Nature-based solutions for climate change adaptation and water pollution in agricultural regions

Lot 2: TSM in a continental environment

Feasibility Study

Contractor: IRIDRA	***Contracting Entity:*** Joint Research Centre (JRC)
Project Manager: Fabio Masi (IRIDRA)	***Data:*** 23th June 2021
Team: Giulio Conte (IRIDRA) Riccardo Bresciani (IRIDRA) Anacleto Rizzo (IRIDRA) Alessandro de Carli Leonardo Borsacchi (PIN)	***Contracting Entity technical referent:*** Alberto Pistocchi
Contract number: JRC/IPR/2019/OP/0394	***Version:*** n° 14

Contents

List of tables

List of figures

Authors

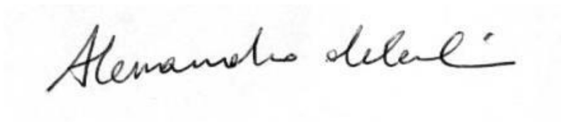
In alphabetical order

Leonardo Borsacchi

Riccardo Bresciani

Giulio Conte

Alessandro de Carli



Fabio Masi

Anacleto Rizzo

EXECUTIVE SUMMARY

The present study analyses how Nature-based solutions (NBS) may contribute to reduce water pollution by treating pollutant loads generated by farm manure (Nitrogen, Phosphorus), also investigating the potential interest in the so-called side-benefits, i.e. the capability of NBS to deliver additional benefits for the local community or for the environment.

The study site

Sasa Snc is a company dedicated to intensive breeding for fattening pigs. The facility is located in San Rocco di Piegara, in the hearth of the Lessinia region, an area characterized by a strong agricultural vocation linked to traditional products such as chestnuts, cherries, strawberries, wine, and honey. Itineraries and nature trails favour the development of tourism with the presence of hotels, restaurants and agritourisms. The historical presence of dairy cattle farms, with meadows and intensely managed pastures, together with pig and chicken farms, beside contributing to the local economies, creates the typical landscape of this hilly region.

The SASA pig farm is located in a quite isolated and barely visible hilly position, about 3 km away from the town and about 600 m from the first house. The facility has a maximum capacity of 7848 animals, but it currently hosts 3145.

The choice to use NBS to treat manure

Until 2013, the farm was equipped with a conventional technological solution for the treatment of the liquid fraction of pig manure, an activated sludge followed by a membrane stage, i.e. analogous to the treatment scheme of a membrane bioreactor (MBR), designed to discharge into surface water according to Italian law. During the renewal of the authorisation to discharge the regional Environmental Authority (ARPAV) requested to change the authorisation terms, requiring more stringent water quality standards to discharge on soil. The increased expected costs, especially in terms of OPEX, to adapt the MBR reactor to the new water quality standards led to the closing of the activity. After a successful pilot test and thanks to local funding (Rural Development plan, PSR as per the Italian terminology), the farm owner decided to install a "Nature Based" treatment system which, thanks to lower operational and maintenance costs, was expected to make the re-opening of the farm financially sustainable. Due to limited available space, the chosen solution was a "hybrid" solution (NB and technological): an aerated constructed wetland (CW) plus a reverse osmosis (RO) final polishing stage. The new system was sized to treat the liquid fraction of the manure produced by half of the farm capability, i.e. 3000 pigs, maintaining the possibility of an upgrade to 6000 pigs just installing a new treatment stage, while the RO and the primary treatment (a centrifuge for solid/liquid separation) was designed for the full capacity of the farm, i.e. 6000 pigs.

The NBS design

Due to the strict Italian water quality standards to discharge on soil, the full-scale CW was designed with a high level of flexibility in terms of possible functioning to enhance the nitrogen removal by denitrification. Indeed, the CW consists of 5 beds, each one of 448 m^2 (total area available 2240 m^2) and can be set up with several different operations (in series or in parallel). The **Forced Bed Aeration** (**FBA^{TM}**) technology was used to design the aerated wetlands. During the monitored period for this study, the system almost always worked with the 5 beds in parallel. The beds were aerated 22 hours per days for most of the monitored period. Although possible by the system design, neither the recirculation nor the addition of endogenous carbon has been used to boost the denitrification. A Supervisory Control And Data Acquisition (SCADA) system remotely controls the NBS, setting several parameters and monitoring energy consumption.

The pollutant removal capacity of the NBS

The removed mass load is given by the difference between the input and output mass load and it is expressed as a percentage. The CW WWTP showed high mass removal efficiencies on average: total suspended solid (TSS) 87%; chemical oxygen demand (COD) 88%; ammonium nitrogen ($N\text{-}NH_4^+$) 90%; Total Kjeldahl Nitrogen (TKN) 87%; total nitrogen (TN) 73%; total phosphorous (TP) 80%.

The costs analysis

A detailed cost analysis was carried out for the current aerated wetland WWTP (AEW - 3000 pigs, 25 m^3/d) and for the previous technological membrane bioreactor (MBR - 6000, 50 m^3/d), to clearly highlight the costs and benefits of the two solutions and the reasons why the owner decided to shift from a technological to a nature-based solution.

To allow a comparison between the different possible treatment solutions (technological and nature Based), a simplified cost analysis was also provided for the possible NB alternatives serving a capacity of 6000 pigs, as the original MBR did:

— upgrade of the existing AEW with an additional AEW stage to reach the full original farm capacity (6000 pigs, 50 m^3/d)

— upgrade of the existing AEW with an additional stripping stage to reach the full original farm capacity (6000 pigs, 50 m^3/d) as well as to recover nitrogen

— a passive CW system for the original farm capacity (6000 pigs, 50 m^3/d)

For the 4 alternatives serving 6000 pigs, two possible scenarios have been envisaged: **Scenario 1**, discharging on soil, i.e., the current situation; **Scenario 2**, outflow discharging into surface water. For the sake of simplicity, tertiary treatment (either technological – RO – or NBS – FWS) have been considered only for Scenario 1, assuming that the secondary treatment would be able to fulfil the requirements to discharge into surface water. A cash flow analysis was developed for all the alternatives to compare them from a cost-benefit perspective.

The results of the cost analysis are summarized in the following tables that show that, under both scenarios, NBS **are highly competitive with conventional solutions from a purely economic point of view. The discounted costs over a 20-year period (quite precautionary for NBS that may last over 30 years) is significantly lower for all the typology of NBS.**

		Soil discharge scenario			
	Unit	**A1 MBR**	**A2 Upgrade AEW**	**A3 Upgrade AEW + stripping**	**A4 Passive NBS**
Investment	€	1,576,000	1,256,000	1,247,000	2,715,200
OPEX	€/yr	383,800	211,100	217,600	88,700
Lifetime	yr	20	20	20	20
Discounted Costs (T= 20 y; i= 5%)	€	6,358,996	3,806,773	3,878,777	3,111,398

		Surface water discharge scenario			
	Unit	**A1 MBR**	**A2 Upgrade AEW**	**A3 Upgrade AEW + stripping**	**A4 Passive NBS**
Investment	€	1,456,000	1,438,200	1,320,800	2,554,200
OPEX	€/yr	319,800	172,600	154,600	87,100
Lifetime	yr	20	20	20	20
Discounted Costs (T= 20 y; i= 5%)	€	5,441.415	3,589,178	3,247,458	3,639,659

The main considerations concerning the costs of the different solutions can be summarized as follows:

1) CWs are generally more convenient than MBRs for this type of effluents
2) Permitting standards play an important role (soil vs surface water)
3) CWs usually entail land costs, so in many practical situations they need "intensification" with appropriate technologies (aeration, stripping) to save space
4) On the other hand, more passive systems have a much lower O&M, so whenever land acquisition is not a problem, they should be considered.

The social analysis

A Social Analysis was carried out between October 2019 and February 2020, interviewing different actors of the local community, with the overall objective of identifying the main issues affecting the social sustainability of the application of NBS in the treatment of manure from the SASA pig livestock. Both the possible drawbacks of the application of the NBS and the side benefits perceived by the local community were analyzed.

The Social analysis clearly shows that no cultural barrier hinders the recourse of NBS but, on the other hand, natural solutions are not perceived by the local community as an added value. Indeed, the economic criterion is the most relevant one for local stakeholders while the interest towards other benefits is limited both in quantitative terms and in local perception. Such weak interest from the local community is due to the fact that the NBS is located just nearby the pig breeding stables in an area not accessible to the general public. However, such condition is very common for CW treating effluents of husbandry activity and food and beverage industry; these conclusions apply to all potentially disturbing activities located far from settlements. In more general terms, NBS usually show a high potential in minimising landscape impacts and nuisance when activities interact with neighbourhood wellness.

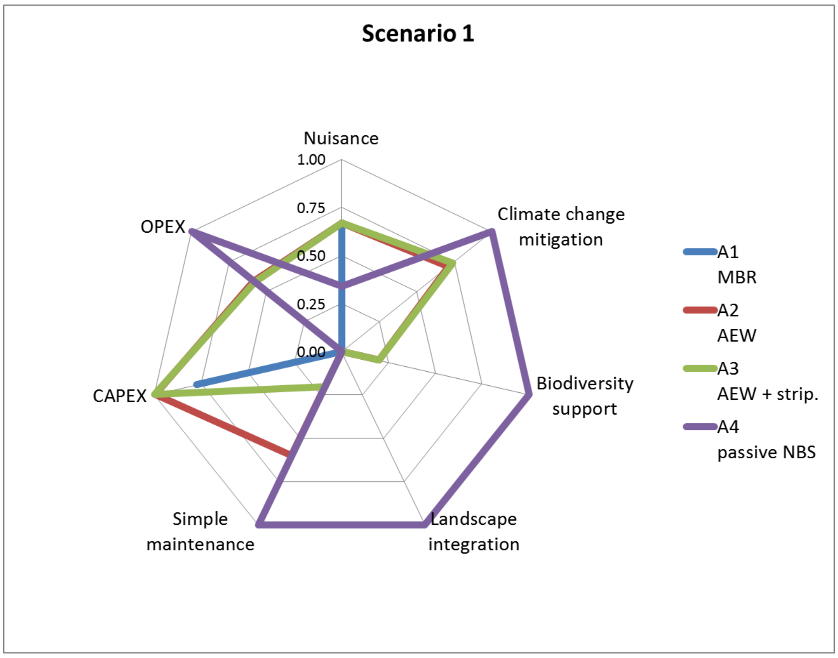
The quantification and evaluation of costs and benefits

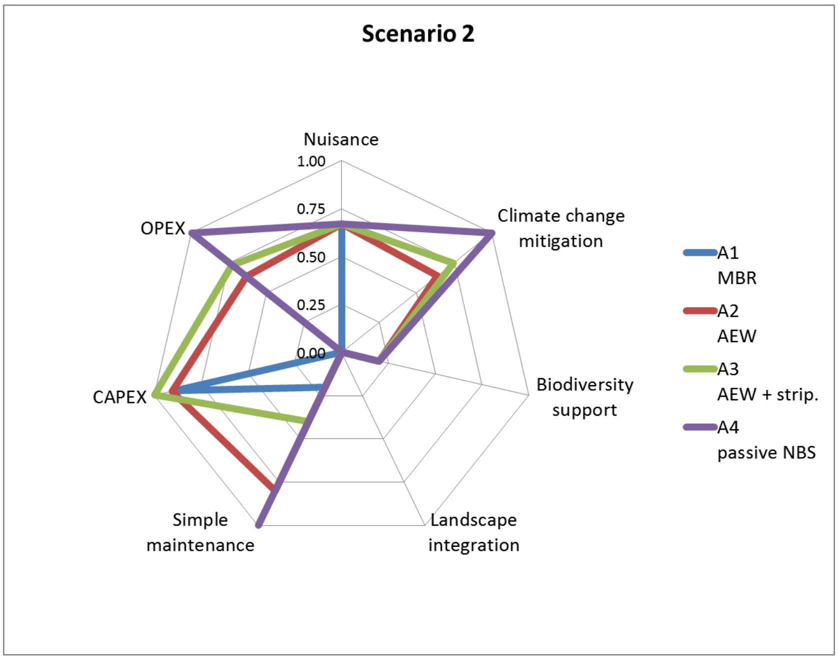
To assess the "side benefits" of the different alternatives and compare them to consider all the possible advantages and disadvantages, a *multicriteria* approach was applied. The criteria selected for the analysis are listed here below: for each criterion a quantification method has been developed. The relative importance of each criterion was assigned by weighting them, considering the results of the social analysis (which shows that the economic/financial aspects are the most relevant, but also that simple system maintenance is highly appreciated)

- Nuisance
- Climate change mitigation
- Biodiversity support
- Landscape integration
- Simple maintenance
- CAPEX
- OPEX

The comparison among the 4 treatment alternatives shows that all NBS are by far preferable to technological solutions, under both scenarios.

	Scenario	A1 MBR	A2 AEW	A3 AEW + strip.	A4 passive NBS
Final rank of the 4 alternatives under the 2 scenarios (S1, S2)	S1 (discharge on soil)	0.29	0.67	0.60	0.66
	S2 (discharge in water)	0.35	0.68	0.67	0.63





Graphical representation of the criteria performances for all the alternatives and the two considered scenarios (1 – discharge on soil; 2 – discharge into surface water).

The simple management – not requiring particular expertise – of NBS and the consequent low O&M costs, are highly appreciated by the pig farm enterprises and is one of the most interesting features of NBS to favour their diffusion.

The comparison of the alternatives for **environmental benefits** as expected show NBS having a better performance than technological solutions for climate change mitigation (with the passive CW, A4, ranking higher than the "hybrid" NBS). The CO_2 absorption capacity of NBS (of lesser importance) and the lower energy consumption (more substantial) give an added value to NBS on technological MBR in terms of sustainability; it must be noted that regarding GHG emissions, the use of stripping (Alternative A4) performs better than simply adopting a NBS since part of the nitrogen load is precipitated as ammonium sulphate instead of being released as gas with the biological nitro-denitro process. The result of such process is the reduction of N_2O emissions (N2O has a global warming potential around 300 times higher than CO_2).

Finally, NBS solutions have a minor advantage in comparison to technological ones in terms of **social benefits**, due to slightly better performance with nuisance, visual impact, and noise mitigation.

Conclusions

The analyzed case study shows that NBS could be a solution for the treatment of swine manure. It must be highlighted that the NBS object of this study it is not a "pure" NBS, but somehow a "hybrid" between an NBS and a technological system. It is, in fact, an "aerated" vertical flow constructed wetland (CW): a natural system equipped to be artificially enriched by forced air ventilation to increase its oxidation capacity. The choice to build an aerated system depends mainly on the unavailability of land, and theoretically if larger areas were available, a "passive" CW could have been built.

The most widespread pig farm manure disposal system in Italy is spreading the manure on the fields as fertilizer. In "nitrate sensitive" areas, the stricter regulation based on the Nitrates Directive requires pig farm enterprises to find larger areas where to spread the manure. Therefore, the best option to minimize manure management costs is to have fields available for spreading manure at a reasonable distance from the pig farm (usually about 5-10 km). If the farm has no available areas on its property, they can rent others' property, and management costs will still be much lower than any other "treatment" alternative.

A pig farm may only be interested in setting up a treatment system when fields to spread the pig manure are not available nearby: in this case the high cost of transporting manure over a long distance makes the solid/liquid separation and the construction of a treatment plant for the liquid fraction interesting for the company.

Even though NBS could be optimal treatment solutions, being less known than other treatment technologies, they would highly benefit from a public financial support, at least for the first 10-15 years, until they get an established position in the market.

Finally, it must also be considered that a legislative framework aimed at promoting the circular economy should somehow encourage treatment solutions that include the production of fertilizers. The fertilising products derived by the treatment (i.e. ammonium sulphate recovered from stripping reactor) should be sustained into the market by ad hoc policies, since currently the market value is too low to justify the risk and the investment by pig farm owners.

1 INTRODUCTION

1.1 Objectives of the feasibility study

The present study analyses how Nature-based solutions (NBS) may contribute to reduce water pollution by treating pollutant loads generated by farm manure (Nitrogen, Phosphorus), investigating also the potential interest in the so-called side-benefits, i.e., the capability of NBS to also provide additional benefits such as biodiversity.

More specifically the present study, along with other similar ones being developed in different areas, will provide evidence to address the following questions:

- How can NBS contribute to mitigate farm water pollution (nutrients)?
- What are the costs and cost drivers of NBS?
- What are the benefits they deploy?
- What are the technical, capacity, governance, management, and financial constraints hampering their take-up?

To answer these questions, an NBS in North Eastern Italy (Veneto Region) was selected, an area where agriculture and animal breeding is practiced at industrial scale, causing relevant water pollution problems (see next paragraph).

The analyzed NBS is described in terms of its design (layout, illustrative design drawings such as cross sections or sketches) in chapter 2 and their effectiveness to remove pollutants generated from manure is analysed in depth, relying on real data monitored (chapter 3).

Investment, operation, and maintenance costs of the examined NBS and potential other alternatives (both green and grey) are provided in chapter 4, together with a cash flow analysis.

To explore the main issues affecting the possible support or opposition to the NBS by the local community, a comprehensive social analysis has been conducted, adopting a robust participatory methodology based on the active involvement of all key stakeholders (chapter 5).

A quantification of the direct and indirect benefits together with possible negative effects (e.g., odours, nuisance to farming practice, etc.) has been done. Benefits and Drawbacks have been estimated for the studied NBS (chapter 6).

Finally (chapter 7), bottlenecks and barriers for the implementation of NBS and possible governance and financial tools to overcome them were identified to delineate a possible "business model" that could be proposed for a broader implementation of NBS for treatment of manure.

1.2 Overview of the proposed case study

The most diffused pig farm manure disposal system in Italy is spreading the manure on the fields as fertilizer. In "nitrate sensitive" areas, the stricter regulation based on the Nitrates Directive requires pig farm enterprises to find larger areas where to spread the manure. Therefore, the best option to minimize manure management costs is to have fields available for spreading manure at a reasonable distance from the pig farm. If the farm has no available areas on its property, they can rent others' property, and management costs will still be much lower than any other "treatment" alternative.

The SASA farm is located in a hilly area, mainly surrounded by woods and with a too small surface of cultivated fields to spread the manure. Only the unavailability of fields where to spread the pig manure brought the SASA pig farm to change manure management system, shifting from spreading on the fields to local treatment. They implemented a solid/liquid separation plant and an activated sludge followed by a membrane stage, i.e. analogous to the treatment scheme of the Membrane Bio Reactor (MBR) for the liquid fraction treatment. Once treated, the liquid fraction could be discharged locally into a small ditch. This solution allowed the enterprise to sharply reduce (to less than $1/20^{th}$) the amount of solid to be brought away to be disposed, reducing consequently the cost of transport.

In 2013, with the renewal of the outflow discharge permit, the regional Environmental Authority (ARPAV) requested to change the authorisation terms, requiring more stringent water quality standards to discharge on soil (in fact, the ditch where the farm discharges the treated effluent was ephemeral). To fulfil the new requirements the treatment system should have been upgraded by installing new membranes and adding a Reverse Osmosis system to remove chlorides, which are passive to biological treatments and are not even removed by the MBR membranes. The increased expected costs, especially in terms of OPEX, to adapt the MBR reactor to the new water quality standards led to the closing of the activity.

After a successful pilot test (Masi et al., 2017) and thanks to local funding (Rural Development plan, PSR as per the Italian terminology), the farm owner decided to install a new NBS WWTP which, thanks to lower operational and maintenance costs, was expected to make the re-opening of the farm financially sustainable. Due to limited available space, the chosen solution was the installation of an aerated constructed wetland (CW) plus a reverse osmosis (RO) final polishing stage. Considering the novelty of the proposed solution, the farm owner decided to have first a testing phase of the new NBS WWTP. The new NBS WWTP was sized to treat the liquid fraction of the manure produced by half of the farm capability, i.e., 3000 pigs, maintaining the possibility of an upgrade to 6000 pigs by just installing a new treatment stage, while the RO and primary treatment was designed for the full capacity of the farm, i.e., 6000 pigs.

Therefore, the case study:

— Verifies the suitability of NBS + RO for such high stringent water quality standards

— Compares the technical and financial sustainability of different NBS solutions in comparison to conventional technological solution for the treatment of swine manure, assuming the following alternatives:

  - use a fully technological solution (MBR)
  - upgrade the current CW WWTP from 3000 to 6000 pigs (i.e. the full capacity of the farm) increasing the wetland area
  - installing a stripping reactor upstream the current wetland beds, adding the option to recover the nutrient excess from manure as potential fertiliser (ammonium sulphates); this approach fits well with a Circular Economy based approach for the management of pig slurry
  - use a larger passive CW to reduce the complexity of the system and the O&M costs

— Investigates the social acceptance of NBS solutions as well potential co-benefits observed in the case study area

2 CHARACTERIZATION of the NBS

2.1 The context

The site of interest is a pig farm in San Rocco di Piegara (Verona – Italy latitude 45°33'41.50"N, longitude 11° 4'24.76"E, Figure 1).

Figure 1. Geographical localization of the proposed NBS case study.

The main climatic characteristics were assumed from the nearest measuring station, i.e. the Grezzana – Station[1], about 7 km from the study site. Mean potential evapotranspiration was estimated with the Thornthwaite method. For more details, see Annex 2.

Table 1: Climatic data characteristic of the San Rocco di Piegara site (Verona – Italy) - Source Grezzana Station

Month	Rainfall (mm)			Mean Potential evapotranspiration (mm)
	2017	2018	2019	
January	14.00	42.00	25.00	5.1
February	73.60	37.20	70.80	9.6
March	19.60	84.60	8.80	29.0
April	87.20	82.80	110.00	54.6
May	42.80	149.20	237.60	95.0
June	42.80	54.60	7.20	132.3
July	39.60	74.40	96.60	154.2
August	12.20	75.20	99.20	138.2
September	99.60	250.80	106.60	84.9
October	32.80	131.20	53.20	49.5
November	77.40	107.60	267.60	20.7
December	56.20	36.80	84.40	6.4

[1] ARAPV. https://www.arpa.veneto.it/bollettini/storico/ (Access March 2020)

2.2 The NBS

The NBS is an "aerated" constructed wetland (CW), integrated with other technical solutions, treating the swine wastewater produced by the pig farm sited in San Rocco di Piegara (Roverè Veronese - VR - Italy) and consists of the following stages: (1) primary treatment for solid fraction separation; (2) aerated CW for swine wastewater treatment; (3) reverse osmosis (RO) for polishing of the effluent and discharge on soil according to the Italian water quality standards for industrial wastewater (COD < 100 mg/l; TSS < 25 mg/l; TN < 15 mg/l; TP < 2 mg/l; chlorides < 200 mg/l). The WWTP is designed to treat the swine wastewater produced by up to 3000 pigs (up to 38 m^3/d).

The treatment plant was designed on the basis of the experience gained from the previous pilot study discussed in Masi et al. (2017), which showed excellent performances in terms of TSS, COD removals and nitrification, but limited denitrification. Due to the strict Italian water quality standards for effluents discharging on soil, the full-scale CW WWTP was designed with a high level of flexibility in terms of possible functioning to enhance the denitrification. Indeed, the CW WWTP is composed of 5 beds, each one of 448 m^2 (total area available 2240 m^2) and can be set up with several different operations. The **Forced Bed Aeration** (**FBA™**) technology was used to design the aerated wetlands[2]. During the monitored period for this study, the system almost always worked with the 5 beds in parallel. The beds were aerated 22 hours per day for most of the monitored period. Although possible for a flexible functioning of the system, neither the recirculation nor the addition of exogenous carbon has been used to boost the denitrification. A SCADA system remotely controls the NBS, setting several parameters and monitoring energy consumption. Plan layout and flow diagram of the WWTP are pictured in **Figure 4** and **Figure 5**, respectively. The polishing pond (Stagno di finissaggio) shown in **Figure 4** was included in the original design but then it proved not functional to the treatment and presently it is used as temporary stormwater detention pond.

