Industrial wastewater treatment configuration: insights from a Northern Italy textile manufacturing district

M. Negri[1], E. Cagno[1], C. Salemme[2], A. Trianni[3]

[1] Department of Management, Economics and Industrial Engineering, Politecnico di Milano, Milano, Italy

[2] Ambiente, Territorio e Sicurezza, Sostenibilità, Confindustria Como, Italy

[3] Faculty of Engineering and Information Technology, University of Technology Sydney, Sydney, Australia

marta.negri@polimi.it
enrico.cagno@polimi.it
c.salemme@confindustriacomo.it
andrea.trianni@uts.edu.au

Abstract – **Industrial wastewater treatment is getting increased attention from academics, practitioners and regulators, due to the environmental hazard of discharging poorly treated wastewater into the environment. This paper analyzes the case of Como's textile district in Italy, to explore what factors are considered by firms in selecting the most appropriate wastewater treatment system configuration. The case studies highlighted that Como's wastewater consortium benefits the firms in the district, and it is a better solution compared to the presence of sub-optimal private treatment plants. The firms mentioned internal stakeholders, factors related to the wastewater and technology, and economics as the most relevant.**

Keywords - **Industrial wastewater treatment, treatment system configuration, adoption factors, framework, textile sector**

I. INTRODUCTION

Industrial wastewater is gaining momentum lately, due to the hazardous consequences that the discharge of poorly treated wastewater has on the environment and human health [1]. With the increasing pressures from several stakeholders urging firms to improve their sustainability, there are growing concerns for firms to take responsibility of the wastewater produced and related treatment before discharging it into the environment.

Within the industrial sector, textile manufacturing industries are a major contributor to the generation of wastewater, that originates from removing impurities from raw materials and from the use of reagents during processing. Wastewater coming from those processes thus may contain acids, alkalis, dyes, starch, surfactants, soap, metals [2], high BOD concentrations, colors [3].

There are several options for firms to reduce the environmental damages of their wastewater. Companies can adopt several options in terms of technologies, by operating either chemical, physiochemical, or biological treatment, or a combination of the above depending on the degree of treatment necessary [3]. Besides, firms may rely entirely on their own treatment plants, or outsource the treatment to a third party [4].

By more closely observing the different options that can be put in place for industrial wastewater treatment, the problem of how to select the most suitable option emerges. In this regard, literature has so far been limited by either the analysis of technological solutions to provide decisional tools to firms, or by policy frameworks to provide insights to regulators on how to promote wastewater treatment. An intermediate perspective is however missing, even though it is extremely interesting to provide firms with a tool that could encompass the technological and managerial perspectives and ease the decision-making process.

Starting from the issues identified above, the purpose of this article is to give a contribution to the academic research in this domain by performing an exploratory study concerning wastewater treatment system configurations and provide some insights on the reasons that could push firms to adopt a similar solution. More specifically, the aim is to study the configuration selected by a sample of firms, identifying and evaluating the major factors firms consider when making their decision. We have chosen the textile manufacturing district in Como (Northern Italy) as empirical setting for our exploratory investigation, given its relevance for the regional economy and sustainability issues. Our empirical findings could contribute towards building a holistic framework able to best support decision-makers – as well as policy-makers – in identifying the major factors leading companies to the implementation of a certain industrial wastewater configuration, so to in turn drive decisions towards more sustainable industrial wastewater configurations.

II. LITERATURE BACKGROUND

As observed by previous literature, the selection of treatment system configuration involves decisions along three main axes, namely: the wastewater collection, the wastewater treatment and the wastewater disposal [5]. By more closely looking at wastewater collection, studies tend to identify that the different wastewater flows can either be combined or separated [1].

