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Environmental assessment of wastewater treatment plants

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***Abstract*— the objective of the present study was to evaluate the environmental impacts associated with the treatment of wastewater released from pharmaceutical company SAIDAL of Médéa city (Algeria) into its wastewater treatment plant (WWTP). This plant is located in the center of Algeria and has been in operation since 1986. This study is conducted employing life cycle assessment (LCA) and performed using SimaPro 7 software for inventory and impact assessment phases. Operation and maintenance phase, the transportation of chemicals to the WWTP, sludge incineration and landfilling were all taken into consideration. The study revealed very different impacts for the studied plant, drawing attention to the importance of the choice of water treatment chemicals and energy source.**

***Keywords*— Environmental impacts, Life cycle assessment, Pharmaceuticals, WWTP**

I. INTRODUCTION

Pharmaceutical wastewater treatment plants are designed to help human beings to protect themselves and the environment from pharmaceuticals such as anomalies in the reproduction system of fish due to hormones [1-2]. Pharmaceutical wastewater treatment involves protection against microorganisms, removal of natural organic matter, removal of toxic substances, pharmaceuticals, aesthetic quality.

However, wastewater treatment plants en general may be responsible for significant global environmental impacts, the most common amongst which are the depletion of natural resources and indirect release of pollutants into the water, land and air through chemicals and energy consumption.

Wastewater treatment plants (WWTPs) is considered as one of the main emission source of the greenhouse gases (GHG).

To alleviate these problems, a holistic approach based on LCA methodology is recognized to assess the generated and the avoided impacts of pharmaceutical WWTP throughout its lifecycle, from the cradle to the grave.

In this study, the construction and demolishment phase were excluded from this study due to the lack of data. The methodology has been standardized by ISO-14040-44 (ISO-International Organization for Standardization, 2006).

Four stages are necessary to conduct an LCA [3-4]: goal, scope and functional unit definitions (ISO 14040), life cycle inventory (LCI) (ISO 14044), life cycle impact assessment (LCIA) (ISO 14044), and Life cycle interpretation (ISO 14044).

The LCI is a flow tree of all relevant processes used to produce, transport, use and dispose of the selected product. Inflows (raw material, energy, other processes, etc.) and outflows (emissions, wastewater, etc.) are listed for all relevant processes.

The LCIA transforms inflows and outflows into a number of environmental impacts (climate change, resource depletion, etc.). Conducting an LCA requires the use of commercial software such as SimaPro [5] or GaBi.

These software products usually include several inventory databases (European reference Life Cycle Data system, U.S. Life-Cycle Inventory database, Ecoinvent, etc.) and impact assessment methods (Impact2002+, Traci, Ecoindicator, etc.).

Since the databases were developed primarily in the European context, they usually have to be adapted when applied to other locations. Another important challenge is that several processes used for water treatment are not included in existing databases. This may limit the achievement of robust water treatment LCA.

To the best of our knowledge, several articles have been published regarding the use of life cycle assessments (LCA) for wastewater treatment plant in the last decade [6]. Among them, only few treat the application of LCA analysis for wastewater treatment in pharmaceutical industries.

This study was carried out in Algeria, where electricity generation is based mainly on natural gas to evaluate environmental impacts of a pharmaceutical WWTP.

II. MATERIALS AND METHODS

Life Cycle assessment methodology is based on four stages; details are given in the following:

1. Goal and scope: The goal of this study is to evaluate the environmental impacts of a pharmaceutical WWTP from the cradle to the grave located in Médéa city (Algeria country).
2. Functional unit and impact assessment methodology: The quantity of water treated per a year and the impact assessment methodology was impact 2002+.
3. System boundaries: In this study, the construction and demolishment phase were excluded from this study due to the lack of data.
4. Life Cycle Inventory: This study is conducted on wastewater treatment plant (WWTP) located in the pharmaceutical company of Saidal of Médéa, Algeria country. This company is considred as one big production plant with 31 ha located in 100 km south of Algiers (capital).

Specializing in the production of penicillanic and non-penicillanic antibiotics. It has two units of semi-synthesis for oral and injectable products, a unit for pharmaceutical specialties and two buildings: one devoted to penicillanic products, other to non-penicillanic.