Figure 2. View of the realized NBS (spring left, winter right)

Figure 3. View of technological components of the SASA WWTP: primary treatment (centrifuge, left); polishing step (reverse osmosis – RO, centre); remote control (SCADA, right)

[2] http://www.iridra.eu/en/fitodepurazione-en/fitodepurazione-21/fitodepurazione-aerati-en.html

Figure 4. Planimetry of the aerated CW treatment plant of SASA Srl.

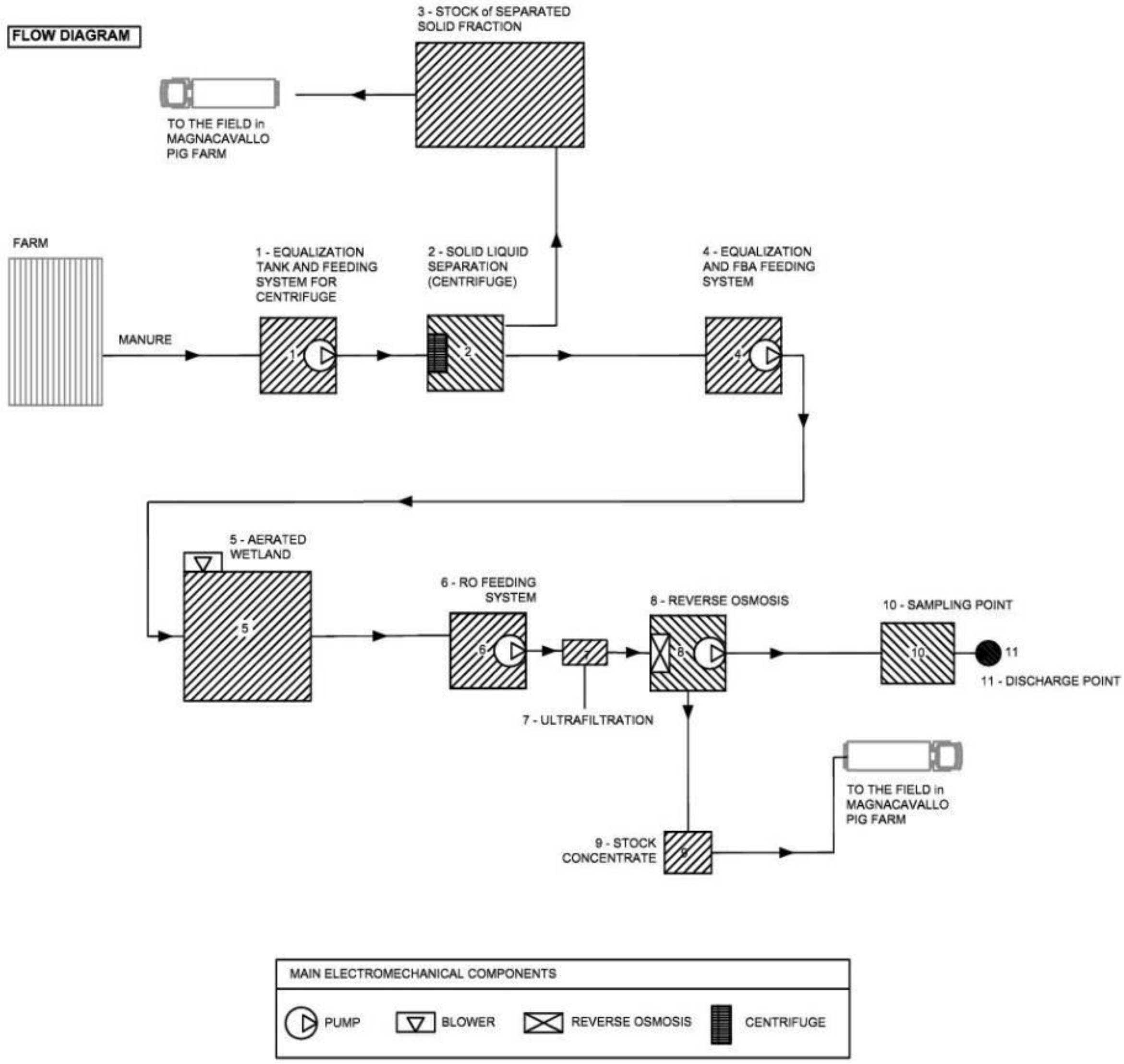


Figure 5. Flow diagram of the WWTP of Sasa Srl

2.2.1 The case history and why the case is of general interest

The Italian law for environmental protection is the Legislative Decree 152/2006, which transposes the Nitrates Directive (91/676/CE) and the Water Framework directive (2000/60/CE). The Nitrates Directive sets the limits for nitrogen load that can be spread on land as follows:

- 170 kgN/ha/y for areas sensitive to nitrate pollution
- 340 kgN/ha/y for areas not sensitive to nitrate pollution

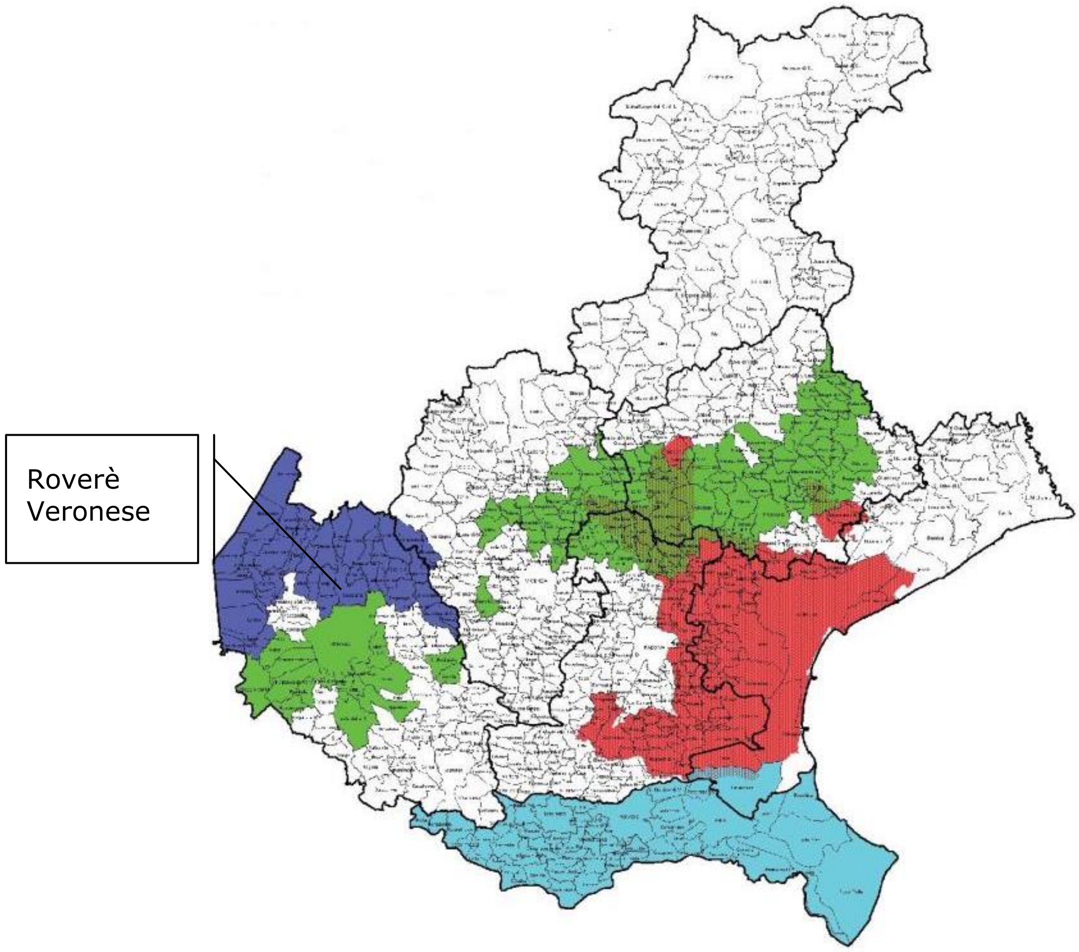


Figure 6. Map of the areas defined as vulnerable to nitrates for the Veneto Region (www.regione.veneto.it – Access 17/04/2020). Hatched areas are nitrate vulnerable zones.

Since Roverè Veronese is located, according to the National and Regional law (**Figure 6**) in an area sensitive to nitrate pollution, the possibility of spreading the manure generated by the SASA farm on land is limited. Therefore, the SASA farm needs to locally treat the pig manure and discharge the treated effluent (swine wastewater) according to Italian legislation, for which swine manure is catalogued as **industrial wastewater** which can be discharged:

— into surface water, respecting the water quality target defined by Table 3 of the Annex 5 of the part 3 of the d.lgs. 152/2006

— On soil, respecting the water quality target defined by Table 4 of the Annex 5 of the part 3 of the d.lgs. 152/2006

The emission standards are reported in Annex 3. The following table summarizes the most challenging parameters to be guaranteed in the treatment of swine wastewater and in the passage from water to soil discharge, according to Italian legislation

	Discharges into Surface water **Table 3, Annex 5 to part 3 of d.lgs 152/2006**	**Discharges on soil** **Table 4, Annex 5 to part 3 of d.lgs 152/2006**
COD	≤160	≤100
BOD5	≤40	≤20
Chlorine	≤1200	≤200
Total Phosphorus	≤10	≤2
Ammoniacal Nitrogen (NH_4^+)	≤15	N/A
Nitrous oxide (as N)	≤0.6	N/A
Nitrite (as N)	≤20	N/A
Total Nitrogen	≤ 35.6*	≤15

* Not fixed by the legislation but included in the table for comparison with discharge limits for discharge on soil, summing the limits of all the nitrogen forms set for discharge into surface water.

Originally, the SASA wastewater treatment plant (WWTP) was authorised to discharge treated industrial wastewater in water bodies, which allowed the possibility of meeting less stringent water quality standards. Subsequently, the local Environmental authority (ARPAV) registered that the small stream nearby the SASA farm does not have a sufficiently continuous water flow to be defined as a "water body" according to Italian law (discharge into surface water). Therefore, the discharge authorisation was changed in "discharge on soil" with the necessity of meeting more stringent water quality standards.

The CW is designed for the strictest Italian effluent water quality standards. Therefore, the NBS case study is representative of different possible cases:

1. The case of a pig farm spreading its manure on the soil, to reduce the nitrogen load and consequently the area needed for manure spreading; in this case the NBS only allows a sufficient load reduction without technological RO
2. The case of a pig farm that cannot spread its manure and therefore must discharge its effluent into surface water or on the soil; in this case NBS alone does not allow to reach the very stringent targets and a final technological treatment with RO is needed

The target manure of the NBS case study, i.e., both **separated liquid source and slurry pig manure**, is estimated with a European production of about 150 million tonnes per year, accounting for the 11% of European manure production, i.e., the second manure source after cattle (and greater than poultry), according to Foged et al. (2011). Therefore, the NBS is generalizable for a fundamental source of N to be managed at European level, especially considering that most manure producers are located in nitrate sensitive areas in Europe (**Figure 7**).

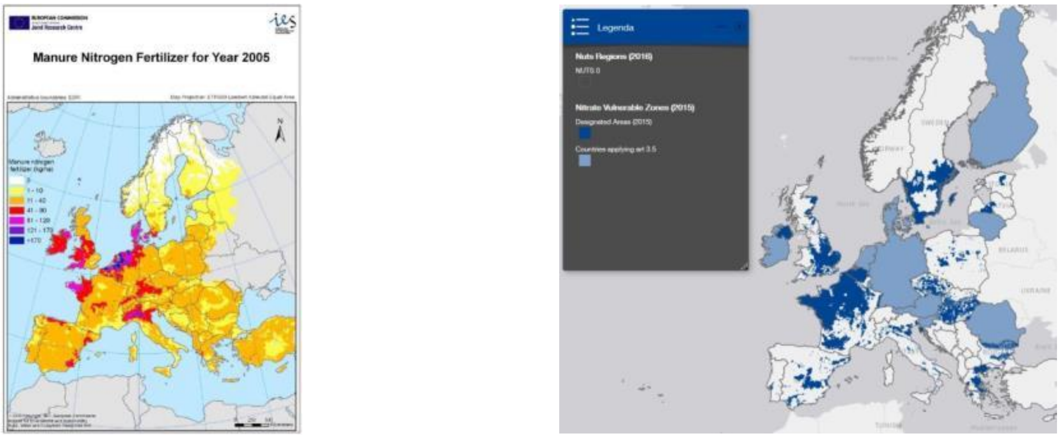


Figure 7. European manure application (left – Bouraoui et al., 2011) and sensitive areas (right - https://water.jrc.ec.europa.eu)

The NBS case study uses an **innovative intensified Constructed Wetland**, reducing the areal footprint by 5-10 times in comparison to conventional solutions (Wu et al., 2014), making the proposed NBS easier to be applied if compared with passive CWs.

3 MATERIAL FLOW ANALYSIS

3.1 Source of data and assumptions

The material flow analysis is based on **monitored data** gathered during two sampling campaigns, one at the start-up of the WWTP (from 10 October 2017 to 8 February 2018 - Rizzo et al., 2018) and a second after 1 year of functioning (from January 2019 to January 2020)[3]. The used data regard:

— wastewater quantity: monitored influent flow rate

— wastewater quality: influent and effluent water quality samples from the CW, as well as effluent samples from the RO outlet, regarding the following parameters

- Total suspended solid (TSS)
- Chemical oxygen demand (COD)
- Ammonium nitrogen ($N\text{-}NH_4^+$)
- Nitrate nitrogen ($N\text{-}NO_3^-$)
- Total nitrogen (TN)
- Total phosphorous (TP)
- Chlorides (Cl^-)

The material flow analysis is also complemented by **literature data** in terms of effluent wastewater quantity estimation, which will be assessed on the basis of both methods for evapotranspiration proposed by literature (Kadlec and Wallace, 2009) and flow meter available at RO treatment. Literature data are also used to test the proper functioning of NBS in terms of oxygen transfer rate (Nivala et al., 2013).

The **NBS effectiveness in terms of pollution removal** is linked to dimensional parameters with a statistical analysis of the dataset, e.g., mean plus st. deviation of nutrient areal removal rates (removed gN per m^2 of NBS per day).

All the data and the analysis of this chapter regard the CW WWTP currently installed, i.e., treating the manure generated by up to 3000 pigs. Performance of other alternatives is estimated on the basis of these data and of emission standards, as described in section 6.4.2.

Data described in this chapter was used to elaborate the mass balance flow diagram, which is reported at the end the chapter.

3.2 Mass flow diagram

The mass flow diagram for the SASA WWTP is visible in **Figure 8**. All the details related to the calculation used in **Figure 8** are discussed in the next sections of this chapter.

[3] The second sampling campaign (from January 2019 to January 2020) is the additional one integrated during the case study period, in agreement to what was proposed in the Technical offer.

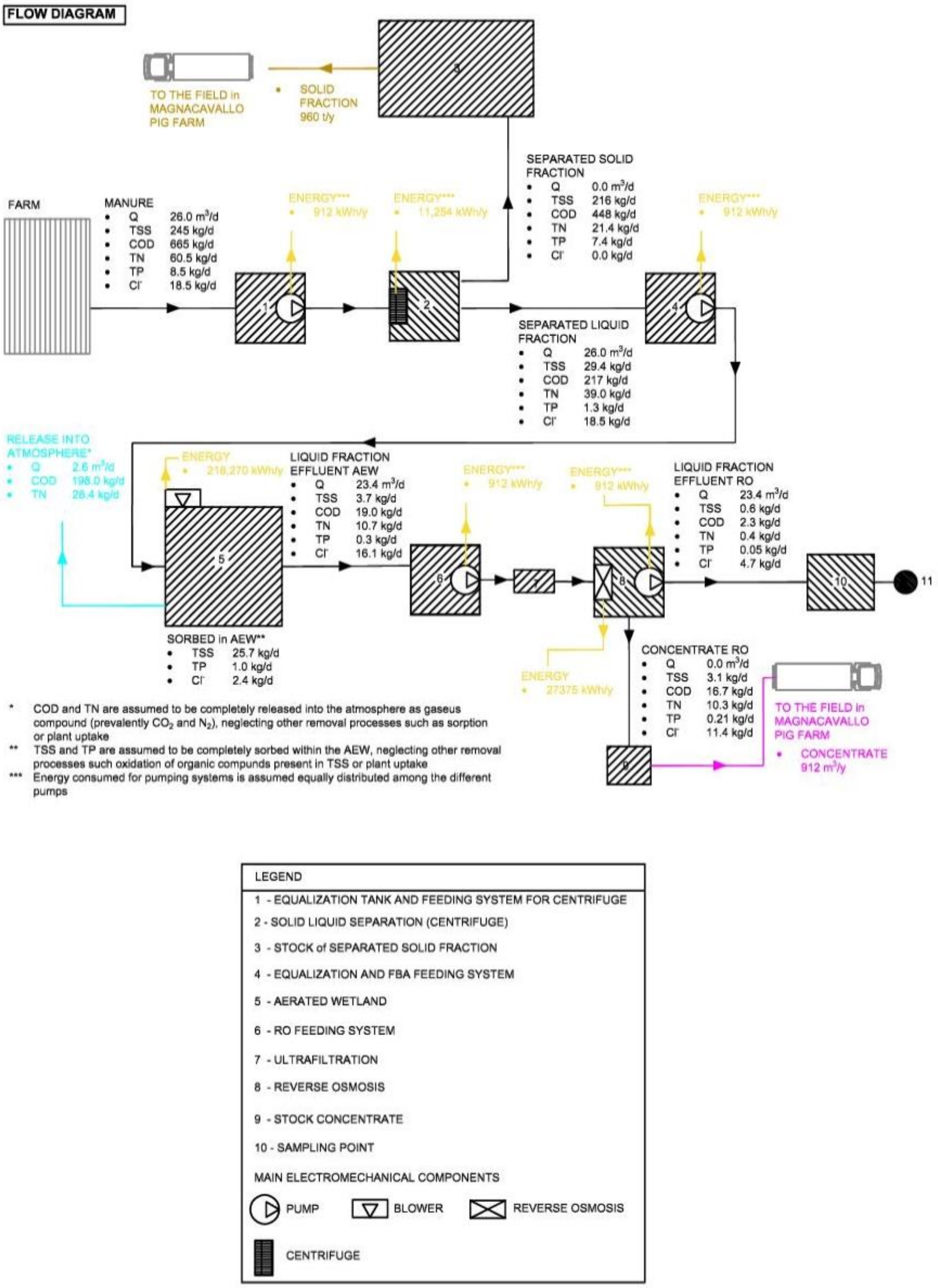


Figure 8. Mass flow diagram of the SASA WWTP

3.3 Pollution material flow analysis

3.3.1 Pig manure characterization

The chemical composition of the pig manure to be treated is indicated in **Table 2**, elaborated from the samples taken in the period between 24 March 2017 and 9 May 2017. Despite the few samples, the data clearly show very high concentrations in terms of solid, carbon, and nitrogen content. This is particularly relevant if compared with the emission standards to be met, also shown in **Table 2**, which are up to three orders of magnitude lower than the concentration of pig manure to be treated.

Table 2. Statistical analysis of pig manure to be treated by the CW WWTP.

		TSS	COD	BOD_5	N-NH_4^+	TKN	TP	pH	ST	Cond.
		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l		g/l	µS/cm
Discharge into surface water		80	160	40	15		10	5.5-9.5		
Discharge on soil		25	100	20			2			
Pig Manure	**24-mar-17**	8900	23100	12800	1880	1743	200	7.4		
	14-apr-17	6900	24600		2600	2893	548	7.5	21.0	15500
	30-may-17	12600	29100	16000	2660	2344	249	7.7	21.4	15590
	mean	**9467**	**25600**	**14400**	**2380**	**2327**	**332**	**7.53**	**21.2**	**15545**

3.3.2 Aerated wetland treatment performance

The statistical analysis of the monitored water quality parameters is presented in **Table 3** and **Figure 9**. The primary treatment (membrane plus centrifuge) is able to satisfactorily provide a swine wastewater influent to the aerated beds with low TSS concentrations (>85% removal). The CW WWTP has shown high mean removal efficiencies (see **Table 2**): TSS 86%; COD 90.3%; N-NH_4^+ 88.8%; TKN 85.5%; TN between 69.4% (based on calculation of average TKN plus average oxidized nitrogen) and 69.5% (measured data); TP 77.2%. <u>The percentage of pollutant removal is based only on the concentrations of pollutants recorded at the inlet and outlet of the aerated wetland system.</u>

Table 3. Statistical analysis of pollutants concentrations of treated swine wastewater in and out of the aerated CW WWTP, compared with limits to discharge on soil according to Italian law 152/2006. Data collected from the 10th of October 2017 to the 24th of January 2020, during which the WWTP had a parallel functioning of the 5 aerated CW beds.

