



Green Leather Industry for the Environment (greenLIFE) is a project run by a group of industry partners in Italy's Arzignano tanning cluster. The project partners have committed to sharing their findings by publishing a series of papers in World Leather. The fifth of six greenLIFE articles comes from the cluster's wastewater treatment service provider, Acque del Chiampo.

greenLIFE 5: Lifecycle assessment of the domestic and industrial wastewater treatment service at the Arzignano treatment works

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Introduction

Acque del Chiampo Spa is a company dedicated to the centralised 360-degree management of water supply, sewerage, wastewater treatment and sludge disposal services. More specifically, Acque del Chiampo manages the Arzignano treatment plant which, in addition to treating domestic wastewater from the seven municipalities in the Chiampo valley, also treats effluent from the tanning industry.

Acque del Chiampo is a partner in the

greenLIFE project, the aim of which is to develop and implement new leather tanning processes. The company's role is to provide technical-analytical consultancy services and process the analytical data obtained from effluents and, in part, the resulting by-products. Acque del Chiampo's aim is to assess the potential impact on the operation of the consortium treatment plant if the new processes being investigated were to be adopted by the tanneries, and subsequently by other (or all) affected businesses connected to the treatment plant.

In order to be able to assess the potential impact on the treatment activities created by the introduction of these new technologies, Acque del Chiampo has, in collaboration with Aequilibria, carried out a lifecycle assessment (LCA) of the treatment of the effluents arriving at the Arzignano treatment plant. The purpose is to determine the environmental impacts and then evaluate how these impacts could change in line with variations in the characteristics of the incoming industrial effluent.



1. Arzignano treatment plant

The Arzignano treatment plant was designed in the 1970s to treat industrial effluent from approximately 160 tanneries, connected directly to the plant through 40 kilometres of dedicated wastewater pipes, and domestic wastewater from approximately 40,000 inhabitants in the seven municipalities of the Chiampo valley. The plant has a capacity for a population equivalent (PE) of approximately 1,600,000.

The plant was built in stages and is currently undergoing extensive expansion and restructuring work designed to improve the capacity and treatment performance, in line with the increase in industrial activities and to comply with environmental standards.

The treatment plant covers an area of approximately 155,000 square metres and treats 12,000-15,000 m³/d of domestic wastewater and approximately 30,000 m³/d of industrial effluent from tanneries.

The plant is divided into two treatment lines:

- Water line, which treats the wastewater discharges, consisting of one line for industrial effluent and one line for domestic wastewater;
- Sludge line, which treats the sludge resulting from the wastewater treatment process.

1.1 Water Line

The water line of the Arzignano treatment plant receives different types of wastewater to treat:

- industrial effluent carried by a sewerage system dedicated specifically to the tanneries and liquid effluent transported to the plant by tankers;
- domestic wastewater from another sewerage system carrying wastewater originating from dwellings and other small- and medium-sized industrial and craft enterprises;

At the treatment plant, the two types of wastewater (industrial and domestic) are treated separately. The liquid flows are only combined at the end of the treatment, prior to a tertiary treatment process common to both types. This final treatment is called "clariflocculation".

Even though industrial effluents only account for around 55% of the flow, they account for around 90% of the organic load and other pollutants (see Table 1).

Table 1 - Characteristics of wastewater treated in 2014

Parameter	U.M.	Industrial Line	Domestic Line
pH		8.5	7.7
COD	mg/l	6117	152
TKN	mg/l	433	12
TSS	mg/l	2361	104
Chlorides	mg/l	2607	66
Sulfates	mg/l	1538	43
Sulfides (S=)	mg/l	63	-
Chrome (Cr ³⁺)	mg/l	74	0.148

The industrial line consists of a number of treatment phases, namely:

- screening;
- grit removal;
- homogenising;
- primary sedimentation;
- biological denitrification;
- biological oxidation-nitrification;
- flotation.

The treated effluent is then sent to the clariflocculation unit for the final treatment.

The domestic line consists of a number of treatment phases that have the same functions as the industrial line:

- screening;
- grit removal;
- storm water run-off storage;
- denitrification;
- biological oxidation;
- sedimentation;
- clariflocculation.

The wastewater treated in this manner is sent to an outfall pipeline that also receives treated wastewater from four other treatment plants. This line conveys and discharges the effluent, after ultraviolet disinfection, into a river at a point outside the groundwater recharge zone.

1.2 Sludge treatment line

The sludge separated during the industrial effluent and domestic wastewater treatment phases is treated in the sludge line. This sludge line consists of the following phases:

- dewatering;
- drying, with its annexed cogeneration.