Fig. 1 SAIDAL Group locations

This WWTP was inaugurated in 1986 to treat all sort of wastewater from fermentation and pharmaceutical production. It occupies about one fifth the surface of the company. It has been sized based on the following parameters: average iflunet flow is approximatevly 2400 m^3/d, with a maximum flow of 130 m^3/h and an average flow of 100 m^3/h, Chemical oxygen demand COD of 3500 mg/L, Biological Oxygen Demand BOD5 of 2200 mg/L and a suspended solids of 1900 mg/L. This effluent treatment plant consists of three sections: physico-chemical treatment, biological treatment and sludge incineration (fig. 1). Table 1 shows the quality of water before and after treatment. It can be seen that, the treated water quality is conform to the world health organisation standars (WHO).

TABLE 1

WATER QUALITY PARAMETERS BEFORE AND AFTER TREATMENT (ANNUAL AVERAGE VALUES)

		Before treatment			
Parameters	**T**	**pH**	**DCO**	**DBO_5**	**MES (Suspended solids)**
Unit	°C	-	mg/l	mg/l	mg/l
Standards	Ambiante	6.5-8.5	3500	2200	1800
Result	19.00	4.86	285.71	50	17.00
			After treatment		
Standards	<= 30 °C	6.5-8.5	<= 130	<= 40	<= 40
Result	18.60	6.90	100	17.00	44.00

Organic matter, such as Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) is not characterized in Life Cycle Impact Assessment (LCIA) methods and its removal is therefore not included in the inventory. The system boundaries are given in figure 2.