Concerning wastewater treatment, the process can be on-site, close to the point of generation [1]. In literature, this solution is also referred to as decentralized [6]. Alternatively, the treatment can be made off-site, in a central or municipal facility [1]. In this latter case, the treatment is also called centralized [6]. Both solutions present advantages and disadvantages, and firms should

select the most suitable one according to their specific needs. For instance, on-site treatment allows a greater customization to local needs, is more reliable and provides more opportunities for water reclamation, as previous research noted [6]. On the other hand, on-site treatment is usually characterized by higher initial investment and requires more expertise by operators [1]. Off-site schemes, instead, can enjoy economies of scale and synergic effects for the mixing of different streams of wastewater that neutralize one another [7]. Nevertheless, they should be located close to discharge points. Additionally, pipelines to convey the wastewater to a unique central point of treatment might be very expensive, as observed by Asano et al. [8].

Finally, companies can discharge the final effluent into water bodies or into a third-party treatment facility. This choice strongly depends on the availability of discharge points close to the firm and on the decision made for the other two axes.

In literature, despite being clearly interconnected, the three axes have been managed separately [5]. The concept of treatment system configuration, instead, allows to describe how the firms deal with the three decisions in a complete way.

Concerning the reasons driving firms to the adoption of a specific treatment system configuration, previous literature has offered a scattered approach. Interesting contribution to the discussion have been provided by [9], [10], who have identified the influent characteristics as of course major element to be encompassed. Further, as Zeng et al. note, economic aspects can play an important role in choosing a certain configuration and should be carefully considered [11]. Additionally, other important elements to be encompassed are potential environmental damages and benefits [12], but also technological complexity and reliability of the solutions [13].

Most studies, however, analyse only the technical level of the selection problem [14], or are developed by taking the perspective of the utility [15], rather than that of the industrial company generating a certain wastewater flow.

To authors' knowledge, there is a lack in literature of studies that are focused at industrial level, thus by encompassing the technical and managerial implications coming from the adoption of a given industrial wastewater treatment configuration, representing an important research gap that would be important to address by creating a framework of all factors to be considered. Furthermore, most of the literature has provided a theoretical contribution to the academic debate by theoretically pointing out possible factors to be considered. However, there is a lack of empirical evidence in assessing which factors effectively result more important for companies when undertaking decisions concerning the selection of their wastewater treatment configuration.

In the present study we aim at giving a contribution towards the aforementioned research gap by conducting an exploratory investigation among manufacturing firms, as described in the following Sections.

III. METHODOLOGY

The present study is based on exploratory case studies [16], [17] in the textile district of Como (Northern Italy), with the aim to collect insights on the treatment system configuration installed by firms and the important elements that firms consider when selecting it. We have interviewed 10 companies, belonging to the dye-works and textile-printing manufacturing firms. The firms have been selected with the collaboration of Unindustria Como, a local association of industries, that offered the first contact with the interviewees.

The interviewees were the people in charge of the wastewater treatment in the firms, and whenever possible, the owner of the firm.

The interview was conducted with the aid of a pre-compiled questionnaire, so to standardize the questions asked and minimize the impact of contextual effects [18]. Besides, open-ended questions and free comments were added to improve the understanding of the firm situation [19]. Additional data were gathered also from the firms' website and articles, in order to have more than one information source and gain additional knowledge about the firms' sustainability attitude and ongoing projects [20]. By collecting evidence through multiple sources we allowed to ensure internal validity through pattern matching [20], which represents a crucial condition for case study methodology. Additionally, reliability was ensured through the use of a case study protocol [21]. Given the particular design of the research, the cases were selected to ensure literal replication [17].

The interview has been structured into three main parts and lasted between 30 and 120 minutes. Firstly, interviewees were asked to provide a general description of their firm, with main processes in place as well as major use of water. Secondly, interviewees described the wastewater treatment configuration currently in place, by identifying the wastewater collection, the wastewater treatment and the wastewater disposal. Thirdly, we have asked them to assess the importance regarding several categories of factors they considered when choosing their wastewater treatment configuration, by using a 4-point Likert scale (from 1=not important to 4=very important), built by reviewing extant literature as described before. The choice of a pairwise Likert scale was aimed at minimizing the number of neutral answers [22], taking inspiration from previous research.