2. Lifecycle assessment (LCA)

The lifecycle assessment (LCA) is a tool used to evaluate the environmental impact of a product through all the phases of its lifecycle. In other words, from raw material extraction, through

production, transport and use, to disposal ("cradle-to-grave"). It can be limited to just some phases of the cycle ("cradle-to-gate" or "gate-to-gate"). It is important to point out that the term "product" in this case refers to both goods and services. The LCA identifies the phases of the lifecycle with greatest impact and allows the intervention priorities to be determined.

The standards governing LCA (ISO 14040:2006 and ISO 14044:2006) indicate the following four distinct study phases:

- **Goal and scope definition**

Preliminary phase, which defines the aims of the study, the functional unit (FU), the system boundaries, the communication requirements and the critical review considerations.

- **Inventory analysis**

Includes the collection and processing of data relating to the input and output flows of the different phases during the lifecycle of the product being studied.

- **Impact assessment**

Assessment of the impacts relative to the different impact categories considered.

- **Interpretation**

The interpretation involves not only the final results but also the preceding phases, which could be remodelled according to need through an iterative process.

3. LCA scope of application

3.1 System boundaries

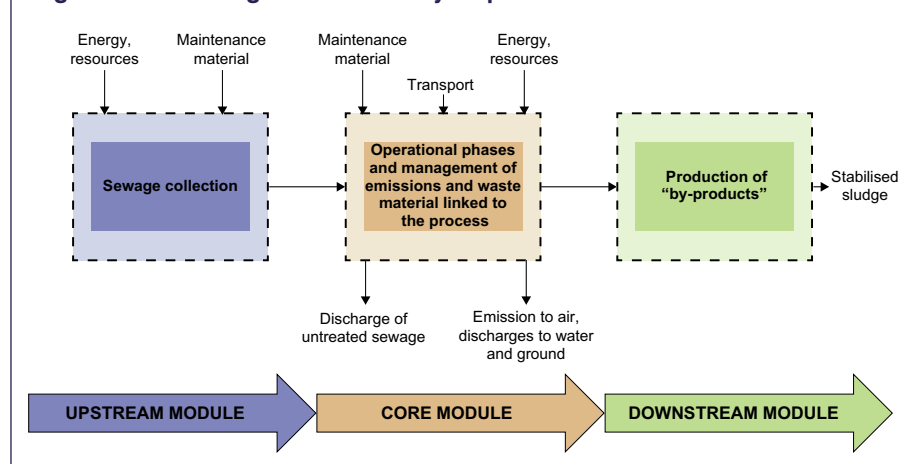
The system boundaries identify the process units to include in the LCA.

This particular LCA is a "cradle-to-grave" study and, as a result, considers all the lifecycle phases from raw material extraction, necessary for the treatment process, up to the final disposal of the sludge.

The study includes the phases detailed in Figure 1, applied to the three principal modules: upstream, core and downstream.

It was decided to exclude the sewerage system and the treatment plant construction and dismantling phase from the study. This decision is backed-up by various studies that have documented the fact that these phases have a negligible impact.

As far as this study is concerned, the upstream module includes processes relating to the collection of wastewater, in particular the maintenance of the sewerage system (with the relative

**Figure 1 - Flow diagram of the lifecycle phases**

materials used), the electricity consumption of the pumping systems and the transport of wastewater to the treatment plant by tankers.

The pre-treatment processes carried out by the tanneries (screening, pH balancing and hair recovery) are excluded from the upstream module. It is considered, in fact, that the pre-treatment processes are tannery functions and are included within their system boundaries and not those of the treatment plants.

The core module includes:

- production of the chemical reagents applied in the various phases;
- the material used for plant maintenance;
- the production of polypropylene big bags for disposing of screenings, grit, sludge and for the sale of sulphur;
- the transport of the reagents and big bags from the production site to the plant;
- the energy consumption of the entire works (in terms of electricity and natural gas);
- the production of electricity through cogeneration and a photovoltaic plant;
- the various materials used for plant maintenance;
- the production and transport of elemental sulphur produced by odour abatement using a catalytic column (called the LO-CAT system);
- the quantities of produced waste (except in the case of sludge, which is considered in the downstream phase) and its disposal by landfill;
- the transport of waste produced by the plant to the treatment/recovery site.

