LIFE CYCLE ASSESSMENT

OF A

COMMON EFFLUENT TREATMENT PLANT

A Dissertation submitted to

SCHOOL OF ENERGY AND ENVIRONMENT

THAPAR INSTITUTE OF ENGINEERING & TECHNOLOGY, PATIALA

(Deemed to be university)

in partial fulfilment of the requirement

for the award of degree of

Masters of Technology

in

Environmental Science and Technology

by

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June 2018

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To Whom It May Concern

This is to certify that the Dissertation entitled "**Life Cycle Assessment of a Common Effluent Treatment Plant**" is a bonafide record of independent research work done by **Anubha Aggarwal**, (Roll Number: 601601004) under my supervision and submitted to Thapar Institute of Engineering and Technology, Patiala in partial fulfilment for the award of the Degree of **Master of Technology in Environmental Science and Technology**.

Signature of the supervisor
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DECLARATION CUM CERTIFICATE

I hereby declare that the project work entitled "**Life Cycle Assessment of a Common Effluent Treatment Plant**" is an authentic record of my own work carried out at CSIR-National Environmental Engineering Research Institute, Nagpur as requirements of one year project internship for the award of degree of M.Tech (Environmental Science and Technology), Thapar Institute of Engineering & Technology, Patiala, under the guidance of Dr. N.N. Rao and Dr. Amit Dhir, during 12th June'2017 to 15th June'2018.

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Certified that the above statement made by the student is correct to the best of our knowledge and belief.

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ACKNOWLEDGEMENT

I have taken efforts in this project. However, it would not have been possible without the kind support and help of many individuals. I would like to extend my sincere thanks to all of them.

I'm highly grateful to **Dr. N.N. Rao, Chief Scientist and Head, WWTD, CSIR-NEERI, Nagpur** for assigning me this topic and helping me find suitable direction for the project as well as for his constant guidance, providing necessary information regarding the project and allowing me to go for site visit of CETP of interest.

I would like to appreciate **Dr. Amit Dhir, Associate Professor, SEE, TIET, Patiala** for his constant guidance, motivation and supervision for the project as well as helping me in finding ways to solve problems associated in understanding of concepts.

I would like to appreciate **Dr. S.A. Praveen, Scientist, CTMD, CSIR-NEERI, Nagpur** for allowing me to work on SimaPro software and helping me with any software related issue. Also, I appreciate cooperation from **Punam**, received during Material and Energy Balance.

Also, I'm highly grateful to **Mr. Babubhai Patel** for allowing me to collect data about his CETP. Also, I would like to appreciate the cooperation and support shown by **Mr. Lalubhai Dave, Mr. Sudhir Verma and Mr. Mayur Parekh** for data collection and site visit.

Lastly, thanks to **My Parents** for all the moral support and the amazing chances they've given me over the years.

Anubha Aggarwal

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ABBREVIATIONS & NOTATIONS

ISO – International Organisation of Standardization

LCA – Life Cycle Assessment

LCIA – Life Cycle Impact Assessment

CSR – Corporate Social Responsibility

WWTPs – Wastewater Treatment Plants

GHG – Green House Gas

CETP – Common Effluent Treatment Plant

AOP – Advanced Oxidation Process

ISO 14040 and 14044 - International standard guidelines for LCA

CSIR – Council for Scientific and Industrial Research

NEERI – National Environmental Engineering Research Institute

ReCiPe Midpoint (E) – LCIA method

TRACI 2.1 – LCIA method

IPCC GWP (2013) – LCIA method

GIDC – Gujarat Industrial Development Corporation

NIA – Nandesari Industries Association

R & D – Research and Development

HC – Hydrodynamic Cavitation

SS – Suspended Solids

COD – Chemical Oxygen Demand

BOD_5 – Biochemical Oxygen Demand for 5 days

PVC – Poly Vinyl Chloride

PNG – Piped Natural Gas

VECL – Vadodara Enviro Channel Limited

NECL – Nandesari Environment Control Limited

LCI – Life Cycle Inventory

GaBi – Life Cycle Assessment Software

SimaPro – Life Cycle Assessment Software

CO_2 – Carbon Dioxide

CH_4 - Methane

N_2O – Nitrous Oxide

VOCs – Volatile Organic Carbon

TKN – Total Kjedahl Nitrogen

NH3-N – Ammonical Nitrogen

EPDs – Environmental Product Declarations

PCRs – Product Category Rules

ELCD – European Life Cycle Database

ILCD – International Reference Life Cycle Data System, a Handbook

GLO - Global

RoW – Rest of the World

Alloc - Allocation

Def - Default

GPCB – Gujarat Pollution Control Board

CF – Characterization Factor

CO_2 eq. – Carbon dioxide equivalent

CFC-11 eq. – Chlorofluorocarbon equivalent

SO_2 eq. – Sulphur dioxide equivalent

P eq. – Phosphorus equivalent

N eq. – Nitrogen equivalent

1, 4 – DB eq. – 1,4 Dichlorobenzene equivalent

NMVOC eq. – Non-Methane Volatile Organic Compounds

PM_{10} eq. - Particulate Matter with diameter greater than 10 microns

U235 eq. – Uranium 235 equivalent

Fe eq. – Iron equivalent

O_3 eq. – Ozone equivalent

CTU h – Comparative Toxic Unit for Human

CTU e - Comparative Toxic Unit for ecotoxicity

$PM_{2.5}$ eq. – Particulate Matter with diameter greater than 2.5 microns

GWP – Global Warming Potential

HP – Horse Power

KL – Kilo Litres

kWh – Kilo Watt Hour

Pt – Eco-Indicator Point units, i.e., one thousandth of the yearly environmental load of an average European citizen

BDL – Below Detectable Limit

CPCB – Central Pollution Control Board

EIA – Environmental Impact Assessment

MoEF – Ministry of Environment, Forest

FIGURES

TABLES

GLOSSARY

- **Recalcitrant:** non-biodegradable by biological process
- **CSR activity:** Corporate Social Responsibility is a corporation's initiatives to consider and take responsibility for the company's effects on environmental and social well-being. It applies to efforts ahead of what may be required by regulators or environmental protection groups. [12]
- **Carbon Footprint:** A carbon footprint is historically defined as the total set of greenhouse gas emissions caused by an individual, event, process, organisation, or product, expressed as carbon dioxide equivalent. [36]
- **Attributional LCA:** It estimates the environmental burden of a product (pollution and resource flows) attributed to the delivery of a specified amount of the functional unit.
- **Consequential LCA:** It assesses the environmental consequences of a change in demand, such as how pollution and resources flows within a system; respond to a change in output of the functional unit.
- **Life cycle Stages:** These are the sections of product life cycle such as manufacturing, extraction of raw materials, use/ maintenance and end disposal phase. It includes the sections of product, process or service from its cradle to grave.
- **Life cycle assessment Phases:** These are the portions of LCA procedure which helps in conducting the LCA study. These are four in number as defined by ISO 14040 standards. It includes Goal & Scope definition, Life Cycle Inventory, Life Cycle Impact Assessment, Interpretation. These are followed in the sequence as mentioned. They help in performing LCAs in a systematic manner.
- **Goal:** Goal includes reason of study, type of approach, targeted audience, use of final results.
- **Scope:** Scope includes product system studied, function of the system, functional unit, initial data quality.
- **Functional Unit:** The functional unit refers to the function fulfilled by each product/process or quantifies the function delivered by the process. In case of wastewater treatment plants, functional units generally adopted were related to

treated water, population equivalent and wastewater produced by particular amount of hide production (specifically for tannery industry).

- **System Boundary:** A set of criteria specifying which unit processes are part of a product system
- **Classification:** Elementary flows from the inventory are assigned to the impact categories according to the substances ability to contribute to different environmental problems.
- **Impact Category:** Scientific definition linking specific substances to a specific environmental issue. Any emissions type which contribute as sources of that impact are then classified as contributors. Substance can contribute to more than one impact category.
- **Damage category:** These are environmental impacts translated into issues of concern, such as human health, natural environment and natural resources. These can be communicated easily and easily understandable. [6]
- **Elementary Flows:** The emissions or extractions to and from the environment
- **Characterization:** Each LCI result is multiplied with a characterization factor before they can be added. The characterization factor (CF) is different in different impact assessment methods.
- **Normalization:** It means to what extent an Impact category indicator result has a relatively high or relatively low value compared to a reference. The reference, for example, one average European person inhabitant equivalents per year, can be used. It solves the incompatibility of the units. Impact category Indicator results are divided by the normalized value. In other softwares, normalized value is multiplied, but in SimaPro it is considered as if normalized value is impact category indicator result is 0, the normalized result comes out to be 0.
- **Weighting:** Relative importance of each impact category is assessed and default weights are determined. This scales results to a certain level of seriousness. It is a subjective step.
- **State of the Art:** The most recent stage in the development of a product, incorporating the newest ideas and features.

ABSTRACT

This LCA study is performed on Common Effluent Treatment Plant which treats recalcitrant wastewater with the help of Hydrodynamic Cavitation Technology. There have been LCA studies on various AOP based wastewater treatment plants but no study on Hydrodynamic Cavitation Technology, in particular. This project work includes complete 3 phases of Life Cycle Assessment and 4^{th} phase of LCA is performed partially. SimaPro v8.3 LCA software is used. 3 LCIA methods were chosen based on objectives. ReCiPe Midpoint (E) and TRACI 2.1 are used to identify environmental hotspots in the processes of CETP. IPCC GWP (2013) 100a is also chosen to calculate the Carbon Footprint of processes of CETP. The results show that transportation of effluent by diesel fuelled tankers and utilization of liquid chlorine for hydrodynamic cavitation are showing maximum possible environmental impacts in almost all impact categories considered. The impacts of one process are linked to its input processes. Also, the electricity utilized for pumping of industrial effluent from collection tank and electricity utilized for the working of hydrodynamic cavitation reactor sumps is also high. There are few other processes also which are showing considerable amount of possible environmental impacts. Based on the analysis, the transportation of industrial effluent and chemicals used should be modified for decreasing CETP's overall possible environmental impacts.

Keywords: Common Effluent Treatment Plant, Hydrodynamic Cavitation, SimaPro, Diesel, Chlorine.

It is Not the Product, but the Life Cycle of the Product That Determines Its Environmental Impact

CHAPTER 1: INTRODUCTION

Background:

The main purpose of WWTPs is to remove the undesired pollutants from the water and reduce the pollution load in the receiving stream. In the course of treatment process, greenhouse gases and water pollutants are released. When WWTPs are seen beyond this thought and phases of WWTP starting from setup to final dismantling are considered, impacts on environment are noticed outside the WWTPs also. While people have focused on CO_2 emissions from construction, transportation and power generation to decide standards of emissions, Wastewater treatment plants (WWTPs) also play a significant role [16]. USEPA (2011) have listed WWTPs as the 7th largest contributors to both CH_4 and nitrous N_2O emissions [16]. There are direct and indirect both kinds of GHG emissions associated with the treatment process also. Other than air emissions, water emissions during the production of raw material, chemicals.

Need for this study:

Previous studies of wastewater treatment plants or advanced oxidation process do not mention full plant scale Life Cycle Assessment Study for Common Effluent Treatment Plant using Advanced Oxidation Process as main treatment process. Therefore, this LCA study is required to be performed.

Project Description:

This is M.Tech Thesis Project conducted in the CSIR-National Environmental Engineering Research Institute (NEERI), Nagpur for the partial fulfilment of the M.Tech degree. This project was executed by self interest and guidance was given by host organization and university mentors. The support regarding data availability was provided by the Common Effluent Treatment Plant (CETP) personnel. Advanced Oxidation Process (AOP) based technology is adopted by the CETP as the main treatment unit. The type of AOP used in this CETP is Hydrodynamic Cavitation based Reactors. This CETP was selected as plant of interest due to setup of advanced oxidation process technology on large scale and cooperative industry personnel. The site was visited once during the project and secondary data is used for the calculations. Assumptions were made in between the calculations, as and when required.

SITE DESCRIPTION:

Common Effluent Treatment Plant (CETP):

The industrial sector has grown about 4 times the size during the past 50 years. They majorly contribute to water pollution because of their coloured and toxic wastewater which is generally in high volume. The most common waste water generating industries in India are dye, paint, petrochemical, fertilizer, inorganic chemicals requiring industries, pesticides, pharmaceutical, textile, pickle, etc.

Small and Medium scale industries are increasing in number hence, the high quantity and degraded quality wastewater is generated more in amount, majorly. Step were taken to minimize the impacts due to these industries, which include cleaner production technologies and waste minimization circles are being encouraged in India. A central facility to treat effluent of many industries proves to be a viable approach to overcome the limitations of small to medium enterprises. The first CETP was setup in Jeedimetla, Hyderabad before 1990. In 1991, the Ministry of Environment & Forests (MoEF), Government of India initiated an innovative financial support scheme for CETPs to ensure the growth of the small and medium entrepreneurs (SMEs) in an environmentally compatible manner.

The CETP concept is similar to municipal domestic sewage treatment facility for each home. This collective effort was taken for cluster of small scale industrial units which may not setup their individual setups and may not reach the permissible limits as per the central government guidelines. CETP serves as a central collection point, where industrial effluent is treated collectively. The associated industries may be of same or different types, based on type of products.

The advantages of setting up a CETP are:

- Proper technical assistance by trained personnel as fewer plants will require fewer people.
- Effluent quality monitoring as per guidelines by regulating body.
- Decreasing the cost of pollution treatment for each industry and also saving natural resources.
- Reduced the land requirement.
- Controlled disposal of sludge and to develop the recycling and reuse potential.

NIA (Nandesari Industries Association) – CETP: [8, 9 and 15]

M/s NIA-CETP is commissioned in 1984 by GIDC (Gujarat Industrial Development Corporation). That time, the industrial effluent was transported to CETP via pipelines. In 1994, M/s NIA (Nandesari Industries Association) took it over and operating till now. Many changes in the process of treatment, transportation etc. were done till now. The industrial effluent is recalcitrant in nature. So, by no way it can be treated biologically. Physical and chemical treatment units were required to be used. Biological treatment process units were soon stopped and the same constructed treatment units were modified in such a way that they are used for Physico-chemical treatment process. Electro-oxidation process was used for few years. Then, Hydrodynamic Cavitation Reactors were studied using pilot setup. The comparative cost of Electro-Oxidation related to Hydrodynamic reactors was high. After intensive R & D, an advanced oxidation process known as Hydrodynamic Cavitation (HC) is constructed at large scale with the help of CSIR-NEERI, Nagpur. Hydrodynamic cavitation reactors are currently the main process of CETP and have been successfully implemented at large scale and running as expected.. Now, Reuse of the treated effluent using Forward Osmosis and Multiple Effect Evaporator are under research experiments. For potable water within plant premises, Capacitive Deionization process is used. New techniques are also being experimented to be implemented at large scale.

Industrial effluent is received by surrounding industries (maximum upto 5Km distance from CETP). Various industries like organic, inorganic, engineering units, dye intermediates, pesticides, pharmaceutical, agro-chemical, bromine recovery unit, ice factory, solvent recovery, plasticizer units discharge their effluent in the M/s NIA-CETP. Also, there is few zero discharge units associated with the NIA. Some of these industries are more polluting and some do not pollute at all. Maximum amount of industries are Organic and Inorganic in nature. The industries discharging organic effluent are highly polluting. Inorganic effluent is received via pipelines. Since, this do not pollute much, it helps in dilution of organic effluent.

Table 1: Type of industries discharging their effluent in CETP [8]

S.No.	Type of Industry	Number of Industries
1.	Organic	37
2.	Inorganic	18
3.	Engineering unit	3
4.	Dye Intermediate	48
5.	Pesticide	6
6.	Pharmaceutical	23
7.	Agro-chemical	1
8.	Bromine recovery unit	3
9.	Ice factory	3
10.	Solvent recovery	3
11.	Plasticizer	4
12.	Zero discharge	61

Organic industries mean that raw materials and products manufactured by the industry are organic in nature and hence the effluent produced by the processes may have maximum amount of organic compounds present. **Inorganic industries** mean that raw materials and products manufactured by the industry are inorganic in nature and hence the effluent produced by the processes may have maximum amount of inorganic compounds present. Based on chemistry, Organic compounds contain carbon atom, often with hydrogen atom to form hydrocarbon, while almost all Inorganic compounds do not contain either of those 2 atoms. They may contain either of the two atoms but not both [32].

The industries book their effluent at the booking office at the CETP. The wastewater from different industries is brought to the treatment plant via tankers. The tankers are put on hold outside the CETP premises for sample collection and analysis. Sample is collected from individual tankers, coded and sent to the CETP laboratory. If the sample is as per the inlet norms, the lab issues clearance slip to the booking office. The tanker then discharges the effluent in to the designated collection sump [15]. Tankers have maximum of organic components and minimum inorganic [8].

The existing cost for wastewater treatment at this CETP is Rs. 160 /m^3 of wastewater.

Industries also have their own pre-treatment WWTP which dispose of the effluent to CETP via tankers. It can be accepted or rejected. If rejected, effluent is again treated in the pre-treatment unit. If accepted, the effluent goes to collection tank. Sewage from GIDC colony comes through pipelines and stored in lamella settler to remove suspended solids present in the sewage.

CETP is undertaking a CSR (Corporate Social Responsibility) activity also. Under this, GIDC colony’s domestic sewage is collected via pipelines and treated with the normal flow of CETP. The sewage is pumped to lamella settler which has inclined plates inside it. Sewage is allowed to move from bottom to top which allow suspended solid particles to settle at the bottom.

Fig. 2: Project Overview [Google maps]

The CETP is located in the Industrial region of Vadodara, Nandesari. Tankers and pipelines (for effluent transport) are used within 5Kms of radius. Sludge is transported to the approximately 2Km of distance. Chemicals are transported via trucks. Chlorine Tonners are transported from 7Kms and Lime from Rajasthan.

CETP has 7 collection tanks to store Industrial effluent received. Sewage from GIDC Colony comes via pipelines. It is stored in Lamella Settler having pipe flocculator.

Complete wastewater is then supplied to equalization tanks and finally to hydrodynamic cavitation reactor sumps. Treated effluent is transported to intermediate holding tank and treated water holding tank for storage. Sludge produced in almost all treatment units is pumped to filter press house via pumps.

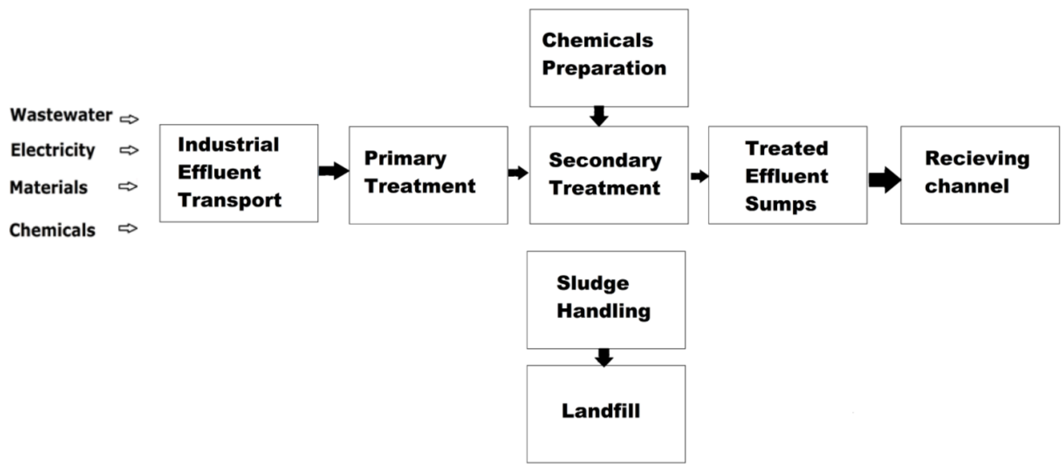

Fig. 3: Treatment Scheme of NIA – CETP

Industrial effluent transport: It includes transport of organic and inorganic effluents and domestic sewage to CETP.

Primary treatment: It includes collection tanks and equalization tanks.

Secondary treatment: It includes hydrodynamic cavitation reactor sumps.

Chemical preparation: It includes hot water boiler, vaporizer, and lime slurry preparation tanks.

Treated effluent sumps: It includes intermediate holding tank and final holding tank.

Sludge handling: It include filter press house.

***Treatment Units*:** [8, 9]

1. Lamella Settler:

1 Lamella settler is present in the plant to collect the sewage from the GIDC Colony. 30 minutes retention time is provided for the sewage. Flow rate of sewage inside the Lamella Settler is 700m3/day. Sewage flows upwards from bottom through the Parallel plate separator of inclined PVC plates and sludge moves downwards. The sludge is removed by opening the bottom valve in the Lamella settler. Sludge is transported to one of the filter press for dewatering. The inclination of these PVC pipes is generally between 30^o – 60^o. The 45^o is optimum. Below 30^o inclination, the effluent may not move. Above 60^o inclination, the effluent may not allow solids to settle down. This is theoretical inclination related information. The actual inclination of PVC plates in the Lamella settler is unknown.

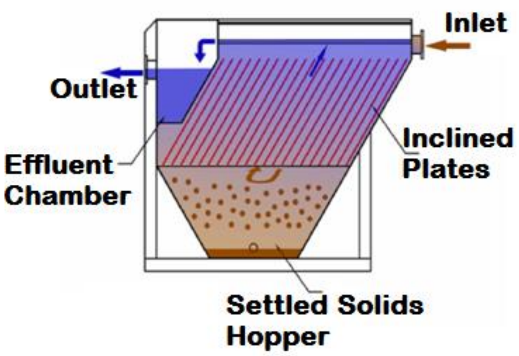

Fig. 4: Schematic diagram of Lamella Settler

Fig. 5: Lamella Settler in CETP

2. Collection tanks:

Total 7 collection tanks are present, 1 circular and 6 rectangular. The approximate retention time in all collection tanks are 4 hours. Retention time depends on the frequency at which water is fed to HC reactor sumps. 14 pumps are employed in these collection tanks, which work for 24 hours. The output wastewater flow rate is 250KL/hr. These are simple rectangular tanks used for the storage of the effluent received from the industries. Different type of collection tanks are there.

1st collection tank is largest rectangular tank which collects the effluent which contains chemical compounds like $CaCl_2$, $Ca_3(PO_4)$ etc. which precipitate after getting in contact with each other.

2nd collection tank is the only circular tank which collects the inorganic effluent via pipelines.

3rd collection tank collects sewage from lamella settler.

4th to 7th collection tanks collect organic effluent via tankers.

The settled sludge is cleaned in every 3 months and sent to filter press via pumps. 1st tank has capacity of 2070KL, 2nd tank has capacity of 1385.44KL and 3rd to 7th tanks have capacity of 192KL each. Approximately, 4 hours retention time is provided in all tanks.

Fig. 6: 5 Collection Tanks of CETP at the back of tankers

3. **Equalization tanks:**

Total 2 equalization tanks are present whose capacity is recently increased by increasing their depth by 2.5metres. The industrial effluent is first transported to equalization tanks to homogenize the quality of effluent received and maintain flowrate for further units. The flow rate of 250 KL/hr from equalization tank is maintained using outlet pumps of 60 HP which work for 24 hours.

It is also a rectangular tank with 1 baffle in centre. The water moves from top to bottom across the baffle. This movement causes sludge to settle at the bottom, which is pumped after every 3 months.

The water keeps flowing so, no retention time. Capacity of each tank is 2700KL.

Fig. 7: 2 Equalization Tanks in CETP

4. **Hydrodynamic Cavitation Reactor Sumps:**

There are total of 9 HC reactor sumps in the plant premises, 8 rectangular and 1 circular. 2 chemicals are added in all these sumps when working, lime and chlorine gas. Lime is added in slurry form with 10% of hydrated lime, which is dosed using pumps. Chlorine gas is prepared by vaporizing the liquid chlorine and then injected inside the vacuum region of venturi's converging end. There are 72 venturi pumps in 4 HC reactor sumps, 48 venturi pumps in another 4 HC reactor sumps and 20 venturi pumps in circular HC reactor sump. Power requirement by each pump is 7.5HP and working hours is 6-8 hours. So total of 144 venturi pumps are used. Retention time of effluent in the HC reactor sump is 6-8 hours. Out of 4 HC reactor sumps at one place, 2 HC reactor sumps are used at one time. There is no mixing device in the sump as recirculation of effluent by pumps produces mixing action. Capacity of rectangular tanks is 576KL each and capacity of 1 circular tank is 482.54KL.

Fig. 8: Hydrodynamic Cavitation Reactor

Fig. 9: Old image of Hydrodynamic Cavitation Reactor Sump of CETP

a. Lime Dosing Tanks:

There are 2 lime dosing tanks. The lime bags from the lime shed are emptied in the lime dosing tanks manually. Each tank has 2 stirrers each of power 7.5 HP and working for 24 hours. Also, 1 chemical dosing pump of 5 HP power is also used at the outlet of tank, which gives varying flowrate of lime slurry as per the requirement for maintaining the pH in Hydrodynamic Cavitation Reactor Sumps. Capacity of each tank is 7.2KL. Lime slurry is of 10% hydrated lime concentration.

Fig. 10: Lime dosing tank of CETP

b. Hot water Boiler:

1 PNG fired Hot water boiler is used for steam generation. Ash amount is almost negligible as fuel source is gas. Since gas is completely burnt, so stack emissions are very less. Tubes are provided inside the boiler in which water flows and flame is present in centre to burn PNG. The PNG fuel is burnt in furnace and the heat generated during the process is used to heat water when water tubes come in contact with flame and/or exhaust gas. The boiler produces the steam at the flowrate of 6000Kg/day. Capacity of boiler is 0.424KL.

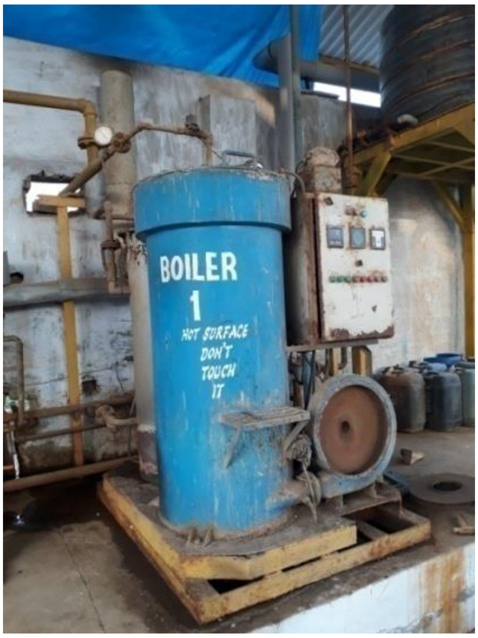

Fig. 11: Hot water boiler of CETP with small stack behind it at top.

c. Vaporizer:

There are 3 vaporizers present. Liquid Chlorine and steam are fed to vaporizer. By heat conduction, Liquid chlorine converts to chlorine gas. This chlorine gas is then fed to hydrodynamic cavitation reactors

Fig. 12: Vaporizer of CETP

5. Intermediate Holding Tank:

The treated effluent from the hydrodynamic cavitation reactor sumps is transported to the intermediate holding tank via 2 pumps (120 HP and 160 HP) which work for 24 hours. The flowrate of water in and out is maintained as 250 KL/hr. Capacity of tank is 482.54KL.