		TSS	COD	N-NH_4^+	TKN	N-NO_3^-	N-NO_2^-	TN	TP	Cl^-
		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Discharge into surface water		80	160	15		20	0.6	35.6*	10	1200
Discharge on soil		25	100					15	2	200
IN aerated CW	**mean**	1131	8355	1936	1787	2.3	0.03	1502	49	713
	std	1532	3278	502	567	2.99	0	402	2	58
	min	110	4000	1400	1100	0.1	0.03	1101	47	647
	max	4700	14000	2800	2800	5.7	0.03	1906	50	757
	80° p	1404	11800	2380	2300	3.86	0.03	1743	50	749
	n°	8	12	12	12	3	3	3	3	3
ae ra te	**mean**	158	814	217	258	176	112	458	11	688

	TSS	COD	N-NH_4^+	TKN	N-NO_3^-	N-NO_2^-	TN	TP	Cl^-
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Discharge into surface water	80	160	15		20	0.6	35.6*	10	1200
Discharge on soil	25	100					15	2	200
std	292	679	140	178	157	153	177	2	81
min	16	228	38	94	15	1	256	8	596
max	1220	3400	562	842	700	610	810	13	803
80° p	140	900	291	298	238	196	596	13	766
n°	16	21	19	19	20	19	19	8	8

* Sum of N-NH_4^+, N-NO_2^-, N-NO_3^-

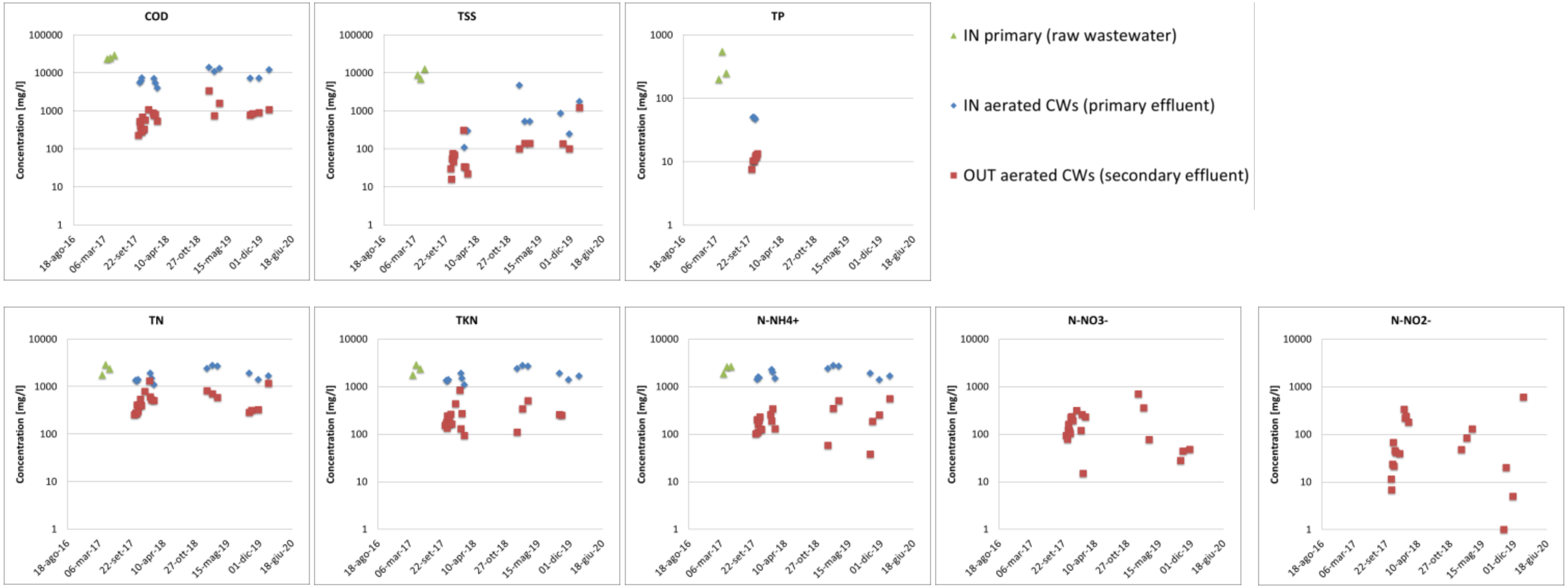


Figure 9: Inlet and outlet concentration in the monitored pollutants: influent to the centrifuge, i.e., the primary treatment for solid-liquid separation (green triangles); effluent from the centrifuge and influent to the aerated CW, i.e., the secondary treatment for the liquid fraction (blue diamonds); effluent from the aerated CW (red squares). Note that y-axis is in logarithmic scale

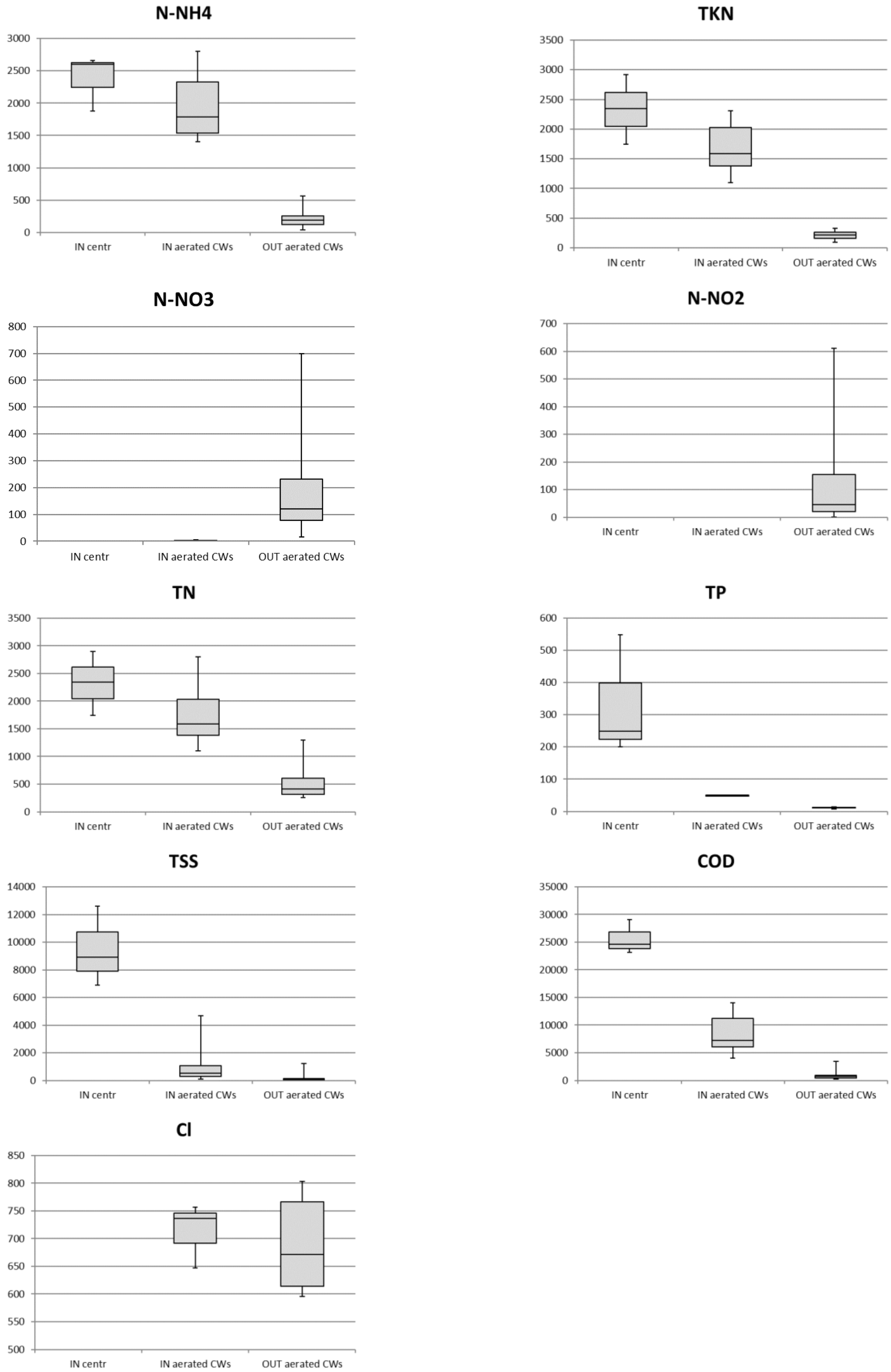


Figure 10. Box and whisker plots of the inlet and outlet concentration in the monitored pollutants: influent to the centrifuge, i.e., the primary treatment for solid-liquid separation; effluent from the centrifuge and influent to the aerated CW, i.e., the secondary treatment for the liquid fraction; effluent from the aerated CW.

3.3.3 Aerated wetland mass load removal

The annual hydraulic and mass balances are carried out for the years 2017, 2018 and 2019; considering the total CW WWTP area of 2240 m^2.

The inlet flow rate has been registered by the SCADA system and varied from 24 to 35 m^3/d in the monitored period (**Figure 11**). Since the WWTP misses a flow rate measurement at the outflow, a simplified yearly hydraulic mass balance was calculated to estimate ET losses and effluent treated wastewater volume. To this end, the inflow flow rate was assumed equal to the average value during the monitored period, i.e., 26 m^3/d. The precipitation value in **Table 4** is obtained as the average annual rainfall recorded by the Grezzana station n°128 for the years 2017, 2018 and 2019 (see section 2.1 and annexes). It is converted into an inlet flow multiplied by the total area of CW WWTP, equal to 2240 m^2. The average potential evapotranspiration value, for the years 2017, 2018 and 2019, is calculated with the Thornthwaite formula, based on the climatic values recorded by the Grezzana station (see section 2.1 and annexes), i.e. the nearest weather station with public data available (ARPAV). The estimated actual ET of the CW beds have been calculated multiplying the potential ET by the average crop coefficient, assumed for CW equal to 1.66 according to literature values (Kadlec and Wallace, 2009) (**Table 4**). Infiltration is zero, since the aerated wetland beds are completely waterproofed. The hydraulic balance was based on a simplified approach: inflow from primary effluent and precipitation; effluent calculated as a balance between inflow and evapotranspiration losses (calculated with the Thornthwaite method). The results of the hydraulic balance are shown in **Table 4**.

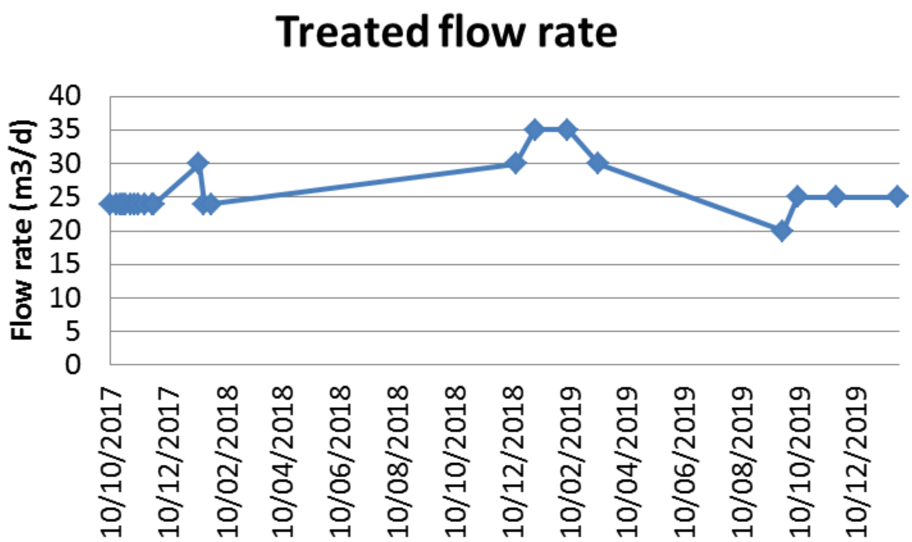


Figure 11. Treated flow rate at the SASA CW WWTP during the monitored period

Table 4: Hydraulic balance for the CW WWTP. The reported values are yearly mean average values for the years 2017, 2018 and 2019

P	ET	Manure in (estimated)	Q in (Measured)	Q out (Estimated)
m^3/d	m^3/d	m^3/d	m^3/d	m^3/d
5.9	8.6	28.5	26.0	23.4

Mass balance is performed for the following pollutants: TSS, COD, $N\text{-}NH_4^+$, TKN, TN, and TP, considering the average pollutants concentration of both monitoring campaigns, and are summarized in **Table 5** . The removed mass load is given by the difference between the input and output mass load and it is expressed as a percentage. The mass load removed per unit area is also calculated for the AEW, in order to compare the obtained values with those reported in literature. The CW WWTP showed high mean mass removal efficiencies (**Table 5**): TSS 87%; COD 88%; N-NH_4^+ 90%; TKN 87%; TN 73%; TP 80%. Moreover, it must be noted that the combined removal efficiency of the centrifuge plus the AEW is significantly high: TSS 98.5%; COD 97.1%; N-NH_4^+ 91.8%; TKN 90%; TN 82.3%; TP 97%. Although the additional removal efficiency of RO is low compared to previous stages (overall efficiency of centrifuge + AEW + RO: TSS 99.8%; COD 99.6%; TN 99.4%; TP 99.5%), RO is fundamental to fulfil the requirements of the effluent emission standards, especially in terms of TN and chlorides.

Table 5. Pollutant mass balance for the CW WWTP system

	Unit	TSS	COD	NH4	TKN	TN	TP	Cl^-
Concentrations								
C IN Centrifuge	mg/L	9467	25600	2380	2327	2327	332	
C IN AEW	mg/L	1131	8355	1936	1787	1502	49	713
C OUT AEW	mg/L	158	814	217	258	458	11	688
C OUT RO	mg/L	25	100			15	2	200
Masses								
M IN Centrifuge	kg/d	246.1	665.6	61.9	60.5	60.5	8.6	
M IN AEW	kg/d	29.4	217.2	50.3	46.5	39.1	1.3	18.5
M OUT AEW	kg/d	3.7	19.0	5.1	6.0	10.7	0.3	16.1
M OUT RO	kg/d	0.6	2.3			0.4	0.05	4.7
Relative mass removal efficiencies								
Mass Removal Centrifuge Percentage	%	88.1%	67.4%	18.7%	23.2%	35.4%	85.3%	
Mass Removal AEW Percentage	%	87.5%	91.2%	89.9%	87.0%	72.6%	79.8%	13.3%
Mass Removal RO Percentage	%	84.2%	87.7%			96.7%	81.8%	70.9%
Absolute mass removal efficiencies								
Mass Removal Centrifuge + AEW Percentage	%	98.5%	97.1%	91.8%	90.0%	82.3%	97.0%	13.3%
Mass Removal Centrifuge + AEW + RO Percentage	%	99.8%	99.6%			99.4%	99.5%	74.8%
Areal mass removal								
Areal Mass Removal AEW	g/m^2d	11.48	88.49	20.21	18.05	12.66	0.45	1.10

3.3.4 Literature verification of the aerated wetland mass balances

On the basis of COD and N-NH_4^+ removal, the average oxygen transfer rate (OTR) is 179 $gO_2/m^2/d$. According to Nivala et al. (2013) literature review, this OTR is higher than passive vertical flow systems (5.7-92 $gO_2/m^2/d$ – full scale) and in line with intensified aerated systems (40-1000 $gO_2/m^2/d$ – full scale). However, the ranges reported by Nivala et al. (2013) mostly refer to BOD. The aerated CW receives wastewater effluent from a strong solid-liquid separation (centrifuge), therefore the BOD/COD ratio can be expected near to 1.

On average, the aerated CW was subjected to an organic loading rate of 97±38 $g_{COD}/d/m^2$, showing an average areal removal rate of 88 $g_{COD}/d/m^2$. This result is almost the double in comparison to the aerated CW pilot plant described in Masi et al. (2017) (average value of 29 $g_{COD}/d/m^2$), and in agreement with the best results shown so far in literature by the aerated pilot plant discussed by Zhang et al., (2016) (49±52 $g_{COD}/d/m^2$). The better performance on areal organic loading rate here observed can be attributed to a higher influent COD concentration (8,355±3,278 mg_{COD}/l) compared to the COD concentration influent to the aerated stage of the pilot plant of Masi et al. (2017) (1,013±456 mg_{COD}/l). This is also in accordance with the higher performance of Zhang et al. (2016), where the aerated pilot plants also received high influent COD concentration (6,644±3,517 mg_{COD}/l), i.e., in line with those observed by the aerated CW WWTP of San Rocco di Piegara, therefore confirming the direct relation between the COD removal rate and the concentration value in the influent.

Regarding the nitrogen load, the aerated CW WWTP was loaded with an average areal nitrogen loading rate of 17±5 $g_N/d/m^2$, showing a mean TN areal removal rate of 12 $g_N/d/m^2$. The observed TN areal removal rate is high in comparison to the previous and anyway quite different experiences reported in literature regarding CW for swine wastewater treatment: the hybrid CW proposed by Meers et al. (2008) as tertiary polishing stage for activated sludge treatment plant removed on average 0.89 $g_N/d/m^2$, with peak values in the range of 5-10 $g_N/d/m^2$; median TN areal removal rate for the hybrid CW plant exposed by Borin et al. (2013) was 17.5 $g_N/d/m^2$; the hybrid CW treatment plant reported by Zhang et al. (2016) removed on average 6±4 $g_N/d/m^2$. Therefore, the proposed aerated CW WWTP is able to provide high TN removal in line with literature with minimum area occupancy, thanks to forced aeration. Due to the observed TN removal efficiency of 73% (relative mass removal efficiency of AEW - **Table 5**), the proposed treatment plant could allow to reduce by more than a half the amount of land required for spreading the swine wastewater, in accordance with European Nitrates Directive, with a significant reduction of operational and maintenance costs. However, the water quality standards for discharging on soil according to Italian legislation are far from being met (COD 100 mg/l, TN 15 mg/l). Therefore, due to lack of available areas for a tertiary NBS (hilly area) the SASA WWTP requires a technological tertiary reverse osmosis (RO) not only for chlorides but also for other conventional pollutants. This is clear by analyzing the results reported in **Table 5**. The AEW was able to provide a significant denitrification thanks to the intermittent aeration (22 hours aeration, 2 hours stop per day), with a relative mass removal efficiency of 73%[4]. However, the effluent concentrations remain far from the discharge values (mean value of 458 mg/l in comparison to 15 mg/l required for discharge on soil – see section 2.2.1). Similar considerations can be done for COD. Despite a relative mass removal efficiency of 91%, the effluent COD concentrations from the AEW are still significantly higher in comparison to the discharge values (mean value 814 mg/l in comparison to 100 mg/l required for discharge on soil – see section 2.2.1).

3.3.5 Reverse osmosis performance

Despite very high removal efficiencies, the use of NBS alone with such low availability of space does not permit to be in line with the water quality targets, neither into surface water nor on soil (**Table 3**). The results suggest that a polishing tertiary stage is needed to meet these standards. A rough estimation of needed area for passive NBS tertiary stage can be done on the basis of the experience reported by Meers et al. (2008), which regards a full-scale passive constructed wetland used for tertiary treatment after a nitro-denitro activated sludge reactor treating pig manure in Belgium[5]. Meers et al. (2008) report effluent concentrations in line with Italian legal discharge criteria (Belgium standards: COD 125 mg/l, TN 15 mg/l, and TP 2 mg/l), highlighting the feasibility of pure NBS solution for tertiary treatment of swine wastewater[6]. However, Meers et al. (2008) also report an average areal removal rate of 0.89 $g_N/d/m^2$, which

[4] In case the total relative TN removal of the AEW is assumed due to denitrification. Indeed, 10-15% of the removal efficiency could be due to plant uptake in vegetative seasons.

[5] Note that the use of areal removal rate monitored at the SASA WWTP for AEW bed is not recommended for a preliminary sizing of a tertiary stage. Apart from the switch between intensified and conventional passive CW, biological areal treatment performance of secondary stage is expected higher than the tertiary one. Indeed, biological processes are boosted at high influent concentrations, while lower concentration values faced by tertiary stages become more proximal to *background concentration*, leading to a decrease in CW treatment performance. Usually expressed with the term C^*, the background concentration represents the value below which a wetland is not able anymore to improve the removal efficiency. Background concentration depends on the pollutant type and can be due to several reasons (Kadlec and Wallace, 2009): (i) portion of incoming chemical resistant to storage or conversion in CW (e.g., recalcitrant COD fraction); (ii) association of the chemical with particulates released as TSS by the CW; (iii) input generated by the CW natural system itself (e.g., COD from root exudates or root decomposition). For instance, Kadlec and Wallace (2009) suggest values of BOD5 background concentration for FWS up to 20 mg/l, i.e., exactly the emission standard set by the Italian legislation to discharge on soil.

[6] The suitability of passive NBS to be a tertiary stage for SASA WWTP should be verified in terms of chlorides, since the chlorides sorption capacity of CW is very limited (Kadlec and Wallace, 2009) and Meers et al. (2008) do not report effluent chloride concentrations from the full-scale CW in Belgium.

is significantly lower than values observed for AEW beds of SASA WWTP. Assuming the treatment performance of Meers et al. (2008) for a rough estimation, a fully passive NBS tertiary treatment stage for the SASA WWTP would need an area of about 12000 mq, i.e., 5 times greater than the AEW secondary stage and not compatible with the local landscape constraints (unavailability of the area owned by the pig farm owner). Therefore, a RO polishing stage was installed in the SASA WWTP to fulfil the discharge standards (especially in terms of chlorides, but also for other pollutants such as COD, TN, TSS, and TP). An example of the concentrations effluent from the RO stage is given in the following table, which highlights the fulfilment of all the parameters for discharge on soil according to Italian legislation.

Table 6. Effluent concentration from the WWTP of SASA, i.e., effluent from the RO stage

		05/04/2018	
		OUT RO treated wastewater	**Limit for discharge on soil**
COD	mg/l	<25	100
TN	mg/l	12.4	15
pH		6	6-8
Coarse material (> 1 cm)		absent	absent
TSS	mg/l	<5	25
BOD_5	mg/l	<5	20
Cu	mg/l	<0.01	0.1
Zn	mg/l	<0.05	0.5
Cl_2	mg/l		0.2
SO_4^{--}	mg/l	<1	500
Cl^-	mg/l	5.58	200
TP	mg/l	<0.5	2
S.A.R.			10
E. coli	ufc/100 ml	0	5000
Toxicity test: Daphnia	mortality in %	3.33	50

3.4 Material flow analysis of other components of interest

The following components have been quantified on the basis of real data from the functioning of SASA WWTP in 2019, i.e., for the current NBS WWTP (3000 pigs):

- Energy consumption
- Weight of separated solid fraction
- Volume of RO concentrate

The energy consumption was estimated in detail for the different electromechanical components, on the basis of the SCADA remote control records for 2019 and they are summarised in **Table 7**. The total energy consumption was **260,549.17 kWh/year**, with predominant energy consumption due to the forced aeration of wetland beds, as expected.

Table 7. Detailed energy consumption for the SASA CW WWTP in 2019

	Energy consumption in 2019 [kWh/year]
Centrifuge	11,254.17
Aeration of constructed wetland (CW)	218,270.00
Pumping system	3,650.00
Reverse osmosis (RO)	27,375.00
Total	**260,549.17**

Both the weight of the separated solid fraction (from the centrifuge) and the volume of disposed concentrate (from the RO) were estimated on an annual basis from the observed production in 2019. As a result, it was calculated that both concentrate and solid fraction are about 10% of the initial manure volume, therefore, we estimate a total mass flow of **960 t/y** of separated solid fraction (density 1.05 t/m^3) and **912 m^3/y** of concentrate. Both the separated solid fraction and the concentrate are transported to the Magnacavallo pig farm, also owned by the SASA company and about 80 km far from the San Rocco farm. The concentrate and the separated solid fraction are then mixed with manure produced at the Magnacavallo pig farm and the mixture is then spread on land[7].

[7] Land spreading authorization at the Magnavallo farm includes the residues from both the Magnacavallo farm itself and the SASA farm.

4 COST ANALYSIS

A detailed cost analysis was carried out for the current aerated wetland WWTP (AEW - 3000 pigs, 25 m^3/d) and for the previous technological membrane bioreactor (MBR - 6000, 50 m^3/d), to clearly highlight the costs and benefits of the two solutions and the reasons why the owner decided to shift from a technological to a nature-based solution.

Additionally, a simplified cost analysis was also provided for the other alternatives, i.e.:

— upgrade of the existing AEW with an additional AEW stage to reach the full original farm capacity (6000 pigs, 50 m^3/d)

— upgrade of the existing AEW with an additional stripping stage to reach the full original farm capacity (6000 pigs, 50 m^3/d) as well as to recover nitrogen

— a passive CW system for the original farm capacity (6000 pigs, 50 m^3/d)

A cash flow analysis was carried out for all the alternatives to compare them from a cost-benefit perspective.

4.1 Detailed cost analysis

4.1.1 Source of data and assumptions

Detailed costs were estimated for the WWTP installed by SASA up to 2010, when it closed after the change of the authorisation (see section 2). The WWTP was a full technological solution using, as main treatment stage, a membrane bioreactor (MBR). The investment and operational and maintenance costs have been reconstructed based on an interview with the SASA farm owner and an expert-based cost actualisation to 2019.

Detailed costs were also calculated for the current WWTP of the SASA farm, described in section 2. It is composed of a NBS main treatment stage, i.e., aerated CW, and technological primary (centrifuge) and polishing (reverse osmosis – RO) stages. The investment costs have been estimated by reverse engineering of the detailed design done in 2016 with the latest price list of the Veneto Region while the operational and maintenance costs have been estimated according to data on labour time provided by the farm owner and on labour units costs provided by the Veneto Region statistics[8].

4.1.2 Investment costs

The investment costs estimation was based on a simplified analysis, which has considered only the following expenditure items in the **financial framework**:

— 1: Working cost

— 2: Technical design services and Building site supervision and Safety management (abbreviated in Italian with the acronym DDLL).

The working cost was calculated defining a bill of quantity for the following items:

— 1: Working cost[9]

- 1.1 Civil Works;
- 1.2: Tank waterproofing;
- 1.3: Electromagnetic works and pipes;
- 1.4: Tertiary treatments;

[8] https://www.regione.veneto.it/web/lavori-pubblici/prezzario-regionale-aggiornamento-2015-2018 (Access April 2020)

[9] Investment cost for civil and electromechanical works

- 1.5: Reverse Osmosis;

The estimated working costs are summarized in **Table 8**. It shows the comparison between the investment cost of the existing MBR system and the new CW WWTP system. The total working costs are equal to **1,366,000.00 €** and **675,000.00 €** for MBR and CW WWTP+RO, respectively.

Table 8. Estimated working cost

WORKING COSTS 2019	MBR	CW WWTP +RO
Features	6000 pigs 50 m^3/d Surface water discharge	3000 pigs 25 m^3/d Soil discharge
1. Working cost		
1.1 Civil Works	800,000.00 €	240,000.00 €
1.2 Tank waterproofing	0.00 €	15,000.00 €
1.3 Electromagnetic works and pipes	486,000.00 €	300,000.00 €
1.4 Tertiary treatments	80,000.00 €	0.00 €
1.5 Reverse Osmosis	0.00 €	120,000.00 €
Total	**1,366,000.00 €**	**675,000.00 €**

Technical design services and construction supervision have been considered for the **financial framework**. The financial framework results in a total investment cost for the MBR equal to **1,456,000.00 €**. The total investment cost for the CW WWTTP + RO is equal to **730,000.00**. All the reported costs are excluding VAT.

