Ref. Ares(2018)3765067 - 16/07/2018

ECWRTI | TOTAL WATER RECYCLING IN TEXTILE INDUSTRY

LCA case study report

Deliverable 2.8

TOTAL WATER RECYCLING
IN TEXTILE INDUSTRY

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Deliverable title & number
Deliverable 2.8: LCA case study report

Type & dissemination level
Public

Lead beneficiary name & contact details
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Due date (according to GA)
28 February 2018

Actual submission Date
16 July 2018

Contents

1. Summary

Global freshwater availability is under permanent stress. Increasing population will rise the global water consumption dramatically over the coming years, leading to an increasing stress on available freshwater sources, increased local drought risks and reducing the availability of potable water for consumption. On this background the EColoRO concept was developed to remove the majority of all pollutants, colorants and chemicals from wastewater. The goal is to close the water loop by separating the water, organometallics and salty brine and creating a produced clean water that can be fully re-used.

The ECWRTI project (Electro Coagulation for Water Recycling in Textile Industry) sets a leading industrial example by demonstrating the scale-up of the EColoRO concept in the textile sector. To evaluate the environmental effect of EColoRO a Life Cycle Assessment LCA) has been conducted. The analyses have been done for two different textile plants in two regions, Belgium and Italy.

For the plant at Utexbel in Belgium a significant reduction of environmental impacts by factors of 2 to 3 can be achieved implementing EColoRO. This result has been validated by performing uncertainty calculations with Monte Carlo analysis and sensitivity analysis. Hence, the results are significant.

The main reasons for this result are:

- Reduction in water use:
  Belgium has medium water scarcity, similar to e.g. the Netherlands, Italy or Spain. If the EColoRO technique were applied to a region with high water stress, like the South of Spain or Algeria, or even extreme water stress like Jordan or Oman, the benefits would be even higher. The worse the water scarcity situation, the bigger the advantages of EColoRO.
- Reduction of water pollutants:
  Utexbel has no pre-treatment of wastewater. The wastewater goes to the municipal WWTP. The reduction of pollutants with EColoRO by 30% to 90% leads to a discharge of the municipal WWTP and in consequence to lower emissions to the water body.

Of course, the operation of the EColoRO technique is linked with environmental burdens, but they are lower than the benefits. The following improvements would lead to lower environmental impacts:

- reduced energy consumption
- type of electricity used
- reduction of the pollutants in waste water
- higher percentage of water reuse

The assessment of the textile plant Tintoria Pavese has shown that there is an environmental improvement using EColoRO technology compared to the current situation. However, the reductions are not as high as at the Utexbel textile plant in Belgium. The reasons for this result are:

- The region of Pavia has low water scarcity at the present. There is enough water from the Alps. This could probably change in the future, which would lead to a higher benefit of the EColoRO technology compared to the results given in this report for the base scenario.
- Tintoria Pavese does water pre-treatment with a Fenton reactor. For the pollutants where no data was available regarding the elimination rate of the EColoRO technology the experts assumed the same elimination rate as with a Fenton reactor. This is a conservative assumption. Presumably, the elimination rate of EColoRO is higher.

Based on the results of these two case studies the implementation of EColoRO technology in textile plants can be recommended from an environmental point of view. Especially in regions with medium or higher water stress, or in the case of textile plants with no waste water pre-treatment, the benefit of the EColoRO technology is very high.

2. Introduction

Global freshwater availability is under permanent stress. The United Nations Environment Programme (UNEP) has calculated that due to increasing population the global water consumption will rise dramatically over the coming years, leading to an increasing stress on available freshwater sources, increased local drought risks and reducing the availability of potable water for consumption. It is very clear that both European Environment Agency (EEA) and the UNEP call for action to increase the efficiency in water use. Quoting the UNEP 5 report: "Increasing water-use efficiency in all sectors is vital to ensure sustainable water resources for all uses".

On this background the EColoRO concept was developed. The core of the concept is formed by Electro Coagulation followed by several membrane treatment steps. Electro coagulation is an energy efficient additive-free process to remove the majority of all pollutants, colorants and chemicals from wastewater. The goal is to close the water loop by separating the water, organometallics and salty brine and creating a produced clean water that can be fully re-used.

The ECWRTI project (Electro Coagulation for Water Recycling in Textile Industry) sets a leading industrial example by demonstrating the scale-up of the EColoRO concept. In the project the EColoRO concept will be demonstrated on full industrial scale in the textile sector. The textile sector is selected as the prime sector for full-scale demonstration because it poses some unique challenges, for instance the sector is highly water intensive and characterized by producing wastewater that is difficult to treat.

The application of the EColoRO concept will lead to a reduction in water consumption and will have an environmental benefit regarding this important topic. On the other hand, energy, equipment and auxiliary substances are used and the provision of them is also linked with environmental impacts and resource depletion. The question therefore arises if, in an assessment taking into account all the different environmental impacts, the overall burden from the EColoRO process is lower than its benefits. To answer this question a Life Cycle Assessment LCA) will be conducted. This LCA study has the following tasks:

- Evaluating the differences in impacts of textile manufacturing without and with EColoRO concept in two textile manufacturers.
    - At Utexbel in Belgium the following two cases will be analyzed:
        - Current operation
        - Fully implemented EColoRo concept – full recycling of water
    - At Tintoria Pavese in Italy the following two cases will be analyzed:
        - Current operation with Fenton process for waste water treatment (WWT)
        - EColoRO concept without water reuse
        - Fully implemented EColoRO process with water reuse.

The institute of Ecopreneurship from the University of Applied Science Northwestern Switzerland (FHNW) was selected to do this LCA study, because it has two leading experts in the field of LCA and WWT among its staff. Dr Fredy Dinkel has more than twenty-five years of experience in conducting LCA studies and has expert knowledge in LCA of WWT. Prof Dr Thomas Wintgens is a well-known expert in water technologies.

3. Methodological approach

To evaluate the environmental impact of a product, process or a system the most comprehensive method today is Life Cycle Assessment (LCA). Characterizations of this method are:

- It considers not only few single substances or resources but a wide range of different emissions and their environmental impacts as well as the use of the different resources.
- It considers not only local emissions but also the whole life cycle of a product or system.
- It evaluates the different environmental impacts to meaningful indicators allowing decision making
- It is based on scientific models.

LCA is a method accepted worldwide and according to the European Union *"LCAs provide the best framework for assessing the potential environmental impacts of products or systems currently available".*
Experts from industry, government, and other organizations agree that conducting life cycle approaches is part of the way we design products, develop services, make policies and decide what to consume or what not to consume. Therefore, LCAs will help to halt and possibly reverse some of the damaging trends in our communities and environments.

3.1. Life cycle assessment (LCA) – background

In the life cycle approach the emissions to the environment and the resources used for a product, a company, a service or a system are gathered all the way from resources to reuse, recycling or disposal. This is also called "from cradle to grave". This set of emissions and use of resources is then evaluated according to their environmental impacts. The results of this assessment can be used to detect hot spots, to find efficient optimisation potentials as well as to evaluate different options according to their environmental effects. Furthermore, the results of an LCA can easily be combined with economic figures, allowing interpretation of the eco-efficiency of systems and to determine how money is best invested.

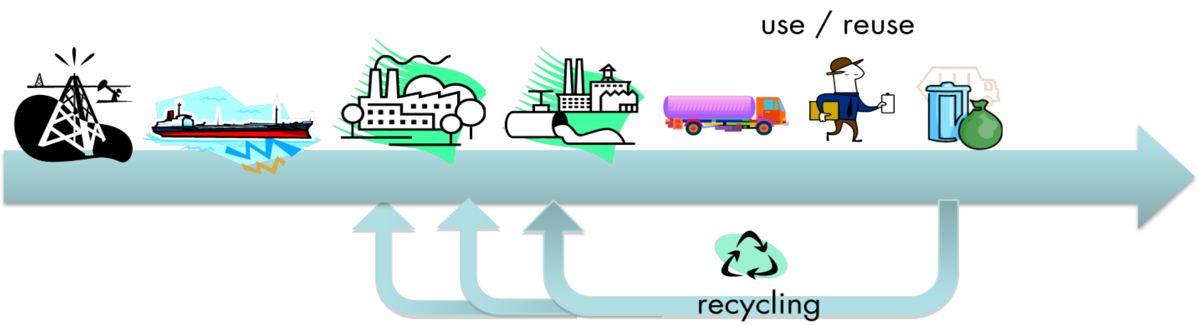


Figure 1 **Life Cycle Assessment: the evaluation of environmental impacts from cradle to grave.**

According to ISO 14040ff (ISO 14044, 2006, S. 14), an LCA study consists of the following four steps:

1. Defining the **goal and scope** of the study.
2. Establishing a model of the product's life cycle with all the environmental inflows and outflows. This data collection effort is usually referred to as the life cycle **inventory** (LCI) stage.
3. Understanding the environmental relevance of all the inflows and outflows; this is referred to as the life cycle **impact assessment** (LCIA) phase.
4. The **interpretation** of the study.

As shown in Figure 2, this is not a linear process but an iterative process. This means that one starts with initial choices and initial requirements that can later on be adapted as more information becomes available or if the results show that further information is needed.

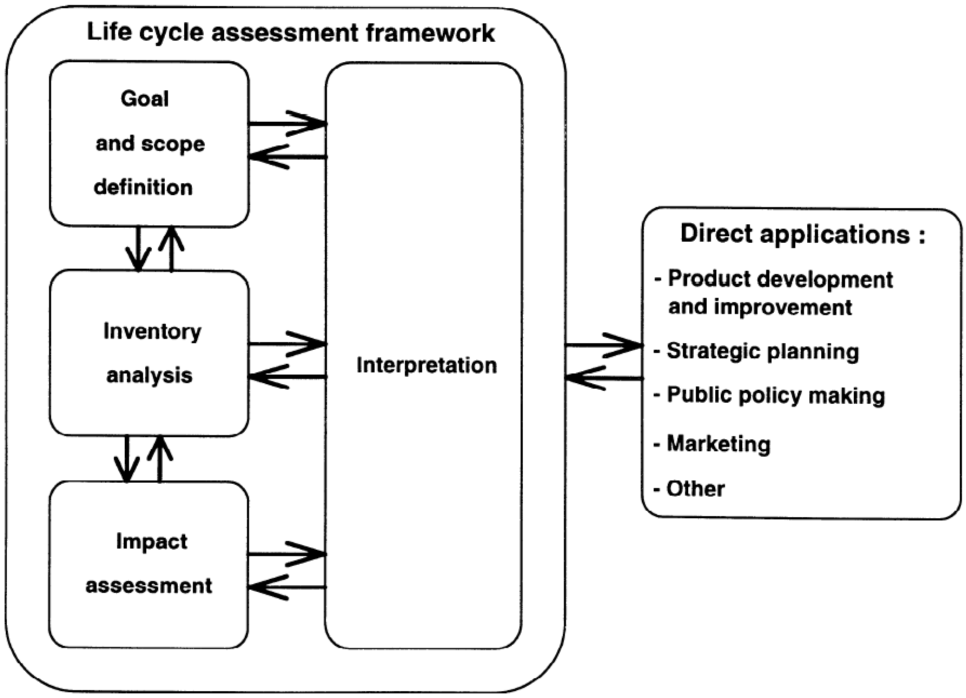


Figure 2 **Steps in Life cycle assessment, according to ISO 14040ff**

3.1.1. Goal and scope

The goal of the study is to evaluate the differences in environmental impacts of textile plants without and with ECoIoRO concept in two European textile manufacturers.

- At Utexbel in Belgium the following two cases will be analyzed:
  - Current operation
  - Fully implemented ECoIoRo concept – 70% recycling of water
- At Tintoria Pavese in Italy the following two cases will be analyzed:
  - Current operation with Fenton process for waste water treatment (WWT)
  - ECoIoRO concept without water reuse
  - Fully implemented ECoIoRO process with 70% water reuse.

Therefore, mainly the following questions have to be answered:

- Does the ECoIoRO concept lead to a reduction of environmental impacts compared to the current situation?
- Where are the sources of the relevant environmental impacts?
- Do improvement potentials exists?

The scope of the study describes the most important methodological choices, assumptions and limitations, like the description of the system under study, the system boundaries and the basis for the comparison, the so called functional unit.

System boundaries

In accordance with the goal of the study the focus is placed on the aspects impacted by the new ECoIoRO concept. This means the system boundaries are set so that the following aspects will be taken into account:

- Fresh water intake and water scarcity in the region
- Water discharge to the environment, therefore also the WWTP, where the wastewater is treated, has to be taken into account
- Quality of the water discharge
- Energy and chemical consumption due to the ECoIoRO plant
- Infrastructure used for the ECoIoRO process
- All the upstream processes to deliver the energy, materials and services for the ECoIoRO process.

The textile plant itself, the chemicals, other materials than water and energy used in the textile plant are outside the system boundaries; see also Figure 3 and Figure 4, dotted line.

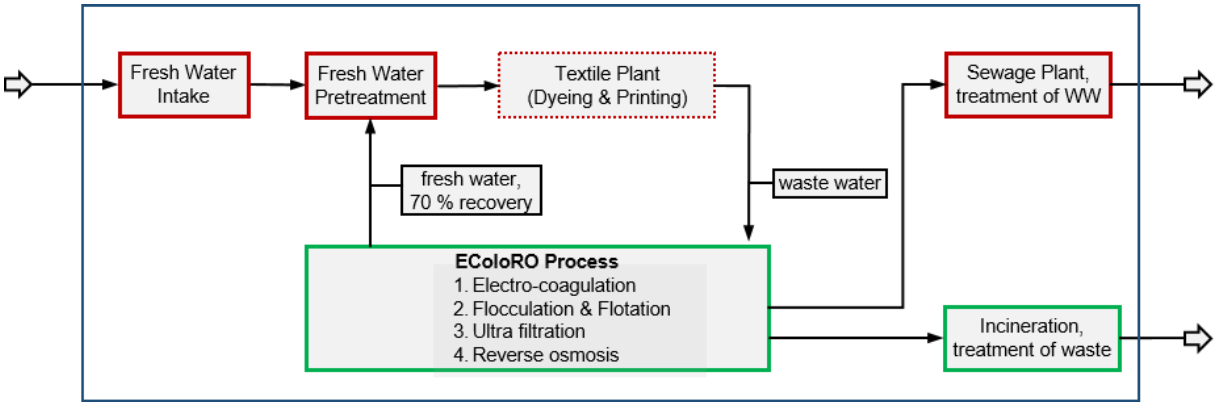


Figure 3 **System boundaries at Utexbel: Overall system (Blue), System without ECoIoRO (red), ECoIoRO technology, Textile plant is not considered in the analysis**

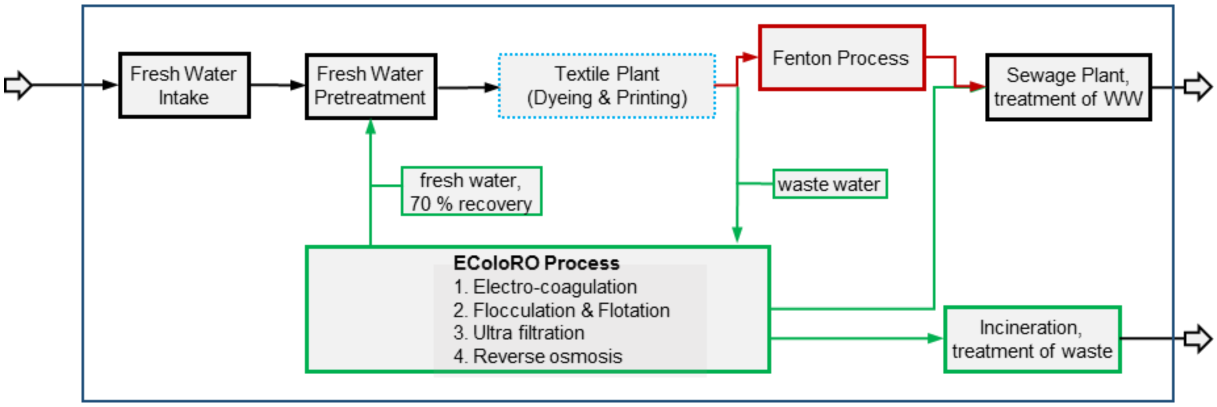


Figure 4 **System boundaries at Tintoria Pavese: Overall system (Blue), System without ECoIoRO (red), ECoIoRO technology, Textile plant is not considered in the analysis**

Functional unit and reference flow

A particularly important issue in process or product comparisons is the functional unit (FU) or comparison basis. Meaningful comparisons can only be carried out where the products or services to be compared have the same use or fulfil the same function. Furthermore, it is important that the FU be chosen so that results answer the given questions. In this study the focus is on used water, thus the FU was chosen as:

1m^3 of water used by the textile plant, see blue arrow in Figure 5.