Fig. 13: Intermediate Holding Tank of CETP

6. Treated effluent holding tank:

Treated effluent is transported to this tank via 2 pumps of power 20 HP which work for 24 hours. The tank is cleaned once in 6 months. The retention time is 12 hours 15 minutes. The flowrate of water in and out from this is 250 KL/hr. Capacity of tank is 2440.35KL. The effluent is then discharged to VECL pump house via gravity and in between its way 3 industries discharge their treated effluent at 2 different points. The COD of treated effluent is approximately 250mg/l.

Fig. 14: Treated Effluent Holding Tank of CETP

7. Filter Press house:

8 filter presses with pumping of sludge at inlet of each are provided in the filter press house. Sludge is pumped to filter press from various treatment units for dewatering purpose. Each filter Press has a clamping mechanism which is used to move the plates forward and backward during the process. 1 Pressure jet is occasionally used in a day for removing sludge cakes from the filter plates. 7 filter presses have 90 plates each and 1 filter press has 110 plates. Area of plates is 48*48 $inch^2$ and 60*60 $inch^2$ for respective type of filter press plates.

The sludge from the filter press is collected directly into the tractor trolley from the bottom of Filter press and disposed off in the TSDF of NECL, Nandesari. As reported by the NECL personnel, they accept the sludge with moisture content less than 40%. Also, the calorific value of the sludge must be less than 250 Kcal/kg. If the sludge meets this moisture and calorific value parameters, the sludge can be disposed in the NECL landfill site.

In case, the TSDF is not accepting the sludge for disposal, the sludge is collected in leak proof HDPE bags and stored in the sludge storage yard. [15]

Fig. 15: Filter Press house of CETP

LIFE CYCLE ASSESSMENT:

Life Cycle Assessment is a detailed study of any process, product or system considering all the direct and indirect inputs and outputs of any process, product or system. Generally, Life Cycle Assessment is termed as "Cradle to Grave" study which must consider all kind of inputs and outputs starting from raw material acquisition to final disposal and all possible environmental impacts [26].

Nowadays, life cycle assessment study is incorporating the sustainable development approach also. This approach can be attained when study is done for "Cradle to Cradle" because everything that we obtain from nature (air, water, land) will finally dispose to the nature at the end.

Life cycle assessment is a tool for identifying quality and quantity of environmental hotspots associated with the complete life cycle of product, process or service. The complete life cycle includes stages like extraction of raw material, transportation, production, use, maintenance, final disposal and recycling of waste materials. This study involves consideration of complete material and energy balance in all life cycle stages i.e., all kinds of inputs and outputs are considered.

Life cycle assessment is most commonly used for:

- Identification of environmental hotspots throughout the life cycle of the product. It helps in improving material and energy inputs/outputs to get benefit in terms of economic, sustainability or social growth.
- Analysis of overall environmental load of the complete system.
- Comparison of alternative to the conventional products, processes or services.
- Standardizing a method for the development of particular product, process or service by showing its positive impacts on environment.
- Sustainability of the system in respect of environment.

Active LCA Practitioner is capable of communicating almost all environmental impacts of the product, process or service to the Concerned Authority. [34].

Challenges for LCA are: [28]

- Absence of a perceived need for LCA
- Scarcity of LCA expertise
- Access to high quality data, and
- Wrong perception of the LCA use and its tools.

PRINCIPLES OF LCA [19]:

1. **Life cycle perspective.** LCA considers the complete life cycle of a product, from raw material extraction and acquirement, through energy and material production and manufacturing, to use and end of life management and final disposal. Using this approach, the shifting of environmental impacts among life cycle stages can be identified and removed.
2. **Environmental focus.** LCA addresses the environmental aspects and impacts of a product system. Economic and social approach and impacts are, usually, outside the scope of the LCA. Different tool like Net Benefit approach and multi – criteria approach may be used in conjunction with LCA to get holistic assessments.
3. **Relative approach and functional unit.** LCA is a comparative approach, which is well thought-out around a functional unit. This functional unit defines what is being studied. All subsequent analyses are then relative to that functional unit as all inputs and outputs in the LCI and consequently the LCIA profile is related to the functional unit.
4. **Iterative approach.** LCA is an iterative technique. Each LCA phase uses results of its previous LCA phase which makes it dependent on the inputs to the system. The iterative approach within and between the phases contributes to the comprehensiveness and consistency of the study and the reported results.
5. **Transparency.** LCA practices are complex in every aspect. Transparent approach towards LCA may lead it towards correct results and conclusions.
6. **Comprehensiveness.** LCA considers all attributes or aspects of natural environment, human health and resources. By taking into account all attributes

and aspects within one study in a cross-media viewpoint, potential tradeoffs can be identified and assessed.

7. **Priority of scientific approach.** Decisions within an LCA are rather based on natural science. If this is not possible, other technical approaches like social and economics can be used or international conventions can be referred to.

It is explained that these principles are fundamental and should be used as guidance for decisions relating to both the planning and the conducting of an LCA. As a general obligation in ISO 14044 it is stated that LCA is to be conducted in accord with the principles and the framework described in ISO 14040.

Advantages of LCA [28]:

- It includes the processes and products beyond the Environmental Impact Assessment studies.
- Gives both quantitative and qualitative nature of environmental impact.
- It helps in tracking the possible impacts by proposed activity.
- The scale of study may vary as per the requirement. It can incorporate many linked processes, if data is available.
- The results are reliable and can be used for decision making.

Limitations of LCA [28]:

- Data shortage may affect the results; also quality of data is important.
- Expensive databases might be required and ISO standards for reviewing.
- Abnormal events cannot be considered such as man- made or natural hazards
- The data generally vary with the regional difference; hence results may not be applied to a generalized way.
- Generally possible worst case scenarios are considered which gives only extreme results (all or nothing). Practical applications work under average or neutral conditions.

There are 2 ISO standards which provide standard procedure to perform the LCA study. These standards are:

1. ISO 14040 – Principles and Framework
2. ISO 14044 – Requirements and Guidelines

The most important aim is to adhere to the ISO standards. Many LCA studies follow ISO standards partly as per their convenience because the language written is little vague, difficult to adhere and meet all requirements. The LCA practitioners cannot claim that their studies completely conform international standards of LCA and hence it will be more difficult to convince others of the reliability of their results.

Based on ISO standards, Life cycle assessment consists of four main phases:

Phase 1 – Goal and Scope Definition

Phase 2 – Life Cycle Inventory (LCI)

Phase 3 – Life Cycle Impact Assessment (LCIA)

Phase 4 – Life Cycle Interpretation

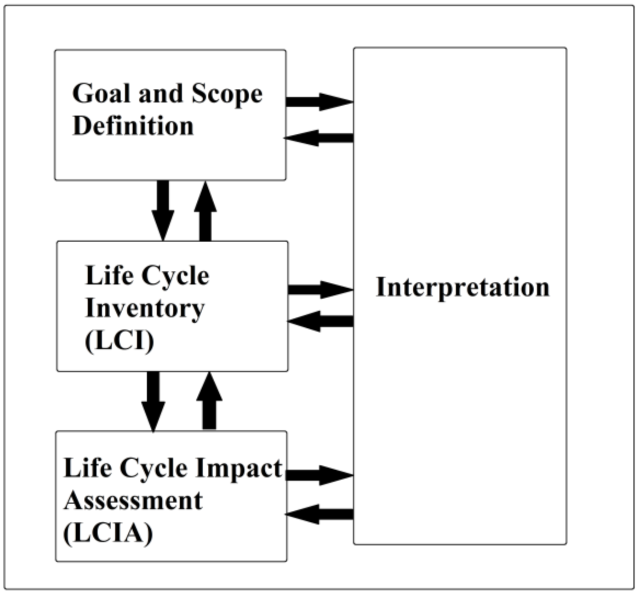

Fig. 1: LCA Framework or LCA Procedure to carry out studies

GOAL AND SCOPE DEFINITION [34]

Goal includes steps like:

- Reason for this study
- Definition of product, its life cycle and its function
- Definition of functional unit
- Definition of system boundaries
- Data and data quality requirements, assumptions and limitations
- Requirements regarding the LCIA procedure and subsequent interpretation to be used
- Intended audience and the way the results will be communicated

Some LCA studies provide results to internal and external decision makers. This dual purpose should be clearly described.

Scope includes steps like:

- Functional unit – functional unit is used for comparison purpose which is defined based on the most common function of the system considered.
- System boundaries – This involves drawing of the system and identifying the boundaries of system. The definition of system boundaries depends on 3 factors:
    - Data availability (primary data, secondary data)
    - Corresponding percentage of environmental impacts associated with particular sub-process, product (material or energy) or service.
    - Objectives of the study.

System Boundary is a set of criteria specifying which unit processes are part of a product system. System boundaries are decided based on the order of analysis. In first order, only production and transportation are included. In second order, all stages of life cycle except equipments and ancillary goods. In third order, a comprehensive analysis of the whole product/ process considering all possible goods is done [4].

System boundaries can be decided based on time and space. Time here refers to the time period/ instant for which data is available like daily data, monthly or annual average data and Space refers to the treatment units and operations/processes which are considered within the system boundary like single unit operation, many of unit operations within plant area and/ or including related processes. The System boundaries can include processes which are outside the plant area like manufacturing, mining of raw materials and production of energy, electricity.

While defining the system boundary, several life cycle stages, unit processes and flows should be taken into deliberation, for example, the following: [26]

- Acquirement of raw materials;
- Inputs and outputs in the main manufacturing/processing sequence;
- Circulation/Transportation;
- Production and Use of fuels, electricity and heat;
- Use and Maintenance of products;
- Disposal of process wastes and products;
- Reclaim, Recycling and energy revival;
- Manufacture of additional materials;
- Manufacture, Maintenance and Disposal of capital equipment;
- Additional operations, such as illumination and heating.

The inclusion of inputs and outputs depends on one of the following 3 criteria:

1. If the mass of the inflow is greater than a certain percentage. (only for materials)
2. If the economic value of an inflow is greater than a certain percentage of the total value of the product system.
3. If the contribution from an inflow to the environmental load is above a certain percentage. (most suitable but limitation is that environmental load is not defined unless flow is investigated)

When we deal with multifunctional processes, the modelling of system can be done in 2 ways which are as follows:

1. Consequential modelling (or system expansion)

2. Attributional modelling (or allocation procedure)

Consequential modelling involves scrutinize the consequences of an alternative in comparison to some baseline study. This modelling procedure is very complex and data demanding. It is a quite subjective way of modelling. Attributional modelling involves determination of environmental hotspots of a product or 2 products with same functional unit. Overall environmental load is calculated. The results of this modelling give carbon footprint, water footprint etc.

The sum of allocation percentages of outputs or main products should be 100%. It is advised to document the reason behind assigned allocation percentages. We can express allocation percentages in the form of parameters. There are controlled at project level. On changing allocation parameters, LCA results change by rerun of LCA. Parameters can be set for 2 or more products in the form of formula.

LIFE CYCLE INVENTORY [34]

Inventory involves data collection and processing as per the requirements. Based on time and budget of project, missing data can be obtained.

Data to be used for LCA is of 2 types:

1. Foreground data – data which is obtained directly from the industry. It includes primary and secondary data.
2. Background data – This is obtained from software databases and literature. It includes production of raw materials, energy, transport etc.

The practical approach to data collection involves rough LCA in which missing data is assumed. It helps developing better focus on the data which really needs attention. If data contribute more than 0.1% to any impact category, it should be collected from the industry. Estimation of missing data is made using similar process.

Relevant research data should be searched. Books can describe industrial processes and provide clear enough descriptions to estimate missing data. This is a good starting point for preparing questionnaires.

Foreground data collection involves:

1. Communication with data providers
2. Developing questionnaires. It involves detailed information about generic information, allocation, explanation, data sections, data quality and simplicity.

Background data is usually available in databases or can be found in literature. The data found in databases must fill or closely resemble the requirements of the project.

Databases available to LCA community are:

1. Ecoinvent database
2. Input- Output database

The key characteristics of Ecoinvent database are:

- Broad range of data

- Well documented
- Emissions specified with sub-compartments.
- Regularly updated by Ecoinvent centre.

6 dataset versions of Ecoinvent database in SimaPro are:

1. Allocation default, unit processes
2. Allocation default, system processes
3. Allocation recycled content, unit processes
4. Allocation recycled content, system processes
5. Consequential, unit processes
6. Consequential, system processes

Input – Output databases contain data per economic sector rather than per process as seen in conventional databases.

SimaPro has iterative calculation method for networks/ trees. It can also calculate "looped" data structures. When we try to make tree visualization, SimaPro will first check for loops within processes. If loops exist, SimaPro will automatically switch to networks.

LIFE CYCLE IMPACT ASSESSMENT [34]

We need to make decision on required level of combination of results. This depends on audience to be addressed and level of understanding of audience. SimaPro has wide range of LCIA methods, each containing 10 to 20 number of impact categories. SimaPro allows adding or subtracting any impact category to and from methods and editing it separately. Completely new methods can be made in SimaPro. LCIA phase is used to properly understand and analyze the quality, quantity and significance of potential environmental impacts of desired product system.

ISO distinguishes between:

- Obligatory elements
  - Classification
  - Characterization
- Optional elements
  - Normalization
  - Ranking
  - Grouping
  - Weighting

Impact categories should be selected by expert judgement and should cover all objectives. SimaPro produces a table containing hundreds of "elementary elements" which represent emissions or extractions to and from the environment. This table is called as Life Cycle Inventory Result.

Classification: Impact categories are assigned to Inventory data of processes (elementary flows) based on their possible environmental impacts.

Characterization: Different impact categories have different characterization factors. These characterization factors differ for each LCIA method too. The elementary flow values are multiplied by the respective characterization factors.

The choice of LCIA method is done based on following scientific criteria:

- Completeness of scope
- Environmental relevance
- Scientific robustness and certainty
- Documentation, transparency and reproducibility
- Applicability

The best way to choose LCIA method is to look at existing studies, or assess the concerns on the relevant stakeholders.

The Impact category indicators at mid-point level are somewhere between the inventory result (i.e., emissions) and the "end-point", whereas end-point level are chosen close to the inventory result and have lower uncertainty. However, indicators at endpoint level are much easier to understand and interpret by decision makers than indicators at midpoint level.

Few of LCIA methods present in SimaPro are:

- TRACI 2.1
- IMPACT 2002^{+}
- CML-IA baseline
- EPS 2000
- ReCiPe Endpoint
- Recipe Midpoint
- Climate change only
- Energy (GER) only

LIFE CYCLE INTERPRETATION [34]

This Phase includes interpretation of results found in LCIA phase, Identifying Environmental Hotspots in the product system and giving possible suggestions or possible modifications to overcome impacts.

This phase also includes different types of checks to test whether correct conclusions are obtained or not. This phase can be achieved in following ways:

1. Uncertainty analysis
2. Sensitivity analysis
3. Contribution analysis
4. Inventory analysis

Uncertainty analysis

3 types of uncertainties are checked, which are as follows:

1. Data variation
2. Model representativeness
3. Model incompleteness

Data variation is checked using statistics or standard deviations. Representativeness of model can be checked by reviewing subjective choices we made. Subjective choices are like consequential/Attributional modelling, waste treatment scenarios, functional unit etc.

This analysis is done in SimaPro using Monte Carlo Method.

Sensitivity analysis is a better approach than uncertainty analysis.

Sensitivity analysis

In this analysis, influence of most important assumptions on the results is analyzed. The only principle used for this analysis is, change the assumption and recalculate the LCA. If any assumption change has higher effect on results, valid expression needs to be given. You may also conclude that there is no single answer as everything depends on the assumptions used. SimaPro parameters can be used as switches to change assumptions quickly. With the change of one parameter, we can automatically change any connected process in LCA. This can be used for processes such as electricity grid, allocation procedures, etc.

Contribution analysis

This approach helps finding important processes which affect results significantly. Here, all contributions from a single process are added and total contribution of processes can help finding most important process.

This can be prepared in 2 ways:

1. Graphical depiction of the process tree or network
2. Contribution analysis section of the result display

Process tree of network has disadvantage that it cannot add all contributions of particular process, say electricity grid mix is contributing to various processes but only the individual contribution is shown in graphs of process tree or network.

Inventory analysis

It is a list of all substances like emissions to soil, water, and air, and raw materials extraction.

It is unaffected by uncertainties introduced in impact assessment, which makes it advisable to analyze the inventory results.

CHAPTER 2: LITERATURE REVIEW

Life Cycle Assessment is a study of any product, process or service from cradle to grave for its inputs and outputs, in both quantitatively and qualitatively way. LCA serves to assess the global environmental damages potentially caused by a product, a process or a service in a “cradle to grave” approach. LCA can be used to study and judge several processes or systems from first to last, their contribution to global environmental impacts. The definition of the functional unit is an important issue that allows fair comparison of different systems through LCA. LCI is a flow tree of all relevant processes used to produce, transport, use and dispose of the selected product [3].

The document [28] on LCA has basic introduction of LCA and its procedure based on SETAC guidelines, but it is easy to relate it to ISO standards with this document. Life Cycle Assessment started in 1960s and the approach is limited to industries [35]. This approach was initially practiced in industries for energy efficiency and product modification. Then, in 1991, this technique was used for marketing purpose also, which created conflicts between LCA practitioners. Manufacturers claimed suitability of their products based on LCA results. Till 1990s, there was no standardization of method and hence, the results of different LCA studies cannot be accepted worldwide. ISO took responsibility of standardizing the LCA procedure, guidelines and requirements [21]. ISO 14000 series, International standards specifically for LCA studies was developed in 1997. It increased awareness about LCA techniques. In Late 1990s, researches in this topic increased and concept of LCA is used in various fields such as agriculture, transportation, quality services, wastewater treatment plants, etc. The advantages like policy making, product development and strategic planning were direct applications due to advancement of LCA based studies. In 2006, ISO standards were revised and made more readable and easy to apply [19]. ISO 14040:2006 and ISO 14044:2006 are 2 important international standards which are accepted and followed worldwide. Technical changes were made in ISO 14000 series which includes additional guidelines and few clarifications. Formal changes were also done which includes compilation of ISO 14040, 14041, 14042 and 14043. ISO 14040 is the framework for LCA procedure which state guidelines and principles to be followed in LCA studies. ISO 14044 contains all the technical requirements and guidelines. ISO

14044 is the core reference document which is most important to be followed by LCA practitioners to conduct LCA studies in order to adhere to ISO standards. The year 2000 to 2010, is called as decade of elaboration and divergence, as various studies on LCA were published in different areas of interest. It also helped in setting environmental criteria and establishment of eco-labels [5]. There was a study conducted by [5] for leather industry to establish environmental criteria. The findings of the study includes that cattle raising and tannery process are the most environmental harming processes because greenhouse gases are produced during cattle raising and toxic chemicals are discharged to the environment during tanning of leather. So, the impacts of particularly these processes must be decreased by industrialists using modified techniques or approaches in order to obtain Eco-Label for their product. Eco-labelling involves set of environmental friendly guidelines and modifications which an industry should follow, in order to obtain eco-label from the concerned authority.

Life Cycle Assessment started in 1970s with the objective of energy analysis. The complete LCA studies including impact analysis and economics started in 1980s. Then, social and consequential LCAs started in first decade of 21st century. Nowadays, LCA linked to sustainability questions are more focused. It was assumed that year of 2010 – 2020 is the decade for sustainable approach because only modifying based on present situation may not actually decrease environmental impacts rather, approach to completely vanish possible environmental impacts using cradle to cradle approach is more beneficial [21]. It broadens the scope of the study. It includes People, Planet and Prosperity.

Till now in India, there is not much scope in the field of Life Cycle Assessment because of unawareness about its benefits. People use arbitrary solutions based on their perceptions and past studies. These solutions do not have any valid proof with guidelines. Life cycle assessment must be used for design of wastewater treatment plants for industrial effluents. The status of current WWTP with respect to modified design should be analyzed. Environmental Impact Assessment (EIA) is generally conducted by all industries to get clearance from government bodies such as MoEF and CPCB. LCA is a detailed study which may benefit the industry in economic manner also.

Wastewater water treatment plants have been analyzed through LCA approach since 1990s and many studies in different fields of wastewater were performed. First LCA study on Wastewater Treatment plant was published in 1995 by Emmerson et.al. [17] They studied impacts of small-scale sewage treatment using Life Cycle Analysis. The main objectives of the study were to compare different processes and determining environmental hotspots with possible modifications. This study is useful and stimulating for future studies.

According to Azapagic [1], the correct selection off Best Practicable Environmental Option (BPEO) may decrease environmental impacts on-site, but increases them in other stages of product's life cycle. This study also shows few case studies supporting this argument. The BPEO for abatement of SO2, NOx and VOCs are shown. This study provides a framework for process selection, design and optimization.

Corominas et. al [10] wrote a review paper in 2013 discussing almost all LCA studies done in the area of wastewater treatment. It is a review of 45 papers in the same area published in the last 17 years. The papers were analyzed for their selections and choices in LCA procedure. This paper covers many aspects for comparison such as inclusion of which LCA phases, choice of methods for LCIA, system boundaries, functional units, process selection and life cycle stages, databases used, type of impact categories considered, etc. There was high variability in the decisions for the above mentioned points. Hence, there is a strong need for development of specific LCA guidelines and requirements for LCA studies of wastewater treatment systems for comparability of studies. The paper also describes challenges in the field of LCA of WWT as accurate data for every WWT design in each geographic area is not yet available in the database. This leads to various assumptions and uncertainty in results increases.

Heimersson et. al [23] is a recent review paper in the field of LCA of WWTPs. It was published in 2016 and covers 62 studies on LCA of WWTPs. The limitation is that it has only LCI phase and choice of reviewed papers include nutrient flows only. This paper also shows variability in the selections in LCA procedure. It was also identified that there is need for more process specific modelling. More detail in this paper may be done for future research.

A study on water and wastewater re-use was conducted by Ortiz et. al [33]. In this study, a conventional activated sludge process based wastewater treatment was analyzed and few proposed tertiary treatment units were included in analysis to compare LCIA results. The study states that including tertiary treatment with the wastewater treatment is beneficial as it shows minimal or no environmental impacts. This system can be used in water scarce areas. Even there are possible ways to utilize pure treated water. It also decreases environmental impact at some point. This approach is highly dependent on the inlet wastewater quality. If tertiary treatment requires more material and energy inputs during its life cycle, the results will be opposite.

The LCA application includes development of new technologies with lower environmental load. Such study was conducted by Braglia et. al [4]. The developed an oxidative unhairing process for leather industry using hydrogen peroxide. This new technique appears to be environmentally friendly alternative for 2 impact categories. Such kind of approach in LCA may give rise to new creative ideas and innovations. Patents play an important role in this respect. People obtain patent for their ideas. It promotes organizations and institutions to explore and have visions in LCA for the sustainable environment. New inventions were also studied for its sustainability and suitability with respect to environmental impacts. [37] Mentions how various countries obtained patents in the field of LCA. The patents offer researchers some recognition and incentives which encourage them to think more innovative ideas. It promotes creative approaches towards modification of life cycle of any product, process or service. Innovations are good advantage of conducting LCA studies. LCA practitioners develop new methods and calculation setups based on their individual requirements, which benefit future researchers.

A study by chatzisymeon et. al [7] was conducted for 3 different Advanced Oxidation Processes. The findings from this study was that electrochemical oxidation technique is most environmentally friendly among chosen options and UV/TiO2 is least environmentally friendly because UV/TiO2 requires non-environmentally friendly materials and chemicals and it is highly energy intensive. Such researches were done for different other advanced oxidation processes also, but never for hydrodynamic cavitation technology till now. Hence, Environmental impacts due to hydrodynamic cavitation technology are needed to be found and researched.

Dixon et. al [14] assessed 2 secondary treatment units, one conventional technology (aerated biological filter) and other alternative technology (reed bed filter). The study included embodied energy of every process, which is an important parameter in this case. The finding from this study was that conventional technology has lesser environmental footprint than alternative technology as alternative technology has higher embodied energy.

Machado et. al [30] studied 3 wastewater treatment designs, Activated sludge process, slow rate infiltration and constructed wetland. The study includes LCI and LCIA phase. The finding was that ASP is energy intensive and other 2 treatment designs are material intensive. The better choice between the given options depends on the individual requirement and expectation from the system. Such studies were conducted for other wastewater treatment plants also, in which 2 or more treatment designs were compared. This kind of study provides comments for decision makers and future researchers.

The LCIA methodology should be chosen based on the input type, say nutrient removal systems can be better analyzed by CML 2 Baseline 2000 method. [30] [4]

The final stage of wastewater treatment plants, dismantling has lowest impacts as compared to construction and operation stages as analyzed by [30] [31]. Hence, this phase may be left outside the system boundaries of the study.

Godia et. al [13] combined LCA study with Net Environmental Benefit (NEB) approach. This study concludes that NEB can tell correct efficiency of WWTP set-up in terms of environment. Till now we analyzed the treatment efficiency of the WWTPs before discharging the treated wastewater into the receiving body, but main aim should be to This kind of approach was found to be beneficial for conforming results and reaching suitable decision. [11] Also used 2 approaches. [32] Used 3 approaches.

[2] this paper used more than 1 LCIA methodology for the same LCA study. The purpose of each was defined properly and reasonable. In my LCA study, I considered 3 LCIA methods based on required objectives to be filled.

Li et. al [27] compared conventional municipal wastewater treatment plant with 2 other published studies which focused on advanced treatment technologies such as constructed wetland and 5-stage Bardenpho simulated process. The results show that Constructed wetland has maximum impacts. If electricity use is replaced from coal power to wind power, conventional municipal wastewater treatment plant shows minimum impacts. The impact categories chosen for comparison in this study were limited to only 4. Hence, more exploration in LCIA phase needs to be done.

Lorenzo – Toja et. al [29] included additional wastewater quality parameter, Pharmaceutical and Personal Care Products (PPCPs) to analyze which was not done before. They analyzed the flow of PPCPs in the wastewater treatment plant. Also, this study considered 2 different WWTPs from 2 different climatic regions. The data used for this study was primary and accurate. The study revealed that seasonal effect is significant and it needs to be considered while using data of another climatic region area. This study also conclude that construction phase showed negligible impacts for given facility.

