“*GHEORGHE ASACHI*” TECHNICAL UNIVERSITY OF IAŞI

STUDIES ON THE ENVIRONMENTAL PERFORMANCE OF THE WATER TREATMENT SYSTEMS

PhD Thesis - Extended abstract

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"GHEORGHE ASACHI" TECHNICAL UNIVERSITY OF IAŞI
R E C T O R A T E

To

We inform you that, on the (date) **12.04.2019** at (time) **10^{00}**, în **Council Room, "Cristofor Simionescu" Faculty of Chemical Engineering and Environmental Protection**, there will take place the public defence of the doctoral thesis titled:

"STUDIES ON THE ENVIRONMENTAL PERFORMANCE OF THE WATER TREATMENT SYSTEMS"

Written by Madam **GÎLCĂ Andreea-Florina (căs. DEREVLEAN)** in order to obtain the title of PhD.

The doctoral committee comprises of:

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With this occasion we invite you to participate in the public defence of the doctoral thesis.

ROMÂNIA
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UNIVERSITATEA TEHNICĂ „GHEORGHE ASACHI" IAŞI

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Note: The numbering of the chapters, tables, figures and abbreviations are those corresponding with the complete PhD thesis.

INTRODUCTION

The decreasing quality of water resources is one of the main challenges of the 21^{st} century, which induces problems to the the entire population, and generates impacts on human health and ecosystems that limit or reduce the effectiveness of actions taken in certain sectors, which ultimately translate in environmental, social and economic issues (Zhu *et al.,* 2017).

Unlimited access which does not require any restriction on water resource use for drinking purposes or the operation of sanitation services at safe and qualitative parameters is considered an essential human right to the health and well-being of people (UNESCO, 2015). A new challenge in terms of drinking water quality, with potentially serious threats to human health or terrestrial and aquatic ecosystems is the appearance of new pollutants, the so-called *emerging pollutants* (Teodosiu *et al.,* 2018).

Innovative solutions for ensuring proper drinking water quality are based on pollution prevention and control technologies and on advanced water treatment technologies. The potential of advanced water treatment technologies, for emerging pollutant removal offers promising solutions for solving the issues related to global water resources depletion both in developed countries or developing countries.

The efforts of the authorities in charge with water resource management as well as of those responsible for the quality of these resources support the promotion of scientific, technological and legislative solutions for making the best decisions regarding the improvement, prevention, reduction and pollution control of the water resources. Institutions that have as activity profile water supply services, in the last decades, they have made efforts and strive to improve their environmental, economic and technological performance due to the multiple challenges they face in terms of quality and availability of water resources, industrialization, climate change, urban population growth and aging infrastructure (Xue *et al.,* 2018).

Integrated Water Resources Management (IWRM) is an extensive and complex process of planning, development and management of water resources in terms of quantity and quality, involving institutions, with the aim to protect water resources needed for each activity in the field of drinking water systems and sanitation, food production, energy generation, transport, as well as supporting aquatic ecosystems and the protection of aesthetic and spiritual values of lakes, rivers and estuaries (WHO, 2011).

In the context of sustainable development, IWRM consists in establishing a social, economic and environmental sustainability balance between the quality of water essential to human health, ecosystems (terrestrial and aquatic) and water resources depletion, which can rapidly lead to immediate changes against the integrity of the ecosystems (Hering and Ingold, 2012; Khadse *et al.,* 2012).

Degradation of water quality is a major challenge to providing enough water of good quality to meet human, environmental, social and economic needs to support the development of all activity sectors.

Advanced drinking water treatment technologies are needed for pollutant removal from water, but also involve the use of large amounts of reagents and electricity which translates into high secondary environmental impacts.

Therefore, the adoption of advanced drinking water treatment technologies to remove pollutants, must take into account the complete assessments regarding the performance on issues like technical, environmental and economic aspects to ensure the sustainability of the treatment systems.

The environmental performance assessment of the water treatment systems is achieved in this thesis by applying the life cycle assessment methodology (LCA). There has been recorded an increase in the number of studies that have applied this methodology to assess environmental performance of the water treatment systems in order to identify the environmental problems.

Life cycle assessment has been adopted as a tool for assessing the environmental performance of water treatment systems, because it is possible to identify the environmental effects generated by a product or process through the entire life cycle (extraction, production, use, disposal, reuse, recycle) (Vince *et al.,* 2008).

In the water sector LCA has received a growing attention, being mainly used for applications like: evaluation of the whole water use cycle (Barjoveanu *et al.,* 2014; Loubet *et al.,* 2014), environmental assessment of water and wastewater treatment technologies (Corominas *et al.,* 2013). Related to water treatment, LCA was extensively used to compare the environmental impacts of various treatment processes, technologies and development scenarios. Most of the LCA studies have been oriented towards the operational phase of the water production steps, and only few have considered the construction and decommissioning phases of water production facilities (Friedrich and Buckley, 2002; Igos *et al.,* 2014).

The studies presented in the PhD thesis on the assessment of the environmental performance of water treatment systems, through the variety of perspectives proposed for assessment, highlight the contribution of all inputs / outputs to the environmental performance of the treatment process and the importance of the water resources used.

The entire research effort justifies the importance of the quality of water resources for humans and ecosystems, the influence of electricity consumption and the contribution of the reagents used in the treatment process in which they are involved and the efficiency of the technologies used.

The goal and objectives of the thesis

The PhD program is based on an agreement for PhD co-supervision, between "Gheorghe Asachi" Technical University of Iasi, “Cristofor Simionescu”Faculty of Chemical Engineering and Environmental Protection, **scientific coordinator Prof. PhD eng. Carmen Teodosiu** and Politecnico di Torino, Department of Engineering for Environment, Land and Infrastructures (DIATI), **scientific coordinator prof. PhD chem. Silvia Fiore.**

The general objective of the PhD thesis is to assess **the environmental performance of two water treatment systems, the Chiriţa drinking water treatment plant (Iaşi, Romania) and Po drinking water treatment plant (Torino, Italy), by using the Life Cycle Assessment (LCA) as an impact assessment tool, in order to identify the main problems caused by the water treatment process and the weaknesses of the water treatment system.** The following specific objectives have been developed to achieve the general objective:

- Analysis of the real or pilot scale studies presented in the literature on the occurrence, evolution, impact and removal of priority/emerging pollutants and disinfection by-products in water treatment processes;
- Assessment of the environmental performances of the two drinking water treatment systems (Chirița and Po) through the Life Cycle Assessment methodology;
- General characterization of the environmental impact generated by the activity of the two water treatment plants;
- The influence of the reagents and materials used in the treatment process on the environmental profiles of the two studied system;
- The environmental effects generated by the use of energy, reagents/materials and transport;
- Identifying the stage in the treatment process that generates the greatest environmental impact;
- Development of scenarios for the assessment and comparative analysis of the environmental performance of water treatment systems;
- Develop and implement a new analysis framework to identify and compare the performance of water treatment systems in Italy and Romania based on a set of indicators for assessing the sustainability of these systems.

Research plan

A research plan was elaborated to fulfil all the objectives. In order to apply the LCA methodology, required data were obtained from the two companies (directly or from Sustainability reports), from scientific literature, databases or previous studies. The data were centralized and processed, and subsequently were introduced in SimaPro software, to generate the life cycle inventory and then obtain the results of the environmental performance of the drinking water treatment system.

Beside the LCA study, a sustainability assessment framework of indicators was proposed in order to evaluate the performance of water treatment systems. For this framework, different indicators have been selected (technical, environmental, economical and social) in order to describe the sustainability of the assessed systems. The data were obtained directly from the companies, sustainability reports, Eurostat databases, previous studies and on different web sites.

This study considers the major research topics approached in this field at international level as well as identifying the issues that may represent additional research directions.

Thesis structure

The PhD thesis consists of an "**Introduction**" chapter presenting the general and specific objectives of the PhD thesis, 5 chapters which cover the current stage of the researches existing in the literature, the applied methodology on the two studies to assess the performance of water treatment systems and the results obtained after their analysis. Chapter 6 contains general conclusions and some recommendations on assessing the environmental performance of water treatment systems.

The PhD thesis has a total of 212 pages, contains 27 tables, 68 figures and 278 bibliographic references, of which 36 are web references.

In "**Introduction**" there are presented the advantages and disadvantages of the life cycle assessment methodology for assessing the performance of water treatment systems. The objectives and the structure of the PhD thesis are also presented in this chapter.

Chapter 1 presents the **State of the art in the assessment of environmental performance of the water treatment systems,** by means of advanced water treatment technologies focused on priority and emerging pollutants removal from surface water. Previous studies have been collected and analysed in detail to obtain data on the occurrence, evolution, health effects, impact and removal of priority / emerging pollutants and disinfection by-products through advanced water treatment technologies from surface sources. It also presented a synthesis of the experimental research, at full scale or pilot scale on the assessment of the performance of water treatment systems through the LCA methodology.

Chapter 2 presents in detail the **LCA methodology applied for the assessment of environmental performances of the water treatment plants**.

Chapters 3, 4 and **5** present the **original contributions** obtained following the process of assessing the environmental, social and economical performances of the two water treatment plants located in Romania and Italy.

In **Chapter 3** were studied the **environmental impact generated by the drinking water treatment process** from drinking water treatment plant Chirița. **The environmental performance of the system was assessed through LCA methodology,** at the same time being identified and analyzed the factors that generate environmental impacts.

The life cycle impact assessment has considered the production of **1 m^3 of treated water** in STAP Chirița as functional unit, has assumed the quantification of all resources / raw materials (inputs) and emissions, by-products (outputs) to generate environmental impact profiles (human health, resources and ecosystems impacts). The main objective of this study is to identify the water treatment inventory inputs that generate environmental impacts and to understand how the energy and reagent consumption, natural gases and transport of the reagents involved in the drinking water treatment process contribute to these environmental profiles.

The assessment study of the drinking water treatment system concludes with a life cycle impact assessment at endpoint level, which consists in identifying the impact generated in the three areas of protection (human health, ecosystems quality and resources).

In **Chapter 4** it is assessed the **environmental performance of the drinking water treatment plant (Po) located in Turin, Italy.** This drinking water treatment plant treats water from a surface source (Pad River) and it is composed of three drinking water treatment lines. In this chapter the environmental performance of Po1 and Po2 treatment lines are assessed together and Po3 treatment line is assessed individually, according to the local plant configuration. In this study, a new perspective to assess the environmental performance is on treatment line was used, in order to identify the treatment stage with higher impact against the environment.

In **Chapter 5** it is presented a **comparative analysis** between the two drinking water treatment systems from Romania and Italy. Also, a **scenario analysis was performed to evaluate the possibilities to improve the environmental performance of the two systems**. Also, in this chapter it is **developed and applied a framework based**

on sustainability indicators in order to identify, analyse and compare the performances of the two systems from social, economical and environmental standpoints.

Chapter 6 contains the **general conclusions** obtained after the analysis of the environmental performances of the two drinking water treatment systems. In this chapter are presented the main conclusion, accompanied by some suggestions / recommendations regarding the future action / activities.

The PhD thesis finalizes with the bibliographic references consulted in drawing up the current state of the research in the thesis topic and to support the statements and interpretation of the results after the development of the two case studies.

At the and of the PhD thesis it is presented the list with scientific papers published in international and national journals, ISI ranked and the list with participations at national and international conferences.

The originality of the research consists in the variety of perspectives considered for the analysis of the environmental performance of the two water treatment systems. The proposed perspectives offer a clear and objective view of the causes and impacts generated by the activity of Chirița and Po drinking water treatment plants, the influence of reagents and materials used in the treatment process and the environmental effects of energy, reagents, materials and transport.

The innovative character of this PhD thesis is the development of scenarios for the critical analysis of the environmental performances. Another element of originality is the development and application of a framework based on sustainability indicators in order to analyse, identify and compare the performances of the two systems (social, economical and environmental).

The results obtained during the period of the PhD study were disseminated in: 5 articles published in national and international journals (3 articles with impact factor, ranked ISI and 2 articles submitted for publication) and 4 papers presented at national and international conferences as a poster.

CHAPTER 1. STATE OF THE ART ON THE ASSESSMENT OF ENVIRONMENTAL PERFORMANCE OF THE WATER TREATMENT SYSTEMS

1.1. Integrated Water Resources Management

Global Water Partnership (GWP), through the Advisory Technical Committee provides a generally accepted definition of Integrated Management of Water Resources as a "process to promote the coordinated development and management of water resources, the sustainable use of land and other resources in order to maximize economic performance and social welfare in a fair manner, without compromising the sustainability of living ecosystems" (GWP, 2009; Teodosiu *et al.,* 2011a).

With regard to the concept of sustainable development in the field of water resources management, water quality is essential for human health, aquatic and terrestrial ecosystems, both from a social, economic and environmental point of view. Exhaustion of fresh water resources can rapidly produce immediate changes to the status, functions and integrity of the ecosystems (Hering și Ingold, 2012; Khadse *et al.,* 2012).

The concept of sustainability in integrated water resource management is guided by the following principles (GWP, 2009; www.worldwatercouncil.org):

Principle 1: Water is a finite and vulnerable resource essential to the health of people and ecosystems, their development and for the proper functioning of the environment;

Principle 2: Improving the quality and management of water resources should be based on a participatory approach, involving users, planners and decision-makers at all levels;

Principle 3: The role of women in processes such as the provision, management and conservation of water resources is essential, and their participation in decision-making processes is essential;

Principle 4: Water has an economic value in all sectors in which it is used and should be recognized as an economic good and valuable;

A compilation of these principles ensures sustainable management of water resources, based on environmental sustainability, economic efficiency and social equity (Teodosiu *et al.,* 2011a).

1.1.1. Current challenges of Integrated Water Resources Management

The current challenge is to manage the freshwater resources of the planet in a sustainable and efficient way, so that population requirements are met with water that meets the highest quality requirements and standards Figure 1.4.

Of the total amount of water available on earth, only 3% is freshwater, which is one of the major sources of drinking water for human consumption. For sectors such as agriculture, industry, energy production, the degradation of water quality is therefore a major challenge in ensuring sufficient water quality to meet human, environmental, social and economic needs.

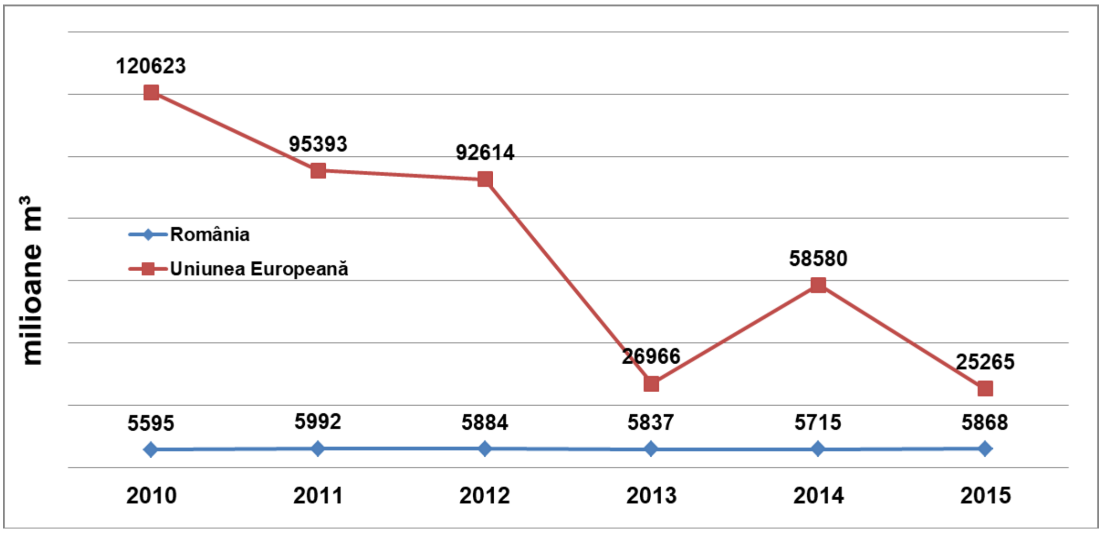


Figura 1.4. Freshwater resources variation for Romania and UE.

Source *www.ec.europa.eu/eurostat/*

Particular attention should be paid to surface water used for drinking purposes as they are most exposed to contamination with industrial pollutants, agriculture, livestock manure, and leachate infiltration from landfills (Schwarzenbach, 2006; WHO, 2011; Rosenfeld *et al.,* 2011).

1.1.2. Legislative issues concerning water management

EU water policy was updated by Directive 2013/39/EU, which amends Water Framework Directive (WFD) 2000/60/EC. This new directive is based on the preventive actions and the polluter pays principles (CE, 2013).

WFD is transposed into national law by the legislative regulementation (*www.ec.europa.eu; www.mmediu.ro; www.rowater.ro)*.

Worldwide, emerging pollutants are newly introduced into regulatory regulations. Most of the priority pollutants (PPs) are classified as emerging pollutants (EPs) and are well regulated.

Directive 2013/39/EU defines a list of **45-priority pollutants** grouped as single or classes of substances, which contains pesticides, industrial additives and by-products, pharmaceuticals, personal care products, steroid hormones, drugs of abuse, food additives, flame/fire retards, surfactants and others (Teodosiu *et al.,* 2018, Ribeiro *et al.,* 2015), from which an initial 10 compounds form a *watch list*.

The first PPs included in the watch list are diclofenac, 17-beta-estradiol (E2) and 17-alfa-etiniestradiol (EE2), and measures to avoid the risks involved by the release of these contaminants into aquatic environment will be established (CE, 2013; Geissen *et al.,* 2015; Ribeiro *et al.,* 2015; Barbosa *et al.,* 2016).

1.1.3. Conventional water treatment processes and advanced drinking water treatment processes

Conventional DWT processes are dedicated to the removal of solids of various sizes (large solids, grit, suspended solids and colloids), organic matter (natural or synthetic) and microorganisms/pathogens. The usual conventional processes related to DWT refer to: barscreening, grit removal, pre-oxidation, coagulation-flocculation, sedimentation, rapid/slow sand filtration, disinfection.

The widespread use of chemicals, PPCPs, pesticides and solvents made necessary the adoption of advanced drinking water treatment technologies, because conventional drinking water treatment technologies were not designed to remove EPs which are characterized by low concentration and high environmental persistence with health related effects. This situation is exacerbated by the increasing pressures on water resources due to population growth, deterioration of natural water sources, knowledge of new EPs and therefore new guidelines and regulations involving more restrictive concentration limits. In consequence, the adoption of advanced drinking water treatment technologies is highly recommended, taking the advantage of the available mature technical solutions.

1.2. Advanced drinking water treatment (ADWT) processes for emerging/priority pollutants removal

Large-scale use of chemicals, personal care products and pharmaceuticals, pesticides, and solvents used in various industries has led to the adoption of advanced drinking water treatment technologies because conventional water treatment systems have not been designed to remove pollutants from water characterized by high persistence in the environment, low concentrations and harmful effects on human health (Miniero *et al., 2014*).

1.2.1. Emerging/priority pollutants sources and classification

The Norman Network (2016) defined EPs as "*substances detected into environment but currently not included in routine environmental monitoring programmes and which may be candidate for future legislation due to its adverse effects and/or persistency*". More than 1000 substances, gathered in 16 classes (algal toxins, antifoaming and complexing agents, antioxidants, detergents, disinfection by-products, plasticizers, flame retardants, fragrances, gasoline additives, nanoparticles, perfluoroalkylated substances, personal care products, pharmaceuticals, pesticides, anticorrosives), are classified as EPs addressing their environmental and health effects and some of their sources.

Huge efforts are still being made both for the analysis and for a more accurate classification of these pollutants (Figure 1.7).

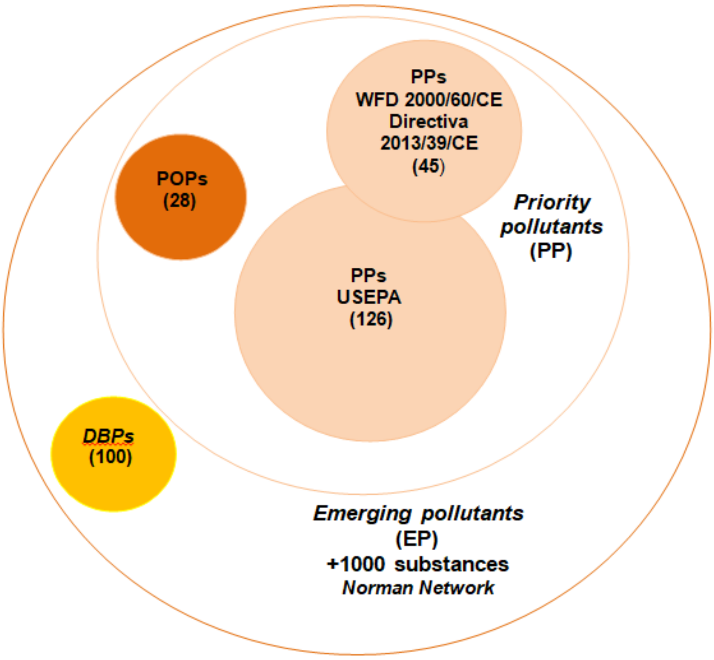


Figure 1.7.Classification of persistent and priority organic pollutants in the context of emerging pollutants.Source *Teodosiu et al., 2018*

Insufficient or inadequate wastewater treatments, excessive use of pesticides or wastewater discharges from hospitals are important causes of surface water pollution by EPs. River freshwater is the most exposed to contamination from industrial, agricultural and animal farming discharges and also leachate infiltration from landfills (Geissen *et al.,* 2015). Pharmaceuticals and personal-care products (PPCPs) that occur in surface waters due to inefficient wastewater treatment affect the environment and human health through their persistence and bioaccumulation tendency (Hernando Guil *et al.,* 2014) (Figure 1.8).

1.2.2. Emerging/priority pollutants removal through advanced drinking water treatment technologies

Recent studies have demonstrated the importance of removing emerging pollutants from drinking water using advanced treatment technologies, highlighting the toxic potential and the negative impacts that they can have it on consumer health and aquatic ecosystems**.**

Advanced water treatment technologies used for PPs/PEs removal from surface waters and having as final end-use water supply, should consider at least the following criteria before being implemented: (i) range of treated pollutants, treatment efficiency and removal mechanisms, (ii) environmental friendliness, (iii) simplicity of operation and maintenance, (iv) cost-effectiveness and (v) social acceptance.