All the systems/processes that ensure that the treated wastewater to be

discharged complies with discharge legislation are included within the system boundaries. Acque del Chiampo discharges its effluent into the sewerage system managed by the A.Ri.C.A Consortium (Aziende Riunite Collettore Acqua), which determines the discharge limits to be respected. Consequently, the system boundaries finish at the discharge into the sewer.

The downstream module concerns the production of by-products, including dewatered and dried stabilised sludge which is disposed of in landfill.

3.2 Temporal boundaries

The study refers to the entire year of 2014. The selected specific and general data refers to that period only.

3.3 Declared unit

The main purpose of the declared unit is to provide a reference to which the incoming and outgoing flows can be linked. The declared unit was one cubic metre of wastewater treated by the treatment plant.

4. Environmental impacts

The impact categories considered were as follows:

- Global warming potential: kg CO₂ (carbon dioxide) equivalents
- Ozone layer depletion: kg CFC-11 (trichlorofluoromethane) equivalents
- Fresh water aquatic ecotoxicity: kg 1.4-DB (dichlorobenzene) equivalents
- Marine aquatic ecotoxicity: kg 1.4-DB (dichlorobenzene) equivalents
- Photochemical oxidation: kg C₂H₄ (ethylene) equivalents
- Acidification: kg SO₂ (sulphur dioxide) equivalents
- Eutrophication: kg PO₄³⁻ (phosphate) equivalents

5. Results and considerations

The distribution of the impacts and resource consumption for the lifecycle phases is summarised in Table 2.

The significant processes are:

- Arzignano plant electricity consumption;
- Arzignano plant thermal energy (natural gas) consumption;
- cogeneration system;
- discharge to receiving watercourse;
- sludge disposal to landfill.

Table 3 reports the percentage impacts on the total of the five processes for each impact category.

To better assess the environmental impact created by the wastewater treatment service, it would be useful to also take into account the benefits deriving from the treatment, in particular of the industrial effluent.

In this particular study, it was decided to compare the impact assessment results for the treatment service offered by the Arzignano treatment plant using

Table 2 - Quantification of the total environmental impacts

1 m ³ of wastewater treated by the Arzignano plant in 2014			UPSTREAM	CORE	DOWN STREAM
Impact category	Unit of measurement	Total	Wastewater collection	Wastewater and sludge treatment process	Sludge disposal landfill
Global warming	kg CO ₂ eq	5.59E+00	2.05E-02	3.46E+00	2.11E+00
Ozone layer depletion	kg CFC-11 eq	4.14E-07	3.17E-09	3.90E-07	2.09E-08
Fresh water aquatic ecotoxicity	kg 1.4-DB eq	5.85E-01	1.02E-02	4.58E-01	1.17E-01
Marine aquatic ecotoxicity	kg 1.4-DB eq	1.74E+03	2.48E+01	1.40E+03	3.12E+02
Photochemical oxidation	kg C ₂ H ₄ eq	7.90E-04	3.82E-06	5.38E-04	2.48E-04
Acidification	kg SO ₂ eq	9.48E-03	9.03E-05	7.94E-03	1.45E-03
Eutrophication	kg PO ₄ ³⁻ eq	8.39E-02	4.36E-05	7.70E-03	6.48E-04

**Table 3 - % impacts on the total of the selected processes**

Impact category	Unit of measurement	Electricity consumption	Natural gas consumption	Cogeneration	Discharge to receiving watercourse	Sludge disposal to landfill
Global warming	kg CO ₂ eq	24.67%	12.88%	13.13%	0	37.73%
Ozone layer depletion	kg CFC-11 eq	35.62%	25.84%	23.75%	0	5.06%
Fresh water aquatic ecotoxicity	kg 1.4-DB eq	47.27%	4.58%	3.68%	4.45%	19.94%
Marine aquatic ecotoxicity	kg 1.4-DB eq	55.07%	4.66%	3.99%	0.91%	17.95%
Photochemical oxidation	kg C ₂ H ₄ eq	34.47%	8.07%	11.06%	0	31.43%
Acidification	kg SO ₂ eq	52.07%	7.56%	11.21%	0	15.26%
Eutrophication	kg PO ₄ ³⁻ eq	16.16%	2.00%	3.13%	62.56%	7.72%

the following scenarios:

- “no treatment” scenario;
- bibliographic scenario.

This approach could also be used for other similar studies to simplify the comparison between the environmental benefits and the environmental impacts of the treatment service.

For the comparison of the scenarios, only the impacts of the three categories concerning water quality (fresh water ecotoxicity, sea water aquatic ecotoxicity and eutrophication) were considered. This enabled the comparison to focus on the benefits linked to the reference origin of the wastewater discharges to be treated.