Chatzisymeon et.al [7] conducted LCA study on treatment of olive mill wastewater using AOPs. Olive mill wastewater is recalcitrant in nature and hence AOPs are best to treat it. The ultimate goal of this work was to identify the key environmental hotspots of 3 AOPs using LCA in order to provide feedback to support the sustainable development of future AOP units for scaling up. Environmental sustainability of AOPs is strongly related to the energy requirements of these technologies, thus an increase of the process energy consumption enhances the environmental impacts of the whole process. UV/TiO2 has higher score onto human health, fossil fuel resources and ecosystem on bench-scale lab unit operating under Greek conditions.

Different options for wastewater treatment have different performance characteristics and also different direct impacts on the environment. These impacts occur over the whole life cycle of the treatment system. The study by Dixon et. al [14] is limited to impacts during the construction and operation phases. Energy use, CO_2 emission and solid emissions were chosen as the environmental aspects. Some systems have high energy usage, some use materials that have a high embodied energy, others occupy a lot of land. LCA should be more widely used in the water industry as a decision aid in environmental policy and in environmental improvement activities.

Chatzisymeon et. al [6] conducted a comparative study between organic and conventional pepper cultivation. The aim of the work is to quantify and compare the environmental sustainability of typical conventional and organic pepper cultivation systems. Both midpoint and endpoint levels are used for comprehensive overview. Attributional LCA is used. Results are presented for problem-oriented (midpoint) and damage-oriented (endpoint) approaches, using ReCiPe impact assessment method. LCA results show a dependable, holistic and macro-level identification and measure of net environmental impacts, and so its use is steadily increasing. The case study comprise of 2 open field pepper cultivation, both located in the Anthemountas basin, Northern Greece.

GAP ANALYSIS:

- The studies were not conducted for hydrodynamic cavitation technology, AOP.
- The system boundaries include transportation of the effluent also, which is generally missed in previous studies.
- LCA of Complete Treatment plant which is based on AOP technology was not performed, AOP technologies were analyzed individually only.
- Previous studies have not shown combination of various LCIA methods to show results collectively and in a wide range of impact categories.

Objectives:

Various objectives which were met during the project duration are shown below:

- **Performing Material & Energy Flow analysis of the CETP -** The material and energy flow analysis was performed in Microsoft Excel file. Many suitable assumptions were made to complete meet this objective.

- **Learning about SimaPro software and its use for wastewater treatment plants -** SimaPro software was learned using its manual and tutorials available with the software. Practice on the software was done using assumed data and previous studies' data on different topics.
- **Evaluation of Environmental Performance by Effluent quality parameters -** Environmental performance of CETP was assessed using effluent quality parameters details obtained from latest secondary data.
- **To Identify Environmental Hotspots in Wastewater treatment plant -** Environmental Hotspots were identified using results of LCIA phase in SimaPro software. The 2 types of LCIA methods were used for this objective, ReCiPe Midpoint (E) and TRACI 2.1 method.
- **To Determine Carbon Footprint of the Wastewater treatment plant assigned -** Carbon footprint of all treatment processes was determined using IPCC GWP (2013), a LCIA method in SimaPro. The results were obtained in the form of kilograms of carbon dioxide equivalents.
- **To Suggest Possible and sustainable Modifications/ Alternatives -** Possible modifications were suggested based on perception of interpreted results of SimaPro.

CHAPTER 3: SOFTWARE TOOLS USED

GaBi SOFTWARE

The GaBi software system is a leading tool for life cycle engineering, creating life cycle modelling and balances. The word GaBi came from **Ga**nzheitliche **Bi**lanzierung, a German word which means "**holistic balance**". Life cycle engineering is a method for the assessment of the technical, economic and environment impacts of products, services and systems; GaBi additionally can evaluate socio-economic aspects. The GaBi, LCA software is specially designed for LCA studies. It serves other applications like Life cycle costing, Life cycle working environment, making EPDs. The modelling in GaBi includes generating plans, processes and flows. The transparency of balance results is another major advantage of GaBi. You can calculate the balances of different levels of detail, facilitating the identification of weak points. The databases supplied with the system contain life cycle inventory data obtained by long-term research by the University of Stuttgart and PE International Ag [20]. GaBi has its own Background database which is provided in the full version of software. It is updated frequently with new processes and data.

Input steps:

1. Defining plan of study.
2. Mentioning processes within system boundary defined in goal and scope.
3. LCI data input from given database by using search engine.
4. Input the required LCI data manually, missing in the given database.

Outputs steps:

1. Obtain graphs which show LCIA results.
2. Prepare short report (i-report) to show results in words within software.

This software was chosen at first because more research is need to be done using this software as few researches were done with this software, but it is costly (approximately Rs. 8 lacks for full version). This software is unavailable in NEERI campus. So after November, LCA software was changed to SimaPro software.

SimaPro SOFTWARE

The SimaPro software is available in the NEERI campus and easily accessible. This makes it somewhat suitable for the study purpose.

The SimaPro LCA Software was developed by PRé Consultants. It is developed to collect and analyze the environmental data of various products, system, processes and services. It contains large database which is accessible to all SimaPro users [22] Database is a collection of EPDs, PCRs or environmental data related to the desired process. This software uses eco-invent 3.0 database library and many other libraries like Agri - footprint, ELCD, Swiss Input Output database, EU & DK Input Output database etc. SimaPro supports EPDs (Environmental Production Declarations), GHG Protocol and the ILCD handbook. It uses the default Swedish EPD impact assessment method. The new grouping function allows separating contributions of energy, transport, waste, or other parts of the product system (developing on the PCR) [34]. This software is mostly used for LCA and easy to share with new LCA practioners. The tutorial and Manual provided in the software are easy to understand and accessible even without installing the software [25]. The Inventory data is modelled in the software and results are viewed in the form of LCI result table or LCIA graphs. Software developers cannot claim that the LCAs performed using their software tool conform to the ISO standards as standards are defined in a rather vague language and difficult to access.

Understanding how important is the missing data for this LCA is very important. Based on this analysis, you can develop a much better focus on the data you really need to pay attention to. Search for relevant literature data. The number of literature describes industrial processes and they give clear enough description to estimate energy use, waste and in some cases even emission. This proves to be good start in preparing the preliminary data collection sheet.

Processes can be visualized in the form of Hierarchical tree structure or network structure. Results are displayed as small red thermometer bar which shows contribution of each process to the total score. Green thermometer bar and arrows represent negative damage score, caused by the beneficial effect of the reuse or recovery process.

Different LCIA methods have different impact categories involved.

Based on geographic locations, background database is divided. In this study, Electricity data is available for Indian dataset. Other dataset which we used are GLO (Global) and RoW (Rest of the World).

Alloc.Def. data type is used for this study. "Alloc" refers to the Attributional modelling or allocation procedure is followed and "Def" refers to the Default data or average of products is used.

CHAPTER 4: METHODOLOGY

The project was concentrated on the Life cycle assessment only; hence the methodology followed during complete internship is nearly same as mentioned in ISO guidelines for LCA. The sub-stages of particular phase are project specific, which depend on objectives decided.

PHASES OF COMPLETE INTERNSHIP:

1. **Introduction of topic related literature and software tools**
    - Literature Review
    - Introduction of GaBi software
    - Learning GaBi Software using tutorials and manual
    - Introduction of ISO standards of LCA
    - Introduction of SimaPro software
    - Learning SimaPro Software using tutorials and manual

2. **Life Cycle Assessment Phase 1**
    - Defining Goal and Scope of the project
    - Defining System Boundary and Functional Unit

3. **Life Cycle Assessment Phase 2**
    - Preparation of Preliminary Data collection sheet
    - Site Visit to CETP of Interest
    - Designing Schematic Diagram
    - Data Processing and Data managing as per requirement
    - Performing quick LCA for instant results
    - Material and Energy Flow Analysis
    - Assuming missing and required data
    - Data review, revision and correction were performed repeatedly.

4. **Life Cycle Assessment Phase 3**
    - Learning about LCIA methodology and Decision of selecting LCIA methodologies for this project
    - LCA modelling in SimaPro software several times
    - Finalizing the data
    - Full LCA modelling in SimaPro software
    - Obtaining LCIA Results

5. **Life Cycle Assessment Phase 4**
    - Interpreting results as per objectives
    - Giving possible suggestions and modifications

PRELIMINARY DATA COLLECTION SHEET

The preliminary details of CETP were collected using inventory sheet prepared by me. This helped me to get almost all details needed for the LCA study.

The list includes **three main topics** which are:

1. General questions about the industry
2. Inputs and Outputs from each treatment unit (considering construction and operation phase of each treatment unit)
3. Wastewater quality parameters

The **key points and/or questions** included in the inventory sheet are:

1. <u>General questions</u> include basic details of the industry like plant capacity, introduction, background information, electricity demand and purchase, flowrate, sewer and wastewater transporting pipes, construction materials details, transportation details during construction and operation, life span of treatment units and electronic devices, and many more questions.
2. All possible questions which a person would ask to industry personnel are included in general section.
3. All treatment units given in the plan of treatment plant were considered and possible inputs and outputs during construction and operation phase were written.
4. <u>Treatment units</u> considered were: Equalization tank, Collection tank, Hydrodynamic Cavitation Reactor Sumps, Hot water Boiler, Vaporizer, Lime slurry mixing tanks, 2 intermediate treated water holding tanks, treated effluent channel and Filter press.
5. Some of the inputs for construction & operation phase were volume of concrete, volume of steel, Cleaning process power requirement and details, Chemical requirements and its details, Wastewater flow rate and retention, Pumping power requirement and details, mixing device power requirement and details, sludge withdrawal pumps power requirement and details, etc.
6. Physical specifications of the treatment unit were also mentioned to ask diameter or length and breadth, height, water depth, free board, etc.
7. Both quantitative and qualitative information is asked.

8. Some of the outputs for operation phase were wastewater, amount of sludge due to cleaning, emissions to air (CO_2, CH_4, N_2O and VOCs), sludge flow rate and production, etc.
9. Finally, wastewater quality parameters were asked, to evaluate environmental performance of the CETP and carbon footprint.
10. Wastewater quality parameters considered were: Total Suspended Solids, Total Dissolved Solids, Biochemical Oxygen Demand (27°C for 3 days), Chemical Oxygen Demand, pH, Chlorides (as Cl^-), Total Organic Carbon, Sulphides (as S), Sodium percent, Oil and grease, Boron (as B) , TKN, NH_3-N and Phosphates (as PO_4^{3-}) etc..

The preparation of Preliminary data collection sheet involves following steps:

- Introduction of Treatment scheme of CETP of interest
- Study of CETP treatment scheme in detail
- Theoretical knowledge about wastewater treatment unit of CETP
- Study of design of wastewater treatment units of CETP of interest
- Identifying type of inputs and outputs like mass and energy in each treatment unit
- Determining all possible inputs and outputs
- Study of type of Construction materials used in each treatment unit
- Study of type of Mechanical devices used in each
- Operational phase of each treatment unit is studied with respect of input and outputs
- Type of emissions are identified
- Identifying type of wastewater quality parameters to be analyzed.
- Writing down all the above information in the form of Questionnaire and adding few more questions which may help in identifying quality of inputs and outputs.

Only Material & Fuel flow and Electricity inputs/ outputs of treatment units were obtained and processed from the preliminary data collection sheets.

SITE VISIT TO CETP


Tankers' assembly point


Lamella Settler


5 Collection tanks in the middle of tankers and mixing tank


Final Treated Effluent Channel


Group Photo with personnel of M/s NIA-CETP


2 Equalization tanks with baffle


Mixing tank or Treated Effluent holding tank


Intermediate holding tank


Hydrodynamic Cavitation Reactors sump

Fig. 18: Images clicked during site visit to CETP

The site visit to the CETP was planned and accomplished successfully during time period of 9th November'2017 to 11th November'2017 (3days).

- **1st Day:** Understanding the treatment units employed in the treatment plant and introductory site visit with industry personnel.
- **2nd Day:** Filling of the preliminary data collection list with the help of industry personnel and collection of Environmental Audit Reports
- **3rd Day:** Site visit to landfill in which CETP dispose its sludge and to one CETP's member industry's pre-treatment plant (also gathering their details as much as possible).

A preliminary data collection list made was made by me to collect required data.

NECL Landfill and 1 Pre-treatment unit were also visited but the data obtained is not enough to do LCA. But the experience is worth remembering as I asked questions to industry personnel on my own on the spot, based on my knowledge related to treatment plants and landfill.

The data obtained from 1 pre-treatment plant and NECL Landfill is not sufficient to include them in this LCA study. Also, the collection of data for pre-treatment plant of all industries was not possible for this project work and M/s NIA-CETP is not the only one treatment plant contributing to NECL Landfill waste.

CETP conduct environmental audit 2 times per year. The data was obtained from 2 recent Environmental Audit reports of M/s NIA-CETP i.e., for the months of "October'2016 to March'2017" and "April'2017 to September'2017". Monthly data for 1 year was obtained from the environmental audit report of CETP. This is secondary data. It was assumed that audit report's data is reliable and representative of M/s NIA-CETP. Preliminary data collection sheet questionnaire answers and environmental audit reports were collected from M/s NIA-CETP.

Further coordination with CETP personnel was also done to obtain missing important data.

SCHEMATIC DIAGRAM OF CETP

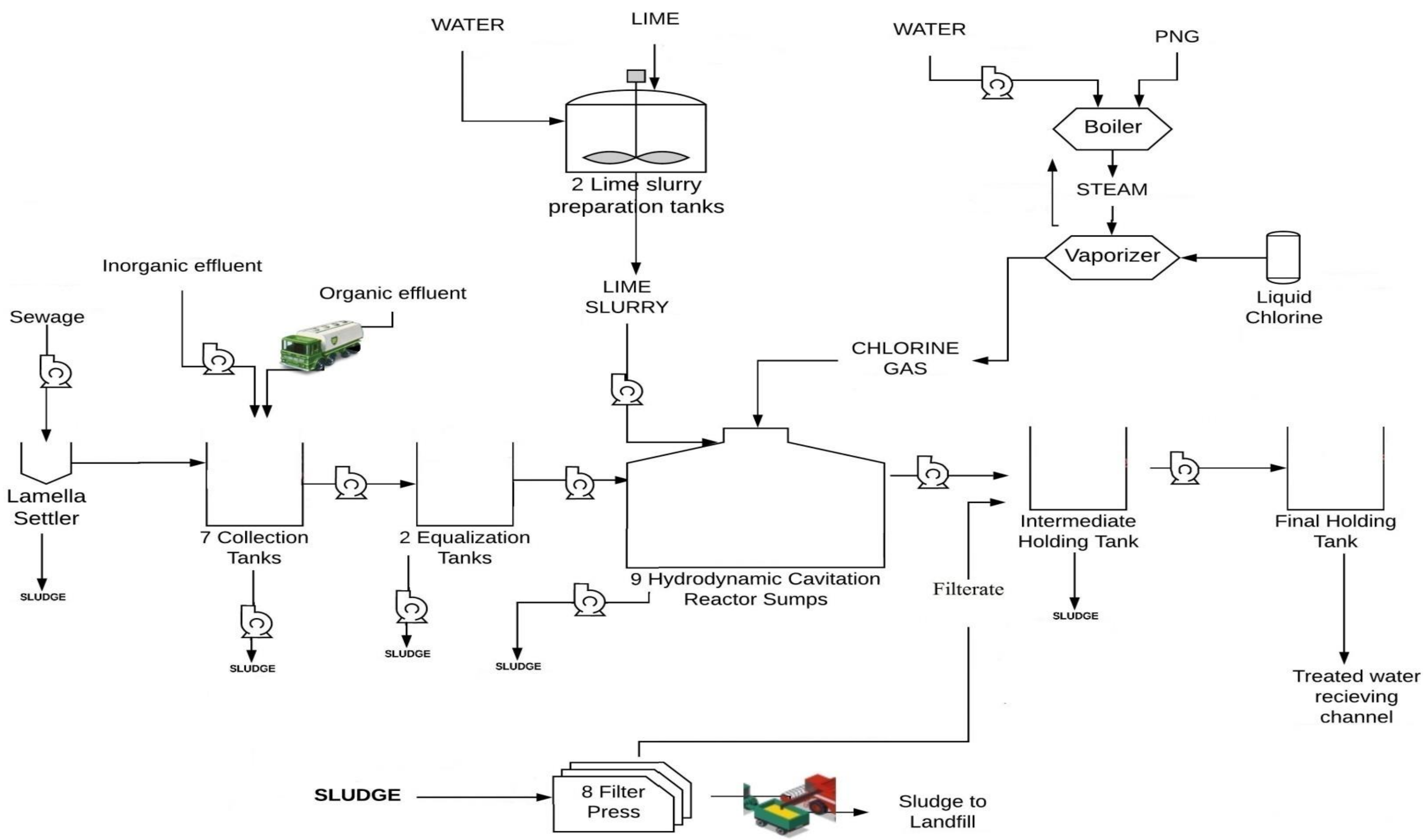

Fig. 19: Schematic Diagram of NIA CETP

4 PHASES OF LCA DESCRIBED IN RESPECT OF THIS PROJECT

In this study, all four phases were performed. These phases are defined below based on requirements of this project work. It has been tried to adhere to ISO standards as much as possible. The decisions and requirements for each phase are given below.

1. Goal and Scope Definition

Goal:

- Reason for this study – LCA studies on AOP based common effluent treatment plant is not done anywhere yet, as per my information regarding research papers published.
- Definition of product, its life cycle and its function – The product in this study is CETP (Common Effluent Treatment Plant). The Life cycle of CETP includes Construction stage, Operational & Maintenance stage and Demolition stage. Operational stage of CETP is considered in the study (construction phase and demolition phase are not included). This treatment plant is used to treat effluent from various chemical manufacturing industries within 5km radius around CETP. Its function is to reduce the harmful impurities present in the water upto permissible limits specified by GPCB.
- Data and data quality requirements, assumptions and limitations – Data was collected using preliminary data collection sheet. This sheet was prepared before site visit. Secondary data is obtained from recent Environmental Audit report of CETP. 1 year data is obtained for this study.
- Requirement regarding the LCIA procedure and subsequent interpretation to be used – LCIA is the 3rd phase of LCA which involves choice of LCIA methodology for the study. In this study, 3 LCIA methods were chosen. LCIA methodologies chosen are ReCiPe (E) Midpoint, TRACI 2.1 and IPCC GWP 2013.
- Intended audience and the way the results will be communicated – Target audience include Host CETP and future researchers. Results will be interpreted as per objectives and if needed, possible alternatives will be communicated to industry.

This study provides results to internal decisions makers only. Further study concentrated on hydrodynamic cavitation may help defining environmental hotspots more clearly.

Scope:

- Functional unit – The functional unit decided for this study is assumed to be kg/year. All data values are converted to kg/year by assuming density of each flow material.
- System boundaries – The system boundaries are mainly defined based on data accessibility. The details are shown below.
- Allocation Procedure – Allocation of products of different processes is defined based on mass. The allocation percentages defined for each product is given below in detail in heading "Data input to SimaPro".

This study follows Attributional Modelling in procedure.

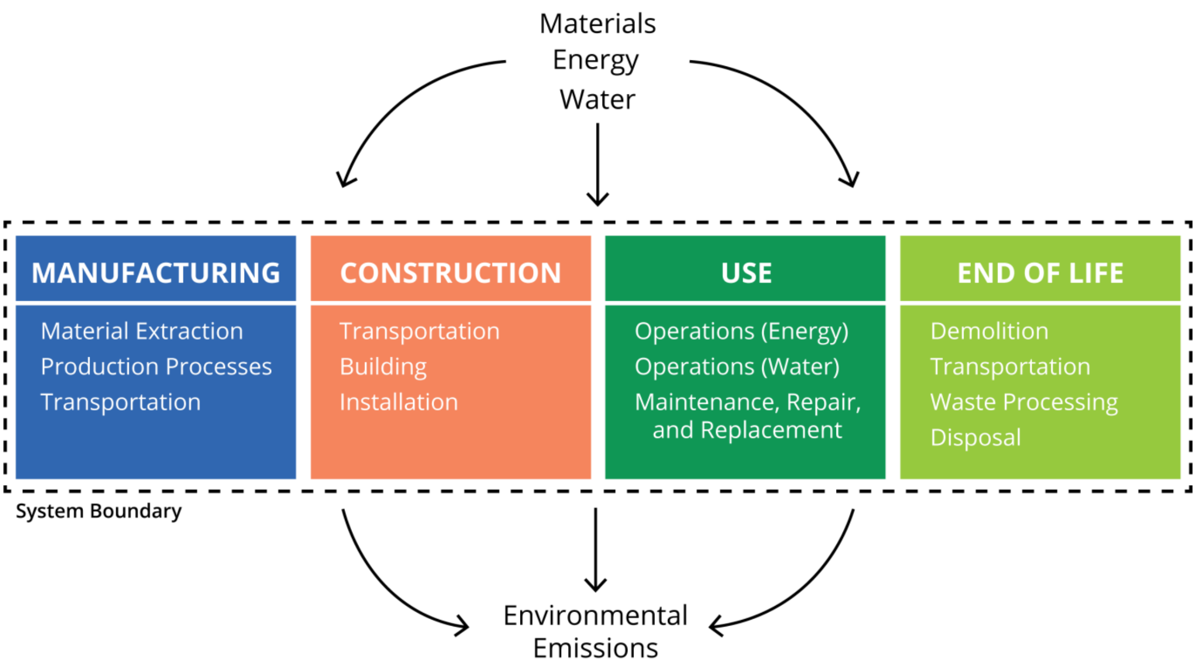

Fig. 16: Ideal System Boundaries of LCA Study

There are 3 Life cycle stages of CETP which are Construction, Operational and Demolition. Out of these, Use (or operational) Stage of CETP is included in this project work as construction data is unavailable by the CETP personnel.

The system boundary defined for this project work is shown below:

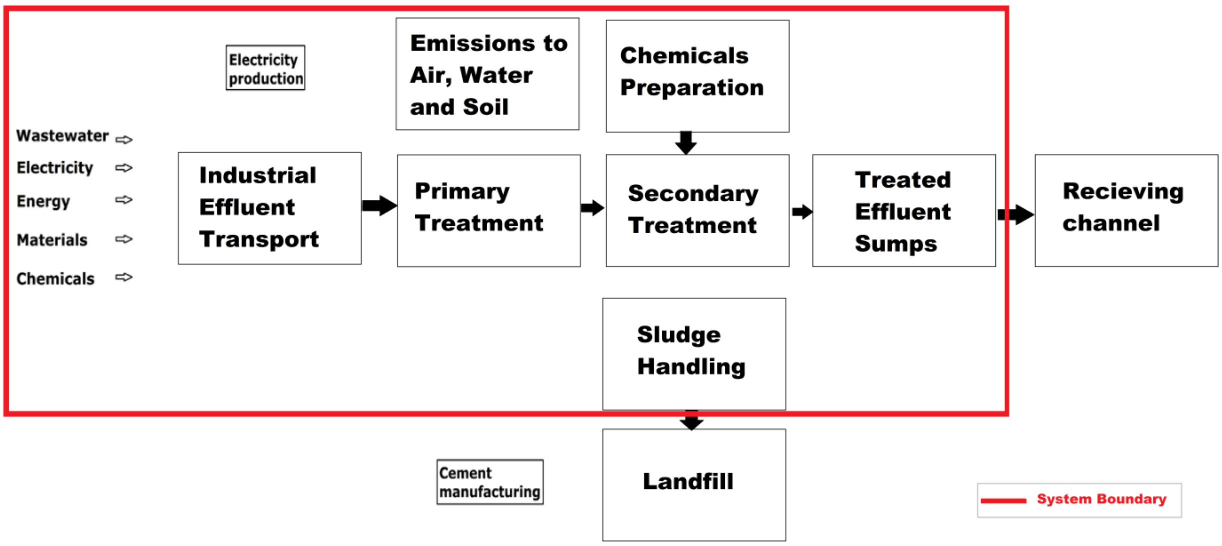

Fig. 17: System Boundaries for this project work

Industrial Effluent Transport includes transportation of organic effluent by diesel powered tankers, transportation of inorganic and domestic sewage by pumps. Industrial effluent also includes Lamella Settler process which is installed inside the CETP premises. Primary treatment units include 7 Collection tanks, 2 Equalization tanks. Secondary treatment units include 9 Hydrodynamic Cavitation Reactor Sumps. Sludge handling units include 1 Filter press house containing 8 Filter Presses. Chemical preparation includes Lime slurry preparation and Liquid Chlorine Vaporization. Treated Effluent Sumps includes Intermediate Holding Tank and Final Holding Tank.

The data for wastewater, electricity, energy (or fuel), materials and chemicals are collected from industry as secondary data and input in the SimaPro software.

Electricity Production data is obtained from Ecoinvent database present in the SimaPro Software as background data. Emissions to air, water and soil are included from background data only which are related to the input processes.

Cement manufacturing process is kept outside the system boundary because the construction data is unavailable and amount of cement concrete utilized is unknown.

Receiving Channel for this CETP is VECL channel in which various nearby industries discharge their treated or untreated effluents. The study concentrates only on this CETP; hence, receiving channel is kept outside the system boundary. Similar is the case for Landfill. Hazardous waste of other industries is also disposed in the landfill.

The system boundaries defined in this project depends on the availability of given quantity and quality of data and its time frame. System boundaries include all the activities performed by the CETP, like Transportation of industrial effluent, treatment units and treatment of Domestic sewage under CSR activity. Such combination of system boundaries was not yet mentioned in any published article.

2. Inventory

The inventory phase of LCA in this study involves preparation of preliminary data collection sheet, site visit and data collection using the same preliminary data collection sheet. The inventory data required for the LCA modelling is decided based on objectives and system boundaries of the study. It is not possible to get all the required data from the industry, so, valid assumptions are made for calculations. Life Cycle Inventory (LCI) Phase is the longest phase in complete LCA study which involves collection of correct data and making suitable assumptions. It also involves series of iterations during calculations and data processing. The data modelling into the LCA software is also included in this phase.

The limitations in Life Cycle Inventory can be due to data quality and quantity. Both are important for obtaining valid results. The small changes in data values may change results and hence conclusions will also change. So, conclusions indirectly depend on the data quality and quantity.

The data used in LCA is of 2 types, foreground data and background data. Foreground data is collected from the field analysis and industry reports. In this study, foreground data is collected from secondary data (recent environmental audit reports). Background data is obtained from in-built databases in the LCA softwares. In this study, Background data is obtained from Ecoinvent database ver3.0. The dataset on Ecoinvent database which is used in this study is “Allocation default, unit processes”. This dataset is chosen because it allows user to perform uncertainty analysis (Life Cycle Interpretation phase). The missing data is assumed. The assumptions are specified in the heading “Calculations of Material, Electricity and Fuel Flow”.

Life cycle data of Materials are available in Ecoinvent database of SimaPro software.