Table 9. Estimated financial framework

FINANCIAL FRAMEWORK 2019	MBR	CW WWTP +RO
Features	6000 pigs 50 m^3/d Surface water discharge	3000 pigs 25 m^3/d Soil discharge
1. Working cost	1,366,000.00 €	675,000.00 €
2. Technical design services and DDLL	90,000.00 €	55,000.00 €
Total	**1,456,000.00 €**	**730,000.00 €**

4.1.3 Operational and Maintenance costs (OPEX)

OPEX are detailed considering the following O&M items:

- Electricity consumption excluding RO;
- Reed harvesting;
- Transport of the solid separated fraction: note that the separated solid fraction is not disposed of (which could lead to a higher OPEX) but only transported to another farm of the same owner in Magnacavallo (MN - Italy), about 80 km from the San Rocco Roverè farm where it is reused;
- Chemicals for the centrifuge;
- Chemicals for the activated sludge and tertiary treatment (MBR);
- Maintenance contract with the external company;
- Ordinary and extraordinary electromechanical periodic maintenance;

— Cost of laboratory and on-site chemical analysis;

— Personnel: includes the cost of workers serving the farm;

— Other general maintenance costs for the MBR functioning;

— RO concentrate disposal;

— Electricity consumption for RO;

— Chemicals for RO;

— Maintenance contract with the external company for RO;

Following an approach similar to the one used by Rizzo et al. (2018b), OPEX items have been estimated with an expert-based mix between detailed data, parametric costs, and an interview with the pig farm owner. OPEX for the MBR have been actualised to 2019. Energetic costs were assumed equal to 0.15 €/kWh.

The details of O&M are summarized in **Table 10**. Since the two alternatives consider different functioning conditions, OPEX have been normalised considering the average number of farmed pigs per year and the cubic meter of treated swine wastewater. As visible from **Table 10**, the MBR would have OPEX equal to 30.77 €/pig and 17.54 €/m^3 in 2019, significantly higher than those of CW (23.01 €/pig and 13.11 €/m^3). All the reported costs are excluding VAT.

Table 10. Details of O&M for studied alternatives

OPEX 2019	MBR	CW WWTP +RO
Features	6000 pig* 10400 pig/y** 50 m^3/d Surface water discharge	3000 pig* 5200 pig/y** 25 m^3/d Soil discharge
Electricity consumption excluding RO	125,000.00	35,000.00
Electricity consumption for RO	0.00	4,000.00
Chemicals for activated sludge and tertiary treatment (MBR)	35,000.00	1,000.00
Chemicals for centrifuge	33,000.00	16,000.00
Chemicals for RO	0.00	3,000.00
Reed harvesting	0.00	3,000.00
Transport of solid separated fraction	48,000.00	14,200.00
Maintenance contract with external company	25,000.00	2,000.00
Ordinary and extraordinary electromechanical periodic maintenance	20,333.33	1,000.00
Cost of laboratory and on-site chemical analysis	3,000.00	1,200.00
Personnel	18,720.00	6,240.00
Others general maintenance costs	12,000.00	0.00
RO concentrate disposal	0.00	17,000.00
Maintenance contract with external company for RO	0.00	16,000.00
Total (€/y)	**320,053.33**	**119,640.00**
OPEX for produced pig (€/pig)	**30.77**	**23.01**
OPEX for treated swine wastewater (€/m^3)	**17.54**	**13.11**
OPEX for treated swine wastewater without RO (€/m^3)	**17.54**	**8.73**

* Average pig presence in the farm. ** Average pig farmed per year

4.1.4 Definition and verification with literature of investment and O&M parametric costs for the studied CW WWTP

The CW WWTP in San Rocco di Piegara (VR – Italy) is made up of 5 beds, each of 448 m^2 (total area available 2240 m^2). The initial investment costs obtained for the CW WWTP system are 730,000.00 €, including osmosis, and 610,000.00 €, excluding osmosis. The unit cost, excluding osmosis, is about **272 €/m²** for the aerated CW, significantly higher than typical unit costs for conventional CWs. On average, the initial investment cost for conventional CW is approximately 100-200 €/m^2 in Italy[10] and it may vary according to the type, size, cost of supply and transport of material for the construction of the system. For instance, Rizzo et al. (2018b) report an investment cost for the CW WWTP of Castelluccio di Norcia (PG – Italy) equal to 124 €/m^2. The higher investment costs of the aerated wetland are mainly due to the additional aeration system within the bed and a more expensive control panel.

The management and maintenance costs for the CW WWTP system are equal to **35.55 €/m²/y**, excluding osmosis. These values are higher than those typically reported in literature for NBS used for municipal wastewater treatment (e.g., Rizzo et al.2018b), principally due to additional forced aeration costs (principally energy) and a more complex wastewater to be managed (e.g., chemicals, solid/liquid separation).

4.2 Simplified cost estimation for additional alternatives

4.2.1 Definition of additional alternatives, sizing, and cost estimation assumptions

Some additional alternatives were defined to compare the use of technological solutions with the **MBR reactor (Alternative 1 – A1)**, i.e., the solution used by the farm owner in the past for the full farm capacity of 6000 pigs.

The first alternative considered in this analysis regards the upgrade of the existing CW WWTP with an **additional parallel stage of the AEW (Alternative 2 – A2)**, scaling both the investment and operational and maintenance costs from the existing 3000 pigs to the full capacity of 6000 pigs.

The second alternative envisages the upgrade of the existing CW WWTP (3000 pigs) to reach the full capacity of the farm (6000 pigs) equipping the treatment system with an **additional stripping reactor (Alternative 3 – A3)** as primary treatment. The stripping reactor is one of the most promising technologies for a sustainable management of nitrogen loads from manure, as recognized also by "RiducaReflui", a local research project by Veneto Agricoltura[11], one of the key regional technical institutions for pig farms. In terms of functioning, stripping reactors aim to remove ammonia from the liquid fraction of the manure exploiting the physico-chemical process of stripping, i.e., the transformation of N from dissolved NH_4^+ to gaseous NH_3 by temperature and/or pH variation. Once in gaseous form, NH_3 is precipitated into a scrubber adding sulphuric acid (H_2SO_4), and ammonium sulphate ($(NH_4)_2SO_4$) is recovered. The by-product of the treatment by stripping reactor is ammonium sulphate, that can be reused as fertilizer in agriculture practices. Within the SASA treatment system, the stripping reactor would allow a reduction of about 60% of the nutrient load of the swine wastewater; consequently, the size of the aerated CWs could be about half that of the first alternative (treating all the liquid fraction by AEW) also helping to decrease the influent concentrations of ammonia and the possible toxic effect of nitrifying bacteria. Therefore, this alternative proposes a "hybrid" technological/NBS solution to treat the manure, also allowing the recovery of fertiliser**,** according to the circular economy principles. The investment and operational & maintenance costs were calculated by scaling those of the detailed cost estimation for the AEW and including those of the stripping reactor. The costs were estimated together with an expert Belgian company, DETRICON (https://detricon.eu/), also estimating the required quantity and

[10] http://www.iridra.eu/en/fitodepurazione-en.html

[11] http://riducareflui.venetoagricoltura.org/index.php/soluzioni-tecnologico-gestionali/tecnologie/processi-di-riferimento/29-soluzioni-tecnologico-gestionali/tecnologie/66-strippaggio

costs of additional chemicals (sulphuric acid). This cost analysis does not consider any revenues from the selling of ammonium sulphates as fertilizer, which are instead taken into consideration in the multi-criteria analysis of chapter 6

Finally, the third additional alternative assumes to treat the manure of the farm at its full capacity (6000 pigs, 50 m^3/d) with a **passive NBS** (Alternative 4 – A4), i.e., with a secondary passive subsurface flow CW followed by a tertiary treatment with a free water surface (FWS) wetland. Parametric values were used for both sizing and cost estimation of this alternative. Moreover, since passive CW are known to be extensive systems with a higher areal footprint, additional land acquisition costs are also considered for this alternative, considering a parametric land cost of 20 €/m^2 [12].

For all the alternatives two possible scenarios have been envisaged: **Scenario 1**, discharging on soil (quality requirements according to Table 4 of the Annex 5 of the part 3 of the d.lgs. 152/2006), i.e., the current situation; **Scenario 2**, outflow discharging into surface water (quality requirements according to Table 3 of the Annex 5 of the part 3 of the d.lgs. 152/2006). For the sake of simplicity, tertiary treatment (either technological – RO – or NBS – FWS) have been considered only for Scenario 1, assuming that secondary treatment would be able to fulfil the requirements to discharge into surface water[13]. Sizing and costs have been estimated considering the quality requirements of both scenarios following a simplified approach based on the detailed cost analysis and mass balance analysis of the previous sections, as well as parametric costs and literature values for the new alternatives.

The parameters used for the simplified sizing are summarized in the following table.

Table 11. Summary of design parameters used for simplified sizing

Parameter	Value	Unit	Note/reference
Aerated CW nitrogen removal rate - secondary	12	gN/m2/d	Mean value from monitored data – see section 3.3.4
Passive CW nitrogen removal rate - secondary	5.0	gN/m2/d	Value according to literature review – see section 3.3.4
Passive CW nitrogen removal rate - tertiary	0.9	gN/m2/d	mean value from Meers et al. (2008)
TN influent concentration	1500.0	mg/l	
TN effluent concentration - soil	15.0	mg/l	
TN effluent concentration - surface water	35.0	mg/l	
Stripping TN removal efficiency	60%		DETRICON expertise

4.2.2 Cost estimation of the additional alternatives

On the basis of the assumptions listed in the previous section, CAPEX and OPEX are calculated for all the alternatives and for the two scenarios. Results are summarised in the following tables.

[12] In order to maintain consistency with the cost estimation of the other alternatives, the additional land acquisition costs are calculated only for the area exceeding the passive CW in comparison to area occupied by other alternatives.

[13] Monitoring results of section 3 show that the AEW secondary stage would not be able, at the current state, to respect water quality targets for discharge into surface water. Therefore, Scenario 2 assumes a higher AEW area for the alternatives using aerated wetlands, suitable to respect Italian limits for discharge into surface water.

Table 12. Financial frameworks for all the considered alternatives for Scenario 1

Scenario 1 - CAPEX (€) **Soil discharge**	**Detailed cost estimation**		**Simplified cost estimation for additional alternatives**		
	MBR (A1)	**AEW**	**Upgrade AEW (A2)**	**Upgrade AEW + strip. (A3)**	**Passive NBS (A4)**
Pigs (n°)	6000	3000	6000	6000	6000
Treated wastewater (m3/d)	50	25	50	50	50
Area CW - secondary (m2)	0	2240	4540	3365	11000
Area CW - tertiary (m2)	0	0	0	0	25000
1. Working cost (1.1+1.2+1.3+1.4+1.5+1.6+1.7)	**1,486,000.00 €**	**675,000.00 €**	**1,176,000.00 €**	**1,167,000.00 €**	**1,881,000.00 €**
1.1 Civil Works (secondary treatment)	800,000.00 €	240,000.00 €	240,000.00 €	240,000.00 €	1,491,000.00 €
1.2 Tank waterproofing	- €	15,000.00 €	15,000.00 €	15,000.00 €	15,000.00 €
1.3 Electromagnetic works and pipes	486,000.00 €	300,000.00 €	300,000.00 €	300,000.00 €	250,000.00 €
1.4 Tertiary treatments	80,000.00 €	0.00 €	- €	- €	250,000.00 €
1.5 Reverse Osmosis	120,000.00 €	120,000.00 €	120,000.00 €	120,000.00 €	- €
1.6 Upgrading through CW tanks (1.6.1+1.6.2+1.6.3+1.6.4+1.6.5+1.6.6)	- €	- €	501,000.00 €	272,000.00 €	- €
1.6.1: Construction of new CW Tanks	- €	- €	*330,000.00 €*	*165,000.00 €*	- €
1.6.2: New sewer connections	- €	- €	*68,000.00 €*	*34,000.00 €*	- €
1.6.3: Building works for anaerobic bath	- €	- €	*19,000.00 €*	*19,000.00 €*	- €
1.6.4: Mechanical, electrical and electromechanical works	- €	- €	*50,000.00 €*	*34,000.00 €*	- €
1.6.5: Accessory works	- €	- €	*20,000.00 €*	*13,000.00 €*	- €
1.6.6: Construction site safety	- €	- €	*14,000.00 €*	*7,000.00 €*	- €
1.7: Upgrading through stripping and recovery of ammonium sulphate	- €	- €	- €	220,000.00 €	- €
2. Technical design services and DDLL	**90,000.00 €**	**55,000.00 €**	**80,000.00 €**	**80,000.00 €**	**80,000.00 €**
3. Additional land acquisition	**- €**	**- €**	**- €**	- €	**629,200.00 €**
Total (1+2+3)	**1,576,000.00 €**	**730,000.00 €**	**1,256,000.00 €**	**1,247,000.00 €**	**2,715,200.00 €**

Table 13. Financial frameworks for all the considered alternatives for Scenario 2

Scenario 2 - CAPEX (€) **Surface water discharge**	**Detailed cost estimation**		**Simplified cost estimation for additional alternatives**		
	MBR (A1)	**AEW**	**Upgrade AEW (A2)**	**Upgrade AEW + strip. (A3)**	**Passive NBS (A4)**
Pigs (n°)	6000	3000	6000	6000	6000
Treated wastewater (m3/d)	50	25	50	50	50
Area CW - secondary (m2)	0	3000	6100	4500	15000
Area CW - tertiary (m2)	0	0	0	0	0
1. Working cost (1.1+1.2+1.3+1.4+1.5+1.6+1.7)	**1,366,000.00 €**	**702,102.53 €**	**1,327,000.00 €**	**1,240,000.00 €**	**2,265,000.00 €**
1.1 Civil Works (secondary treatment)	800,000.00 €	240,000.00 €	240,000.00 €	240,000.00 €	2,000,000.00 €
1.2 Tank waterproofing	- €	15,000.00 €	15,000.00 €	15,000.00 €	15,000.00 €
1.3 Electromagnetic works and pipes	486,000.00 €	300,000.00 €	300,000.00 €	300,000.00 €	250,000.00 €
1.4 Tertiary treatments	80,000.00 €	- €	- €	- €	- €
1.5 Reverse Osmosis	- €	- €	- €	- €	- €
1.6 Upgrading through CW tanks (1.6.1+1.6.2+1.6.3+1.6.4+1.6.5+1.6.6)	- €	150,000.00 €	772,000.00 €	466,000.00 €	- €
1.6.1: Construction of new CW Tanks	- €	150,000.00 €	550,000.00 €	330,000.00 €	- €
1.6.2: New sewer connections	- €	- €	90,000.00 €	45,000.00 €	- €
1.6.3: Building works for anaerobic bath	- €	- €	19,000.00 €	19,000.00 €	- €
1.6.4: Mechanical, electrical and electromechanical works	- €	- €	67,000.00 €	45,000.00 €	- €
1.6.5: Accessory works	- €	- €	27,000.00 €	17,000.00 €	- €
1.6.6: Construction site safety	- €	- €	19,000.00 €	10,000.00 €	- €
1.7: Upgrading through stripping and recovery of ammonium sulphate	- €	- €	- €	220,000.00 €	- €
2. Technical design services and DDLL	**90,000.00 €**	**55,000.00 €**	**80,000.00 €**	**80,000.00 €**	**80,000.00 €**
3. Additional land acquisition	**- €**	**- €**	**31,200.00€**	**–** €	**209,200.00 €**
Total (1+2+3)	**1,456,000.00 €**	**760,000.00 €**	**1,438,200.00 €**	**1,320,000.00 €**	**2,554,200.00 €**

Table 14. Summary of OPEX for all the considered alternatives for Scenario 1

Scenario 1 - OPEX (€/y) **Soil discharge**	**Detailed cost estimation**		**Simplified cost estimation for additional alternatives**		
	MBR (A1)	**AEW**	**Upgrade AEW (A2)**	**Upgrade AEW + strip. (A3)**	**Passive NBS (A4)**
Pigs (n°)	6000	3000	6000	6000	6000
Treated wastewater (m3/d)	50	25	50	50	50
Area CW - secondary (m2)	0	2240	4540	3365	11000
Area CW - tertiary (m2)	0	0	0	0	25000
Electricity consumption excluding RO	125,000.00	35,000.00	70,000.00	52,500.00	2,500.00
Electricity consumption for RO	8,000.00	4,000.00	8,000.00	8,000.00	-
Energy consumption for stripping	-		-	9,000.00	-
Chemicals for activated sludge and tertiary treatment (MBR)	35,000.00	1,000.00	2,000.00	2,000.00	-
Chemicals for centrifuge	33,000.00	16,000.00	32,000.00	32,000.00	32,000.00
Chemicals for RO	6,000.00	3,000.00	6,000.00	6,000.00	-
Chemicals for stripping	-		-	10,000.00	-
Reed harvesting	-	3,000.00	4,000.00	3,000.00	17,000.00
Transport of solid separated fraction	48,000.00	14,200.00	28,400.00	28,400.00	28,000.00
Maintenance contract with external company	25,000.00	2,000.00	2,000.00	2,000.00	1,000.00
Ordinary and extraordinary electromechanical periodic maintenance	20,300.00	1,000.00	1,500.00	1,500.00	1,000.00
Cost of laboratory and on-site chemical analysis	3,000.00	1,200.00	1,200.00	1,200.00	1,200.00
Personnel	18,500.00	6,240.00	6,000.00	6,000.00	6,000.00
Other general maintenance costs for the MBR functioning	12,000.00	0.00	-	-	-
RO concentrate disposal	34,000.00	17,000.00	34,000.00	34,000.00	-
Maintenance contract with external company for RO	16,000.00	16,000.00	16,000.00	16,000.00	-
Repairs, conduction and stripping monitoring	-	-	-	6,000.00	-
Total	**383,800.00**	**119,640.00**	**211,100.00**	**217,600.00**	**88,700.00**

Table 15. Summary of OPEX for all the considered alternatives for Scenario 2

Scenario 2 - OPEX (€/y) **Surface water discharge**	**Detailed cost estimation**		**Simplified cost estimation for additional alternatives**		
	MBR (A1)	**AEW**	**Upgrade AEW (A2)**	**Upgrade AEW + strip. (A3)**	**Passive NBS (A4)**
Pigs (n°)	6000	3000	6000	6000	6000
Treated wastewater (m3/d)	50	25	50	50	50
Area CW - secondary (m2)	0	3000	6100	4500	15000
Area CW - tertiary (m2)	0	0	0	0	0
Electricity consumption excluding RO	125,000.00	46,000.00	94,000.00	52,500.00	2,500.00
Electricity consumption for RO	-	-	-	-	-
Energy consumption for stripping	-	-	-	9,000.00	-
Chemicals for activated sludge and tertiary treatment (MBR)	35,000.00	2,000.00	2,000.00	2,000.00	2,000.00
Chemicals for centrifuge	33,000.00	32,000.00	32,000.00	32,000.00	32,000.00
Chemicals for RO	-	-	-	-	-
Chemicals for stripping	-	-	-	10,000.00	-
Reed harvesting	-	2,600.00	5,500.00	4,000.00	13,000.00
Transport of solid separated fraction	48,000.00	28,400.00	28,400.00	28,400.00	28,400.00
Maintenance contract with external company	25,000.00	2,000.00	2,000.00	2,000.00	1,000.00
Ordinary and extraordinary electromechanical periodic maintenance	20,300.00	1,500.00	1,500.00	1,500.00	1,000.00
Cost of laboratory and on-site chemical analysis	3,000.00	1,200.00	1,200.00	1,200.00	1,200.00
Personnel	18,500.00	6,000.00	6,000.00	6,000.00	6,000.00
Other general maintenance costs for the MBR functioning	12,000.00	-	-	-	-
RO concentrate disposal	-	-	-	-	-
Maintenance contract with external company for RO	-	-	-	-	-
Repairs, conduction and stripping monitoring	-	-	-	6,000.00	-
Total	**319,800.00**	**121,700.00**	**172,600.00**	**154,600.00**	**87,100.00**

4.3 Cash flow analysis

The cash flow of this project is characterised only by the outflow. The cash flow takes into account the above costs and other information concerning the financial sources for the initial investment (equity, debt, public funding grant, etc.), defining the CAPEX of the case study.

The discounted costs of the 4 alternatives were calculated over a period of 20 years and applying a discount rate of 5%, in both scenarios (soil discharge scenario in **Table 16** and surface water discharge scenario in **Table 17**).

Table 16. Discounted costs of studied alternatives – Soil discharge scenario

		Soil discharge scenario			
	Unit	**A1 MBR**	**A2 Upgrade AEW**	**A3 Upgrade AEW + stripping**	**A4 Passive NBS**
Investment	€	1,576,000	1,256,000	1,247,000	2,715,200
OPEX	€/yr	383,800	211,100	217,600	88,700
Lifetime	yr	20	20	20	20
Discounted Costs (T= 20 y; i= 5%)	€	6,358,996	3,806,773	3,878,777	3,111,398

Table 17. Discounted costs of studied alternatives – Surface water discharge scenario

		Surface water discharge scenario			
	Unit	**A1 MBR**	**A2 Upgrade AEW**	**A3 Upgrade AEW + stripping**	**A4 Passive NBS**
Investment	€	1,456,000	1,438,200	1,320,000	2,554,200
OPEX	€/yr	319,800	172,600	154,600	87,100
Lifetime	yr	20	20	20	20
Discounted Costs (T= 20 y; i= 5%)	€	5,441.415	3,589,178	3,247,458	3,639,659

Since no specific revenues are produced from the investment, the Net Present Value (NPV) and the payback index was calculated comparing the NBS's costs (Investment and OPEX) and the avoided costs to treat the effluent with conventional solutions (MBR).

Table 18. Net Present Value of NBS alternatives

		Net Present Value (NPV)		
Scenario	**Unit**	**A2 Upgrade AEW**	**A3 Upgrade AEW + stripping**	**A4 Passive NBS**
Soil Discharge	€	2,552,224	2,480,219	3,247,598
Surface Water Discharge	€	2,769,819	3,111,539	2,719,338

From the entrepreneur's point of view, the payback index provides an indication of the years required for the investment to be repaid and therefore generate a positive net cash flow.

The payback index was calculated for all NBS alternatives (A2, A3 and A4) comparing the alternative investment and the net cash flow. The cash outflow is the O&M costs of the NBS alternatives, and the inflow is the avoided MBR O&M costs:

$$Payback\ Index = \frac{Investment^{NBS}}{Net\ Cost\ saving} = \frac{Investment^{NBS}}{O\&M^{MBR} - O\&M^{NBS}}$$

The pig farm owner received a grant of 300,000.00 € from the Regional Rural Development Plan, corresponding to approximately 41% of the investment cost for the "real" case (3000 pigs). Then, two hypotheses were calculated for the three NBS alternatives and two scenarios:

- Full Costs (FC Hypothesis): the payback index was calculated using the full costs described in previous sections of this chapter (No subsidies);
- Public Grant (PG Hypothesis): the payback index was calculated using an outflow due to the difference between the investment and a grant (40% of investment) for all the technical alternatives.

Table 19 reports the payback indexes of the alternative in the two different scenarios. As visible, the payback indexes are almost the same among the different alternatives. However, it is evident how the entrepreneur had been interested in the investment only thanks to the public grant, since the payback indexes would have been too high in case of full cost option.

Table 19. Payback index of the CW plant alternatives

		Payback index		
Scenario 1 Soil discharge	**Unit**	**A2 Upgrade AEW**	**A3 Upgrade AEW + stripping**	**A4 Passive NBS**
Full Cost	yr	7.27	7.50	9.20
Public Grant (40% investment)	yr	4.36	4.50	5.52
Scenario Surface water discharge	**Unit**	**A2 Upgrade AEW**	**A3 Upgrade AEW + stripping**	**A4 Passive NBS**
Full Cost	yr	9.77	7.06	8.62
Public Grant (40% investment)	yr	5.86	4.24	5.17

5 SOCIAL ANALYSIS

5.1 Introduction

This chapter outlines the main results and findings of the Social Analysis conducted between October 2019 and February 2020. The overall objective of the analysis was the collection of the main issues affecting the social sustainability of the use of NBS for manure treatment in the SASA pig livestock. Within a perspective of local development based on the priorities and needs outlined by local stakeholders, and beneficiaries themselves, this part of the study focused in particular on the following specific objectives:

— to explore the main issues that affect the social sustainability where the NBS solution is in place;

— to understand the main relations among relevant stakeholders and local actors within the value chain and their perception about NBS;

— to collectively identify and evaluate strength and weaknesses of the considered case, also evaluating its replicability on other areas as success model.