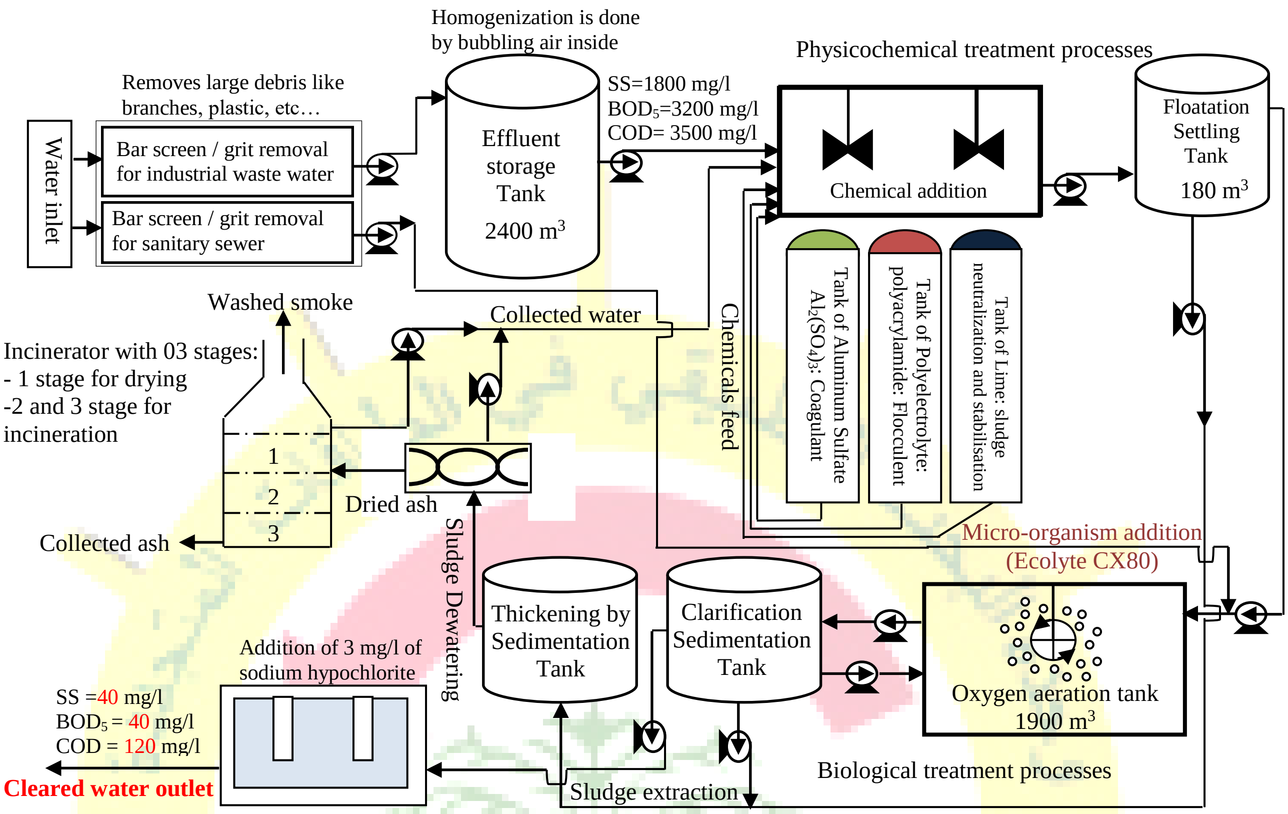

Fig. 2 Simplified flowchart of pharmaceutical wastewater treatment plant boundary (Médéa-Algeria).

Screening: using manual cleaning grid to remove the floating mean sized rubbish on the surface of the water. This grid is composed of rectangular right bars spacing of 25 mm and inclined 60° from the horizontal to facilitate the scraping. After screening, the effluent is pumped to the storage tank that has a sparge system to insure the homogenization of the effluent.

Physico-chimical treatment: pH control: It is always necessary for acidic wastewater.The neutralization is carried out by the injection of appropriate doses of lime in a tank provided with two agitation systems which rotate slowly to create sufficient turbulence to allow instantaneous diffusion of the reagent. Coagulation–flocculation process: the first step destabilizes the particle's charges. Coagulants with charges opposite those of the suspended solids (organic or inorganic colloid) are added to the water to neutralize the negative charges on dispersed non-settlable solids. Following the first step of coagulation, a second process called flocculation occurs. Flocculation, with a gentle mixing stage, increases the particle size from submicroscopic microfloc to visible suspended particles. Chemical consumption for coagulation–flocculation is listed in table 2. The formed flocs will be settled (sludge) and sent to the thickening tank.

Water pH neuralisation: It was decantralised to each laboratory using sodium hydroxide (NaOH) and sulfiric acid (H2SO4) to avoid chimicals loss in the WWTP.

primary settlement: It is sedimentation of minerals and organics.t

Biological Treatment: used to remove biodegradable organic matter. Microorganisms convert organics into: CO_2 and H_2O (aerobic) in the presence of oxygen. An aerobic mixture of lyophilized bacteria Ecolyte CX80 has been used in this WWTP, it contains four microorganisms:

Aeromonas Hydophilia, Citrobacter diversus, Citrobacter Amanolat and Salmonelles Arizona. In addition, the presumptive presence of Rodococus and Bacilus Subtilus. When there is only sanitary sewer, the biological treatment using conventional aerobic activated sludge process to remove biodegradable organic matter. The concentration of oxygen changes between 0.5-3 mg/l and 3g/l of the sludge. When the concentration of the sludge gets higher in the biological tank, the surplus will be directed to the thickening tank.

Sludge wringing and incineration: sludge coming from screening, physicochemical and biological treatment is sent to the thichening and sedimentation tank, after that, sludge oriented to be wringed, then dried in the incinerator under a hot temperature (≈ 700°C) to insure a complete combustion with production of inert ashes. The smoke cleaning system helps neutralize acid gases, to capture heavy metals, dioxins and furans. With its smoke scrubbing system, the incinerator ensures a gas without harmful smoke odor with fine dust released less than 250 mg/Nm^3.

Desinfection : with 30 à 80m^3 /h treated water, this process is needed to eliminate pathogens. Among the chemical used for the disinfection is: sodium hypochlorite.

Energy: it is required at every stage of the treatment plant, including pumping, mixing, light and aeration. Natural gas is used for incineration process.

Chemicals, employees and sludge transportation

Transportation distances of chemicals (PAM, Aluminum sulfate, Lime, Sodium hypochlorite and Ecolyte CX80) to the WWTP are considered between the distribution company of SAIDAL situated in Algiers about 100 km away from the WWTP.

The landfill where the sludge is discharged is situated 3 km away from the WWTP. It was considered that truck (with a maximum payload of 16 t) were used for the transportation of chemicals, a tractor and trailer (with a maximum payload of 10 t) were used for the transportation of sludge. Transportation of employees was also considered taking into account the vehicle type and distance.