The processes for each treatment unit and activities in CETP were made in SimaPro software in the 2nd Phase of LCA procedure. The screenshots of screens are shown in Annexure. The process making in the SimaPro involves 3 stages, Product, Input and Output. Product stage refers to the material or energy outputs of the particular activity in CETP; Input stage refers to the material and energy inputs of particular activity in CETP and Output stage refers to the emissions (Air, water, land) associated to the particular activity in CETP.

3. Impact Assessment

The Impact Assessment phase is performed till characterization step. This was performed in SimaPro software using 3 LCIA methodologies (one used to calculate carbon footprint only). The results and impact assessment related details are mentioned in chapter 5 (results and discussions). The inventory table of LCI results were converted into graphs and understandable tables of different impact categories. The calculations in this phase are done in the software based on the algorithms defined by the LCIA method developer. Each LCIA method has different algorithms for each impact category and each impact category has different characterization factors in different LCIA method.

4. Interpretation

In this phase, interpreting LCIA results, identifying environmental hotspots and giving suggestions and modifications was done. The detail of this is shown in chapter 5 (results and discussions) and chapter 6 (conclusions). Carbon footprint and environmental performance results were also interpreted.

CHAPTER 5: RESULTS AND DISCUSSIONS

ENVIRONMENTAL PERFORMANCE OF CETP

The data is obtained from recent Environmental Audit Report. The Environmental Performance of NIA-CETP was estimated based on wastewater quality analyzed in the September'2017. The data of September'2017 is chosen for determining Environmental Performance of CETP because this gives idea of recent efficiency of CETP plant.

The Wastewater quality parameters analyzed are:

1. pH
2. COD
3. BOD
4. Chloride
5. SS (Suspended Solids)
6. Phenolic Compounds
7. NH_3-N (Ammonical Nitrogen)

Average of 30 days of September'2017 data is used for calculations of Environmental Performance.

COD is the main wastewater quality parameter which is analyzed in the wastewater. Based on inlet COD, the industries are charged for the treatment of their effluent.

During my site visit, the allowable COD limit to CETP in industrial effluent was 2000 mg/l and allowable quantity of wastewater to CETP by all industries was total 6.8 MLD.

Table 2: Wastewater Quality Parameters Analysis report of CETP of September'2017 (30 days)

CETP (NIA) DATA FOR THE MONTH OF SEPTEMBER – 2017															
Date	**pH**		**COD**		**BOD**		**Chloride**		**SS**		**Phenolic Comp.**		**NH_3-N**		
	Inlet (mg/L)	**Outlet (mg/L)**	**Inlet (mg/L)**	**Outlet (mg/L)**	**Inlet (mg/L)**	**Outlet (mg/L)**	**Inlet (mg/L)**	**Outlet (mg/L)**	**Inlet (mg/L)**	**Outlet (mg/L)**	**Inlet (mg/L)**	**Outlet (mg/L)**	**Inlet (mg/L)**	**Outlet (mg/L)**
01-Sep-17	7.38	7.40	2360	360			22333	23822	420	80	4.00	1.13	47.60	0.56
02-Sep-17	7.32	7.30	1920	224			27296	25807	445	85	3.93	1.17	48.16	0.78
03-Sep-17	7.31	7.31	2080	232			27792	26303	475	85	3.93	1.21	47.60	0.89
04-Sep-17	7.31	7.18	2000	232			27296	26800	387	65	3.86	1.24	45.92	0.56
05-Sep-17	7.34	7.30	1920	256	512	42	26800	25311	460	85	3.73	0.99	48.24	0.896
06-Sep-17	7.38	7.31	1920	240			26303	24318	410	85	3.45	0.86	44.80	0.28
07-Sep-17	7.39	7.32	2080	248			29281	26800	435	85	3.82	0.96	44.80	0.56
08-Sep-17	7.36	7.32	1854	225			28785	25807	450	65	4.00	1.13	46.48	0.672
09-Sep-17	7.34	7.24	1920	216			28289	26800	425	50	4.00	1.17	46.48	0.56
10-Sep-17	7.38	7.31	1800	240			29281	27296	415	65	3.97	1.17	49.28	0.1
11-Sep-17	7.32	7.28	1920	208			27296	24815	400	50	3.72	1.17	47.04	0.448
12-Sep-17	7.36	7.30	1920	224	466	36	28785	26303	415	55	4.00	1.15	45.92	0.67
13-Sep-17	7.18	7.31	2000	248			26800	24815	455	80	4.00	1.22	46.48	0.672

14-Sep-17	7.18	7.31	1800	224			26800	25807	460	70	3.72	1.04	44.80	0.67
15-Sep-17	7.34	7.31	1720	208			27792	26303	475	85	4.00	1.22	45.92	0.448
16-Sep-17	7.36	7.31	2040	256			28785	26303	395	75	3.19	1.10	47.60	0.89
17-Sep-17	7.35	7.25	2000	224			24815	22333	360	60	3.89	1.03	46.48	0.784
18-Sep-17	7.31	7.18	2000	248			27296	26303	465	75	3.79	1.08	46.48	0.448
19-Sep-17	7.33	7.31	1760	216			27296	26303	430	70	3.93	1.10	45.92	0.56
20-Sep-17	7.34	7.30	2240	328	389	45	26800	24815	445	65	3.93	1.10	45.92	0.56
21-Sep-17	7.41	7.18	2000	240			27792	26800	465	75	3.65	1.18	47.04	0.45
22-Sep-17	7.38	7.31	1920	256			28785	27296	435	60	4.04	1.17	44.80	0.67
23-Sep-17	7.38	7.28	1880	208			28289	27296	440	60	3.93	1.10	44.24	0.336
24-Sep-17	7.38	7.31	1880	232			27792	26800	445	65	3.78	1.10	47.60	0.89
25-Sep-17	7.36	7.32	1800	224			28785	26800	380	45	3.89	1.10	45.36	0.44
26-Sep-17	7.33	7.30	1720	224			28289	25807	435	60	4.05	1.17	44.80	0.67
27-Sep-17	7.10	7.31	1800	320	412	42	26800	25311	425	65	3.86	1.10	46.48	0.67
28-Sep-17	7.35	7.32	1920	240			28829	27296	440	60	4.04	1.17	44.80	BDL
29-Sep-17	7.01	7.18	1800	232			26800	25807	465	60	3.72	0.96	45.92	0.44
30-Sep-17	7.34	7.27	1920	216			26303	24318	435	70	4.02	1.08	47.60	0.056

Calculations:

% Removal Efficiency = (Inlet - Outlet / Inlet) * 100%

1. **pH**

Average Inlet pH = 219.62/ 30 = 7.32

Average Outlet pH = 218.63/ 30 = 7.29

Permissible limit for Outlet pH = 6.5 to 8.5

The pH of wastewater is within limits.

2. **COD**

Average Inlet COD = 57894/ 30 = 1929.8 mg/l

Average Outlet COD = 7249/ 30 = 241.63 mg/l

% Removal Efficiency of COD = **87.479 %**

Permissible limit for Outlet COD = 250 mg/l

COD of wastewater is within limits.

3. **BOD_5**

BOD_5 was calculated 4 times in the month of September

Average Inlet BOD_5 = 1779/ 4 = 444.75 mg/l

Average Outlet BOD_5 = 165/ 4 = 41.25 mg/l

% Removal Efficiency of BOD_5 = **90.725 %**

Permissible limit for Outlet BOD_5 = 100 mg/l

BOD_5 of wastewater is within limits.

4. Chloride

Average Inlet Chloride = 824385/ 30 = 27479.5 mg/l

Average Outlet Chloride = 776695/ 30 = 25889.83 mg/l

% Removal Efficiency of Chloride = **5.785 %**

Permissible limit for Outlet Chloride = Not defined for marine coastal discharge

Chloride is present in treated waste water in very high concentration; hence it is a brine solution. Brine solution can only be treated with the help of membrane technique. Chloride is considered in total dissolved solids. Since, Final treated water is discharged in man-made surface channel which finally discharge the wastewater to the Gulf of Khambat (marine coastal area), it is permissible to discharge chloride.

5. SS

Average Inlet SS = 12987/ 30 = 432.9 mg/l

Average Outlet SS = 2055/ 30 = 68.5 mg/l

% Removal Efficiency of SS = **84.176 %**

Permissible limit for Outlet SS = 100 mg/l

SS of wastewater is within limits.

6. Phenolic Compounds

Average Inlet Phenolic Compounds = 115.832/ 30 = 3.86 mg/l

Average Outlet Phenolic Compounds = 33.354/ 30 = 1.11 mg/l

% Removal Efficiency of Phenolic Compounds = **71.2435 %**

Permissible limit for Outlet Phenolic Compounds = 1.00 mg/l

Phenolic Compounds of wastewater is exceeding permissible limit by 0.11 mg/l.

7. NH_3-N

Average Inlet NH_3-N = 1390.56/ 30 = 46.352 mg/l

Average Outlet NH_3-N = 16.63/ 30 = 0.554 mg/l

% Removal Efficiency of NH_3-N = **98.805 %**

Permissible limit for Outlet NH_3-N = 50 mg/l

NH_3-N of wastewater is within limits.

Table 3: Inlet norms and Outlet norms of the CETP

	Standard Inlet Norms	**Actual Quality of Effluent received from Industries**	**Standard Outlet Norms**
Flow (m^3/day)	6800	5140	-
pH	5 – 9	7.0 – 9.5	6.5 - 8.5
SS (mg/l)	600	240 - 400	100
COD (mg/l)	2000	1200 – 2000	250
BOD_5 (mg/l)	500	500 – 700	100
Oil and Grease (mg/l)	20	10 – 30	10
Ammonical-N (mg/l)	50	30 – 45	50
Phenolic compound (mg/l)	5	0.8 – 1.5	1

The Environmental Performance of CETP is within CPCB norms.

CARBON FOOTPRINT

Carbon Footprint is used to measure total Green House Gas emissions caused directly and indirectly by a person, company etc. It is measured in Kilograms of carbon dioxide equivalents. The CO_2eq allows the different GHGs to be compared on a like-for-like basis relative to one unit of CO_2. CO_2eq is calculated by multiplying emissions of each 6 GHGs by its 100 year Global Warming Potential (GWP). GHGs like CO_2, CH_4, N_2O, HFCs, PFCs and SF_6.

In this study, Carbon Footprint is determined by IPCC GWP (2013) 100a v1.04, an LCIA methodology to calculate IPCC GWP 100a in the unit of kgCO_2eq. IPCC GWP 100a is Carbon Footprint. In the SimaPro Software, when all processes were compared using IPCC GWP (2013) 100a, an LCIA methodology, the following table and graph were obtained.

Table 4: IPCC GWP 100a values of different processes of CETP of interest

Serial Number	**PROCESSES**	**IPCC GWP 100a (in kg CO_2eq.)**
1.	Chlorine Gas Preparation	1.32
2.	Lime Slurry Preparation	0.2
3.	Steam Preparation	0.0188
4.	Domestic Sewage Inlet	0.000282
5.	Inorganic Effluent Inlet	0.000237
6.	Organic Effluent Inlet	0.133
7.	Total Wastewater Inlet	0.0808
8.	Semi-treated Filtrate	0.483
9.	Semi-treated Domestic Sewage	0.000318
10.	Sludge Collection tank	8.25
11.	Sludge Equalization tank	0.0838
12.	Sludge Final Dried to Landfill	0.483
13.	Sludge HC reactor sumps	0.0898
14.	Sludge Intermediate holding tank	0.0928
15.	Sludge Lamella settler	0.00032
16.	Collection tank Wastewater	0.0824
17.	Equalization tank Wastewater	0.0831
18.	HC reactor sumps Wastewater	0.0897
19.	Intermediate holding tank Wastewater	0.0905

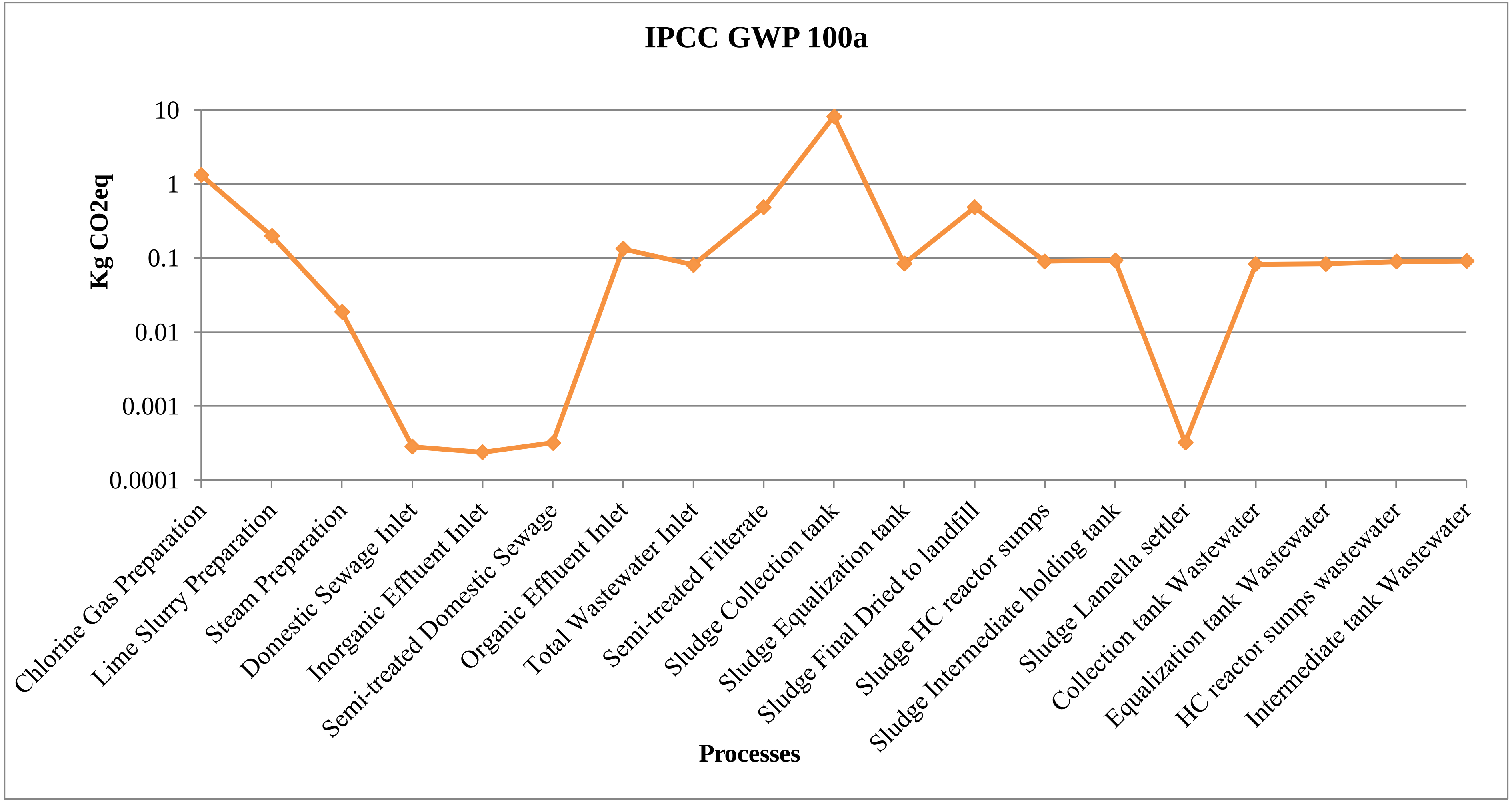

Fig. 21: Graph showing IPCC GWP 100a values (prepared in MS Excel)

Interferences from graph:

The highest percentage of contribution to GWP 100a impact category is by "Sludge Collection tank" process. This is due to more amount of electricity used in this process. Practically, the electricity is more utilized during pumping of wastewater from collection tank to equalization tank. The electricity production process considered in this case is of Indian Scenario. The impact of any process is the result of type of inputs to that process. Hence, Impacts of Transportation of organic effluent are also included in the "Sludge Collection tank" process. The GHG emissions from diesel use are included. Collectively the global warming potential of Collection tanks is highest.

Second highest percentage of contribution to GWP 100a impact category is by "Chemical Preparation Chlorine Gas" process.

Inferences from trends of graph:

The processes are shown in the sequence as per my own convenience.

The "chemical preparation processes" are showing decreasing trend from chlorine gas to steam, i.e., chlorine gas has highest carbon footprint among chemical preparation processes in the CETP.

The "inlet wastewater related processes" are showing increasing trend from domestic sewage to organic effluent transportation, i.e., Organic effluent has highest carbon footprint among all inlet wastewater processes. This is because emissions from diesel use include GHGs (It is mentioned in the Tanker Transportation Process in SimaPro).

The "Sludge flow" are showing uneven trend starting from semi-treated filtrate (filter press) to sludge lamella settler. Sludge from collection tank has maximum carbon footprint.

The "Wastewater flow" are showing slightly increasing trend from collection tank to intermediate tank. This may be due to inclusion of impacts of previous processes, which are added as input to further processes.

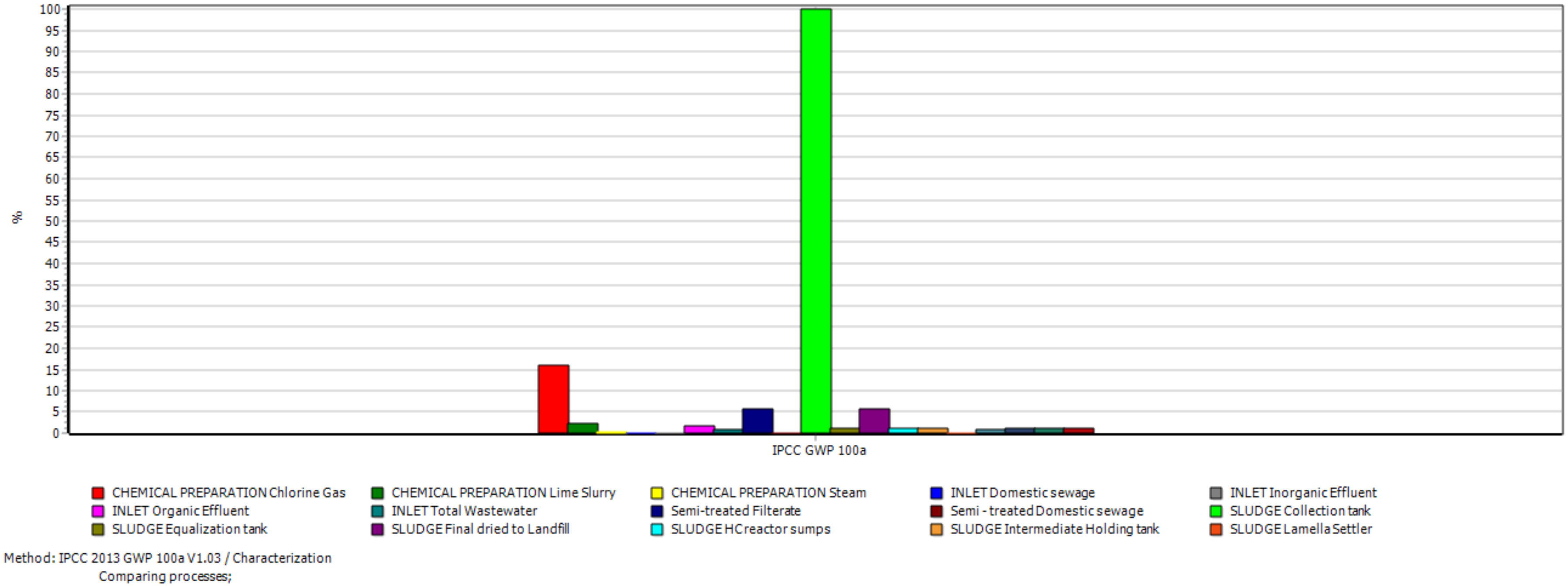

Fig. 22: Characterized Results' Graph obtained in IPCC GWP (2013) 100a, an LCIA Methodology in SimaPro

<u>Description of above graph:</u>

Y- Axis – % contribution to IPCC GWP 100a, an impact category with respect to "Sludge Collection tank" process.

X- Axis – IPCC GWP 100a, an Impact category

Different processes are shown in different colour. The colour coding is shown below graph.

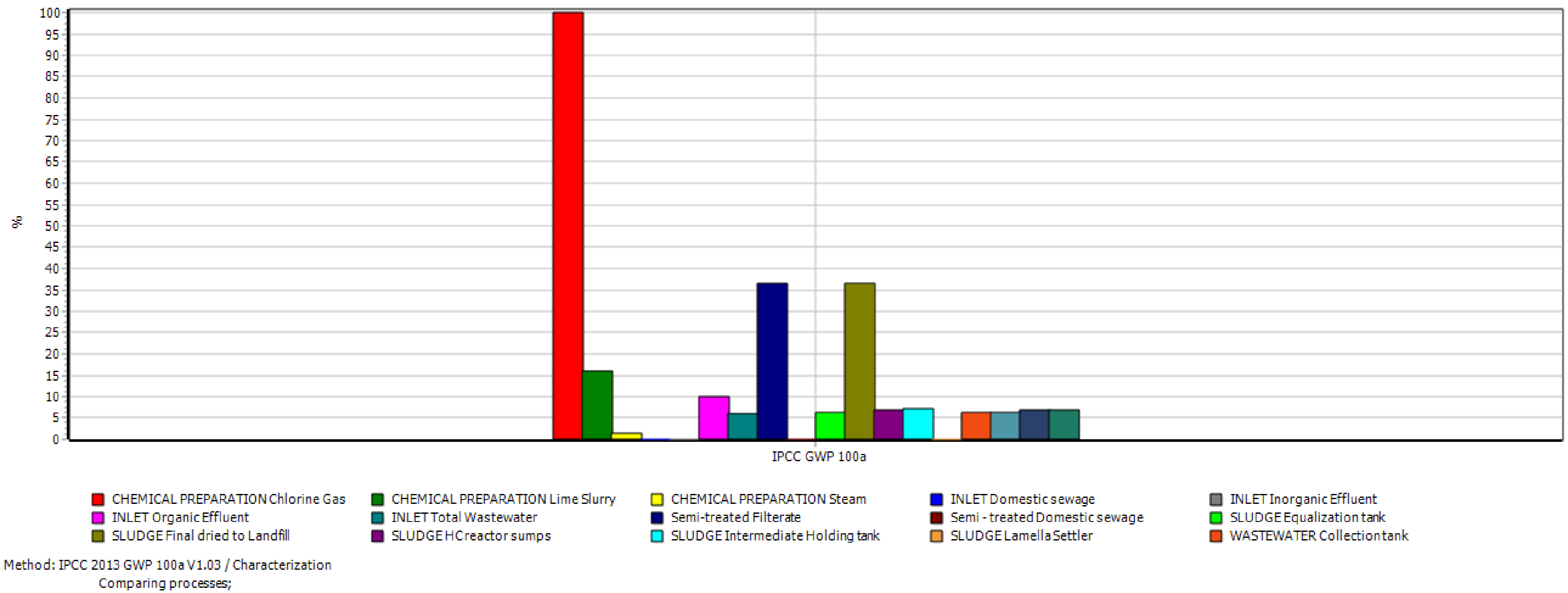

Fig. 23: Characterized Results' Graph obtained in IPCC GWP (2013) 100a, an LCIA Methodology (This graph does not show "Sludge Collection tank" Process) in SimaPro

<u>Description of above graph:</u>

Y- Axis – % contribution to IPCC GWP 100a, an impact category with respect to "Chemical Preparation Chlorine Gas" process.

X- Axis – IPCC GWP 100a, an Impact category

DATA INPUT TO SIMAPRO

Secondary Data was collected during the site visit which is not in the units as required to input in the SimaPro software and many required data was unavailable during and after site visit. The complete data for 1 year was collected.

Simple mathematics is used for this purpose. Microsoft Excel was used for this purpose. Data for 365 days was added or data of 1 day was multiplied by 365 to obtain yearly data. Some data values like Wastewater flow and any other liquid flow were given in volume units. The density of each type of liquid flow was assumed and multiplied with the volume.

$$\text{Mass} = \text{Volume} * \text{Density}$$

The electricity requirements for different mechanical devices are calculated from the power specifications of different mechanical devices. Mechanical devices used in CETP are pumps, mechanical stirrers, pressure jet and clamping mechanisms.

All calculated values for material, electricity and fuel inputs and outputs of CETP are shown below in the figure. All values are shown for 1 year. The detailed calculations involved are given in next sub-heading.

MATERIAL, ELECTRICITY AND FUEL FLOW

Material flow analysis (MFA) is a systematic method to enumerate flows and collection of materials or substances in a well-defined system. This can be performed for Mass and Energy both, as they must be conserved.

Material and Energy balance basically means quantitative analysis of materials and energy respectively.

Basic form can be written as,

Inputs = Output in the form of (Products, Wastes/losses, Stored materials)

Only material and fuel flow and Electricity input to treatment units were processed from the preliminary data collection sheets. Complete mass balance and energy balance cannot be done as various data like heat exchange data, wastewater quality data at each stage of treatment and gaseous emissions in treatment units were unavailable in the field.

The material based calculation was done for this CETP include water, wastewater, sludge and chemicals flow in and out from the system. The data is limited to the quantity of water in wastewater. The density of materials was assumed and shown below. Material flow shows all the wastewater input and output from all treatment units, chemical input to the Hydrodynamic cavitation and chemical preparation units, sludge flow from all treatment units.

The electricity use in the plant premises is majorly due to pumps used for material flow. The electricity requirement by all the pumps employed and few other mechanical devices like stirrer, blower, clamping mechanism etc. are calculated based on their power rating and assumed efficiency. It is assumed that pumps work at 83% efficiency (industry personnel reported approximate efficiency between 80-85%).
The fuel utilized inside the CETP is only PNG. The exact amount of the same was given in the recent Environmental Audit Report provided by the CETP personnel.