IV. RESULTS AND DISCUSSION

A. The case of Como

The textile sector, traditionally important for the Italian economy [23], is organized in highly focused industrial districts. The province of Como, located in Northern Italy, is specialized in the weaving and finishing of silk [24]. It is of particular interest to study the case of industrial wastewater treatment in Como since the specific sample of companies investigated presents similar characteristics (by location, size, production processes) and faces similar challenges and issues. Therefore, they

have historically organized themselves to optimize the treatment for the whole district, rather than focusing on sub-optimal, single solutions [25].

The textile manufacturing sector in Como (within Lombardy region, in Northern Italy) typically includes several contracting companies, mostly small- and medium-sized ones, largely specialized in one or a limited number of phases of the finishing process of fabrics [27]. The finishing phase consists of printing, dyeing, finishing.

TABLE I
Interviewed firms' characteristics

Firms	Size	Textile Sub-Sector	WW generated [m$_3$/day]
1	Medium	Printing	600
2	Large	Printing	1,450
3	Large	Printing	1,500
4	Medium	Printing	300
5	Small	Printing	110
6	Medium	Dyeing	500
7	Medium	Dyeing	1,230
8	Medium	Dyeing	700
9	Medium	Dyeing	270
10	Medium	Printing	550

As shown in Table I, the sample of firms interviewed is mainly composed of medium firms, with only 1 small and 2 large ones. They are printers and dyers, producing for the Italian and foreign market.

Historically, the textile industry in Como has planned and adopted solutions with a systemic approach for the wastewater, favoring options that would not be a burden for the industrial players [25]. Therefore, a consortium wastewater treatment plant was built to be able to treat specifically the textile firms' wastewater. The consortium is owned by local municipal entities and companies themselves [26]. This allowed the firms to outsource the treatment of their wastewater, exploit scale economies with the treatment and enjoy considerable savings.

This countertrends what happened in most Italian industrial districts, where decisions were taken without specific planning at local level. As a consequence, single firms had to autonomously find a solution for treating their wastewater, e.g. with on-site decentralized plants that resulted very expensive for firms and with potential environmental issues, as noted by previous research [6].

B. Case studies

The companies analysed in this study present very similar characteristics. As emerged from the interviews, they all adopted a partial on-site treatment, performing only a small preliminary treatment on-site. This process usually consists of a lamination tank to offset the peaks of contaminants concentration, and oxygenation. The wastewater is then discharged into the consortium facilities for the final treatment and consequent discharge to water bodies. The process currently in place for the investigated sample is shown in Figure 1.
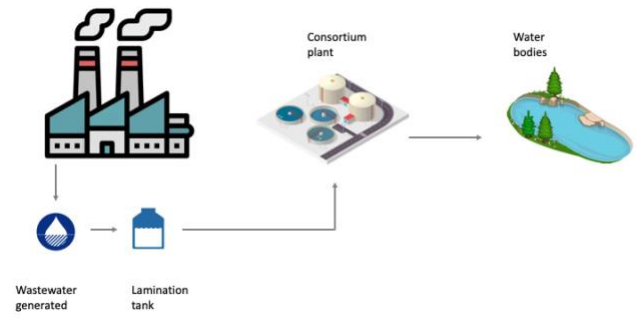

Fig. 1. Description of the wastewater treatment system of textile manufacturing firms in Como, Italy

None of the firms segregates the flow of wastewater, as the volume of wastewater presents homogeneous characteristics and it would not be economically convenient. Only one firm reuses the water after performing a more advanced treatment. Indeed, it emerged from the interviews that the reuse of wastewater does not prove to be economically affordable, since the cost of raw input water is too low to justify the investment. The one firm that does reuse water is driven by image return purposes, as it can claim to be greener than its competitors.