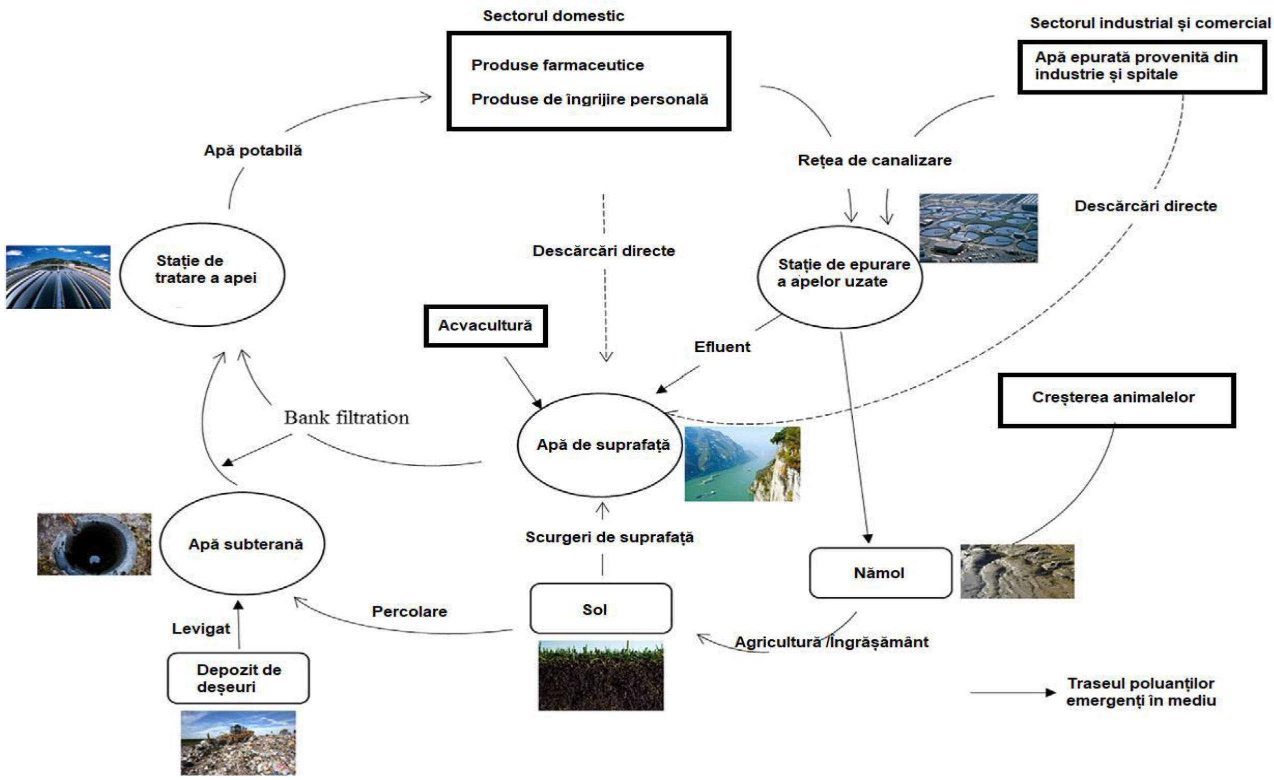


Figure 1.8. Sources and occurrence of EPs/PPs in drinking water sources.

Source: (Yang *et al.,* 2017, Teodosiu *et al.,* 2018)

The most used and promising ADWT technologies for EPs' specific removal at pilot and/or full-scale are membrane processes, adsorption on activated carbon processes and advanced oxidation processes (AOPs) (Teodosiu *et al.,* 2018)

1.2.3. Impact of emerging/priority pollutants on the environment and health effects

EPs transformation through DWT processes can lead to compounds which may be more toxic, persistent and less biodegradable than their predecessors (Farré et al., 2008). The most important environmental effects of EPs refer to: bioaccumulation and biomagnification, persistency, toxicity, endocrine disruption potential, carcinogenic effects, mutagenic and teratogenic effects (Guillén *et al.,* 2012). Some EPs can be harmful for both humans and aquatic organisms, with endocrine disturbing effects, estrogenic or hormone disruption, foetal malformation, or even DNA damages (Fawell and Ong, 2012; Sedan *et al.,* 2013). Human exposure pathways include: ingestion, inhalation and dermal contact through water and food. DBPs may affect humans and their life quality due to effects like: pregnancy duration, menstrual cycle or pregnancy loss, foetal development and congenital malformations or cancer (Villanueva *et al.,* 2015, Gilca *et al.,* 2019).

1.3. Life cycle assessment methodology applied on environmental impact assessment studies generated by the drinking water treatment systems

Advanced drinking water treatment technologies are needed to remove emerging pollutants, which implies high energy consumption and / or additional chemicals, which translates into higher investment and exploitation costs (Bui *et al.,* 2016).

In water resource management, life cycle assessment is considered one of the most appropriate environmental performance assessment tools because it can identify environmental aspects throughout the system from cradle to grave (raw material, production, use and disposal, including recycling and reuse) (Godskesen *et al.,* 2013).

This assessment tools can improve the sustainability profile of a water treatment system identifying the impact and the factors that generate impact (electricity, chemical consumption, transport, etc.) (Lemos *et al.,* 2013; Barjoveanu *et al.,* 2014).

CHAPTER 2. RESEARCH METHODOLOGY

2.1. Life cycle assessment methodology (LCA)

Life Cycle Assessment (LCA) is an environmental assessment tool used to objectively analyze and quantify the environmental implications of the products (goods)/processes during all stages of the life cycle, from extraction of raw materials, to manufacturing until use of goods, including disposal at the end of life.

Depending on the life cycle stages considered when conducting a LCA study following approaches can be distinguished (ISO 14040:2006):

- cradle-to-grave (product full life cycle);
- cradle-to-gate (from material extraction to manufacturers gate);
- gate-to-gate;
- gate-to-grave (after manufacturing and until disposal, including final disposal).

2.1.2. The ISO14040 series of standards

International Organization of Stadardisation (ISO) has developed a series of standards for life cycle assessment (http://www.iso.org):

- ISO 14040:2006 Principles and Framework;
- ISO 14044:2006 Requirements and guidelines;

2.1.3. Life cycle assessment objective

Life cycle assessment methodology monitors and quantifies material and energy consumption, impacts on human health and ecosystems, from extraction of raw materials, to manufacturing until use of goods, including disposal at the end of life (ISO 14040:2006).

2.1.4. Life cycle assessment stages

According to ISO 14040:2006 the LCA phases are briefly detailed in Figure 2.1.

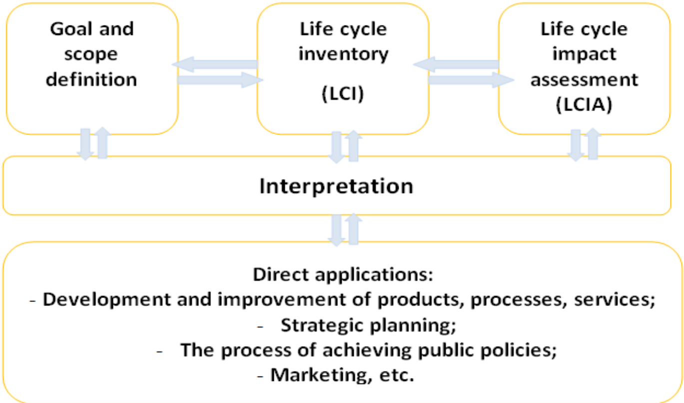


Figure 2.1. Life Cycle Assessment stages (*source: ISO 14040:2006*)

This methodology has four distinct phases as presented in Figure 2.1 (ISO 14040:2006)

2.1.4.1. Goal and scope definition

The LCA **goal** indicates the intention and reasons for applying the assessment. The **scope** of the LCA study includes the product system that is intended to be studied, functional unit, system boundaries, the selected methodology and impact categories, data requirements, limitations and assumptions (ISO 14040:2006).

2.1.4.2. Life Cycle Inventory (LCI)

LCI provides a detailed description of the inputs (raw materials, energy, materials) and outouts (air, water and soil emissions and wastes) for the system under analysis. (ISO 14040:2006).

2.1.4.3. Life Cycle Impact Assessment (LCIA)

Life cycle impact assessment is defined as the stage of the LCA study that aims to understand and assess the magnitude and significance of a potential environmental effect of a process or product.

As specified in ISO 14040, the LCIA stage contains mandatory (Classification, Characterization) and optional elements (Normalization; Grouping; Weighting).

LCIA profile of the product/process system consists of environmental impact indicators results for the selected impact categories (ISO 14040:2006).

2.1.4.4. Interpretation

In this phase the results obtained in the inventory and in the impact assessment steps are combined in accordance with the preset goal and defined objectives. The phase of Interpretation has the aim to derive conclusions and recommendations, necessary to reduce the environmental impact of the processes.

2.2. Methods that can be applied in LCA studies

2.3. The relevant impact categories for LCA studies

2.4. Software instruments used in LCA studies

2.4.1. Databases used in LCA studies

The case studies presented in Chapter 3 and Chapter 4 follow the methodology presented in this chapter for assessing the environmental performance of water treatment systems. The method used to assess the impact generated by the production of 1 m^3 of treated water is ReCiPe and the software used is SimaPro.

CHAPTER 3. ENVIRONMENTAL PERFORMANCE ASSESSMENT OF A ROMANIAN DRINKING WATER TREATMENT SYSTEM. CASE STUDY: S.C. APAVITAL S.A., IAȘI.

3.1. Analysing the environmental performance of water treatment systems by LCA

The LCA methodology has been previously applied in the field of water resource management and following the implementation of numerous studies, which have had as objective the assessment of the impact generated by the extraction, transport, treatment, distribution or the entire urban water supply system, conclusions can be drawn on a wide range of generated impacts.

Environmental performance assessment studies are not only relevant for the analysis of future water resources management but also for the assessment of the production or management of material and natural resources, with the intent to emphasize their impact and importance against the environment (Xue *et al.,* 2018).

The overall objective of the study presented in this chapter is to evaluate the environmental performance of drinking water treatment plant Chirița, Iași, using Life Cycle Assessment as a tool to quantify the impact generated. The purpose of the LCA study is to identify and quantify the main environmental impacts associated with water treatment process.

3.1.1. Water resources management in Romania and Iași County

Generally speaking, water resource management activities include the following water related responsabilities:

- the public drinking water supply;
- water treatment system;
- the water supply, distribution and storage system used for drinking and industrial purposes;
- collection, treatment and discharge of wastewaters.

At national level, the institution dealing with water resources management is *Administrația Națională — Apele Române* (ANAR).

In 2017, the total amount of water supplied is almost 1.125.447,9 $\cdot 10^3$ m^3 from which 46,2% is for human consumption, 29,4% for agriculture, 15,9% for industy and 8,5% for other consumers *(INS, 2018a*).

Water resource management in Iaşi County

S.C. APAVITAL S.A. supplies water for 447.380 residents, with an operating area of 273 localities (Figure 3.2).

Water resources for water supply of the Iași City come from two sources: Timișești source – groundwater source and Chirița accumulation – surface water from Prut River.

The Prut water supply system is located 20 km away from the Chirița drinking water treatment plant while the Timișești water supply system has 297,5 km. The water distribution network în Iași county has 493 km.

Given the overall objective of this chapter, the assessment consides the Chirița drinking water treatment plant because the system uses water from surface sources for treatment. Below, it is presented in detail the technological process of the Chiriţa drinking water treatment system.

3.1.2. Presentation of the Chitița water treatment system

Drinking water treatment plant has a production capacity ranging between 0,6 – 1,15 m^3/s with a variable flow rate between 2.150 m^3/h and 4.100 m^3/h.

The quality parameters of treated water comply with the requirements established by the European Union by Directive 98/83/EC on drinking water quality, transposed into Romanian legislation by **Law no. 458/2002.**

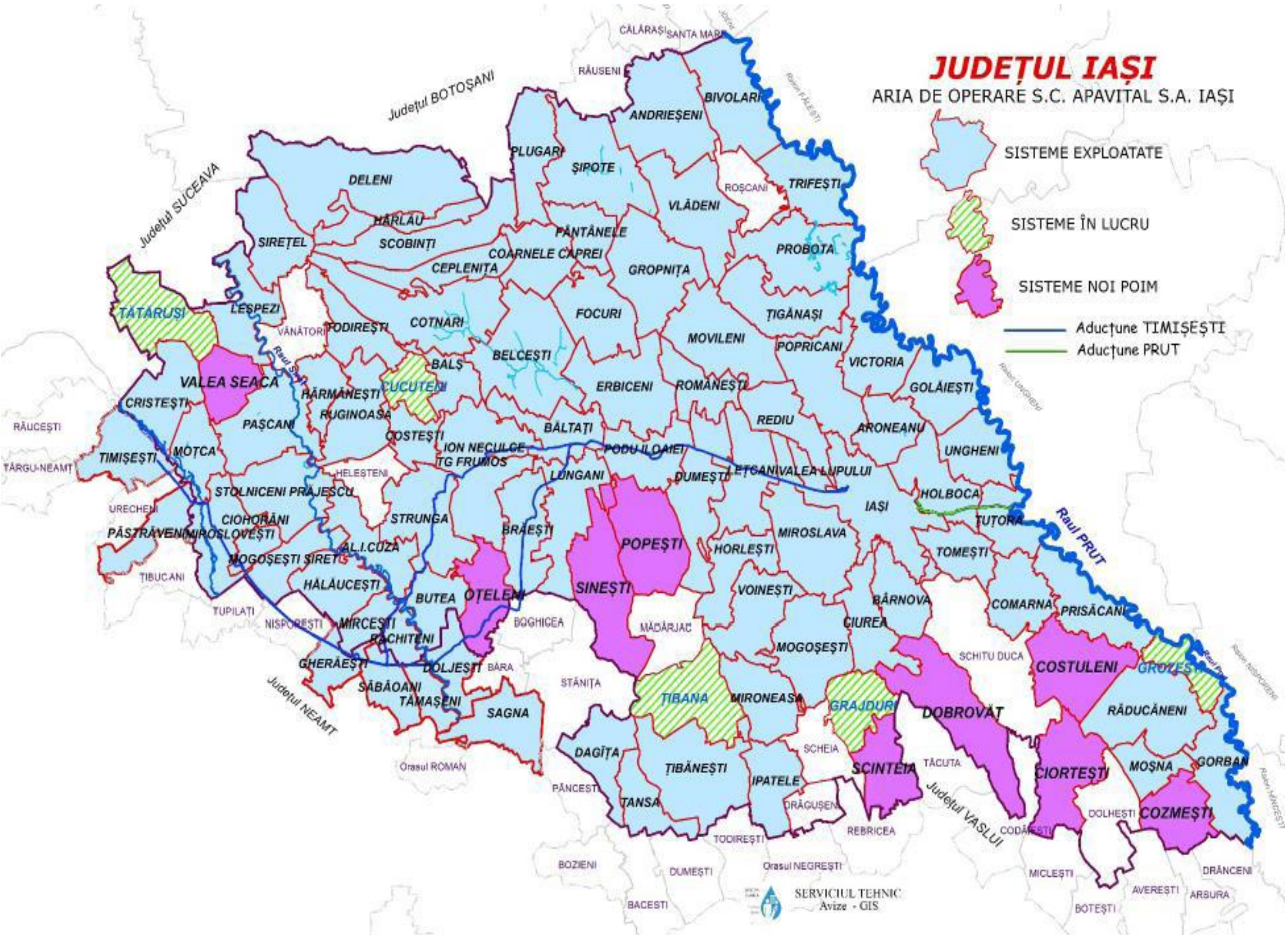
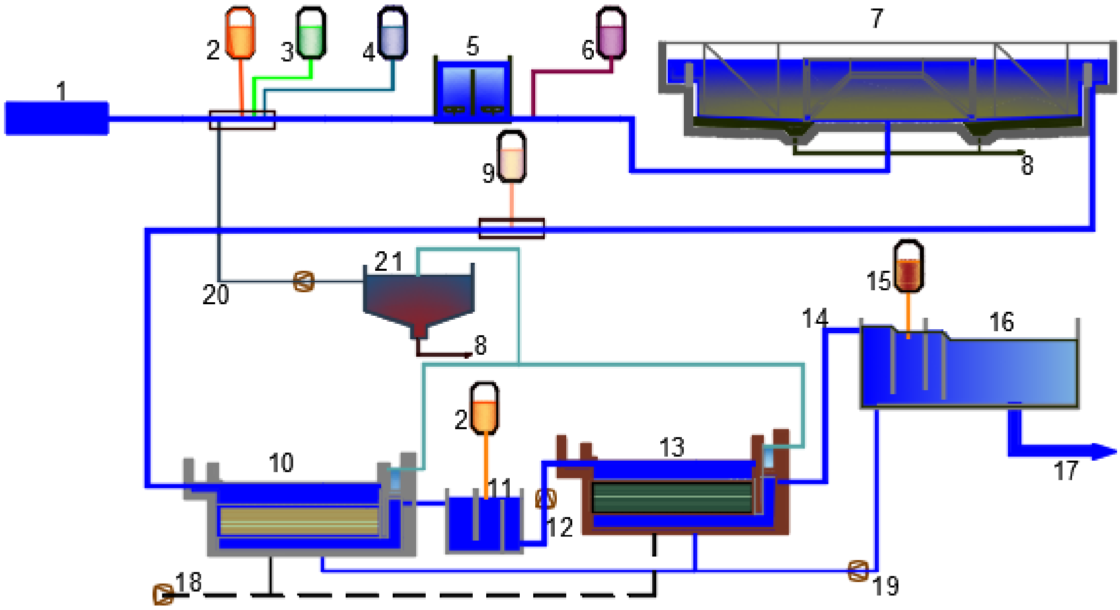


Figure 3.2. Operating area of S.C. Apavital S.A., Iași

Presentation of the technological process of Chirița drinking water treatment plant

The Chiriţa water treatment complex has been upgraded and refurbished on stages and individual units to efficiently control the treatment process. The control of each functional unit is monitored by a computerized system - through a SCADA application (Supervisory control and data acquisition), which provides automatic control of the system. The technological process of Chirița drinking water treatment plant is presented in Figure 3.3. The water supply from Lake Chiriţa is ensured through two pipes. Before reactive dosage, the pH and turbidity parameters are mesured. Reagent dosing chamber is the place where the preoxidation agent (ClO_2), ferric chloride (floculant) and the agent for pH corection (HCl) are added. To increase the size of the flocs and the sedimentation speed, is injected a polymer solution (Polyacrilamide) in water. The water is forwarded gravitationally into the two circular sedimentation basins in which the flocs are removed at the bottom of the basin. The sludge is discharged into the public sewage collection system. From the upper part of the basin the cler water is collected and it is sent to sand filters for filtration. Before that, a pH correction with calcium hydroxide ($Ca(OH)_2$).



1 - Valve chamber
2 - Preoxidation (ClO_2)
3 - Acid dosing (HCl)
4 - Flocculant ($FeCl_3$)
5 - Reaction tank
6 - Polyelectrolite dosing
7 - Sedimentation basin
8 - Sludge disposal into sewer
9 - pH adjustment ($Ca(OH)_2$)
10 - Sand filters
11 - Filtered water reservoir
12 - Filtered water pumping station
13 - GAC filters
14 - Backwash water reservoir
15 - Final disinfection(Cl_2)
16 - Treted water reservoir
17 - Distribution network
18 - Air blowers station
19 - Backwash water pumps
20 - Recycle backwash water pumping station
21 - Recycle backwash water buffer tank

Figure 3.3 Flow diagram of the treatment process in Chirița drinking water treatment plant.

Intermediate oxidation with ClO_2 is used to destroy the biological activity and reducing the volume of organic matter from water. Before the final disinfection, to correct the organoleptic properties and remove the last compounds presents in water, follows a slow filtration on CAG (granular activation carbon). Chlorine gas is used as final desinfectant after to intrroduce treated water in the distribution system.

3.2. Goal and scope definition

This study aims to investigate the environmental impact generated by the production of 1 cubic meter of treated water from surface source, Prut River in the Chirița treatment station in 2015.

In order to accomplish this, the following objectives were set:

- The analysis of the technological process in Chirița treatment plant and identifying the input and output streams;

- Establishing the boundaries of the system under review;

- Identifying and quantifying the environmental impacts generated by natural resources consumption, reagents and material consumption, electricity and transport;

- Performance assessment of the impact caused by the whole process of water treatment on the quality of resources, ecosystems and human health.

Achieving these goals will lead to an assessment of the environmental performance of the water treatment system.

3.2.1. System boundaries

In Figure 3.4 are presented the system boundaries of the studied system with the input and output streams included in life cycle inventory.

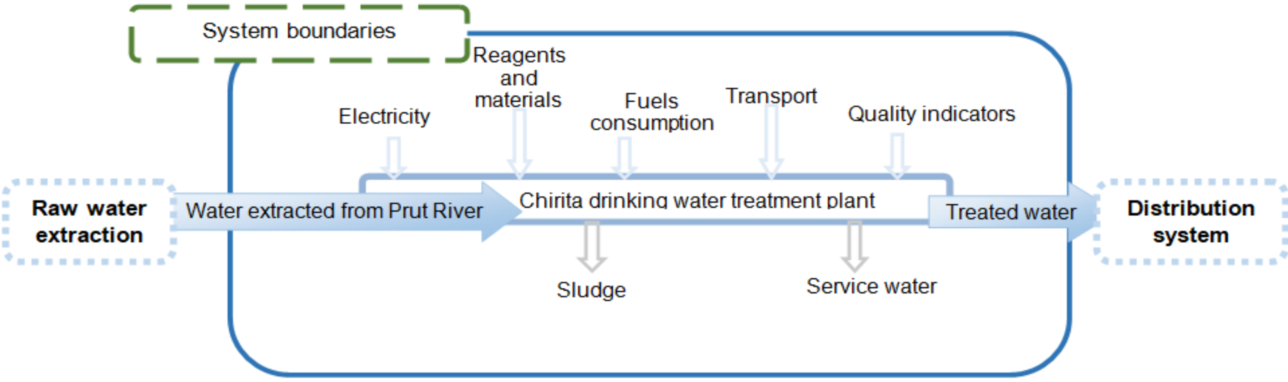


Figure 3.4. System boundaries of the drinking water treatment system Chirița

The analysis does not include the construction and disassembly phases, neither the pumping of the water to the treatment plant or to the distribution system. The influence of the sludge or service water resulted is not considered for the environmental performance assessment.

3.2.2. Functional unit (FU)

The functional unit of the system is **1 cubic meter of treated water**, sent to human consumption and all the impacts generated are related to this functional unit.

3.3. Life Cycle Inventory Analysis (LCI)

Life cycle inventory analysis is performed for the operational phase of the system. The data are obtained directly from the operator of the drinking water supply or from public documents (environment authorization or activity report). In **Section 3.3.1** are presented the inventory data and the collection method for the LCA study and in **Section 3.3.2** are analysed the inventory data according their provenience and accuracy.

3.3.1. Data collection needed for the LCA study

The input data was collected electronically in an Excel document, designed in such a way as to contain complex data on the real situation of the analyzed system.

Table 3.2 presents the data used in the impact assessment study generated by the production of 1 m^3 of water treated in Chirița drinking water treatment plant (Barjoveanu *et al.,* 2018).