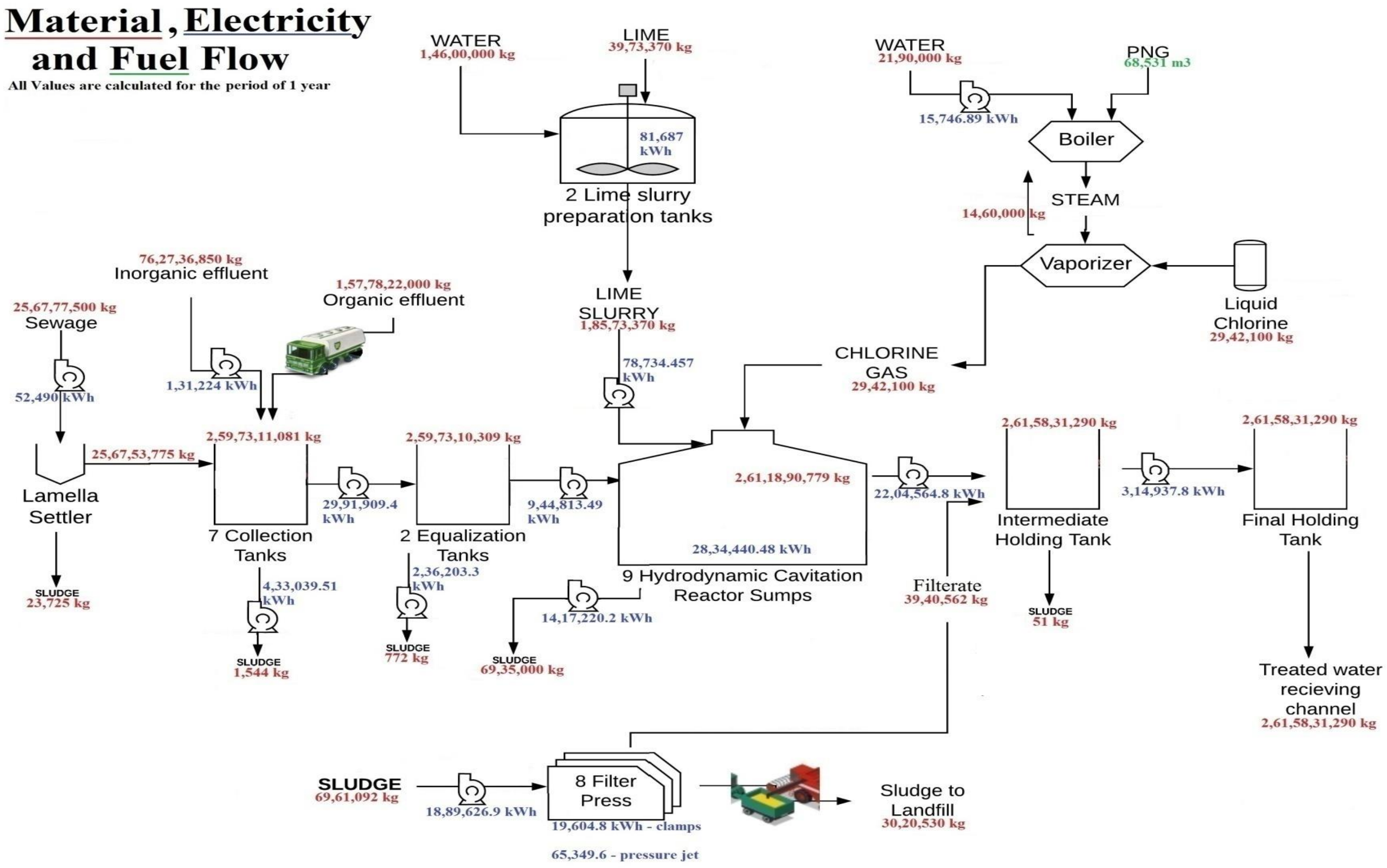

Fig. 20: Material, Electricity and Fuel inputs and outputs of NIA CETP

CALCULATIONS OF MATERIAL, ELECTRICITY and FUEL FLOW

Assumptions:

- Density of Inorganic Effluent = 1010 kg/m^3
- Density of Organic Effluent = 1010 kg/m^3
- Density of Domestic Sewage = 1005 kg/m^3
- Density of Water = 1000 kg/m^3
- Density of Filtrate from filter press = 1000 kg/m^3 (Filtrate is assumed to be pure water)
- Number of days considered in one year = 365 days

1. Transport of Organic Effluent –

18 KL = (18 * 1010) / 1000 = 18.18 tonne

9 KL = (9 * 1010) / 1000 = 9.09 tonne

Assuming,

Number of tankers used per day with 18KL capacity = 70

Number of tankers used per day with 9 KL capacity = 55

Amount of mass transported by 70 tankers of 18 KL (or 18.18 tonne) capacity = 18.18 * 70 * 365 = 464,499 tonne/year

Amount of mass transported by 55 tankers of 9 KL (or 9.09 tonne) capacity = 9.09 * 55 * 365 = 182,481.75 tonne/year

Distance travelled by each tanker = 3Km (2-way)

Number of trips per day = 3

Therefore, Distance travelled by each tanker in 1 year = 3 * 3 * 365 = 3,285 km/year (2-way)

Organic effluent transported by tankers of 18 KL (or 18.18 tonne) capacity in t-km = 464,499 * 3,285 = 1, 52, 58, 79,215 t-km

Organic effluent transported by tankers of 9 KL (or 9.09 tonne) capacity in t-km = 182,481.75 * 3,285 = 59, 94, 52,548.75 t-km

2. Inorganic Effluent –

Inorganic effluent = 2,069 m^3/day

The value for 1 year was calculated by multiplying above value to 365 days and converting it to mass.

Inorganic Effluent = 76, 27, 36,850 kg/year

3. Organic Effluent –

Organic Effluent = 4,280 m^3/day

The value for 1 year was calculated by multiplying above value to 365 days and converting it to mass.

Organic Effluent = 1, 57, 78, 22,000 kg/year

4. Domestic Sewage –

Domestic Sewage = 700 m^3/day

The value for 1 year was calculated by multiplying above value to 365 days and converting it to mass.

Domestic Sewage = 25, 67, 77,500 kg /year

5. Lamella Settler –

Domestic Sewage Inlet = 25, 67, 77,500 kg/year

Domestic Sewage Outlet = 25, 67, 53,775 kg/year

Allocation to semi – treated domestic sewage at outlet of lamella settler = 99.9907 %

6. Lamella Settler Sludge –

Lamella Settler Sludge = 60 - 70 kg/day ≈ 65 kg/day

The value for 1 year was calculated by multiplying above value to 365 days.

Lamella Settler Sludge = 23, 725 kg/year

Percentage of sludge contribution to filter press by Intermediate holding tank Sludge = (23725 / 6961092) * 100 = 0.3048 %

Total electricity required by Filter Press = 1974581.3 kWh

Fraction of Electricity which is used to dewater Lamella Settler Sludge = (1974581.3 * 0.3408) / 100 = 6729.37 kWh

Allocation to lamella settler sludge at outlet of lamella settler = 0.0093 %

7. Industrial effluent transport –

Inlet inorganic effluent = 76, 27, 36,850 kg/year

Inlet organic effluent = 1, 57, 78, 22,000 kg/year

Inlet semi-treated domestic sewage = 25, 67, 53,775 kg/year

Outlet wastewater = 2, 59, 73, 12,625 kg/year

8. Collection tank wastewater –

Collection tank wastewater Inlet = 25, 72,885 m^3/year. *(This value is obtained by adding "Inorganic effluent", "organic effluent" and domestic sewage" values in m^3/year) (This value is not used in SimaPro Modelling)*

Collection tank wastewater Inlet = 2, 59, 73, 12,625 kg/year

Collection tank wastewater Outlet = (2, 59, 73, 12,625 – 1544) = 2, 59, 73, 11,081 kg/year

Allocation to wastewater at outlet of collection tank = 99.99405 %

9. Collection tank sludge –

Collection tank sludge = 25, 72,885 * 0.1 *0.006 = 1, 543.731 Kg/ year ≈ 1,544 kg/year

I assumed Sludge production in collection tank to be 10% of inlet wastewater. Out of this, 0.6% will be the solid content which will finally reach the filter press.

Percentage of sludge contribution to filter press by Intermediate holding tank Sludge = (1544 / 6961092) * 100 = 0.02218 %

Total electricity required by Filter Press = 1974581.3 kWh

Fraction of Electricity which is used to dewater Collection tank Sludge = (1974581.3 * 0.02218) / 100 = 437.962 kWh

Allocation to sludge at outlet of collection tank = 0.00595 %

10. Equalization tank wastewater –

Equalization tank wastewater Inlet = 2, 59, 73, 11,081 kg/year

Equalization tank wastewater Outlet = (2, 59, 73, 11,081 – 772) = 2, 59, 73, 10,309 kg/year

Allocation to wastewater at outlet of equalization tank = 99.99997 %

11. Equalization tank sludge –

Equalization tank sludge = 25, 72,885 * 0.05 *0.006= 771.8655 kg/year ≈ 772 kg/year

I assumed Sludge production in equalization tank to be 5% of inlet wastewater. This low assumption is made based on perception during site visit. Out of this, 0.6% will be the solid content which will finally reach the filter press.

Percentage of sludge contribution to filter press by Intermediate holding tank Sludge = (772 / 6961092) * 100 = 0.011 %

Total electricity required by Filter Press = 1974581.3 kWh

Fraction of Electricity which is used to dewater Equalization tank Sludge = (1974581.3 * 0.011) / 100 = 217.203 kWh

Allocation to sludge at outlet of equalization tank = 0.00003 %

12. Lime Slurry Preparation tank –

Lime = 39, 73,370 kg/year

Water = 40 KL/day

The value for 1 year was calculated by multiplying above value to 365 days and converting it to mass.

Water = 1, 46, 00,000 kg/year

Lime Slurry = (39, 73,370 + 1, 46, 00,000) = 1, 85, 73,370 kg/year

13. Hot Water Boiler –

Water = 6 KL/day

The value for 1 year was calculated by multiplying above value to 365 days and converting it to mass.

Water = 21, 90,000 kg/year

PNG = 68,531 m^3/year (The value of PNG required by CETP in 1 year was obtained by simple addition of data for 365 days)

Steam produced = 21, 90,000 kg/year (assumed based on condensate recycled)

Steam condensate recycled = 4 KL/day

The value for 1 year was calculated by multiplying above value to 365 days and converting it to mass.

Input Steam condensate recycled = 14, 60,000 kg/year

14. Vaporizer –

Liquid Chlorine = 29, 42,100 kg/year

Steam input = 21, 90,000 kg/year

Steam condensate recycled = 14, 60,000 kg/year

Chlorine Gas = 29, 42,100 kg/year

15. Hydrodynamic Cavitation Reactor Sumps –

Chlorine Gas = 29, 42,100 kg/year

Lime Slurry = 1, 85, 73,370 kg/year

Hydrodynamic Cavitation Reactor wastewater inlet = 2, 59, 73, 10,309 kg/year

Hydrodynamic Cavitation Reactor wastewater outlet = ({2, 59, 73, 10,309 + 1, 85, 73,370 + 29, 42,100} – 69, 35, 000 kg/year) = 2, 61, 18, 90,779 kg/year

Allocation to wastewater at outlet of Hydrodynamic cavitation reactor sumps = 99.735 %

16. Hydrodynamic cavitation reactor sumps' sludge –

Hydrodynamic cavitation reactor sumps' sludge = 18 - 20 MT/day (Metric Tonne/day) ≈ 19 MT/day

The value for 1 year was calculated by multiplying above value to 365 days and converting it to kilograms.

Hydrodynamic cavitation reactor sumps' sludge = 69, 35,000 kg/year

Percentage of sludge contribution to filter press by Intermediate holding tank Sludge = (6935000 / 6961092) * 100 = 99.625 %

Total electricity required by Filter Press = 1974581.3 kWh

Fraction of Electricity which is used to dewater Hydrodynamic cavitation reactor sumps' Sludge = (1974581.3 * 99.625) / 100 = 1967176.62 kWh.

Allocation to sludge at outlet of Hydrodynamic cavitation reactor sumps = 0.265 %

17. Filter Press House –

Inlet Sludge = (23,725 + 1,544 + 772 + 69, 35,000 + 51) = 69, 37,367 kg/year

Outlet Dried Sludge = 30, 20,530 kg/year

Filtrate from filter press = (69, 61,092 – 30, 20,530) = 39, 40,562 kg/year

Allocation to dried sludge at outlet of Filter press house = 43.391 %

Allocation to filtrate at outlet of Filter press house = 56.609 %

18. Intermediate holding tank –

Filtrate from filter press = 39, 40,562 kg/year

Intermediate holding tank inlet = (2, 61, 18, 90,779 + 39, 40,562) = 2, 61, 58, 31,341 kg/year

Intermediate holding tank outlet = 2, 61, 58, 61,290 kg/year

Allocation to wastewater at outlet of Intermediate holding tank = 99.999998 %

19. Intermediate holding tank sludge –

Intermediate holding tank sludge = 25, 72,885 * 0.02 *0.001= 51.4577 Kg ≈ 51 kg/year

I assumed Sludge production in collection tank to be 2% of inlet wastewater. This much low assumption is made based on perception during site visit as the tank is cleaned once every 6 months. Out of this, 0.6% will be the solid content which will finally reach the filter press. The value comes out to be very small as compared to other processes.

This sludge value is ignored during SimaPro software modelling because the amount of sludge generated in Intermediate holding tank accounts for 0.0007% of total amount of sludge generated.

Percentage of sludge contribution to filter press by Intermediate holding tank Sludge = (51 / 6961092) * 100 = 0.0007 %

Total electricity required by Filter Press = 1974581.3 kWh

Fraction of Electricity which is used to dewater Intermediate holding tank Sludge = (1974581.3 * 0.0007) / 100 = 13.822 kWh.

Allocation to sludge at outlet of Intermediate holding tank = 0.000002 %

20. Final holding tank –

Final holding tank wastewater inlet = 2, 61, 58, 61,290 kg/year

Final holding tank wastewater outlet = 2, 61, 58, 61,290 kg/year

This process is ignored in the SimaPro software modelling because no change in amount of inlet and outlet values i.e., no new material or energy input and output is observed.

21. <u>Specifications of all the mechanical devices employed in the CETP are shown below:</u>

Based on the following values, the calculation for electricity input is done.

Assumptions:

- Efficiency of all stirrers (with respect of electricity)= 80 %
- Efficiency of all pumps (with respect of electricity)= 83 %
- Efficiency of all clamping mechanisms and pressure jet (with respect of electricity)= 100%
- 1 HP = 0.746 kWh
- Number of days considered in one year = 365 days

Table 3: Specifications and Electricity requirement by different mechanical devices in CETP

Serial Number	**Location**	**Specification**				
		Number of pumps or any other mechanical devices	**Power (in HP)**	**Working Hours (in hours)**	**Electricity (in kWh)**	**Remarks**
1.	Domestic sewage IN	1	20	8	52489.63855	
2.	Inorganic effluent IN	1	20	20	131224.0964	
3.	Collection tank water OUT	6	60	24	2834440.482	12 total (6 working at one time)
		1	20	24	157468.9157	2 total (1 working at one time)
4.	Collection tank sludge OUT	1	60	22	433039.5181	

5.	Equalization tank water OUT	2	60	24	944813.494	
6.	Equalization tank sludge OUT	1	60	12	236203.3735	
7.	HC tank reactors	144	7.5	8	2834440.482	
8.	HC tank water OUT	1	120	24	944813.494	
		1	160	24	1259751.325	
9.	HC tank sludge OUT	3	60	24	1417220.241	7 total (3 working at one time)
10.	Lime dosing tank stirrer	4	7.5	8	81687	
11.	Lime slurry OUT	2	5	24	78734.45783	
12.	Boiler Water IN	1	2	24	15746.89157	2 total (1 working at one time)
13.	Intermediate tank water OUT	1	20	24	157468.9157	
		1	60	8	157468.9157	
14.	Filter press sludge IN	4	60	24	1889626.988	8 total (4 working at one time)
15.	Filter press Clamping mechanism	4	1	18	19604.88	8 total clamping mechanism

						s (4 working at one time)
16.	Filter press Pressure Jet	1	60	4	65349.6	1 pressure jet

LIFE CYCLE IMPACT ASSESSMENT (LCIA) PHASE

It includes 5 sub-steps (or elements) out of which 2 are obligatory for any LCA performed. These sub-steps are Classification and Characterization. In this study, I included classification and characterization elements for getting LCIA results. Optional elements are not included.

In classification, we assign each LCI result table element to a particular impact category based on their possible environmental impacts. For example, CO_2 and CH_4 will be assigned to Global warming potential impact category. For example, Nitrogen will be assigned to Eutrophication impact category.

In characterization, LCI results are converted in the units of impact category by multiplying it to characterization factor. For example, CO_2 and CH_4 values are converted to CO_2eq. By multiplying CO_2 and CH_4 LCI results values with respective Characterization Factor (C.F.).

These elements are performed using LCIA methodologies present in the LCA software. I'm using following LCIA methods to meet the objectives:

a. ReCiPe Midpoint (E)
b. TRACI 2.1
c. IPCC GWP 2013

I have chosen ReCiPe Midpoint (E) and TRACI 2.1 LCIA methods because these 2 methods cover almost all impact categories present in the given SimaPro software version. This helps in identifying all possible environmental impacts of the processes of CETP of interest.

IPCC GWP (2013), LCIA method is chosen to calculate the Carbon Footprint of all the processes of CETP of interest. This method gives values of Global Warming Potential (GWP) in Kilograms of Carbon-dioxide equivalents, which is similar to the units of Carbon Footprint. Hence, this method is selected.

Table 6: Impact categories considered in ReCiPe and TRACI methods (To be read in conjunction with graphs below)

Serial Number	**Impact Categories**	**Unit**
ReCiPe Midpoint (E) v 1.13		
1.	Climate change	kg CO_2 eq
2.	Ozone depletion	kg CFC-11 eq
3.	Terrestrial Acidification	kg SO_2 eq
4.	Freshwater Eutrophication	kg P eq
5.	Marine Eutrophication	kg N eq
6.	Human toxicity	kg 1,4-DB eq
7.	Photochemical oxidant formation	kg NMVOC
8.	Particulate matter formation	kg PM_{10} eq
9.	Terrestrial ecotoxicity	kg 1,4-DB eq
10.	Freshwater ecotoxicity	kg 1,4-DB eq
11.	Marine water ecotoxicity	kg 1,4-DB eq
12.	Ionizing radiation	kBq U235 eq
13.	Agricultural land occupation	m2a
14.	Urban land occupation	m2a
15.	Natural land transformation	m^2
16.	Water depletion	m^3
17.	Metal depletion	kg Fe eq
18.	Fossil depletion	kg oil eq
TRACI 2.1 v 1.04		
19.	Ozone depletion	kg CFC-11 eq
20.	Global Warming Potential (GWP 100a)	kg CO_2 eq
21.	Smog	kg O_3 eq
22.	Acidification	kg SO_2 eq
23.	Eutrophication	kg N eq
24.	Carcinogens	CTUh
25.	Non-Carcinogens	CTUh
26.	Respiratory effects	kg $PM_{2.5}$ eq
27.	Ecotoxicity	CTUe
28.	Fossil Fuel Depletion	MJ Surplus

Impact Categories:

The units of all Impact Categories were defined based on one reference compound. Other chemical compounds which contribute to the same Impact Category, are multiplied by their respective characterization factors.

Say for example, Global Warming Potential is measured in CO_2eq because CO_2 is the basic compound contributing to Global Warming. Other compounds may have less or more impact on global warming with respect to CO_2. This relationship between impact of CO_2 and impact of any other particular compound is defined in the form of characterization factor. Each LCIA method has different characterization factors for same impact category.

Other units such as CFC-11 eq, PM_{10} eq, etc. also have a reference compound with respect of which characterization factors are defined. Some of these are shown below in tabular form. Complete list of indicators is not shown because there are hundreds of indicators that are considered in SimaPro. Characterization factors in Hierarchist approach are shown.

Table 5: Characterization Factors of different Impact Category Indicators

Global Warming Potential Indicators:

Indicator	Characterization Factor
CO_2	1
CH_4	4.8
N_2O	78.8
CFC - 11	875.4
1, 2 – Dichloroethane	0.2
SF_6	34368.5

Ozone Depletion Indicators:

Indicator	Characterization Factor
CFC - 11	1
CCl_4	0.895
CFC - 12	0.82
N_2O	0.017
CH_3Cl	0.02
HCFC - 22	0.04

Ionizing Radiation Indicators:

Indicator	Characterization Factor
Co – 60 (emission to air)	1

I - 129 (emission to air)	10.5
Sr - 90 (emission to air)	2.45
Kr - 85 (emission to air)	0.00000848
Actinide (emission to air)	1.58

Photochemical Ozone Formation Indicators:

Indicator	Characterization Factor
NO_x	1
NMVOC	0.18
Aldehydes	0.174
Hydrocarbons, aromatic	0.163
Hydrocarbons, chlorinated	0.0266
Hydrocarbons, aliphatic	0.0984

Particulate Matter Formation Indicators:

Indicator	Characterization Factor
NH_3	0
NO_x	0
SO_2	0.29
$PM_{2.5}$	1

Terrestrial Acidification Indicators:

Indicator	Characterization Factor
NO_x	0.36
NH_3	1.96
SO_2	1

Freshwater Eutrophication Indicators:

Indicator	Characterization Factor
P (freshwater)	1
PO_4^{3-} (freshwater)	0.33
P (agricultural soil)	0.1
PO_4^{3-} (agricultural soil)	0.033
P (seawater)	0
PO_4^{3-} (seawater)	0

Mineral resource Indicators:

Indicator	Characterization Factor
Copper	1
Aluminium	0.10074
Beryllium	84.2466
Platinum	13795.14
Zinc	0.115714

Fossil Fuel Indicators:

Indicator	Characterization Factor
Crude oil	1
Natural gas	0.84
Hard coal	0.42
Brown coal	0.22
Peat	0.22

Land Occupation Indicators:

Indicator	Characterization Factor
Annual crops	1
Pasture	0.55
Artificial area	0.73
Permanent crops	0.7
Managed forest	0.3

The Processes' name is given by me for my own convenience. There is no rule to Name a Process in SimaPro.

Combined Results of ReCiPe Midpoint (E) and TRACI 2.1 are shown below in the form of graphs and tables. The graphs are obtained in MS Excel. SimaPro LCIA results/ graphs are also shown for reference with Excel graphs.

The results are shown in various groups, which are:

1. **Sludge flow** – This group consists of all the sludge related processes. It includes Semi-treated Filterate, Sludge Lamella Settler, Sludge Collection tanks, Sludge Equalization tanks, Sludge HC reactor sumps, Sludge Intermediate holding tank and Sludge Final Dried to Landfill.
2. **Chemical Preparation** – This group consists of all the chemical preparation processes which are used to convert material state of any chemical or making chemical as per requirement. It includes Preparation of Chlorine Gas, Lime Slurry and Steam.
3. **Inlet Wastewater** – This group consists of all processes which show activities of Transporting Industrial Effluent and Domestic Sewage to Collection Tanks. It includes Inlet Domestic Sewage, Inlet Inorganic Effluent, Inlet Organic Effluent, Semi- treated Domestic Sewage and Total Inlet Wastewater.
4. **Wastewater Flow** – This group consists of all the wastewater flow related processes or all treatment units which are employed in the CETP. It includes

Wastewater Collection tank, Wastewater Equalization tank, Wastewater HC reactors sumps and Wastewater Intermediate Holding tank.

5. **Total Results** – This group consists of all the processes created in the SimaPro. It includes all Processes.

1. Sludge Flow

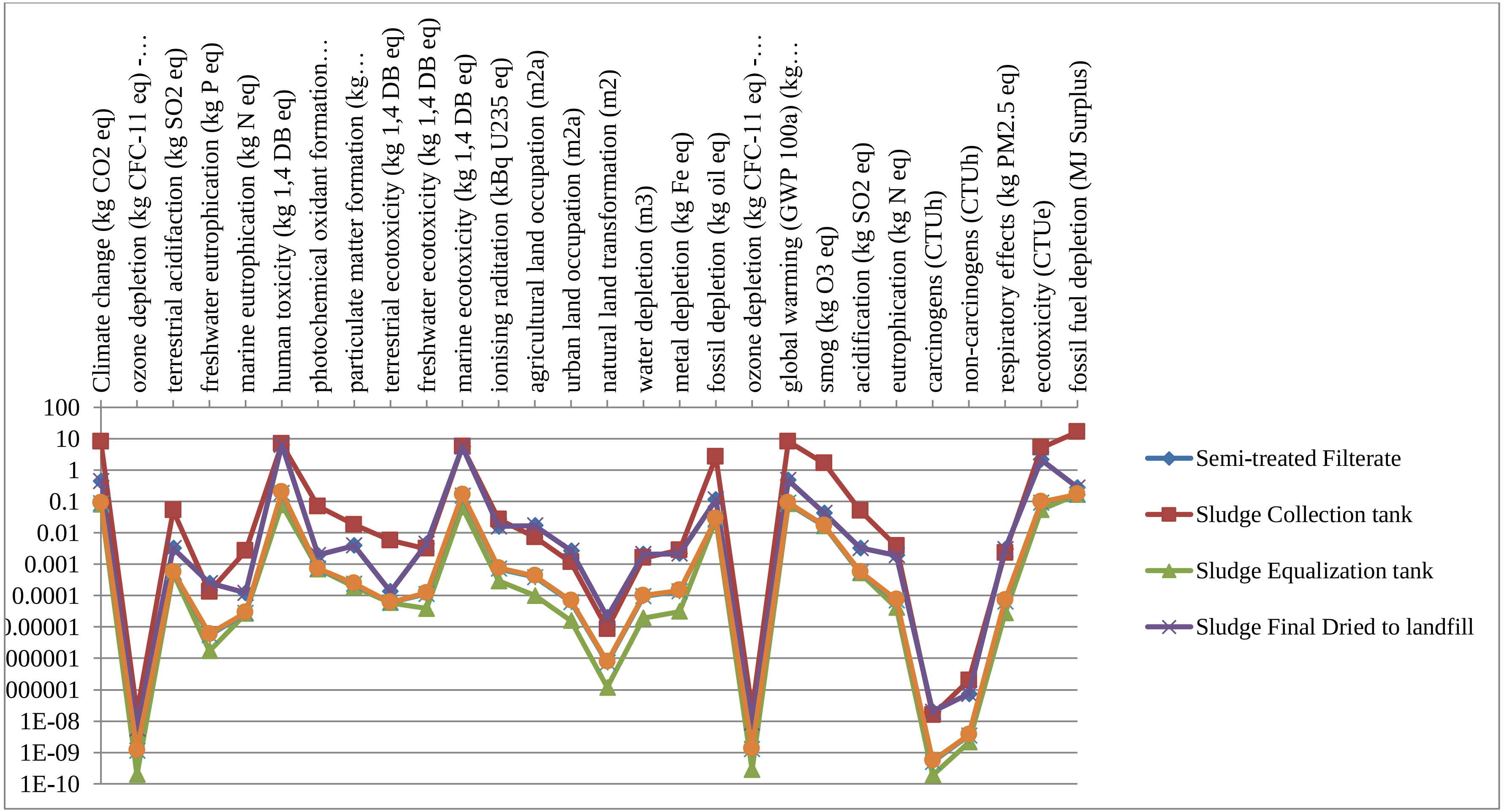

Fig. 24: Possible Environmental Impacts by different Sludge flow processes

The process with highest environmental impacts in almost all impact categories is "Sludge Collection Tank". There are 6 impact categories which are showing maximum possible environmental impacts which are Climate Change, Human Toxicity, Marine Ecotoxicity, Fossil Depletion, Global Warming and Ecotoxicity.

