What factors affect the selection of industrial wastewater treatment configuration?

Abstract

Industrial wastewater treatment is gaining significance in literature due to stricter environmental policies and increased environmental awareness. The selection of the wastewater configuration encompasses both the treatment as well as several decisions around wastewater collection and disposal pertaining industrial decision-making sphere. However, so far in the wastewater literature, research has mostly discussed either technical features of wastewater technologies, or wastewater policy issues at broader level, without focusing on the industrial decision-making issues and driving factors leading to the selection of a specific configuration.

Starting from a literature review, the present study provides an innovative framework of the possible options for wastewater system configuration, as well as major adoption factors by industrial decision-makers. The factors have been classified according to 7 categories, namely: influent-related, technological, economic/financial, internal socio-cultural, external socio-cultural, regulation, site characteristics.

The framework, validated with acknowledgeable experts, policy makers and firms, has been preliminarily applied to Italian and Australian food firms. Our investigation reveals that the framework was able to include all relevant problems faced by industries in the selection of a treatment system configuration; besides, the relative importance of factors has been assessed: legal requirements emerge as the most critical factors, followed by volume and discharge fee, the latter particularly interesting for policy makers purposes, since it may guide the decision-making process. Further, the wastewater volume seems to play a key role in our exploratory investigation, with smaller firms preferring a complete off-site treatment to reduce the complexity, whilst larger firms preferring instead more partial or complete on-site treatment configurations for compliance costs reduction. In conclusion, we have provided policy and managerial implications stemming from the study as well as sketched interesting future research avenues.

Keywords

industrial wastewater treatment, treatment system configuration, adoption factors, framework, empirical evidence from food sector.

List of Acronyms

BOD	Biological Oxygen Demand
COD	Chemical Oxigen Demand
TSS	Total Suspended Solids
NSW	New South Wales
WWT	Wastewater Treatment

1 Introduction

Manufacturing industries have primary responsibility in reducing their wastewater toxicity and related environmental impact (Corcoran et al., 2010). They generate considerable amounts of wastewater during their operations (WWAP, 2017), with evidence that the water used in input ends up almost entirely as wastewater, receiving often no or minimal treatment (Ranade and Bhandari, 2014).

The academic debate around WWT is mostly focused on either how to improve the level of treatment among industries or the preferred WWT technology (Liu and Liptak, 2000; Tchobanoglous et al., 2014). However, this set of managerial decisions is influenced by a number of factors, such as e.g., discussion with authorities at various level (Corcoran et al., 2010), internal capabilities and awareness to manage the treatment (Garrone et al., 2018). Further, such decisions go beyond the type of treatment, and include outsourcing possibilities, type of connections, the final discharge (Tchobanoglous et al., 2014), potentially influenced by the specific context of operations (O'Reilly, 2000).

Despite the wealth of literature on either technical problems (Mao et al., 2020) - i.e specific treatment technologies (Heller et al., 1998) - or on municipal wastewater facilities (Balkema et al., 2002) - the broader treatment system selection has been largely overlooked. Previous academic literature has just offered initial attempts to develop support tools for managers selecting an adequate treatment (Castillo et al., 2017; Zeng et al., 2007), with only in limited cases considerations for eco-efficiency or cost-effectiveness over specific solutions (see e.g., Gómez et al., 2018; Mahjouri et al., 2017; Muga and Mihelcic, 2008). To authors' knowledge, research is yet lacking a comprehensive framework for the identification and selection of the most appropriate WWT configuration and factors driving such choice, to support industrial decision makers in assessing and comparing alternative solutions.

However, a better understanding of the main issues considered by industrial decision-makers in the selection process could help regulators shape better incentives and policies driving companies towards more sustainable production. In fact, traditional command-and-control measures might result unsuccessful in some contexts (Garrone et al., 2018), and even tighter environmental contraints and increased penalties might result in a reduced environmental performance (Lu et al., 2017). Further, regulation should be based on Best Available Technologies rather than on the Cheapest Available Technology Narrowly Avoiding Prosecution (Starkl et al., 2018). At present, studies indicate that the actions to reduce polluting sources or to improve the level of treatment are mostly undertaken on a voluntary basis (Corcoran et al., 2010).

Starting from such research gap, this study aims at contributing to the academic discussion by providing a framework to firstly identify the possible WWT system configurations; secondly, to include all the major decision-making factors. The proposed framework aims at linking the choice of configuration with the importance of the adoption factors, thus offering a novel perspective on the issues faced by firms in the selection of their WWT configuration. The framework has been validated with experts from the wastewater sector and a firm sample, by means of exploratory case studies. Subsequently, we performed a preliminary application of the framework with a second sample of firms.

The remainder of the manuscript is organized as follows: in Section 2 we present our literature review over WWT configurations and factors driving their adoption. This lays the ground for the development of our novel framework, discussed in Section 3. Section 4, 5 are devoted to the validation of the proposed framework respectively with experts and industries, whilst Section 6 to the exploratory investigation in the considered context. We discuss our findings in Section

7, providing concluding remarks, policy and managerial implications, as well as suggestions for further research in Section 8.

2 Literature review

The decision over the WWT configuration is often a relatively complex process for a company, encompassing important decisions:

- on-site treatment or third-party outsourcing of the treatment (Capodaglio, 2017).;
- how to discharge the effluent and how to manage the wastewater flow (Tchobanoglous et al., 2014).

Since multiple reasons may drive these decisions, it is crucial to understand the factors leading to the selection of a configuration. Hence, in the following (Sections 2.1 and 2.2), we present the literature review concerning the treatment system configuration and the adoption factors, respectively.

2.1 Industrial WWT system configuration

The selection of WWT configuration involves decisions concerning three different areas: wastewater collection, treatment and disposal or reuse (Zaharia, 2017). The three axes identified constitute the basic elements of all WWT systems (Crites and Tchobanoglous, 1998; Zaharia, 2017). However, they have been mostly studied separately in literature, with greater emphasis on the treatment stage (Mao et al., 2020).

Wastewater collection

The collection system conveys the wastewater from the point of generation to the treatment facility. Building the sewage infrastructure (including pumps and piping) can be extremely expensive, even more than 60% of the total costs for centralized configurations (Wilderer and Schreff, 2000; Zaharia, 2017) and, as observed by Capodaglio (2017) with a considerable environmental impact, even greater than the construction and operation of the treatment plant itself. Depending on the availability of the connection system, firms might decide whether to opt for an on-site or an off-site treatment (Liu and Liptak, 2000). Separating wastewater streams can sometimes bring benefits (such as cost abatement and contaminants treatment), in particular when wastewater includes a great variety of pollutants for removal, or when the dilution with less concentrated streams would lower the treatment efficiency (World Water Assessment Programme, 2006). Therefore, firms shall decide whether to segregate the wastewater flows by conveying them into different treatment facilities, or keep the volume united.

Wastewater treatment

The treatment aims to discharge a harmless effluent, for human health or the environment (Pescod, 1992) and, according to the degree of treatment, is usually classified into preliminary, primary, secondary, tertiary and/or advanced. The level of treatment required depends on the final use of the effluent (e.g. irrigation, potable use, animal use), but also on the local regulations, the initial characteristics of the wastewater, and social acceptability (Salgot and Folch, 2018). The treatment is often divided into centralized and decentralized, and there is a nourished debate on the advantages and disadvantages of the two solutions, as summarized in Table 1. Alternatively, treatment is classified as on-site or off-site (Hophmayer-Tokich, 2006; WWAP, 2017). On-site treatment, traditionally more diffused (Kohler et al., 2016), is performed close to the point where wastewater is generated, whilst off-site treatment is performed in a municipal or third-party facility. Also mixed solutions can be found, where wastewater is treated by two different plants (European IPPC Bureau, 2016).

	Off-site (centralized)	**On-site (decentralized)**
Advantages	Economies of scale (Capodaglio, 2017; Sgroi et al., 2018)	Lower capital required (Capodaglio, 2017)
	Better hydraulic stability (Mareddy, 2017)	Greater customization to the specific local needs. Water homogenously flows from well-defined sources (Asano et al., 2007)
	Affordable professional control over the treatment (Mareddy, 2017)	Greater reliability (Asano et al., 2007)
	Elimination of multiple discharges in the area (Mareddy, 2017)	Increased opportunity for water reclamation, nutrients and energy recovery (Salgot and Folch, 2018; WWAP, 2017)
	Better wastewater management (Mareddy, 2017)	
	Potential to reject the influents with poor quality standards (Mareddy, 2017)	
Disadvantages	High investment costs (Sgroi et al., 2018)	More awareness and skills required to operate (Massoud et al., 2009)
	Proximity to discharge points (e.g. water bodies) (Tchobanoglous et al., 2014)	Lack of synergic effects among different wastewater streams mixing (European IPPC Bureau, 2016)
	Plants over-dimensioned and with idle capacity surplus, for possible future plans (Capodaglio, 2017)	Many less efficient plants could be a suboptimal solution (WWAP, 2017)

Table 1 - Advantages and disadvantages of on- and off-site schemes

Wastewater disposal/Reuse

The choice of wastewater disposal or reuse depends on the availability of discharge points, i.e. surface waters, sewage and collection infrastructure (Adams et al., 1997). The success of the many possible reuse applications (e.g., irrigation, industrial processes, groundwater recharge, potable use) depends on tailored policies (Sgroi et al., 2018). In case of disposal instead, the wastewater flows from the company to a third party treatment plant or water bodies.