Table 3.2 Inventory data for the LCA study (Chirita drinking water treatment plant)

Inventory data	Units of measure	Total	Amount / 1m^3 of treated water	Treatment step
Inputs				
Volume of extracted water	m^3	13.365.175	1,0605	-
Volume of treated water	m^3	12.601.903	1	-
Volume of distributed water	m^3	12.492.191	0,9913	-
Ferric chloride	kg	340.850	0,0255	Coagulation
Chlorine gas	kg	24.822	0,0018	Desinfection
Sodium chlorite	kg	47.262	0,0035	Desinfection
Polielectrolite (poliacrilamidă)	kg	256	$1{,}915 \cdot 10^{-5}$	Flocculation
Quartz sand	kg	17.280	0,0013	Sand filtration
Granular activated carbon	kg	4.800	0,00036	GAC filtration
Natural gas	m^3	6.757	0,0005	-
Electricity	kWh	796.955	0,0596	-
Transport	tkm	71.128,12	0,00532	-
Outputs				
Sludge	m^3	6,91144	$5{,}484 \cdot 10^{-6}$	Discharged into the public sewage collection system
Service water	m^3	763.272	0,0692	Reused before the reagent dosing chamber

The quality and objectivity of inventory data has been ensured by carefully observing and monitoring the data collection process for the operational phase of the treatment process.

3.3.2. Data inventory analysis

Primary data are the data given by the operator of the drinking water system, studies, reports, authorities. Secondary data are data from scientific literature and databases, adapted as much as possible to the characteristics of the system. For each component of the system (process, materials, fuels, etc.) the Ecoinvent database was used to accurately identify the environmental impact (www.ecoinvent.org). The processes in the Ecoinvent database used for the LCA study are detailed in Table 3.3.

Table 3.3. Data source used in the LCI for Chiriţa water treatment plant

No.	Inventory data	Units of measure	Observation	Data source	Ecoinvent process
1	Extracted water	m^3/an		Measured	Water, fresh - river
Chemical reagents and materials used in drinking water treatment process					
2	Ferric chloride	kg		Measured	Iron (III) chloride, without water, in 40% solution state {RoW}| iron (III) chloride production, product in 40% solution state | Alloc Rec, S
3	Chlorine gas	kg		Measured	Chlorine, gaseous {RoW}| market for | Alloc Rec, S
4	Sodium chlorite	kg	Quantified as sodium hipochlorite	Measured	Sodium hypochlorite, without water, in 15% solution state {GLO}| market for | Alloc Rec, S
5	Polielectrolite	kg	Polyacrilamide	Measured	Polyacrylamide {GLO}| market for | Alloc Rec, S
6	Quartz sand	kg	Size particles <0.8 mm; Liftime: 15 ani	Measured	Sand {GLO}| market for | Alloc Rec, S
7	Granular Activated Carbon	kg	Cocs petrolier: granulometric spectrum: 7-9 mm. Lifetime: 10 ani	Measured	Activated carbon, at plant/RER Mass
Reagent and material transport					
8	Ferric chloride	tkm	Transport of all the reagents and material used	Measured	Transport, freight, lorry 16-32 metric ton, EURO5 {GLO}| market for | Alloc Rec, S
9	Chlorine gas	tkm			
10	Sodium chlorite	tkm			
11	Polyelectrolite	tkm			
12	Quartz sand	tkm			
13	Granular Activated Carbon	tkm			
Fuels					
14	Natural gas	m^3		Measured	Natural gas, high pressure {RoW}| market for | Alloc Rec, S
Energetic consumption					
15	Electricity	kWh	Energy consumption in the Chirita drinking water treatment plant	Measured	Electricity, high voltage {RO}| market for | Alloc Rec, S
Outputs					

No.	Inventory data	Units of measure	Observation	Data source	Ecoinvent process
16	Sludge	kg	Discharged into the public sewage collection system		
17	Service water	m^3	Reused and injected before the reagent dosing chamber		

For the reagent transport was used a truck with 16 – 32 tones capacity, Euro 5.

3.4. Life Cycle Impact Assessment (LCIA)

Life Cycle Impact Assessment is defined as the stage of the LCA study that aims to identify, quantify, understand and assess the magnitude and significance of potential environmental effects of a process or product.

The environmental impact assessment of the life cycle of Chirița drinking water treatment plant was performed using the ReCiPe method, version 1.13, which allowed the generation of complex environmental profiles which presented and discussed in the following sections (Table 2.2). Life cycle assessment methods translate the results of LCI into potential environmental (positive or negative) impacts, so that some conclusions and recommendations can be developed.

Table 2.2. Impact categories of ReCiPe midpoint method. *Source: www.lcia-recipe.net*

Impact category	Abbreviation	Reference unit	Normalization factor
Climate change	CC	kg (CO_2 in air)	0,0000892
Ozone depletion	OD	kg (CFC-11[5] in air r)	45,4
Terrestrial acidification	TA	kg (SO_2 in air)	0,0291
Freshwater eutrophication	FE	kg (P in water)	2,41
Marine eutrophication	ME	kg (N in water)	0,0988
Human toxicity	HT	kg (14DCB in air)	0,00159
Photochemical oxidant formation	POF	kg (NMVOC6 in air)	0,0176
Particulate matter formation	PMF	kg (PM_{10} in air)	0,0671
Terrestrial ecotoxicity	TEtox	kg (14DCB in soil)	0,121
Freshwater ecotoxicity	FEtox	kg (14DCB in soil)	0,0909
Marine ecotoxicity	MEtox	kg (14-DCB[7] in marine water)	0,115
Ionising radiation	IR	kg (U^{235} in air)	0,00016
Agricultural land occupation	ALO	m^2*yr (agriculture land)	0,000221
Urban land occupation	ULO	m^2*yr (urban land)	0,00246
Natural land transformation	NLT	m^2*yr (land)	6,19
Water depletion	WD	m^3 (water)	0
Metal depletion	MD	kg iron)	0,000643
Fossil depletion	FD	kg (oil)	0,000643

The general environmental profile was issued in the LCIA characterization stage and shows the impact generated by the production of 1 cubic meter of treated water. In the next phase, the normalization of the results was attempted, applying a normalization factor, specific to each impact category.

Environmental performance is assessed from the following perspectives:

a. Overall characterization of the environmental impact of the Chirița drinking water treatment plant activity;

For each analyzed perspective, the life cycle impact assessment phase involves the characterization and normalization of the results after life cycle inventory analysis.

Life cycle impact assessment of Chirița drinking water treatment system highlights those factors that contribute to the environmental impact. The environmental profile of Chirița drinking water treatment plant is presented for the characterization phase in Figure 3.5.

From Figure 3.5 it can be observed that the major impact is caused by the ferric chloride reagent, used as coagulant which is responsible for 20 – 90% of the total impact generated in all the impact categories.

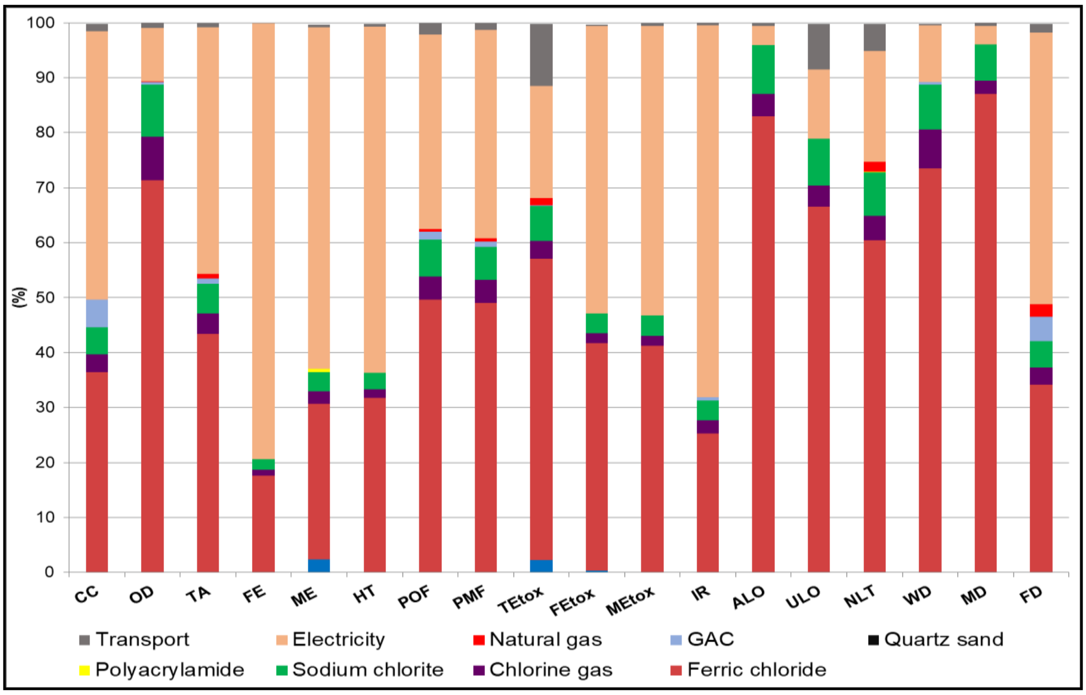


Figure 3.5.Environmental profile of the Chirita drinking water treatment plant.

The second factor that contributes to the impact generated is the energy consumption needed for equipment and installations operation within the drinking water treatment plant (10 – 79%). Fuel consumption and disinfection agents (ClO_2 and Cl_2) produce impact in ***Climate change*** **(CC),** ***Ozone depletion*** **(OD),** ***Fossil depletion*** **(FD),**

***Freshwater ecotoxicity* (FEtox), *Water depletion* (WD), *Urban land occupation* (ULO)** and ***Agricultural land occupation* (ALO)** impact categories.

The impact caused by electricity consumption is mainly in ***Freshwater eutrophication* (FE), *Ionising radiation* (IR), *Marine eutrophication* (ME), *Human toxicity* (HT), *Freshwater ecotoxicity* (FEtox)** and ***Marine ecotoxicity* (MEtox)** impact categories with values starting from 19% up to 97,3% from the total impact. Ferric chloride (coagulant agent) induces impact in ***Metal depletion* (MD), *Agricultural land occupation (*ALO), *Ozone depletion* (OD), *Urban land occupation* (ULO)** and ***Natural land transformation* (NLT)** (87,1%; 83%; 71,4%; 66,5%, respectively 60,4%) impact categories. Polyacrilamide, sodium chlorite and GAC generate less than 10% of the total impact in each impact category. The impact caused by the transport of the reagents has consequences on ***Terestrial Ecotoxicity* (TA)** (11,3%), ***Urban Land Occupation*** (**ULO**) (8.26%) and ***Natural Land Transformation* (NLT)** (4.89%). Quartz sand produces an insignificant impact on the environment (< 0.6%).

Normalized results of the impact produced by the Chirita drinking water treatment plant shows that the higher impacts are registred in ***Freshwater ecotoxicity* (FEtox); *Marine ecotoxicity* (MEtox); *Freshwater eutrophication* (FE), *Human toxicity* (HT)** and ***Natural land transformation* (NLT)** impact categories produced by the energy and ferric chloride consumption. Minor contribution on the environmental performances of the Chirita drinking water treatment plant are brought by disinfection reagents used and filtering material (quartz sand or GAC).

b. Influence of reagents and materials used in the treatment process;

The environmental performance of the Chirita drinking water treatment plant is influenced by the reagent consumption. From Figure 3.9 it can be observed the graphical representation of the normalized values of the environmental profile and the influence of the reagents consumption.

Ferric chloride is responsible for the freshwater and marine ecotoxicity impacts (**FEtox and MEtox), *Freshwater and marine eutrophication* (FE) and *human toxicity* (HT)** impacts, also sodium chlorite cause impact in these impact categories (10 – 12%) from the total impact generated.

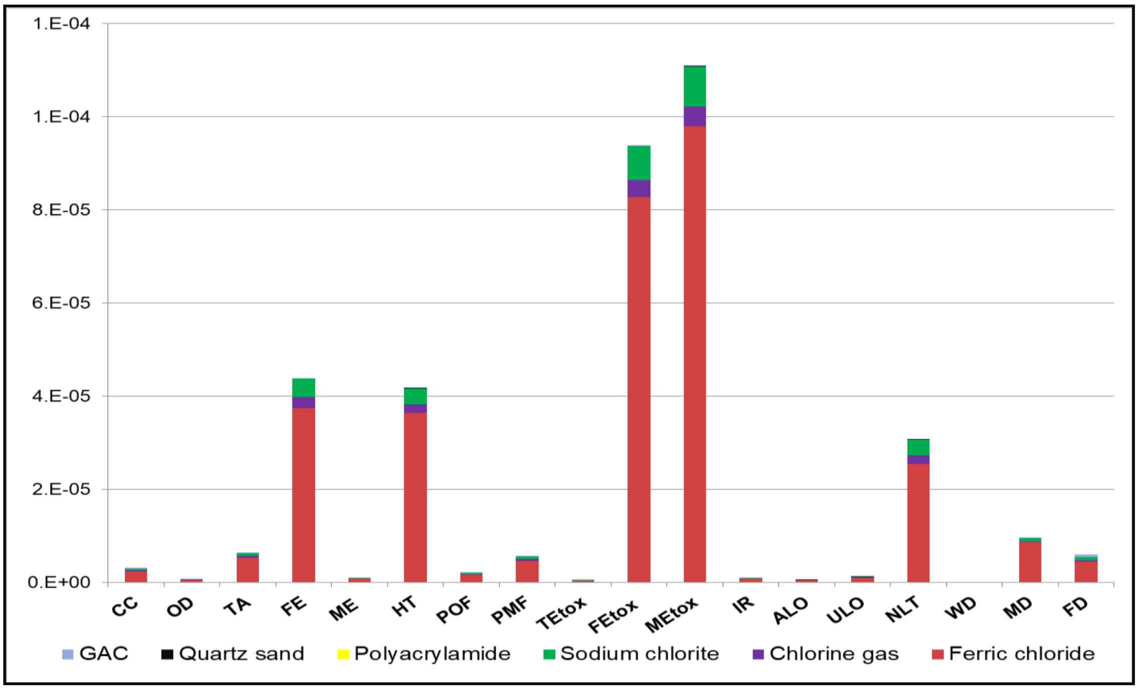


Figure 3.9. Environmental profile of the normalized values of reagent consumption

Chlorine gas used as disinfectant causes impact (<10%) in all impact categories analyzed compared to impacts generated by ferric chloride. Polyacryamide used to increase the sedimentation capacity of the flocs has a potential risc (1.71%) on ***marine eutophication*** **(ME)** impact category. Granular activated carbon and quartz sand (filter materials) generate impact (<10%) against ***Climate change*** **(CC)**, ***Fossil depletion*** **(FD), *Photochemical oxidant formation*** **(POF)**, ***Particulate matter formation*** **(PMF)** and ***Terrestrial acidification*** **(TA)** impact categories.

c. Environmental effects generated by the energy consumption, reagents and materials, fuels and transport.

The environment impact caused by the reagents, electricity, transport and fuels consumption to produce **1 cubic meter of treated water in Chirita drinking water treatment plant** reveal that the electricity used for the good operation of the equipments and the reagents used improve the quality of the water are the main responsables for the impact. Every input into the system causes a certain grade of impact, for example energy consumption generate from 5 to 80% of the total impact in each impact category, reagent consumption between 19 – 94% and a reduced impact is provoked by the fuels used (<2%).

Figure 3.7 describes the environmental profile of the Chirita drinking water treatment plant. After the characterization phase, the impact categories affected to the greatest extent by enegy consumption are ***Freshwater eutrophication*** **(FE)**, ***Marine eutrophication*** **(ME)**, ***Human toxicity*** **(HT)**, ***Freshwater ecotoxicity*** **(FEtox)**, ***Marine***

ecotoxicity **(MEtox),** ***Terrestrial ecotoxicity*** **(TEtox),** ***Climate change*** **(CC),** ***Fossil depletion*** **(FD)** and ***Terrestrial acidification*** **(TA).**

Normalized values of the impact generated by the treatment of 1 cubic meter of treated water in drinking water treatment plant indicate the impact categories most affected by electricity and reagent consumption as being ***Marine ecotoxicity*** **(MEtox),** ***Freshwater ecotoxicity*** **(FEtox),** ***Freshwater eutrophication*** **(FE),** ***Human toxicity*** **(HT)** and ***Natural land transformation*** **(NLT).**

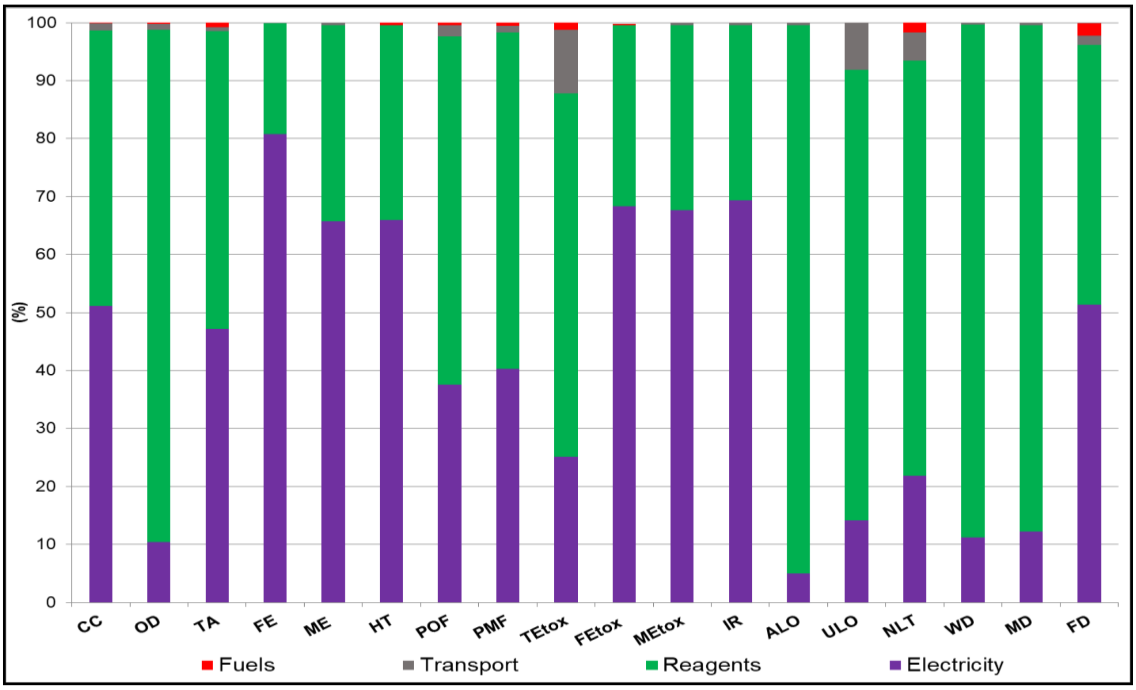


Figure 3.7. Environmental profile of the Chirita treatment plant.

In Table 3.4 are presented the normalized results for each of the three analyzed situations and the impact categories against who is identified the higher impact.

Table 3.4. Normalized results for each situation assessed and impact categorie in Chirita drinking water treatment plant.

Perspective assessted		**a**	**b**	**c**
Impact categories	**CC**	0.74	0.90	0.61
	OD	0.09	0.19	0.07
	TA	1.38	1.79	1.13
	FE	24.45	12.21	20.67
	ME	0.31	0.26	0.25
	HT	13.20	11.64	11.19
	POF	0.38	0.57	0.31
	PMF	1.08	1.59	0.88
	TEtox	0.08	0.13	0.07
	FEtox	23.00	26.17	26.99
	MEtox	27.29	30.94	31.32
	IR	0.34	0.26	0.28

Perspective assessted		a	b	c
	ALO	0.06	0.15	0.05
	ULO	0.16	0.31	0.13
	NLT	4.83	8.57	3.86
	WD	0.00	0.00	0.00
	MD	1.14	2.65	0.98
	FD	1.46	1.66	1.19

The results presented in Table 3.4, indicate as percent the impact generated against one impact categorie, related to the entire environmental impact.

As can be observed from the table, the impact categories affected by the drinking water treatment process in the highest proportion in all three analyzed situations are ***Freshwater ecotoxicity*** **(FEtox),** ***Marine ecotoxicity*** **(MEtox),** ***Freshwater eutrophication*** **(FE),** ***Human toxicity*** **(HT) and** ***Natural land transformation*** **(NLT).**

In the case of surface waters used to produce drinking water (river, lakes), in the operation phase of the treatment, physico-chemical characteristics require a complex water treatment process which implies a high consumption of electricity and a variety of reagents, in order to ensure proper water quality.

3.5. Partial conclusions

Following the application of the life cycle assessment methodology to assess the environmental performance of the Chitita drinking water treatment system, the following ideas can be concluded:

- Every input in the treatment process, generates an impact;
- Electricity consumption is the major contributor to the impact generated in the majority of the impact categories;
- Reagents cause impact against freshwater and marine ecotoxicity and on humans health;
- Among reagents, the ferric chloride is the reagent with the higher contribution on the impact;
- Drinking water treatment process involves higher reagent consumption due to surface water quality, which influences the treatment process adopted.

CHAPTER 4. ENVIRONMENTAL PERFORMANCE ASSESSMENT OF AN ITALIAN DRINKING WATER TREATMENT SYSTEM. CASE STUDY: SMAT S.p.A - TORINO.

4.1. Analysing the environmental performance of water treatment systems by LCA

The main objective of this study is to assess the environmental performances of the public water treatment system from Turin, Italy, through LCA methodology (Po drinking water treatment plant). With this performance assessment instrument there are identified the main issues caused to ecosystems by the drinking water treatment process and the weekness of the system. The analisys of the entire system takes into account all the inputs and outputs included in the life cycle inventory, which are quantified in impact against ecosystems, resources and human health.

By comparison with the environmental performance assessment performed in Chapter 3 on Chirita drinking water treatment system, the differences consist in: higher treatment capacity of the Po drinking water treatment system, differences on the reagents used, raw water qualitative caracteristics and the adopted treatment technology. Impact assessment is achieved from the point where the water is extracted from the Pad River (Italian Po), until the water is introduced into the distribution network for consumers.

4.1.1. Water Resources Management in Italy and Turin County

Water Framework Directive 2000/60/CE were adopted into Italian law through Legislative Decree no. 162 from 2 April 2006. Through this legislative decree, national territory was divided in 8 river basins districts and provides the elaboration of a Water Resources Management Plan for each river basin. The authority dealing with water resources management is Regional Authority of the River Basin.

In Italy the availability of resources is estimated at just 58 bilions cubic meters from wich 72% is from surface sources (river. lakes) while 28% from groundwater sources.

Water volume used for domestic purposes is almost 78.8% from the total volume of billed water, the rest being distributed to agriculture, industrial, energetic, zootehnic and commercial sectors (www.adbpo.it).

Water resource management in Turin county

Metropolitan Water Society of Turin (SMAT S.p.A.) is certified ISO 14001:2005 to carry out the following activities, in terms of water resource management:

- Exploitation of diversified water sources for distribution to the population for drinking purposes;

-Monitoring and expanding the distribution network and drinking water treatement system

- Monitoring of municipal and industrial wastewater collection networks, wastewater treatment plants, and purification and reuse of treated water;
- Energy production from renewable sources: biogas production from the burning of the sludge from the wasewater treatment plant and from photovoltaic panels.