The amount of water released after treatment is around 3000 m^3/d. The major chemicals rejected in wastewater are listed in table 2.

TABLE 2

MAJOR CHEMICALS IN THE EFFLUENTS TO BE TREATED

Organic compounds	Quantities (mg/L)
Spawn	670
versene	110
Esther	130
Tween 80	5
dimethyl aniline	200
Amine ethyl	15
phenol	10
Antibiotic residues	**Quantities (mg/L)**
Tetracycline base	23
Tetracycline HCl	traces
Complex tetra Ca	17
Penicilline GK and penicilline V	50
Solvent	**Quantities (mg/L)**
Ethyl acetate	60
Buthyl acetate	230
acetone	37
butanol	550
ethyl Cellosolve	45

The functiuonal unit of this system was the quantity of water treated throw a year. All the inventoried processes were normalised with respect to the functional unit.
All the inThe LCA was carried out using SimaPro software version 7.3 [5] which allows life cycles to be modelled and analysed. This software was chosen because it includes several databases and impact assessment methods, a powerful graphical interface that easily shows the processes having the most impact and an uncertainty computation module. The Ecoinvent 2.0 database [7] was chosen for the inventory analysis of inputs (resources, energy) and outputs (emissions) of each chemical and materials process. Table 3 presents a list of energy, materials and chemicals inventoried for WWTP.

It was assumed that the LCI of polyacrylamide polymer was close to the LCI of acrylonitrile which is the main compound (monomer) in its production.

TABLE 3

INVENTORY DATA FOR THE PLANT

Compound	**Goal**	**Weight (kg/year)**	**Transportation distance (t.km/y)**
Polymer (polyacrylamide ≈ acrylonitrile) $[-CH_2-CH(-CONH_2)-]_n$	Flocculant (Lorry transport)	4000 (2× 200 km)	1600
Aluminum sulfate $Al_2(SO_4)_3$	Coagulant (Lorry transport)	5000 (2 × 200 km)	2000
Lime	pH neutralization	1000 (2 × 200 km)	400
Sodium hypochlorite	Water disinfection	315 (2 × 200 km)	126
Ecolyte CX80	Micro-organism mixture	-	-
Employees	Transport (car passengers)	7 × 314 × 40	88760 person.km
Sludge	Landfill (trailer - tractor)	50 × 25 × 12 15000 kg/year= 15 t/year	15 × 12 × 2= 360 t.km
Average electricity consumption (kWh/y) (40Am)	pumping, mixing, light and aeration	4109886.96 kW/d	-
Natural gaz	Incinerator	29280	-