5.2 Actors description

The main actor involved is SASA srl, the intensive pig breeding where the NBS is operating: SASA Srl was included among the “stakeholders” falling into the category of farmers with a peculiar point of view. Other key stakeholders, considered in the present study, are:

- The Municipality of Roverè Veronese, representing the local community
- Other local farmers and the farmers organisation

Before going on with the description of the interviews with the stakeholders, different kinds of interests and roles have been identified in the following table.

Table 20. Stakeholders involvement (Salado et Al. 2008, Impronta etica 2016)

Stakeholder	Type of interest	Involvement	Type of change	Connection level
SASA Srl	Client and direct beneficiary	Support	Economic condition Environmental benefits	High
Municipality of Roverè Veronese	Beneficiary in terms of the environmental effects generated	Support/ negative/ neutral	Environmental benefits of the area	Low/ medium
Other farmers	Beneficiary in terms of the environmental effects generated Potential interest in the use of same technologies	Support/ negative/ neutral	Environmental benefits of the area	low
Veneto Farmers Association	Beneficiary in terms of the environmental effects generated Potential interest in the use of same technologies	Support/ negative/ neutral	Environmental benefits of the area	low

SASA SNC

Sasa Snc is a company dedicated to intensive breeding for fattening pigs (from an initial weight of 30 kg to a slaughter weight of 175 kg), sited in San Rocco di Piegara and bought in 1995 by the Savoia, a family with a long tradition in pig rearing.

The facility is quite isolated and barely visible, about 3 km away from the town and about 600 m from the first house. The facility has a maximum capacity of 7848 animals, but it currently hosts 3145. The Savoia family owns 3 other pig breeding facilities in Magnacavallo (Mantova province).

Before going into detail regarding the analysis of the company, it is important to describe the local context in order to better understand the history and the choices made by the company.

The Lessinia area is characterized by a strong agricultural vocation linked to traditional products such as chestnuts, cherries, strawberries, wine, and honey. Itineraries and nature trails favour the development of tourism with the presence of hotels, restaurants and agritourisms. The connection between land and animals has also influenced the landscape of Lessinia, ensuring an important maintenance and management function. The economic activity generated by dairy cattle farms, with meadows and intensely managed pastures, together with pig and chicken farms, makes an important contribution to these local economies.

The Lessinia area well represents the difficulties that the zootechnical field is experiencing in mountain territories. It is characterized by the presence and fragmentation of several small farmers, with a deep link to rural communities and traditional systems. Today, there is a progressive specialization towards medium-large size farms, and a clear decrease in both heads and production units. This phenomenon particularly affects the cattle sector but also the pig sector. The implementation of the Nitrates Directive 91/676/EEC concerning the protection of water against pollution caused by nitrates from agricultural sources and the other constraints due to the European legislation (e.g. animal welfare, hygiene and safety package etc.) strongly impacted the production costs, especially for feeding. It should be noted that in recent years many small farmers closed their activities due to financial problems and the legislative constraints.

The SASA company, that beside the San Rocco di Piegara farm owns a larger farm (Magnacavallo) in the plain, where they can spread the manure on the fields, in 2013 decided to close the Farm in San Rocco due to too high OPEX for swine wastewater treatment. In fact, the MBR treatment plant they built at the beginning of the 2000s to treat the manure – in the area there are no agricultural fields to spread it – needed to be upgraded to fulfil the stricter quality standards set by the Regional Authority. Even if they could bear the investment cost of the upgrading, the O&M costs would have been not affordable for the financial balance of the company.

In 2013 the company was closed for two years, due to too high OPEX for swine wastewater treatment using MBR technological solution. This kind of plant required high management costs in terms of labour, energy consumption and adding treatments and transport necessary for the generated surplus sludge.

The need to have an efficient purification system was related to different elements:

- Lack of owned land available to spreading of manure and slurry
- The area is "vulnerable" according to the Nitrate Directive 91/676/EEC nitrates directive, so the limits to the sewage spreading on the soil are more stringent compared to other areas;
- The emission limit values in the surface water where the purified liquid fraction is discharged, has been recently made more stringent, moving from table 3 to table 4 of Legislative Decree 152/06.

The more restrictive legislative constraints imposed the farm to install an expensive reverse osmosis plant. In addition, the area has been designated as nitrates vulnerable zone. This is one of the main reasons why several farmers decided to stop their activity in the last years. In 2016, a pilot installation tested an innovative NBS solution to treat swine wastewater, i.e.

intensified aerated wetland (FBA™, Forced Bed Aeration™). The pilot tests were carried out at the Magnacavallo farm, another farm owned by the SASA company. The results of the pilot tests are fully described in Masi et al. (2017) and were satisfactorily enough to convince the SASA company to install a full-scale system in another farm of theirs, the San Rocco breeding farm, i.e. the site object of this case study. Since the new NBS aimed to replace the old and abandoned MBR technological treatment plant, the new constructed wetland treatment plant tried to reuse as much as possible of the existing facilities, particularly in terms of equalization tanks.

Thanks to the significant reduction in OPEX, in 2017 the pig farm opened again. Therefore, the choice for NBS technology was driven by financial reasons.

SASA was the first company in the area, and one of the few in Italy, to choose constructed wetland as treatment for their pig manure. Three people currently work in the company, including the two owners (business partners) and one employee, who also takes care of the management of the purification plant, almost entirely automated.

Regarding the supply chain, SASA does not have a deep interaction within the local community. Indeed, pigs are sent outside Veneto for slaughter at the time they have reached 170-180 kg, for the production of traditional certified Italian hams (Parma and San Daniele ham). They do not generate typical local products.

Similar considerations are also valid for the constructed wetland. Although the company has been working for years, there is no tight connection to the local area in terms of direct impacts generated by the plant. Industrial symbiosis opportunities are not appropriate, as the technology must be tailored to individual cases. According to the owner of the SASA company, the main benefits related to the transition from MBR to constructed wetland technology are:

— Cost reduction in terms of system management: compared to the previous system, maintenance and energy consumption decreased, thanks to the reduced production of sludge and the consequent saving of sludge transport costs. In particular, the energy cost reduction is up to 50%;
— interruption of the use of chemical reagents for secondary treatment, necessary for the previous activated sludge stage of the MBR;
— Overall sludge reduction (secondary sludge);
— Aesthetic improvement.

Labour used for the construction: 8 workers including plumbers and electricians and 6 people for masonry works. All 14 people were workers from Mantova companies. For that reason, the generation of work at local level must be considered negligible. **Municipality of Roverè Veronese – conversation with the Deputy Mayor**

It was not possible to arrange a meeting with local citizens' committees in order to discuss about the topic of animal manure disposal; thus the Deputy Mayor of the Municipality of Roverè Veronese, where SASA is located, has been interviewed to collect information about the acceptance of the new manure treatment facility.

According Mr. Loris Corradi, although Alta Lessinia is designated as a Nitrate Vulnerable Zone (NVZ) within the EU Nitrates Directive, the issue related to wastewater management practice is not perceived as a social threat by citizens. On the contrary, the restrictions applied to the practice of *land spreading are considered by farmers as barriers to the economic development of the area.*

In this context, according to the Deputy Mayor, neither the community nor the other breeders are aware of the technology adopted by SASA. However, since the plant was active, no complaints from neighbours about odour nuisance have been reported (But there is only one house close to the farm, where the only full-time worker lives). He also noted that the constructed wetland slightly mitigates the visual impact, particularly from the mountainside, since it was implemented enhancing the pre-existing masonry structures and greening the old gravel square.

On behalf of the Municipality, the Deputy Mayor outlined the main barriers hampering the diffusion of NBS treatment systems among the pig breeders of the area and on a larger scale as follows:

— Lack of information and public involvement;

— Lack of appropriate funding for the pig meat sector;

— Complexity of AVEPA (Agenzia Veneta per i Pagamenti in Agricoltura) calls;

— High investment costs;

— Limitations related to the hilly morphology of the area.

Other farmers

Piggly Società Agricola SRL is the closest pig farm to SASA, represented by Sergio Visini and located in the Grezzana district, on the hill in front of San Rocco di Piegara. Like SASA, Piggly Società Agricola SRL breeds fattening pigs and does not have its own land for manure spreading. They treat the manure with a complex system composed of a stripping primary treatment and nitro-denitro[14] activated sludge reactors. The generated sludge is stored in tanks and periodically removed and brought down in the plain (in areas not vulnerable to nitrates), where the company rents an agricultural field to spread the sludge as final disposal. They claim that such treatment system implies high OPEX (in particular related to the sludge transport) and significant problems with storage tanks, linked to the limitation on sludge spreading for long periods during winter months. That is why the company is considering other technological options including constructed wetlands.

Despite being geographically close to SASA Srl, few synergies between the companies have been developed in terms of sharing of knowledge and problem-solving experiences. Visini knew of Savoia's technology only as hearsay. He considers the natural treatment technique of constructed wetlands as a good opportunity for future developments, well accepted by institutions and local community.

Azienda Agricola Biologica FERRARI MARISA, located in San Rocco di Piegara, raises swine and cattle in the natural state using strictly organic methods and has not significant interactions with SASA. The company was not aware of the techniques adopted by SASA and they are not interested in the topic of treating manure since, as organic producers, they have land available and all the manure is reused internally in the natural cycle.

Farmer organization

Veneto Farmer Association

Farming is an important part of Veneto’s economy and shapes the countryside around the communities. Spreading of manure and slurry is an acceptable part of farming practice, provided it is done with care.

The Association confirms that in the Veneto region 99% of swine breeding farms still use the spreading as main disposal technique, as the most convenient. Only a few farmers have adopted wastewater treatment systems, such as nitro-denitro activated sludge plants, with high operating costs. Small farmers cannot afford the costs of these advanced and specialized systems, especially in terms of the need for specialized personnel for daily operation. For this reason, the development of simple and cost-effective natural wastewater treatment systems is particularly interesting.

The main barriers to the implementation of constructed wetlands are related to:

[14] Activated sludge reactor designed to remove nitrogen using a combination of nitrification and denitrification biological processes.

- The long residence times and wide surface areas these treatments require to be effective, in fact they are called extensive systems;
- the amount of dry matter produced by the solid/liquid separation processes: most of the famers are used to deal with slurry spreading on the soil but they don’t know how to manage the dry matter resulting by the separation process;
- clogging problems of the installed equipment.

5.3 Analysis of the impacts

Considering the data obtained from the available literature and the interviews carried out, the results of the social impact analysis are shown in the following **Table 21**:

Table 21. Analysis of social impacts

SOCIAL VALUES	**Potential OUTCOMES**	**INDICATOR**	**Results**	**Judgment (low/medium/ high)**
Visual impact	Improved aesthetic quality of the landscape	Conservation/ change of the landscape	The visual impact of NBS is generally perceived as positive, while “grey” infrastructures, such as anaerobic bioreactors or activated sludge plants generate negative visual impact. However, swine intensive farms take place in large sheds similar to industrial buildings, therefore the presence of additional infrastructure doesn’t significantly modify the visual perception of the whole facility. The importance of the visual impact must be considered low. More in detail, for what concerns the SASA NBS, the farm is located in a hilly area, surrounded by the forest and it is visible only from the bottom along the road that connects San Rocco di Piegara with San Vitale, while there is not visual impact along the route boarding the place. The constructed wetland has been implemented on gravel squares, at about 50 meters from the breeding, maintaining the existing old structures and enhancing the storage pond. The NBS improves overall the landscape from and aesthetic point of view and mitigates the visual impact through the reuse of the old structures and the greening of the 5 gravel areas.	Low
Nuisance (odours, noise, presence of insects, obstacles to common farming and citizens practises)	Mitigation of Odour; mitigation of Noise; Presence of insects or other animals; Obstacles to farming and citizens practises Mitigation of Odour; mitigation of Noise; Presence of insects; Obstacles to farming practises; plants emitting allergic pollen.	Odour	The problem of odour due to the treatment plant in swine breeding farm is minor, cause the main source of odour is the breeding itself. The odour emissions are absolutely tolerable compared to ambient air quality standards. In general, the odour emission has decreased: no complaints from inhabitants have been observed since the plant has been carried out. The facility is located near to the breeding, far from the nearest town and at least 1 km from the nearest major road. There is only one house close to the farm, where the only full-time worker lives. People's perception is that the odour level has decreased compared to the previous technological plant. The constructed wetland prevents and mitigates the development of odours and the proliferation of aerosols and insects. In addition, the good quality of the wastewater discharged in terms of chemical and biological parameters, avoids problems of aerosol and smells. The slurry is transported by pipeline using gravity as the impelling force, which prevents the generation of road traffic and noise, odour or relevant cost linked to it.	Low
		Noise	No problem of noise has been observed. Compared to the previous plant, the noise generated has decreased as the slurry moves by gravity and the installed compressor is placed in a soundproofed cabin.	Low

SOCIAL VALUES	**Potential OUTCOMES**	**INDICATOR**	**Results**	**Judgment (low/medium/ high)**
		Mosquitos and other animals/insect	Not Detected	-
		Obstacles to farming practises	Not Detected	
		Increased in allergies and air humidity	Not detected	-

5.4 SWOT analysis

STRENGHTS	WEAKNESSES
In the area, there are farmers potentially interested in a sustainable management of wastewater and manure. The local communities are actively involved in farming and zootechnical activities and in the market of typical products of the region, which are part of the attractions of the area.	Weak collaboration among farmers at local level. Absence of phenomena of symbiosis. Nowadays few livestock are active in the area.
OPPORTUNITIES	**THREATS**
Repeatability of the model in other pig farm facilities of the area or in similar areas.	The high costs of manure management and wastewater treatment have progressively affected the numerous pig farms largely diffused in Lessinia during the past. Difficulty accessing finance by small farmers. Cultural barriers. Each breeder / farmer only thinks about his own individual activity Fear of possible legislative constraints arising by changing the slurry management practice.

6 QUANTIFICATION of DIRECT and INDIRECT BENEFITS

To assess the direct and indirect benefits of the different possible solutions a Multi Criteria Analysis (MCA) was applied. In the technical offer for the feasibility study the following categories of direct and indirect benefits have been identified:

- Social
- Environmental
- Technical
- Economic

The direct and indirect benefits were identified according to the results of the analysis done and reported in the previous chapters. The assessment criteria are illustrated in the next paragraph. The indicators used to quantify them, and the tools used to estimate their value is contained in paragraph 6.4

The technical offer also includes the use of value transfer method to monetize the direct and indirect benefit of NBSs. On the other hand, the social analysis (chapter 5) has clearly highlighted the scarce relevance of additional benefits for the local stakeholders. Only low advantages have been identified in terms of nuisance and visual impact, with no interest in other indirect benefits often considered for NBS, such as flood risk, biodiversity, or social benefits. In these conditions, a value transfer has scarce interest, since the benefits of NBS are already clearly highlighted by a conventional cost-benefit analysis.

6.1.1 Direct and indirect benefits identification

6.1.1.1 Social benefits

According to the results of the social analysis (see **Table 21**) the importance of social criteria proposed is very limited. The capacity to contribute to **awareness/educational**, **flood risk reduction**, and **well-being** is <u>negligible</u> in the studied area.

The most important social impact of pig farms wastewater is the **nuisance** due to odours caused by the practise of spreading on agricultural fields. The social analysis confirmed a benefit of CW in mitigating the odour nuisance. However, this benefit was judged only <u>low</u> by the social analysis, since *"people's perception is that the level has decreased compared to the previous activated sludge plant"*, but *"today, the main source of odour is the breeding itself"*.

Another social impact recognised was the **visual impact**. Indeed, the use of NBS led to *"Greening of the gravel squares"* and to a *"Mitigation of visual impact"*. Even in this case, the visual impact effect of NBS was ranked <u>low</u>, since the *"farm is located in a hilly area, surrounded by the forest, at the same time is situated in a heavily man-made context"*.

Noise was also identified to be favourably impacted by the NBS, since *"Noise generated has decreased"*. The benefit was ranked low mainly due to the fact that *"compared to the previous plant, the noise generated has decreased as the slurry moves by gravity and the installed compressor is placed in a soundproofed cabin"*.

Finally, neither **mosquitos** nor **other issues** (obstacles to farming practices, increased air humidity) have been identified.

<u>Nuisance (intended as both odour and noise, to avoid redundancy), and visual impact – landscape integration, will then be considered in the evaluation process, through an "expert judgment" approach</u>. Indeed, all the social impacts not detected by the social analysis in the local context have not been considered.

6.1.1.2 Environmental benefits

The main environmental benefit of the analysed treatment solutions is the **improved water quality**; however, all the treatment solution analyzed could be considered equivalent in terms of pollutant removal capacity: therefore, this criterion will not be considered in the MCA.

Climate change mitigation, in terms of reduction of CO_2 emissions, is another NBS benefit expected in comparison to technological solutions. Indeed, NBS reduces the energy consumption and costs (see **Table 10**) as well as stocking CO_2 in plant biomass (Maucieri et al., 2017). A simplified approach "proxy" indicator is assumed to consider climate change mitigation, i.e., the emitted CO_2 due to:

— Energy consumption

— Greenhouse gas emissions, N_2O

— CO_2 stock in plant biomass

For what concerns **biodiversity**, the reed beds (patches of *Phragmites australis*) could contribute to the landscape diversification and are interesting habitat for many bird species. However, as already highlighted by the social analysis, the NBS has a limited surface area in comparison to the man-made surface area of the farm and aerated wetland have proved to have less healthy reeds in comparison to passive conventional constructed wetland (Butterworth et al., 2016). Therefore, a <u>low</u> effect of NBS solution of SASA was considered in comparison to technological options. Indeed, a higher biodiversity value is considered only if a free water surface, FWS, stage is used according to expert-based judgement as well as literature evidence (e.g., Hsu et al., 2011).

6.1.1.3 Technical benefits

From a technical point of view, the social analysis conducted with the local stakeholders confirmed the key role of **simple operational and maintenance** of the manure treatment plant for a successful application. Particularly, the SASA experienced *"high management costs in terms of labour"* for the MBR (Alternative A1), while the use of CW simply requires *"one employee, who also takes care of the management of the purification plant, almost entirely automated"*.

Simple operational and maintenance attribute will then be considered in the evaluation process, through an "expert judgment" approach.

6.1.1.4 Economic effects

The Social analysis has highlighted that the economy is the real issue of interest for local stakeholders. The market product, i.e., pigs produced, and the reduction of costs are the most important "economic effect" for a pig farm. In other words, the economic performance needs to consider **"costs"** instead of "benefits".

In terms of indirect economic benefit, the **contribution to local economy** is <u>neglected</u> since few local workers have been used, as confirmed by the interview with the SASA owner (section 5.2).

According to the multi-criteria analysis carried out within the RiducaReflui project of the Veneto Farmers Association, the indirect benefits in terms of **revenues from recovered fertilizer** has been considered in the calculation of the OPEX: the annual value gained by selling the fertilizer has been detracted by the annual Operation and Maintenance costs.

6.2 Overview of the applied methodology: the Multi-Criteria Analysis (MCA)

The Multi-criteria (or multi-attribute) analysis involves the use of different types of variables aimed at providing a framework that allows preferences to be quantified. This is particularly useful in the field of sustainability, where variables with different units are involved. One widely accepted framework for standardising different units is the value function (Nijkamp and Beinat 1998).

Defining the value function requires measuring preference, or the degree of satisfaction produced by a certain alternative option for a measurement variable (indicator). Each measurement variable may be given in different units; therefore, it is necessary to standardise them into units of value or satisfaction, which is basically what the value function does. The method proposed rates satisfaction on a scale from 0 to 1, where 0 reflects minimum satisfaction (Smin) and 1 reflects maximum satisfaction (Smax).

To determine the satisfaction value for an indicator a few preliminary steps must be guaranteed (Alacron et al., 2010):

- Definition of the orientation (increase or decrease) of the value function.
- Definition of the points corresponding to the minimum (Smin, value 0) and maximum (Smax, value 1) performance/satisfaction.
- Definition of the kind (ordinal or cardinal) and of the shape (linear, concave, convex, S-shaped) of the value function.
- Definition of the mathematical expression of the value function

The following paragraphs report how the value function has been built to predict the effects of the designed alternatives on the attributes described in the previous paragraph. Some value functions have been built on a forecast of the performance based on existing data and models (e.g., costs, nutrient recovery). For other attributes, the prediction of the effects relies on Expert judgement. Expert knowledge has gained momentum as a source of information for decision making, particularly in contexts where empirical information is sparse or unobtainable (Sutherland 2006). MCA is naturally suited to incorporate expert knowledge through value functions. These are expert preferences for objectives on a standardised scale. How the expert judgement has been converted into an ordinal scale for each of the attribute relying on this method is specified in the next paragraphs.

6.3 Definition of the MCA structure

6.3.1 Alternative definition

Alternatives are defined considering the full capacity of the pig farm, i.e., 6000 pigs and 50 m^3/d. **Four alternatives** have been selected for MCA analysis, following the cost estimation done in section 4:

- <u>Alternative 1</u>: technological solution with the MBR reactor, i.e., the solution used by the farm owner in the past
- <u>Alternative 2</u>: intensified aerated wetland (AEW), i.e., the upgrade of the current NBS solution used by the farm owner
- <u>Alternative 3</u>: intensified aerated wetland (AEW) plus stripping, i.e., the upgrade of the current NBS through the use of an additional stripping reactor, also used for fertiliser recovery
- <u>Alternative 4</u>: passive wetland, i.e., an NBS with neither intensification nor use of grey solutions (i.e. no reverse osmosis, no stripping, no forced aeration within the wetland beds): a large subsurface flow wetlands (SFS) for secondary treatment in

scenario 1 and a hybrid CW composed by a SFS and a surface flow wetland (free water surface – FWS for tertiary treatment) in scenario 2.

All the alternatives have been sized following the same design assumptions done for cost estimation in section 4.

6.3.2 Scenario definition

Two scenarios are defined for the MCA analysis, according to the two possible discharging points allowed by Italian legislation and considered in cost estimation of section 4:

— Scenario 1: discharge on soil, in which all the alternatives are assumed with a tertiary treatment stage to fulfil strict water quality targets (reverse osmosis – RO – for Alternatives 1, 2, and 3; extensive passive NBS – free water surface, FWS, wetland – for Alternative 4)

— Scenario 2: discharge into surface water, in which all the alternatives are assumed without tertiary treatment stages, due to less strict water quality targets

6.3.3 Criteria and weights definition

The evaluation criteria have been selected according to the analysis reported in paragraph 6.1.1 and are summarised in **Table 22**.

Weights have been chosen by experts, with values representative of the local interests emerged from the social analysis (section 5). The highest importance is given to the criteria related to costs, followed by the social and technical aspects more related to manure treatment issues, i.e., nuisance and simple maintenance. Since this case study is related to NBS for climate change issues, an average importance is given to climate change mitigation, even if a scarce local interest was registered for environmental topics. Finally, low relative importance is assigned to other benefits, i.e., landscape integration and biodiversity support, for which scarce local interest was registered.

Table 22. Weights of sub-attributes given by experts

WEIGHT		
Criteria	**Relative importance**	**Weight**
Nuisance	7	0.17
Climate change mitigation	5	0.12
Biodiversity support	2	0.05
Landscape integration	2	0.05
Simple maintenance	7	0.12
CAPEX	10	0.24
OPEX	10	0.24
Total	**41**	**1.00**

6.4 Prediction of the effects - Quantification of criteria

6.4.1 Social benefits

6.4.1.1 Nuisance

The Nuisance (odour, noise, mosquito) benefit was assessed through expert judgment with an ordinal value function, negative orientation, expressed by an indicator ranging between 0 (Smin) and 3 (Smax), as follows:

Intensity of effect (from worst to best performance)	Scores
None	0
Low	1
Mean	2
High	3

Alternative without surface flow wetlands (A1, A2, A3) were scored with low nuisance, while those with surface flow wetland (A4 in Scenario 2) were scored with mean nuisance effect due to potential mosquito breeding.