In the Piedmont region, SMAT provides drinking water for 293 municipalities near Turin (Figure 4.2). The volume of water billed is de 181.242.579 m^3 for almost 2.236.740 inhabitants. Distribution network has a total length of 12.428 km and covers an area of 6.268 km^2 (www.istat.it).

SMAT is based in particular on groundwater water supply instead of surface water source (Figure 4.4),

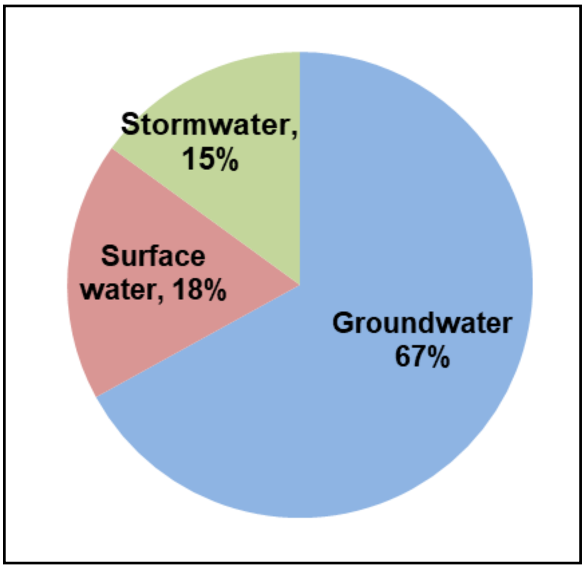


Figure 4.4. Distribution of types of water sources available in Turin

Taking into account the general objective of this analysis, the analysed system is Po drinking water treatment plant, located in Turin, Italy.

Water treated is from surface sources, from Pad River. In the next Subchapters is presented the treatment system of the drinking water treatment plant (www.smatorino.it[b]).

4.1.2. Presentation of the water treatment system – SMAT.S.p.A – Turin

SMAT Company is among the first Italian water service operators which treat water from surface sources. Thanks to modern treatment and quality control systems, Po drinking water treatment plant has the capacity to produce 17% of the water distributed into the netwok.

The drinking water treatment plant complex of the Pad River has three treatment lines that will be described in the next section.

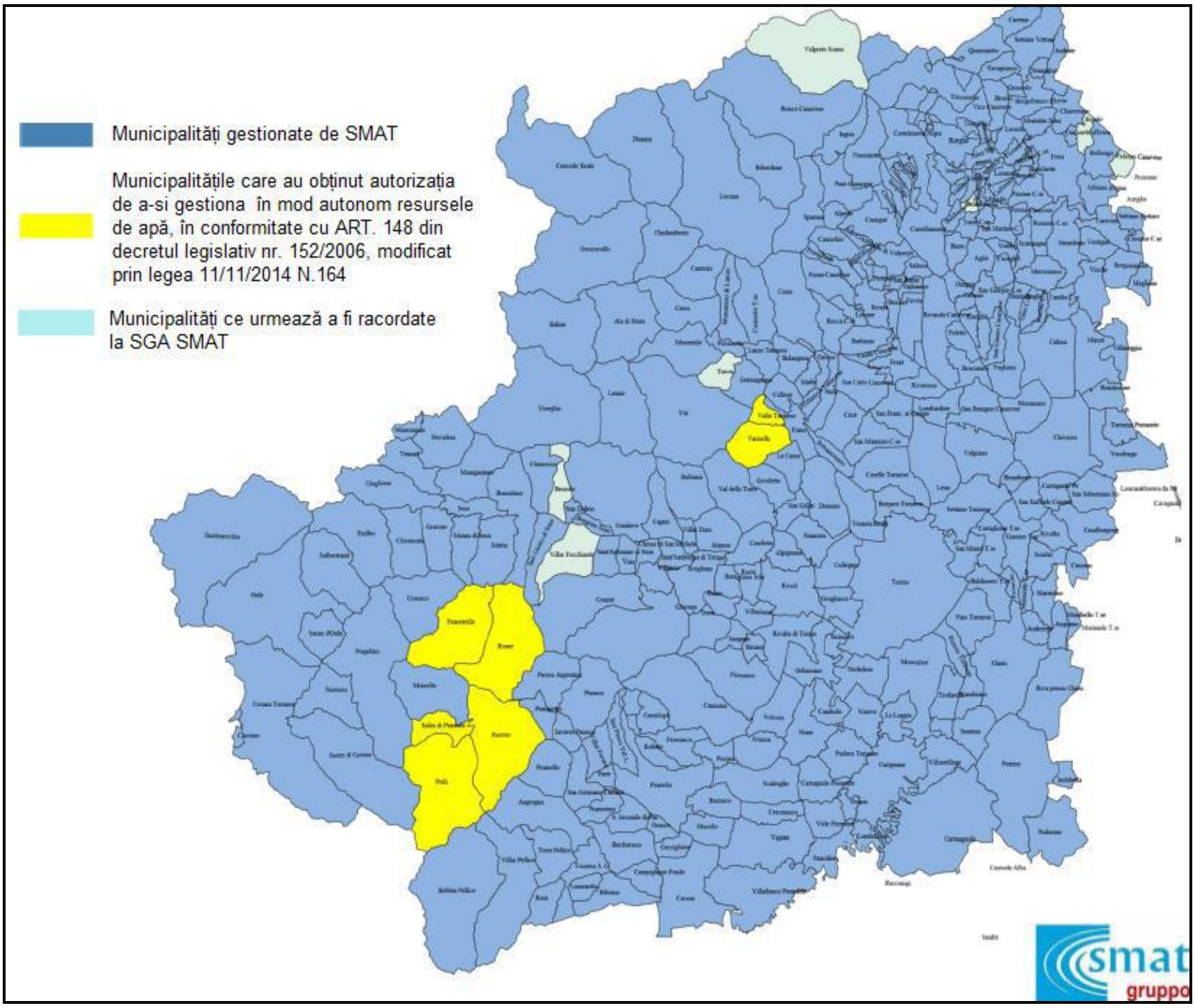


Figure 4.2. Operation area of SMAT Group. *Source: www.smatorino.it*[b]

Presentation of the technological process of Po drinking water treatment plant

PO plants are delivering water for consumption through a distribution network over than 6200 km with an average daily flow up to 7000 l/s. PO plants are located on left side of the Po River at the confluence with Sangone stream and divided in three treatment lines: Po1 and Po2 which are similar with a total production capacity of 86400 m^3/day (1 m^3/s) and Po3 with a production capacity of 130000 m^3/day (1.5 m^3/s).

In this study Po1 and Po2 treatment lines will be analyzed together and Po3 treatment line separately because even though both are using as final disinfectant chloride dioxide, after presettling Po1 and Po2 lines follows a primary oxidation with chlorine dioxide while Po3 treatment line has a primary oxidation step with ozone (O_3 which is generated on a plant site). Recently, before presettling basin it was introduced a dosing system with powdered activated carbon (PAC) and ferric chloride to remove organic microcontaminants which can remove specific smells or tastes. PAC addition step is used if raw water at extraction point presents some particular water characteristics or is identified the presence of some fats or oils. Coagulation/Flocculation step take place in

Accelerator basin (Po1 and Po2) and in Cyclofloc basins for Po3 line were is added aluminium polychloride as flocculant and sodium hypochlorite as oxidant, microsilica sand for a better removal and faster sedimentation in Po3. Sludge resulted is separated from microsand through centrifugation and the amounts of sludge resulted from presettling is pumped into the sewer network. Filtration step is performed with Ganular Activated Carbon, double filtration layer for Po3 and single filtration layer for Po1 and Po2. After filtration step are removed all contaminated particles, disagreeable smells, flavors colors and organic microcontaminants. Final disinfection with chlorine dioxide is obtained by combining hydrochloric acid and sodium chlorite and is used in order to avoid the bacterial growth and smells during distribution network. After disinfection water is pumped into the distribution network to customers (www.smatorino.it[b]).

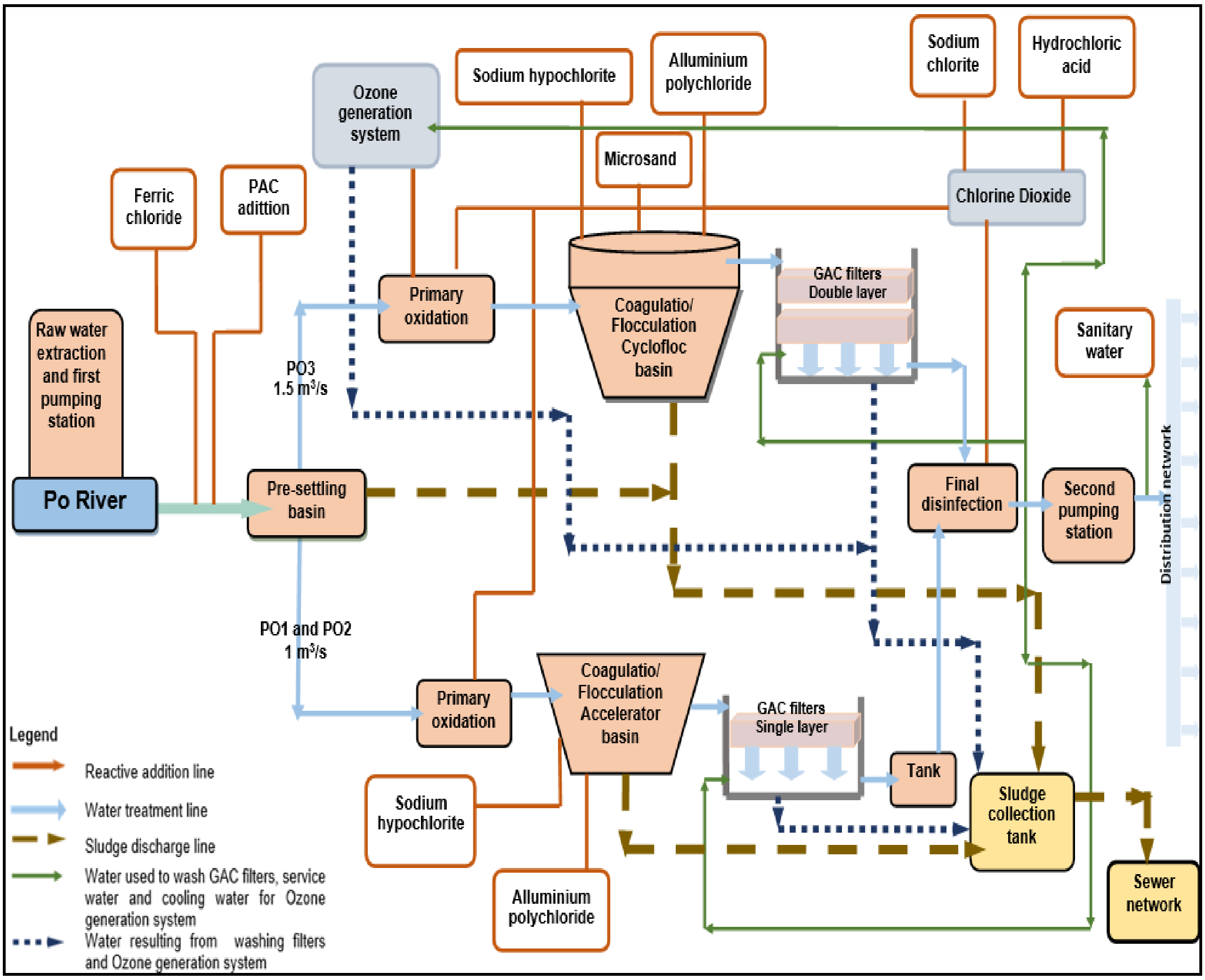


Figure 4.7 Flow diagram of the treatment process in Po drinking water treatment plant.

Outflows resulted from different stages of the drinking water treatment process as can be seen in Figure 4.7 are the wash water resulted from washing the GAC filters, cooling water from O_3 generation system, sanitary water and sludge dischargers from presettling basin and coagulation/ flocculation treatment step, are sent to the sewer network (Gilca *et al.*, 2019).

4.2. Goal and scope definition

The main purpose of this study is to assess the environmental impact of the water treatment process within Po drinking water treatment plant from Torino (Italy), taking into account the contribution of the reagents used, the electricity consumption and the transport of the reagents.

In order to accomplish this, the following objectives were set:

- Overall characterization of the environmental impact generated by the activity of the 3 treatment lines within Po drinking water treatment plant;
- Influence of the reagents and materials used in the treatment process;
- Effects on the environment of the energy, reagents and materials consumption and transport.
- Identifying the stage in the treatment process that generates the most significant impact on the environment.

4.2.1. System boundaries

The approach of this study is "cradle to gate" (from the point of water extraction to the point where treated water is injected into the distribution network), taking into account the energy required to pump raw water to Po drinking water treatment system and to distribution network (Table 4.8). LCA analysis does not take into account the impact of solid or liquid waste resulted from the treatment process.

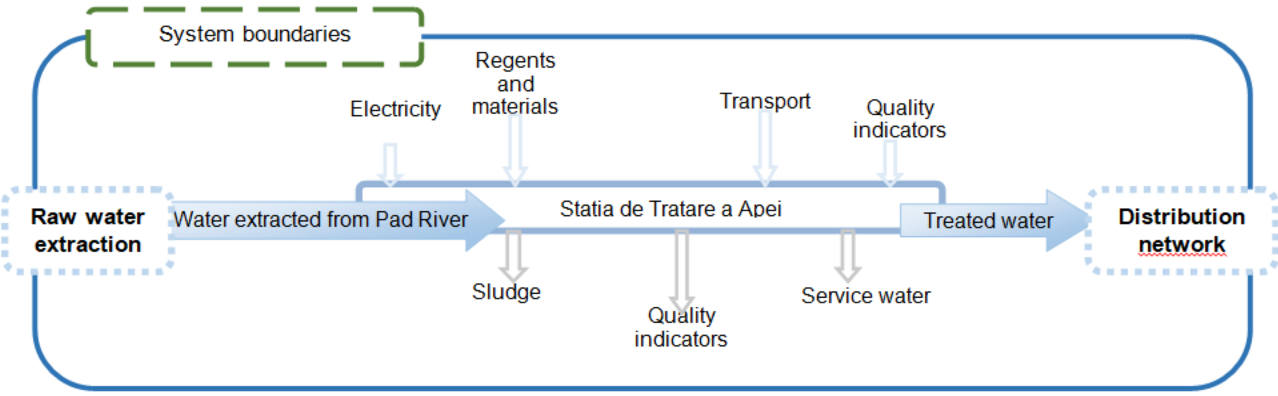


Figure 4.8. System boundaries of the Po drinking water treatment system

As in the same study, the analysis does not involve the construction and disassembly phases.

4.2.2. Functional unit (FU)

The functional unit of the system is **1 cubic meter of treated water.**

4.3. Life Cycle Inventory Analysis (LCI)

The data needed to compile the inventory are procured from the Sustainability Report for 2015, published on the company's website and from data presented in studies and research projects (articles) (Zappone *et al.,* 2014; Gilca *et al.,* 2019). In **Section 4.3.1** are presented the inventory data and the collection method for the LCA study and in **Section 4.3.2** are analysed the inventory data.

4.3.1. Data collection needed for the LCA study

The inventory data required to carry out the life cycle impact assessment analysis of the Po drinking water treatment plant were collected as a table in an Excel document and are based on the operational information declared by SMAT S.p.A. in the Sustainability Report and on the information/results obtained in previous studies.

Table 4.3 presents the data used in the impact assessment study generated by the production of 1 m^3 of water treated in Po drinking water treatment plant for each treatment line (Gilca *et al.,* 2019).

Table 4.3. Inventory data for the LCA study

Treatment phase	Inventory data	Unit of measure	Po system Treatment line Po1+Po2	 Linia Po3	Amount / $1m^3$ of treated water
Raw water extraction and first pumping	Raw water	m^3	2.28E+07	3.42E+07	1,3713
	Electricity	kWh	2.37E+06	3.55E+06	0,1425
Pre-settler	Electricity	kWh	1.73E+04	2.60E+04	0,0010
Pre-oxidation	Ozone	kg	-	2.80E+05	0,0112
	Chlorine dioxide	kg	1.30E+04	-	0,0150
	Transport	km	1.64E+03	2.05E+03	0,0002
	Electricity	kWh	-	1.86E+06	0,0746
	Cooling water	m^3	-	1.18E+05	0,0047
Coagulation/Flocculation	Sodium hypochlorite	kg	5.97E+05	8.96E+05	0,0359
	Electricity	kWh	8.38E+05	1.76E+06	0,0504/0,0706
	Aluminium polychlorite	kg	9.82E+05	1.47E+06	0,0591
	Transport	km	6.28E+03	9.62E+03	0,0120/0,0121
	Ferric chloride	kg	3.20E+03	4.80E+03	0,0002
	Microcilicea	kg	-	3.50E+04	0,0014

	Sludge	m^3	3.32E+05	4.98E+05	0,0200
GAC filtration	Electricity	kWh	8.78E+05	7.09E+05	0,0528/0,0284
	GAC	kg	4.84E+04	7.26E+04	0,0147
	GAC reactivated	kg	1.97E+05	2.95E+05	
	Transport (GAC)	km	1.10E+04	1.10E+04	0,0320
	GAC wastes	kg	2.45E+05	3.68E+05	0,0014
	Wash water	m^3	5.12E+06	5.52E+06	0,3086/0,3713
Final disinfection	Electricity	kWh	-	-	-
	Chlorine dioxide	kg	2.41E+06	3.90E+05	0,0150
	Transport	km	1.40E+02	1.40E+02	-
Second pumping to the distribution network	Distributed water	m^3	1.66E+07	2.49E+07	0,7292
	Electricity	kWh	6.23E+06	1.22E+07	0,3851/0,4891
	Service water	m^3	1.04E+06	3.61E+06	0,0627

The inventory data collection process has been carefully planned and performed. Data was obtained from the Sustainability Report and from the previous studies which unfortunately do not specify precise data distribution on materials, reagents, energy consumption and transport used for water treatment on each treatment line from Po drinking water treatment plant.

4.3.2. Data inventory analysis

As in the other study, primary data are the data given by the operator of the drinking water system, studies, reports, authorities. Secondary data are data from scientific literature and databases, adapted as much as possible to the characteristics of the system. The Ecoinvent database was used to accurately identify the environmental impact (www.ecoinvent.org). The processes in the Ecoinvent database used for the LCA study are detailed in Table 4.4.

Table 4.4 Data source used in the LCI for the environmental performance assessment of the Po drinking water treatment plant.

Inventory data	Unit of measure	Observation	Data source	Ecoinvent process
Raw water extracted	m^3/an	Water extracted from Pad River	Measured and calculated individually for the three treatment lines	Water, fresh - river
Electricity	kWh/an	Energy consumption	Measured	Electricity, high voltage {IT}| market

				for | Alloc Def, S
Reagents and material used in drinking water treatment process				
Chlorine dioxide	Kg	-	Measured	Chlorine dioxide {GLO}| market for | Alloc Rec, S
Granular Activated Carbon	kg	GAC from vegetal sources	Measured	Charcoal, at plant/GLO S
Ferric chloride	Kg	-	Measured	Iron (III) chloride, 40% in H2O, at plant/CH S
Aluminium polichloride	Kg	-	Measured	Aluminium Polychloride 9 HB
Microsilicea	Kg	-	Measured	Silica sand, at plant/DE S
Sodium hypochlorite	Kg	-	Measured	Sodium hypochlorite, 15% in H2O, at plant/RER S
Ozone	Kg	Internally produced	Measured	Ozone, liquid, at plant/RER S
Transport	tkm	Distance covered by autovehicules	Measured	Transport, lorry 20-28t, fleet average/CH S
Solid/liquid outputs				
Sludge	kg	Sent to sewer network		
Liquid outputs	m^3	Washwater sent to sewer network		

4.4. Life Cycle Impact Assessment (LCIA)

Life cycle impact assessment of the Po drinking water treatment process highlights the contributing factors on environmental impacts.

Environmental performances of the Po drinking water treatment system (Po1+Po2 and Po3 treatment line) are assessed from the following perspectives:

a. Overall characterization of the environmental impact of the Chirița drinking water treatment plant activity;

The environmental profile of the Po1 and Po2 treatment lines are graphicaly represented in Figure 4.9. For the assessment of the environmental performances of the PO1 and Po2 treatment lines are included all the inputs in the system.

As can be seen from Figure 4.9, the energy consumption generates impact (>60%) in ***Freshwater eutrophication*** **(FE),** ***Human toxicity*** **(HT),** ***Ionising radiation*** **(IR),** ***Marine eutrophication*** **(ME),** ***Freshwater ecotoxicity (*****FEtox)** and ***Marine ecotoxicity*** **(MEtox)** impact categories. Aluminium polychloride, the flocculant reagent, cause impact in ***Terrestrial ecotoxicity*** (**TEtox),** ***Agricultural land occupation*** **(ALO),** ***Water***

depletion **(WD),** ***Metal depletion*** **(MD),** ***Ozone depletion*** **(OD)** impact categories. The disinfection agent (chlorine dioxide) has significant effects on ***Water depletion*** **(WD),** ***Metal depletion*** **(MD),** ***Ozone depletion*** **(OD)** and ***Agricultural land occupation*** **(ALO)**. The coagulant agent and sodium hypochlorite also produces impact (***Water depletion*** **(WD),** ***Agricultural land occupation*** **(ALO),** ***Metal depletion*** **(MD)** and ***Urban land occupation*** **(ULO)**).

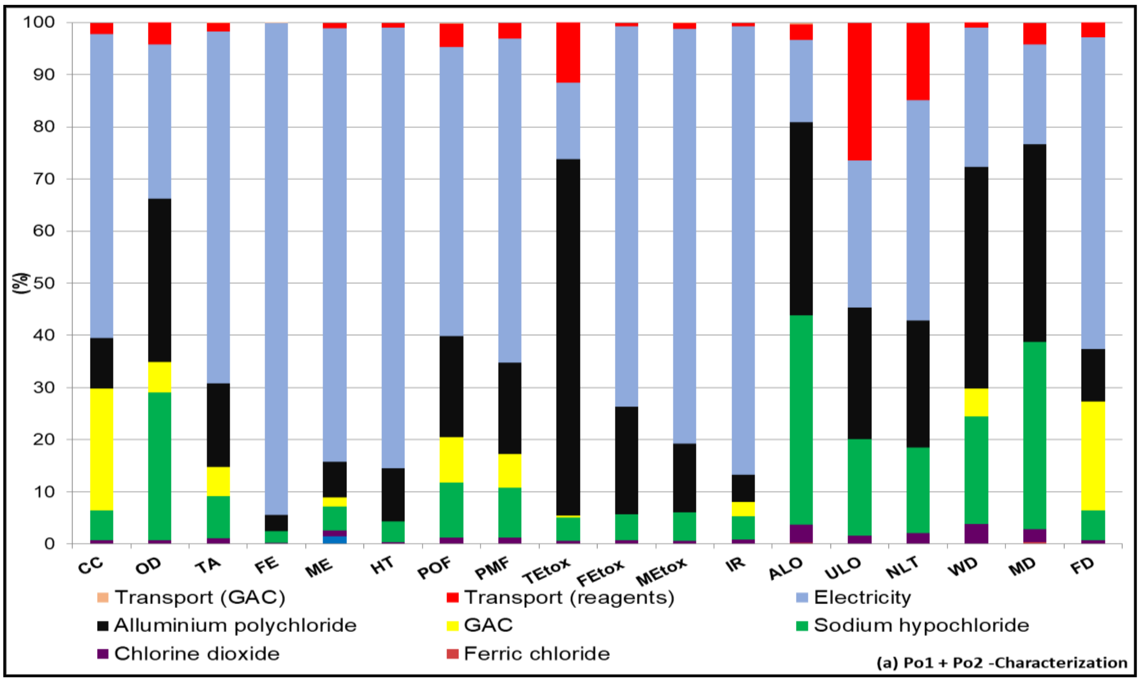


Figure 4.9. Environmental profile of the Po1 and PO2 treatment lines

The environmental performances of the Po3 treatment line (Figure 4.10) is influenced in most impact categories also by energy consumption. Beside the coagulation/flocculation reagent impacts, ozone used as preoxidant cause impacts on ***Agricultural land occupation*** **(ALO),** ***Photochemical oxidant formation*** **(POF),** ***Particulate matter formation*** **(PMF),** ***Terrestrial acidification*** **(TA)** and ***Climate change*** **(CC)** impact categories***.***

Granular activated carbon, used as filter material in all 3 treatmet lines cause impact on **FD, CC, POF, PMF** and **TA** (20 – 3%) impact categories.