The possible impacts depend on the inputs to the process. When individual process "Sludge Collection Tank" is studied, it revealed that "Inlet Total Wastewater" process is showing maximum impacts.

On analyzing individual process "Inlet Total Wastewater", it revealed that "Inlet Organic Effluent" process is showing Maximum impacts among all inlet processes. This is due to Transportation of Organic Effluent by diesel fuelled tankers. Hence, the environmental impacts of "Sludge Collection Tank" process are associated indirectly to the emissions to environment due to diesel utilized in tankers.

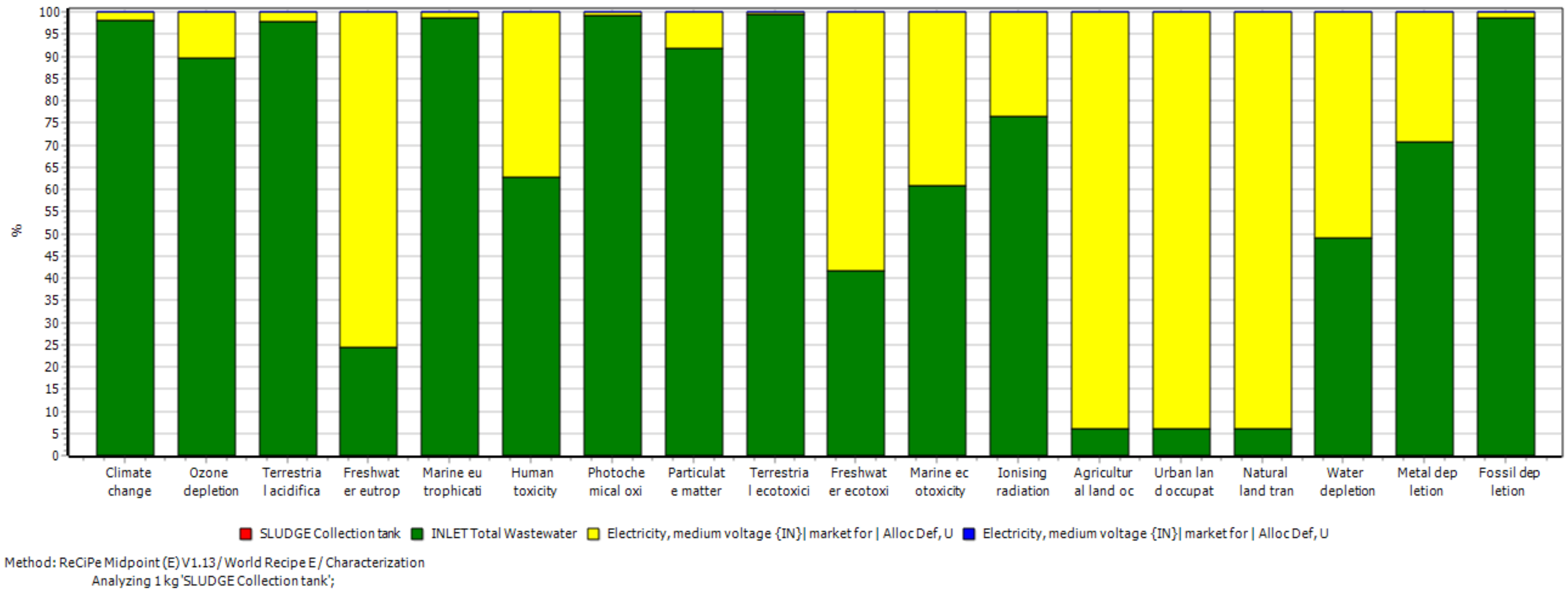

Fig. 25: Characterized LCIA results of Sludge Collection Tank by ReCiPe Midpoint (E) method

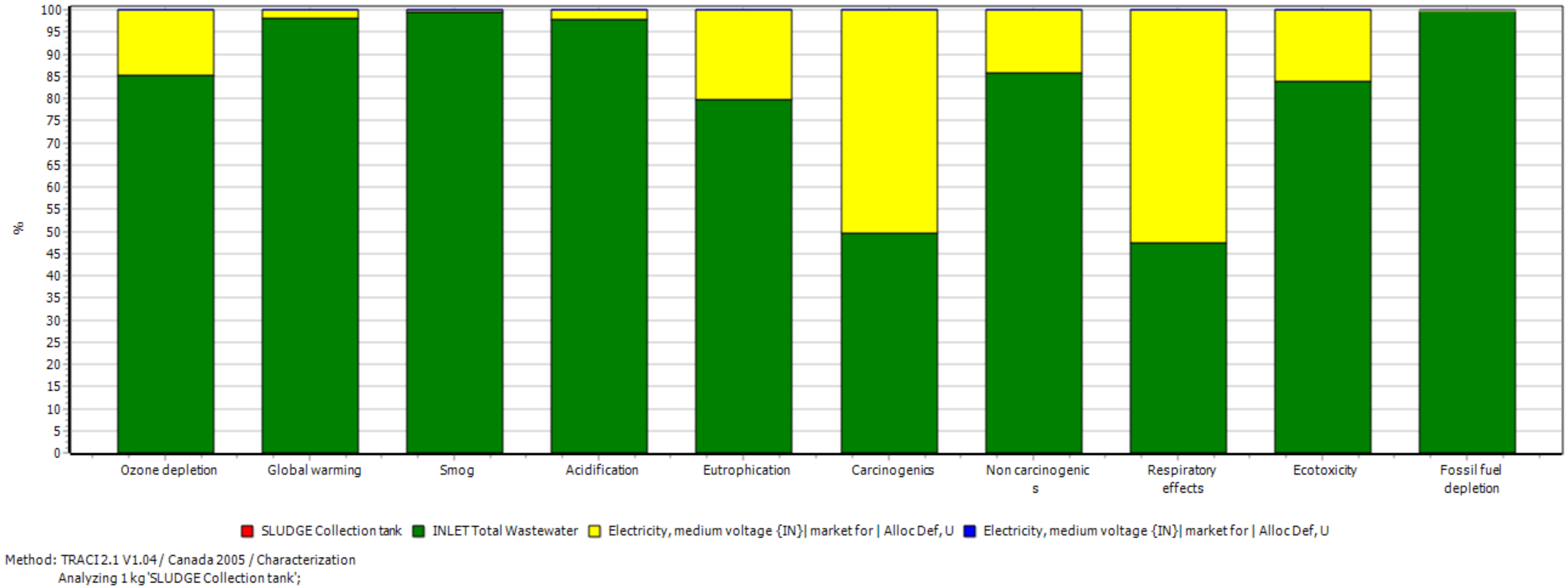

Fig. 26: Characterized LCIA results of Sludge Collection Tank by TRACI 2.1 method

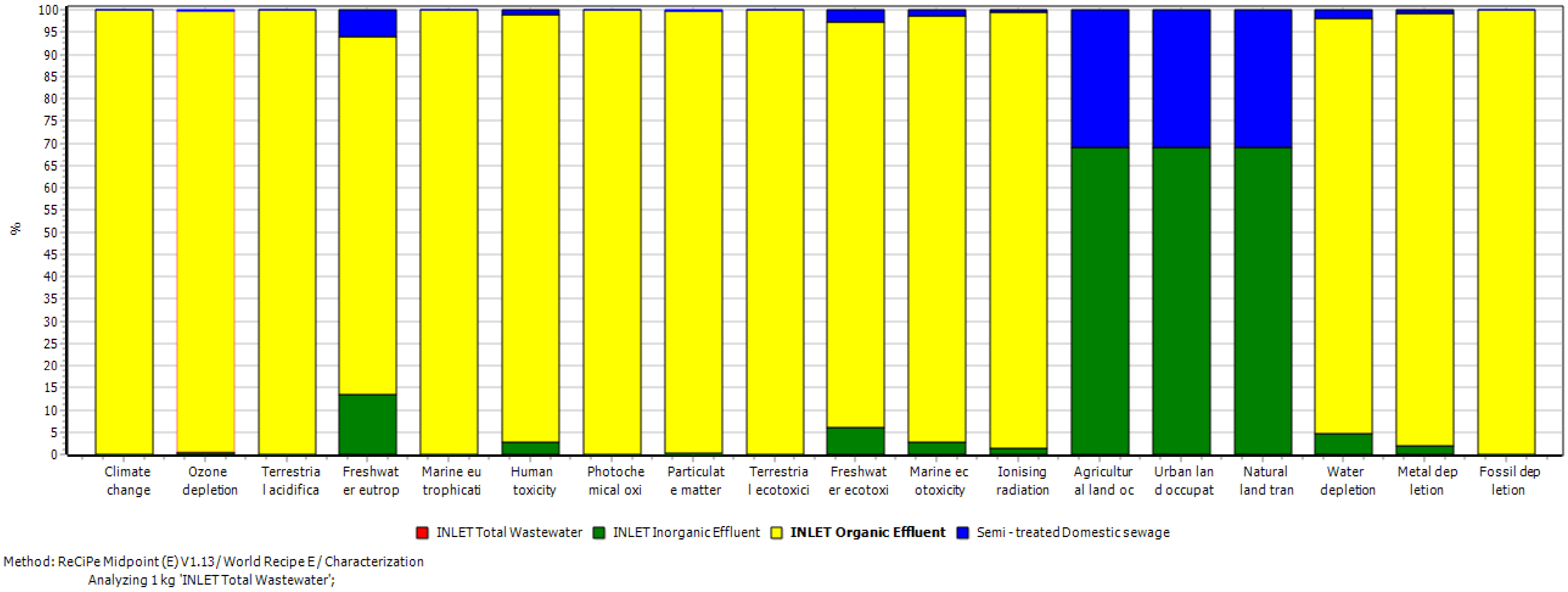

Fig. 27: Characterized LCIA results of Inlet Total Wastewater by ReCiPe Midpoint (E) method

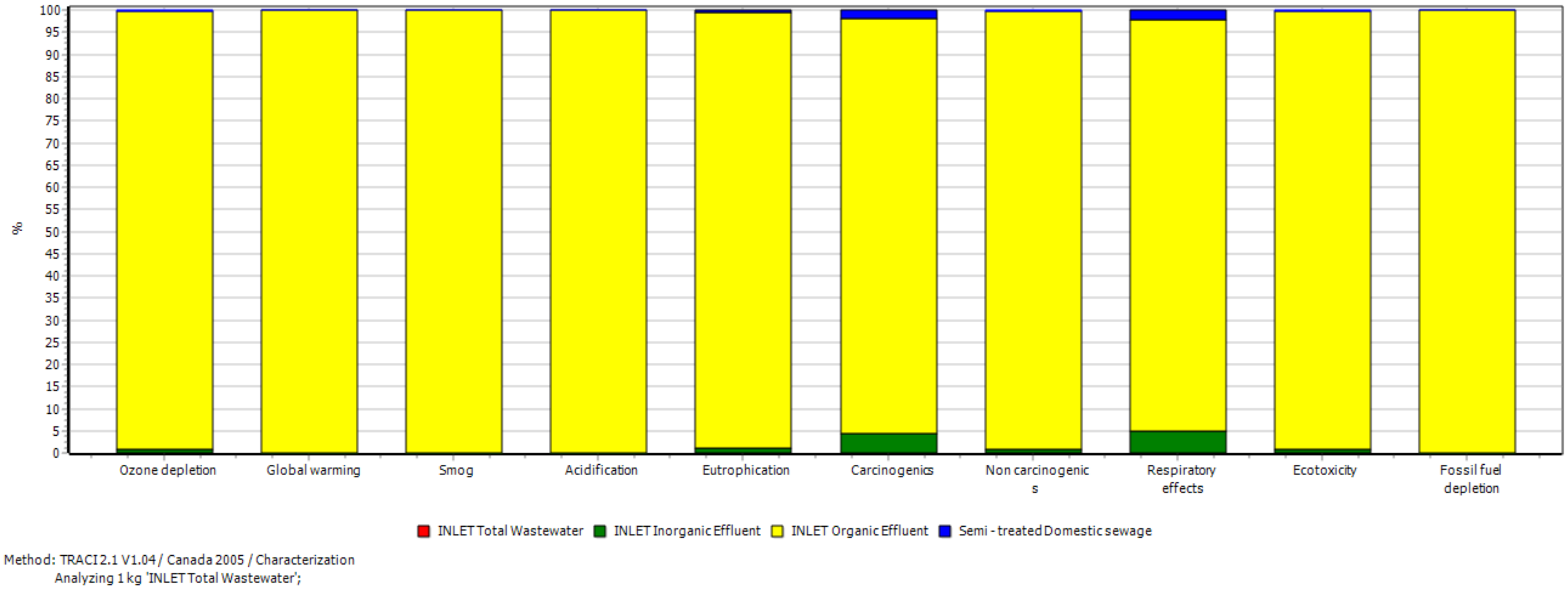

Fig. 28: Characterized LCIA results of Inlet Total Wastewater by TRACI 2.1 method

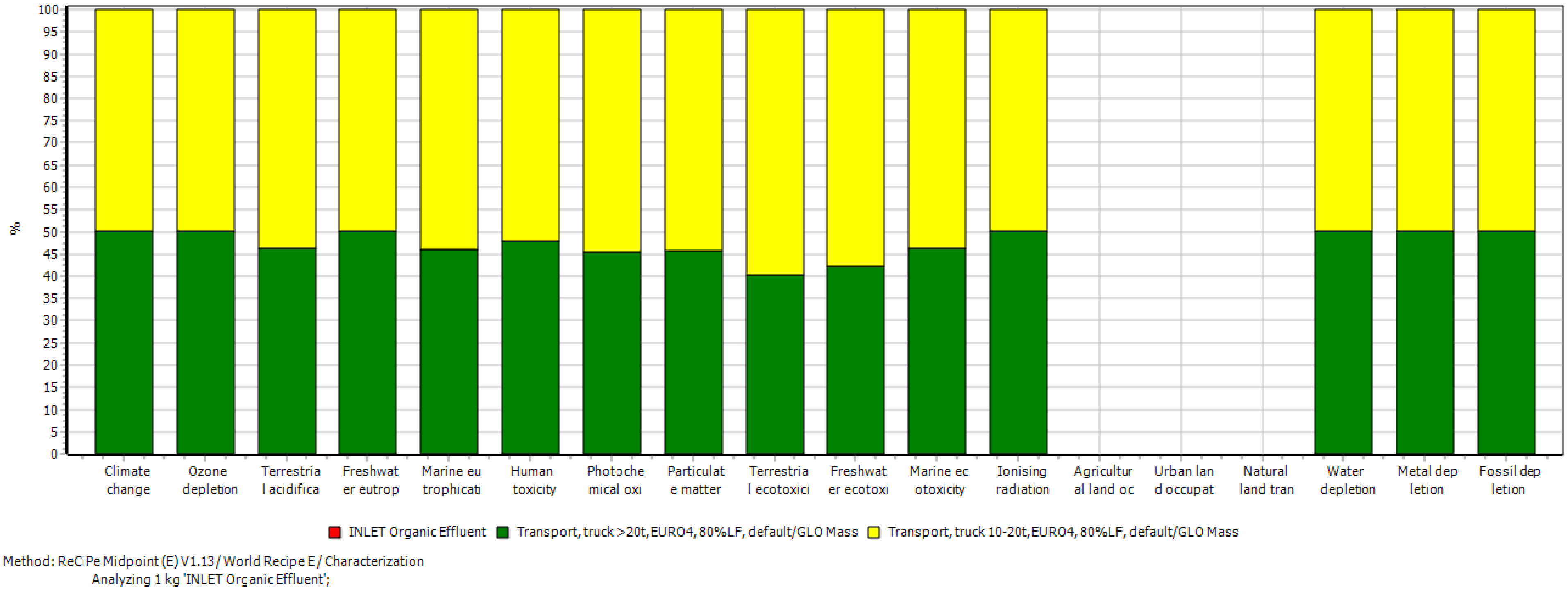

Fig. 29: Characterized LCIA results of Inlet Organic Effluent by ReCiPe Midpoint (E) method

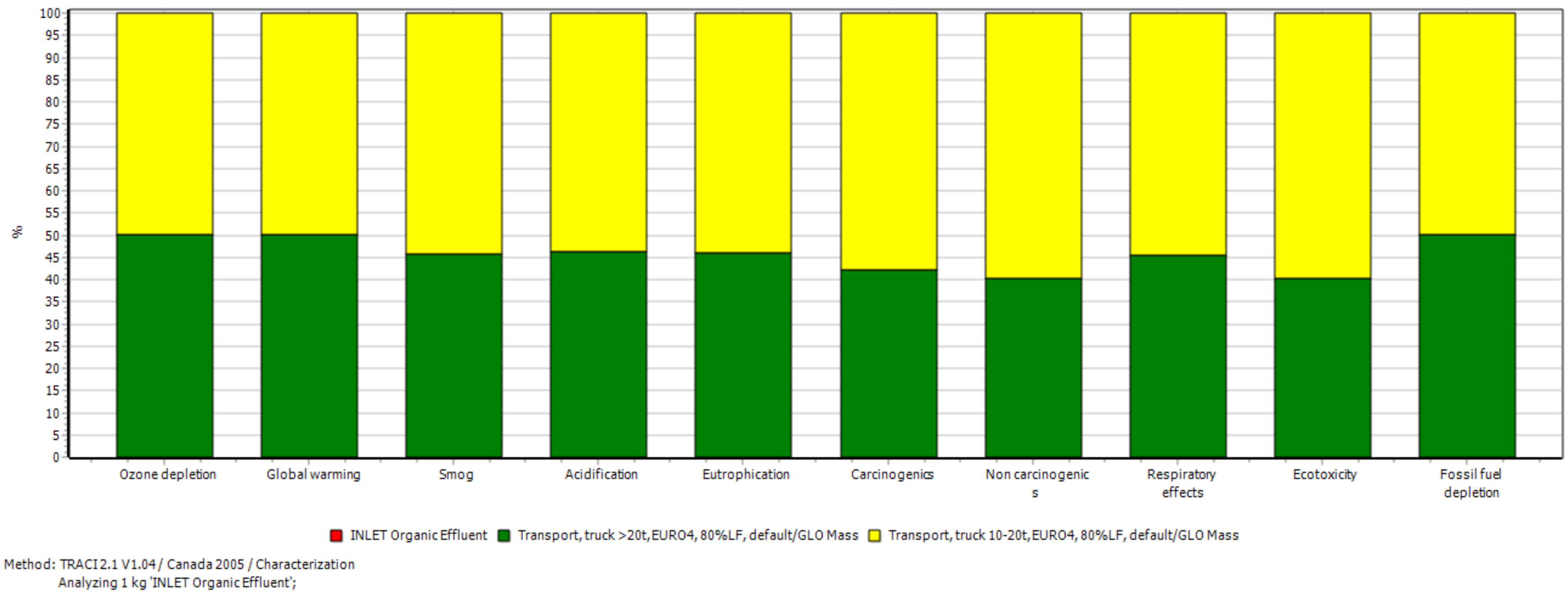

Fig. 30: Characterized LCIA results of Inlet Organic Effluent by TRACI 2.1 method

2. Chemical Preparation

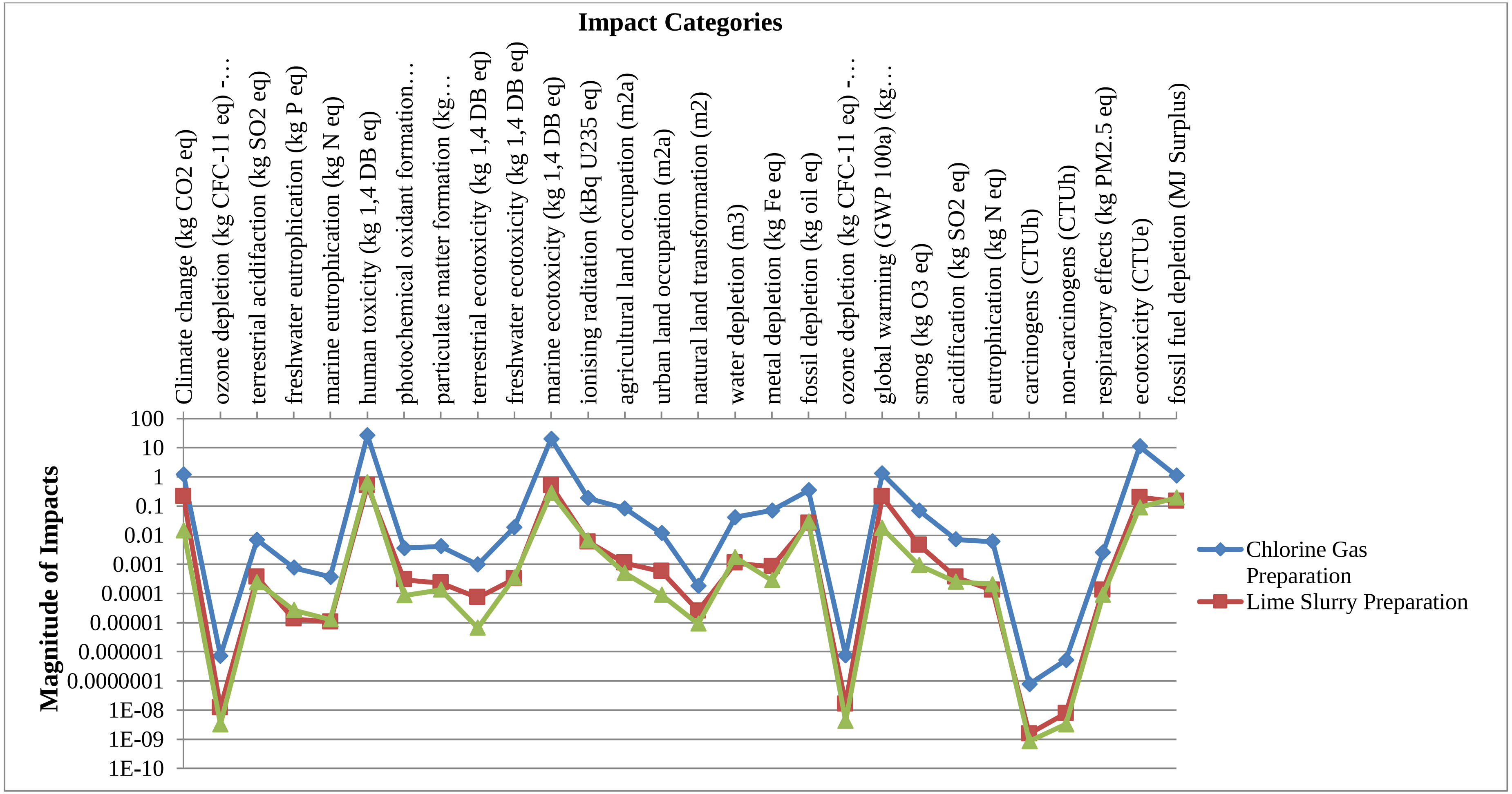

Fig. 31: Possible Environmental Impacts by different Chemical Preparation processes

The process with highest environmental impacts in almost all impact categories is "Chlorine Gas Preparation". There are 6 impact categories which are showing maximum possible environmental impacts which are Climate Change, Human Toxicity, Marine Ecotoxicity, Fossil Depletion, Global Warming and Ecotoxicity.

The possible impacts depend on the inputs to the process. When individual process "Chlorine Gas Preparation" is studied, it revealed that "Liquid Chlorine" process (Background data) is showing maximum impacts.

The inputs to "Liquid Chlorine" process are "Gaseous Chlorine" and "Electricity". The process of conversion of gaseous chlorine to liquid chlorine requires electricity. The possible impacts of this conversion process are very high. Hence, the environmental impacts of "Chlorine Gas Preparation" process are associated indirectly to the conversion of gaseous chlorine to liquid chlorine in chemical industry.