6.4.1.2 Landscape integration

Visual impact is considered in terms of landscape integration through expert judgment with an ordinal value function, positive orientation, expressed by an indicator ranging between 0 (Smin) and 1 (Smax), as follows:

Intensity of effect (from worst to best performance)	Scores
No landscape enhancement	0
Landscape enhancement	1

Only alternatives with surface flow wetland (A4 in Scenario 2) have been scored with a positive landscape enhancement.

6.4.2 Environmental benefits

6.4.2.1 Climate change mitigation

Climate change mitigation is considered estimating the GHG emissions in terms of CO_2 equivalent (CO_2e). Beside CO_2 the only GHG compound considered is nitrogen dioxide (N_2O), since the main target of the manure treatment is nutrient removal. Methane emissions have been considered negligible: its main source is in fact in the animal breeding practice, rather than in the manure treatment.

Two sources of CO_2e emissions are considered:

— WWTP energy: electricity consumed due to the functioning of the WWTP;

— WWTP emissions: N_2O emitted due to the biological treatment.

The parameters used for the estimation of CO_2e are summarized in **Table 23**. The GHG emissions are assumed as a function of the emission factors (EFs), taken from Mander et al. (2014) for CWs and Mannina et al. (2018) for MBR; EF defines the N_2O emissions function of the influent TN. The GWP for N_2O emission is assumed from the most recent IPCC report of 2013. On the basis of European Environmental Agency data, the average value for Italy[15] is 256 g_{CO2}/kWh. Energy consumption values are those used for OPEX estimation (section 4.1.3).

Mass loads of nitrogen are calculated considering the flow rate in line with those assumed in the cost analysis (section 4.2), i.e. 50 m^3/d. Particularly, stripping (alternative 3) is assumed with a 60% of efficiency in TN removal, accounting from the benefit of N precipitation before entering in biological stage, i.e., reducing N_2O emissions[16]. Following the approach proposed by de Klein et al. (2014), C stock into the plant biomass is considered, assuming biomass parameters from literature.

The CO_2e estimated for all the alternatives are summarized in **Table 24**. The greater contribution to CO_2e emission is given by energy, making the reduction of energy consumption also a relevant climate change mitigation action. Plant biomass C stock is able to compensate N_2O emissions. Stripping reduces the overall CO_2e emitted while the higher N_2O EF of the MBR makes such a solution poorly sustainable from the environmental point of view. The satisfaction is defined assuming: (i) a negative orientation; (ii) relative maximum and minimum values, i.e., equal to the maximum and minimum values among those calculated for all the alternatives.

Table 23. Parameters used for the climate change mitigation attribute

Parameter	Value	Unit	Reference
mean EF_VF_N2O	0.02%	% N_2O-N/TNin*	[Mander et al., 2014] equal to vertical flow CW
mean EF MBR	1.00%	% N_2O-N/TNin*	[Mannina et al. 2018] batch feed MBR
mean energy carbon footprint	256	gCO_2e/kWh	EEA data – Italy 2016
GWP N2O - 100 years	298		IPCC 2013
aboveground biomass CW	1300	$g/m^2/y$	[Avellan2019] median for *Phragmites A.*in CW
below/above ground biomass for new roots	35%		[deKlein et al., 2014]
C content in dry biomass	0.44	gC/g_dw	[deKlein et al., 2014]
carbon molecular weight	12	g/C	
CO2 molecular weight	44	g/CO_2	
nitrogen molecular weight	14	g/N	
N2O molecular weight	44	g/N_2O	
TN stripping efficiency	60%		

* N2O Emission factor (EF): Percentage of N lost as N2O per unit total N inflow

Table 24. CO_2-e emission estimated for all the alternatives in the two scenarios.

Scenario 1 Soil discharge	WWTP Energy [kWh/y]	WWTP Energy CO2e [tCO_2e/y]	WWTP emission N2O [tN_2O/y]	WWTP emission CO2e [tCO_2e/y]	CW stock [tCO_2e/y]	Total CO2e [tCO_2e/y]
A1 – MBR	886667	227.2	0.8615	256.7	0	483.9
A2 – AEW	520000	133.2	0.0198	5.9	12.9	126.3
A3 – AEW + strip.	463333	118.7	0.0119	3.5	9.5	112.7
A4 – passive NBS	16667	4.3	0.0198	5.9	29.7	-19.6

[15] Co2 emission intensity calculator for Italy 2016 (most recent data from www.eea.europa.eu)

[16] The stripping reaction takes place in a closed reactor, therefore it can be assumed the absence of N loss in any other form during the process

Scenario 2 Surface water discharge	WWTP Energy [kWh/y]	WWTP Energy CO2e [tCO_2e/y]	WWTP emission N2O [tN_2O/y]	WWTP emission CO2e [tCO_2e/y]	CW stock [tCO_2e/y]	Total CO2e [tCO_2e/y]
A1 – MBR	833333	213.5	0.8615	256.7	0	470.2
A2 – AEW	626667	160.6	0.0198	5.9	17.3	149.2
A3 – AEW + strip.	410000	105.0	0.0119	3.5	12.7	95.8
A4 – passive NBS	16667	4.3	0.0198	5.9	42.5	-32.3

6.4.2.2 Biodiversity support

The benefit of biodiversity support has been assessed through expert judgment with an ordinal value function, positive orientation, expressed by an indicator ranging between 0 (Smin) and 5 (Smax), as follows:

Intensity of effect (from worst to best performance)	Scores
None	0
Very low	1
Low	2
Mean	3
High	4
Very high	5

Alternatives with subsurface flow wetlands (A2, A3, A4 in Scenario 1) were scored with very low, while those with surface flow wetland (A4 in Scenario 2) were scored with very high. No effect has been considered for technological solutions (A1).

6.4.3 Technical benefits

The only technical benefit considered in the MCA is the **simple maintenance**, which has been assessed through expert judgment with an ordinal value function, positive orientation, expressed by an indicator ranging between 0 (Smin) and 5 (Smax), as follows:

Intensity of effect (from worst to best performance)	Scores
None • Alternative 1 – Scenario 1: MBR + RO	0
Very low • Alternative 2 – Scenario 1: AEW + stripping + RO • Alternative 1 – Scenario 2: MBR	1
Low • Alternative 2 – Scenario 2: AEW + stripping	2
Mean • Alternative 3 – Scenario 1: AEW + RO	3
High • Alternative 3 – Scenario 2: AEW	4
Very high • Alternative 4 – all Scenario: passive NBS	5

Alternatives are scored as reported in the previous table, considering the increasing complexity of a WWTP for manure going from passive NBS (full green infrastructure) up to most technological solution (full grey infrastructure).

6.4.4 Economic benefits

Investment costs and **OPEX** have been taken from the cost analysis in section 4.2.

Parametric values to estimate **revenues** from the selling of recovered ammonium sulphate (only alternative 3) were taken from the RiducaReflui project of the Veneto farmers association (Veneto Agricoltura), which provided a value of 55 €/t for ammonium sulphate selling.

The amount of ammonium sulphate ($(NH_4)_2SO_4$) produced yearly is calculated with stoichiometry, assuming a reduction of 60% in the stripping reactor due to precipitation with acid Sulphuric acid (H_2SO_4); it results a production of about 229 kg/d of ammonium sulphate for alternative 3, which correspond to a revenue of about 4600 €/y.

The satisfaction is defined assuming: (i) a negative orientation for investment costs and OPEX; (ii) relative maximum and minimum values for investment costs, and OPEX, i.e., equal to the maximum and minimum values among those calculated for all the alternatives.

6.5 MCA results

Based on the evaluation methods defined in the previous section, the **effect matrix** is compiled and is visible in **Table 25**. The effect matrix shows the performance of each alternative expressed through the indicators chosen to describe the different attributes. Note that alternatives with aerated wetlands have a higher CAPEX for Scenario 2, since no reverse osmosis is considered as tertiary stage. The use of RO permits to have higher TN effluent concentrations from the secondary stage, since RO can remove the excess of nitrogen load to level in agreement with water quality targets. Therefore, secondary stages need a higher area in Scenario 2 to fulfill water quality targets without a tertiary stage, increasing the investment costs. On the other hand, the lack of a technological tertiary treatment decreases the OPEX going from Scenario 1 to Scenario 2.

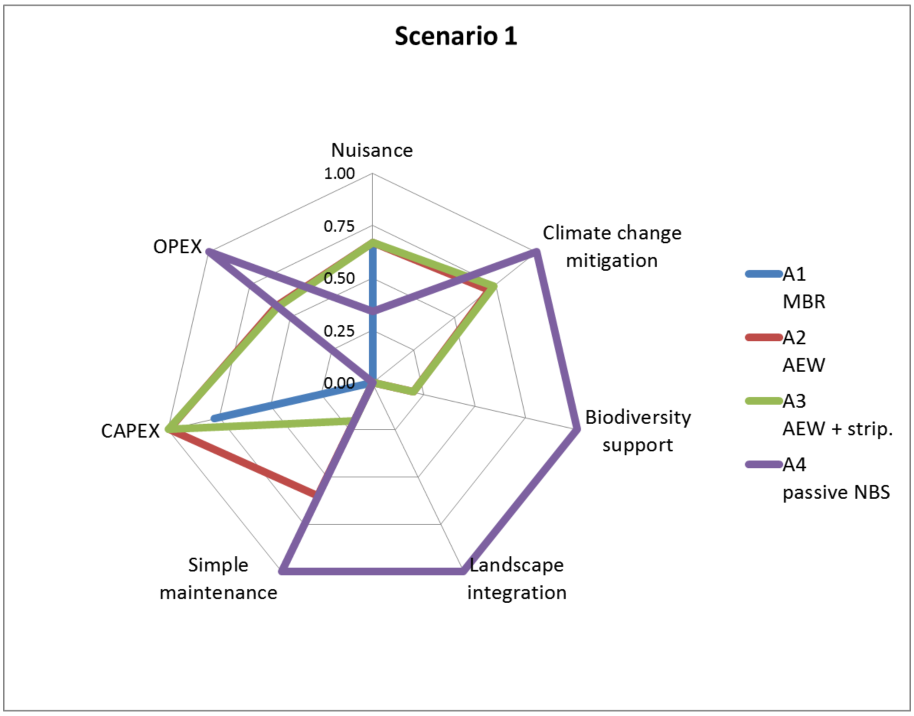
Table 25. Effect matrix for all the alternatives and the two considered scenarios (1 – discharge on soil; 2 – discharge into surface water)

Criteria	Indicator	Orient	Scen.	A1 MBR	A2 AEW	A3 AEW + strip.	A4 passive NBS
Nuisance	Expert judgment (4 classes)	↓	S1	1	1	1	2
			S2	1	1	1	1
Climate change mitigation	emitted CO2e (tCO2e/y)	↓	S1	484	126	113	-20
			S2	470	149	96	-32
Biodiversity support	Expert judgment (6 classes)	↑	S1	0	1	1	5
			S2	0	1	1	1
Landscape integration	Expert judgment (2 classes)	↑	S1	0	0	0	1
			S2	0	0	0	0
Simple maintenance	Expert judgment (6 classes)	↑	S1	0	3	1	5
			S2	1	4	2	5
CAPEX	€	↓	S1	1,576,000	1,256,000	1,247,000	2,715,200
			S2	1,456,000	1,438,200	1,319,200	2,554,200
OPEX	€/y	↓	S1	383,800	211,100	213,000	88,700
			S2	319,800	172,600	150,000	87,100

The normalisation of the attributes and criteria was done following the value function defined for each criterion. Colours varying from red (minimum value – 0) to green (maximum value – 1) were used in the **evaluation matrix** to ease the visualisation of the performances of normalised attributes and sub-attributes. The evaluation matrixes for the 4 alternatives and the 2 scenarios are reported in **Table 26** and graphically represented in **Figure 12**.

Table 26. Evaluation matrix for all the alternatives and the two considered scenarios (1 – discharge on soil; 2 – discharge into surface water)

Criteria	**Scenario**	**A1 MBR**	**A2 AEW**	**A3 AEW + strip.**	**A4 passive NBS**
Nuisance	S1	0.67	0.67	0.67	0.34
	S2	0.67	0.67	0.67	0.67
Climate change mitigation	S1	0.00	0.71	0.74	1.00
	S2	0.00	0.64	0.75	1.00
Biodiversity support	S1	0.00	0.20	0.20	1.00
	S2	0.00	0.20	0.20	0.20
Landscape integration	S1	0.00	0.00	0.00	1.00
	S2	0.00	0.00	0.00	0.00
Simple maintenance	S1	0.00	0.60	0.20	1.00
	S2	0.20	0.80	0.40	1.00
CAPEX	S1	0.78	0.99	1.00	0.00
	S2	0.89	0.90	1.00	0.00
OPEX	S1	0.00	0.59	0.58	1.00
	S2	0.00	0.63	0.73	1.00



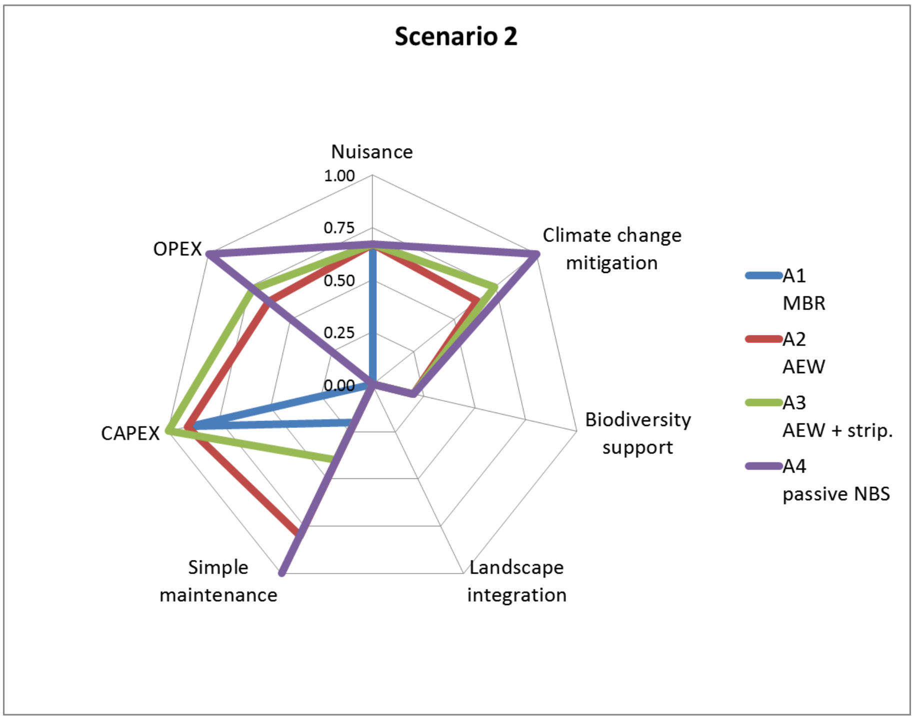


Figure 12. Graphical representation of the criteria performances for all the alternatives and the two considered scenarios (1 – discharge on soil; 2 – discharge in surface water).

The final rank for each alternative and the two scenarios is calculated using the weights defined by the experts. The results are summarised in **Table 31** and graphically represented in **Figure 13**.

Table 27. Final rank for all the alternatives and the two considered scenarios (1 – discharge on soil; 2 – discharge into surface water)

	Scenario	A1 MBR	A2 AEW	A3 AEW + strip.	A4 passive NBS
Final rank	S1	0.29	0.67	0.60	0.66
	S2	0.35	0.68	0.67	0.63

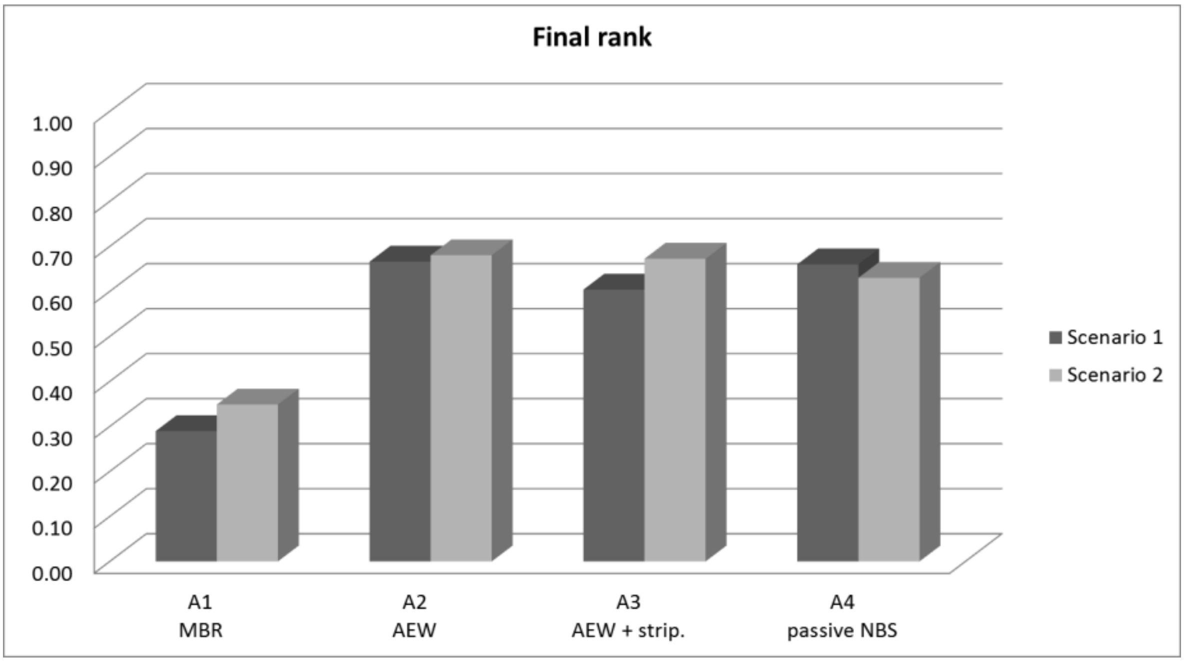


Figure 13. Graphical representation of the final rank for all the alternatives and the two considered scenarios (1 – discharge on soil; 2 – discharge into surface water)

Starting from the most important for local stakeholders, the **economic benefits**, it is interesting to notice that the most "natural" alternative (A4) presents the highest investment costs, due to the large size and the wide area required, while the other alternatives do not differ much one from the other. For what concerns OPEX, as expected A4 shows the best performance while the most "technological" alternative (A1 – MBR) has the highest O&M costs. The combination of NBS with stripping does not lead to a significant increase in investment cost and OPEX but provides almost negligible advantages in terms of revenues from recovered fertiliser (ammonium sulphate). The main considerations concerning the costs of the different solutions could be summarized as follows:

— CWs are generally more convenient than MBRs for this type of effluents

— Permitting standards play an important role (soil vs surface water)

— CWs usually entail land costs, so in many practical situations they need "intensification" with appropriate technologies (aeration, stripping) to save space

— On the other hand, more passive systems have much lower O&M, so whenever land acquisition is not a problem, they should be considered.

From the point of view of **technical benefit**, NBSs are advantaged in comparison to technological solutions, as also confirmed by the Social Analysis (chapter 5). Even if the installation of stripping reactors (alternative A4) does not significantly increase the investment and OPEX costs, it adds a new technological step in manure treatment chain, compromising the NBS advantage in terms of technical benefit; since the revenues from the selling of recovered fertiliser is almost negligible, it is clear why a farmer might not be interested in this solution (*"why should I manage a more complicated treatment stage without gaining anything if I can avoid it?"*).

The comparison of the alternatives for **environmental benefits**, shows that only the large "natural like" wetland envisaged by A4 provides a significant benefit to biodiversity. Regarding climate change adaptation, the CO_2e absorption by NBS (less) and the lower energy consumption (more) increases the performance of the most passive solution (A4), followed by the hybrid solutions (A3 and A2) and finally by the MBR; it must be noted that the use of stripping (Alternative A3) + AEW produces less GHG emissions than the AEW alone. This is due to the fact that part of the nitrogen pollutant load is precipitated as ammonium sulphates instead of being released as gas with the biological nitro-denitro process, decreasing the amount of emitted N_2O (a molecule having a global warming potential 298 times higher than CO_2).

Finally, the NBS solutions have a minor **social benefit** advantage in comparison with the technological ones due to slightly better performance in nuisance, visual impact, and noise mitigation.

The final results of the MCA, using relative importance weights reflecting the view of the farm owner, shows that alternative 2 reaches the highest ranking, immediately followed by A3 and at short distance A4, while A1 is by far the least performing solution.

It is important to highlight that among the analyzed alternatives, only alternative 4 is able to provide significant side benefits in terms of landscape and biodiversity improvement: the other two NBS (A2 and A3) are hybrid technological/natural solutions, and do not perform significantly in terms of "ecosystem services". On the other hand, the alternatives A2 and A3 are doing much better than A1 in terms of GHG emissions, even though they do not reach the performance shown by A4.

Alternatives A2 and A3 appear to be the best "trade off" solution, among the four analyzed alternatives. They perform quite similarly under all the criteria selected, with the only exception of the "technical" simplicity, where A2 is better than A3, not requiring the management of the stripping reactor and of the relative by-product: this is most likely the reason why A2 ranks better than A3. A4 is by far the best performing one under all environmental and technical criteria and in terms of O&M costs, however its investment costs are almost double those of the other alternatives and that is why it is ranked after A2 and A3. Besides that, A4 is a pure theoretical option, because a similar system is not technically feasible in the area, for geographical constraints. Finally, the pure technological solution (A1) is by far the less performing solution, even though such solution is probably more diffused than NBS, due to the lack of knowledge about natural treatment systems.

7 BUSINESS MODEL ANALYSIS

The business model of the analyzed case study is mainly based on the market. The SASA company closed down for two years in 2013 because the activity revenues did not allow to cover the high management costs of the existing manure treatment system (MBR) to discharge the effluent fulfilling the new, more stringent limits. In 2016 by taking advantage of a non-repayable loan provided by the Regional Rural Development Plan, covering more than 40% of the investment costs, the entrepreneur was able to set up a NBS to manage the pig manure, but with a treatment capacity lower than the previous MBR plant, due to the limited area available to build the constructed wetland.

The entrepreneur, during the interview, clearly stated that the reason why he decided to leave the existing MBR treatment plant (giving up an important investment done at the beginning of the years 00', and so largely amortized) and shift to NBS, was the high O&M cost of the MBR.

The availability of the financial support provided by the Rural Development Plan (RDP) to promote NBS for manure treatment, certainly encouraged the entrepreneur to realize a treatment CW; however the analysis done doesn't allow to exclude that the company would have faced the risk of the full investment costs, to be able to reopen the Piegara pig farm: in fact at the beginning of the years 2000s they decided to put in place a more expensive treatment system (MBR) bearing the full cost of the investment. It is reasonable to expect that an existing pig farm experiencing similar problems as SASA SrL and willing to continue the production, would be available to accept to cut its profits for a certain period of time and make the investment by itself, just finding the needed financial resources on the market.

What is clear from the Cash Flow analysis (see chapter 4.3) is that any kind of treatment NBS – even though NBS are less expensive than conventional treatment systems in terms of discounted costs over a 20-year period – has a quite long payback index (between 4 and 9 years).