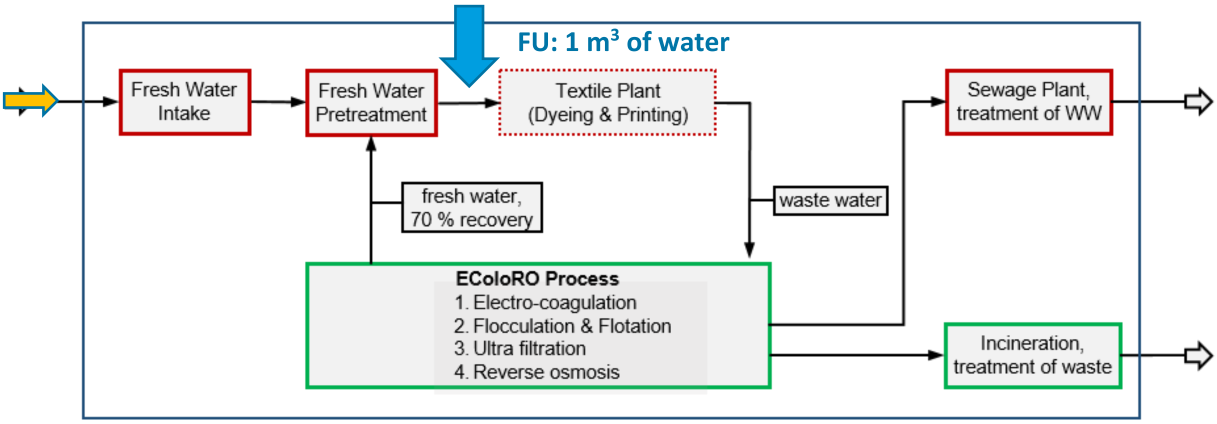


Figure 5 **Functional unit (FU): 1 m^3 at the entrance of the textile plant, blue arrow.**

It is important to choose the FU at the entrance of the textile plant, blue arrow in Figure 5, and not at the entrance of the system we look at, yellow arrow, because with this FU it is possible to measure the effect of water reuse.

3.1.2. Inventory

The most demanding task in doing an LCA is data collection. To reduce this effort, databases containing LCA inventories will be used. Therefore it is useful to distinguish two types of data:

1. Foreground data
2. Background data

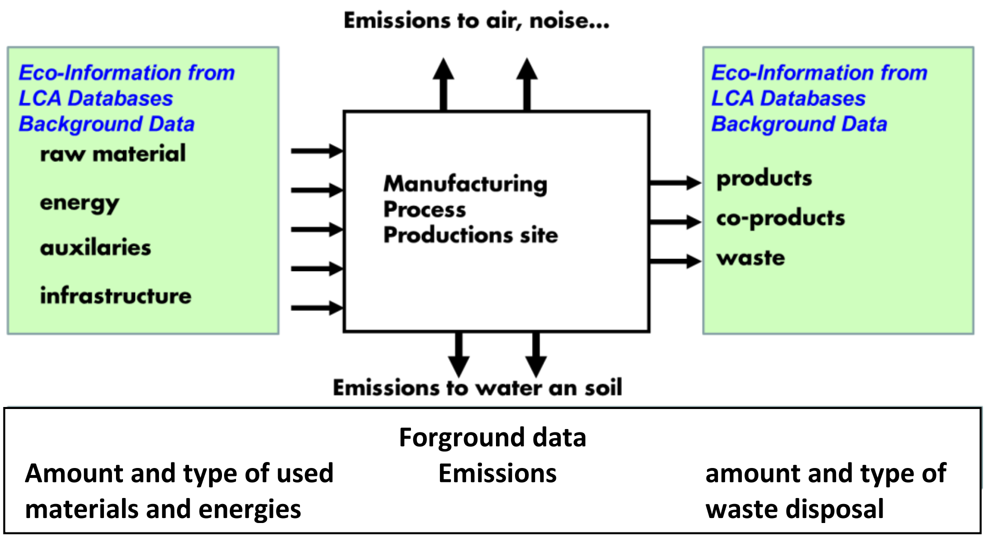


Figure 6 **Data acquisition for a process or production site, distinguishing foreground from background data**

Foreground data refers to the specific data needed to model the system. In this case e.g. all the materials and energy used by the EColoRO system, the local water scarcity, the specific water pollutions etc.
For production of materials, provision of energy, delivering transport services and waste management background data will be used.
The foreground data have been delivered by the industry and the project partners and have been validated before use in the LCA. For the background data ecoinvent v3.3 allocation cut off has been used (ecoinvent, 2016) as well as own processes from other projects.
The EColoRO system we looked at is given in Figure 7. Figure 8 shows a three dimensional model of the EColoRO plant.

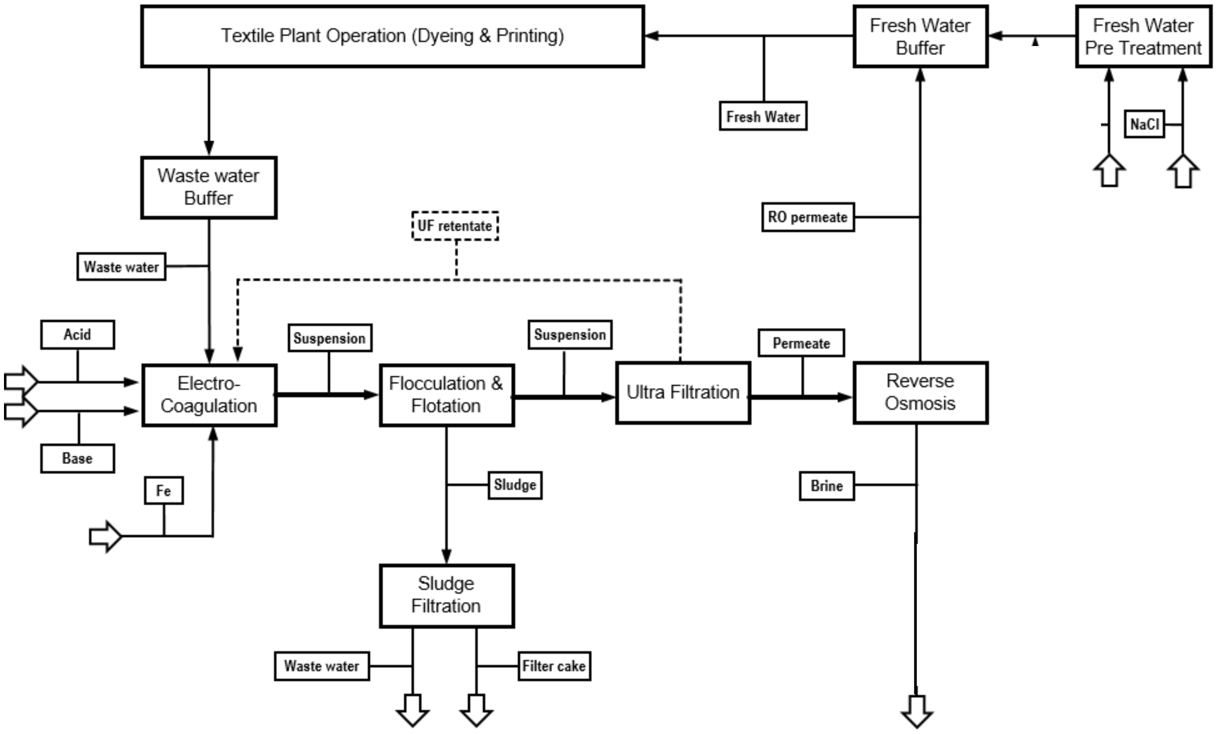


Figure 7 **Detailed EColoRO process scheme**

Figure 8 **A 3D-impression of the EColoRO concept screening unit, showing 3 out of 4 containers. Approximate total size is 30 x 11 metres**

Differences between Utexbel and Tintoria Pavese
In the current situation in Utexbel the wastewater from the textile plant goes to the WWTP in Ronse. As Figure 3 shows in the EColoRO case the wastewater goes to the EColoRO process and will be purified so that 70% of the water can go back to the textile plant. The major part of the pollutants will end up in the sludge and will be disposed of. The pre-treated water goes to the WWTP in Ronse.
For Utexbel the following two scenarios have been calculated:

- Utexbel wastewater without EColoRO
- Utexbel wastewater with EColoRO

In the textile plant Tintoria Pavese, we have a different situation compared to the Utexbel plant in Belgium. The main differences are:

- Tintoria Pavese has an internal WWT based on a Fenton reactor, after this treatment the wastewater goes to the WWTP of Pavia.
- The water scarcity in the region of Pavia is low, there is enough water available.
- The load of the wastewater is different

For this plant, the following three different scenarios have been calculated:

- Textile plant with EColoRO technology but without water reuse
- Textile plant with full EColoRO technology with 70% of water reuse
- Textile plant with Fenton reactor for wastewater pre-treatment, current situation

For the organic pollutants – as well as for phosphorous, ammonia, nitrate, and sulphate and most of the metals – measured data concerning the elimination rate of the Fenton reaction are available. For the EColoRO technology, estimations based on measurements are also available for most of these pollutants. For the metals, the experts assumed that the elimination rate is similar.

3.1.3. Impacts assesment (LCIA)

In this step the impacts on the environment due to the emissions and the used resources will be calculated based on the method ILCD (Hiederer u. a., 2011). This method takes into account the most comprehensive set of environmental impacts given in Table 1.

Table 1 Impact categories used in the ILCD method.
Legend: HH: human health; E: eco systems

Impact category	Unit
Climate change	kg CO_2 eq
Ozone depletion	kg CFC-11 eq
Human toxicity, non-cancer effects	CTUh
Human toxicity, cancer effects	CTUh
Particulate matter	kg PM2.5 eq
Ionizing radiation HH	kBq U235 eq
Ionizing radiation E (interim)	CTUe
Photochemical ozone formation	kg NMVOC eq
Acidification	molc H+ eq
Terrestrial eutrophication	molc N eq
Freshwater eutrophication	kg P eq
Marine eutrophication	kg N eq
Freshwater eco toxicity	CTUe
Land use	kg C deficit
Water resource depletion	m^3 water eq
Mineral, fossil & ren resource depletion	kg Sb eq

The calculation of all these impacts is based on scientific models. Therefore, these results have a high acceptance. On the other hand, however, it can be difficult to interpret the results of a comparison if some impacts show a lower environmental burden for one system but higher burdens for other impacts. In evaluating systems for WWT, like EColoRO, there are typically lower burdens concerning water resources and water pollutions, but higher burdens concerning energetic resources and air pollutions. To come to a decision in such cases, it is necessary to valuate the different impacts. Of course, this cannot be achieved solely on a scientific basis because there is no scientific theory evaluating human health in barrels of oil or in flowers in a meadow.

To solve this problem and come to a conclusion, two steps can be done:

- Normalization to detect the relevancies
  To evaluate the relevancies of the different impacts, a normalization of the different impacts can be done. In the normalization the magnitude of category indicator results is calculated relative to a reference information. As reference for the normalization, the emissions EU27 (2010) will be used. This means that the result of every impact category will be divided by the average impact of a European inhabitant during a year. If all the relevant impacts show a clear result then a good decision can be taken.
  An additional advantage of the normalization is that, after the normalization step, all impacts have the same unit and can be compared.
- Weighting of the different impacts
  If the normalization does not give a clear result, a weighting or valuation of the different impacts – usually the normalized impacts will be used – has to be done.

The valuation will be discussed in the next section.

3.1.4. Interpretation

Weighting is the most controversial and difficult step of an LCA because it can only be done based on socio-cultural or individual values. This is the reason why ISO 14'044 does not allow to use methods valuating the different impacts to one single score for comparative studies disclosed to the public. Nevertheless it is very often necessary to do this step to come to a decision, see e.g. (Kägi u. a., 2016). Especially in studies dealing with WWT or technologies to reduce water consumption a valuation of the different environmental impacts are necessary because in these cases mostly there is a benefit concerning the water, resource or pollutions, but higher burdens e.g. in climate relevant emissions. That is the reason why we will use single score methods in this study and go in this point beyond the ISO Norm.

In this study, we used the following two single score methods:

- ILCD (Huppes u. a., 2011), EU 27 Normalization, equal weighting
- Ecological scarcity 2013 (Frischknecht & Büsser Knöpfel, 2013)

These two methods have been chosen because they are the only ones taking into account water scarcity, which is a central aspect of this study.

ILCD v1.08 single score

This methods takes into account sixteen different impact categories given in chapter 3.1.3. The normalization factors are based on "Normalisation method and data for Environmental Footprints" (Benini u. a., 2014). The weighting factors are based on "Environmental Footprint Pilot Guidance document" (European Commission, 2016) giving all impact categories the same weight in the baseline approach.

Ecological Scarcities ("Eco point method")

This method (FOEFL 1990, revisions 1997, 2006 and 2013) was developed with the aim of reducing the indicators to one single indicator (whose unit is "Ecopoints" or "Environmental impact points" UBP). This is a material flow method that takes into account the existing flows in a certain region, as well as the environmental goals of Switzerland. The valuating is according to the distance between the existing situation and the environmental targets. The larger the environmental impacts of a product, the more environment impact points it will get, and the worse it will be rated.

Uses of the methods

In this project the ILCD method will be used as main method because it has been develloped by the EU and the normalization of the impacts is based on the environmental situation of the EU-27 countries. The method of ecological scarcity being based on the einvironmental situation and the environmental goals of Switzerland will be used as a sensitivity analysis concerning the valuation to ensure and discuss the results. This is helpful because of the fact, that valuation can not be based on scientific models.

4. Results

First the results for the impact assessment are given for both plants. Then the results of the valuation methods are shown and discussed.

4.1. Impact assessment

The results of the impact assessment are given in relative numbers because of the fact that the different impacts use diverse units, see Table 1, and cannot be compared to each other. Therefore, the highest values for each impact category will be set to 100% and the other values of the same impact category in relative numbers to that.

4.1.1. UTEXBEL

Figure 9 presents the result of the impacts assessment of the situation at Utexbel in Belgium. The figure shows that more than half of the impacts are higher for the situation with EcoloRO and about a third of the impacts are lower for the situation with EcoloRO. As expected the impacts concerning the resource water and the water pollution are lower for the EcoloRO technology and the impacts related to energy – like climate change or Ionizing radiation from electricity – are higher for the EcoloRO technology. From these results no conclusion can be drawn concerning the environmental advantage or disadvantage of the EcoloRO system.