We noted that companies are also largely aligned in terms of the motivations leading them to adopt their specific wastewater configuration. Firstly, interviewees highlighted the complexity of managing an on-site treatment. In most of the cases, companies pointed out a lack of internal resources to be allocated in specifically managing the wastewater facilities. In other cases, even if they may have the internal competences to manage the wastewater process, they prefer to have it implemented through external experts to limit the risk of penalties and fines, so asking a third party to be in charge of the treatment.

Secondly, particular attention was given to economic aspects. In particular, companies highlighted that the initial costs to bear to install and operate a treatment plant are considerable, and most of the times the investment does not seem worth given the relatively small volumes that the firms should handle.

Thirdly, several companies highlighted that differences in production volumes deeply affect the wastewater volumes. Therefore, considering the substantial variations in production volumes incurred over the last years, as also noted by local reports [28], installing and operating an on-site wastewater treatment plant would limit the flexibility required by the market. Finally, many firms pointed out space constraints that do not allow them to have an on-site treatment plant.

Furthermore, the choice for a centralised wastewater treatment plant managed by the consortium was partially influenced by the existence of the plant when companies

started their activities: therefore, for companies it resulted much easier to connect to the consortium facilities rather than developing and operating their own internal wastewater treatment plant.

We have summarised the frequency of the responses to the different categories of factors in Figure 2.
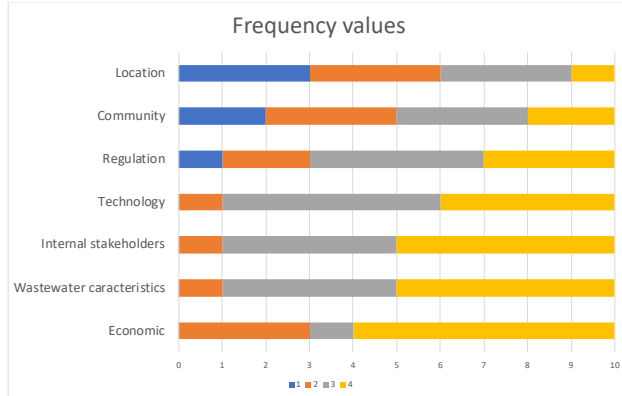

Fig. 2. Values' frequency of the factors identified by the firms

Interestingly, and somehow unexpected, several firms highlighted the primary importance of economic factors when choosing treatment system configurations. Indeed, managers declared to be reluctant in sustaining the investment necessary to install and operate a fully on-site treatment plant. Similar findings are present in [11]. More in detail, a number of interviewees mentioned the personnel cost and the discharge fees as the two most relevant economic factors considered. However, it should be noted that the cost structures vary largely depending on the types of treatment performed and the contaminants present in the wastewater [29].

It is noteworthy that regulation is not among the very first factors considered by firms, as literature suggests [30], [31]. Despite being recognized as an important pressure to adopt wastewater treatment, regulation does not play an important role in the treatment system configuration selection.

Internally, the treatment system configuration seems to depend on image returns enjoyed by firms: as stated by the interviewees, the decisions seem often guided by the market. Therefore, managing an on-site wastewater treatment plant could affect the image of the company in case of environmental issues. This was emphasized in the interviews also by considering the local nature of the textile manufacturing district, with tight connections with the surrounding environment (in terms of proximity to towns, in a high densely populated area, with more than 1,500 inhabitants/km2).

The uncertainty that the entire Como district has been experiencing over the last years (i.e. increasing competition from developing countries, raise speed of product life cycle, radical changes in the end markets) seemed to make the consortium plant an optimal configuration for the interviewed companies, as it avoids the extra complexity of managing the wastewater treatment.

Additionally, the innovativeness of the working environment and the environmental awareness of managers and workers emerged as critical elements to be considered. Further, the factors related to the wastewater characteristics should always be considered, as the treatment system needs at least to be able to handle the volume and the types of contaminant generated by the firm. Finally, firms seemed to be driven by the willingness to avoid extra complexity of non-core activities.