In Italy very few pig farms treat their manure, as most of them spread the manure on the fields since it is the most cost-effective solution. This can be easily confirmed also for the case study of San Rocco Piegara with a simple parametric cost analysis. The land required for spreading of manure would be about 161 hectares, considering the full capacity of the farm (6000 pigs, 50 m^3/d of manure). According to "RiducaReflui", a local research project by Veneto Agricoltura, the parametric cost for solid manure spreading up to 5 km from the farm is 4.5 €/m^3 while the land fee is about 200 €/ha per year, leading to an annual operational and maintenance cost of about 114,300.00€. The OPEX of land spreading is therefore lower than the one estimated for MBR (319,800.00 €), AEW (172,600.00 €) and AEW plus stripping reactor (154,600.00 €), considering the most advantageous scenario of discharging into surface water investigated in Chapter 4 (Scenario 2, **Table 14**). OPEX of land spreading are higher than a full passive NBS (87,100.00 €, Scenario 2, **Table 14**), but land spreading does not require any CAPEX investment. Therefore, it is evident from a simple cost-benefit perspective why the treatment of manure is not diffused in Italy. Such situation is not expected to change in the future, unless some new regulation makes the "spreading" solution less profitable than it is now.

The "market" for manure treating NBS is therefore limited to those farms that cannot spread their manure for any reason. Among those farms, according to the knowledge of the study team, very few use NBS, being this solution much less known compared to more conventional treatment technologies, such as activated sludge or MBR plants. Certainly, some information effort involving the main stakeholders (e.g., farmers' associations, Environmental Agency, Regional Park etc.) could help the diffusion of NBS to treat manure. However, according to the experience of the study team, the most important information channel among the farmers is the "word of mouth": for instance, NBS for wastewater treatment of wineries grew in Tuscany without any information campaign, after the first 5/10 experiences showed good performances and reasonable

OPEX and CAPEX, while in other areas (Abruzzo, Marche), where the technology is still poorly practised, information events promoted by the local public administration and the food industry organizations doesn't show significant effects.

In the present case study, the entrepreneur gave his attention to NBS cause the RDP offered the subsidy: to catch the financial support opportunity he gathered information about nature-based treatment system and – after a testing phase showing the good treatment performance of the system – decided to implement a full-scale plant. Therefore, the existence of a subsidy by the RDP not only provides financial support but also contributes to spread the knowledge about NBS: it could be expected that even a lower contribution to the investment (less than 40%) may have the same effect on the market, keeping in mind that the contribution should bring the owner of the farm to overcome the distrust towards treatment solutions that are not established in the market as other treatment technologies are.

For what concerns the choice of the NBS technology, the results of MCA show that, even in the absence of technical constraints hindering the possibility of realizing a completely passive NBS, the company would have most likely developed a hybrid technological/NBS solution rather than a passive CW, that would have required a too large area and a too big initial investment.

It must also be considered that a legislative framework aimed at promoting the circular economy should somehow encourage treatment solutions that allow the production of fertilizers. The fertilising products derived by the treatment (i.e., ammonium sulphate recovered from stripping reactor) should be sustained into the market by ad hoc policies, since currently the market value is too low to justify the risk and the investment by pig farm owners. Particularly, Sigurnjak et al. (2019) have recently reviewed the policy barrier in reusing recovered fertiliser from the treatment of manure. This is principally due to their origin from manure itself, according to Nitrates Directive, which mandatorily limits the use of ammonium sulphates at the same limit of land spreading, i.e., 170 kg N ha^{-1} in sensitive area[17].

[17] From original text of Sigurnjak et al. (2019). Legend: AS, Ammonium sulphate; AN, ammonium nitrate.

"According to the current Fertilizer regulation EU2003/2003 AS and AN are nitrogen fertilizer solutions and can be recognized as 'EC fertilizer' (category C1 n°1) if the N-concentration is at least 15% (European Commission, 2003). This threshold can be reached by AN since the use of HNO_3 increases the N-concentration (13–20%) of the end-product. For AS this threshold is higher than the N-concentrations (3–9%) obtained from the existing (stripping-)scrubbing installations that use H_2SO_4. The current draft of the new European fertilizer regulation for 'inorganic liquid compound macronutrient fertilizer' proposes lower N concentration criteria (1.5 or 3%; European Commission, 2016) which could be met by both AS and AN. However, if AN and AS are obtained from animal manure, their utilization is officially limited by the Article 2.g. of the Nitrates Directive where the following is stated: 'livestock manure': means waste products excreted by livestock or a mixture of litter and waste products excreted by livestock, even in processed form (European Commission, 1991). This means that AS and AN from animal manure origin are identified as animal manure and fall under the limitation of 170 kg N ha^{-1}. As a result, these products have to fulfil requirements of animal manure, and therefore have to compete with animal manure. In some EU regions air cleaning pathway is used frequently and therefore a derogation from the Nitrates Directive is currently the subject of a study on safe criteria for processed manure carried out by JRC in the period of 2018–2020 (European Commission, 2017)."

References

European Commission, 1991. Directive of the Council of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EC). Off. J. Eur. Commun. L375, 1–8.

European Commission, 2003. Regulation (EC) No 2003/2003 of the European Parliament and of the Council of 13 October 2003 relating to fertilisers. Off. J. Eur. Commun. L304, 1–194.

European Commission, 2016. Circular economy packages. Annexes to the Proposal for a regulation of the European Parliament and of the Council laying down rules on the making available on the market of CE marked fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009.

European Commission, 2017. Developing criteria for the use of processed manure in the context of the Nitrates Directive. Nitrates Expert Group, Brussels, Belgium. Available from: <http://ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupDetailDoc&id=33119&no=3>.

During the social analysis other pig farm owners in the area have been interviewed to check their point of view on NBS. One of them appears to be interested to the solution and his interest suggested the possibility to imagine among the possible business models a sort of “industrial symbiosis”, where several pig farms come together to implement a common NBS facility for manure treatment. This hypothesis, however, depends on the technical possibility to deliver the manure to the treatment facility using the farm tractor, without making recourse to specific transportation, which would increase the treatment costs too much. In the present case study, such solution does not appear feasible, since the hilly morphology does not allow building large enough NBS. In other geographical contexts, however, it is theoretically possible to imagine a similar model: but what would be the advantage for a farm to choose this solution rather than a single farm facility? For completely passive CW the economies of scale are nearly negligible, and the size of the wetland is already quite large: 3 farms with 10.000 pigs each require 30 hectares of land available to build a common facility: it is probably much easier to find 3 areas of 10 hectares each and the costs of building and managing 3 facilities would not be significantly higher than building and managing only one. For hybrid technological/NBS solution some advantages may arise by sharing the investment and O&M costs of the technological treatment steps (i.e., Reverse Osmosis and possibly stripping reactor), but further analysis would be needed to investigate advantages and disadvantages of each solution. However, a business model envisaging a “multi-property” manure treatment NBS, whereas feasible, certainly would not change the business “scenario” for this solution that remains limited to a tiny fraction of the pig farms, unable to spread the manure without any treatment.

The study team had assumed the possibility of applying a “Payment for Ecosystem Services” (PES) scheme for the manure treating NBS at the beginning of the study. This possibility, however, has not been considered feasible after the results of the social analysis, that show that the local community has a very limited interaction with the SASA pig farm, nor is there a large business company in the area that could replicate a PES scheme similar to the Vittel case in North-Eastern France[18].

[18] In order to address the risk of nitrate contamination caused by agricultural intensification in the aquifer, the world leader in the mineral water bottling business is financing farmers in the catchment to change their farming practices and technology (Perrot-Maître, D. 2006)

Figure 14. Key actors involved in the business model

The main steps/conditions of the proposed business model and the key actors involved are reported in **Figure 14**. The first condition is the presence of farms willing to treat their manure; the second is that they are informed about the possible use of NBS and its advantages (at least from the financial point of view). The third condition, i.e. a financial support, may not be strictly necessary but would surely help the diffusion of such solution, considered though the long payback time of the investment.

8 CONCLUSIONS

The analyzed case study shows that NBS could be a solution for the treatment of swine manure. It must be highlighted that the NBS object of this study it is not a "pure" NBS, but somehow a "hybrid" between an NBS and a technological system. It is, in fact, an "aerated" vertical flow constructed wetland (CW): a natural system equipped to be artificially enriched by forced air ventilation to increase its oxidation capacity. The choice to build an aerated system mainly depends on the unavailability of land, and theoretically if larger areas were available, a "passive" CW could have been built. However very few examples of existing passive CW are recorded in the scientific literature and the toxicity for the vegetation and micro-biota due to the high ammonium concentration at the inlet must be considered.

The NBS shows to be effective in removing the most important pollutants of a pig farm: the removal efficiency observed is 73% for total Nitrogen and 80% for total phosphorus, but it goes up to 90% for ammonium and COD. The removal capacity per area unit for nitrogen and phosphorus is respectively of 12.66 and 0.45 g/m^2 per day.

Going to the costs issue, the most diffused practice to spread the manure on the fields for fertilization is by far the cheapest solution compared to the construction and management of a manure treatment system. Even if the farm is located in a "nitrate sensitive" area and the stricter regulation due to the Nitrates Directive requires pig farm enterprises to find larger areas for the spreading of the manure, the best option to minimize manure management costs is the spreading of the manure on fields if there are some available at a reasonable distance from the site.

A pig farm could be interested in realizing a treatment system only when fields to spread the pig manure are not available nearby: in this case the high cost of the transportation of manure over a long distance makes the solid/liquid separation and the construction of treatment plant for the liquid fraction interesting for the company.

Among possible treatment systems, NBS solutions appear convenient, compared to technological solutions with comparable removal effectiveness such as Membrane Bio Reactors (MBR), both in terms of construction (CAPEX) and maintenance and operation (OPEX) costs.

The Social analysis clearly shows that no cultural barrier hinders the recourse of NBS but, on the other hand, natural solutions are not perceived by the local community as an added value: the economic criterion is the most relevant one for local stakeholders, while the interest towards other benefits are limited both in number and in local perception. Such a weak interest from the local community depends on the fact that the NBS is located just nearby the pig breeding stables in an area not accessible to the general public: such condition is, however, very common for CW treating effluents of husbandry activity and food and beverage industry.

Considering the environmental side benefits of the NBS, only large passive wetlands would provide interesting effects in terms of ecosystem services. The "hybrid" solution implemented in the present case study provides a significant contribution only to climate change mitigation, through the absorption of CO_2 by NBS (less important) and the lower energy consumption (more important), compared to pure technological treatment systems. It must be noted that, in terms of GHG emissions, the use of stripping (Alternative A4) performs better than simple NBS. This is due to the fact that part of the nitrogen pollutant load is precipitated as ammonium sulphates instead of being released as gas with the biological nitro-denitro process, decreasing the amount of emitted N_2O, which has a global warming potential 298 times higher than CO_2.

Going to the possible business model, the large recourse to the practise of manure spreading sharply narrows the market for manure treatment NBS. Even though NBS could be optimal treatment solutions, being less known than other treatment technologies they would highly benefit from a public financial support, at least for the first 10-15 years, until they get an established position in the market.

Finally, it also must be considered that a legislative framework aimed at promoting the circular economy should somehow encourage treatment solutions that allow the production of fertilizers. The fertilising products derived by the treatment (i.e., ammonium sulphate recovered from stripping reactor) should be sustained into the market by ad hoc policies, since currently the market value is too low to justify the risk and the investment by pig farm owners.

9 REFERENCES

Peer review papers

Alarcon, B., Aguado, A., Manga, R. and Josa, A., 2010. A value function for assessing sustainability: application to industrial buildings. Sustainability, 3(1), pp.35-50.

Avellán, T. and Gremillion, P., 2019. Constructed wetlands for resource recovery in developing countries. Renewable and Sustainable Energy Reviews, 99, pp.42-57.

Bernal M. P. et Al. 2015. Evaluation of manure management systems in Europe. Life + Manev Project.

Borin, M., Politeo, M. and De Stefani, G., 2013. Performance of a hybrid constructed wetland treating piggery wastewater. Ecological engineering, 51, pp.229-236.

Butterworth, E., Richards, A., Jones, M., Brix, H., Dotro, G. and Jefferson, B., 2016. Impact of aeration on macrophyte establishment in sub-surface constructed wetlands used for tertiary treatment of sewage. Ecological engineering, 91, pp.65-73.

de Klein, J.J. and van der Werf, A.K., 2014. Balancing carbon sequestration and GHG emissions in a constructed wetland. Ecological engineering, 66, pp.36-42.

Hsu, C.B., Hsieh, H.L., Yang, L., Wu, S.H., Chang, J.S., Hsiao, S.C., Su, H.C., Yeh, C.H., Ho, Y.S. and Lin, H.J., 2011. Biodiversity of constructed wetlands for wastewater treatment. Ecological Engineering, 37(10), pp.1533-1545.

Liquete, C., Udias, A., Conte, G., Grizzetti, B. and Masi, F., 2016. Integrated valuation of a nature-based solution for water pollution control. Highlighting hidden benefits. Ecosystem Services, 22, pp.392-401.

Masi, F., Rizzo, A., Martinuzzi, N., Wallace, S.D., Van Oirschot, D., Salazzari, P., Meers, E. and Bresciani, R., 2017. Up-flow anaerobic sludge blanket and aerated constructed wetlands for swine wastewater treatment: a pilot study. Water Science and Technology, 76, 1, 134-146, 2017.

Mander, Ü., Dotro, G., Ebie, Y., Towprayoon, S., Chiemchaisri, C., Nogueira, S.F., Jamsranjav, B., Kasak, K., Truu, J., Tournebize, J. and Mitsch, W.J., 2014. Greenhouse gas emission in constructed wetlands for wastewater treatment: a review. Ecological Engineering, 66, pp.19-35.

Mannina, G., Chandran, K., Capodici, M., Cosenza, A., Di Trapani, D. and van Loosdrecht, M., 2018. Greenhouse gas emissions from membrane bioreactors: analysis of a two-year survey on different MBR configurations. Water Science and Technology, 78(4), pp.896-903.

Maucieri, C., Barbera, A.C., Vymazal, J. and Borin, M., 2017. A review on the main affecting factors of greenhouse gases emission in constructed wetlands. Agricultural and forest meteorology, 236, pp.175-193.

Meers, E., Tack, F.M.G., Tolpe, I. and Michels, E., 2008. Application of a full-scale constructed wetland for tertiary treatment of piggery manure: monitoring results. Water, air, and soil pollution, 193(1-4), pp.15-24.

Nivala, J., Wallace, S., Headley, T., Kassa, K., Brix, H., van Afferden, M. and Müller, R., 2013. Oxygen transfer and consumption in subsurface flow treatment wetlands. Ecological Engineering, 61, pp.544-554.

Rizzo, A., Bresciani, R., Martinuzzi, N. and Masi, F., 2018b. French Reed Bed as a Solution to Minimize the Operational and Maintenance Costs of Wastewater Treatment from a Small Settlement: An Italian Example. Water, 10(2), p.156.

Sigurnjak, I., Brienza, C., Snauwaert, E., De Dobbelaere, A., De Mey, J., Vaneeckhaute, C., Michels, E., Schoumans, O., Adani, F. and Meers, E., 2019. Production and performance of bio-based mineral fertilizers from agricultural waste using ammonia (stripping-) scrubbing technology. Waste Management, 89, pp.265-274.

Sutherland WJ. 2006. Predicting the ecological consequences of environmental change: a review of the methods. *J Appl Ecol.* 2006; 43: 599–616

Wu, S., Kuschk, P., Brix, H., Vymazal, J. and Dong, R., 2014. Development of constructed wetlands in performance intensifications for wastewater treatment: a nitrogen and organic matter targeted review. Water research, 57, pp.40-55.

Zhang, X., Inoue, T., Kato, K., Harada, J., Izumoto, H., Wu, D., Sakuragi, H., Ietsugu, H. and Sugawara, Y., 2015. Performance of hybrid subsurface constructed wetland system for piggery wastewater treatment. Water Science and Technology, 73(1), pp.13-20.

Conference proceedings papers

Rizzo A., Masi F., Dion Van Oirschot, Scott D. Wallace, Bresciani R., 2018a "Aerated constructed wetlands for swine wastewater treatment: experiences from the start-up of a full scale system in Italy", oral, 16th IWA International Conference on Wetland Systems for Water Pollution Control, ICWS 2018. 30 September - 4 October. Valencia, Spain.

Books

Beinat E. and Nijkamp P. (Eds.) 1998. Multicriteria Evaluation in Land-use Management: Methodologies and Case Studies, Springer

Kadlec, R.H. and Wallace, S., 2009. Treatment wetlands. CRC press.

Reports

Bernal, M.P., Bescós, B., Burgos, L., Bustamante, M., Clemente, R., Fabbri, C., Flotats Ripoll, X., García-González, M.C., Herrero Mallén, E., Mattachini, G. and Moscatelli, G., 2015. Evaluation of manure management systems in Europe.

Bouraoui, F., Grizzetti, B. and Aloe, A., 2011. Long term nutrient loads entering European seas. European Commission, Luxembourg, 72.

Foged, Henning Lyngsø, Xavier Flotats, August Bonmati Blasi, Jordi Palatsi, Albert Magri and Karl Martin Schelde. 2011. Inventory of manure processing activities in Europe. Technical Report No. I concerning "Manure Processing Activities in Europe" to the European Commission, Directorate-General Environment. 138 pp.

Perrot-Maître, D. 2006 The Vittel payments for ecosystem services: a "perfect" PES case? International Institute for Environment and Development, London, UK.

Salado R. et Al. 2008. Environmental, economic and social impacts of the use of sewage sludge on land. Final Report. Part II: Report on options and impacts. DG Environment under Study Contract DG ENV.G.4/ETU/2008/0076r.

Final report of the project "Riduzione del carico inquinante generato dai reflui zootecnici nell'area del bacino scolante della laguna veneta – RiduCaReflui" finanziato dalla Regione Veneto con D.G.R. 4031 del 30/12/2008" http://riducareflui.venetoagricoltura.org/index.php/59-progetti-in-home/riducareflui/126-pubblicazioni-riducareflui (Access April 2020)

Web sites

Da Rocha S.M. et Al. 2017. Social and cultural values and impacts of nature-based solutions and natural areas. Deliverable 1.3 Part IV. Naturvation Project. https://naturvation.eu/result/social-and-cultural-values-and-impacts-nature-based-solutions-and-natural-areas

Impronta Etica, SCS Consulting. 2016. Linee guida per la misurazione dell'impatto sociale. https://www.improntaetica.org/wp-content/uploads/2016/08/Linee-Guida-Impatto_def.pdf

Knowledge Hub on Water and Agriculture (https://water.jrc.ec.europa.eu)

Value transfer method (https://oppla.eu)

- Bernal M. P. et Al. 2015. Evaluation of manure management systems in Europe. Life + Manev Project.
- Da Rocha S.M. et Al. 2017. Social and cultural values and impacts of nature-based solutions and natural areas. Deliverable 1.3 Part IV. Naturvation Project. https://naturvation.eu/result/social-and-cultural-values-and-impacts-nature-based-solutions-and-natural-areas.
- Salado R. et Al. 2008. Environmental, economic and social impacts of the use of sewage sludge on land. Final Report. Part II: Report on options and impacts. DG Environment under Study Contract DG ENV.G.4/ETU/2008/0076r.
- Ramboll. 2017. Minsk wastewater treatment plant. Environmental and social impact assessment.
- www.iridra.eu

ANNEX 1: Landscape framework maps

Landscape is investigated considering the following features and sources:

- Satellite view: Google Earth
- Land use and infrastructure: Corine Land Cover (https://land.copernicus.eu/)
- Topography: technical regional map (Carta Tecnica Regionale – CTR - https://www.regione.veneto.it/))
- Soil type: Regional soil type map (https://www.regione.veneto.it/)

Drawings for each feature and each NBS are given in following pages, in A3 format and in scale.

All attached drawings are summarised in the following table.

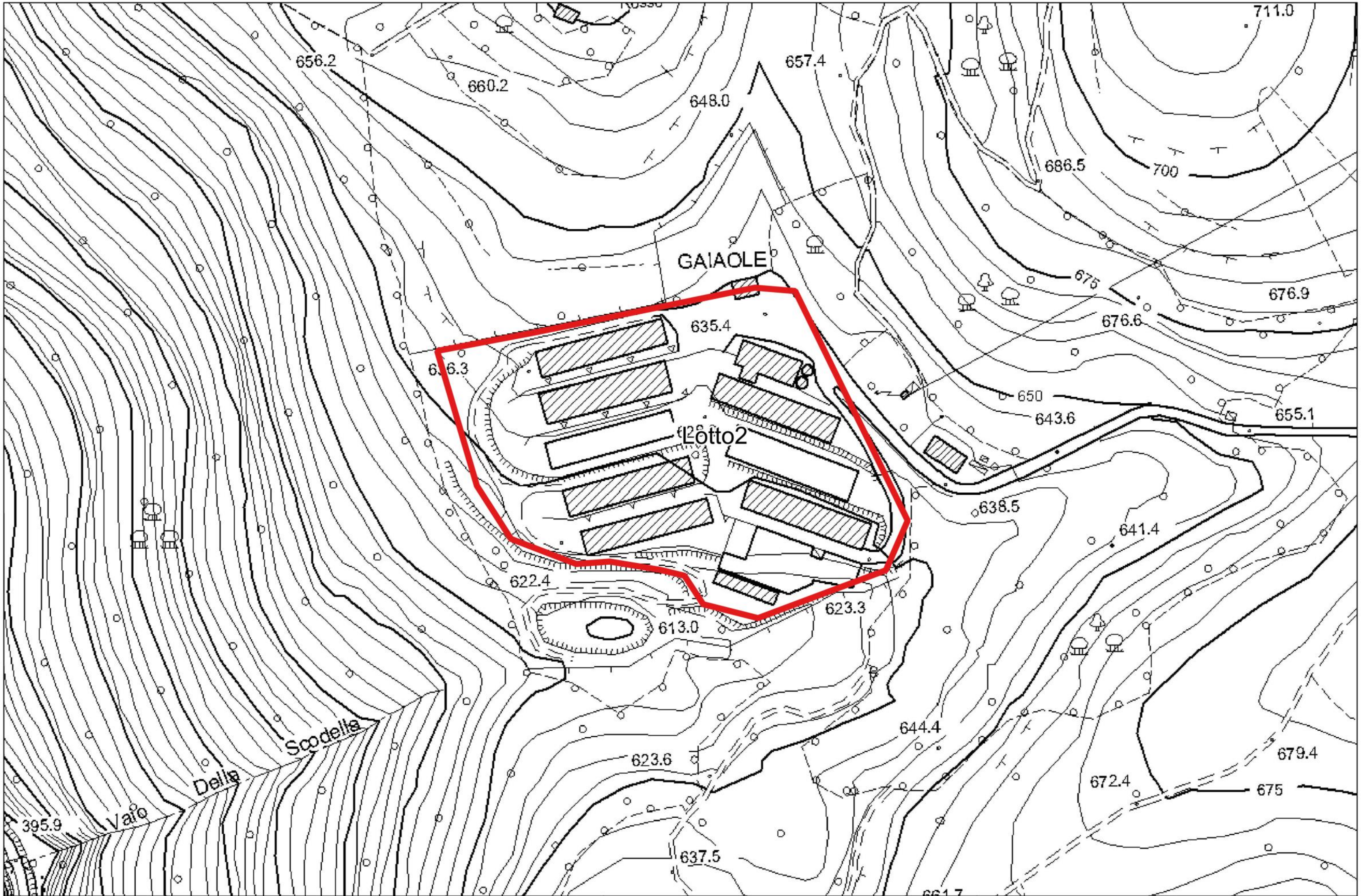
ID	Title	Scale
01	Satellite view	1:5000
02	Topography	1:2000
03	Soil type	1:5000
04	Land use and infrastructure	1:5000

The following tables summarize the features of the sites.