The transport of the reagents by truck causes a certain impact because the distances between productions places and Po drinking water treatment line. The transport is higher especially on ***Agricultural land occupation*** (**ALO**), ***Urban land occupation*** (**ULO**), ***Natural land transformation*** **(NLT),** ***Photochemical oxidant formation*** **(POF),** ***Particulate matter formation*** **(PMF)** and ***Terrestrial acidification*** **(TA)** impact categories. The general characterization of the treatment process presents the factors that influence environmental performances of the treatment system as being the energy consumption.

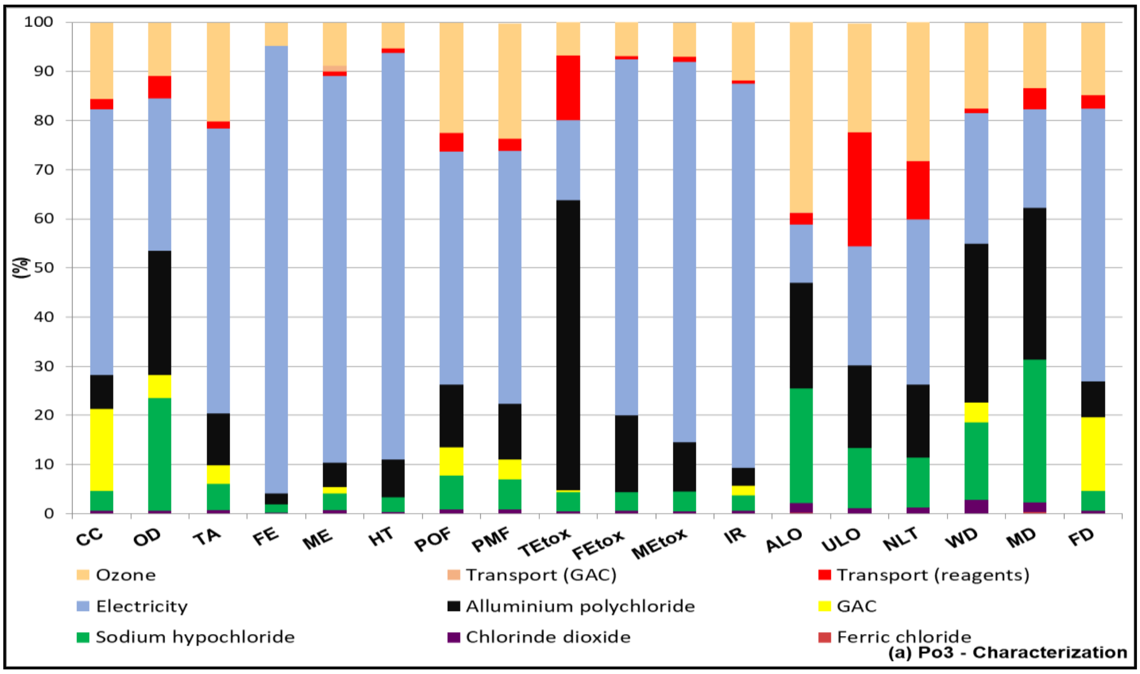


Figure 4.10. Environmental profile of the Po3 treatment line.

The normalized results presented in Table 4.5 the impact categories affected to the greatest extent by the treatment process.

Situația evaluată		a. (Po1+Po2)	a. (Po3)	b. (Po1+Po2)	b. (Po3)	c. (Po1+Po2)	c. (Po3)	d. (Po1+Po2)	d. (Po3)
Impact category	CC	0.87	0.90	3.89	4.27	4.70	4.85	0.75	0.98
	OD	0.04	0.04	0.30	0.26	0.22	0.20	0.08	0.08
	TA	1.27	1.43	4.45	6.25	6.88	7.67	9.14	10.72
	FE	28.66	28.62	3.34	4.26	16.91	16.79	0.70	0.74
	ME	0.31	0.32	0.36	0.44	0.38	0.42	1.17	1.29
	HT	13.73	13.50	12.40	9.87	8.21	7.12	0.62	0.84
	POF	0.34	0.38	1.52	1.99	1.82	2.04	1.48	1.64
	PMF	0.92	1.07	3.64	5.28	4.95	5.71	32.20	29.50
	TEtox	0.16	0.13	1.31	1.02	0.84	0.72	20.85	13.62
	FEtox	22.90	22.28	30.87	23.00	17.57	14.19	0.30	0.29
	MEtox	25.13	24.90	11.76	9.33	8.43	7.36	9.34	11.49
	IR	0.37	0.39	0.27	0.36	0.52	0.55	12.65	15.39
	ALO	0.02	0.03	0.18	0.23	0.11	0.14	0.49	0.45
	ULO	0.10	0.11	0.53	0.64	0.55	0.61	0.21	0.24
	NLT	3.20	3.89	15.58	22.83	17.29	20.87	7.18	9.49
	WD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	MD	0.28	0.26	2.45	2.11	1.52	1.39	1.54	1.42
	FD	1.69	1.75	7.16	7.85	9.11	9.37	1.29	1.81

Environmental performances of the tree treatment lines show the same impact categories affected by the treatment process, energy and reagent consumption in the majority of cases.

b. Influence of reagents and materials used in the treatment process;

Production capacity of the treatment line influence the impact caused against resources, ecosystem and human health. For Po1 and Po2 treatment lines (Figure 4.11) with a production capacity of 1m^3/s, the reagent consumption is lower. Beside that, the reagents used in coagulation/flocculation process (aluminium polychloride and sodium hypoclorite) cause impacts on ***Ozone depletion*** **(OD)**, ***Freshwater eutrophication*** **(FE)**, ***Human toxicity*** **(HT)**, ***Freshwater ecotoxicity*** **(FEtox)**, ***Marine ecotoxicity*** **(MEtox)**, ***Terrestrial ecotoxicity*** **(TEtox)**, ***Agricultural land occupation*** **(ALO)**, ***Urban land occupation*** **(ULO)**, ***Natural land transformation*** **(NLT)** and ***Metal depletion*** **(MD)** impact categories.

For Po3 treatment line the performance of the system is influenced by ozone consumption in preoxidation process. The impact caused by the use of ozone causes adverse effects on ***Natural land transformation*** **(NLT), *Particulate matter formation* (PMF), *Terrestrial acidification* (TA), *Photochemical oxidant formation* (POF), *Ionising radiation* (IR), *Freshwater eutrophication* (FE), *Marine eutrophication* (ME)** and ***Climate change*** **(CC).**

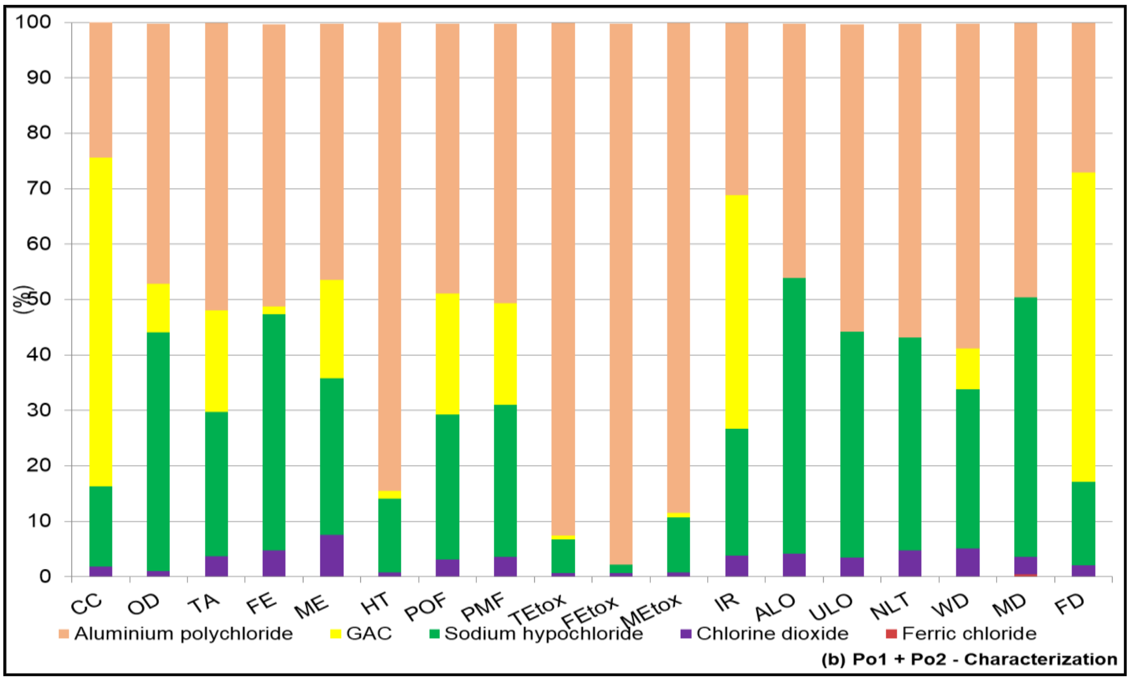


Figure 4.11 Environmental profile of the Po1 and Po2 treatment lines, generated by the use of reagents

The amount of GAC, used in Po3 treatment line is higher that the amount used in the other two treatment lines. The treatment performance of this line is influenced by the amount of GAC used. Assessment of the environmental performance from reagent and material consumption point of view, give us a objective environmental profile, because is presented the contribution of each reagent against resource exhaustion, ecosystem quality and human health.

Normalized values point out the use of aluminium polychloride being the reagent with higher contribution against environmental performances of the entire system. From Table 4.5 it can be observed the use of reagent impacts caused especially on ***Freshwater ecotoxicity*** **(FEtox),** ***Human toxicity*** **(HT)**, ***Natural land transformation*** **(NLT),** ***Marine ecotoxicity*** **(MEtox),** and ***Fossil depletion*** **(FD)** impact categories in both situations.

c. Environmental effects generated by the energy consumption, reagents and materials, fuels and transport.

The energy consumption is one of the major contributors of the environmental impacts (Figure 4.15). The analysis of the environmental profile given by the analysis of energy, reagent and transport present that the higher impact is on ***Freshwater eutrophication*** **(FE),** ***Freshwater ecotoxicity*** **(FEtox),** ***Marine ecotoxicity*** **(MEtox),** ***Agricultural land occupation*** **(ALO),** ***Metal depletion*** **(MD)** and ***Human toxicity*** **(HT)** impact categories. A higher amount of energy is needed for the raw water extraction and pumping system to the treatment system and to the distribution system respectively.

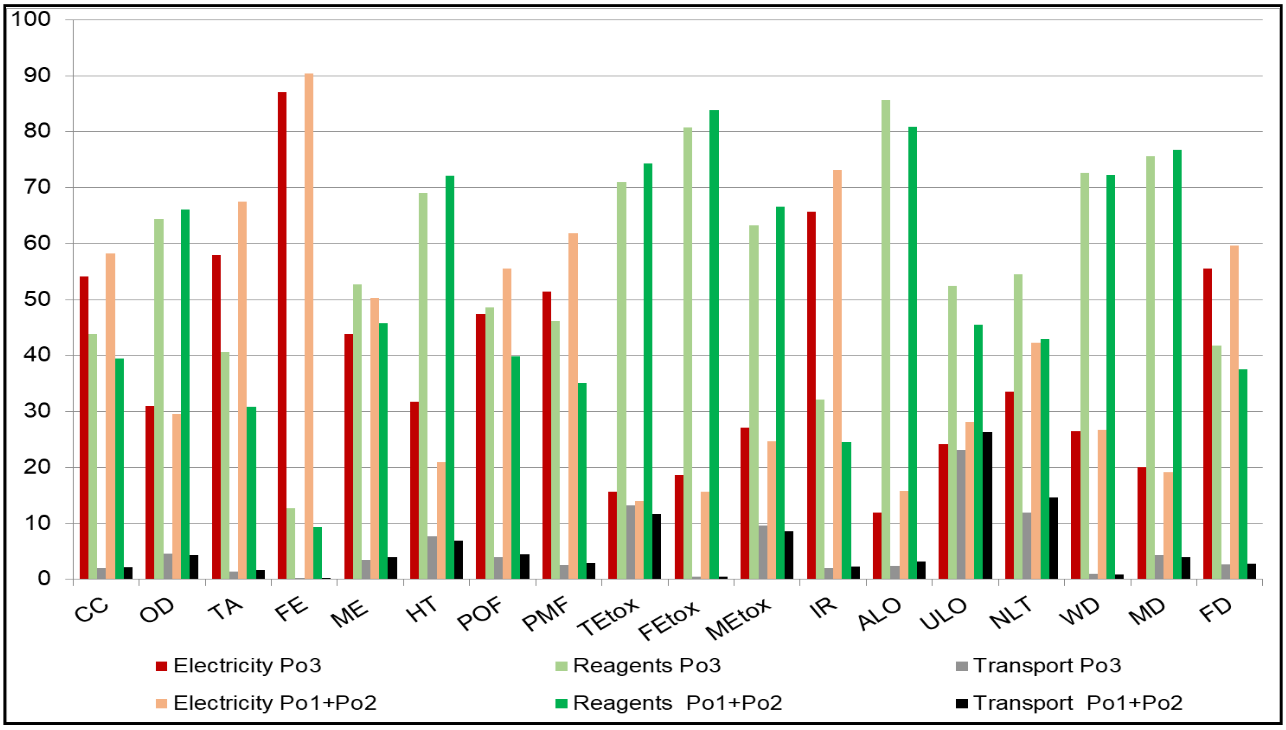


Figure 4.15. Comparison between environmental profile of the Po1+Po2 and Po3 treatment lines.

The reagent transport is one of the factors with effects against environmental performances of the system. The impact categories affected are especially ***Urban land***

occupation (*ULO)** and ***Natural land transformation (**NLT)**, due to the long distances between production place and Po drinking water treatment plant.

After normalizing the results, from Po1+Po2 and Po3 treatment lines analysis, major contributor on environmental impact is the electricity and reagent consumption. In case of Po3 treatment line, was observed an increase of the impact caused by electricity consumption, due to ozone production on Po drinking water treatment plant location.

Table 4.5 presents the percentage of normalized value of the impacts caused after the analysis of the reagent, electricity and transport contribution and identify the ***Freshwater ecotoxicity*** (**FEtox)**, ***Natural land transformation*** (**NLT)**, ***Marine ecotoxicity*** (**MEtox)**, ***Freshwater eutrophication*** (**FE)** and ***Fossil depletion*** **(FD)** impact categories most affected by the activity of the Po drinking water treatment plant.

d. Identifying the stage in the treatment process that generates the most significant impact on the environment.

Impact assessment profiles of every treatment step, has had the aim to identify the treatment process with the major contribution in each impact category.

The impact caused by 1 m^3 of potable water produced on Po1 and Po2 treatment line highlight the treatment step from the entire drinking water treatment process the most significant for the environmental performance of the treatment system (Figure 4.16).

As can be seen from Figure 4.16, the treatment step with the highest impact on environmental performance from the entire system is the raw water extraction and the pumping to distribution network phase, conditioned by energy consumption.

If these two phases would be excluded, the coagulation/flocculation process will be the major contributor on environmental performance of the system, followed by the filtration phase.

The coagulation/flocculation and filtration steps are the most important phases from the entire drinking water treatment process due to reagent and material consumption. The impact is caused most of the time on ***Human toxicity*** (**HT*), Ozone depletion (*OD*),*** ***Ionising radiation (*IR*), Terrestrial acidification (*TA*), Freshwater eutrophication (*FE*),*** ***Marine ecotoxicity (*MEtox*)*** and **Fossil depletion** (***FD)*** impact categories***.***

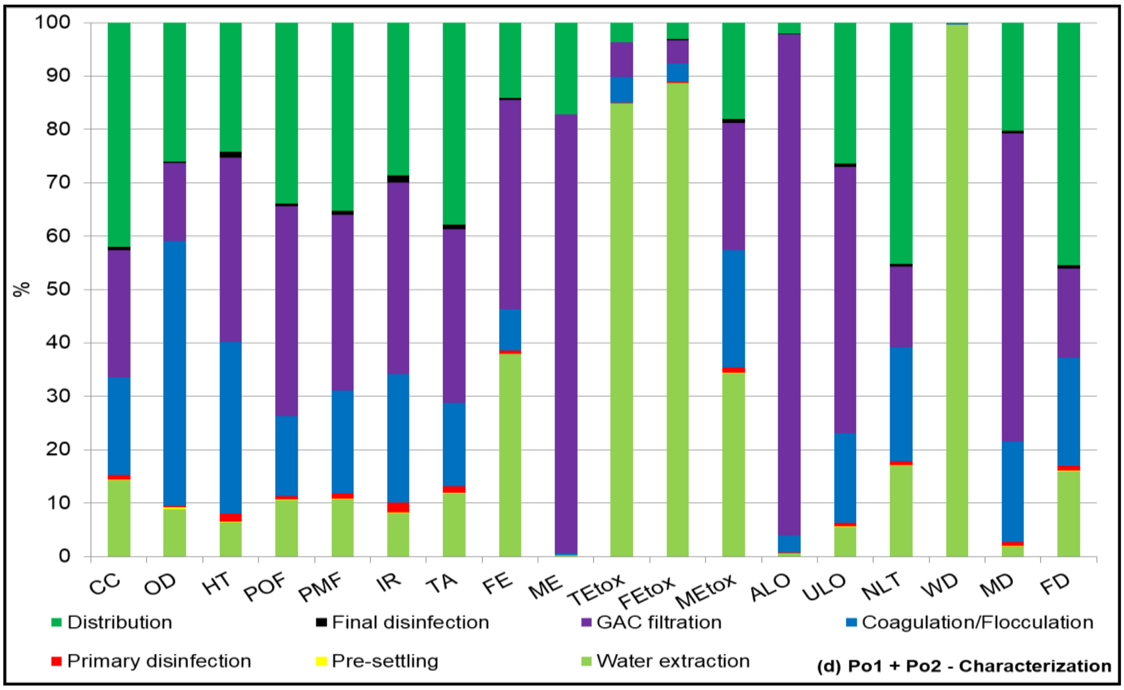


Figure 4.16. Environmental profile of Po1 and Po2 treatment lines on treatment steps.

Compared with Po1 and Po2 treatment lines, the Po3 treatment line involves a pre-oxidation phase with ozone. The ozone is produced locally, on plant site and require large amounts of electricity. In Figure 4.17, it can be observed the contribution of O_3 on the caused environmental impact.

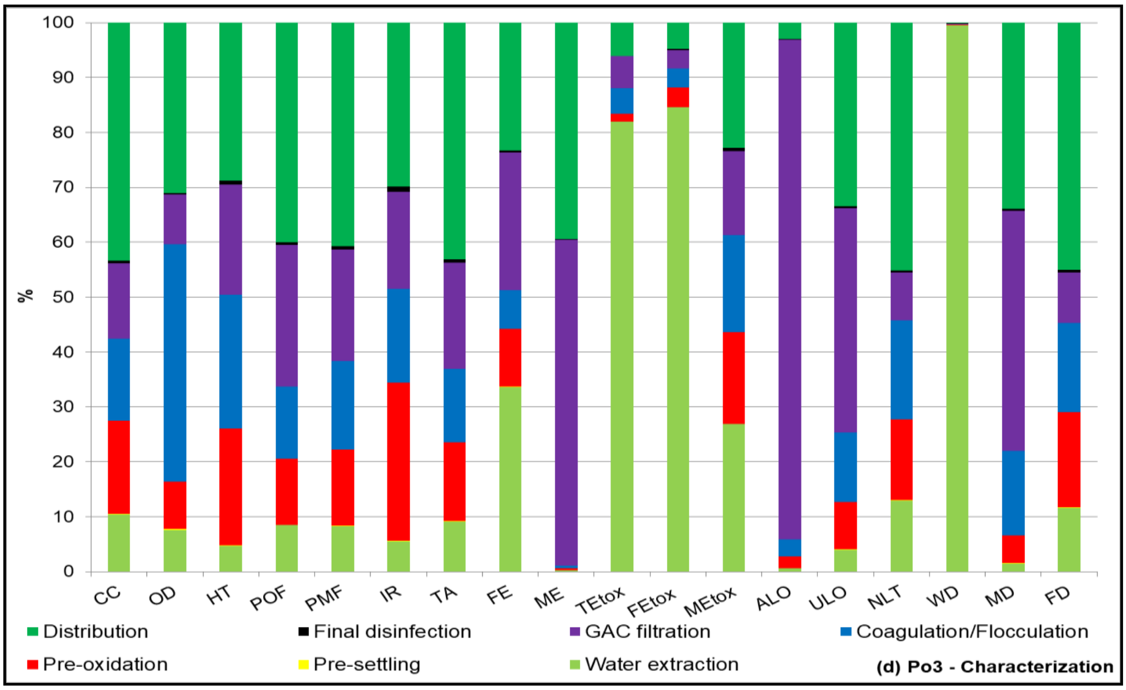


Figure 4.17. Environmental profile of Po3 treatment line, on treatment steps.

Aluminium polychloride, sodium hypochlorite and ferric chloride are the reagents responsible for the impact caused on FEtox, FE, MEtox, NLT and HT impact categories.

The energy required for raw water extraction and pumping to distribution network influence the freshwater ecotoxicity and eutrophication capacity.

Environmental performance assessment of Po drinking water treatment system on treatment step the impact categories affected are ***Particulate matter formation*** **(PMF),** ***Terrestrial ecotoxicity*** **(TEtox),** ***Ionising radiation*** **(IR),** ***Terrestrial acidification*** **(TA),** ***Marine ecotoxicity*** **(MEtox)** and ***Natural land transformation*** **(NLT)**, by the electricity and reagent consumption.