Despite the lack of a complete framework able to describe all possible configurations considering the three axes, the three choices are related: for instance, the treatment option is constrained by the availability of discharge points, and the possibility to connect to a municipal plant depends on the availability of connections (Liu and Liptak, 2000). The connections among the choices lead to a specific WWT system configuration.

2.2 Adoption factors for the treatment system configuration

A literature review of the factors for the selection of industrial WWT system configuration in industries has been performed, encompassing contributions also from specific sectors, (e.g. metal finishing, food, textile).

The *influent-related characteristics* are considered relevant for the selection of the treatment (Salgot and Folch, 2018; Tchobanoglous et al., 2014). Wastewater characterization is usually in terms of BOD, COD, TSS (Castillo et al., 2017), flowrate and applicable flowrate variability (O'Reilly, 2000). The effluent quality requirements are listed among the influent-related factors (Castillo et al., 2017; Liu and Liptak, 2000). The requirements, in turn, depend on the wastewater destination, such as e.g. reuse applications, rivers, sensitive areas or sewer pipe. Conversely, Mahjouri et al. (2017) consider requirements in terms of reliability, by including also shutdown problems, enduring shock loads, performance variation due to weather conditions. Other authors describe reliability as either effluent quality variation due to peak shocks (Tchobanoglous et al., 2014), as a technical factor with adaptability, durability, robustness, maintenance required (also in Tchobanoglous et al., 2002).

Complexity is also extremely relevant (Heller et al., 1998), and dependent on the number of permeate and concentrate stages of the treatment design. Construction, start-up, operation and maintenance, advanced control techniques, imported equipment, applicability to different scales (Mahjouri et al., 2017), routine and emergency operations (Tchobanoglous et al., 2014) are factors that increase complexity (Castillo et al. 2017), with impact on the *professional skills* required to manage the daily operations of the treatment plant (Zeng et al., 2007; Muga and Mihelcic, 2008).

The *efficiency* of the treatment is usually computed as removal percentage of nutrients, metals, oil and grease (Mahjouri et al., 2017; Zeng et al., 2007; Arroyo and Molinos-Senante, 2018) and research also highlights the importance of its variability (Tchobanoglous et al., 2014).

Economics may play a key part in the evaluation. Among cost items, academics list energy (Arroyo and Molinos-Senante, 2018), biosolid, urea, reactants (Castillo et al., 2017; Molinos-Senante et al., 2010), construction, land area (Zeng et al., 2007), operations and maintenance, waste (Mahjouri et al., 2017; O'Reilly, 2000), labour (Molinos-Senante et al., 2010; O'Reilly, 2000). Costs are usually divided into investment and operational costs (Balkema et al., 2002), but studies highlighting which of them are more relevant in detail (e.g, capital availability, cost of plant, cost of connection, maintenance, labour) are lacking. WWT plants may generate revenues (Rawal and Duggal, 2016), e.g. by selling recovered nutrients or biogas (Castillo et al., 2017).

Space is an environmental prioritizing factor by Castillo et al. (2017) and Arroyo and Molinos-Senante (2018), or a general constraint (Tchobanoglous et al., 2014). Sludge and waste management are either a technical factor (Liu and Liptak, 2000; Heller et al., 1998; Tchobanoglous et al., 2014; Zeng et al., 2007), an environmental one (Arroyo and Molinos-Senante, 2018), or listed as a cost (Mahjouri et al., 2017). Other environmental factors to be considered are odour, noise, visual impact, insects and parasites, eutrophication potential, OHS and satisfaction (Mahjouri et al., 2017), energy consumption (Castillo et al., 2017), wind and proximity to residential areas (Tchobanoglous et al., 2014), resource utilization (Arroyo and Molinos-Senante, 2018), land fertility, biodiversity, emissions, quality of effluent or sludge.

Sustainability can be found in Mahjouri et al. (2017): life expectancy, upgrading ability, optimal resource utilization and reuse, but similar considerations are suggested by Tchobanoglous et al. (2014). However, the role of sustainability is disputed: some argue it should drive the decisions of companies and the regulation set by policy-makers (Balkema et al., 2002); others rather claim that companies are mainly driven by economic considerations, with environment preservation used only as a prioritizing driver in case of alternatives with same economics (Castillo et al., 2017).

Balkema et al. (2002) notes a *socio-cultural* category of factors, including institutional requirements, acceptance, expertise, stimulation of sustainable behaviour, but a thorough consideration of the social dimension is still lacking. Stakeholders support is potentially crucial for the success of WWT projects (Mankad and Tapsuwan, 2011).

Further, climatic constraints, treatment residuals, personnel requirements, compatibility, ancillary processes, economic life cycle analysis are possible factors driving the decision (Tchobanoglous et al., 2014).

Table 2 summarizes the main factors emerged from our literature review. We can note that most of extant studies limit their considerations to factors related to the wastewater characteristics and economic factors, some expand to environmental factors, but social ones are largely overlooked.

Title	Authors	Journal	Year	Influent related	Costs	Environmental impact		Operational complexity	Skills required	Efficiency	Reliability	Flexibility	Space	Desiderable output	Undesiderable output	Consent limits/Compliance	Geograpgic setting	Sensitivity of local area /Absorptive capacity	Infrastructure	Financial	Social acceptance	Product availability/Revenues
						Resource consumption	Footprint															
Expert Membrane System design and selection for metal finishing waste water treatment	Heller, M., Garlapati, S., Aithala, K.	Expert Systems with Applications	1998	✓	✓								✓	✓								
Waste water treatment process selection: An industrial approach	O'Reilly, A. J.	Process Safety and Environmental Protection	2000	✓	✓											✓	✓					
Wastewater Treatment	Liu, D.H.F., Liptak, B.G.	CRC Press	2000	✓				✓		✓					✓				✓			
Optimization of wastewater treatment alternative selection by hierarchy grey relational analysis	Zeng, G., Jiang, R., Huang, G., Xu, M., Li, J.	Journal of Environmental Management	2007	✓	✓			✓	✓	✓	✓											
Sustainability of wastewater treatment technologies	Muga, H.E., Mihelcic, J.R.	Journal of Environmental Management	2008		✓	✓			✓				✓								✓	
Economic feasibility study for wastewater treatment: A cost–benefit analysis	Molinos-Senante, M., Hernández-Sancho, F., Sala-Garrido, R.	Science of the Total Environment	2010		✓															✓		
Wastewater Engineering: treatment and resource recovery	G. Tchobanoglous, H. Stensel, R. Tsuchihashi, F. Burton	McGraw-Hill Education	2014	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓				✓	
Life Cycle Costing Assessment-Based Approach for Selection of Wastewater Treatment Units	Rawal, N., Duggal, S.K.	National Academy Science Letters	2016		✓																	✓
Selection of industrial (food, drink and milk sector) wastewater treatment technologies: A multi-criteria assessment	Castillo, A., Vall, P., Garrido-Baserba, M., Comas, J., Poch, M.	Journal of Cleaner Production	2017	✓	✓	✓							✓			✓		✓				
Optimal selection of Iron and Steel wastewater treatment technology using integrated multi-criteria decision-making techniques and fuzzy logic	Mahjouri, M., Ishak, M.B., Torabian, A., Manaf, L.A., Halimoon, N., Ghoddusi, J.	Process Safety and Environmental Protection	2017		✓	✓	✓	✓	✓	✓	✓		✓		✓	✓					✓	
Selecting appropriate wastewater treatment technologies using a choosing-by-advantages approach	Arroyo, P., Molinos-Senante M.	Science of the Total Environment	2018		✓	✓		✓		✓	✓		✓		✓						✓	✓
Wastewater treatment and water reuse	Salgot, M., Folch, M.	Current Opinion in Environmental Science & Health	2018	✓	✓								✓		✓				✓	✓	✓	

Table 2 - Adoption factors emerged from the literature review

Based on the literature review, we acknowledge that previous research has started investigating the important factors connected to WWT systems, but a comprehensive perspective at industrial level is still lacking, with some key research gaps:

- most studies address the issue from the municipal utilities viewpoint, thus not taking the perspective of a single industrial decision-maker. However, the latter is crucial as it is complementary to the utility one;
- the academic discussion over the factors driving the WWT configuration is scarce, with only very few contributions focusing on firms.
- much of the discussion has focused on the WWT, whilst the connection between the other axes (namely, wastewater collection and wastewater disposal/reuse) has not been explored in depth, despite there may be interdependencies.
- research has little explored the connection between the configuration selected and the relevance of adoption factors.
- the frameworks of factors currently available in literature also fail at integrating two crucial aspects for industries, such as the technological content and a higher-level managerial perspective.

3 Framework definition

The novel framework to address the aforementioned gaps consists of two parts: (i) a treatment system configuration (Section 3.1) and (ii) adoption factors (Section 3.2).

3.1 WWT system configuration scheme

A new scheme for the classification of WWT systems with an industrial decision-maker's perspective is proposed in Figure 1. As discussed earlier in Section 2, firms need to undertake important decisions along three axes, such as the type of treatment, how the flow is managed and the final wastewater destination.