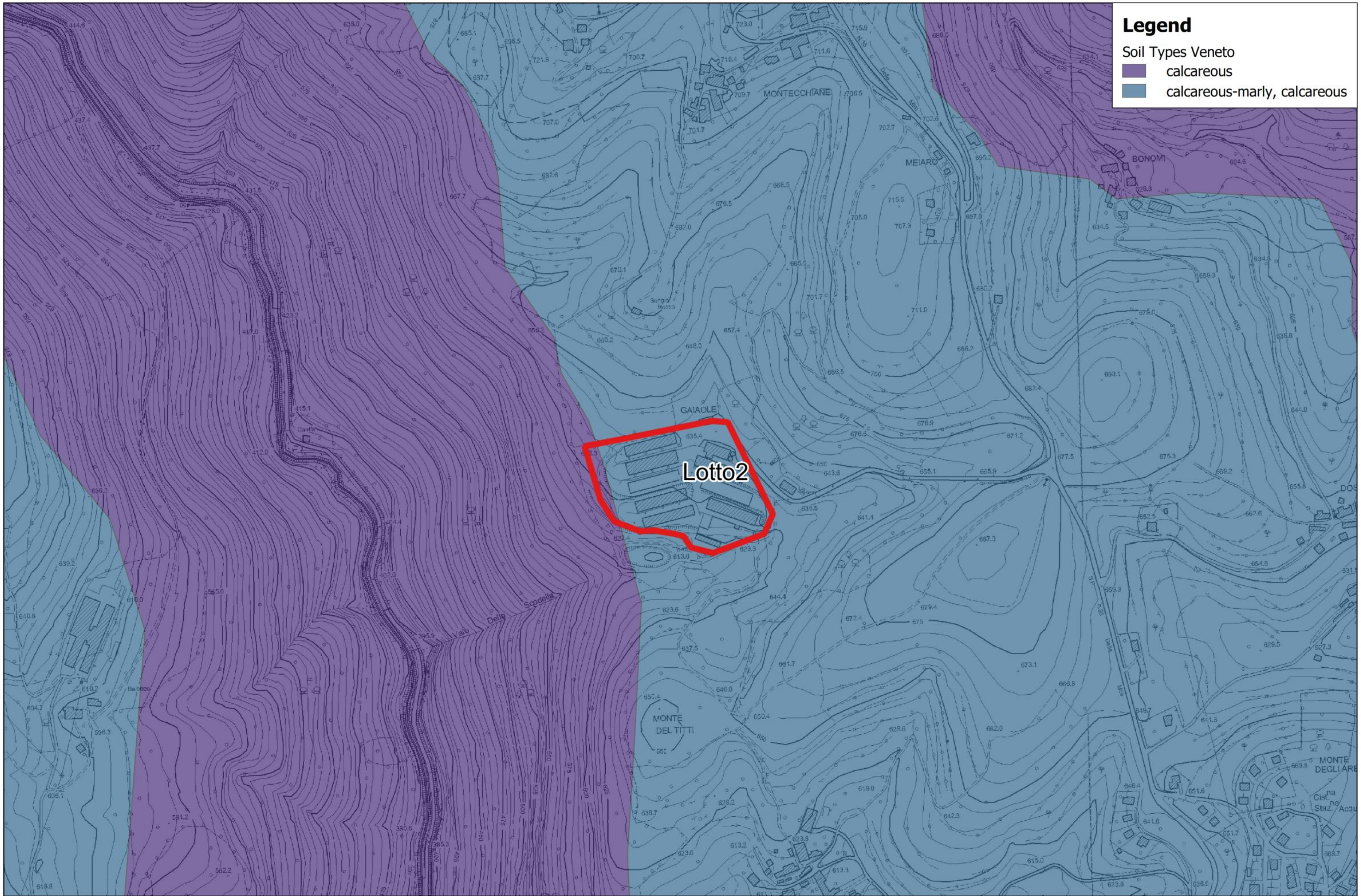
NBS	Features of Soil Type
Lotto2	Calcareous; Calcareous-marly, calcareous

NBS	Features of Land use and infrastructure (Corine)
Lotto 2	Non-irrigated arable land; Broad-leaved forest

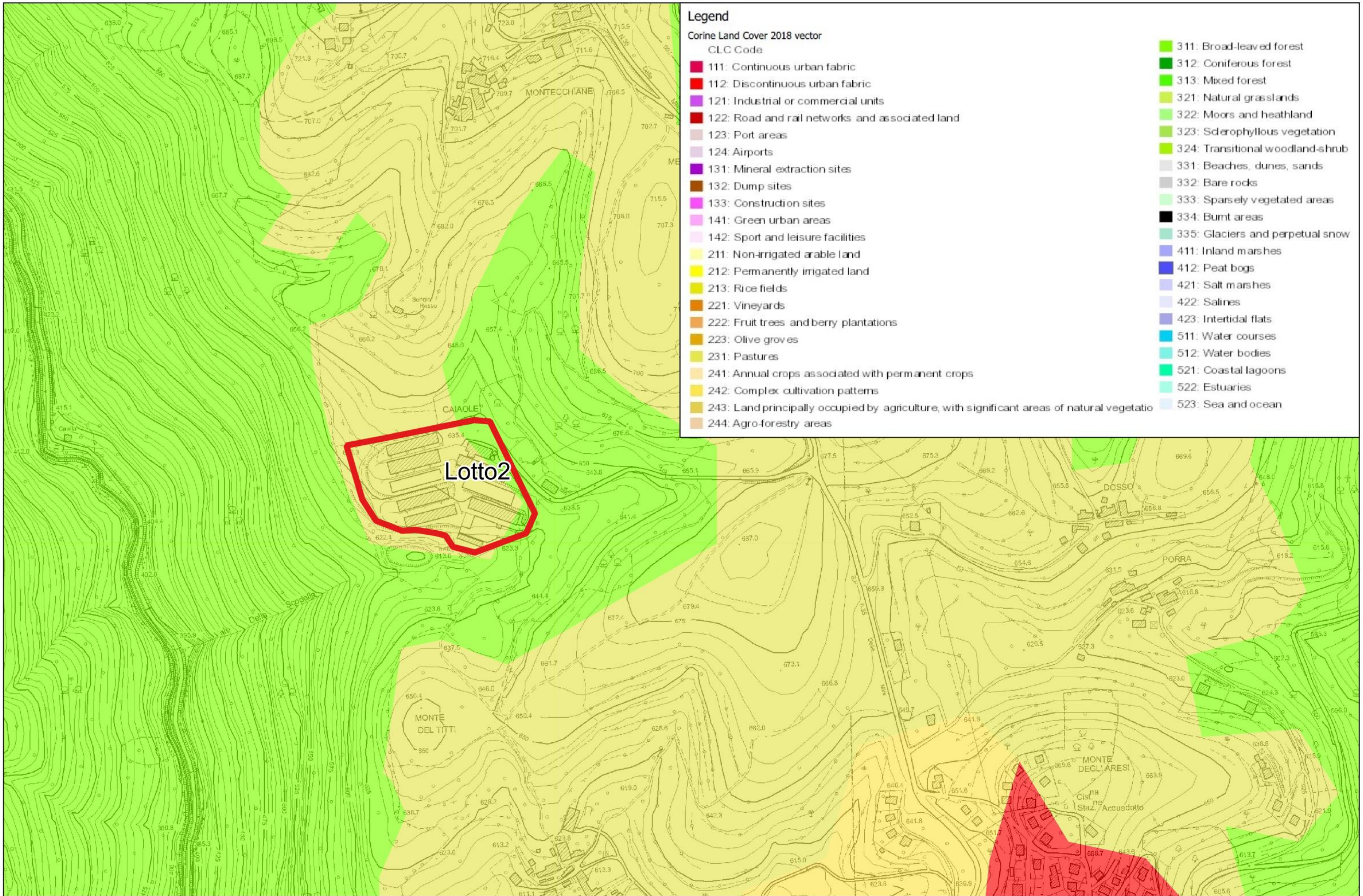
01	**NBS "Lotto 2"**	**Satellite View**	**Source: Google Satellite** **Access: April 2020**	0 100 200 300 400 500 m Scale 1:5000



02	**NBS "Lotto 2"**	**Topography**	**Source: Geoportale Regione Veneto** **Access: April 2020**



03	**NBS "Lotto 2"**	**Soil Types**	**Source: Geoportale Regione Veneto** **Access: April 2020**



04	**NBS "Lotto 2"**	**Land Use and infrastructure**	**Source: Corine Land Cover 2018 Access: April 2020**	0 100 200 300 400 500 m Scale 1:5000

ANNEX 2: Detailed climatic analysis

Annual climatic data of Verona from the Ministry of Agricultural, Food and Forestry Policies (MIPAFF)[19] are reported in **Table 28**.

Table 28. Climate data for Verona city from MIPAAF for the years 2009-2017

Year	MIPAAF	MIPAAF	MIPAAF	MIPAAF
	P	T_{MIN}	T_{MAX}	ET
	[mm]	[°C]	[°C]	[mm]
2009	796.3	8.5	18.4	857
2010	973.5	7.8	16.9	812.8
2011	736.1	8.4	18.8	920.9
2012	871	8.6	19	941.1
2013	1129.7	9.1	18.2	874.7
2014	1294.6	9.9	19	778.4
2015	642.3	9	19.2	893.8
2016	876.2	8.5	18.5	751.9
2017	803.2	8.1	19	832.9

Among the various measuring stations present in the Veneto region, the station nearest to the area under investigation is Grezzana - station n°128[20].

The monthly average climatic values, calculated as the average of the data recorded by the stations for the years 1994-2019, are shown in the **Table 29** and represented in **Figure 15** and **Figure 16**.

Table 29. Monthly average climatic values for the the years 1994-2019 for Grezzana station

Month	Rainfall	T_{max}	T_{med}	T_{min}
	mm	°C	°C	°C
January	49.9	7.6	3.2	-0.1
February	47.5	9.7	4.9	1
March	47.4	14.3	9	4.3
April	74.7	18.4	13	7.9
May	103.6	23.3	17.5	12
June	85.8	27.9	21.9	16
July	82.7	30.2	24.1	18.1
August	90.4	29.8	23.6	17.9
September	95.3	24.7	18.7	13.7
October	87.2	18.9	13.8	9.8
November	105.1	12.8	8.5	5.2
December	62.8	8.2	3.9	0.7

[19] https://www.politicheagricole.it (Access April 2020)
[20] ARAPV. https://www.arpa.veneto.it/bollettini/storico/ (Access March 2020)

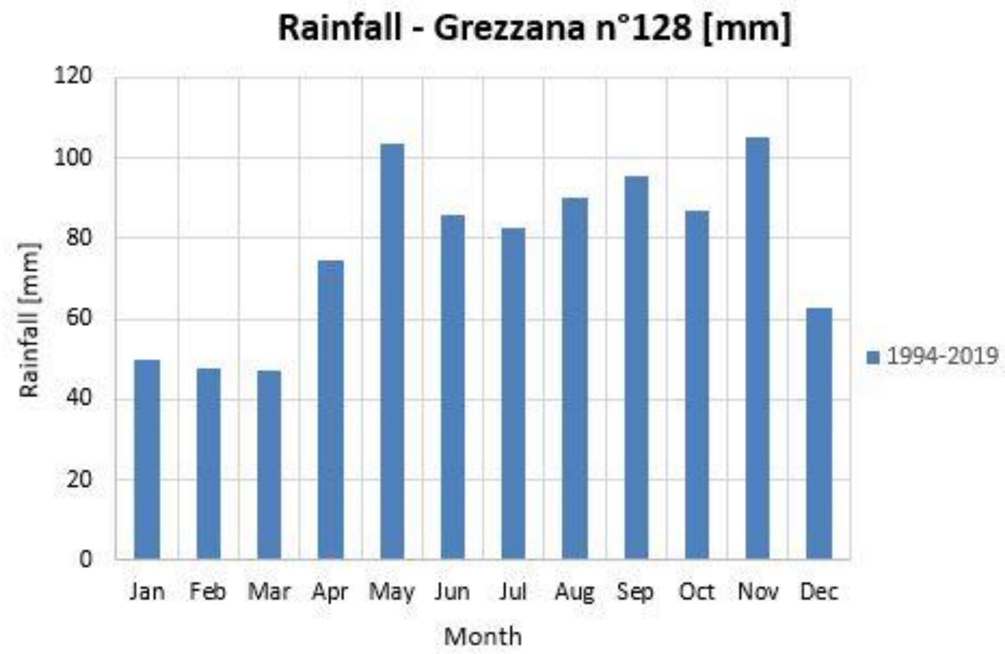


Figure 15. Monthly average rainfall (1994-2019) – Grezzana Station

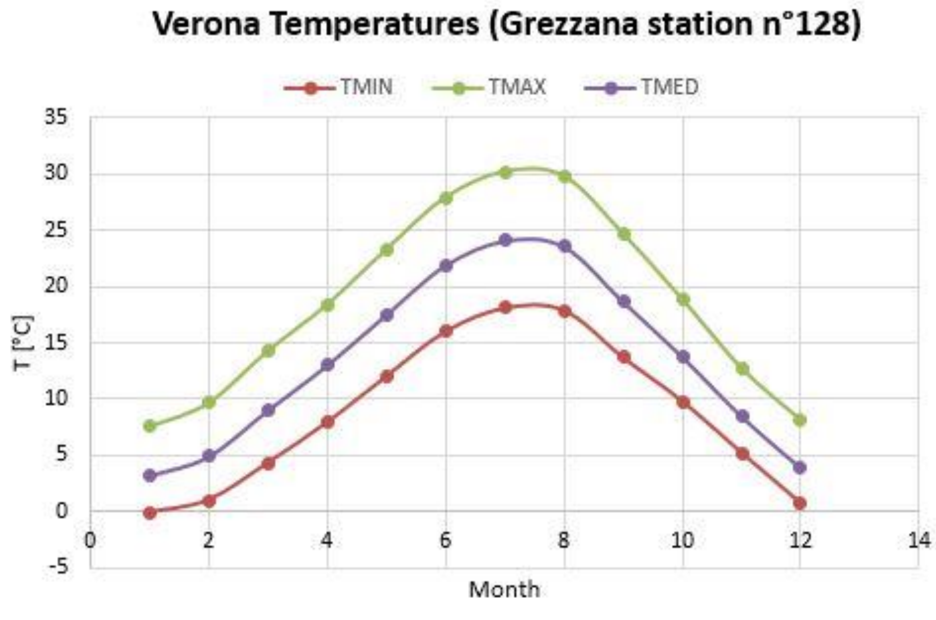


Figure 16. Monthly average temperatures (1994-2019) – Grezzana Station

The monthly average climatic values, for the years 2017-2018-2019, are shown in **Table 30** and **Table 31**.

Table 30. Monthly average rainfall for the Grezzana Station

Month	Rainfall		
	2017	2018	2019
January	14.00	42.00	25.00
February	73.60	37.20	70.80
March	19.60	84.60	8.80
April	87.20	82.80	110.00
May	42.80	149.20	237.60
June	42.80	54.60	7.20
July	39.60	74.40	96.60
August	12.20	75.20	99.20
September	99.60	250.80	106.60
October	32.80	131.20	53.20
November	77.40	107.60	267.60
December	56.20	36.80	84.40

Table 31. Monthly average temperatures for the Grezzana Station

Month	T_{max}			T_{med}			T_{min}		
	2017	2018	2019	2017	2018	2019	2017	2018	2019
January	6.40	10.10	7.60	0.90	5.90	2.90	-2.80	2.70	-0.90
February	10.50	7.00	13.40	6.50	3.60	6.90	3.30	0.70	2.40
March	17.40	10.90	16.40	11.50	7.00	10.10	6.40	3.70	4.60
April	19.10	21.70	17.90	13.70	15.80	13.10	8.60	10.50	8.60
May	23.80	24.20	19.00	17.90	18.80	14.20	12.40	13.70	10.10
June	30.30	28.10	30.90	24.10	22.40	24.70	17.80	16.60	18.30
July	31.10	30.90	30.90	24.80	24.90	25.10	18.40	19.00	19.40
August	32.40	31.50	30.60	25.90	25.40	24.60	19.50	19.70	19.20
September	22.80	26.70	25.10	17.30	20.20	19.30	12.90	15.40	14.50
October	19.90	21.20	20.10	14.10	15.60	15.30	9.80	11.20	11.70
November	12.20	14.10	13.50	7.70	10.20	10.10	4.30	7.40	7.00
December	7.60	8.40	10.60	3.20	3.50	6.00	-0.20	-0.30	2.60

Starting from the monthly temperature data recorded by the weather station, the monthly evapotranspiration value, expressed in mm/month, was defined applying the Thornthwaite method. Through the Thornthwaite formula it is possible to calculate potential evapotranspiration using only the climatic parameter of temperature and latitude.

$$ET_0 = 16\left(10\,\frac{T_i}{I}\right)^a L_i \qquad \text{Equation 1}$$

The annual thermal index "I" is defined according to the formula

$$\sum_{i=1}^{12} \frac{T_i}{5}^{1.514} \qquad \text{Equation 2}$$

where T_i is the average of the monthly temperatures. The parameter "a" is calculated according to the formula

$$a = 675x10^{-9}xI^{3} - 771X10^{-7}xI^{-5}xI + 0.49239 \qquad \text{Equation 3}$$

The parameter "L_i" is a corrective parameter to consider the latitude of the area under investigation.

Having fixed the north latitude of 45° for Verona, the L_i value is provided, for every month, in **Table 32**.

Table 32. Astronomical corrective values of ET_0 calculated according to the Thornthwaite's relation[21]

Latitudine	MESE											
Nord	G	F	M	A	M	G	L	A	S	O	N	D
39°	0,85	0,84	1,03	1,11	1,23	1,24	1,26	1,18	1,04	0,96	0,84	0,82
40°	0,84	0,83	1,03	1,11	1,24	1,25	1,27	1,18	1,04	0,96	0,83	0,81
41°	0,83	0,83	1,03	1,11	1,25	1,26	1,27	1,19	1,04	0,96	0,82	0,80
42°	0,82	0,83	1,03	1,12	1,26	1,27	1,28	1,19	1,04	0,95	0,82	0,79
43°	0,81	0,82	1,02	1,12	1,26	1,28	1,29	1,20	1,04	0,95	0,81	0,77
44°	0,81	0,82	1,02	1,13	1,27	1,29	1,30	1,20	1,04	0,95	0,80	0,76
45°	0,80	0,81	1,02	1,13	1,28	1,29	1,31	1,21	1,04	0,94	0,79	0,75

The average evapotranspiration calculated for the years 1999-2019 by the Grezzana weather station is shown in the **Table 33**, while monthly evapotranspiration for the years 2017-2018-2019 are reported in **Table 34**.

Table 33. Average monthly evapotranspiration for the Grezzana Station (yeas 1994-2019)

Month	ETP
	mm
January	5.1
February	9.6
March	29.0
April	54.6
May	95.0
June	132.3
July	154.2
August	138.2
September	84.9
October	49.5

[21] Antonio Leone; Ambiente e territorio agroforestale: linee guida per la pianificazione sostenibile e gli studi di impatto ambientale

Month	ETP
	mm
November	20.7
December	6.4

Table 34. Average monthly evapotranspiration for the Grezzana Station (yeas 2017-2018-2019)

Month	2017	2018	2019
	ETP	ETP	ETP
	mm	mm	mm
January	0.8	12.4	4.4
February	14.4	6.1	15.7
March	41.3	20.2	34.2
April	58.9	72.3	55.2
May	98.1	105.3	70.3
June	151.9	136.7	157.3
July	160.7	161.7	163.5
August	158.0	153.7	146.7
September	75.9	94.9	88.9
October	51.1	59.1	57.5
November	17.9	26.9	26.5
December	4.8	5.5	11.9

ANNEX 3: Water quality targets for industrial wastewater (d.lgs. 152/2006)

Water quality standard for discharge of industrial wastewater into surface water (Table 3, Annex 5 to part 3 of d.lgs 152/2006)

	Parameters	Unit	Discharges into Surface water
1	pH		5,5-9,5
2	Temperature	°C	-1
3	Colour		imperceptible after being diluted to 1:20
4	Odour		It does not have to be unpleasant
5	Coarse particles		absent
6	Total suspended solids (2)	mg/L	≤ 80
7	BOD_5 (in form of O_2) (2)	mg/L	≤ 40
8	COD (in form of O_2) (2)	mg/L	≤ 160
9	Aluminium	mg/L	≤ 1
10	Arsenic	mg/L	≤ 0,.5
11	Barium	mg/L	≤ 20
12	Boron	mg/L	≤ 2
13	Cadmium	mg/L	≤ 0.02
14	Total Chromium	mg/L	≤ 2
15	Chromium VI	mg/L	≤ 0.2
16	Iron	mg/L	≤ 2
17	Manganese	mg/L	≤ 2
18	Mercury	mg/L	≤ 0.005
19	Nickel	mg/L	≤ 2
20	Lead	mg/L	≤ 0.2
21	Copper	mg/L	≤ 0.1
22	Selenium	mg/L	≤ 0.03
23	Tin	mg/L	≤ 10
24	Zinc	mg/L	≤ 0.5
25	Total Cyanide (in form of CN)	mg/L	≤ 0.5
26	Free Active Chlorine	mg/L	≤ 0.2
27	Sulphide (H_2S)	mg/L	≤ 1
28	Sulphite (SO_3^{--})	mg/L	≤ 1
29	Sulphate (SO_4^{--})	mg/L	≤ 1000
30	Chlorine	mg/L	≤ 1200
31	Fluorides	mg/L	≤ 6
32	Total Phosphorus	mg/L	≤ 10

	Parameters	Unit	Discharges into Surface water
33	Ammoniacal Nitrogen (NH_4^+)	mg /L	$\leq$ 15
34	Nitrous oxide (as N)	mg/L	$\leq$ 0.6
35	Nitrite (as N)	mg /L	$\leq$ 20
36	Grease and animal/vegetal oil	mg/L	$\leq$ 20
37	Total Hydrocarbons	mg/L	$\leq$ 5
38	Phenols	mg/L	$\leq$ 0.5
39	Aldehydes	mg/L	$\leq$ 1
40	Aromatic organic solvents	mg/L	$\leq$ 0.2
41	Organic solvents of nitrogen	mg/L	$\leq$ 0.1
42	Total Surfactants	mg/L	$\leq$ 2
43	Pesticides containing phosphorus	mg/L	$\leq$ 0.10
44	Total Pesticides (excluding Pesticides containing phosphorus)	mg/L	$\leq$ 0.05
	Such as:		
45	- Aldrin	mg/L	$\leq$ 0.01
46	- Dieldrin	mg/L	$\leq$ 0.01
47	- Endrin	mg/L	$\leq$ 0.002
48	- Isodrin	mg/L	$\leq$ 0.002
49	Chloride Solvents	mg/L	$\leq$ 1
50	*Escherichia coli* (4)	UFC/100mL	Nota
51	Acute toxicity test (5)		The sample is not acceptable if after 24 hours the number of the immobile organisms is equal or 50% higher of the total number of organisms

Water quality standards for discharge of industrial wastewater on soil (Table 4, Annex 5 to part 3 of d.lgs 152/2006)

	Parameters	Unit	Values
1	pH		6-8
2	Sodium Adsorption Ratio (SAR)		10
3	Coarse particles	-	Absent
4	Total Suspended Solids	mg/L	25
5	BOD_5	mgO_2/L	20
6	COD	mgO_2/L	100
7	Total Nitrogen	mg N/L	15
8	Total Phosphorus	mg P/L	2
9	Total Surfactants	mg/L	0.5
10	Aluminium	mg/L	1
11	Beryllium	mg/L	0.1
12	Arsenic	mg/L	0.05
13	Barium	mg/L	10
14	Boron	mg/L	0.5
15	Total Chromium	mg/L	1
16	Iron	mg/L	2
17	Manganese	mg/L	0.2
18	Nickel	mg/L	0.2
19	Lead	mg/L	0.1
20	Copper	mg/L	0.1
21	Selenium	mg/L	0.002
22	Tin	mg/L	3
23	Vanadium	mg/L	0.1
24	Zinc	mg/L	0.5
25	Sulphide (H_2S)	mg H_2S /L	0.5
26	Sulphite (SO_3^{--})	mg SO_3^{--} /L	0.5
27	Sulphate (SO_4^{--})	mg SO_4^{-}/L	500
28	Active Chlorine	mg/L	0.2
29	Chlorine	mg Cl/L	200
30	Fluorides	mg F/L	1

31	Total Phenols	mg/L	0.1
32	Total Aldehydes	mg/L	0.5
33	Aromatic organic solvents	mg/L	0.01
34	Organic solvents of nitrogen	mg/L	0.01
35	Acute toxicity test (*Daphnia magna*)	LC5024h	The sample is not acceptable if after 24 hours the number of the immobile organisms is equal or 50% higher of the total number of organisms
36	*Escherichia coli*	UFC/100ml	