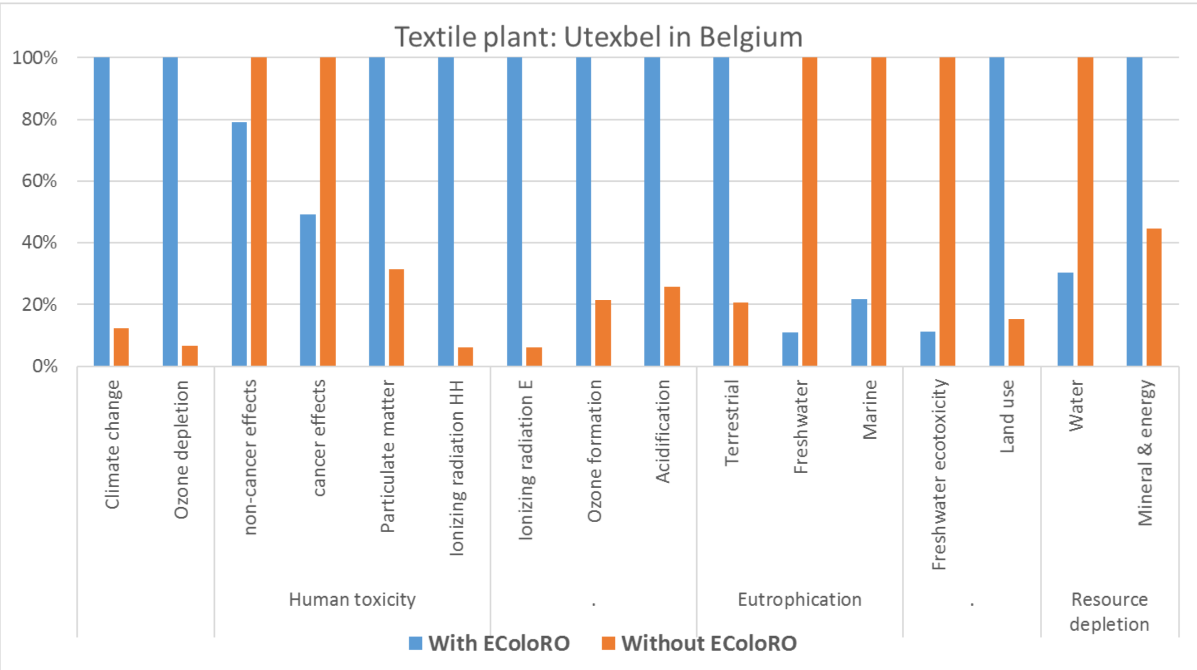


Figure 9 **Impact assessment comparing the WWT with EColoRO and without EColoRO at Utexbel.**

Depending on the system we are looking at the different impacts have various importance. To evaluate the relevancies of the different impact categories a normalization of the impact categories was done using the environmental situation of the EU-27 countries, see also chapter 3.1.3. The results are given in Figure 10.

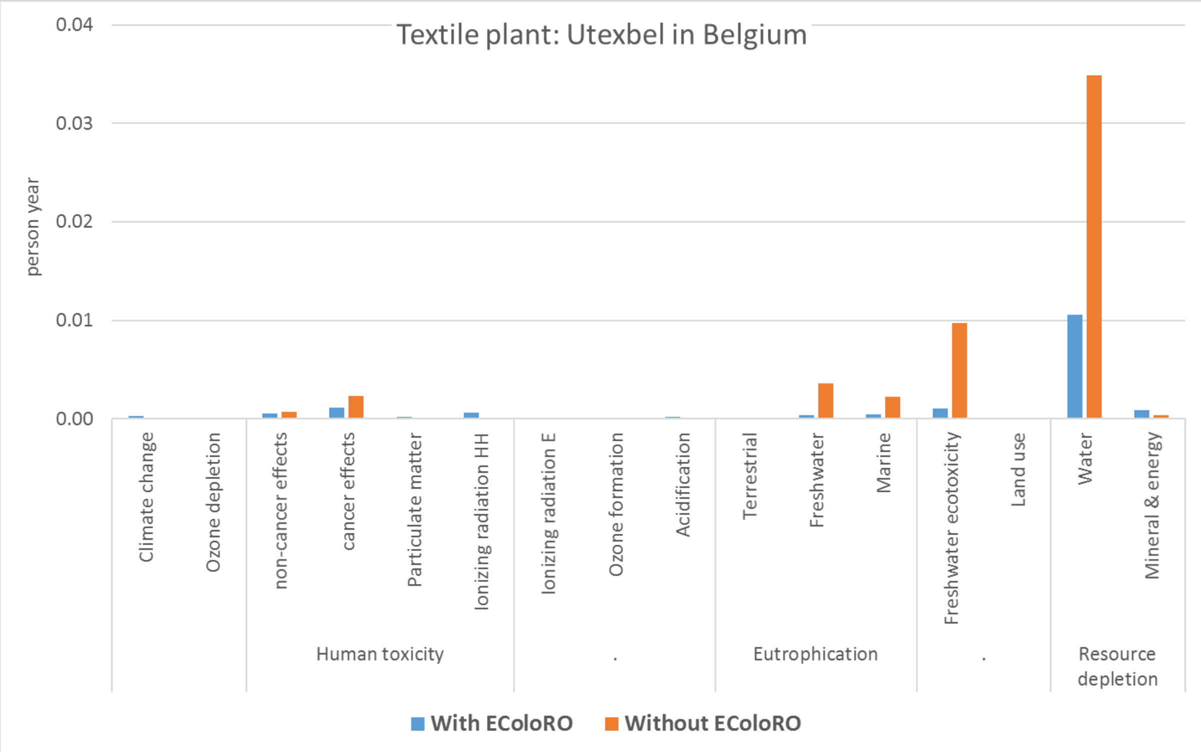


Figure 10 **Normalized impact assessment (EU 27) comparing the WWT with EColoRO and without EColoRO at Utexbel.**

The results of the normalization show that for all relevant impacts the process with EcoloRO has lower environmental impacts than without EcoloRO. Therefore, it can be concluded that in case the use of the EcoloRO technology leads to lower environmental impacts and thus to a benefit for the environment.

4.1.2. Tintoria Pavese

Figure 11 presents the result of the impacts assessment of the situation at Tintoria Pavese in Italy for the three scenarios we looked at:

- Textile plant with EColoRO technology but without water reuse
- Textile plant with full EColoRO technology with 70% of water reuse
- Textile plant with Fenton reactor for wastewater pre-treatment, current situation

The figure shows no clear picture. For nearly half of the impacts the current situation with Fenton process has the lowest impacts. However, for some impacts Fenton has the highest values. From these results, no conclusion can be drawn concerning the environmental advantage or disadvantage of the EColoRO system compared to the Fenton process. What the results show is that the full EColoRO with water reuse leads to lower environmental impacts than the EColoRO process without water reuse.
Unfortunately, the normalized results see Figure 12 do not lead to an unambiguous result as we have seen for the situation at Utexbel in Belgium. In the most relevant impact category, Fenton has the highest value, but in other, also relevant impact categories, Fenton has lower environmental impacts.

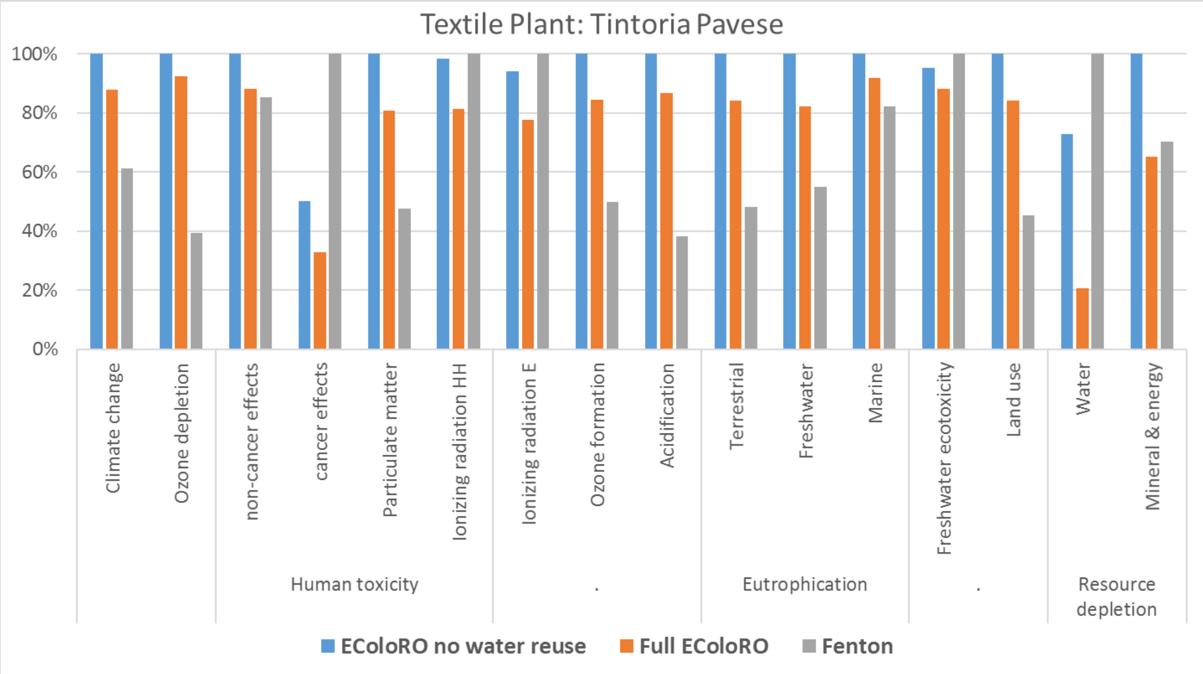


Figure 11 **Impact assessment comparing the WWT with Fenton process, EColoRO without water reuse and full EColoRO process.**

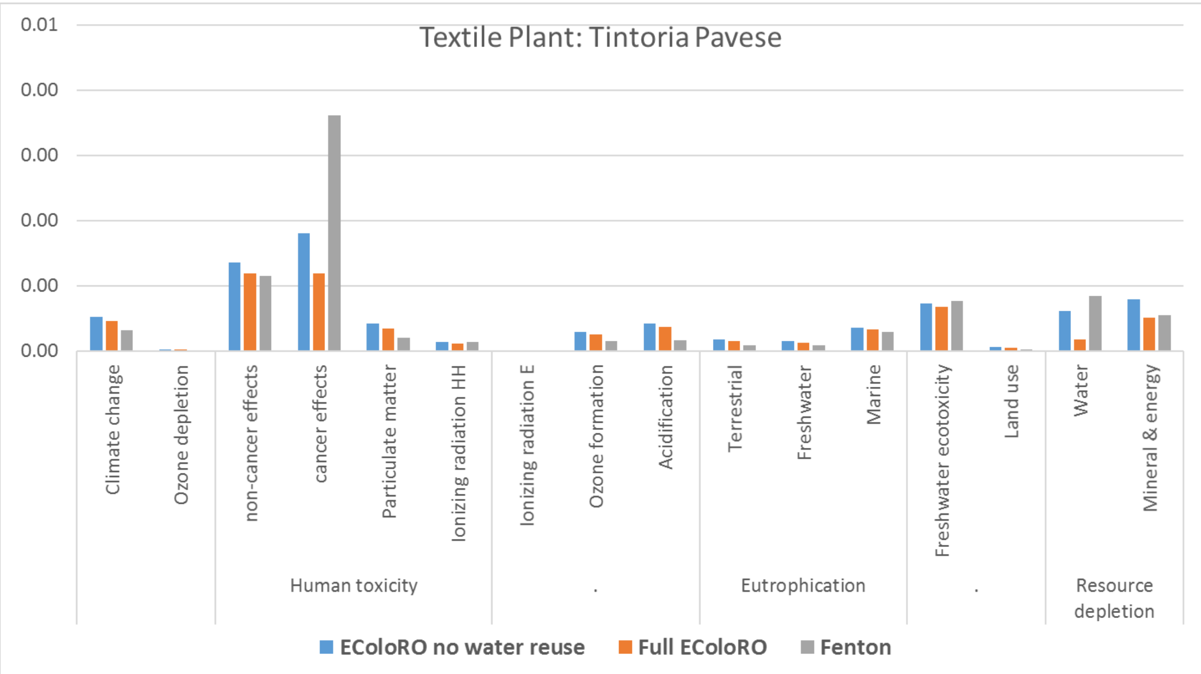


Figure 12 **Normalized impact assessment (EU-27) comparing the WWT with Fenton process, EColoRO without water reuse and full EColoRO process.**

4.2. Single score results

4.2.1. Utexbel

Both methods, ILCD in Figure 13 and ecological scarcity in Figure 14, show that the environmental burdens can be reduced by a factor of 2 to 3 by using the EcoloRO technology. There are, however, differences concerning the valuation of the different impacts:

- Using ILCD, the major contribution to the overall impacts comes from the water resource depletion, even if the average water scarcity of Belgium was used for the calculation, see Figure 15. If the local water scarcity of Ronse were used, the differences would be much higher. The contribution from the water pollutions is the second most important. Even without taking water scarcity into account the result that EColoRO technology reduces the environmental burdens is demonstrated by this method.
- Using ecological scarcity, the major contribution to the overall impacts comes from the water pollutions in the wastewater after the treatment in the WWTP in Ronse, see Figure 16. Although there are differences in the valuation of the different impacts, the overall result is in full accordance with the result of the method ILCD.

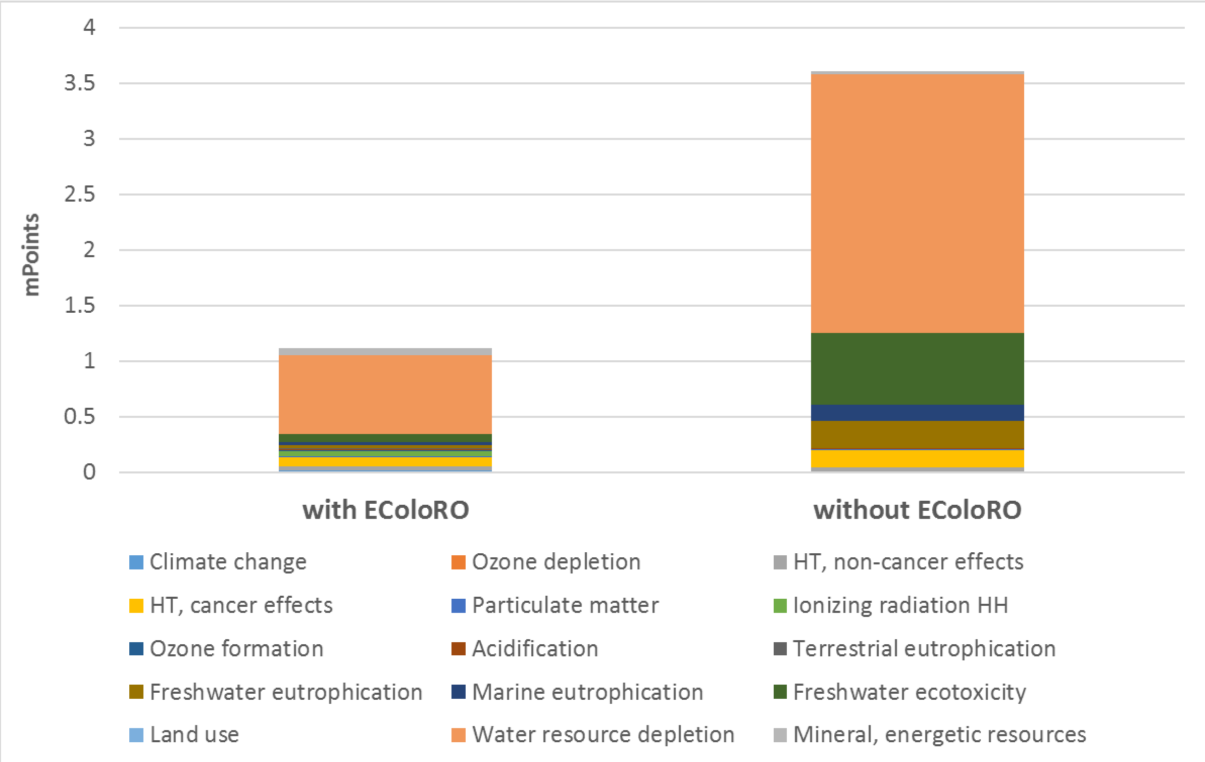


Figure 13 **Environmental impacts: Treatment of $1m^3$ wastewater from the textile industry with and without EColoRO. Method: ILCD 2011 Endpoint-Method. Eco-indicator Point, Pt, divided into 1000 milli-points (mPt).**

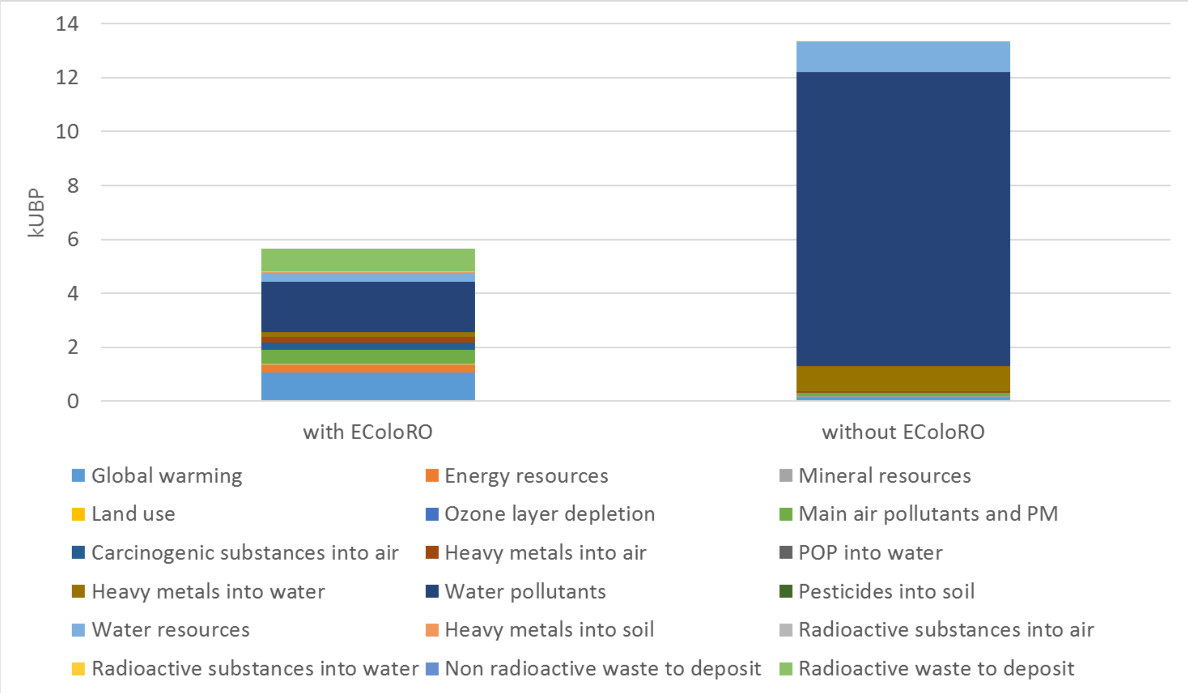


Figure 14 **Environmental impacts: Treatment of 1m³ wastewater from the textile industry with and without EColoRO. Method: Ecological scarcity 2013. Pt = Ecological scarcity points (UBP) → (1 kPt = 1000 points)**

Figure 16, Figure 15 and Figure 17 show the environmental impacts for the different process steps. This analysis supports the conclusions from the results of the comparisons given in Figure 14 and Figure 13. Both methods show that the reduction of water pollutants with EColoRO technology leads to a significant reduction of the environmental burdens. The high valuation of water depletion in the method ILCD leads to the result that the benefit is higher, factor > 3, than with the other method ecological scarcity, factor ≈ 2.