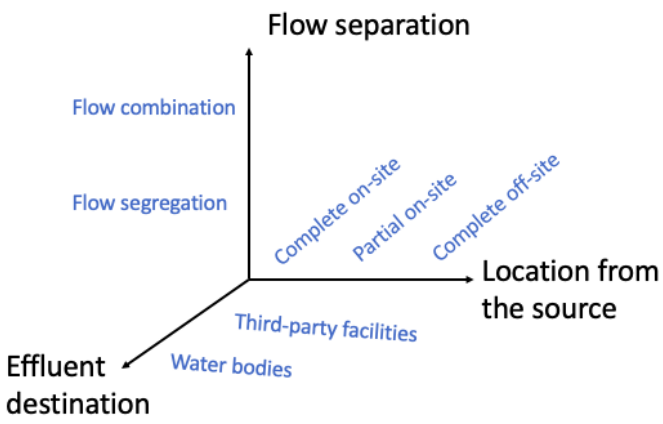

Figure 1 - Axes that define the treatment system configuration

The *location from the source* indicates where the influent is treated, with the following options:

- completely on-site: the wastewater is processed directly where it is generated (Capodaglio, 2017; Mareddy, 2017; Sgroi et al., 2018);
- completely off-site: the volume is treated in a centralized or municipal plant, with in the latter case wastewater transferred through pipes or transported with trucks (Asano et al., 2007).
- partial on-site treatment: the wastewater undergoes a pre-treatment on-site, before being discharged into a central plant or to a municipal one for further processing (European IPPC Bureau, 2016).

Flow separation concerns how the influent is handled along the collection system, with the separation or the combination of the wastewater flows stemming from the industrial premises. By separating different wastewater streams a company could achieve a more efficient processing and recycling of materials, nutrients and energy, with easier recovering activities thanks to the more concentrated streams to be handled (WWAP, 2017). Besides, source separation avoids unnecessary and expensive waste dilution (Capodaglio, 2017).

Effluent destination. Water bodies are the water destination in case of complete on-site treatment, unless treated wastewater is reused (Adams et al., 1997). In case of partial on-site or complete off-site treatment, the effluent destination could be either municipal or centralized premises to complete the treatment. Distinguishing between these alternatives is crucial, as central and municipal facilities charge a fee for the treatment of water usually based on the volume and the types of contaminants within the influent (ARERA, 2017).

3.2 Adoption factors for the treatment system configuration

In the proposed novel comprehensive framework, the adoption factors have been grouped according to two main categories, "internal" and "external", and further in sub-categories, as detailed in Table 3. Taking inspiration from previous literature (Molinos-Senante et al., 2015), *internal factors* refer to the elements on which the firm has direct control, whilst *external factors* refer to factors that are conditions or constraints posed to the firm.

The **internal** adoption factors are divided as follows:

1. *Influent related:* the characteristics of the incoming wastewater (Castillo et al., 2017) may influence the selection of specific treatments for compliance with regulatory standards. The characteristics of the influent are qualitative (Guerrini et al., 2016; Starkl et al., 2018) and quantitative (Gomez et al., 2017).
2. *Technological:* the technical characteristics of the treatment configuration, possibly relevant even in case of a complete off-site treatment. It comprises process constraints (Musa et al., 2018), compatibility (Umamaheswari and Shanthakumar, 2016), flexibility (Roefs et al., 2017), complexity (Rennuit et al., 2018), performance (Al-mamun et al., 2018; Englehardt et al., 2016), environmental impact (Gu et al., 2017), side effects (Prabakar et al., 2018).
3. *Economic/financial:* the economic factors are related to the installation (O'Reilly, 2000) and operation (Heller et al., 1998; Molinos-Senante et al., 2010) of the plant, or to outsource the treatment process. The financial factors refer to the monetary resources available to be devoted to the WWT process (Libralato et al., 2012).
4. *Socio-cultural*: It includes the attitude and behaviours of the stakeholders, namely management, workers, communities (Cheng et al., 2017).

The **external** adoption factors are divided into:

1. *Socio-cultural:* pressure from stakeholders (Saliba et al., 2018; Sgroi et al., 2018), support availability (Garrone et al., 2018), technology accessibility (Cheng et al., 2017) are usually outside the direct control of a firm.
2. *Regulation:* either regulatory pressures or incentives towards the adoption of more advanced WWT solutions by companies (D'Inverno et al., 2018).
3. *Site characteristics:* the features (e.g. climate, presence of water bodies) of the location in which the company operates (Englehardt et al., 2016; Tchobanoglous et al., 2014). In case of upgrade of an existing facility (e.g., to comply with quality standards) this is a constraint (Mosher et al., 2016). However, in case of new applications, this might be considered an internal factor.

Internal Factors		Definition	Main References
Influent Related			
Quality	Type of Contaminants	Nutrients, materials, pollutants, substances within the wastewater.	Castillo et al., 2017; Gomez et al., 2017; Guerrini et al., 2016; Salgot and Folch, 2018; Sapkota et al., 2016; Tchobanoglous et al., 2014
	Contaminants Variation	Variation of the type of contaminants due to changes in product batch or production process.	Guerrini et al., 2016; Salgot and Folch, 2018; Sapkota et al., 2016
Quantity	Volume	Amount of wastewater generated by the production activities of the company (expressed in e.g., m^3/day or year)	Castillo et al., 2017; Gisi et al., 2014; Guerrini et al., 2016; Long et al., 2018; Salgot and Folch, 2018; Sapkota et al., 2016; Tchobanoglous et al., 2014; Umamaheswari and Shanthakumar, 2016
	Volume Fluctuations	Variation in volume of the wastewater generated (expressed in e.g., m^3/day or in percentage).	Guerrini et al., 2016; Long et al., 2018; Salgot and Folch, 2018; Umamaheswari and Shanthakumar, 2016
Technological			
Process Constraints	Ancillary Processes	All the additional or support processes/facilities required for the use of a particular configuration.	Al-mamun et al., 2018; Englehardt et al., 2016; Rennuit et al., 2018; Tchobanoglous et al., 2014
	Operating Conditions	Change in operating conditions required due to the choice of a particular treatment technology.	Al-mamun et al., 2018; Bazrafshan et al., 2015; Gu et al., 2017; Guerrini et al., 2016; Musa et al., 2018; Prabakar et al., 2018; Rehman et al., 2015; Umamaheswari and Shanthakumar, 2016
	Space Requirements	Land requirement needed to implement a specific configuration.	Arroyo and Molinos-Senante, 2018; Castillo et al., 2017; Dubois and Boutin, 2018; Mahjouri et al., 2017; Musa et al., 2018
Compatibility	Process Inertia	Established structure of the production process	Bichai et al., 2018; Neoh et al., 2017; Quezada et al., 2016; Tchobanoglous et al., 2014; Umamaheswari and Shanthakumar, 2016
	Previous Treatment Stages	Number of treatment stages before the considered one.	Neoh et al., 2017; Tchobanoglous et al., 2014; Umamaheswari and Shanthakumar, 2016
Flexibility	Future Requirements	Future plant or production requirements needing a change in the treatment configuration.	Gomez et al., 2017; Mahjouri et al., 2017; Roefs et al., 2017; Tchobanoglous et al., 2014
	Resilience/ Capability to Adapt	Capability of the considered treatment configuration to adapt to different operating conditions due to the current production mix.	Capodaglio, 2017; Chatterjee and Surampalli, 2016; Dong et al., 2017; Mahjouri et al., 2017; Mosher et al., 2016; Rehman et al., 2015; Roefs et al., 2017; Umamaheswari and Shanthakumar, 2016
Complexity	Installation	Management effort required by the company to install a WWT plant.	Crini et al., 2019; Mahjouri et al., 2017