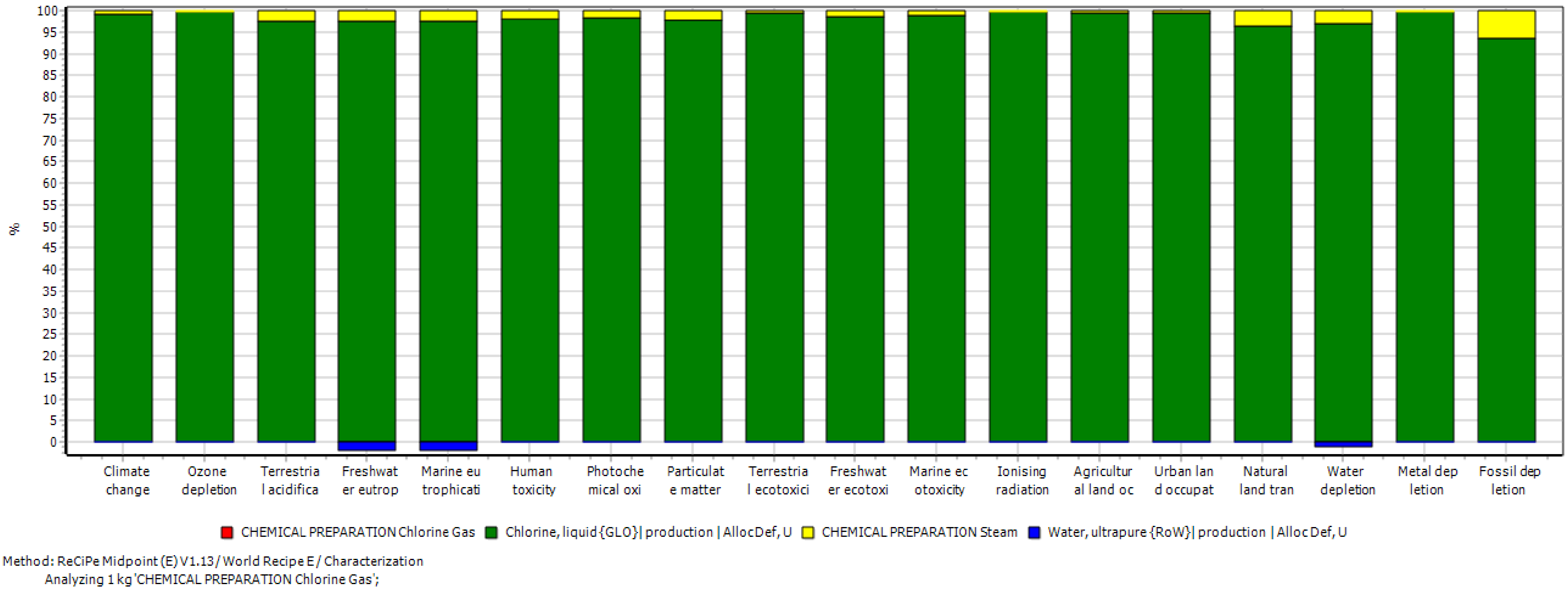

Fig. 32: Characterized LCIA results of Chlorine Gas Preparation by ReCiPe Midpoint (E) method

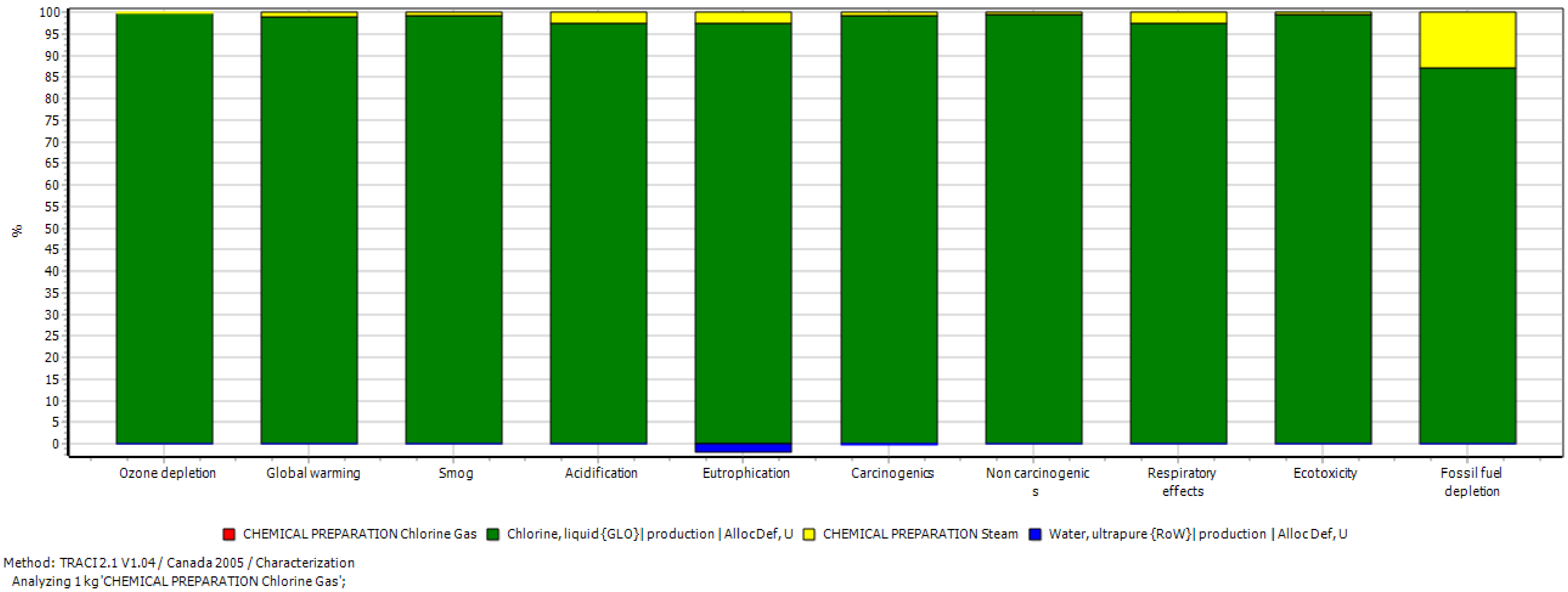

Fig. 33: Characterized LCIA results of Chlorine Gas Preparation by TRACI 2.1 method

3. Inlet Wastewater

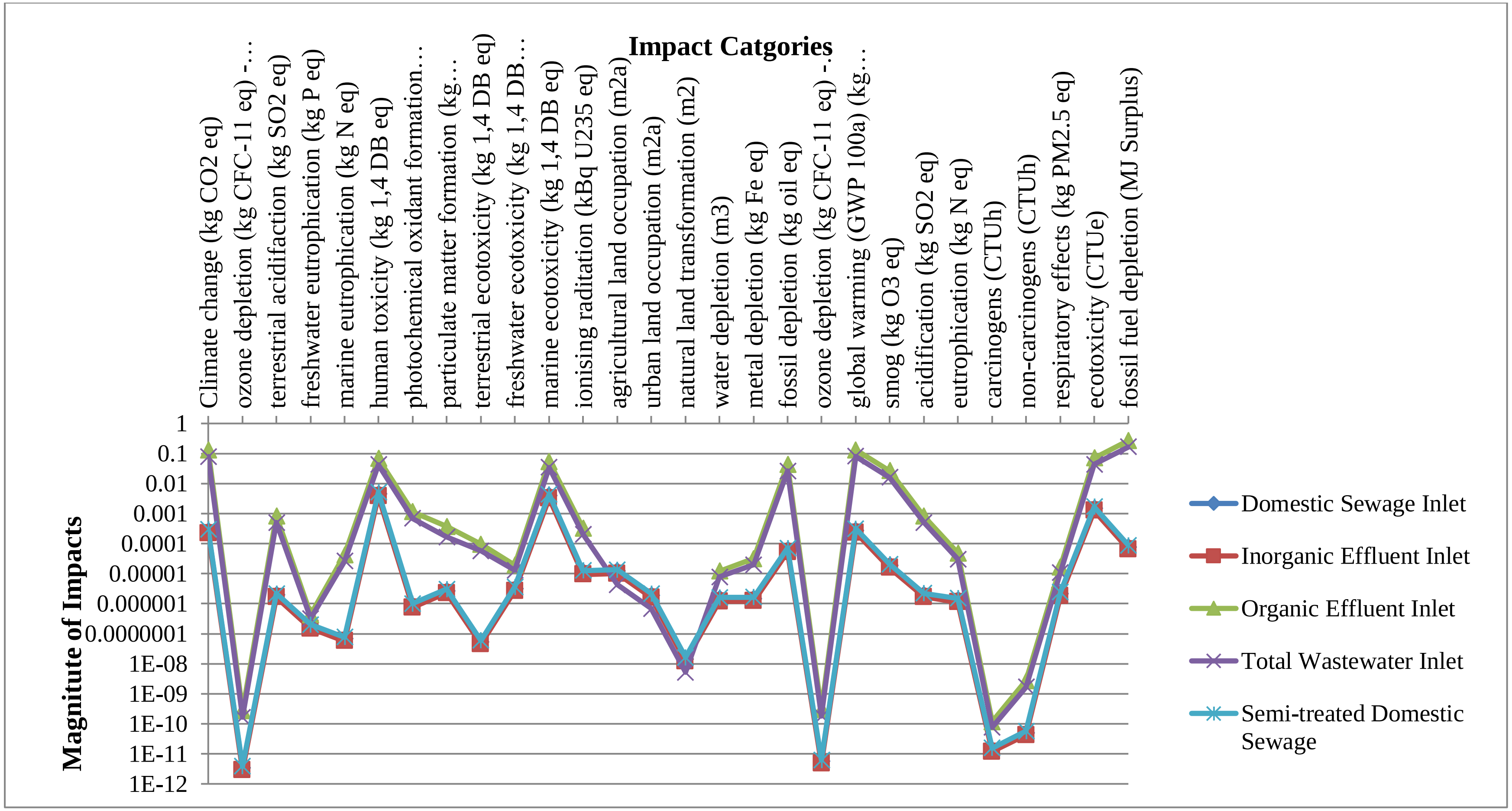

Fig. 34: Possible Environmental Impacts by different Inlet wastewater processes

The process with highest environmental impacts in almost all impact categories is "Organic Effluent Inlet". There are 6 impact categories which are showing maximum possible environmental impacts which are Climate Change, Human Toxicity, Marine Ecotoxicity, Fossil Depletion, Global Warming and Ecotoxicity.

The possible impacts depend on the inputs to the process. When individual process "Organic Effluent Inlet" is studied, it revealed that "Transportation by Diesel fuelled Tankers" process is showing maximum impacts.

3 impact categories "Agricultural Land Occupation", "Natural Land Transformation" and "Urban Land Occupation" are not considered for "Inlet Organic Effluent" transport Process because characterization factors for them are Zero. There is no land requirement for diesel extraction and its transportation activity.

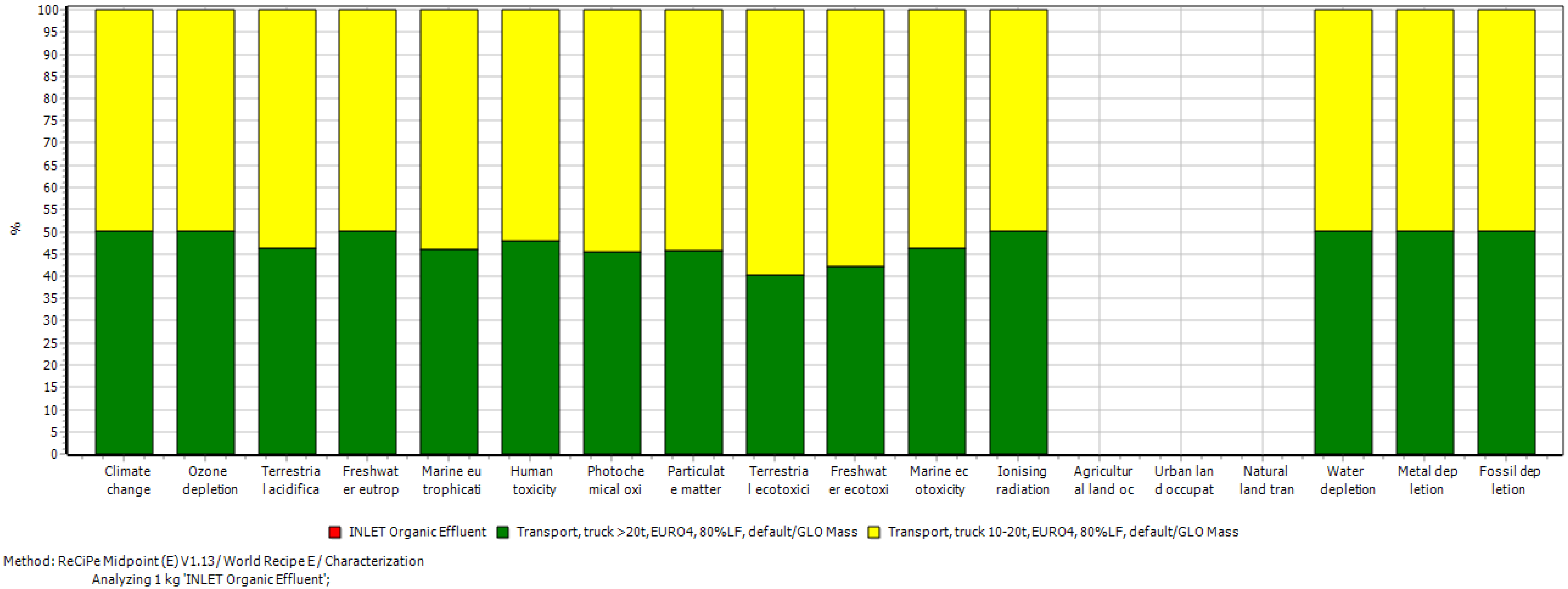

Fig. 35: Characterized LCIA results of Inlet Organic Effluent by ReCiPe Midpoint (E) method

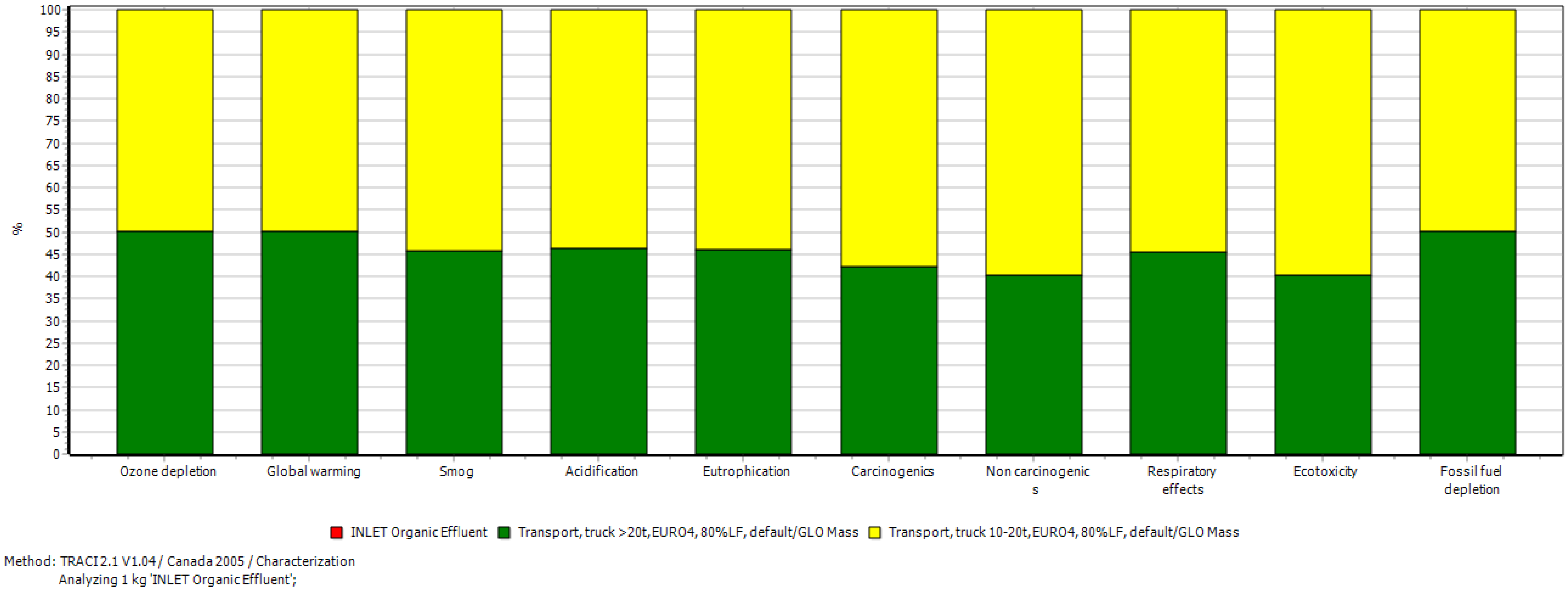

Fig. 36: Characterized LCIA results of Inlet Organic Effluent by TRACI 2.1 method

4. Wastewater Flow

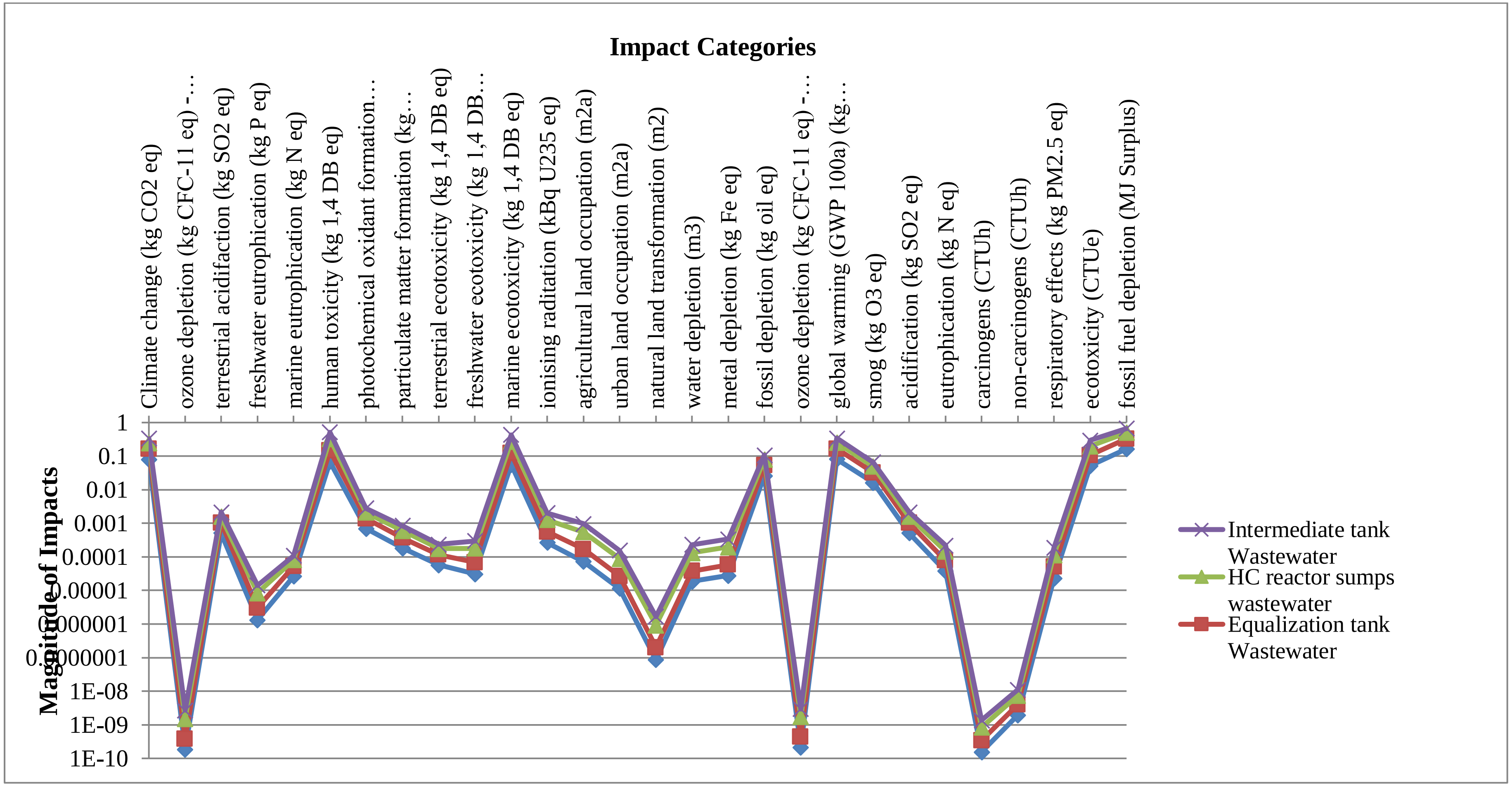

Fig. 37: Possible Environmental Impacts by different Wastewater Flow processes

The process with highest environmental impacts in almost all impact categories is "Intermediate Tank Wastewater". There are 6 impact categories which are showing maximum possible environmental impacts which are Climate Change, Human Toxicity, Marine Ecotoxicity, Fossil Depletion, Global Warming and Ecotoxicity.

The possible impacts depend on the inputs to the process. When individual process "Intermediate Tank Wastewater" is studied, it revealed that "HC Reactor Sumps Wastewater" process is showing maximum impacts. On analyzing "HC Reactor Sumps Wastewater" process, it shows that "Equalization tank Wastewater" has maximum impacts. Hence, the impacts are dependent on the inlet wastewater from previous treatment unit to the current treatment unit. The mass allocated to wastewater is higher; hence impacts are associated with wastewater in this case.

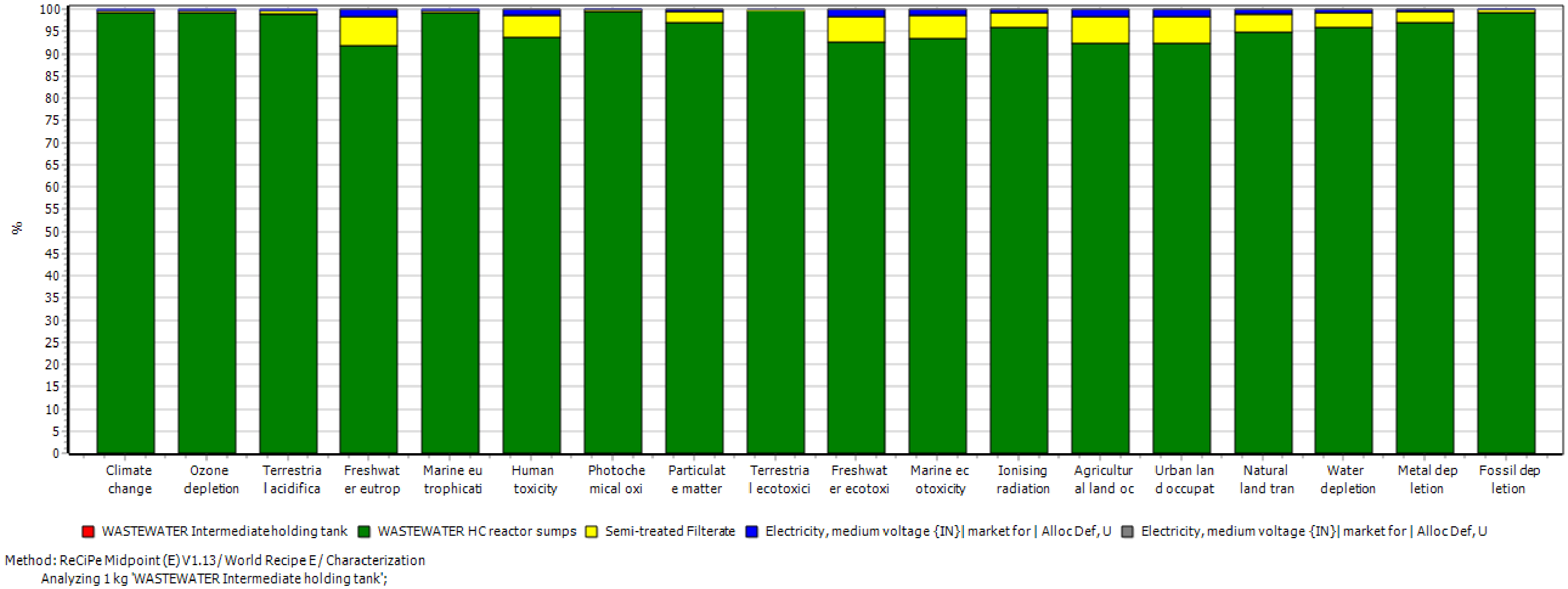

Fig. 38: Characterized LCIA results of Intermediate tank Wastewater by ReCiPe Midpoint (E) method

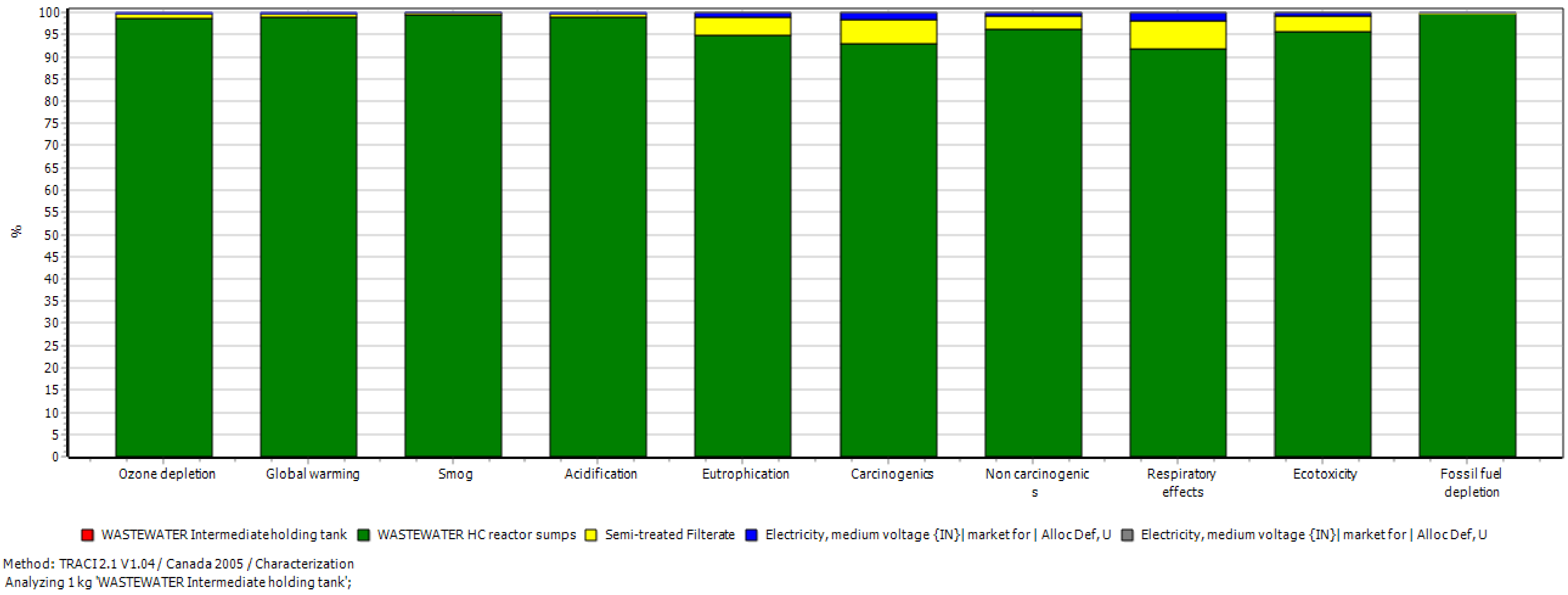

Fig. 39: Characterized LCIA results of Intermediate tank Wastewater by TRACI 2.1 method

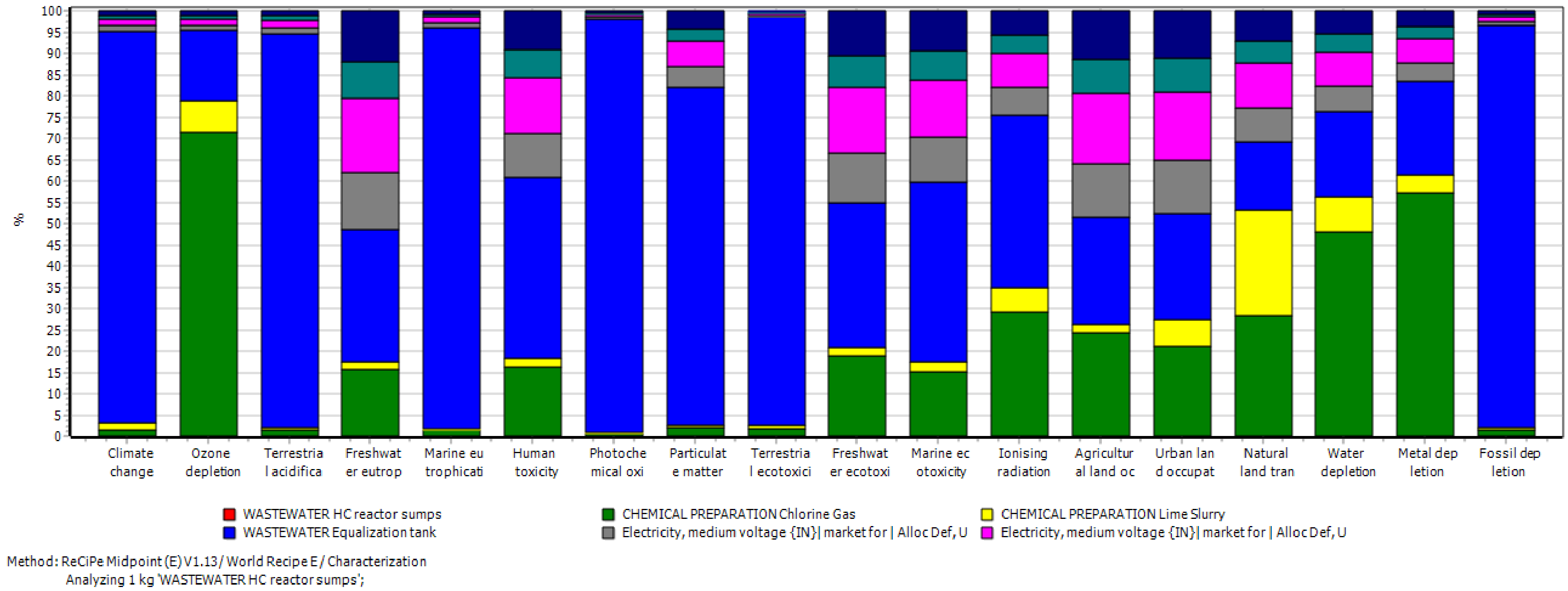

Fig. 40: Characterized LCIA results of HC Reactor Sumps Wastewater by ReCiPe Midpoint (E) method