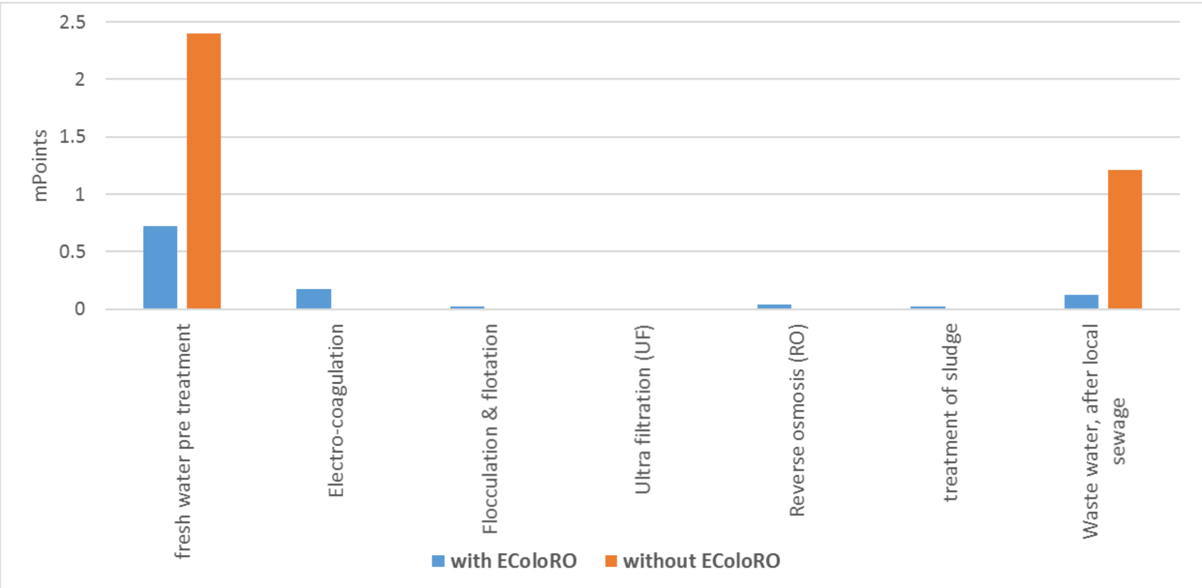


Figure 15 **Environmental impacts: Treatment of 1m³ wastewater from Utexbel with EColoRO.**
Method: ILCD

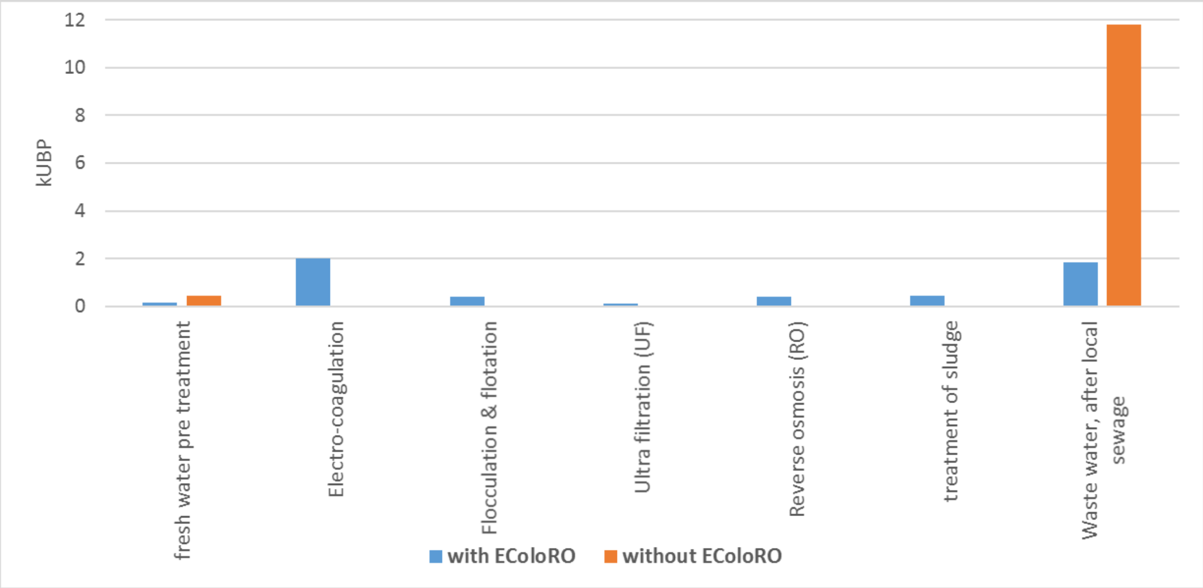


Figure 16 **Environmental impacts: Treatment of 1m³ wastewater from the textile industry Utexbel with and without EColoRO.**
Method: Ecological scarcity 2013. Pt = Ecological scarcity points (UBP) → (1 kPt = 1000 points

Figure 17 shows the most relevant processes contributing at least 2.5% to the overall result of the scenario with EcoloRO using ILCD and Figure 18 using ecological scarcity method. Whilst ILCD method gives the highest valuation to the water consumption, the analysis with ecological scarcity highlights that the most relevant contribution comes from the electricity used for electro coagulation and the pumping energy for RO and UF as well as from the water pollutants. The water consumption is according to this method not so relevant.

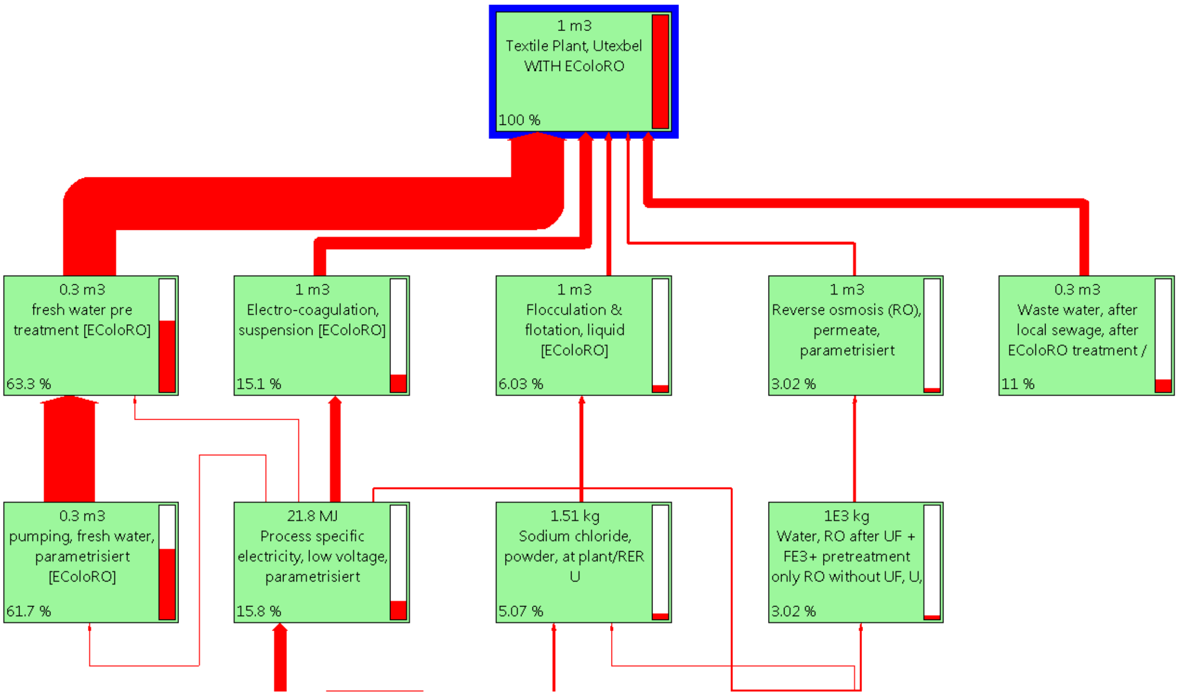


Figure 17 **Relevant processes for the EColoRO process at Utexbel using ILCD method.**
Only the processes contributing more than 2.5% to the overall results are displayed.

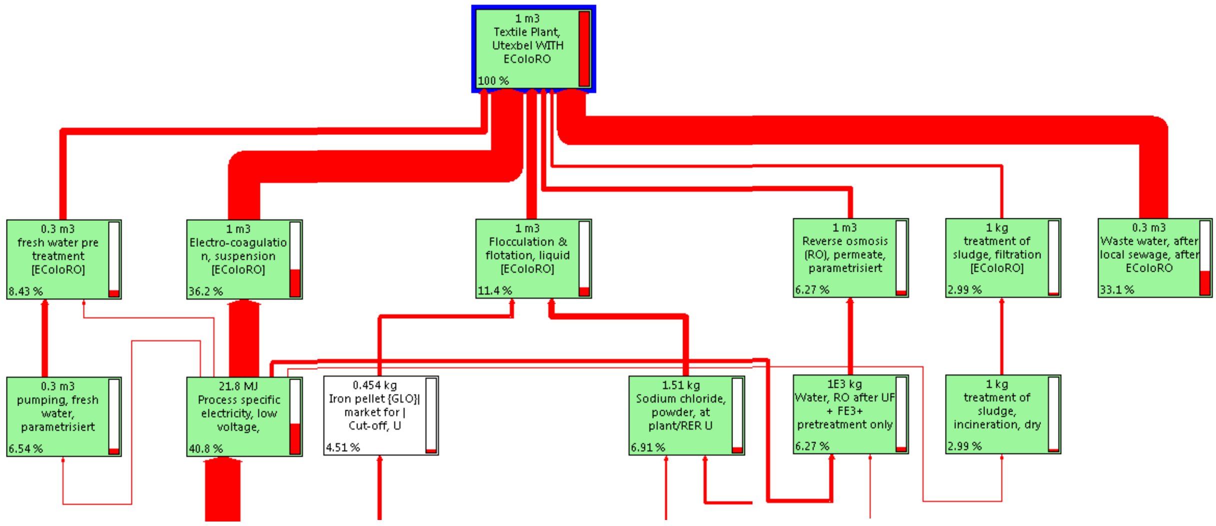


Figure 18 **Relevant processes for the EColoRO process at Utexbel using ecological scarcity method.** Only the processes contributing more than 2.5% to the overall results are displayed.

According to these results, there are different possibilities to further reduce the environmental burdens of EcoloRO, e.g.:

- Further reduction of water consumption
- Reducing the electricity consumption
- By using green electricity.

The influences of these options will be discussed in chapter 0.

Uncertainty analysis

To evaluate the significance of the results, the uncertainty of the results was calculated using Monte Carlo Analysis with 1000 runs. Figure 19 shows the results for the method ecological scarcity where the differences *Utexbel without EcoloRO* minus *Utexbel with EcoloRO* are given. So positive values indicate a reduction of environmental impacts by using EcoloRO. It shows that the difference is significant. There are no negative value at all. The same result was obtained for the ILCD method.

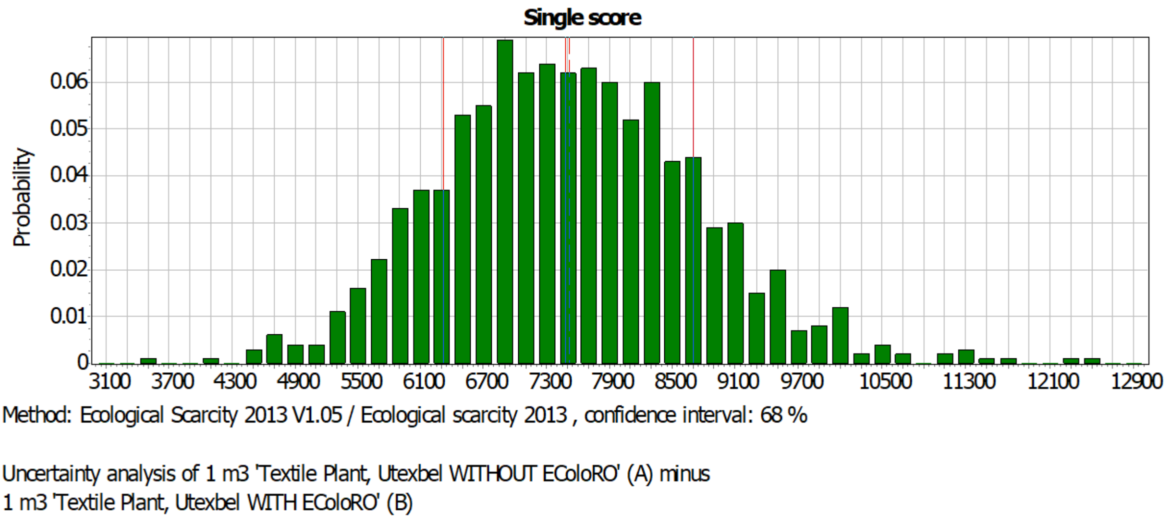


Figure 19 **Monte Carlo Analysis showing that the process with EColoRO technology has always lower environmental impacts than the process without EColoRO.**

4.2.2. Tintoria Pavese

Based on the assumption given in chapter 3.1.2 Figure 20 presents the results of the valuation with the method ILCD. This figure shows that there is an environmental benefit for full EcoloRO process with a 70 % of reduction of water reuse compared to the current situation with a Fenton reaction. If no water is being reused, the environmental impact of the current situation is similar to the EcoloRO process.

On the other hand, the method ecological scarcity shows a different result, i.e. the current situation has a lower environmental impact than the scenarios with EColoRO technology, see Figure 21.