	Number of Stages	Number of stages included in the treatment process before being able to discharge the effluent.	Gisi et al., 2014; Rennuit et al., 2018
	Specific Processes	Complexity of managing specific processes of the WWT.	Arroyo and Molinos-Senante, 2018; Castillo et al., 2017; Crini et al., 2019; De Sanctis et al., 2016; Kyoungjin et al., 2017; Tchobanoglous et al., 2014
	Measurements	Technical measurements to be performed on the effluent before discharging it.	Castillo et al., 2017; Mahjouri et al., 2017
	Change of Maintenance Activities	Modifications to the maintenance activities due to the implemented changes.	Crini et al., 2019; Rennuit et al., 2018; Umamaheswari and Shanthakumar, 2016
Performance	Removal Efficiency	Efficiency to remove contaminants from the wastewater by a selected WWT configuration.	Arroyo and Molinos-Senante, 2018; Cheng et al., 2017; Crini et al., 2019; D'Inverno et al., 2018; De Sanctis et al., 2016; Dong et al., 2017; Englehardt et al., 2016; Gémar et al., 2018; Gisi et al., 2014; Guerrini et al., 2016; Long et al., 2018; Mahjouri et al., 2017; Musa et al., 2018; Zhou et al., 2018
	Process Reliability	Reliability of removal efficiency by the considered configuration.	Arroyo and Molinos-Senante, 2018; Capodaglio, 2017; De Sanctis et al., 2016; Englehardt et al., 2016; Gisi et al., 2014; Long et al., 2018; Mahjouri et al., 2017; Quezada et al., 2016; Sapkota et al., 2016; Zhou et al., 2018
Environmental Impact	Energy/Resources Requirements	Energy and other resources requirements needed to operate a configuration of WWT.	Al-mamun et al., 2018; Arroyo and Molinos-Senante, 2018; Castillo et al., 2017; D'Inverno et al., 2018; Di Fraia et al., 2018; Dong et al., 2017; Gomez et al., 2017; Gu et al., 2017; Henriques and Catarino, 2017a; Lu et al., 2017; Mustapha et al., 2017; Opher and Friedler, 2016; Panepinto et al., 2016; Radcliffe, 2010; Rehman et al., 2015; Smith et al., 2016; Wang et al., 2016
	Energy/Resources impact	Environmental impact of energy and other resources due to the WWT.	Englehardt et al., 2016; Gémar et al., 2018; Gomez et al., 2017; Gu et al., 2017; Jiang et al., 2018; Jin et al., 2018; Lu et al., 2017; Mo and Zhang, 2013; Musa et al., 2018; Mustapha et al., 2017; Opher and Friedler, 2016; Papa et al., 2016; Piippo et al., 2018; Wang et al., 2016
	Impact of Modifications in Operating Conditions	Variation in the overall WWT environmental impact due to a deviation from the plant nominal conditions.	Englehardt et al., 2016; Gomez et al., 2017; Gu et al., 2017; Lu et al., 2017
Side Effects	By Products Generation	By-products unintentionally generated.	Crini et al., 2019; D'Inverno et al., 2018; Gomez et al., 2017; Mahjouri et al., 2017; Salgot and Folch, 2018; Umamaheswari and Shanthakumar, 2016
	Waste Generation	Waste generated by the WWT.	Arroyo and Molinos-Senante, 2018; F Calise et al., 2018; Cieślik and Konieczka, 2017; D'Inverno et al., 2018; De Sanctis et al., 2016; Dubois and Boutin, 2018; Guerrini et al., 2016; Jin et al., 2018; Öberg and Mason-Renton, 2018; Prabakar et al., 2018
Economic/Financial			
Investment Cost	Upfront Cost	Initial payment necessary to install a treatment technology.	Angelakis et al., 2018; Capodaglio, 2017; Cheng et al., 2017; Dong et al., 2017; Englehardt et al., 2016; Jiang et al., 2018; Libralato et al., 2012; Mosher et al., 2016; Rawal and Duggal, 2016

	Hidden Costs	One-time expenses not included in the upfront cost.	Alnouri et al., 2016; Capodaglio, 2017; Dong et al., 2017; Rawal and Duggal, 2016; Roefs et al., 2017
O&M	Cost of Personnel	Economic burden of skilled personnel for the WWT.	Capodaglio, 2017; Gémar et al., 2018; Gomez et al., 2017; Jiang et al., 2018; Salgot and Folch, 2018
	Cost of Inputs	Cost of inputs to the treatment plant required for correct operations.	Alnouri et al., 2016; Bazrafshan et al., 2015; Capodaglio, 2017; Castillo et al., 2017; Chatterjee and Surampalli, 2016; Englehardt et al., 2016; Gémar et al., 2018; Gomez et al., 2017; Jiang et al., 2018; Long et al., 2018; Rawal and Duggal, 2016; Salgot and Folch, 2018; Tchobanoglous et al., 2014
	Discharge Fee	Fee to be payed to municipal treatment plants or central plants for the WWT.	Alnouri et al., 2016; Beecher and Gould, 2018; Capodaglio, 2017; Gomez et al., 2017; Long et al., 2018; Mahjouri et al., 2017
	Sludge Disposal Cost	Cost of sludge disposal due to regulatory requirements.	Alnouri et al., 2016; F Calise et al., 2018; Capodaglio, 2017; Rawal and Duggal, 2016; Rennuit et al., 2018; Salgot and Folch, 2018
	Maintenance Cost	Costs for maintaining the equipment and facilities.	Capodaglio, 2017; Cheng et al., 2017; Gémar et al., 2018; Gomez et al., 2017; Jiang et al., 2018; Long et al., 2018; Mahjouri et al., 2017; Rawal and Duggal, 2016
Cost Saving Potential	Synergies	Possible co-location synergies for WWT (i.e. merging the volumes and treating wastewater in a single plant).	Alnouri et al., 2016; Long et al., 2018; O'Dwyer et al., 2018
	Material and Energy Recovery	Monetary revenues from biogas energy recovery and/or nutrients recovery.	Adapa et al., 2016; Al-mamun et al., 2018; Angelakis et al., 2018; Castillo et al., 2017; Chatterjee and Surampalli, 2016; Cheng et al., 2017; Cieślik and Konieczka, 2017; de Boer et al., 2018; Elahi et al., 2017; Englehardt et al., 2016; Gu et al., 2017; Jin et al., 2018; Kayhanian and Tchobanoglous, 2016a; Mosher et al., 2016; Piergrossi et al., 2018; Prabakar et al., 2018; Radcliffe, 2010; Salgot and Folch, 2018; Sgroi et al., 2018; Smith et al., 2016; Urban, 2017; Bichai et al., 2018; F Calise et al., 2018; Carraresi et al., 2018; Cooperative Research Centre for Water Sensitive Cities, 2014; Drangert et al., 2018a; Mo and Zhang, 2013; Musa et al., 2018; Neoh et al., 2017; Opher and Friedler, 2016; Puchongkawarin et al., 2015; Puyol et al., 2017; Rennuit et al., 2018; Schröder et al., 2010; Umamaheswari and Shanthakumar, 2016; Van Der Hoek et al., 2016; Van Loosdrecht and Brdjanovic, 2014; Vasco-Correa et al., 2018
Financial	Capital availability	Financial resources available to implement WWT projects.	Quezada et al., 2016; Salgot and Folch, 2018
	Payback Time	Number of years needed to completely recover the investment.	Di Fraia *et al.* 2018; Mankad and Tapsuwan 2011; Panepinto *et al.* 2016; Rennuit *et al.* 2018
Socio-Cultural			
Management Attitude	Commitment to Environ. Issues	Management awareness and engagement towards environmental sustainability.	Cheng *et al.* 2017; Garrone *et al.* 2018; Sousa-Zomer *et al.* 2018; Mankad and Tapsuwan 2011
	Dynamic Working Environment	Innovativeness of the business, market or company and workers.	Sousa-Zomer et al., 2018; Wehn and Montalvo, 2018
	Image Return	Green image from implementing more advanced WWT.	Quezada et al., 2016

Workers Concerns	In House Expertise	Skills, knowledge, expertise within the company.	Garrone *et al*. 2018; Chatterjee and Surampalli 2016; Sousa-Zomer *et al.* 2018; Umamaheswari and Shanthakumar 2016
	Personnel Safety	Personnel safety may influence the decision of WWT configuration.	Capodaglio 2017; Mahjouri *et al.* 2017; Rehman *et al.* 2015
Community Concerns		Risks for the community due to e.g., leaks.	Arroyo and Molinos-Senante, 2018; Capodaglio, 2017; Cheng et al., 2017; Elahi et al., 2017; Garrone et al., 2018; Jiang et al., 2018; Papa et al., 2016; Saliba et al., 2018; Wester et al., 2016
External Factors		**Definition**	**References**
Socio-Cultural			
Pressure from Stakeholders		Level of external pressure from different stakeholder to improve the environmental performance.	Adapa et al., 2016; Bichai et al., 2018; Englehardt et al., 2016; Garrone et al., 2018; Mankad and Tapsuwan, 2011; Papa et al., 2016; Saliba et al., 2018; Sgroi et al., 2018; Smith et al., 2016; Wester et al., 2016
Support Availability		Degree of external support available to guide the company in its decision-making process.	Adapa et al., 2016; Bichai et al., 2018; Garrone et al., 2018; Gisi et al., 2014; Öberg and Mason-Renton, 2018; Quezada et al., 2016; Watson et al., 2017
Technology Accessibility		Easiness to access suitable technology.	Cheng *et al.* 2017; Salgot and Folch 2018
Regulation			
Legal Requirements		Law enforcements regarding effluent quality, emissions, waste disposal, personnel safety.	Bichai et al., 2018; D'Inverno et al., 2018; Giordano, 2015; Grizzetti et al., 2016; Krantzberg and Hartley, 2018; Lu et al., 2017; Öberg and Mason-Renton, 2018; Radcliffe, 2010; Salgot and Folch, 2018; Sgroi et al., 2018; Smith et al., 2016; Watson et al., 2017
Incentives		Any economic or non-economic stimulus towards the adoption of a treatment configuration.	Cheng et al., 2017; Flores et al., 2017; Gisi et al., 2014; Grizzetti et al., 2016; Quezada et al., 2016; Smith et al., 2016; Watson et al., 2017
Bureaucracy		Complexity and length of regulatory procedures to obtain permissions to operate according to the considered WWT.	Englehardt et al., 2016; Grizzetti et al., 2016; Watson et al., 2017
Site Characteristics			
Climate Related	Climatic Constraints	Particular climate conditions that constrain the configuration choice.	Sapkota et al., 2015; Zhou et al., 2018; D'Inverno et al., 2018; Furlong et al., 2016; Kayhanian and Tchobanoglous, 2016; Tchobanoglous *et al.* 2014
	Water Availability	Availability and abundance (or scarcity) or water resources in the territory.	Adapa et al., 2016; Furlong et al., 2016; Kayhanian and Tchobanoglous, 2016a; Urban, 2017
Location Related	Infrastructure Availability	Availability of proper infrastructures for the collection and transport of	Angelakis et al., 2018; Capodaglio, 2017; Castillo et al., 2017; Cheng et al., 2017; D'Inverno et al., 2018; Giordano, 2015; Schröder et al., 2010

		effluent (i.e. sewage system).	
	Proximity to Discharge Points	Distance from any discharge point.	Capodaglio, 2017; Castillo et al., 2017; Englehardt et al., 2016; Jiang et al., 2018
	Topographic Constraints	Restrictions posed to the choice of configuration because of topographic issues (e.g., lack of space, proximity to residential areas).	Castillo et al., 2017; Englehardt et al., 2016; Furlong et al., 2016; Gu et al., 2017; Libralato et al., 2012; Mahjouri et al., 2017; Mosher et al., 2016; Opher and Friedler, 2016; Salgot and Folch, 2018; Sapkota et al., 2016; Schröder et al., 2010

Table 3 - New framework of adoption factors

4 Methodology

The framework validation (Dooley, 2002) has been carried out with both selected industry experts and policy-makers of the wastewater sector, and with a sample of firms. Subsequently, the framework has been implemented with a second sample of firms in order to collect some empirical data and gain insights on the framework's actual usefulness.