5.1 “No treatment” scenario

In this case, the impacts that the wastewater arriving at the Acque del Chiampo plant would have if it were discharged directly into the receiving watercourse, in the absence of the treatment plant, were calculated. In order to not underestimate the impact of the wastewater, it was decided to enter the parameters of the industrial effluent only in that the pollutant load derives mainly from the industrial line.

From the comparison between the Arzignano treatment plant data and that of the “no treatment” scenario (*Table 4*), substantial environmental benefit can be seen in both the “fresh water aquatic ecotoxicity” and “eutrophication” categories due to the presence of the treatment plant. In particular, for the “eutrophication”, the presence of the treatment plant results in a 98% reduction in the impacts.

The “marine aquatic ecotoxicity” has distinctly greater impacts. The energy consumptions contribute more than 63% to the calculated impact of the marine aquatic ecotoxicity, both in terms of magnitude and quality (type) of

resource with which it was produced (national energy mix). This can be attributed principally to the coal mining operations, as confirmed by the Ecoinvent dataset. Such a clear difference places some doubt regarding the impact components on which the assessment is based. As such, this would benefit from further investigation.

Consideration must also be given to the fact that the comparison is based on just one cubic metre of treated wastewater, whereas the Arzignano plant treats around 15.2 million m³ per year. In order to be able to carry out an assessment in absolute terms of the impact variation in the two scenarios, it would be necessary to also take into consideration the overall mass of pollutants discharged during the year and not just those contained in the one

cubic metre of treated wastewater. This has an effect on the self-purification capacity of the watercourse and worsens the impact that cannot be accounted for when analysing the characteristics of one cubic metre of treated wastewater.

5.2 Bibliographic scenario

Research within the Ecoinvent database identified the process “Wastewater, average {RoW} | treatment of, capacity 1.1E10 l/year | Alloc Rec, U”. This process represents an average size municipal plant of capacity 11 million cubic metres per year that treats domestic wastewater from a declared 71,100 population equivalent (PE). The parameters of the treated wastewater from this dataset are compared with the specific monitoring data from the Arzignano plant (*Table 5*). Unfortunately, the database does not contain an industrial effluent treatment process, which would have been closer to the characteristics of the Acque del Chiampo plant. A comparison between the data from the Arzignano treatment plant and secondary bibliographic data from the database was nevertheless carried out, even if the plant is not comparable with the Arzignano treatment plant, which had a total treated volume in 2014 of 1,260,500 PE purely for the industrial line, to which the previously mentioned domestic part

Table 4 - Comparison between “no treatment” and Arzignano treatment plant scenarios

Impact category	Unit of measurement	No treatment scenario	Arzignano treatment plant	% difference between no treatment and the Arzignano treatment plant
Fresh water aquatic ecotoxicity	kg 1.4-DB eq	0.90	0.59	-35.32%
Marine aquatic ecotoxicity	kg 1.4-DB eq	187.06	1,737.70	828.96%
Eutrophication	kg PO ₄ ³⁻ eq	0.49	0.008	-98.29%

Table 5 - Comparison between the bibliographic and Arzignano treatment plant scenarios

Impact category	Unit of measurement	Bibliographic scenario	Arzignano treatment plant	% difference between bibliographic and the Arzignano treatment plant
Fresh water aquatic ecotoxicity	kg 1.4-DB eq	0.48	0.59	21.72%
Marine aquatic ecotoxicity	kg 1.4-DB eq	673.53	1,737.70	158.00%
Eutrophication	kg PO ₄ ³⁻ eq	0.013	0.008	-37.24%



must be added, i.e. 1,283,500 PE, well over 44 times higher.

The impacts of the bibliographic scenario are lower than for the Arzignano scenario analysed, though the difference between the two is not very significant considering that the bibliographic scenario refers to the treatment of domestic wastewater, while the Arzignano plant treats mostly industrial effluent from tanning activities. Comparable values can, in fact, be found in the “fresh water aquatic ecotoxicity” and “eutrophication” categories.

It can also be seen that, in the bibliographic scenario, the extent of the impact in the “marine aquatic ecotoxicity” category is not dissimilar to the Arzignano treatment plant scenario. On the one hand, this confirms the general reliability of this study and, on the other, the importance that the energy consumptions have on the “marine aquatic ecotoxicity” impact category, as already highlighted in section five.