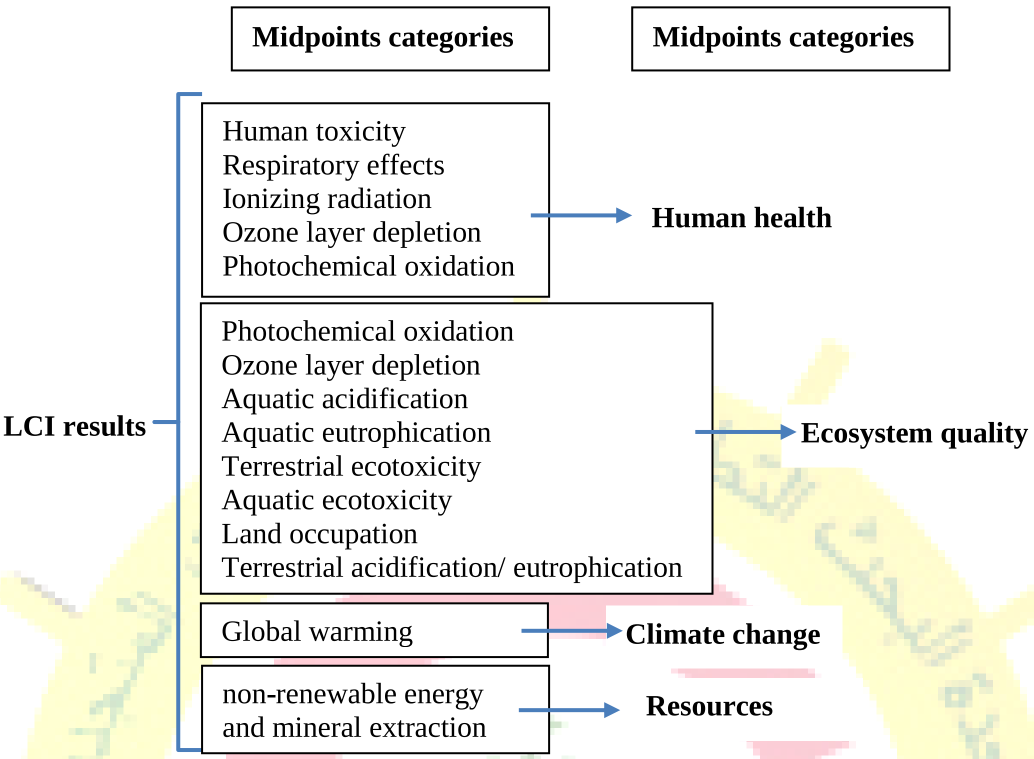

Fig. 3 Overall scheme of the IMPACT 2002+ framework, linking LCI results via the midpoint categories to damage categories [8].

The impact assessment was performed using Impact 2002+ [4]. The input and output data of the LCI were weighted and sorted into 13 intermediate impact categories (ozone layer depletion, global warming, carcinogens, mineral extraction, etc.) that are called mid-point impacts.

Mid-point impacts were weighted and grouped into four damage categories (end-point impacts): human health, ecosystem quality, climate change, and resource depletion. (see fig 3)

The impact categories considered in the present study include human health, ecosystem quality, climate change, and resources. These impact categories are further subdivided into carcinogens, non-carcinogens, respiratory inorganics, ionizing radiation, ozone layer depletion, aquatic ecotoxicity, terrestrial ecotoxicity, respiratory organics, terrestrial acid/nutrient, land occupation, global warming, non-renewable energy, and mineral extraction. The network of all scenarios is presented in Fig.5.

III. RESULTS INTERPRETATION

Once the impact assessment carried out, the last phase of LCA is the interpretation of results. This interpretation is to present the results of the LCA in accordance with the objectives of the study. The interpretation may result in recommendations for the use of the product or ways for re-design to reduce potential environmental impacts of the product studied. During interpretation, it is sometimes possible to distinguish the phase of the life cycle that has the greatest impact or determine the origin of the most significant environmental impacts.

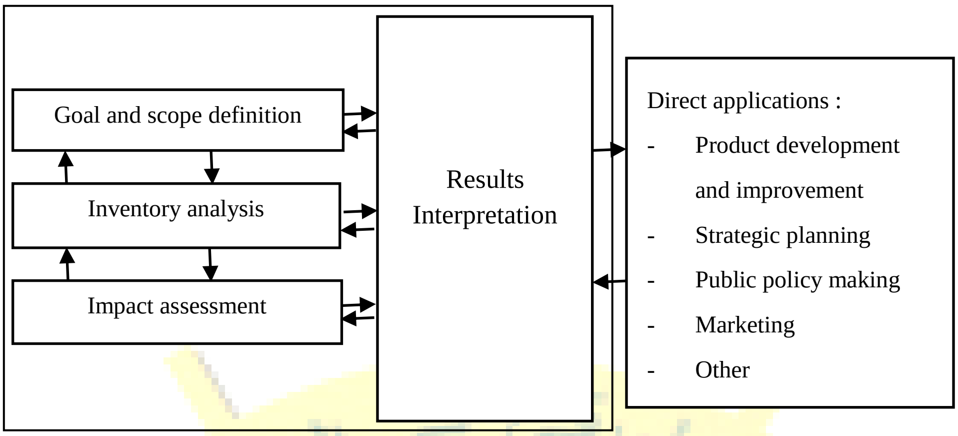

Fig. 4 Different stages of a LCA according to ISO 14040

In our study, carbon dioxide, $Ca(OH)_2$ and H_2SO_4 were used to adjust pH, alkalinity and water hardness. Other chemicals, such as HCl, $CaCO_3$ or Na_2CO_3 could be tested in order to reduce the global environmental impact of water treatment.

The impact categories considered in the present study include human health, ecosystem quality, climate change, and resources. These impact categories are further subdivided into carcinogens, non-carcinogens, respiratory inorganics, ionizing radiation, ozone layer depletion, aquatic ecotoxicity, terrestrial ecotoxicity, respiratory organics, terrestrial acid/nutrient, land occupation, global warming, non-renewable energy, and mineral extraction.