The validation phase has been conducted in firms with a treatment system configuration already in place. The usability of the framework has been tested by analysing the behavior of firms in retrospective (i.e. those having a WWT system in place), so to be able to check whether the framework could grasp the factors driving the decision undertaken.

Both the validation and the application phase are executed by means of multiple exploratory case studies (Voss et al., 2002; Yin, 2009). Given the characteristics of the research, such research method has been considered appropriate since it allows the direct observation of the firms behaviour and systematic interviewing, seeking generalizability of the results (Ketokivi and Choi, 2014). Multiple case studies were conducted in order to increase the robustness of the results and reduce the observer bias (Voss et al., 2002).

4.1 Firms' selection

We have sampled companies within the food manufacturing sector. This sector is particularly interesting given its relevance in terms of number of firms (ISTAT, 2018), revenues and number of employees. Differently from other industrial sectors, the food wastewater usually contains a low amount of toxic compounds, making it more suitable for treatment and recycling projects (Gurnari and Barbera, 2018), even though safety regulation for reuse applications inside the production process itself is tighter (The European Parliament and The European Council, 2004).

Northern Italy represents our first context of investigation, given its relevance for the economy and industry (Regione Lombardia, 2017). Typically, treated wastewater is discharged to water bodies, but the quality of the discharged effluent is usually poorer than that of the receiving bodies, thus potentially causing health and safety problems (ARPA Lombardia, 2006).

New South Wales (Australia) represents the second investigation context: here the food sector employs about one third of the workers in the manufacturing industry and is responsible for an annual turnover of AUD102 billion. NSW is the largest Australian economy making up to about one third of the domestic GDP (NSW Government, 2019).

The sampled companies are heterogeneous in terms of size (by taking the European classification of SMEs, 2020), location and configuration adopted, to obtain more robust results (Baškarada, 2014; Eisenhardt, 1989). The goal was to ensure analytical generalization, by comparing the results with previous studies in literature (Baškarada, 2014), and conduct a cross-case comparison (Yin, 2016).

4.2 Data collection and analysis

Sampled companies have been approached by e-mail followed by a phone conversation upon their preliminary acceptance to partake to the research. For such companies, secondary firm data were collected as a complementary evidence to understand the firms' attitude, ensuring construct validity through comparison of multiple sources of information (Voss et al., 2002; Yin, 2016).

We conducted semi-structured interviews, which lasted approximately one hour, by selecting people fully responsible and knowledgeable of the WWT and management in the company. Pre-structured questionnaire supported the interview, so to standardize the questions asked and to minimize the impact of contextual effects (Patton 1990). Besides, open-ended questions and free comments were added to improve the understanding (Dicicco-Bloom and Crabtree 2006). The information collected was interconnected in different ways (Dooley, 2002) to ensure internal validity (Yin, 2016). Interviews were analyzed immediately after being performed, to allow further questions and build a deeper knowledge of the topic (Dicicco-bloom and Crabtree 2006).

The first part of the interview was the same for both the validating sample and the application sample: interviewees were asked to provide general information about the company, products manufactured, industrial process, markets served. Secondly, they were asked to describe the WWT configuration in place, with data about wastewater generation and contaminants; then, the motivations driving the firm towards the current configuration.

Subsequently, the interview was tailored to the validation or application purposes: with the validation sample, the interviewees have been asked to assess the framework of factors, commenting on its relevance, level of detail, intelligibility, independence. In case factors not included in the framework emerged, these would be examinated by the interviewers and discussed further. If a new factor could not be referred to any already listed in our framework, it would be added with proper justification.

Instead, with the application sample, the interviewees were asked to assess the importance of each factor in the decision-making process, on a 4-point Likert even scale from 1 (not relevant) to 4 (extremely relevant) to minimize the number of neutral answers.

Once collected, the interviewed were transcribed and qualitatively analysed, by means of the coding technique (Miles et al., 2014), that is the analytic process examining data looking for concepts (Strauss and Corbin, 1998). Constructed codes were generally preferred, by analysing information paragraph by paragraph and line by line. Codes were successively "clustered together according to similarity and regulatity", to retrieve patterns, categories and their connection (Saldana, 2012).

During this phase, interviews were analysed to retrieve comments on the treatment system configuration, the adoption factors and the link between them. Each interview was transcribed and analysed shortly after the interview was concluded, in order to provide further insights for the following ones. Due to the exploratory nature of our investigation and the sample size, we limited our quantitative analyses to the frequency of values for the importance of the adoption factors.

5 Validation

A preliminary version of the framework has been presented and validated with acknowledgeable experts of the wastewater sector. Shortly, Table 4 reports their main comments. The experts have been contacted both in Italy and in Australia, in order to have a complete overview of the wastewater sector in both countries. The main contributions were provided by two regulatory bodies, in charge of setting tariffs for the WWT. Beside a general positive appreciation of the proposed framework, that resulted clear, complete and relevant, a thorough detail over the economics of WWT was deemed crucial for a proper understanding of the adoption factors. Therefore, upon their suggestion, the specific factors "capital availability" and "payback time" have been added to the framework for further validation with companies.

COUNTRY	ACTORS	COMMENTS ON THE FRAMEWORK
AUSTRALIA	Regulator of New South Wales on wastewater reuse and recycling	Importance of economic factors, that are likely to strongly influence the decision-making process of firms. Regulation should be taken into account, but firms are not really proactive. Firms should have risk management approaches to manage WWT to minimize the likelihood and the impact of problems.

	Local council of New South Wales	Firms are more pushed by economic motivations.
	Technology provider and consultant	Regulation got tighter in the last decades, and firms are starting to catch up. Collaboration between firms and regulators could foster the adoption of more environmentally sound practices.
ITALY	Consortium facility for the treatment of wastewater of an industrial district	Central WWT facilities should be designed to answer the needs of firms. This includes setting tariffs that are berable by them. Regulation and increased awareness allowed to improve significantly the quality of the final effluent, and the quality of the receiving water bodies. The relationship with the local communities has improved because now there is high attention to their needs.
	Policy maker for economic tariffs	Many decision-makers still evaluate investments based solely on the investment cost, operating costs come at a second stage.

Table 4 - Types of actors interviewed and comments collected on the framework

The validation was carried out in 10 firms, whose comments are presented in Table 5. Overall, these interviews allowed to have a more complete view of the challenges faced by companies when dealing with the selection of the WWT configuration. The factors resulted to be clear, relevant, non-overlapping, therefore allowing to proceed for more widespread application into companies. No additional factors were mentioned by firms, and therefore the framework was deemed ready for the application phase.

	COMMENTS
V1	Everything is clear. From my point of view, the most important elements to take into account are costs and the quality of the product.
V2	The "ancillary services" factor is not very clear. Maybe it should be clarified during the interviews to make people understand.
V3	Space in general is an important element, especially in the initial planning phase. All considerations concerning the topographic constraints are relevant.
V4	All environmental considerations nowadays are fundamental, they cannot be excluded by any decisional framework. We should operate so that the environment in which we live thrives.
V5	Managing waste from depuration should be included, it is a burden for firms and the regulation is very tight.
V6	There should be something related to the history of the firm. We were born with this configuration and now it is very hard to change it.
V7	This framework is ok. I think it's also a matter of external help and consultancy you can get.
V8	The image return is very important. This should be included.
V9	For sure complexity should be there. The simpler you keep the plant, the easier it will be to manage. And for firms this is really important.
V10	All clear. Maybe quality problems with the product should be encompassed. For instance, we irrigate the treated wastewater to our vineyard, we don't want to ruin it with contaminated wastewater.

Table 5 - Comments of the validating firms

6 Application

The characteristics of the interviewed firms in the application phase are reported in Table 6.