6. Initial conclusions

The results of the impact assessment have primarily brought to light how the main impact of the plant is in the core phase and is linked to the consumption of electricity. This is clearly due to the high consumptions that the plant must endure for the wastewater treatment and the sludge treatment process. Most of the electricity is consumed in the wastewater treatment line, in particular in the biological oxidation lines (approx. 70%). High consumptions were also recorded during the sludge drying (14%) and flotation (10%) phases.

The consumption of natural gas was also quite high and is principally due to sludge treatment, used to remove as much water as possible from the sludge after the mechanical dewatering phase, reducing the quantities to send to landfill. 52% of the gas is consumed directly during drying, while 47% is used for the cogeneration plant that produces heat for the sludge drying and electricity.

Significant impacts are also linked to the downstream phase and, in particular, to the disposal of wastewater sludge and the gradual release of pollutants over time, arriving at 38% of the overall impact in terms of “global warming” and approximately 31% for “photochemical oxidation”.

The analysis of the environmental impact linked to wastewater treatment cannot overlook the enormous environmental benefits of the

wastewater treatment process itself, wastewater that would otherwise seriously pollute the watercourse into which it is discharged.

7. A step forward

In the last phase of the project, Acque del Chiampo conducted a lifecycle assessment to analyse the potential environmental impacts if all the tanneries based in Arzignano adopted one of two new liming processes.

7.1 Conventional liming with bath recovery and sludge recovery after sedimentation

Should this new liming technology be adopted throughout the Arzignano tanning district, it would be possible to reach important environmental goals such as:

- 24% reduction in sludge production;
- 6% decrease in electricity consumption;
- 12% drop in methane consumption;
- 2% decrease in the use of chemical reagents.

Reducing the use of energy and chemical products, as well as decreasing sludge production, would result in significant improvement in the impact categories analysed (*Table 7*).

7.2 Oxidative liming with sludge recovery after precipitation with phosphoric acid

In this second case, the adoption of the new liming technology throughout the Arzignano tanning district would result in the following improvements:

- 21% reduction in sludge production;
- 10% decrease in electricity consumption;
- 10% in methane consumption;
- 3% decrease in the use of chemical reagents.

This would lead to improvements in the impact categories analysed (*Table 8*).

The scenario analysis of these two methods has proven to be a useful programming tool that has enabled:

- the evaluation, through the calculation of LCA, of the changes in the environmental impact of the water treatment process should the new liming processes be adopted;
- the stimulation of a cooperative approach, also desirable for the future, to assess the effects of the introduction of different processes that would affect the eco-sustainability of the Arzignano district;
- the provision of new ideas for the future development of the LCA methodology. 🌱

Table 7: Effect on environmental impacts of conventional liming with bath recovery and sludge recovery after sedimentation.

Impact category	Unit of measurement	Upstream	Core	Downstream	Whole cycle
Global warming potential	kg CO ₂ eq	0.0%	-4.9%	-25.4%	-12.6%
Ozone layer depletion	kg CFC-11 eq	0.0%	-5.8%	-21.6%	-6.6%
Fresh water aquatic toxicity	kg 1.4-DB eq	0.0%	-2.3%	-21.6%	-6.1%
Marine aquatic toxicity	kg 1.4-DB eq	0.0%	-2.6%	-21.6%	-5.9%
Photochemical oxidation	kg C ₂ H ₄ eq	0.0%	-3.9%	-21.6%	-9.4%
Acidification	kg SO ₂ eq	0.0%	-3.5%	-21.6%	-6.2%
Eutrophication	kg PO ₄ ³⁻ eq	0.0%	-0.4%	-21.6%	-1.8%

Table 8: Effect on environmental impacts of oxidative liming with sludge recovery after precipitation with phosphoric acid.

Impact category	Unit of measurement	Upstream	Core	Downstream	Whole cycle
Global warming potential	kg CO ₂ eq	0.0%	-6.3%	-22.5%	-11.9%
Ozone layer depletion	kg CFC-11 eq	0.0%	-6.9%	-17.9%	-7.4%
Fresh water aquatic toxicity	kg 1.4-DB eq	0.0%	-5.6%	-17.9%	-8.0%
Marine aquatic toxicity	kg 1.4-DB eq	0.0%	-6.3%	-17.9%	-8.3%
Photochemical oxidation	kg C ₂ H ₄ eq	0.0%	-6.2%	-17.9%	-9.8%
Acidification	kg SO ₂ eq	0.0%	-6.6%	-17.9%	-8.2%
Eutrophication	kg PO ₄ ³⁻ eq	0.0%	-0.9%	-17.9%	-2.0%