The network of the presented study is depicted in Fig 5. It should be noted that electricty is one of the most processes that contribute several negative effects to the environment, followed by naturel gaz used to heat the incinerator, diesel used as fuel for transporting passengers, ash and chemical products.

From Fig. 6, it shows that the environmental damages on climate change, human health and resources are much more important relative to the damage on ecosystem quality.

The basic structure of impact assessment methods in SimaPro is characterization, damage assessment, normalization and weighting. The last three steps are optional according to the ISO standards [9].

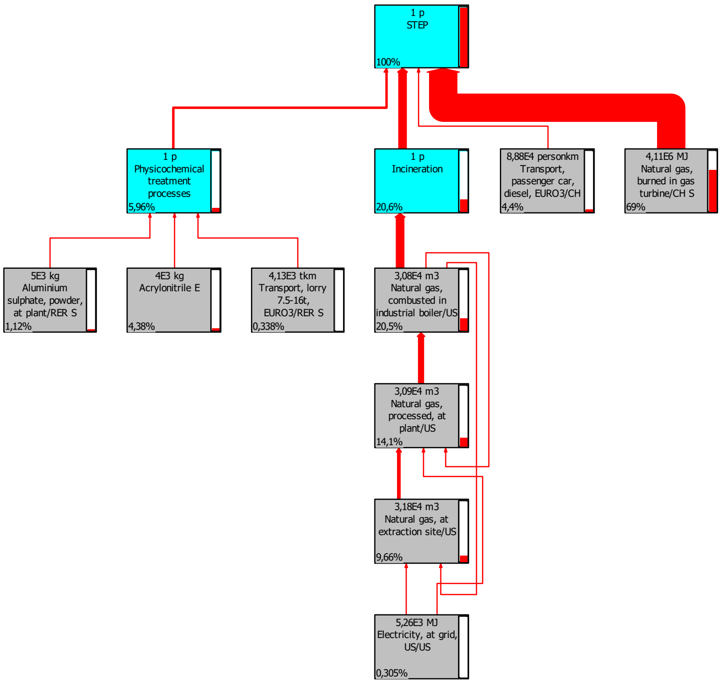

Fig. 5 Processes contributions of the studied WWTP

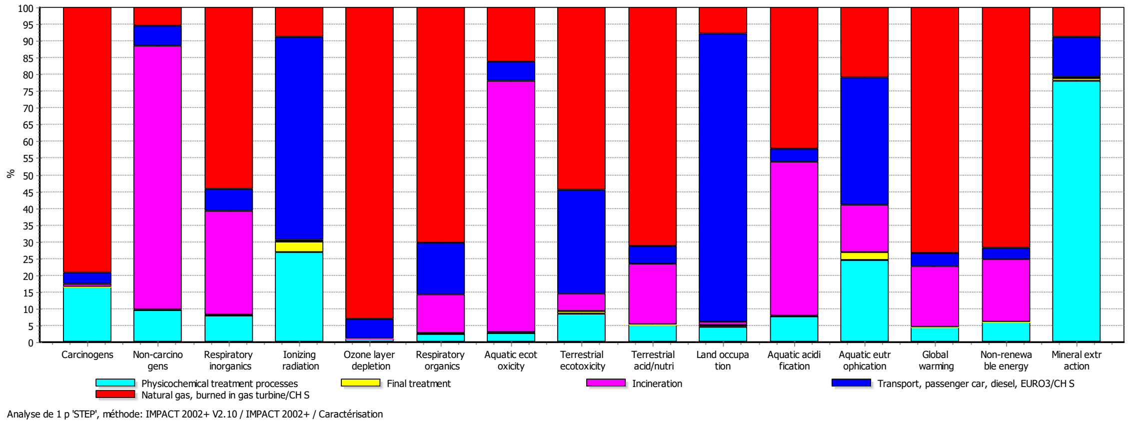

Fig. 6 Comparison of damage assessment.

In SAIDAL WWTP (figures 7-8), the total damage contributed was 21 points. It can be also identified that incineration process is the most contributed to human health, ecosystem quality, climate change and resources, respectively.