	COUNTRY	SIZE (EMPLOYEES)	SUB-SECTOR	WW VOLUME
A1	Italy	Medium	Dairy	430
A2	Italy	Small	Confectionery	1
A3	Italy	Medium	Confectionery	3
A4	Italy	Large	Confectionery	600

A5	Italy	Medium	Meat	220
A6	Italy	Large	Dairy	2,190
A7	Italy	Small	Manufacture of oils and fats	1
A8	Italy	Small	Meat	26
A9	Italy	Small	Dairy	165
A10	Italy	Small	Confectionary	2
A11	Italy	Small	Dairy	55
A12	Italy	Small	Powder mixes (b2b)	2
A13	Italy	Large	Dairy	33,333
A14	Australia	Small	Meat	1
A15	Australia	Small	Dairy	2
A16	Australia	Large	Ginger products (snacks and beverages)	150
A17	Australia	Medium	Confectionary	15
A18	Australia	Large	Wine	750
A19	Australia	Medium	Meat	600
A20	Australia	Medium	Bakery and confectionary	9,000
A21	Australia	Medium	Meat	700
A22	Australia	Large	Meat and bakery	65
A23	Australia	Small	Dairy	1
A24	Australia	Small	Wine	0.55
A25	Australia	Small	Tea	0.5
A26	Australia	Large	Rice products	100
A27	Australia	Medium	Meat and diary	10
A28	Australia	Small	Meat	1
A29	Australia	Large	Meat	60

Table 6 - Characteristics of the companies interviewed

6.1 WWT system configuration

The interviewees have been asked to describe their current WWT system configuration, according to the three axes of the framework. The boxes 1, 2 and 3 exemplify the main information retrieved from interviews, showing the capability of the framework to thoroughly capture the specific WWT system configurations and factors driving the choices. The overall empirical results are instead summarized in Table 7.

The firm is an Italian and global market leader in the segment of premium cheese. Located in Brescia, Italy, it employes approximately 250 people who process 100-150 tonnes of raw milk per day. It generates 430 m³/day of wastewater, that contains organic contaminants, BOD, COD, N, P, chlorides, iron.
The firm has adopted the following configuration:

Flow separation: no segregation
Location from the source: complete on-site
Effluent destination: water bodies

After a complete on-site treatment, the wastewater is discharged to water bodies. The firm does not segregate its flows and it does not reuse its wastewater. The treatment consists of a gross grit removal then enters an accumulation and homogenization tank. Afterwards, the volume is sent to a biological treatment, that consists of a percolator, a sedimentation, oxidation and it is sent to a final sedimentation basin. Finally, the sludge is aerobically digested, pressed and stored until agricultural companies come to dispose of it onto fields.
The main adoption factors highlighted by the firm for choosing this configuration are the lack of connection to the sewage, which is also underdimensioned compared to the volumes that would be necessary for the firm to discharge its entire volume into the sewage. Having to install an on-site treatment, firm A relied on external consultants for the proper technology selection, that was chosen prioritizing the reliability of the treatment and with idle capacity to handle shock loads. The main concern of firm A is that problems with the depuration could force a production stop.
Firm A is environmentally aware, and it has been invested during the years to minimize its impact. For instance, it installed photovoltaic panels on top of its plants, so to reduce its energy needs and obtain savings.

Box 1 – Firm A1

Firm A26 is a large Australian enterprise, operating in 50 countries and employing 2,200 people. It manufactures mainly rice products but owns more than 30 brands. It generates 100 m³/day of wastewater, that contains mainly BOD, COD, suspended solids. Firm A26 has a partial on-site treatment, after which the wastewater is sent to the local council for the final treatment. It does not segregate the flows. The preliminary treatment consist of solid flotation and pH correction, and finally passive aeration.

Flow separation: no flow segregation
Location from the source: partial on-site
Effluent destination: local council

The most important adoption factors resulted to be the willingness to reduce the complexity to operate an on-site plant, which would also imply higher costs with respect to the current configuration. They wanted the preliminary treatment to be manageable by the internal personnel and skills they had. A complete off-site configuration was not feasible by law, since they do not meet the quality standards necessary to discharge their wastewater directly into the local council system.
They do not reuse wastewater in any way, and perceive the reuse options for wastewater almost non-existent in Australia, unless one has a field near-by where to irrigate it.

Box 2 – Firm A26

Firm A3 is a medium-sized company specialized in the segment of chocolate decorations, sugar plates, serigraphy paintings and more generally dessert decorations. Most of its wastewater originates from refrigeration activities and oradinary washings to the equipment, and therefore it is discharged without treatment to the sewage.
Part of its wastewater, however, originates from washings to the serigraphy machinery. This volume of wastewater is larger than the other, since washings are much more frequent in number, and it contains a polyelectrolyte used to fix colours to the frames. This particular type of contaminant cannot be discharged to the sewage, and therefore the firm has to treat this volume of wastewater internally with a partial on-site treatment. They have a flotation plant that generates a sludge waste, which is disposed of to an authorized third-party. The liquid part is again discharged to the sewage.
The flow separation is performed due to regulations, since the firm is not able to discharge directly the polyelectrolyte to the sewage. The remaining volume of wastewater is treated off-site, since the volume is relatively small and the discharge fee low.

Flow separation: segregation of flows
Location from the source: partial on-site
Effluent destination: sewage system

Box 3 – Firm A3

		A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A22	A23	A24	A25	A26	A27	A28	A29
Location from the source	Complete off-site		✓								✓		✓		✓											✓				
	Partial on-site			✓	✓				✓			✓		✓			✓	✓		✓			✓				✓	✓		
	Complete on-site	✓				✓	✓	✓		✓						✓			✓		✓	✓		✓	✓				✓	✓
Effluent destination	Water bodies	✓				✓	✓	✓		✓																				
	Municipal plant		✓	✓	✓				✓		✓	✓	✓		✓		✓	✓		✓			✓			✓	✓	✓		
	Central plant													✓															✓	✓
	Reuse applications													✓		✓			✓		✓	✓		✓	✓					
Flow separation	Yes			✓			✓			✓											✓									
	No	✓	✓		✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 7 - Configuration selected by the interviewed firms

Concerning the location from the source, most companies (13 out of 29) opted for a complete on-site treatment (decentralized). The second most common solution is the partial on-site (11 out of 29). Overall, our preliminary findings show that sampled firms prefer a decentralized solution on their site over an off-site one. As for the effluent destination, the majority of firms discharge its wastewater to municipal plants (15 firms), some to water bodies (5 firms) and only few to central third party facilities (3 firms). Reuse applications are present only in case of on-site treatment, as expected. Also, from the cases it appears that the firms with a complete on-site treatment discharge the final effluent to water bodies. Finally, most firms do not segregate their wastewater volume. Only few firms do so (firm A3, A6, A9, A20), with very different motivations:

- compliance with regulation (e.g. firm A6), as some municipalities impose to separate the rain-related wastewater, that are considerably less polluted than industrial wastewaters and would negatively impact the treatment performed at the municipal wastewater plant;
- capability to separate its wastewater and perform the on-site treatment only on the part that is more polluted and would result outside the limits to discharge it to the sewage (e.g., firm A3);
- capability to reuse a larger part of wastewater volume by separating different flows (e.g., firm A20).

At first sight, smaller firms seem to privilege a complete off-site solution, discharging to municipal plants and without performing any flow separation, mainly because of their smaller volume compared to larger firms and lack of competences. Medium firms, instead, have either partial or complete on-site solutions, discharging often to municipal plants but also to water bodies. They might perform flow separation. It appears that in this case firms have more mixed configurations. Finally, larger firms seemed to be reluctant to completely outsource the treatment. As per our preliminary findings, they either adopted a partial on-site or a complete on-site one; all effluent destination possibilities are encompassed, and mainly they operate no flow separation.

When looking at geographical location, Italian sampled firms seemed to adopt all range of options in terms of configuration: both partial on-site, complete on-site treatment and complete off-site system, presenting municipal plants as effluent destination. In the majority of cases, this is due to the small volume of wastewater generated. Only one of the firms interviewed reuses water, despite decentralization could bring to an increased water reuse, as noted by previous studies (Capodaglio, 2017). A different picture could be found for the Australian sampled companies, where the complete on-site represented the most common treatment configuration. As several companies noted (A21, A23, A24, A28), this was largely due to a lack of infrastructure. In all cases, complete on-site treatment brought firms to reuse water via irrigation, for either lower treatment costs (firm A18) or revenues by the sale of crops (firms 20, 21, 29).

6.2 Adoption factors for the treatment system configuration

According to our preliminary investigation, the two major factors driving the configuration are *legal requirements* and *volume* (Figure 2). Companies highlighted that *legal requirements* are crucial (deemed extremely important by 21 out 29 sampled firms), and a configuration unable to meet the legal requirements should not even be considered. The factor *regulation* also included the discharge limits applied by the municipal plant to allow firms discharging their effluents.

The *volume* of wastewater generated was deemed at least important in 24 out of 29 cases. The volume helps discriminate among the configurations, especially regarding the choice of on-site or off-site treatment. In absolute terms, as the wastewater generated by the firm increases, it makes more economic sense to have an on-site treatment compared to an off-site solution due to increased discharge fees paid to the municipal plant, showing the role of possible relationships between different categories of factors (in this case *influence-related* and *economic*) driving the decision over WWT configuration. The *influence-related* factors proved to be the most relevant category.

Discharge fee was deemed the most important cost item for firms. Being usually determined by encompassing volume, contaminants' concentration and capacity occupied in the treatment facility (ARERA, 2017), such factor may represent an effective leverage for local policy makers to drive changes into WWT towards increased on-site treatment, e.g., by increased discharge rate fees (Lu et al., 2017), therefore reducing the burden of centralized WWT facitilites.

Environmental concerns were ranked less relevant than performance and technical considerations. This may infer that environmental factors were not considered by companies as important in selecting the treatment configuration as e.g., influent related factors. We believe that this preliminary finding, thanks to the new framework proposed, should be further investigated and could offer valuable room for further discussion, in terms of policies leading to increased awareness over sustainability issues and more sustainability-oriented decision-making.