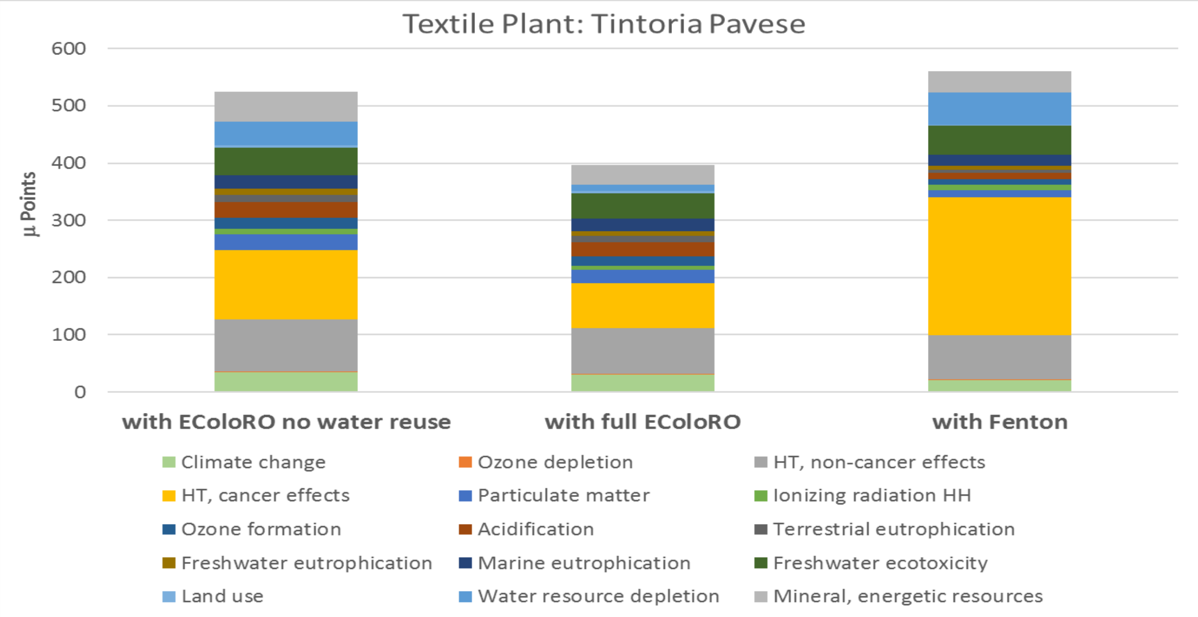


Figure 20 **Environmental impacts: Treatment of 1m³ wastewater from the textile industry with and without EColoRO.** Method: ILCD 2011 Endpoint-Method. Eco-indicator Point, Pt, divided into 1000 milli-points (mPt).

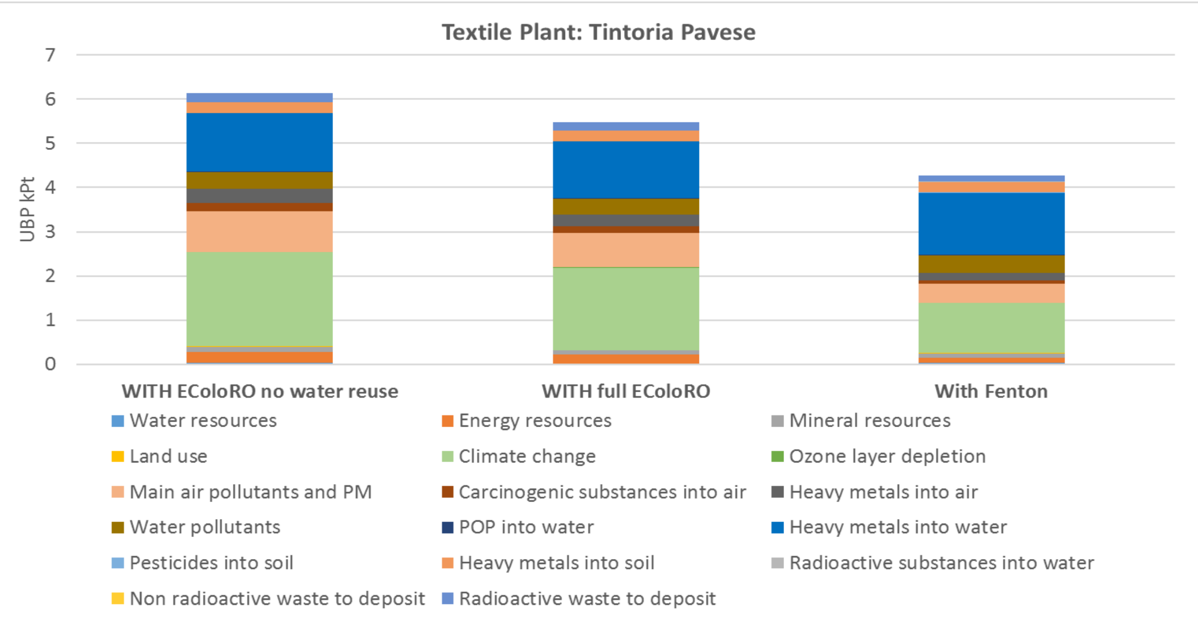


Figure 21 **Environmental impacts: Treatment of 1m³ wastewater from the textile industry Tintoria Pavese with and without EColoRO**. Method: Ecological scarcity 2013. Pt = Ecological scarcity points (UBP) → (1 kPt = 1000 points)

The discussion of these different results will be done by

- analysing the contribution of the different emissions and raw materials to the results, see Figure 22 and Figure 24
- analysing the process contribution to the total environmental impacts, see Figure 26, Figure 27 and Figure 28
- discussing the valuation step of these methods.

For this discussion, we will focus on the two variants “textile plant with full EcoloRO” and “textile plant with Fenton”. The difference to the variant “EcoloRO no water reuse” is mainly due to the influence of the difference in “Water use, low water stress”.

Using the method ILCD, the main contributions to the results come from the following impact categories, see Figure 20:

- Human toxicity (HT), cancer effects
- Human toxicity (HT), non-cancer effects
- Water resource depletion

The impact category “climate change” contributes little to the overall result. Therefore, this method considers this effect for the system under study to not be very relevant.

Using the method ecological scarcity, the main contributions to the results come from the following impact categories, see Figure 21Figure 20:

- Climate change
- Heavy metals into water

The impact category “Water resource depletion” contributes little to the overall result. Therefore, this method considers this effect for the situation under study, “low water scarcity”, to not be very relevant.

These different results show the problem of valuating the different environmental impacts. It is evident that the valuation of e.g. the two different damages “human health” and “resource depletion” is a socio-political and not a scientific question. Therefore, there is no scientific model to evaluate which valuation method produces the right or the wrong result. As discussed in chapter 3.1.4 in this project we use ILCD as the main method because it is a European method. Another reason why ILCD is the adequate method for this project is that it gives more weight to water scarcity being the major focus of this project. The following detail analysis will support this decision.

Detailed analysis

Figure 22 and Figure 24 show the emissions and raw materials contributing at least 0.5% to the overall results. The major impacts for the process with Fenton using the ILCD method are chromium emissions and water use. Figure 23 shows that the chromium emissions does not come from the textile water process, but from the production of hydrogen peroxide used by the Fenton process and the infrastructure of the WWTP. Therefore, it is difficult to reduce these impacts as long as hydrogen peroxide is used.

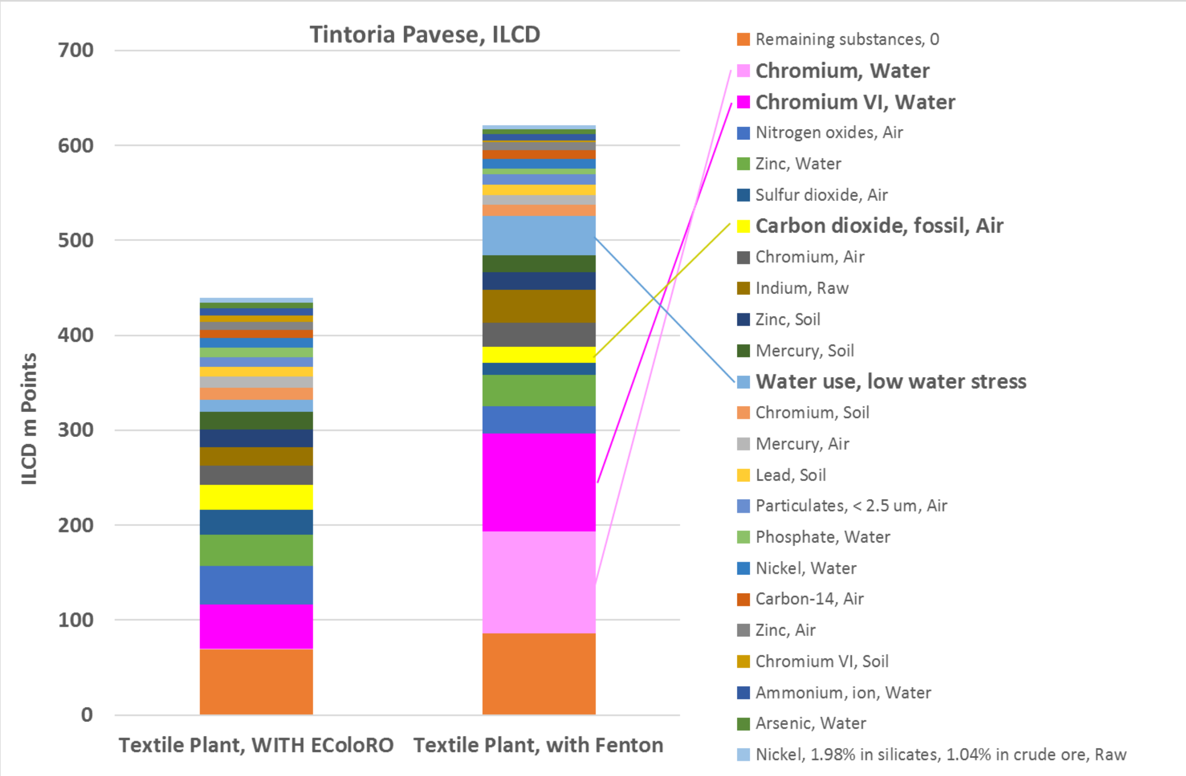


Figure 22 **Contribution of the different emissions and raw materials to the environmental impacts: Treatment of 1m³ wastewater from the textile industry with and without EColoRO.** Method: ILCD 2011 Endpoint-Method. Eco-indicator Point, Pt, divided into 1000 milli-points (mPt). This figure shows only the emissions and raw materials contributing to more than 0.5 % to the result. The item "remaining substances" summarizes the other substances and raw materials.

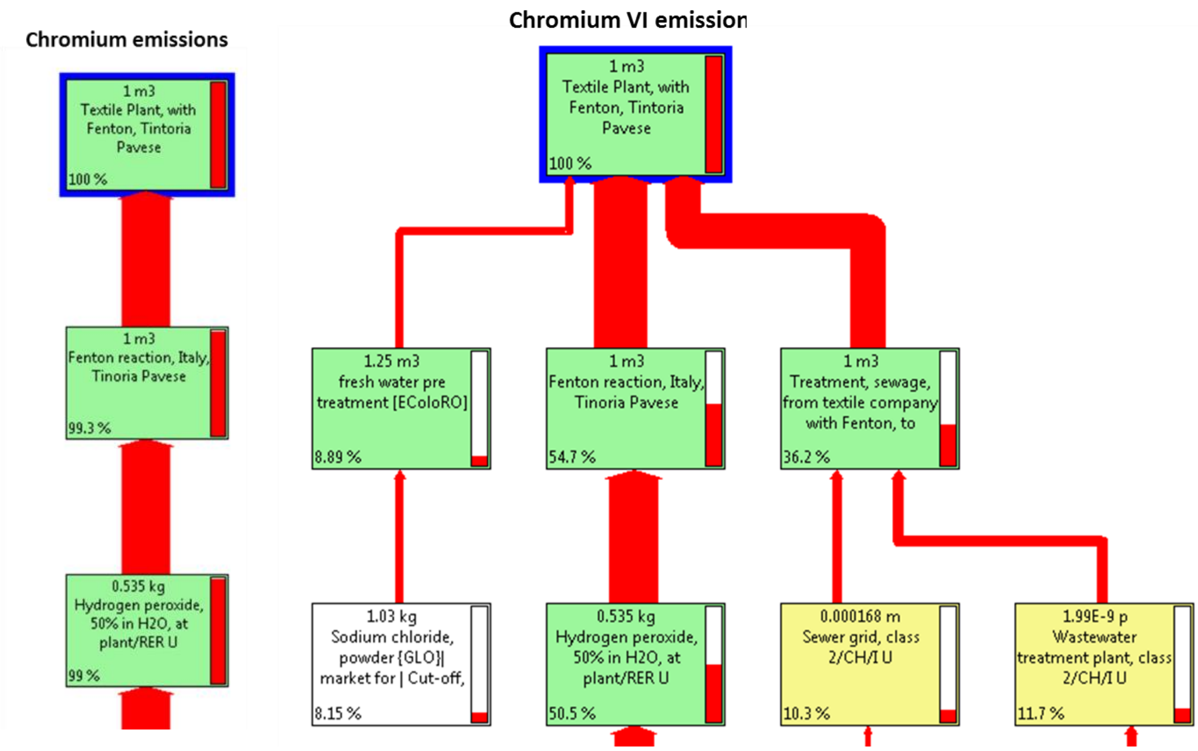


Figure 23 **Origin of chromium emissions.** Process tree showing only the processes contributing more than 3 % to the overall result.

Figure 24 shows that the main contribution to the EcoloRO process by Tintoria Pavese using the ecological scarcity method comes from the carbon dioxide emissions due to the electricity consumption, see Figure 25. Of course, climate change is a very important topic and it makes sense to reduce this impact. The positive aspect is that there are possibilities to reduce carbon dioxide emissions even using the same amount of electricity by changing the electricity mix. This will be discussed in chapter 4.3.2.

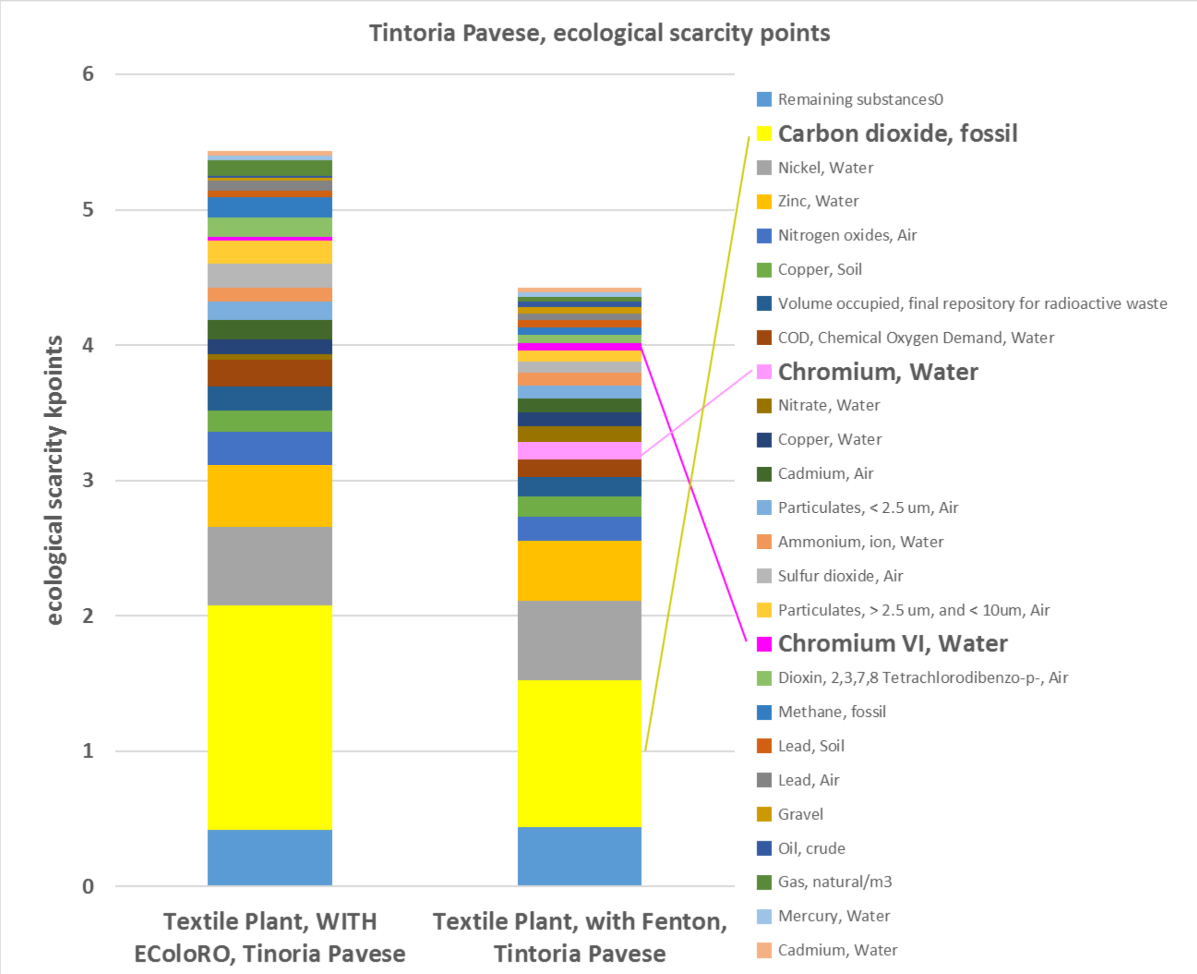


Figure 24 **Contribution of the different emissions and raw materials to the environmental impacts: Treatment of 1m^3 wastewater from the textile industry with and without EColoRO.** Method: Ecological scarcity 2013. Pt = Ecological scarcity points (UBP) → (1 kPt = 1000 points). This figure shows only the emissions and raw materials contributing to more than 0.5 % to the result. The item "remaining substances" summarizes the other substances and raw materials.