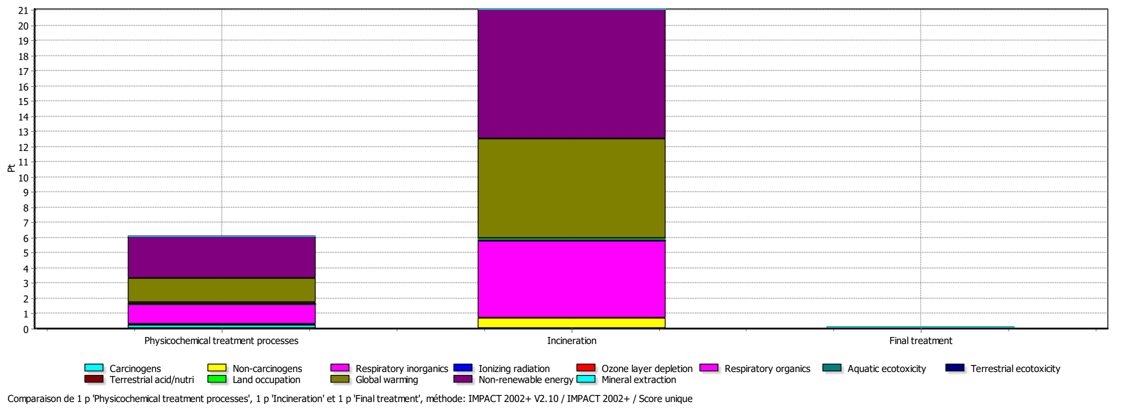

Fig.7 Global eco-score of damage in terms of impact categories.

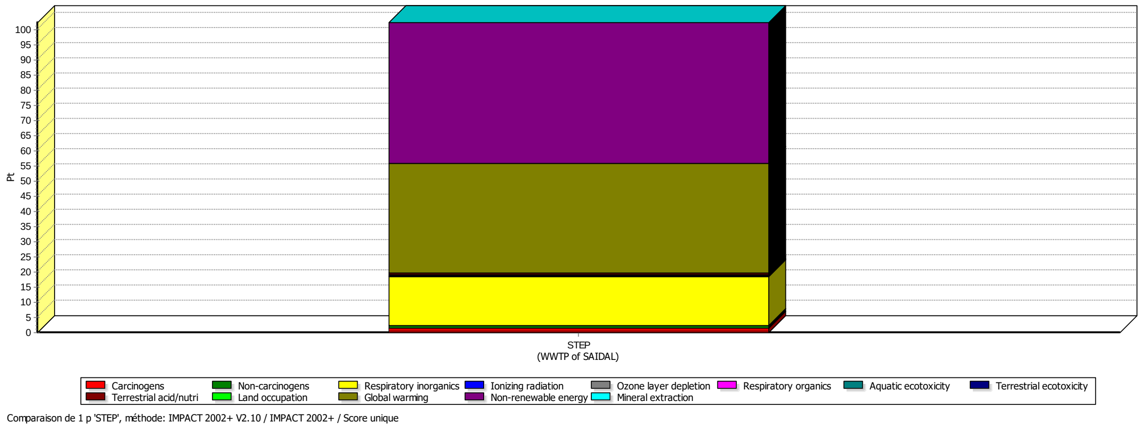

Fig. 8 Global eco-score of damage in terms of impact categories.

IV. CONCLUSION

The IMPACT 2002+ methods is one of the methods in SimaPro 7 package software, it was applied to evaluate environmental indicators for SAIDAL WWTP in Médéa City. Different environmental impacts generated during operation and maintenance, and transportation of chemicals and sludge were quantified. These conclusions can be written:

- The treated water is used for the irrigation for several plants.
- This study proposes the substitute of natural gas with sustainable electricity generation from renewable sources for wastewater treatment plants for enhancing the effluent quality and decrease the environmental impact.
- Aerobic treatment is generally not an environmentally friendly treatment technology because it requires more electricity consumption than the anaerobic treatment.
- Mineral resources are mainly consumed during alumine sulfate solution preparation; Ozone layer depletion originates mostly from tetrachloromethane emissions during alumine sulfate production.
- Sludge incineration produces heat, this latter can be used to generate electricity to supply part of energy requirement in the plant, while part of heat can be used to satisfy other needs.
- Lorry transport impact is based mostly on direct emissions of diesel combustion.

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