S*pace requirements, compatibility with previous treatment stages, incentives* and *climatic constraints* were ranked very low by respondents. As highlighted by companies, land requirements only become important when space is a constraint for firms. Besides, the compatibility of previous treatment stages only is relevant in cases of upgrades to the plant. Firms also reported that the selection of their WWT configuration was not primarily based on incentives, as they might be in place for a limited time and subject to revision, thus not representing a solid basis for investment decisions. Likewise, the wastewater regulator of NSW highlighted similar considerations, representing an interesting point slightly differing from previous literature, where many academics have stressed the importance of incentives to support the development of more sustainable technologies (Carraresi et al., 2018; Cheng et al., 2018; Goulden et al., 2018; Smith et al., 2017; Vasco-Correa et al., 2018). Finally, despite climate factors may play a role in the selection of the treatment technology for the treatment (Tchobanoglous et al., 2014), in our cases they were not deemed relevant for WWT configuration selection.

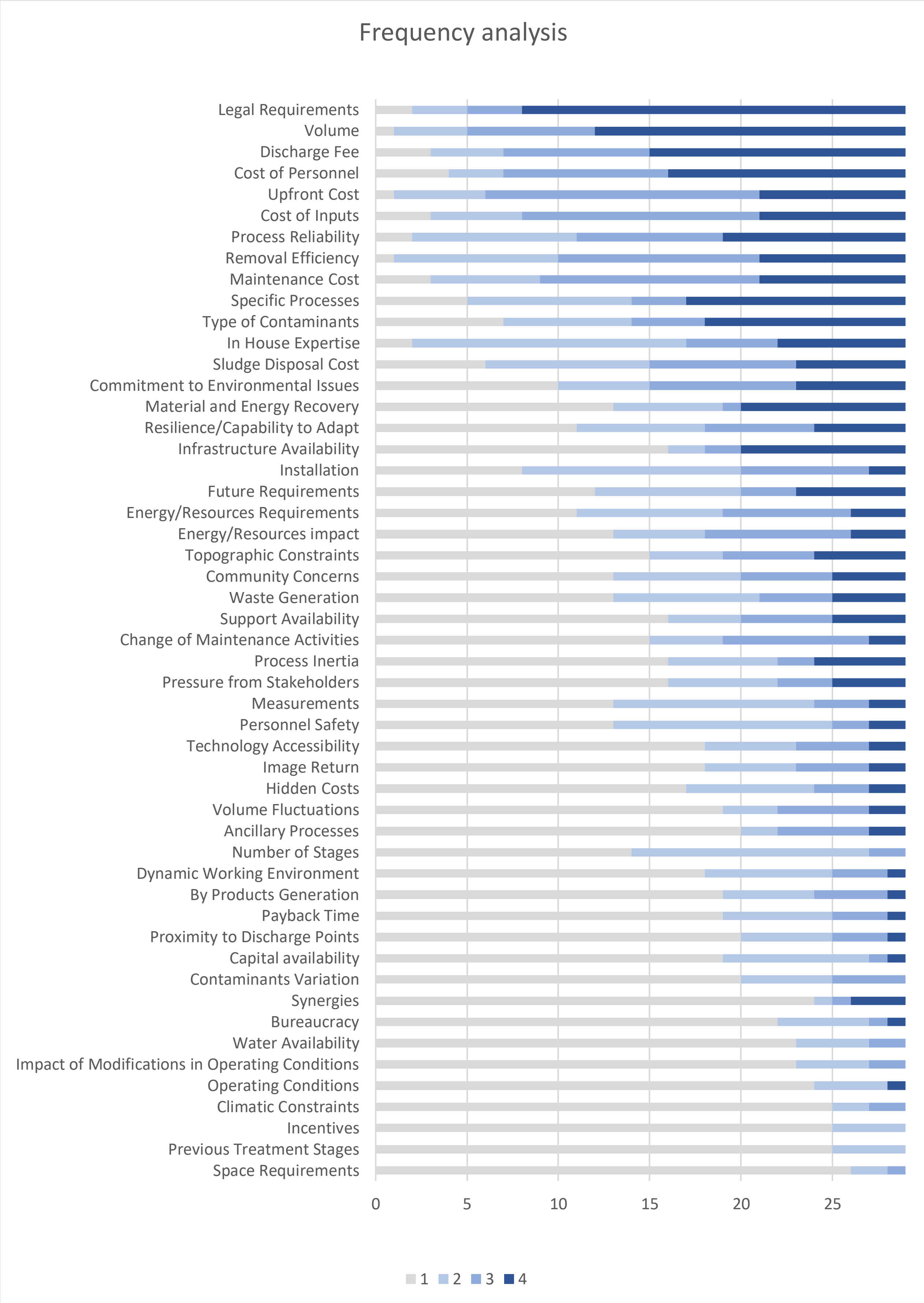

Figure 2 - Frequency analysis of the adoption factors

We have also preliminary looked at some contextual factors that may shape the response from firms, namely firm size and country. Figure 3 shows the variation from the total average values. For this analysis, only variations of ±30% have been commented, as most interesting for the analysis. Given the small sample of firms interviewed, in the following we report our preliminary considerations, acknowledging the need for further investigation.

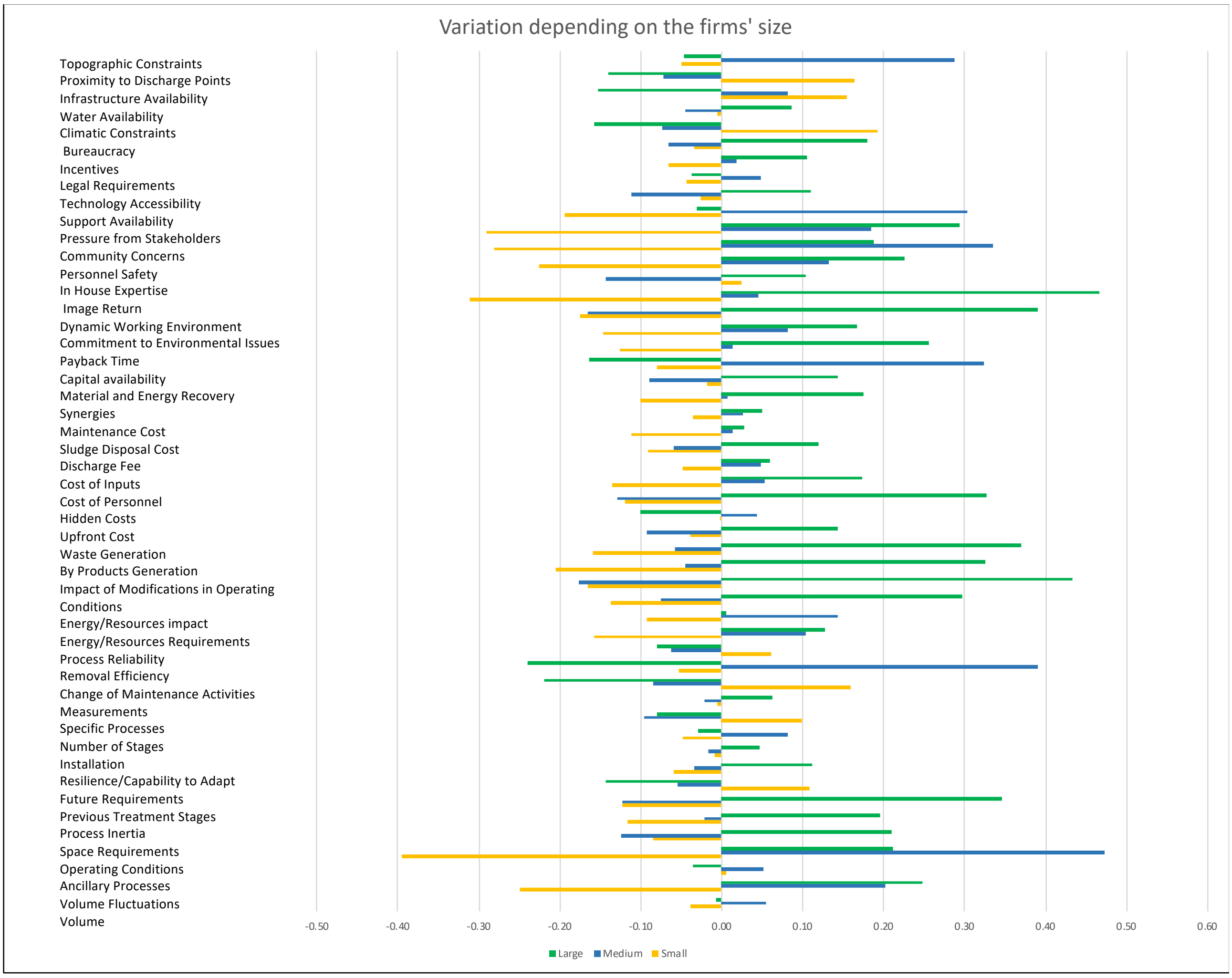

Figure 3 - Adoption factors relevance according to firm size

Space is perceived as more relevant by larger firms (+35%), as they are more likely to have space restrictions. Larger firms seemed also more aware about *hidden costs* (+33%) and their *green image* (+47%), plus they are more respondent to a *dynamic working environment* (+39%). Further, according to this preliminary study, they also seemed more concerned with environmental impact and about by-products generation, likely due to their higher visibility and responsibility (and related pressures) from local communities.