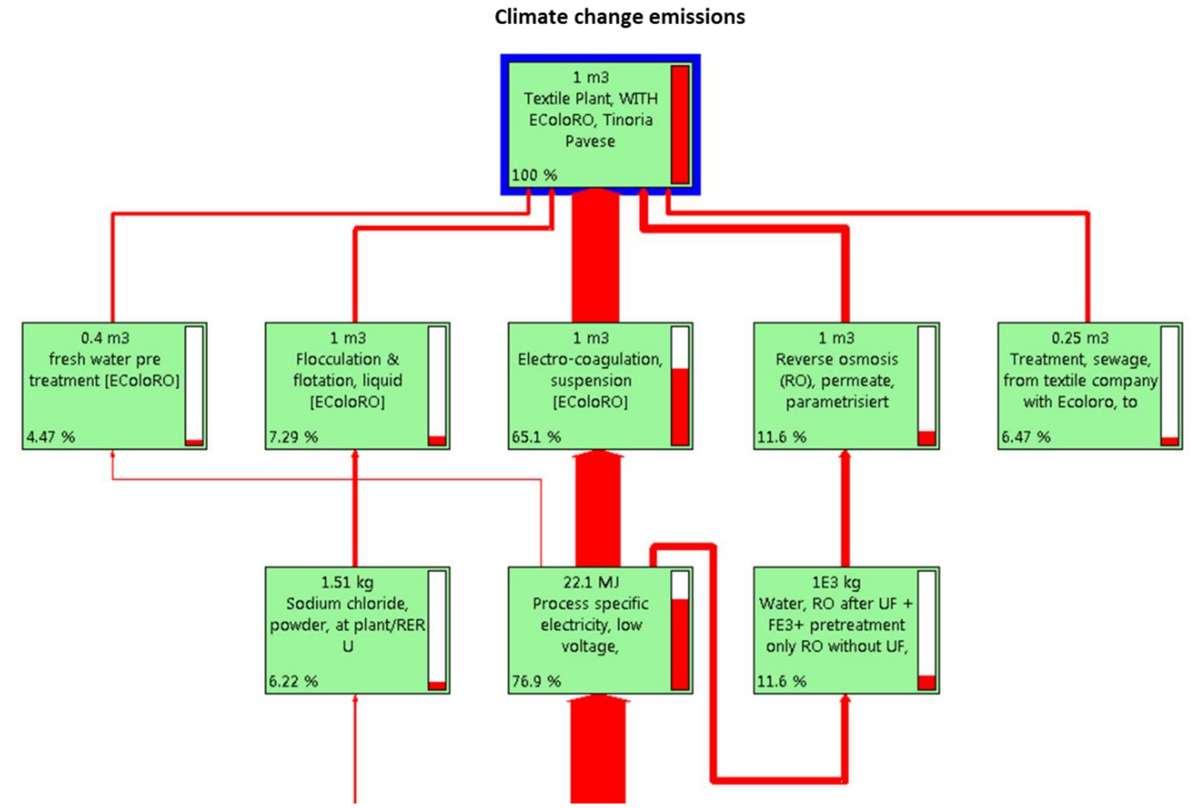


Figure 25 **Origin of climate change emissions using IPCC.** Process tree showing only the process contributing more than 3 % to the overall result.

Process step analysis

Using the ILCD method, the following process steps have the major environmental impacts in the textile plant of Tintoria Pavese with Fenton reaction, see Figure 26:

1. Fenton reaction
2. Emissions from wastewater after local sewage
3. Water used

Using the ecological scarcity method, the same process steps show the major environmental impacts but with a different order concerning the importance, see Figure 27

For the textile plant Tintoria Pavese with EcoloRO technology using ILCD method the following process steps are the most relevant:

1. Emissions from wastewater after local sewage
2. Electro coagulation because of electricity use see Figure 28
3. Water used

Using the ecological scarcity method, the same process steps show the major environmental impacts, with even the same order concerning the importance, see Figure 27

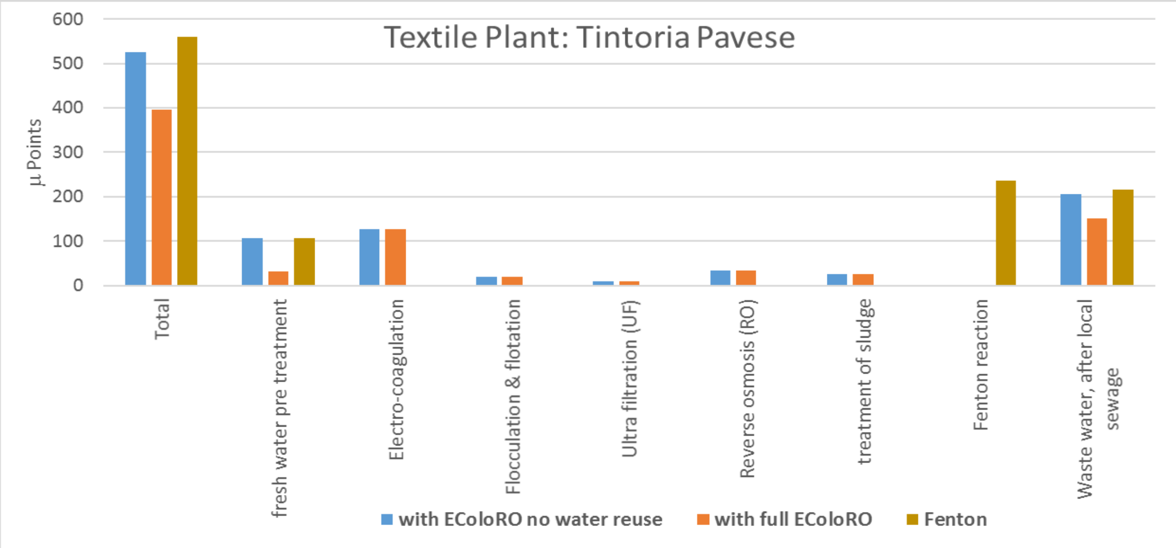


Figure 26 **EColoRO-Technology: Environmental impacts of the different process steps**, Method: ILCD 2011.

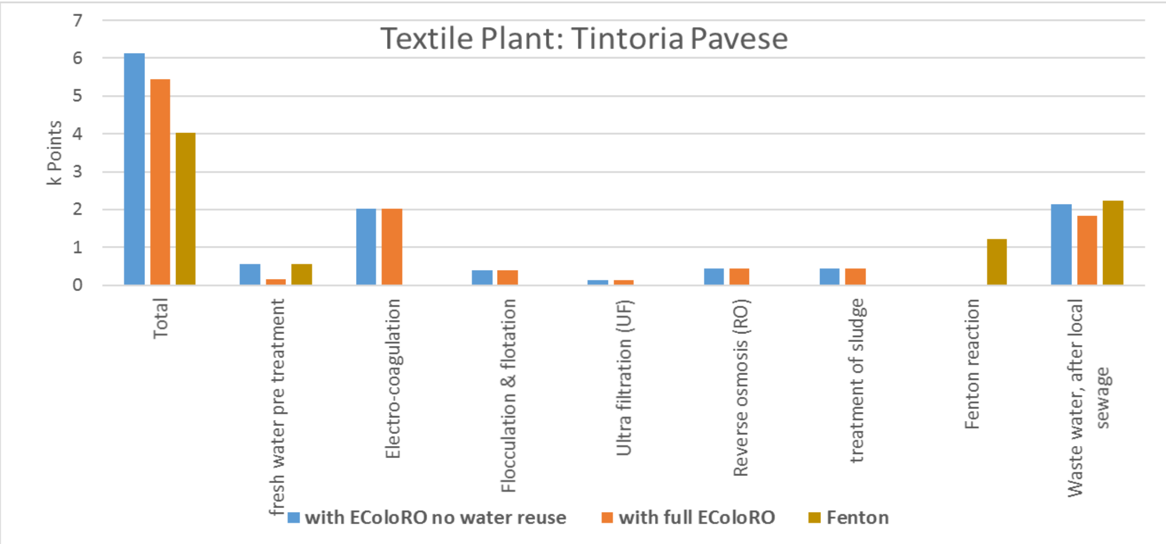


Figure 27 **EColoRO-Technology: Environmental impacts of the different process steps.** Method: Ecological Scarcity 2013.

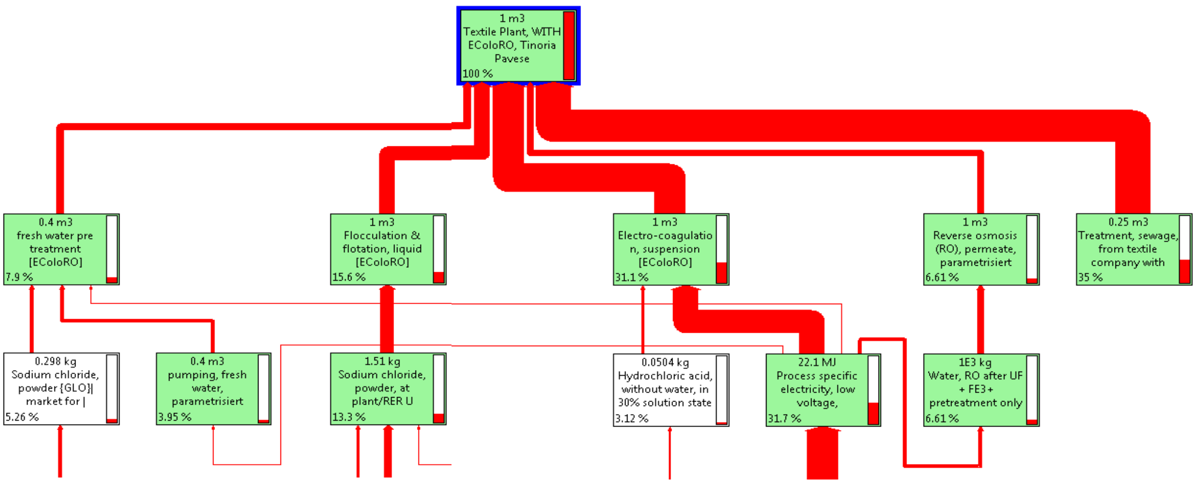
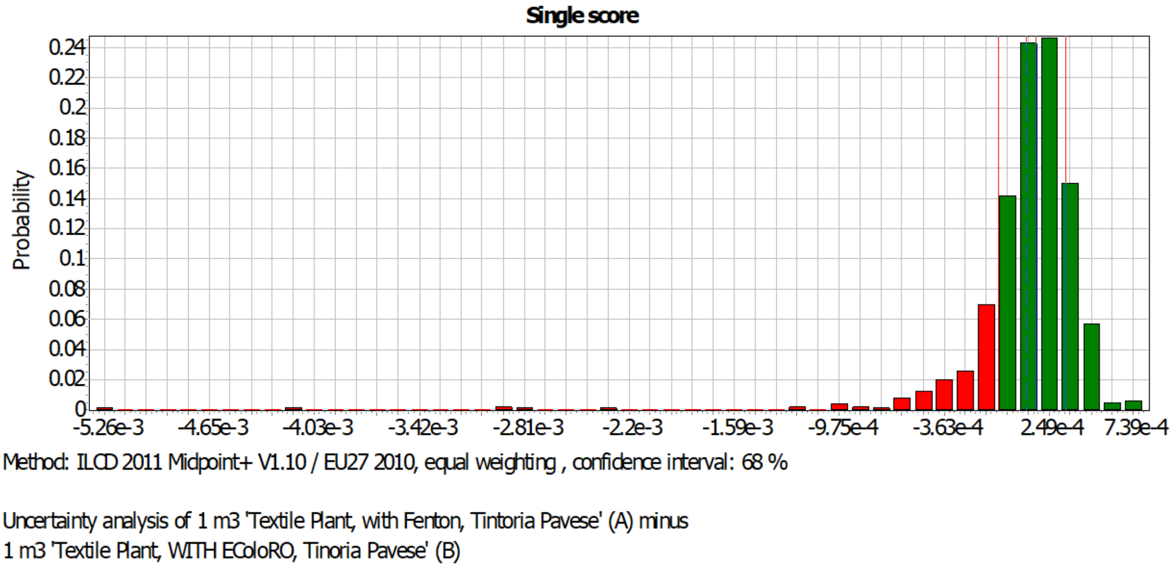


Figure 28 **Relevant processes for the EColoRO process at Tintoria Pavese using ILCD method.** This figure shows only the processes contributing more than 2.5 % to the overall results.

Uncertainty analysis

To evaluate the significance of the results, the uncertainty of the results was calculated using a Monte Carlo Analysis with 1000 runs. The calculation with the ILCD method, see Figure 29, shows that there is a significant difference between the two treatments. In 80 % of the runs the full ECol-oRO process has lower environmental impacts than the process with Fenton. Considering this, there is an environmental benefit of the EColoRO technology under the circumstances of the textile plant Tintoria Paves in Pavia, Italy but it is not as high as under the circumstances at Utexbel in Belgium. The reason for this lower benefit compared to the Utexbel case is due to the following facts:

- the environmental impacts from the wastewater are similar for all three scenarios
- the environmental impacts from the EColoRO process are slightly higher than from the Fen-ton process due to the higher electricity consumption, see Figure 26 and Figure 28.
- the water scarcity is low



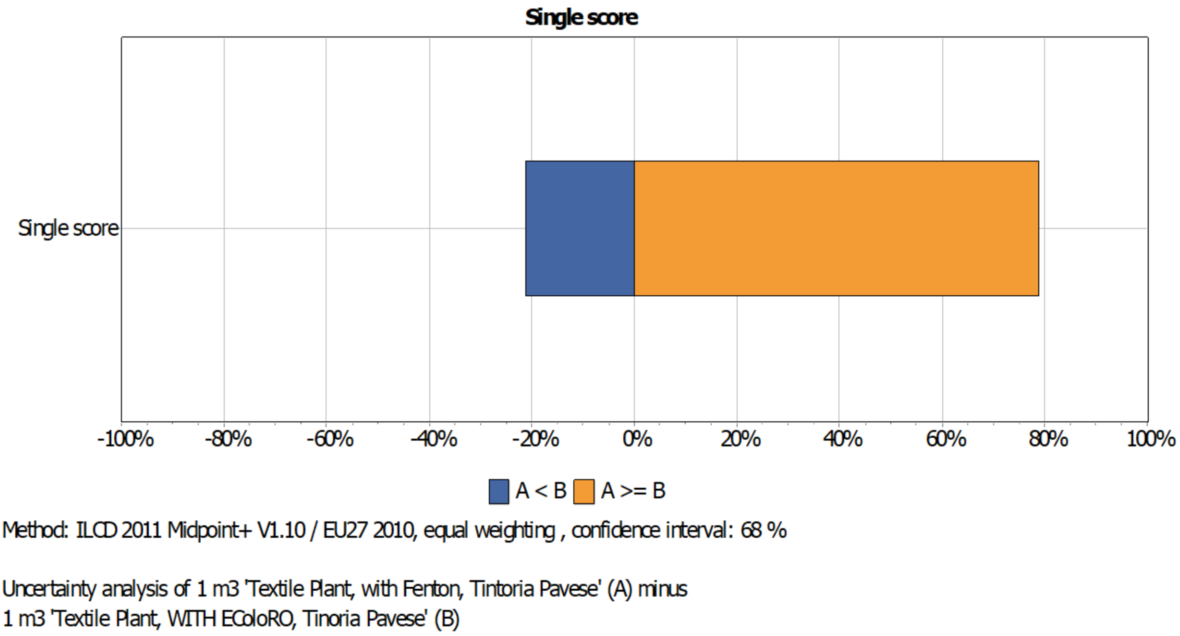


Figure 29 **Monte Carlo Analysis showing no significant difference of the environmental impacts of the Fenton process compared to the full EColoRO using the method ILCD.**

4.2.3. Discussion

The main reasons for the reduction of environmental impacts by the ECoLoRO technology comes from:

- Reduction of water use
- Reduction of water pollutants

Reduction of water use

Especially in regions where water is scarce, the reduction of water use is crucial. This is valid for Belgium and, of course, even more so for southern countries like Spain or the south of Italy. However, in the region of Pavia, there is no water scarcity and thus the results do not show a high benefit concerning the reduction of water. This result depends also on the valuation of the different environmental impacts. Using the valuation scheme from ILCD, a higher weight is given to the water scarcity than in the method ecological scarcity.

