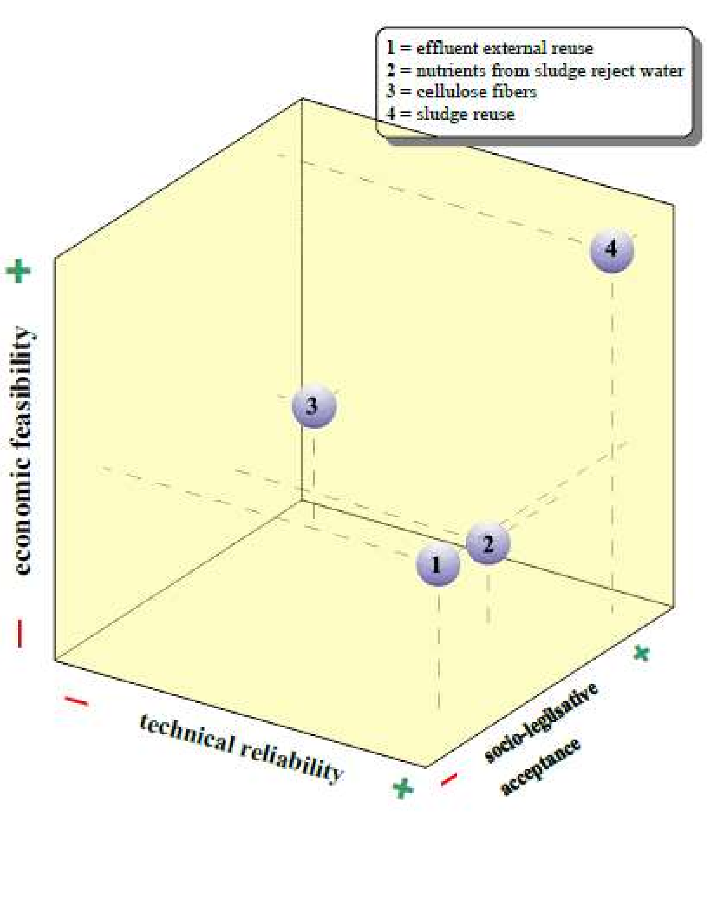


Figure 6. Conceptual framework of key factors driving the implementation of resources recovery options in wastewater treatment, and qualitative representation of some case studies.

Size	# of WWTPs	Total treated load (PE)
SMALL (< 10,000 PE)	457	≈ 1,000,000
MEDIUM (10,000 - 100,000 PE)	129	≈ 4,000,000
LARGE (>100,000 PE)	41	≈ 15,000,000
TOTAL	**627**	**≈ 20,000,000**

Table 1. Size distribution of surveyed WWTPs.

Size	WWTPs performing at least 1 resource recovery option	
	# of WWTPs	% of surveyed plants
SMALL	132	≈ 30%
MEDIUM	78	≈ 60%
LARGE	35	≈ 85%
TOTAL	**245**	**≈ 40%**

Table 2. Summary of "virtuous" WWTPs, i.e., plants performing at least one type of resource recovery action, together with size distribution.