Further, we could spot some differences regarding the importance of *volume*, that was deemed particularly critical for Italian sampled companies. As per additional comments and insights gathered through the interviews, considerations about volume were done both in absolute terms to evaluate the feasibility of an on-site plant, but also in relative terms compared to the capacity of the local municipal facilities. Our sampled Australian companies seem to rather attribute a higher importance to *legal requirements* (at least relevant for 11 firms). *Upfront cost* was perceived as more relevant than operational costs, whilst for Italian sampled companies the discharge fee was the most critical. Interestingly, on average, sampled Australian firms seemed to be more interested for the overall cheapest and simplest configuration meeting legal requirements.

7 Discussion

The present study represents a first-of-a-kind in the academic literature over WWT configuration systems, by offering a novel framework and a comprehensive set of decision-making factors, also allowing to put forward some considerations compared with previous studies. The capability to assess the single cost items proved particularly useful to position the firms' comments, and it allowed to verify that the most relevant cost item is the *discharge fee*, which results particularly critical for Italian sampled companies, rather than economic incentives. To some extent, our findings differ from earlier literature discussing the importance of incentives (Cheng et al., 2018), and offer ample room for further research into prioritising decision-making factors over WWT configuration. As noted by interviewees, whilst incentives may not be in place for such long-term investment decisions and/or may be revoked based on specific environmental circumstances, a specifically designed discharge fee could encourage (or discourage) specific WWT configurations. Further, the relationship between increased wastewater cost and lower water use in input is interesting, although this relationship has been previously argued (Beecher and Gould, 2018). In previous literature, studies slightly differs from our results (Vasco-Correa et al., 2018), with regulation and incentives such as tax exemptions and other economic incentives (e.g., for renewable energy use or nutrient load reduction) might foster the development of WWT. Other research also argues that incentives properly set and a well-structured monitoring program of improvements could improve the WWT performance (Gisi et al., 2014). Thus, our research seems to highlight that local and regional policy-makers should carefully consider such elements to foster more sustainable WWT configurations. In this regard, the newly proposed framework brings a novel perspective to the discussion interestingly allowing to take a holistic view when assessing the relative importance of factors, by providing a comprehensive list of factors and allowing to point out also the major role of influence-related factors - such as *volume* and the *types of contaminants*, over specific economic ones (Zeng et al., 2007) or reliability considerations (Tchobanoglous et al., 2014).

Previous literature noted the important role for regulation, on the one hand setting the discharge limits that companies need to comply with (Starkl et al., 2018), on the other hand encouraging encourage knowledge dissemination and know-how transfer (Garrone et al., 2018). Indeed, *Legal requirements* appear in our study as the most important factor looked by firms when selecting their WWT configuration, e.g., opting for off-site solutions to avoid possible problems in case of strict regulatory requirements. Here we can thus see that a careful design of policies could lead to a more effective treatment of wastewater and better environmental performance (Lu et al., 2017).

The operating cost structure varies largely depending on the type of treatment performed and the presence of specific nutrients to be removed (Molinos-Senante et al., 2010). The low relevance of *personnel costs* in our case does not find confirmation in previous literature, where personnel and related costs emerged as more important (O'Reilly 2000; Molinos-Senante et al., 2010). A possible explanation for such difference can be related to higher personnel costs, driving firms (and particularly smaller ones with more limited resources) to opt for off-site schemes. Rather, our sampled firms highlight the relevance of upfront costs , similarly to Zeng et al. (2007), even though firms are starting to consider other factors as well, e.g., possible increased returns on investment from water re-use or heat recovery. As mentioned, the importance of the *discharge fee* might represent a leverage for regulators to drive decisions towards more sustainability-oriented configurations.

Among the technical factors, our sampled firms noted *removal efficiency*, *process reliability* and *complexity of specific processes* of the treatment, similarly to the results by (Zeng et al., 2007), with many firms highlighting that off-site solutions usually allow to ensure better performances. However, this is also related to internal skills and competences: in fact, in firms with more internal skills, the complexity of WWT is deemed as less relevant, whilst those without sufficient internal skills seem to rely on external competencies rather than developing them in-house.

Interestingly, environmental concerns appear to be still poorly developed among the companies, showing that the role of this category of factors is still disputed and deserves additional research. In fact, although firms show a general high awareness concerning environmental issues, these became poorly relevant in the WWT configuration selection. Given that firms need to comply with regulatory and moral standards, environmental factors are not particularly important in deciding whether to treat on-site or off-site. Configurations allowing for water reuse, instead, were also connected to higher importance of environmental factors. On the contrary, Castillo et al. (2017) suggest that environmental concerns should drive the decision among two equally performing solutions. In the context of metal finishing WWT, Heller et al. (1998) found that environmental factors were ranked first in all the cases analysed. We can see ample room for further academic discussion in this area, as the vast majority of firms reported economics to be far more relevant than the environmental performance. Further, interviewed firms tended to hold regulators responsible for setting the right environmental protection policies, while firms' concern should be on compliance with such regulations.

Moreover, the novel framework brings additional value to the discussion by encompassing the socio-cultural aspect in the broader decision-making process. In fact, even though previous research highlighted that firms should include all stakeholders into the decision-making process to make the project succeed (Sapkota et al., 2016), the socio-cultural indicators were on average considered poorly relevant for the configuration selection in our sample, showing a lack of culture and attitude to encompass such considerations. Exceptions were observed, e.g., in case of strong odours or noise, of evident spills in local water bodies. Hence, our preliminary investigation reveals an overall lack of awareness of socio-cultural issues and the need to develop adequate strategies for higher commitment over the role, the responsibility and the impact of actions by firms in moving towards more sustainable WWT system configurations.

8 Conclusions and limitations

The novel framework developed in this study represents a useful tool to study the configurations adopted by firms for WWT. Furthermore, the proposed framework allows to have a holistic view of the factors that firms consider crucial in selecting their WWT configuration. There are several elements of novelty in the present study. It advances the discussion in literature about WWT, offering a novel perspective on the topic. Indeed, this research is positioned at an intermediate level between the technological sphere and the managerial one, highlighting the breadth of factors (beyond technical ones) to be encompassed when making decisions over an important issue such as the WWT configuration with several sustainability implications By focusing on the importance of WWT decisions inside firms, it aims to offer a valuable insight on how the decision-making process unfolds. The novelty relies in particular in analysing all the issues pertaining to the treatment of wastewater, but by taking the perspective of the single firm. Therefore, external factors such as regulation or pressures from external stakeholders are analyzed from the firm's perspective, acting either as constraints or facilitators driving a firm towards a specific configuration. Furthermore, the proposed framework allows the identification of relevant relationships between factors, so to offer additional insights on the issues faced by firms.

Despite the present work represents a preliminary attempt and the empirical evidence gathered in the present work is just preliminary, this research paves the way for a greater understanding of the major wastewater industrial practices to be revised for improved sustainability, by providing initial considerations on the configurations currently adopted by companies for WWT. The results of this study seem to suggest that larger volumes of wastewater might be more cost-effectively treated on-site, also limiting the additional infrastructures for collection and treatment, positively contributing to sustainability and reduced footprint of industrial activities. Rather, smaller volumes could more easily and conveniently treated off-site, especially in case of highly-contaminated wastewater and lack of competencies. In view of the literature discussion, our results do not seem to be specific for the food sector that has been investigated here. Indeed, thanks for the proposed framework, future research could more extensively investigate important contextual factors potentially leading to different factors driving decisions over WWT configurations.

The present research also gives a contribution to industrial practices, by guiding decision-makers towards their choices in selecting the treatment configuration. The present has examined firms that had already a treatment system configuration in place but, after this preliminary validation and application, further research could extend the application of the framework to companies deciding over new WWT systems. In particular, thanks to the breadth of factors encompassed, industrial decision-makers could be more aware of the multitude of aspects to be encompassed, so to pursue more sustainablility-oriented decisions.

Finally, our framework may support policy makers by providing effective insights on the relative importance of the factors for practitioners, therefore leading to more effective interventions to improve the sustainability of industrial WWT.

In conclusion, we acknowledge some study limitations that offer valuable opportunities for future research. Firstly, the sample of the firms interviewed is limited and focused exclusively to the food sector: by enlarging the sample and scope of investigation – in terms of sectors and context – more in-depth information could be obtained and robust statistical considerations could be drawn. Secondly, interviewees have participated to the research voluntarily, thus potentially leading to a biased sample, given that the topic is highly sensitive and with several (and potentially severe) legal implications. In this domain, future research could expand the sample by means of anonymous surveys to capture additional insights on the topic, particularly related to regulatory issues. Thirdly, future research could more deeply investigate the relevance of the factors in light of different regulatory settings, thus aiming to explore the relationship between decision-making over WWT configuration and wastewater policies. Fourthly, the research has been limited to the selection of WWT configuration, therefore not discussing wastewater efficiency or cleaner production practices currently in place, including prevention at source rather than treatment. However, we see here that many different elements are intertwined, with wastewater efficiency practices affecting decisions over WWT and viceversa. For this reason, we believe deeper research is needed on how to drive more sustainable wastewater configurations, together with a characterisation of the practices that could and should be implemented and how their adoption should be promoted within companies.

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