Reduction of water pollutants

If there is no other pre-treatment of the wastewater from the textile plant, a major advantage of the EColoRO technology is the removal of pollutants from the wastewater. This is the case at Utexbel in Belgium.

For the textile plant Tintoria Pavese, the existing Fenton reactor leads to similar reductions of pollutants as the EColoRO technology. This result is also a consequence of the probably conservative assumptions made by the experts concerning the removal of metals from the wastewater by the EColoRO technology. If data for the removal of metals with EColoRO was available, we would suggest redoing the evaluation. This could lead to different results.

Major environmental impacts from EColoRO

The main contributions to the environmental impacts of the EColoRO comes from

- The electricity used in the Electrocoagulation.
- Remaining waste water

The electricity consumption of EColoRO contributes up to 50% to the environmental impacts of the EColoRO process analysed in this study. If there is the possibility to reduce this consumption this will have a positive effect on the environment. Another possibility is to change the production mix of the electricity. The effect of this will be discussed in chapter 4.3.2.

The remaining pollutants in the wastewater contributes to about one third to the overall environmental impact of the EColoRO processes analysed in this study. Therefore, further reduction of pollutants up to zero water discharge could reduce the environmental effect.

4.3. Sensitivity analysis

To evaluate the influences of the different situations and assumptions on the results, the following sensitivity analyses have been performed:

- Water scarcity
  This sensitivity shows the environmental impacts caused in locations with different water scarcities.
- Electricity
  This sensitivity shows the results for different electricity sources
- Elimination rates
  The elimination rate was not available for all pollutants, hence assumptions have been used. The influence of these assumptions has been evaluated with this scenario.

The selection of the sensitivities is according to the relevancies of these influence factors, see also Figure 27 and Figure 26. The sensitivity analyses are done only for the case at Tintoria Pavese, because in this case the environmental benefit of the EcoloRO technology is lower than for the case at Utexbel.

4.3.1. Water scarcity

To evaluate the influence of water scarcity to the results, different scenario analysis have been performed.
On the basis of the textile plant Tintoria Pavese the calculations have been carried out for regions with different water scarcities. The countries given in the legend of Figure 31 and Figure 30 are examples of countries with more or less this water stress. These results show very clearly that the benefit of the EcoloRO process increases with higher water scarcity.

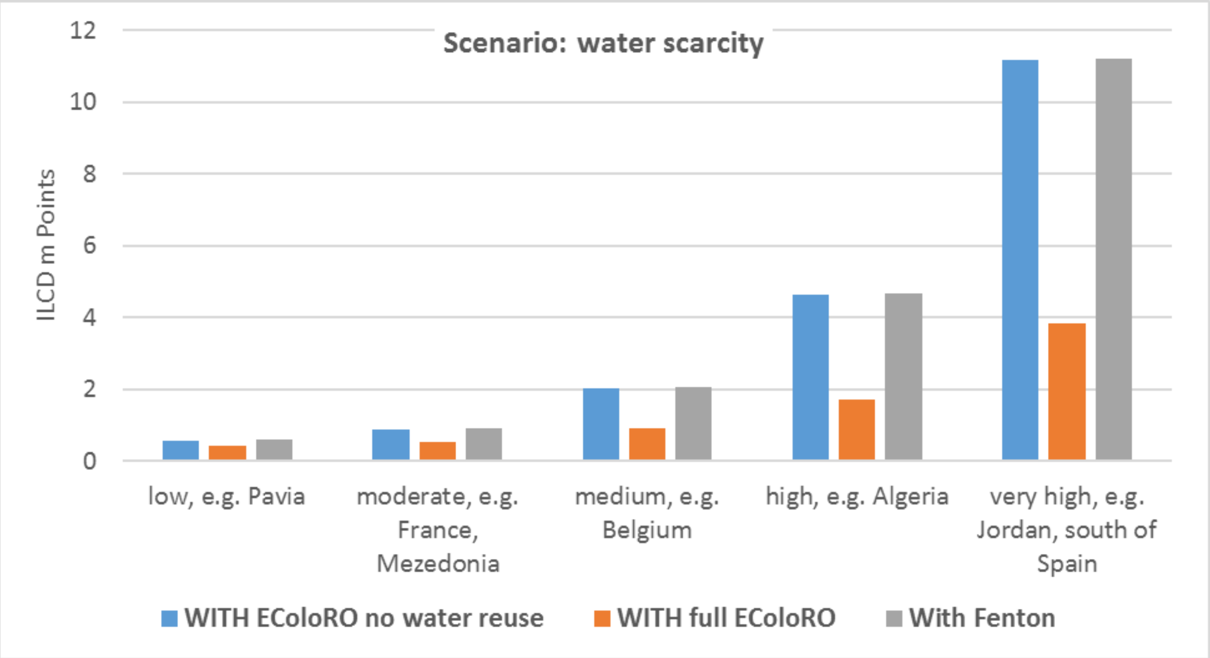


Figure 30 **Environmental impacts in regions of different water scarcity.** Based on the processes at Tintoria Pavese using the method ILCD.

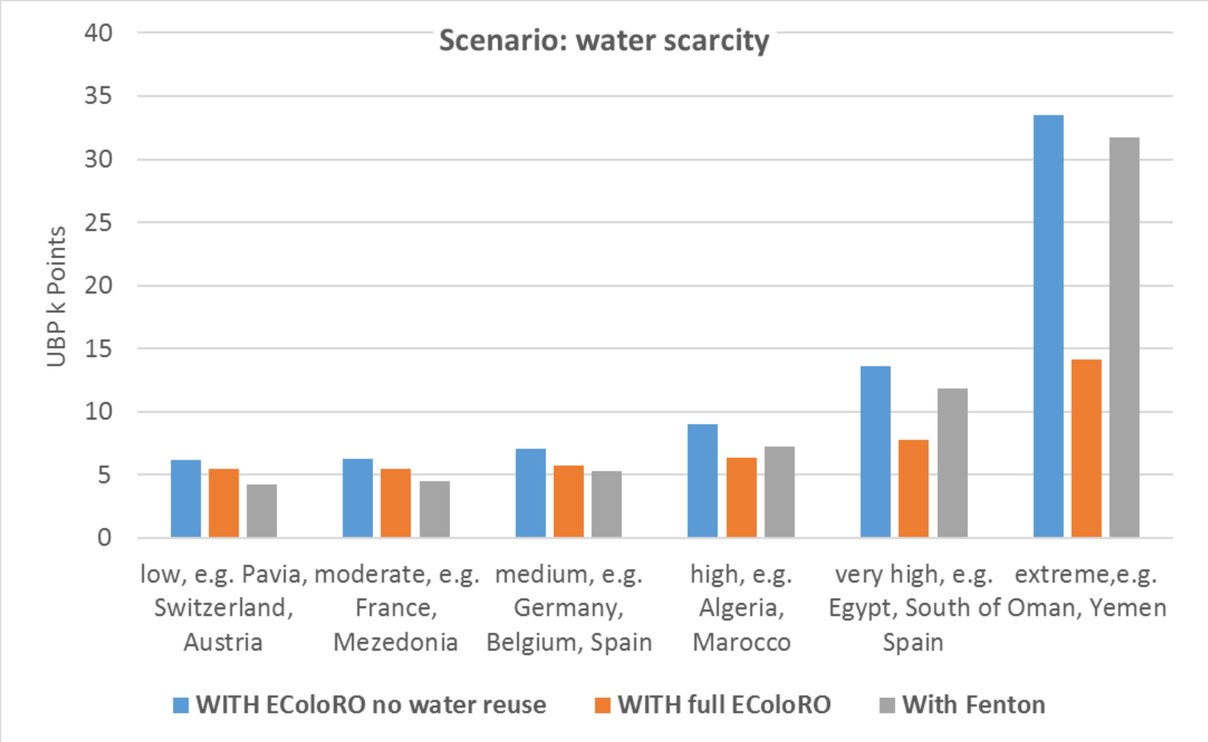


Figure 31 **Environmental impacts in regions of different water scarcity.** Based on the processes at Tintoria Pavese using the method: ecological scarcity.

4.3.2. Electricity

The results given in Figure 32 and Figure 33 show that the environmental impacts of the EcoloRO technology can be reduced further by using an eco-friendly electricity production like wind, hydro or PV. With these electricity productions EcoloRO technology leads to a reduction of the environmental impacts in both cases studied in this project, independent from the valuation method used.

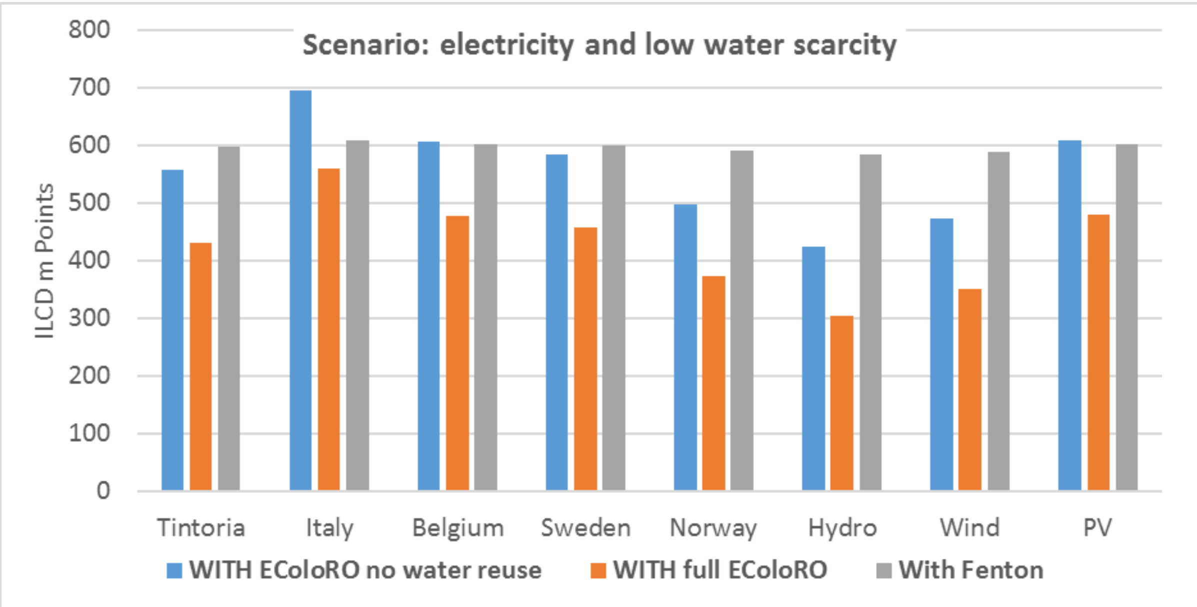


Figure 32 **Environmental impacts with different electricity productions and low water scarcity.** Based on the processes at Tintoria Pavese using the method ILCD.

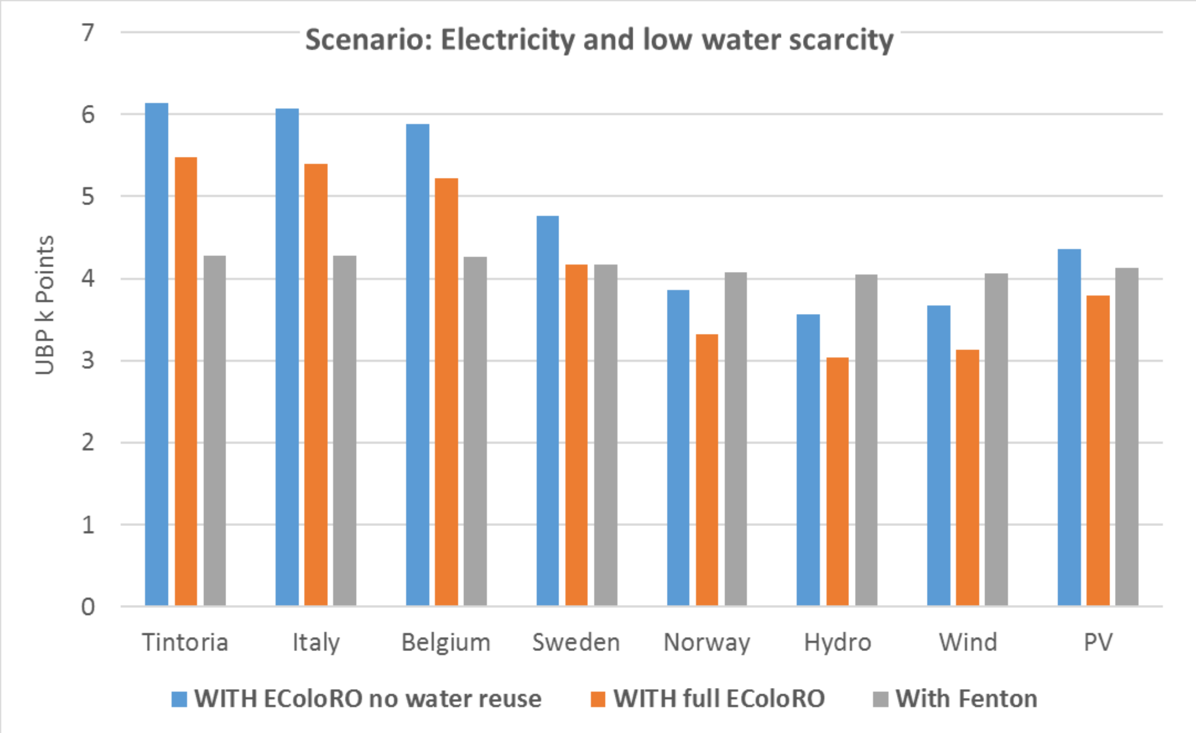


Figure 33 **Environmental impacts with different electricity productions and low water scarcity.** Based on the processes at Tintoria Pavese using the method ecological scarcity.

4.3.3. Elimination rates

Because no data was available for the elimination rates of the EColoRO process the same elimination rate for heavy metals as for the Fenton process has been chosen as a conservative assumption. A higher elimination rate leads of course to lower environmental effects and will not lead to a different outcome, the results discussed in the previous chapter are therefore robust.