We noted that at present all firms seemed to be well satisfied with the solution of partial on-site treatment, and the costs were perceived as adequate to the firms' needs. The firms mentioned that very few elements could make them change the current configuration. Among these, interviewees pointed out a high increase in the level of contaminants discharged to the consortium, as it would result in a discharge fee increase. In this regard, the role of the policy makers seems to be crucial in facilitating the adoption of innovative technologies at a small scale and with reasonable costs, so that the firms can both improve their environmental performance and be competitive on the market.

V. CONCLUSION

We have conducted an exploratory investigation about industrial wastewater treatment configuration within the textile manufacturing district of Como, Northern Italy, in order to point out major factors driving companies in the adoption of their current configuration. Our preliminary findings seem to show that investigated firms were satisfied with the current wastewater treatment configuration, i.e. a partial on-site treatment coupled with a consortium facility, which has proved to be effective in complying with the environmental regulation currently in place, thus representing a success case.

Firms have pointed out image return as extremely important for their business, and the need to limit the complexity of managing a complete internal on-site treatment. On the contrary, exploiting the synergies of a consortium plant seems to be the best option.

The exploratory nature of our research does not allow to take any strong general conclusion, except from the need to build a comprehensive framework of detailed factors able to best support decision-makers in understanding and assessing the most important elements to be considered when choosing a certain configuration of industrial wastewater treatment. Further research could indeed follow up on the present study and building such framework to be useful both to industrial players, that face the decision of selecting a proper wastewater treatment, as well as to policy makers, that are in charge of tuning regulatory and economic mechanisms so to best promote the most sustainable options for industrial

wastewater treatment. Additionally, an extensive application of such framework in different contexts (e.g., sectorial, or geographical) could allow to interestingly contrast different samples and bring additional insights for local and regional policy-makers purposes.

ACKNOWLEDGMENTS

REFERENCES

[1] WWAP, "Wastewater, the untapped The United Nations World Water Development Report 2017," Paris, 2017.

[2] V. M. Correia, T. Stephenson, and S. J. Judd, "Characterisation of textile wastewaters - a review," *Environ. Technol. (United Kingdom)*, vol. 15, no. 10, pp. 917–929, 1994.

[3] S. Arslan, M. Eyvaz, E. Gürbulak, and E. Yüksel, "A Review of State-of-the-Art Technologies in Dye-Containing Wastewater Treatment – The Textile Industry Case," in *Textile Wastewater Treatment*, 2016.

[4] G. Libralato, A. Volpi Ghirardini, and F. Avezzù, "To centralise or to decentralise: An overview of the most recent trends in wastewater treatment management," *J. Environ. Manage.*, vol. 94, no. 1, pp. 61–68, 2012.

[5] C. Zaharia, "Decentralized wastewater treatment systems: Efficiency and its estimated impact against onsite natural water pollution status. A Romanian case study," *Process Saf. Environ. Prot.*, vol. 108, no. Azapagic 2003, pp. 74–88, 2017.

[6] A. Capodaglio, "Integrated, Decentralized Wastewater Management for Resource Recovery in Rural and Peri-Urban Areas," *Resources*, vol. 6, no. 2. p. 22, 2017.

[7] European IPPC Bureau, "Best Available Techniques. Reference Document for Common waste water and waste gas treatment/management systems in the Chemical Sector," *Integrated Pollution Prevention and Control (IPPC) Bureau*. 2016.

[8] T. Asano *et al.*, *Water Reuse: issues, technologies and applications*. United States of America: McGraw-Hill, 2007.

[9] A. Castillo, P. Vall, M. Garrido-Baserba, J. Comas, and M. Poch, "Selection of industrial (food, drink and milk sector) wastewater treatment technologies: A multi-criteria assessment," *J. Clean. Prod.*, vol. 143, pp. 180–190, 2017.

[10] V. V Ranade and V. M. Bhandari, *Industrial Wastewater Treatment, Recycling, and Reuse: An Overview*. Elsevier Ltd., 2014.

[11] G. Zeng, R. Jiang, G. Huang, M. Xu, and J. Li, "Optimization of wastewater treatment alternative selection by hierarchy grey relational analysis," *J. Environ. Manage.*, vol. 82, no. 2, pp. 250–259, 2007.