4.5. Partial conclusions

Following the characterization of the three water treatment lines from Po drinking water treatment system, the next conclusion can be drawn:

- The use of electricity is the factor that contributes significantly to the generated impact;
- The treatment capacity and the characteristics of the raw water influence the amount of reagents used
- Assessing the performance of the treatment system is a complex and laborious process, and for an accurate and objective analysis of the system, the quality and complexity of inventory data is essential.
- The impact categories significantly affected by the impact of the water treatment process to obtain 1m3 of treated water are ***Freshwater ecotoxicity*** **(FEtox),** ***Marine ecotoxicity*** **(MEtox),** ***Natural land transformation*** (**NLT),** ***Freshwater eutrophication*** **(FE),** ***Human toxicity (*****HT),** ***Fossil depletion*** **(FD)** and ***Marine eutrophication*** (**ME).**

CHAPTER 5. COMPARATIVE ANALYSIS OF THE PERFORMANCE OF STUDIED WATER TREATMENT SYSTEMS

5.1. Development of scenarios regarding the assessment of the environmental performance of the studied systems

Taking into account the results obtained from the application of the Life Cycle Assessment methodology in Chapters 3 and 4, it was considered appropriate to carry out a comparative analysis between the two case studies and to evaluate a series of scenarios regarding the assessment and improvement of the environmental performance of the studied treatment systems.

The comparative assessment of the environmental performance of the two treatment plants analyzed highlights the factors with a major contribution to system efficiency and impact on the environment, which is part of the original contributions of the PhD thesis.

__Comparative analysis of the two water treatment systems__

The comparative analysis of the two treatment systems studied was performed from the following perspectives:

The treatment capacity of the two drinking water treatment systems is 1,15 m^3/s (Chirița) and respectively 2,5 m^3/s (Po) and a population served by 447.380 inhabitants (Iași), compared to 2.236.740 inhabitants (Turin).

The volume of water pumped into the distribution network to consumers is approximately three times higher in the case of Po drinking water treatment system (12,5 mil m^3 compared to 33 mil m^3) and the losses registered in the distribution network represent 20-25% of the total volume of water distributed in both cases.

Influence of the reagent consumption

Figure 5.1 presents the impact generated by the reagent consumption required to treat 1m^3 of water in the two water treatment systems over the assessed period. The comparison shows the predominant and significant impact (>60%) in most impact categories is generated by the Po drinking water treatment system.

On the opposite side, Chiriţa drinking water treatment system, generates impact (<35%) in ***Metal depletion*** (**MD), *Freshwater eutrophication*** (**FE), *Ozone depletion* (OD), *Ionising radiation*** (**IR**) and ***Natural land transformation*** (**NLT)** impact categories.

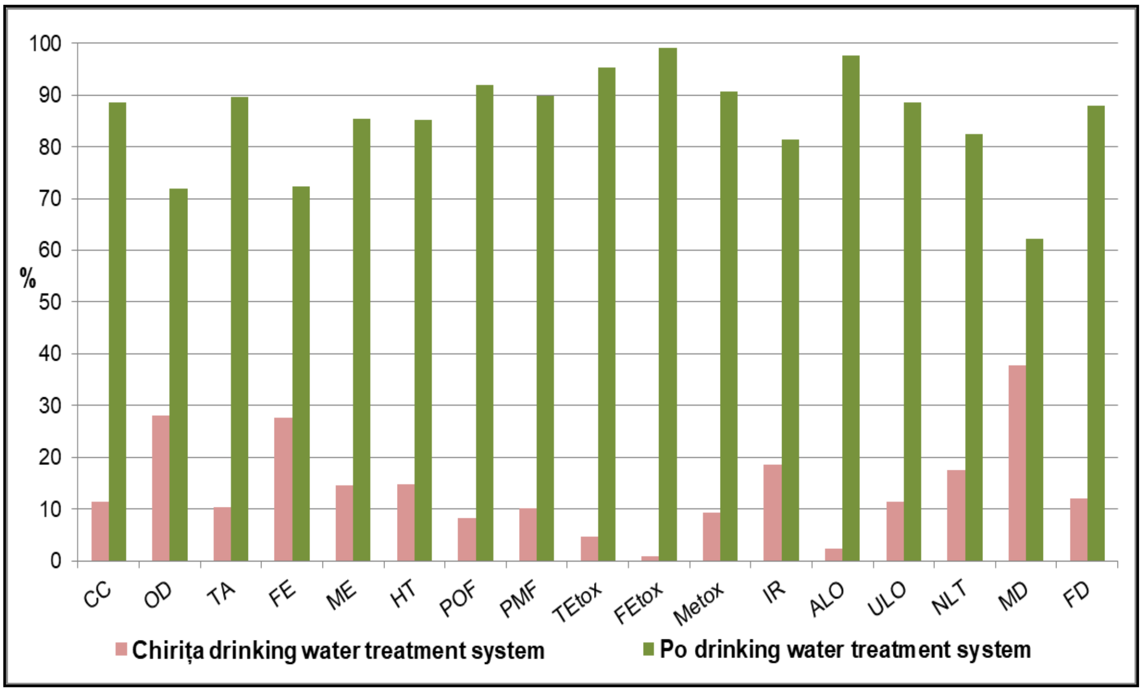


Figura 5.1 The impact of reagent consumption

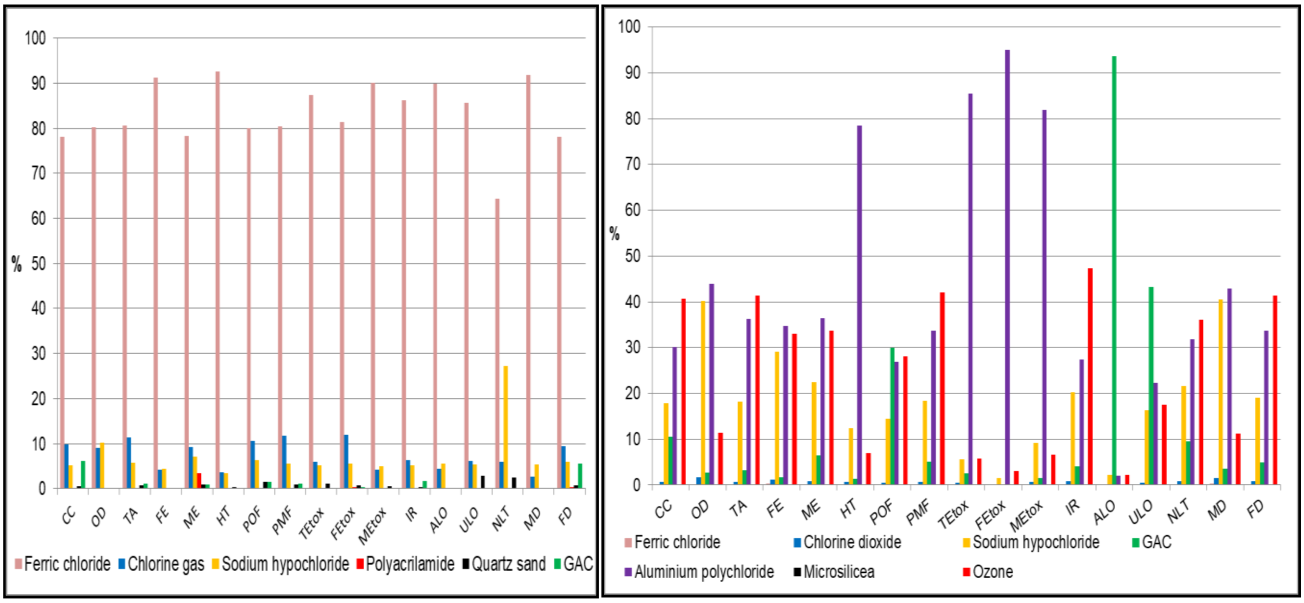
The type and amount of reagents used to meet drinking water quality requirements varies according to the physico-chemical and microbiological parameters of the raw water.

That is why, if the quality of the water is weaker, the consumption of reagents and materials is higher.

Figure 5.2 (a) and (b) present the impact generated by each reagent used in the treatment process within the two evaluated systems. The impact of using the reagent is related to the total impact produced in a given impact category. Ferric chloride acting as flocculant, used in the treatment process (Figure 5.2 (a)) generates almost 100% of the impact in all impact categories.

The environmental performance of the entire system is also influenced by the impact generated by the aluminum polychloride and sodium hypochlorite reagents used in the coagulation/flocculation process.

Sodium hypochlorite generates impact in ***Natural land transformation*** **(NLT),** ***Ozone depletion*** **(OD),** ***Terrestrial ecotoxicity*** **(TEtox),** ***Freshwater ecotoxicity*** **(FEtox),** ***Marine ecotoxicity*** **(MEtox)** and ***Climate change*** **(CC)** (2,5-25%) impact categories (Chirita drinking water treatment system) and on ***Ozone depletion*** **(OD),** ***Metal depletion*** **(MD),** ***Freshwater eutrophication*** **(FE),** ***Marine eutrophication*** **(ME),** ***Natural land transformation*** **(NLT),** ***Ionising radiation*** **(IR),** ***Climate change*** **(CC)** and ***Terrestrial acidification*** **(TA)** (17-40%) impact categories in the case of Po drinking water treatment system.



(a) Chirița drinking water treatment plant (b) Po drinking water treatment plant

Figure 5.2 (a, b) The impact of each reagent in the treatment process

Aluminium polychloide is used in drinking water treatment process from Po treatment system. The impact is predominant on ***Terrestrial ecotoxicity*** **(TEtox),**

Freshwater ecotoxicity **(FEtox),** ***Marine ecotoxicity*** **(MEtox)**, ***Human toxicity*** **(HT)** and ***Ozone depletion*** (**OD)** (> 40%) impact categories.

The impacts categories mostly affected by the use of reagents in the treatment process in both studies are: **Freshwater ecotoxicity (FEtox),** ***Marine ecotoxicity*** **(MEtox)**, ***Freshwater eutrophication*** (**FE),** ***Human toxicity*** **(HT),** ***Fossil depletion*** **(FD)** and ***Natural land transformation*** (**NLT)** that's why, in the future, it is necessary to implement measures to reduce the generated impact.

The impact of electricity consumption

Figure 5.3 presents the impact generated by the electricity required for the operation of installations and equipments at the treatment plant to produce 1m^3 of treated water.

The specific consumption of electricity required to treat 1m^3 of water is 0,0596 kWh for Chirița drinking water treatment systme and 0,1466 kWh for Po drinking water treatment plant.

This difference in energy consumption is due, as mentioned in the previous paragraphs, raw water quality equipments performances, but mostly due to the different processes included in the two life cycle inventories (the Po system also considers pumping processes for raw water extraction and treated water distribution respectively).

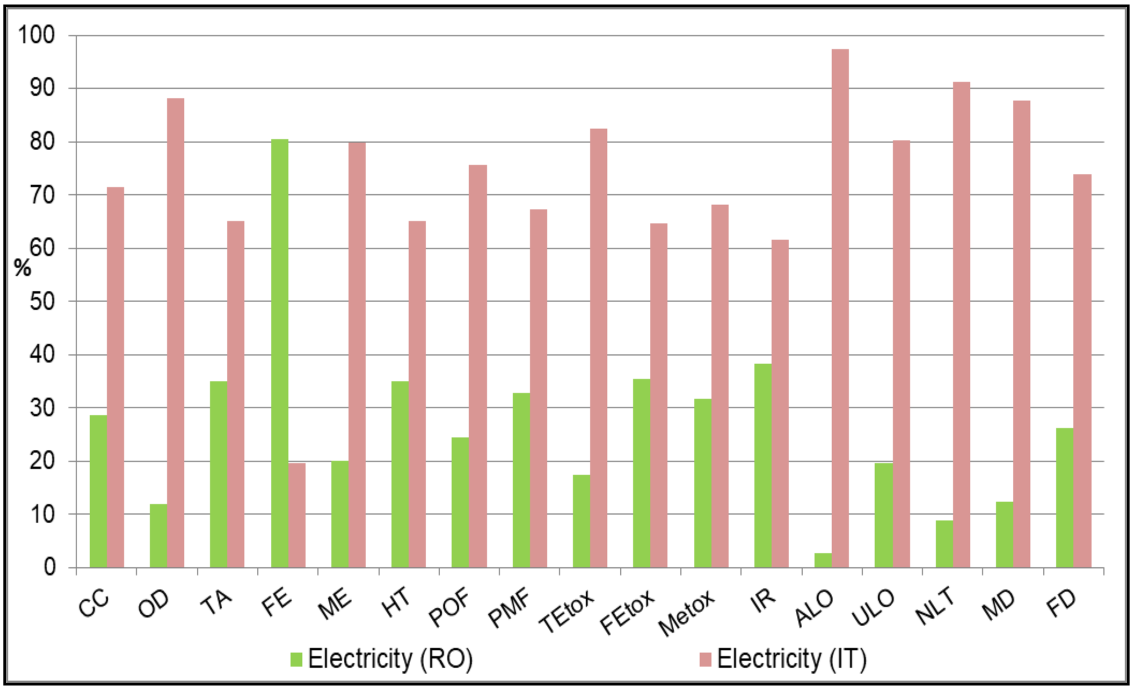


Figure 5.3. The impact caused by electricity consumption

The impact caused by electricity consumption is diferent in the two studied systems because, firstly is influenced by the specific consumption of each system, and secondly, the specific impacts of electricity production processes in the two countries given area, transport network, air emissions and energy looses recorded during transmission (Country specific electricity mixes in the Ecoinvent database). As can be seen from Figure 5.3, the impact of electricity used in Po drinking water treatment system is superior to the impact generated in the Chiriţa drinking water treatment plant.

Development of scenarios regarding the assessment of the environmental performance of the studied water treatment systems

The scenarios proposed to improve the performance of a treatment system are useful to determine the contribution and impact generated by each factor involved in the treatment process and the role it plays in the evolution of the system.

Scenario 1 – Replacing the electricity source used in the two drinking water treatment systems

The scenario supposes the complete reaplacement of the electricity with an electricity source derived from renewable sources for the two analyzed systems. The scenario is hypothetical because in reality the operation of a treatment system of such a magnitude is impossible, first and foremost due to the very high costs of the installations necessary for the production of energy (construction, maintenance) but also in terms of availability of space resources.

Figure 5.4 and Figure 5.5 represent grafically the percentage of the total impact generated by the energy consumption in the two drinking water treatment systems, and for the two distinct situations. From Figure 5.4 it can be observed that the contribution of the solar (photovoltaic panels) and eolian energy consumption on environmental impact and the most affected impact categories, in the case of Chirita drinking water treatment plant. In **Situation 2** (eolian energy) lower impact are recorded (the largest decrease (55%), in ***Metal depletion*** **(MD)** impact category. This value is due to the high raw material consumption required for the construction of wind turbine equipment.

The impact of electricity from photovoltaic panels generates a higher impact on ***Terrestrial ecotoxicity*** (**TEtox**) which account for the toxic substances and emissions on terestrial surface with impact against ecosystems and a high bioacumulative capacity and potentially persistent. Another impact generate is in ***Urban land occupation*** and on ***Natural land transformation*** (**ULO and NLT**), because solar panels require a lot of space to be installed.

In the case of Po drinking water treatment system, the highest impacts are recorded for the current situation (using the grid the electricity mix (Figure 5.5), except the **ULO** impact category in **Situation 1**. This can be explained by the fact that the area required for the location of the photovoltaic panels park is very large, the main disadvantage of this energy production technology.

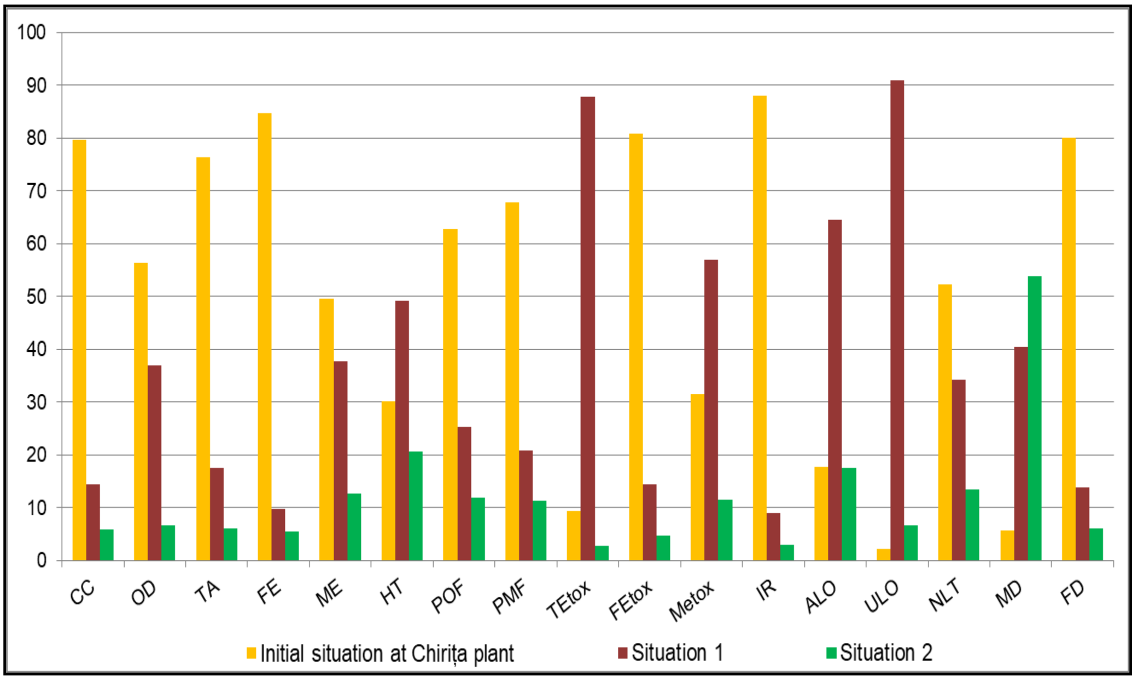


Figure 5.4. Scenarios regarding the electricity source used within Chiriţa drinking water treatment system

The differences in impact profiles and values generated, for the two analyzed drinking water treatment systems (Chirița and Po) may be explained by the consist in the completely different structure of the electricity generation mixes: the current situation refers to the specific national grid power, while **Situation 1** refers to solar enegy. In most of the impact categories the impact caused by electricity used in current situation, is higher than the impact cause by solar energy, except ***Urban land occupation*** **(ULO),** ***Terrestrial ecotoxicity*** **(TEtox),** ***Freshwater ecotoxicity*** **(FEtox),** ***Marine ecotoxicity*** **(MEtox)** and ***Metal depletion*** **(MD).** For the **Situation 2**, higher impact is caused by wind energy in ***Freshwater ecotoxicity*** **(FEtox),** ***Marine ecotoxicity*** **(MEtox)** and ***Metal depletion*** **(MD).** impact categories.

At the end of the analysis, we can talk about one improvement of the performance of the water treatment system by replacing the energy source used, but the adoption of such technology requires investments that can also have an impact on ecosystems, natural resources and people.

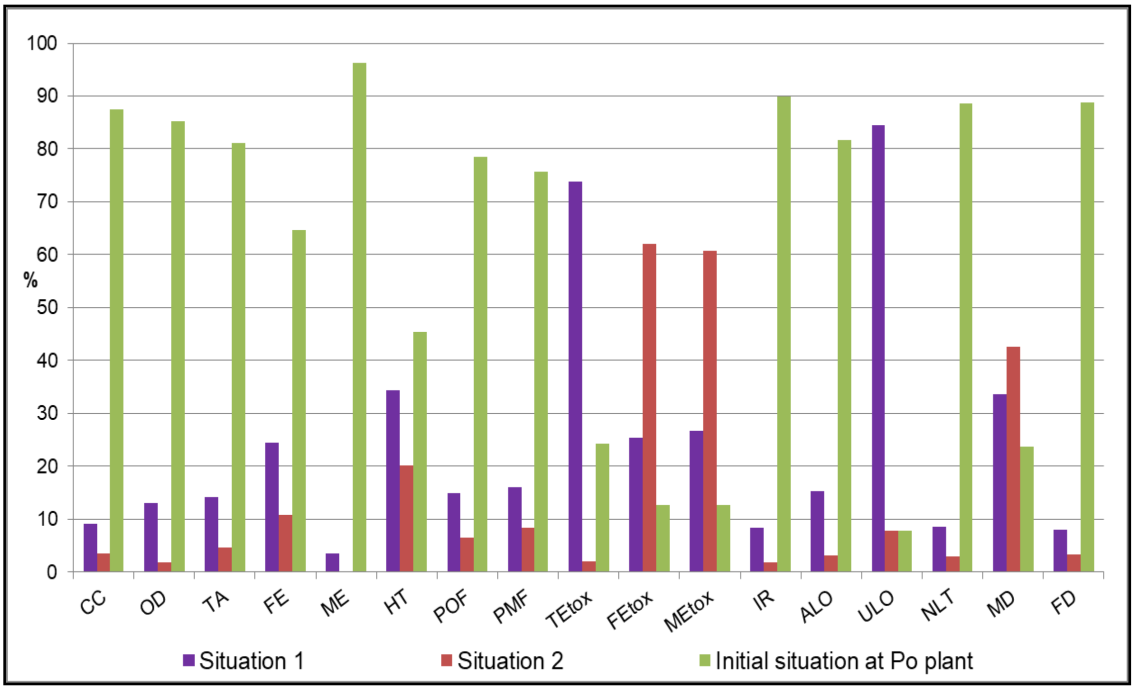


Figure 5.5. Scenarios regarding the electricity source used within Po drinking water treatment system

Scenariul 2: 10% of electricity from the public network comes from renewable sources

For this scenario, it was proposed to replace in the electricity mix used in the original situation from non-renewable natural fuels with a part of the energy coming from renewable sources (solar or wind).

The introduction of 10% of electricity from photovoltaic panels into the electricity mix in the public distribution system does not generate significant changes on the environmental impact. The impact categories affected by this change are ***Urban land occupation*** **(ULO),** ***Terrestrial ecotoxicity*** **(TEtox)** and ***Metal depletion*** **(MD).** In the case of replacement in the energy mix with an additional amount from wind power, the difference of impact (maximum 15%) is observed in the following impact categories ***Freshwater ecotoxicity*** **(FEtox),** ***Marine ecotoxicity*** **(MEtox)** and ***Metal depletion*** **(MD)** (Figure 5.6).

The impact generated in the impact category ***Metal depletion*** **(MD)** is caused by the depletion of the metalliferous resources used for the construction of the energy production facilities and in the case of the ***Freshwater ecotoxicity*** **(FEtox)** and ***Marine ecotoxicity*** **(MEtox)** impact categories, the substances are considered to be toxic and the water emissions can have an impact on aquatic ecosystem with persistent and bioaccumulative potential.

In the case of Chirita drinking water treatment system, the 10% of the energy mix is replaced with energy from renewable sources (solar and wind) (Figure 5.7).