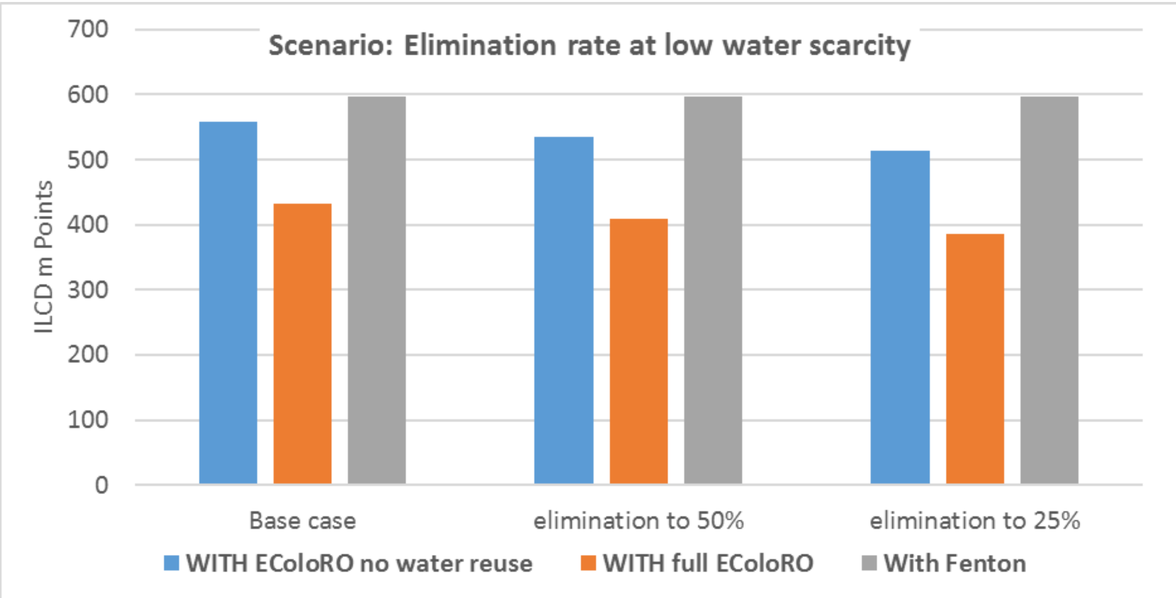


Figure 34 **Environmental impacts with different elimination rates of metals compared to the Fenton process for low water scarcity.** Based on the processes at Tintoria Pavese using the method ILCD.

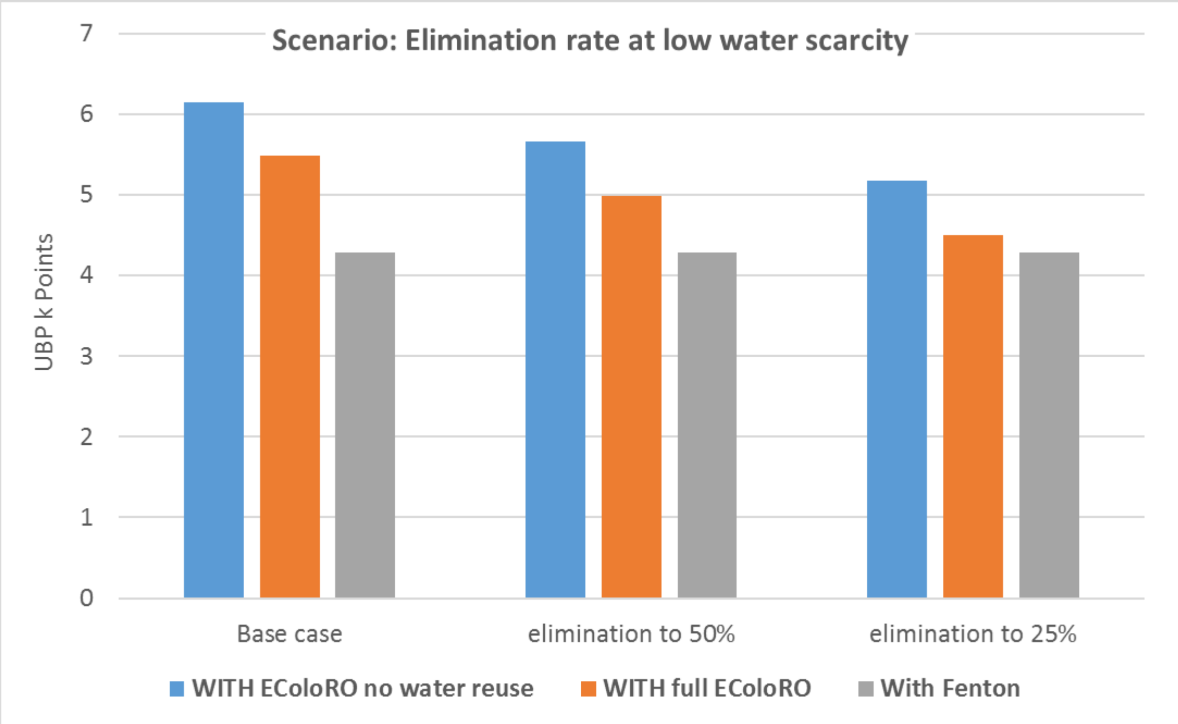


Figure 35 **Environmental impacts with different elimination rates of metals compared to the Fenton process for low water scarcity.** Based on the processes at Tintoria Pavese using the method ecological scarcity.

4.3.4. Discussion of the sensitivity analysis

All sensitivity analyses carried out have shown that the EColoRO technology leads to a higher environmental benefit than the standard scenario. This outcome demonstrates that the results are stable.

5. Conclusions

In this study the environmental effects of the EColoRO technique have been investigated using LCA. The analyses were conducted for two different textile plants in two regions, Belgium and Italy.
For the plant at Utexbel in Belgium a significant reduction of environmental impacts by a factor of 2 to 3 can be achieved by implementing EColoRO. This result has been validated by using two different valuation methods, performing an uncertainty calculation with Monte Carlo analysis and sensitivity analysis. Hence, the results are significant.
The main reasons for this result are:

- Reduction in water use:
  Belgium has medium water scarcity, similar to e.g. the Netherlands, Italy or Spain. If the EColoRO technique were applied to a region with high water stress, like the South of Spain or Algeria, or even extreme water stress like Jordan or Oman, the benefits would be even higher. The worse the water scarcity situation, the bigger the advantages of EColoRO.
- Reduction of water pollutants:
  Utexbel has no pre-treatment of wastewater. The wastewater goes to the municipal WWTP. The reduction of pollutants with EColoRO by 30 % to 90 % leads to a discharge of the municipal WWTP and in consequence to lower emissions to the water body.

Of course, the operation of the EColoRO technique is linked with environmental burdens, but they are lower than the benefits. The following improvements would lead to lower environmental impacts:

- reduced energy consumption
- type of electricity used
- reduction of the pollutants in waste water
- higher percentage of water reuse

The assessment of the textile plant Tintoria Pavese has shown that there is an environmental improvement using EColoRO technology compared to the current situation. However, the reductions are not as high as at the Utexbel textile plant in Belgium. The reasons for this result are:

- The region of Pavia has low water scarcity at the present. There is enough water from the Alps. This could probably change in the future, which would lead to a higher benefit of the EColoRO technology compared to the results given in this report for the base scenario.
- Tintoria Pavese does water pre-treatment with a Fenton reactor. For the pollutants where no data was available regarding the elimination rate of the EColoRO technology the experts assumed the same elimination rate as with a Fenton reactor. This is a conservative assumption. Presumably, the elimination rate of EColoRO is higher.

Based on the results of these two case studies the implementation of EColoRO technology in textile plants can be recommended from an environmental point of view. Especially in regions with medium or higher water stress, or in the case of textile plants with no waste water pre-treatment, the benefit of the EColoRO technology is very high.

6. Literature

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7. Abbreviations

BOD	biological oxygen demand
C	carbon
COD	chemical oxygen demand
CO_2	carbon dioxide
CTUe	comparative toxic units: characterization factor for eco-system toxicity impacts
CTUh	comparative toxic units: characterization factor for human toxicity impacts (human toxicity potential)
ECWRTI	Electro Coagulation for Water Recycling in Textile Industry
eq.	equivalent
GHG	greenhouse gas
GWP	Global Warming Potential
H	hydrogen
HH	human health
ILCD	LCA method to evaluate the environmental impacts
LCA	life cycle assessment
LCI	life cycle inventory
kBq	kilo Becquerel: unit for radioactive radiation
kPt.	kilo point: unit in the LCA method ecological scarcity
µPt.	micro point: unit used in the LCA method ILCD
N	nitrogen
NMVOC	non methane volatile organic carbons
P	phosphorous
PM2.5	particular matter with a diameter smaller than 2.5 µm
PV	Photovoltaic
RO	reverse osmosis
Sb	antimony
TSS	total suspended solids
UF	ultrafiltration
WWT	wastewater treatment
WWTP	wastewater treatment plant

8. Appendix: Inventory

The following tables show the foreground data used for the calculations. The data have been collected by the engineers from the companies and the project partners.

8.1. Energy

For electricity consumption the electricity mix of the counties was used taking into acount the import and export of electricity. Utexbel covers 2% of its electricity with electricity from a PV installation.

Table 2 1 kWh of electricity at Utexbel

Input	amount	unit	source	uncertainty
Electricity, low voltage {BE}| market for	0,98	kWh	Ecoinvent	1.05
Electricity, low voltage {BE}| electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted	0,02	kWh	Ecoinvent	1.05

Table 3 1 kWh of electricity at Tintoria

Input	amount	unit	source	uncertainty
Electricity, low voltage {IT}| market for	1	kWh	Ecoinvent	1.05

8.2. Pre-treatment of water

Table 4 Pumping and softening of input water

Water intake				
Description	amount	unit		
pumping, fresh water	1	m^3		
Input	amount	unit	source	uncertainty
Utexbel: electricity	0,79	kWh	Ecoinvent	1,05
Tintoria Pavese: electricity	0,41	kWh	Ecoinvent	1,05
Softening	1	m^3		
Utexbel: Sodium chloride	0,82	kg	Ecoinvent	1,05
Tintoria Pavese Sodium chloride	0,56	kg	Ecoinvent	1,05

8.3. Electrocoagulation

Table 5 Inventory of the process electrocoagulation at Utexbel given per FU 1 m³ of water input

Input	amount	unit	source	uncertainty
Hydrochloric acid, without water, in 30% solution	0,05	kg	Ecoinvent	1,56
Sodium hydroxide, without water, in 50% solution	0,05	kg	Ecoinvent	1,56
Electricity • 98% from the Grid • 2% solar	5	kWh	Ecoinvent	1,05
Output				
sludge	2.57	kg DM		
dry mass (DM)	50	%		
organic material	55	%		
iron	45	%		

Table 6 Inventory of the process electrocoagulation at Tintoria Pavese given per FU 1 m³ of water input

Input	amount	unit	source	uncertainty
Hydrochloric acid, without water, in 30% solution	0,05	kg	Ecoinvent	1,56
Sodium hydroxide, without water, in 50% solution	0,05	kg	Ecoinvent	1,56
Electricity • 100% from the Grid	5	kWh	Ecoinvent	1,05
Output (data from Utexbel used)				
sludge	1	kg DM		
dry mass (DM)	50	%		
organic material	55	%		
iron	45	%		

8.4. Flocculation und Flotation

Table 7 Inventory of the process flocculation at Utexbel given per FU 1 m3 of water input

Input	amount	unit	source	uncertainty
Iron pellet {GLO}| market for	0,45	kg	Ecoinvent	1,56
Process specific electricity, low voltage	0,5	kWh	Ecoinvent	1,5

Table 8 Inventory of the process flocculation at Tintoria Pavese given per FU 1 m³ of water input

Input	amount	unit	source	uncertainty
Iron pellet {GLO}| market for	0,4	kg	Ecoinvent	1,56
Process specific electricity, low voltage	0,5	kWh	Ecoinvent	1,5
NaCl	1.5	kg		

8.5. Sludge treatment

Table 9 Inventory sludge treatment incineration

Description	amount	unit		
treatment of sludge, incineration, dry mass	1	kg		
Input	amount	unit	source	uncertainty
Transport, freight, lorry 16-32 metric ton, EURO4 {GLO}| market for	0,1	tkm	Ecoinvent	1,3
Process specific electricity, low voltage, parametrisiert	0,03	kWh	Ecoinvent	1,57
Output	amount	unit	source	uncertainty
Raw sewage sludge {CH}| treatment of, municipal incineration	0,8	kg	Ecoinvent	1,05
Iron {RoW}| treatment of iron, municipal incineration	0,2	kg	Ecoinvent	1,05

8.6. Ultrafiltration

Table 10 Inventory of ultrafiltration

Description	amount	unit		
UF	1	m^3		
Input	amount	unit	source	uncertainty
Ultrafiltration UF module	1	m^3	E4Water	1,0
Process specific electricity, low voltage	0,215	kWh	Ecoinvent	1,21

The UF module was used from the E4water project

8.7. Reverse osmosis (RO)

Table 11 Inventory of RO

Description	amount	unit		
Reverse osmosis (RO), permeate	1	m^3		
Input	**amount**	**unit**	**source**	**uncertainty**
electricity	0.782	kWh	E4Water	1.1
All the data for infrastructure and chemical used in operation was taken from the E4Water project				

8.8. Fenton process at Tintoria Pavese

Table 12 Inventory of Fenton process

Description	amount	unit		
Fenton Process per	**1**	**m³ of waste water to be treated**		
Input	**amount**	**unit**	**source**	**uncertainty**
H_2O_2 35%	1.53	kg	Tintoria	1.05
lime	0.943	kg	Tintoria	1.1
Iron sulphate	0.186	kg	Tintoria	1.05
Poly electrolyte	0.00305	kg	Tintoria	1.2
electricity	0.0434	kWh	Tintoria	1.1
Transport	500	km	assumption	1.3
Output	**amount**	**unit**	**source**	**uncertainty**
Sludge 38% dry mass to landfill	1.77	kg	Tintoria	1.05
Transport lorry	170	km	to Torino	1.1
All the data for infrastructure have been estimated based on data from WWTP				

8.9. Wastewater to the municipal WWTP

Table 13 Waste water of Utexbel to the WWT plant in Ronse

	Without EColoRO			**With EColoRO**			
Pollutants				**to the sludge**		**Remaining in Brine**	
	unit	**amount**		**EC**	**UF**		**mg/l**
COD total	mg/l	2133		50%	50%	25%	533.25
TSS	mg/l	300		90%		10%	30.00
BOD5	mg/l	660		50%	50%	25%	165.00
AOX	mg/l	0.7				100%	0.70
P-tot	mg/l	15.4		75%	65%	9%	1.35
N-tot	mg/l	52		50%	70%	15%	7.80
Cl-	mg/l	104		0	30%	70%	72.80
SO42-	mg/l	765		20%	10%	72%	550.80
As	mg/l	0.002		90%		10%	0.00020
Cd	mg/l	0.0001	< detection	90%		10%	0.00001
Cr total	mg/l	0.0144		90%		10%	0.00144
Cu	mg/l	0.07		90%		10%	0.00700
Ni	mg/l	0.008		90%		10%	0.00080
Pb	mg/l	0.008		90%		10%	0.00080
Zn	mg/l	0.257		90%		10%	0.02570
Sb	mg/l	0.68		90%		10%	0.06800
Se	mg/l	0.004		90%		10%	0.00040
V	mg/l	0.035		90%		10%	0.00350
B	mg/l	0.28		90%		10%	0.02800
PAK (hydrocarbons)	mg/l	0.3223		90%		10%	0.03223

Table 14 Waste water of Tintoria Pavese to the WWT plant in Pavia

			Fenton	With EcoloRO			
Pollutants		**after textile plant**	**to municipal WWTP**	**to the sludge**		**Remaining in Brine**	
	unit	**amount**	**amount**	**EC**	**UF**		**mg/l**
COD total	mg/l	558	85	50%	50%	25%	482*
TSS (total suspended solids)	mg/l	24	12	90%		10%	23*
BOD5	mg/l	203	20	50%	50%	25%	159*
P-tot	mg/l	0.05	0.05	75%	65%	9%	0.005
Ammonia NH4	mg/l	4.6	4.6	50%	70%	15%	0.69
Nitrate	mg/l	0.013	0.013	50%	70%	15%	0.002
Cl-	mg/l	393	393	0	30%	70%	275
SO42-	mg/l	1093	1093	20%	10%	72%	787
Al	mg/l		0.25	90%		10%	0.25
Ba	mg/l		0.02	90%		10%	0.02
B	mg/l		0.14	90%		10%	0.14
Cd	mg/l		0.0002	90%		10%	0.0002
Cr total	mg/l		0.02	90%		10%	0.02
Cu	mg/l		0.03	90%		10%	0.03
Hg	mg/l		0.0001	90%		10%	0.0001
Fe	mg/l		1.21	90%		10%	1.21
Mn	mg/l		0.15	90%		10%	0.15
Ni	mg/l		0.087	90%		10%	0.087
Pb	mg/l		0.03	90%		10%	0.03
Zn	mg/l		0.22	90%		10%	0.22

- Data given by Marc Feyaerts, the others are calculated.

8.10. Municipal WWTP

The municipal WWTP was modelled using the modelling tool from Gabor Doka (Doka, 2002).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.642494

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