[12] S. Lim, D. Park, and J. M. Park, "Environmental and economic feasibility study of a total wastewater treatment network system," *J. Environ. Manage.*, vol. 88, pp. 564–575, 2008.

[13] M. Mahjouri, M. Bakri, A. Torabian, L. Abd, N. Halimoon, and J. Ghoddusi, "Optimal selection of Iron and Steel wastewater treatment technology using

integrated multi-criteria decision-making techniques and fuzzy logic," *Process Saf. Environ. Prot.*, vol. 107, pp. 54–68, 2017.

[14] M. Heller, S. Garlapati, and K. Aithala, "Expert membrane system design and selection for metal finishing waste water treatment," *Expert Syst. Appl.*, vol. 14, no. 3, pp. 341–353, 1998.

[15] H. Zhou, X. Li, G. Xu, and H. Yu, "Overview of strategies for enhanced treatment of municipal/domestic wastewater at low temperature," *Sci. Total Environ.*, vol. 643, pp. 225–237, 2018.

[16] L. M. Dooley, "Case Study Research and Theory Building," *Adv. Dev. Hum. Resour.*, vol. 4, no. 3, pp. 335–354, 2002.

[17] S. Baškarada, "Qualitative Case Study Guidelines," *Qual. Rep.*, vol. 19, no. 40, pp. 1–18, 2014.

[18] M. Q. Patton, *Qualitative evaluation and research methods*, 2nd ed. Newbury Park, California: SAGE, 1990.

[19] B. Dicicco-Bloom and B. F. Crabtree, "The qualitative research interview.," *Med. Educ.*, vol. 40, no. 4, pp. 314–21, Apr. 2006.

[20] C. Voss, N. Tsikriktsis, and M. Frohlich, "Case research in operations management," *Int. J. Oper. & Prod. Manag.*, vol. 22, no. 2, pp. 195–219, Jan. 2002.

[21] R. K. Yin, "Case study research: Design and methods," *Can. J. Action Res.*, vol. 14, no. 1, pp. 69–71, 2009.

[22] J. A. Krosnick and L. R. Fabrigar, "Designing Rating Scales for Effective Measurement in Surveys," John Wiley & Sons, Ltd, 1997, pp. 141–164.

[23] Life Prefer, "Il Distretto Tessile Lombardo," 2018. [Online]. Available: http://www.lifeprefer.it/it-it/Progetto/Prodotti/Tessile.

[24] N. Saccon and A. Soru, "Il tessile abbigliamento in Lombardia," 2009.

[25] G. Bergna, "Sinergie tra gestori e utenti industriali nel servizio idrico: il caso del distretto tessile comasco," 2019.

[26] Lariana Depur SpA, "La società," 2020. [Online]. Available: http://www.lariana.it/la-societagrave.html.

[27] A. Bramanti and A. Martignano, *Il distretto serico comasco - qualità, innovazione, servizio*. Enciclopedia delle Economie Territoriali, 2001.

[28] Camera di Commercio Como, "Osservatorio - Distretto tessile di Como," Como, 2018.

[29] M. Molinos-Senante, F. Hernández-Sancho, and R. Sala-Garrido, "Economic feasibility study for wastewater treatment: A cost-benefit analysis," *Sci. Total Environ.*, vol. 408, no. 20, pp. 4396–4402, 2010.

[30] M. Starkl *et al.*, "Interpreting best available technologies more flexibly: A policy perspective for municipal wastewater management in India and other developing countries," *Environ. Impact Assess. Rev.*, vol. 71, no. October 2017, pp. 132–141, 2018.

[31] P. Garrone, L. Grilli, A. Groppi, and R. Marzano, "Barriers and drivers in the adoption of advanced wastewater treatment technologies: a comparative analysis of Italian utilities," *J. Clean. Prod.*, vol. 171, pp. S69--S78, 2018.