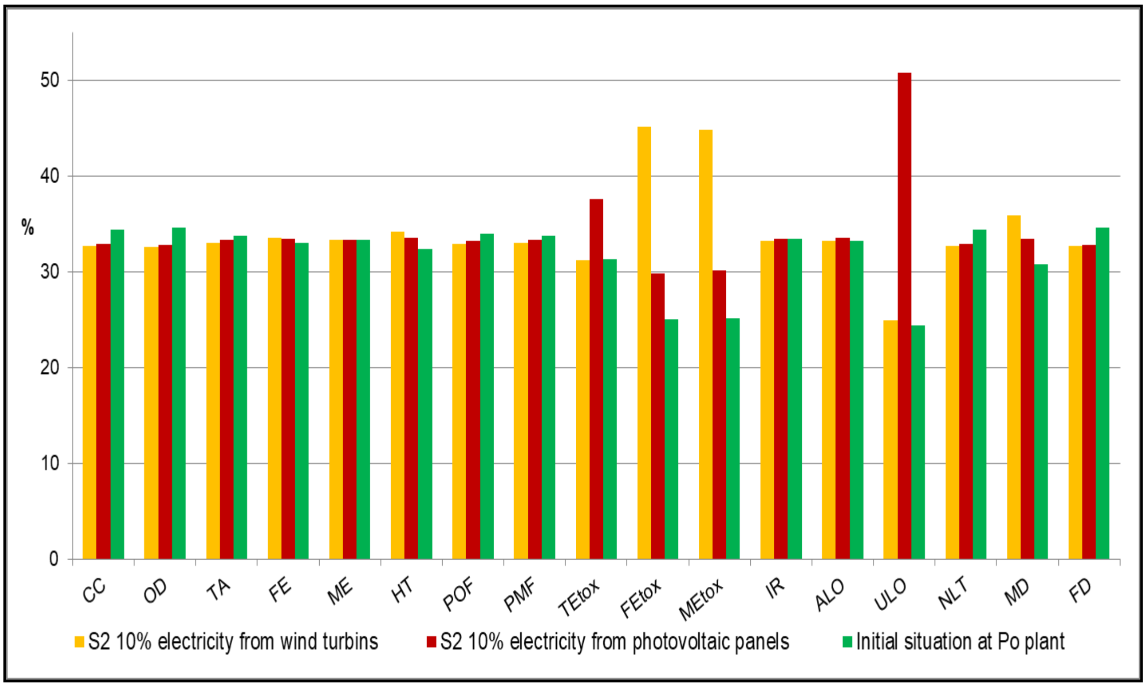


Figure 5.6. Scenarios on the electricity source used in Po drinking water treatment system

A performance improvement was noted in the case of wind power, but in the case of ***Metal depletion*** **(MD)**, ***Marine eutrophication*** **(ME)**, ***Terrestrial ecotoxicity*** **(TEtox)**, ***Freshwater ecotoxicity*** **(FEtox)**, **Marine ecotoxicity (MEtox)** and ***Ozone depletion*** **(OD)** impact categories was observed an impact over the impact gived by the energy mix.

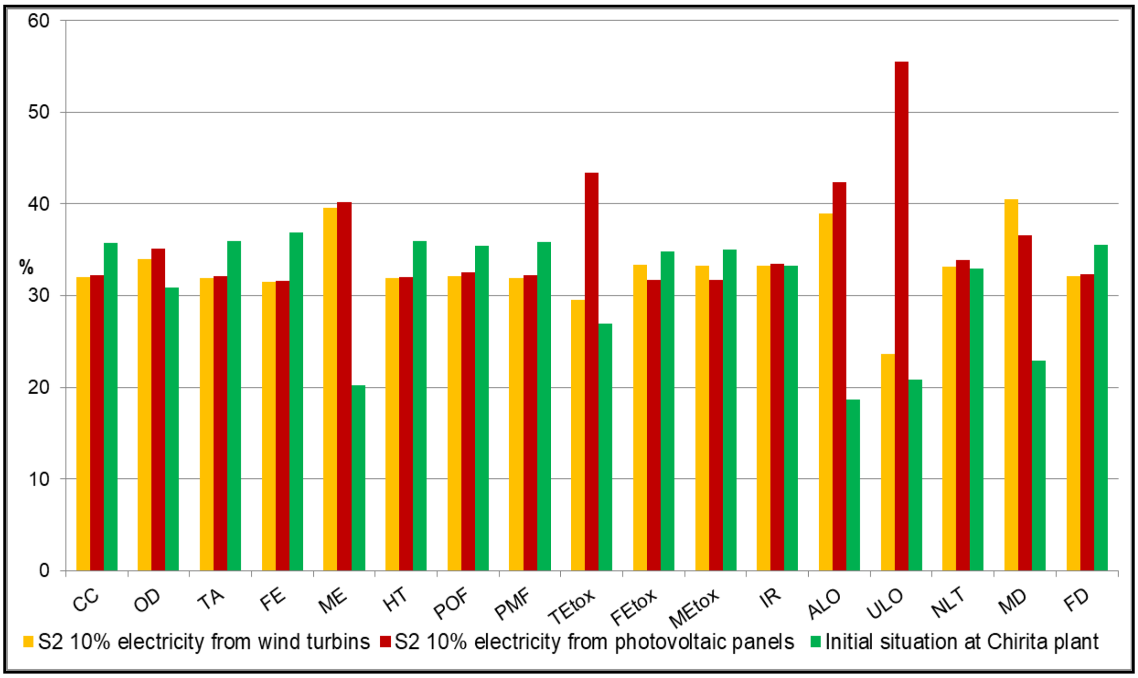


Figure 5.7. Scenarios on the electricity source used in Chirita drinking water treatment system

The energy from photovoltaic panels generates impact over the impact generated by the energy mix used to treat 1 m^3 of water on the impact categories ***Marine***

***eutrophication* (ME), *Terrestrial ecotoxicity* (TEtox), *Agricultural land occupation* (ALO), *Urban land occupation* (ULO)** and ***Metal depletion* (MD)**.

This variation between the two treatment systems is primarily generated by the amount of electricity needed to produce 1 m^3 of treated water and secondly by the composition of the electricity mix, because the same amount of energy, in different situation, it can be composed from different types of energy but in different fractions.

<u>Scenario 3 - The origin of the filtering material</u>

The replacement of GAC used in Chiriţa drinking water treatment plant with GAC derived from a vegetable source can provide a suitable solution for improving the environmental performance of the system. The difference in impact generated by the two types of granular activated carbon is presented in Figure 5.8.

The impact caused by the GAC from vegetal source is 100% on ***Agricultural land occupation* (ALO), *Urban land occupation* (ULO)** and ***Natural land transformation* (NLT)** impact categories, due to the large areas of land used for the cultivation of raw material. Granul activated carbon from vegetal sources requires large amounts of energy and chemical consumption, needed for GAC production.

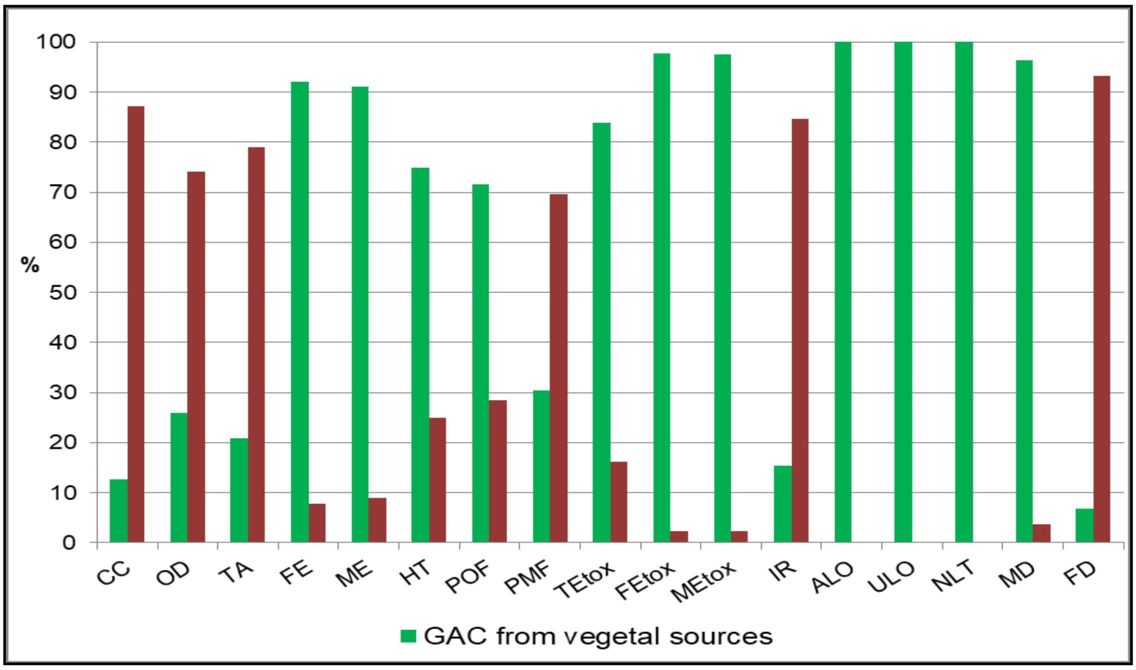


Figura 5.8. The impact generated by the two types of granular activated carbon used in Chirita drinking water treatment system.

The impact is noted on ***Freshwater eutrophication* (FE), *Marine eutrophication* (ME), *Freshwater ecotoxicity* (FEtox), *Marine ecotoxicity* (MEtox)** and ***Terrestrial ecotoxicity* (TEtox)** impact categories. After the comparative analysis of the two types of granular activated carbon, the influence of the GAC analyzed within the treatment system on its capacity to transform and occupy the agricultural and natural lands can be noticed.

Scenario 4 – Reduction of ferric chloride dose used in Chiriţa drinking water treatment system

The ferric chloride used in the coagulation / flocculation process is the main factor contributing to the impact on resources, ecosystem and human health. In order to improve the environmental performance of the treatment process it has been proposed to reduce the ferric chloride amount.

At a minimum consumption of 0,01435 kg ferric chloride to produce 1 cubic meter of treated water, (compared to 0.02548 kg in real situation), the environmental profile (Figure 5.10) show a 10% reduction in impact across all impact categories.

The dose of ferric chloride is calculated according to water characteristics and it varies depending on this.

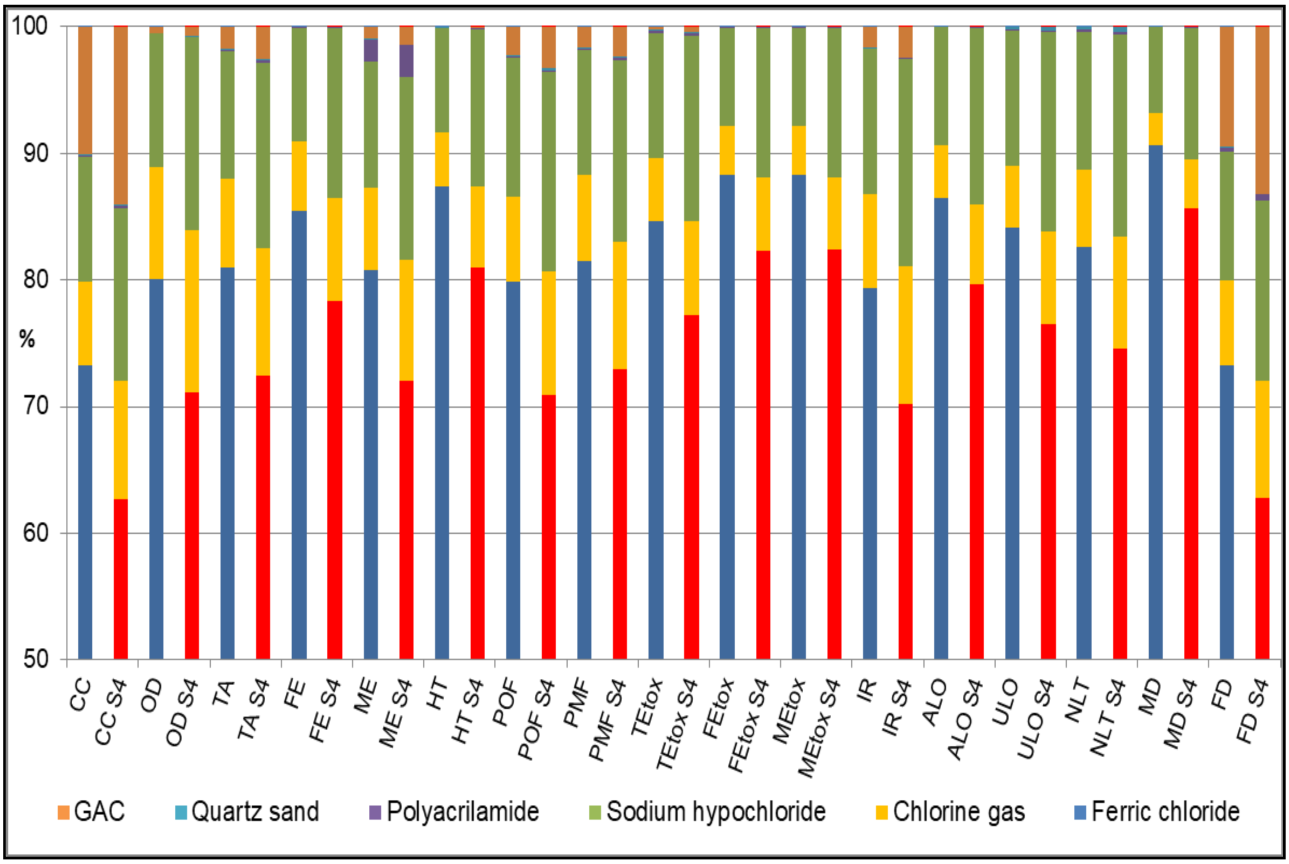


Figure 5.10. The influence of the ferric chloride dose used in the treatment process in Chirița drinking water treatment process

The proposed scenarios, through the variety of perspectives analyzed, have the role of assessing the environmental performance of the analyzed systems and their improvement in order to reduce the impact on the ecosystems, resources and human health.

5.2 Developing a system of sustainability indicators to assess the performance of the treatment systems under review

The best known and widely accepted method of sustainability measurement is the use of a set of indicators that are known as sustainability indicators (Mahedi Al Masud *et al.,* 2018).

From the need to evaluate and compare the performances of the drinkingwater treatment systems in this thesis it was proposed a new framework to carry out this assessment.

This framework analyzes and assesses the most important and commonly encountered socio-economic, environmental and technological aspects of the presented studies. The novelty of this framework is based on a different approach that has been developed to assess the sustainability of drinking water treatment systems.

The relevant indicators selected for an objective assessment of the system are grouped into three categories (economic, social and environmental) for both qualitative and quantitative assessment (Table 5.4). Table 5.4 present impact score granted for each indicator.

Table 5.4 Analysis framework for assessing the social, economic and environmental performance of water treatment systems analyzed.

Code	**Indicator (unit of measure)**	**The system analyzed**			
		Chirița drinking water treatment system		**Po drinking water treatment system**	
			Score		**Score**
Social performance Indicators					
S1	Density (no. loc/km²)	3.856	-	6,596	-
S2	Average consumption per capita (m^3/pers/zi)	0,08	5	0.174	4
S3	Number of employees (no. employees/m^3)	0,00011	3	0,000013	4
S4	Investments for the protection of water resources	Da	5	Yes	5
S5	Integrated management system implementation	Da	5	Yes	5
S6	Training courses	Da	5	Yes	5
S7	Information transparency	Da	5	Yes	5
S8	Involvement of students in educational programs	Da	5	Yes	5
S9	Complaints - Water quality (no./year)	-	-	115	1
S10	Complains - Intimation (no./year)	5179	1	1358	4
S11a	Partnerships with research institute /universities (no./year)	Da	5	Yes	5
S11b		-	-	15	4
S12	Customer satisfaction on the quality of water	-	-	Satisfied – 44%	4

Economic performance indicators					
E1	The average price per m^3 of water (without VAT) (€/m^3)	0,73	4	0.95	3
E2	Maintenance costs (€/m^3).	-	-	0,09	3
E3	Costs of consumables (€/m^3).	-	-	0,06	4
Environmenatal performance indicators					
M1	Total water resources (m^3/an)	34,827 $\cdot 10^6$	-	58.000$\cdot 10^6$	-
M2	Surface water resources (m^3/an)	13,679$\cdot 10^6$	-	3.321$\cdot 10^6$	-
M3	Groundwater resources (m^3/an)	9,600$\cdot 10^6$	-	1.924$\cdot 10^6$	-
M4	Water resource used	Surface water	3	Surface water	3
M5	Extracted water volume (m^3)	13.365.175	4	56.922.000	1
M6	Treatment system capacity (m^3/s)	1,15	3	2,5	5
M7	Volume of water sent to the distribution network (m^3)	12.492.191	3	33.073.789	4
M7a		-	-	78,8%	5
M7b		-	-	1.4%	1
M7c		-	-	13.8%	2
M7d		-	-	6%	1
M8	Length of the distribution network (km)	490	1	11.289	5
M9a	Reagent transport (km/an)	71.128,12	1	16,460	3
M9b		-	-	11.000	1
M10	Water loses in the distribution network (%)	20%	4	25,5%	3
M11	Service water (%)	5,7%	5	27%	3
M12	Degree of supply of drinking water (%)	-	-	99.64%	5
M13	Treatment technology*	A3	1	A3	1
M14	The quality class of the water source	Clasa de calitate III	3	Clasa de calitate III	3
M15	Number of parameters determined (no./46)	22	3	32	4
M16	Degree of compliance (%)	97%	4	99,9%	5
		Ci/Ct		*Ci/Ct*	
IC1	pH	8,26/7,73	5	7,7 / 7,5	5
IC2	Conductivity (µS/cm 20 ºC)	636,88/648, 75	1	420 / 450	1
IC3	Turbidity (NTU)	7,35/0,21	5	10 / 0,2	5
IC4	Temperature (ºC)	-	-	10 / 9	5
IC5	Total organic carbon (mg/L)	9,17/5,92	5	2 / 1,2	5
IC6	Dissolved oxygen (mg/L)	11,86/1,98	5	9,5 / 9,1	5
IC7	Ammonium (mg/L)	0,10/0,01	5	0,4 / -	5
IC8	Nitrate (mg/L)	0,24/0,21	5	0,16 / -	1
IC9	Nitrite (mg/L)	2,59/2,45	5	13 / 14	1
IC10	Iron (µg/L)	-	-	90 / -	5
IC11	Aluminium (µg/L)	-	-	- / 20	1
IC12	Chloride (mg/L)	37,02/43,59	1	16 / 26	1
IC13	Phosphorus (µg/L)	-	-	300 / -	5
IC14	Chlorine dioxide (mg/L)	-	-	- / 0.2	1
IC15	Manganese (µg/L)	-	-	60 / -	5
IC16	Hardness (ºF)	10,24/9,98	5	23 / 22	5
IC17	Alkalinity(ºF)	-	-	18 / 17	5
IC18	Calcium (mg/L)	52,87/51,30	5	76 / 69	5
IC19	Magnezium (mg/L)	17,18/17,00	5	12 / 14	1

IC20	Sulphates (mg/L)	148,53/92,92	5	55 / 48	5
IC21	Silica(mg/L)	-	-	9 / 9	5
IC22	Nickel (µg/L)	-	-	3 / 2	5
IC23	Copper (µg/L)	-	-	3 / 10	1
IC24	Cadmium (µg/L)	-	-	0 / 0	5
IC25	Chrome (µg/L)	-	-	4 / 2	5
IC26	Lead (µg/L)	-	-	1 / 0	5
IC27	Total pesticides (mg/L)	-	-	0,17 / 0,03	5
IC28	TTHM (mg/L)	-	-	- / 2	1
IC29	Coliform bacteria at 37 °C (nr./100 ml)	-	-	70000 / 0	5
IC30	Escherichia coli (nr./100 ml)	-	-	10000 / 0	5
IC31	Enterococcus (nr./100 ml)	-	-	3000 / 0	5
IC32	Colonies at 22 ºC (nr./ml)	-	-	90000 / 0	5
M17	Specific energy consumption (kWh/m^3)	0,0632	3	0,732	1
M18	Energy source used	Neregenerabilă	1	Neregenerabilă	1
M19	The amount of reagents used (kg/m^3)	0,03	5	0,09	4
M20a	Sludge (kg/m^3)	0,0005	5	0,02	3
M20b		wastewater treatment plant discharge	4	wastewater treatment plant discharge	4
M21	GAC wastes	-	-	-	-
M22	Granular activated carbon (regenerated)	-	-	Chemical Regeneration	2
M23	Waste recycling	Da	5	Da	5
M24	Water reuse	Da	5	Da	5
CI1	Freshwater eutrophication (%)	19.10	5	12.70	5
CI2	Marine eutrophication (%)	33.80	4	52.70	3
CI3	Freshwater ecotoxicity (%)	31.30	4	80.80	1
CI4	Marine ecotoxicity (%)	31.90	4	63.20	2
CI5	Water depletion (%)	88.50	1	72.60	2
CI6	Climate change (%)	47.60	3	43.80	3
CI7	Ozone depletion (%)	88.40	1	64.40	2
CI8	Terrestrial acidification (%)	51.30	3	40.60	3
CI9	Photochemical oxidant formation (%)	60.00	2	48,60	3
CI10	Particulate matter formation (%)	58.00	3	46.10	3
CI11	Ionising radiation (%)	30.20	4	32.20	4
CI12	Terrestrial ecotoxicity (%)	62.70	2	71.00	2
CI13	Agricultural land occupation (%)	94.60	1	85.70	1
CI14	Natural land transformation(%)	71.70	2	54.50	3
CI15	Metal depletion (%)	87.30	1	75.60	2
CI16	Fossil depletion (%)	44.80	3	41.80	3

For a better understanding of the indicators, each category of indicators was described. For the evaluation of each of the indicator described, a scorring scale was proposed. There will be allocated a score based on a unitary allocation mode, namely marks from 1 to 5 or 1 or 5, depending on the indicator, 1 being the smalest and 5 being the highest score.

The scores were given in relation to the relevance, importance and potential impact of each indicator (Teodosiu *și colab.,* 2019).

The proposed framework of analysis is aimed to:

- analysis of the treatment system in terms of recorded performance;
- the possibility of elaborating a comparative study between the treatment systems in relation to the profile of the institution targeting the water supply of the population or in terms of resources availability, their quality, the population served and the recorded incomes.

The selected indicators have the role of measuring the essential aspects of the drinking water treatment process. They are grouped according to demographic criteria, system capacity and specifications, economic profile and environmental impact factors (resources, qualitative parameters of raw water and wastes).

In Table 5.4 the quantitative indicators are presented together with the score according to the established criteria.

The framework analysis methodology for performance assessment proposes to give the maximum score for a situation where a positive performance is recorde (5) and a minimum score where it is assumed to be for the performance with negative impact (0 or 1) on the three areas (social, economic and environmental) for which the assessment is carried out.

For a general analysis of the performance of the treatment system, the arithmetic mean of the indicators included in each component, for which the performance is assessed, will be made (Table 5.5).

Table 5.5 presents the results obtained for an overview of the performance of the two treatment systems in the three directions (social, economic and environmental).

	Social performance (1)	**Economic performance (2)**	**Environmental performance (3)**
Total	39	4	164
No. indicators	9	1	49
Chirița drinking water treatment system	4,33/5	4/5	3,35/5
Total	51	10	245
No. indicators	12	3	74
Po drinking water treatment system	4,25/5	3,33/5	3,31/5

The overall analysis of the performance of the two water treatment systems takes into account the profile of the country of the analyzed system, the area and population served, the availability of water resources at national level but also the resources consumed, the waste and the impact on the resources and ecosystems. As mentioned above, the closer the obtained score is to 5, the higher the performance of the system will be. From this analysis, it can be observet that, Chirița drinking water treatment system has higher performance than Po drinking water treatment system in all three directions, but the analysis is general, because, for an objective analysis it is needed the same amount of information for the both analyzed studies.

- **Indicators for assessing the social performance of the treatment systems**

Non-dimensional indicators such as **S4, S5, S6, S7** and **S8** provide information on the sustainability of the system, but they do not fully characterize the performance of the system. A numerical quantification of these indicators can detail the degree of involvement of the organization in potential issues and the communication relationship with the public involved (consumers).

S9 and **S10** Indicators differentiate the two evaluated systems, the higher the number of complaints about water quality, the lower is the performance of the treatment system (Figure 5.12).

Assessing the sustainability of the two drinking water treatment systems (Chirița and Po) from the point of view of social responsibility activities, shows certain equality in the involvement of organizations in meeting the needs of their clients, their involvement and awareness of certain situations to be managed.

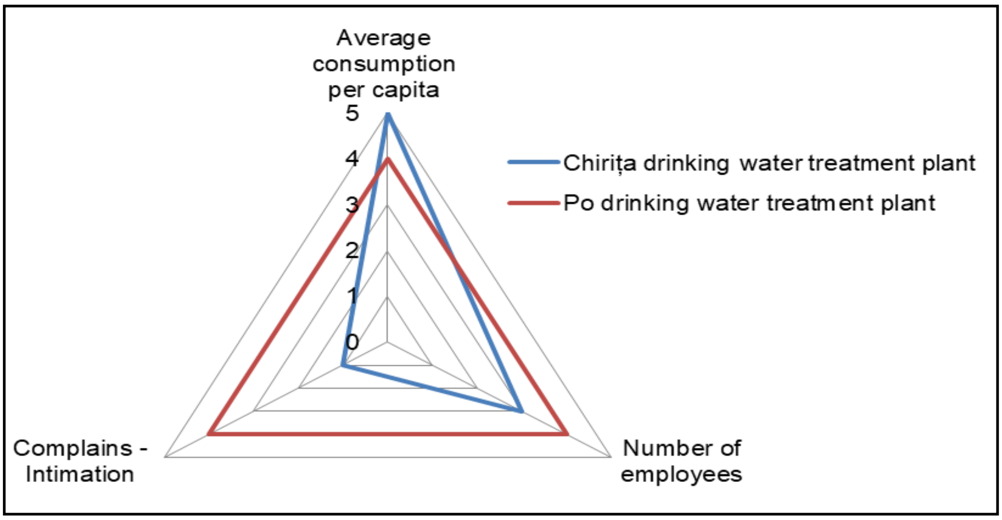


Figure 5.12. The social performance of the two water treatment systems

The number of employees can provide information not only from a social point of view but also about the technological performance of the system. In relation to 1 m^3 of treated water, the number of employees in the case of Po drinking water treatment system is of 0,00013 employees and for Chirita drinking water treatment system is of 0,00011 employees. The lower the number of employees, the higher degree of compliance and drinking water treatment capacity, the management of the treatment process is efficient and has a maximum yield.

- **Indicators for the assessment of the economic performance of the treatment systems**

The **E1** indicator provides an overview of the economic performance of the treatment system as it covers all costs (materials, consumables, maintenance, employees, etc.). In the present analysis, two surface water treatment systems are ranked in the same quality class and following about the same treatment technology, the average cost per m3 of treated water is a indicator that describe the economic preformance of the system. The higher the costs are, the higher the treatment costs, so it is necessary to maintain a balance between the average tariff for 1 m^3 of treated water and the maintenance, consumables, personnel and investment costs, etc.

- **Indicators for assessing the environmental performance of the treatment systems**

The performance of the treatment system takes into account the profile of the country where the system is located, drinking water treatment characteristics, (volume of treated water, volume of water distributed, the degree of supply of drinking water, distribution network and treatment technology), the quality parameters of treated water (Phisico-chemical parameters, microbiological parameters, and compliance degree), the resources used, the waste generated, the pollution prevention measures and the impact of the consumption of reagents on the ecosystem and natural resources.

For a better characterization of the studied drinking water treatement systems (Figure 5.13), from Table 5.4 the **M5, M6, M7, M8, M10** and **M11** indicators were selected.

The degree of compliance refers to the total number of analyzed water quality indicators in relation to the total number of yearly complians. This indicator (**M16**) indicates the effectiveness of the treatment and the quality of treated water. A higher percentage show the degree of accountability of the organization on the quality of the treated water and on services provided.

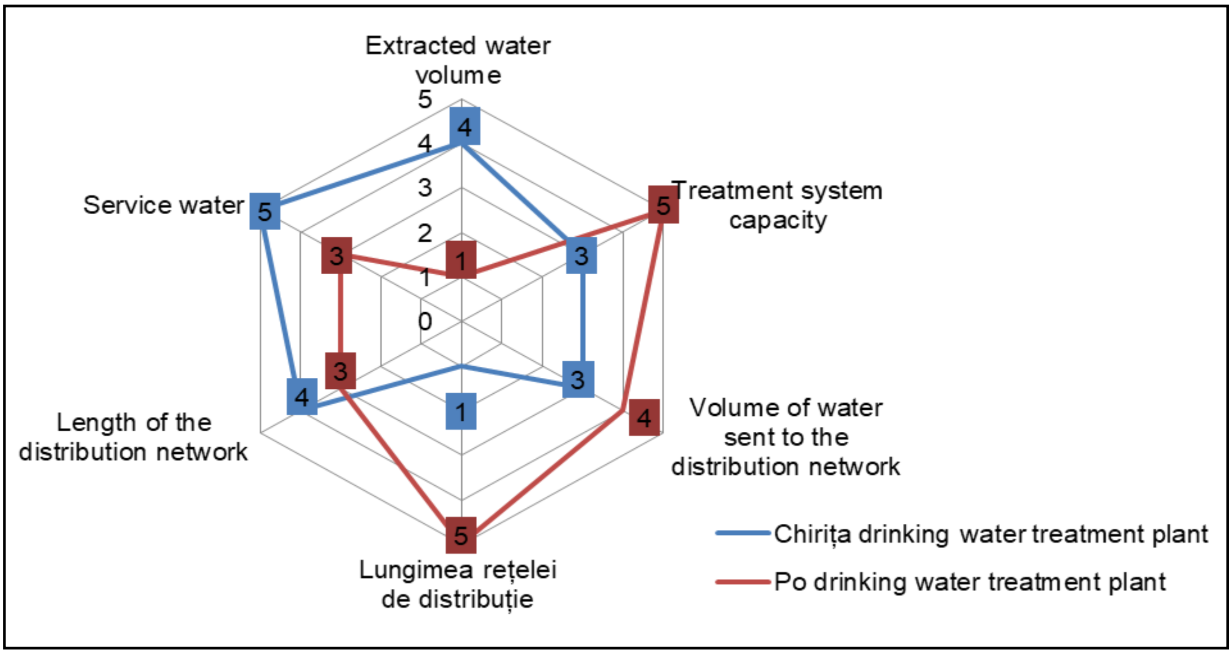


Figure 5.12 Description of the technological performance of the treatment systems analysed.

From Figure 5.13 it can be observed the technological performance of the two analysed drinking water treatment system. With regard to the treatment capacity of the system, Po treatment system, has a higher performance than Chirita treatment system. Also, in the case of service water and loses in distribution network, the Chirița drinking water treatment system mark a higher performance, due to the lower amount of service water produces or lost.

The sustainability assessment indicators for water treatment systems **M14, M15** and **M16** describe the environmental performance from the point of view of the quality parameters of treated water (Figure 5.13).

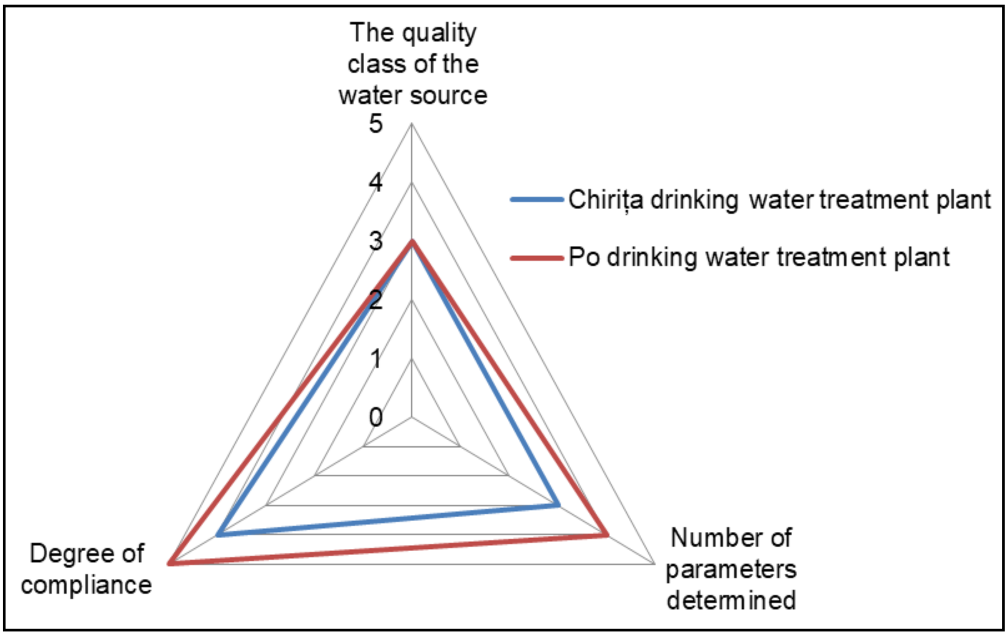


Figure 5.13. Sustainability assessment considering the water quality parameters

Quality indicators of the provided drinking water (**IC1**,...,**IC32**), are determined for the compliant analyzes of the treated water. The compliance with the maximum admissible values set by each country according 83/98/CE Directive, on the quality of water intended for human consumption, indicates the quality of water distributed to consumers. The number of parameters is determined by the drinking water treatment plant capacity, raw water quality and the needs for which it is used.

For Chiriţa drinking water treatment system, we can speak of a higher environmental performance than on Po drinking water treatment system. The number of indicators analyzed shows the organization's involvement in providing quality services and products, but also the existence of some problems that they are currently monitoring (the presence of pesticides, trihalomethanes and viruses) to avoid complaints or sanctions from the side of consumers or competent authorities.

Electricity and reagent consumption are some of the main contributors on environmental performances of the analysed drinking water treatment systems and against environmental impacts (Barjoveanu *et al.,* 2018; Gilcă *et al., 2019*) (Figure 5.14).

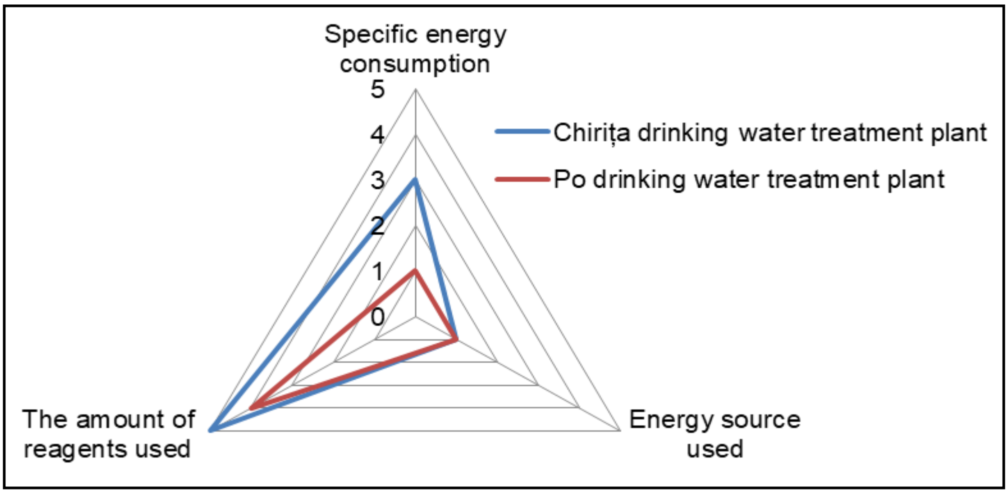


Figure 5.14. Influence of reagent and electricity consumption on the environmental performance of the treatment systems analyzed

The amount of reagents needed to treat 1m3 of water is in most cases the main factor that can generate an impact on ecosystems and resources. From analysis of the two systems (Chirita and Po drinking watertreatment system), only 0,03 kg and respectively 0,09 kg reagent amounts are needed to produce 1 cubic meter of treated water and for a proper operation of the equipments a medium consumption of 0,0632 kWh and 0,732 kWh respectively for each 1000 liters of treated water.

The last indicators proposed to assess the sustainability and the environmental performance of the two drinking water treatment systems (Chirița and Po) are the environmental impact assessment indicators (Water – Air – Soil - Resources). These indicators count the impact caused by the reagent consumption on environment (Figure 5.15).

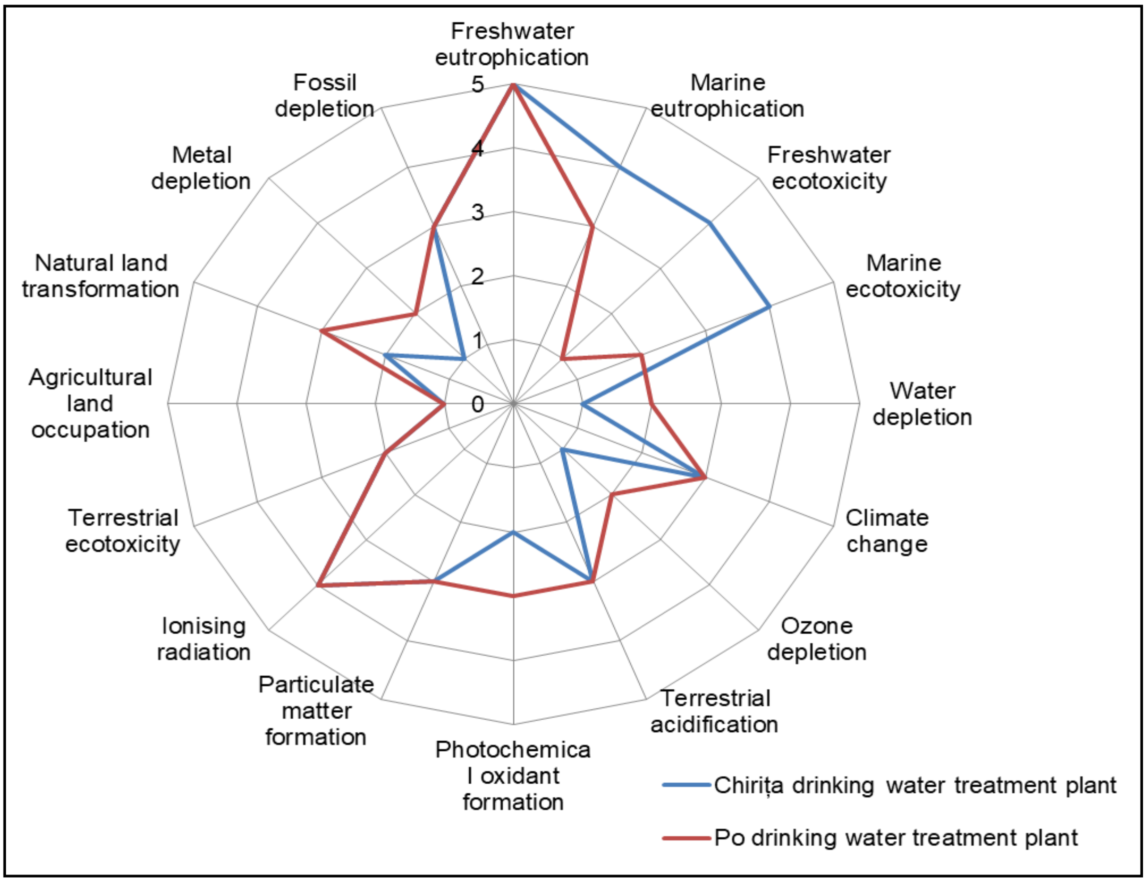


Figure 5.15. Environmental performance due to reagent consumption

Sustainability variation of the drinking water treatment systems is influenced by the consumption of reagents which shows the main indicators affected by their contribution and the environmental performance of the treatment systems analyzed (**CI15, CI14, CI13, CI7** and **CI5)**. Environmental performance of Chirita drinking water treatement system is particularly affected by the **CI5, CI6, CI7, CI8, CI9, CI10, CI12, CI13, CI14, CI15** and **CI16.** As regard the environmental performance of the Po drinking water treatment system, except CI1 and CI11 indicators, rest of them contribute to the impact caused by reagent consumption.

5.3. Partial conclusions

A final conclusion that can be drawn from the comparative analysis of the performances of the two studied water treatment systems can summarize the whole analysis of the following: the electricity consumption is the main contributor of the environmental impact and in the case of the two systems the generating power is higher when the amount of electricity is higher.

The quality of raw water influences the treatment process, the reagents and the amount of reagents used to obtain a product that meets the quality standards imposed by the legislation and does not affect the quality of the ecosystems and has no effect on human health.

Sustainability of treatment systems consists of continuous and balanced improvement of social, economic and environmental performance to meet the sustainability principles.

GENERAL CONCLUSION

The PhD thesis entitled *“Studies on environmental performance of the water treatment systems”* aims to assess the performances of two drinking water treatment system (Chirița, Iași and Po, Turin).

The originality of the research consists in the variety of perspectives considered for the analysis of the environmental performance (by appling the Life cycle assessment methodology) of the two water treatment systems. The proposed perspectives offer a clear and objective view of the causes and impacts generated by the activity of Chirița and Po drinking water treatment plants, the influence of energy consumption, reagents and materials used in the treatment process. The production of 1 cubic meter of treated water in each of the two treatment system needs different amount of energy, reagent, and materials. The impact caused is different according to water characteristics, treatment efficiency, amounts of reagent and electricity used.

Another innovative point of this PhD thesis consists in the development of some scenarios for the critical analysis of the environmental performances. Also, is developed and applied a framework based on sustainability indicators in order to analyse, identify and compare the performances of the two systems (social, economical and environmental).

Following this analysis, we have identified the system with the highest performance, but in the future, for an objective and solid analysis, it would be necessary to have the same amount of data, for all the systems under analysis, for a proper comparative assessment.

It should be noted that both, the methodology applied for the assessment of the environmental performance of the studied drinking water treatment plants, the proposed scenarios for performance assessment, as well as the framework of indicators developed to evaluate and compare the sustainability of the two systems analyzed, provides a solid and fundamental foundation for public operators, knowledge and awareness of the performance of managed systems, the impacts generated and the existing posibilities for improvement.

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RESEARCH ACTIVITY

Scientific papers published in ISI journals / submitted for publication

1. Morosanu I., ***Gilca A.F.,*** Paduraru C., Fighir D., Peptu C. A., Teodosiu C., (2017), *—Valorisation of rapeseed as biosorbent for the removal of textile dyes from aqueous effluents‖* , Cellulose Chemestry and. Technology, 51 (1-2), 175-184;
2. Teodosiu C., ***Gilca A.F.***, Barjoveanu G., Fiore S., (2018), *—Emerging pollutants removal through advanced drinking water treatment: A review on processes and environmental performances assessment‖* , Journal of Cleaner Production., 197 (1), 1210-1221. doi.org/10.1016/j.jclepro.2018.06.247;
3. Bârjoveanu G., Teodosiu C., ***Gilca A.F.***, Roman I., Fiore S., (2019) - *„Environmental performance evaluation of a drinking water treatment plant: a life cycle assessment perspective‖* , Environmental Engineering and Management Journal, 18 (2),
4. ***Gilca A.F.***, Fiore S., Teodosiu C., *—Two different approaches to assess drinking water production systems through LCA. An Italian case study‖* – submitted for publication;
5. **Gilca A.F.,** Fiore S., Teodosiu C., - *Emerging disinfection by-products in drinking water treatment processes‖* – submitted for publication

Paper presented at national and international conferences as poster

1. 10th International Conference on Environmental Engineering and Management, ICEEM 10/ 18 – 21 September 2019, —Gheorghe Asachi‖ Technical University of Iasi, Romania, *—Sustainability indicators framework to assess water treatment systems‖* Autori: Teodosiu C., ***Gilca A.F.***, Fighir D., Silvia Fiore S. – Accepted
2. 4th International Conference on Chemical Engineering - Innovative materials and processes for a sustainable development. 31 Octobrie - 2 Novembrie 2018, —Gheorghe Asachi‖ Technical University of Iași, Romania, Poster session: *—Integrated Assessment of Heavy Metals Pollution in the Prut River Basin: A Case Study for Iași County‖*- Autori: Neamțu R., Slușer B. M., Teodosiu C., ***Gîlcă A.F.***, Gavrilescu D., Mustereț C. P.
3. 9th International Conference on Environmental Engineering and Management, ICEEM09 / 6 – 9 September 2017, „ Alma Mater Studiorum Università di Bologna, Italia‖, Poster session. *„Life cycle assessment of a drinking water production system‖* – Autori: ***Gilca A.F.***, Barjoveanu G., Teodosiu C., Fiore S.
4. 3rd International Conference on Chemical Engineering, Innovative Materials and Processes, ICCE / 09 – 11 November 2016, „Gheorghe Asachi‖ Technical University of Iasi, România, Poster session. *—Evaluation of landfill leachate treatment by combined Fenton oxidation and membrane separation processes‖* - Autori: Fighir D., Musteret C.P., Gherghel A., Morosanu I., ***Gilca A.F.***, Minea M., Apopei P., Teodosiu C.

Member of the team in national and research projects

1. Research assistant in PCCDI no. 26PCCDI/1.0.3.2018 — Integrated and sustainable processes for environmental clean-up, wastewater reuse and waste valorization (acronym: SUSTENVPRO). Project coordinator: Prof. univ. PhD. Eng. Carmen Teodosiu;
2. Laboratory engineer in LACMED (Laborator de Analiză și Control Factori de Mediu), Laboratory Coordinator: Prof. univ. PhD. Eng. Carmen Teodosiu;

Research stage

1. Erasmus intership+ - Research mobility, Period 19/01/2017 – 21/09/2017. Politecnico di Torino – POLITO, Torino (Italia), Dipartimento di Ingegneria dell'Ambiente, del Territorio e delle Infrastrutture (DIATI); Scientific coordinator: Prof. univ. PhD chem. Silvia FIORE.