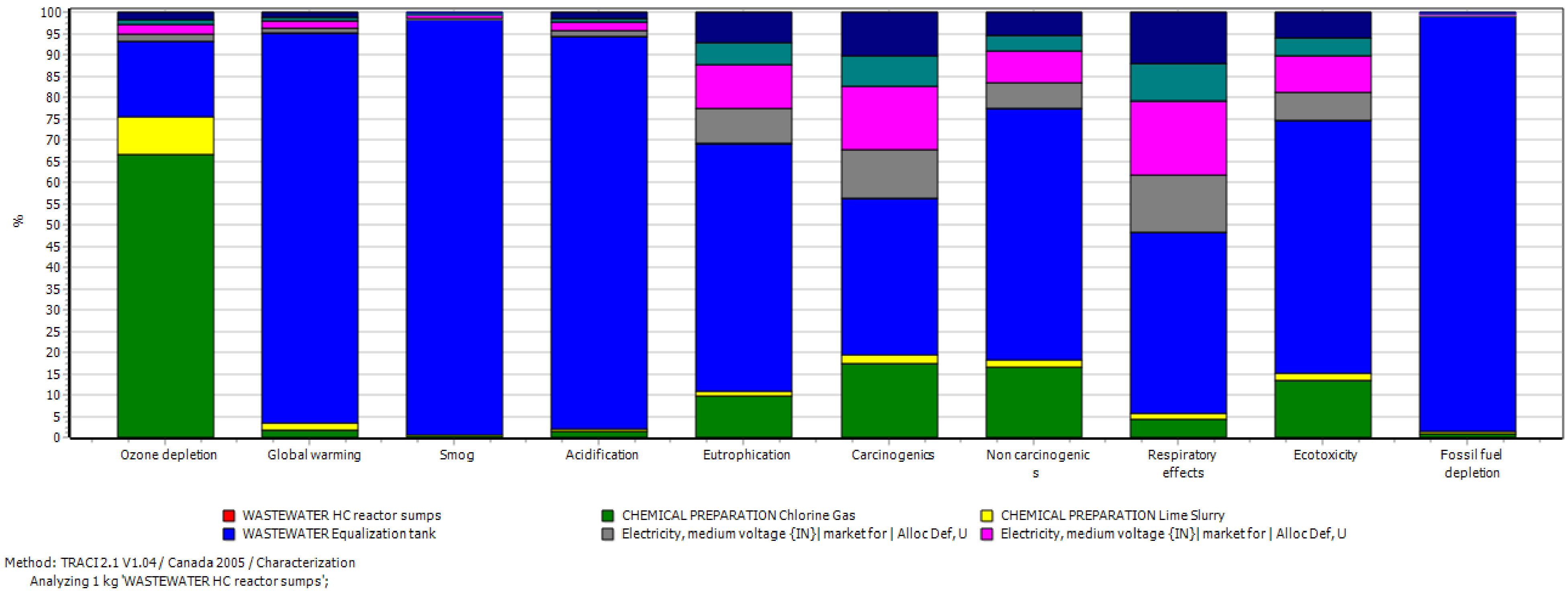

Fig. 41: Characterized LCIA results of HC Reactor Sumps Wastewater by TRACI 2.1 method

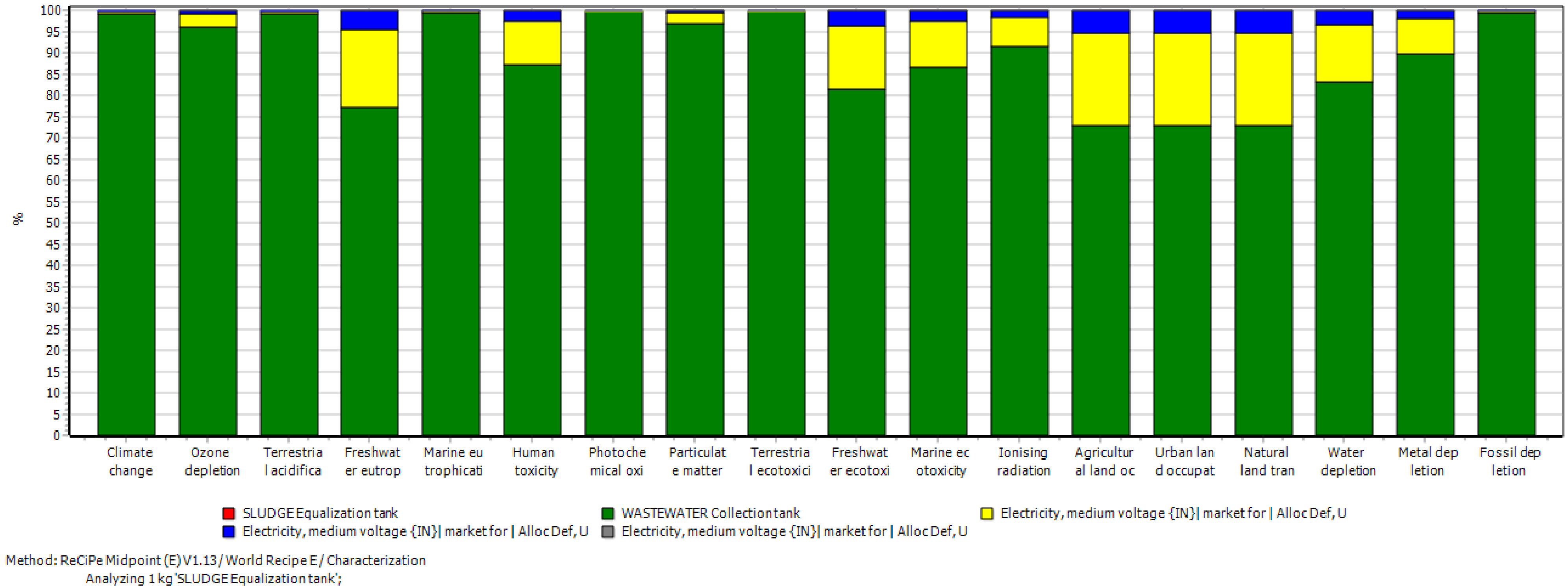

Fig. 42: Characterized LCIA results of Equalization tank Wastewater by ReCiPe Midpoint (E) method

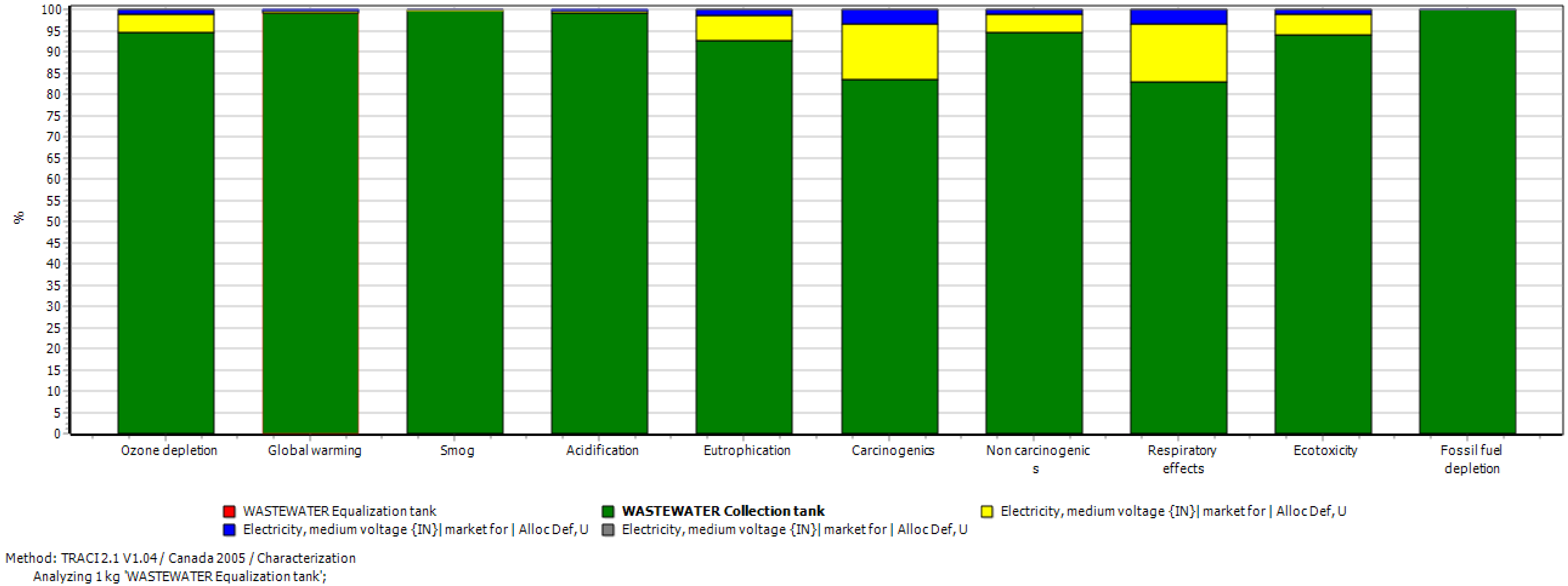

Fig. 43: Characterized LCIA results of Equalization tank Wastewater by TRACI 2.1 method

5. Total Results

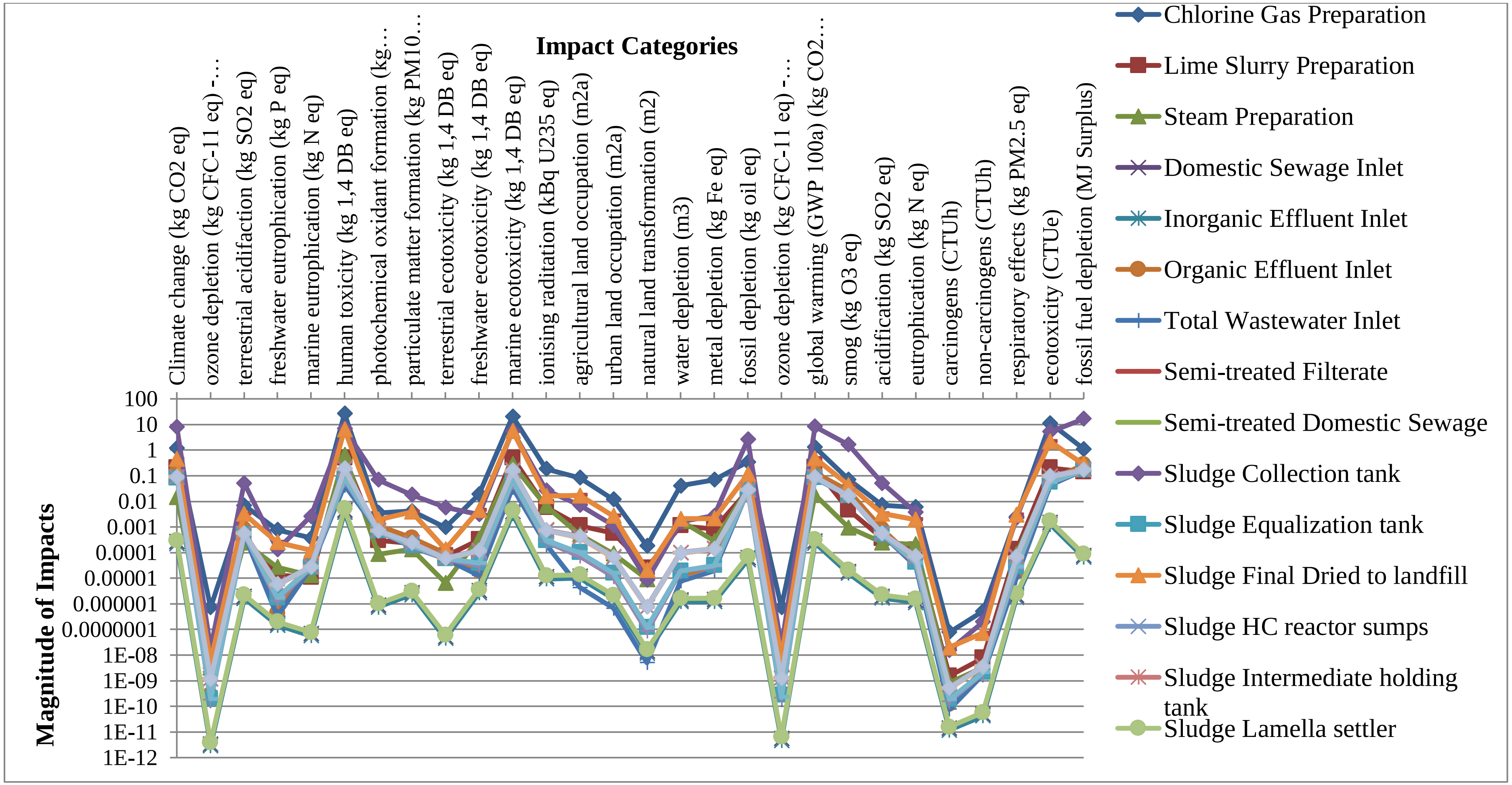

Fig. 44: Possible Environmental Impacts by All processes

The processes with highest environmental impacts in almost all impact categories are "Sludge Collection Tank", "Chlorine Gas Preparation". "Sludge Final dried to Landfill" process is showing impacts slightly closer to above mentioned 2 processes. There are 6 impact categories which are showing maximum possible environmental impacts which are Climate Change, Human Toxicity, Marine Ecotoxicity, Fossil Depletion, Global Warming and Ecotoxicity.

The pattern of graph of all processes is almost same. It shows that possible impacts of all processes are related to each other.

The possible impacts depend on the inputs to the process. When above mentioned 3 processes were studied individually, it revealed that "Inlet Total Wastewater" process is showing maximum impacts in the case of "Sludge Collection Tank"; "Electricity" process is showing maximum impacts in the case of "Sludge Final dried to Landfill" and "Liquid Chlorine" process is showing maximum impacts in the case of "Chlorine Gas Preparation".

The electricity used to pump sludge of all treatment units to filter press is higher than other electricity inputs to filter press house.

Both ReCiPe and TRACI do not consider contribution of Chlorine to ozone depletion. The "Ozone Depletion" impact category in both methods is shown in graphs. The possible impacts on Ozone depletion factor are almost negligible. This is the limitation of the 2 LCIA methods studied.

CHAPTER 6: CONCLUSIONS

Advanced oxidation processes are more energy intensive and few are more material intensive also. In Hydrodynamic Cavitation, both material and energy intensive nature was observed. Based on environmental performance of treatment plant, the pollutants are effectively removed by hydrodynamic cavitation, but at the cost of more environmental load. Electricity required in this technology is highest in the CETP and the chemicals used in the process have more environmental impacts, especially chlorine gas. There is a need for more research in the same topic with more quality and quantity data. The CETP transports organic effluent via tankers. This also has more environmental load because there are emissions related to diesel. This LCA approach was found to be beneficial for identifying actual environmental hotspots in the given CETP. Based on carbon footprint analysis, Sludge from collection tank has highest carbon footprint of about 8.25 kg CO_2eq, followed by Chlorine gas preparation with carbon footprint of 1.32 kg CO_2eq. The carbon footprint in collection tank is highest because there is pumping involved to transport wastewater to further units and transport its sludge to filter press. Also, previous process inputs to collection tank increase its environmental impact. In this study, almost all impact categories possible were studied for same CETP. This gave a broader perspective and chance of identifying impacts in different sections of environment.

SUGGESTIONS AND MODIFICATIONS

- Alternative to transportation of organic effluent from different industries should be found. Pipeline system may be used for transportation. The transportation may be done partially by tankers and partially by pipelines. The effluent can be transported by few groups of industries to some common point via tankers. Further, the effluent can be transported via pipelines thru gravity/ or pumping.
- Number of reactors in the Hydrodynamic cavitation may be reduced to decrease electricity consumption in HC reactor sumps.

FUTURE SCOPE OF RESEARCH

- More impact assessment methods can be used for comparison because all methods have different considerations and different impact categories.
- Conducting same study with more quality and quantity data.
- Comparing Hydrodynamic Cavitation technology based CETP to different AOP based CETPs.
- Efficiency of hydrodynamic cavitation reactor sumps with respect to number of HC reactors used should be found. If possible, number of HC reactor should be minimized.
- Separate LCA on transportation of effluent by pipeline should be conducted to support above suggestion.
- Study of Hydrodynamic cavitation reactor sumps' process in detail for identifying environmental impacts.
- Increasing system boundaries by including industries' pre-treatment units also.

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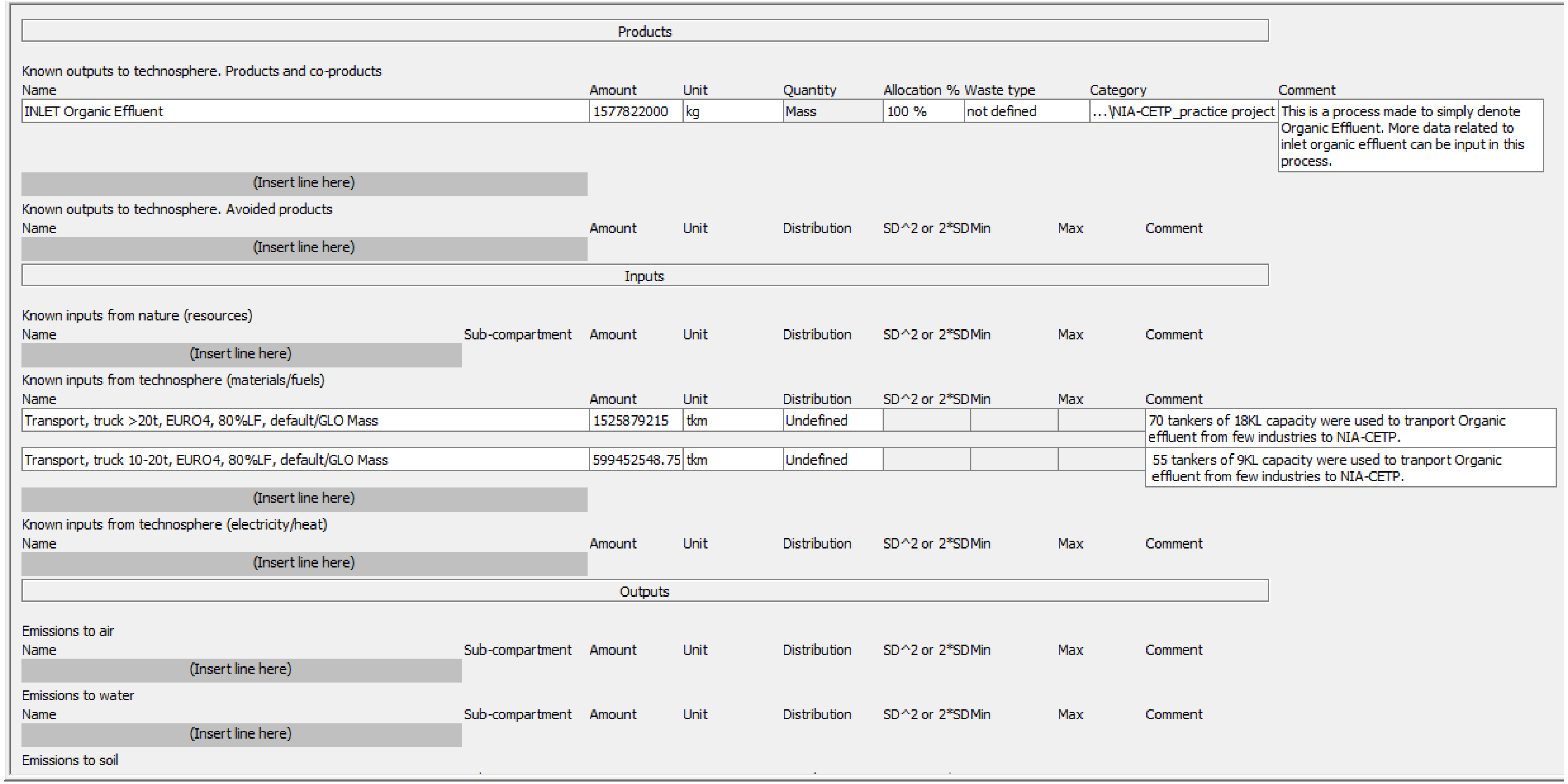
ANNEXURE - PROCESSES MADE IN SIMAPRO



Products

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Waste type	Category	Comment
INLET Organic Effluent	1577822000	kg	Mass	100 %	not defined	...\NIA-CETP_practice project	This is a process made to simply denote Organic Effluent. More data related to inlet organic effluent can be input in this process.
(Insert line here)							

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Transport, truck >20t, EURO4, 80%LF, default/GLO Mass	1525879215	tkm	Undefined				70 tankers of 18KL capacity were used to tranport Organic effluent from few industries to NIA-CETP.
Transport, truck 10-20t, EURO4, 80%LF, default/GLO Mass	599452548.75	tkm	Undefined				55 tankers of 9KL capacity were used to tranport Organic effluent from few industries to NIA-CETP.
(Insert line here)							

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Outputs

Emissions to air

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Emissions to water

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Emissions to soil

Fig. : “Inlet Organic Effluent” process made in SimaPro

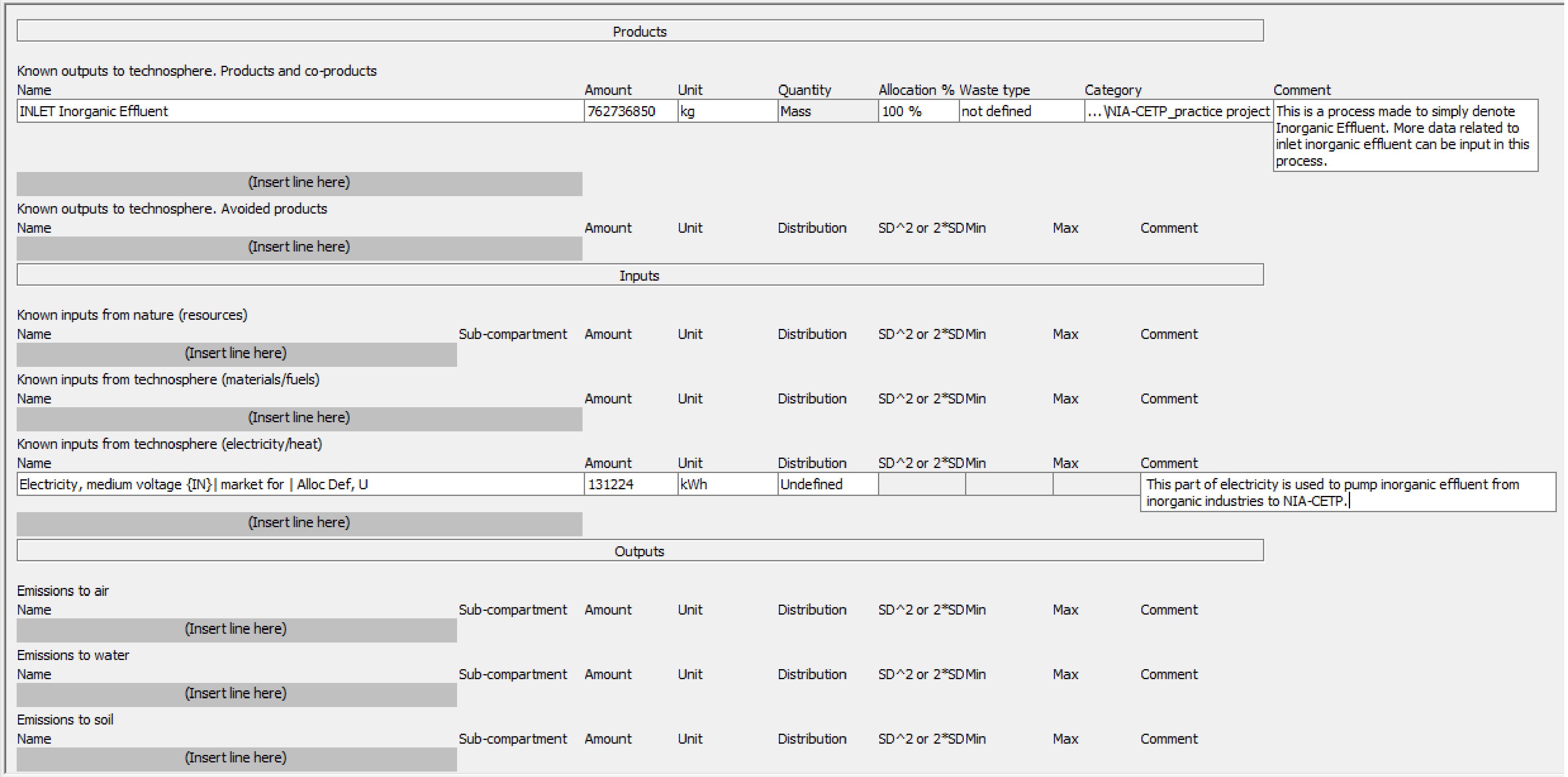


Fig. : "Inlet Inorganic Effluent" process made in SimaPro

Products

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Waste type	Category	Comment
INLET Domestic sewage	256777500	kg	Mass	100 %	not defined	...\NIA-CETP_practice project	This is a process made to simply denote Domestic Sewage. More data related to inlet domestic sewage can be input in this process.
(Insert line here)							

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Electricity, medium voltage {IN}| market for | Alloc Def, U	52490	kWh	Undefined				This part of electricity is used to pump domestic sewage from GIDC colony to NIA-CETP.
(Insert line here)							

Outputs

Emissions to air

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

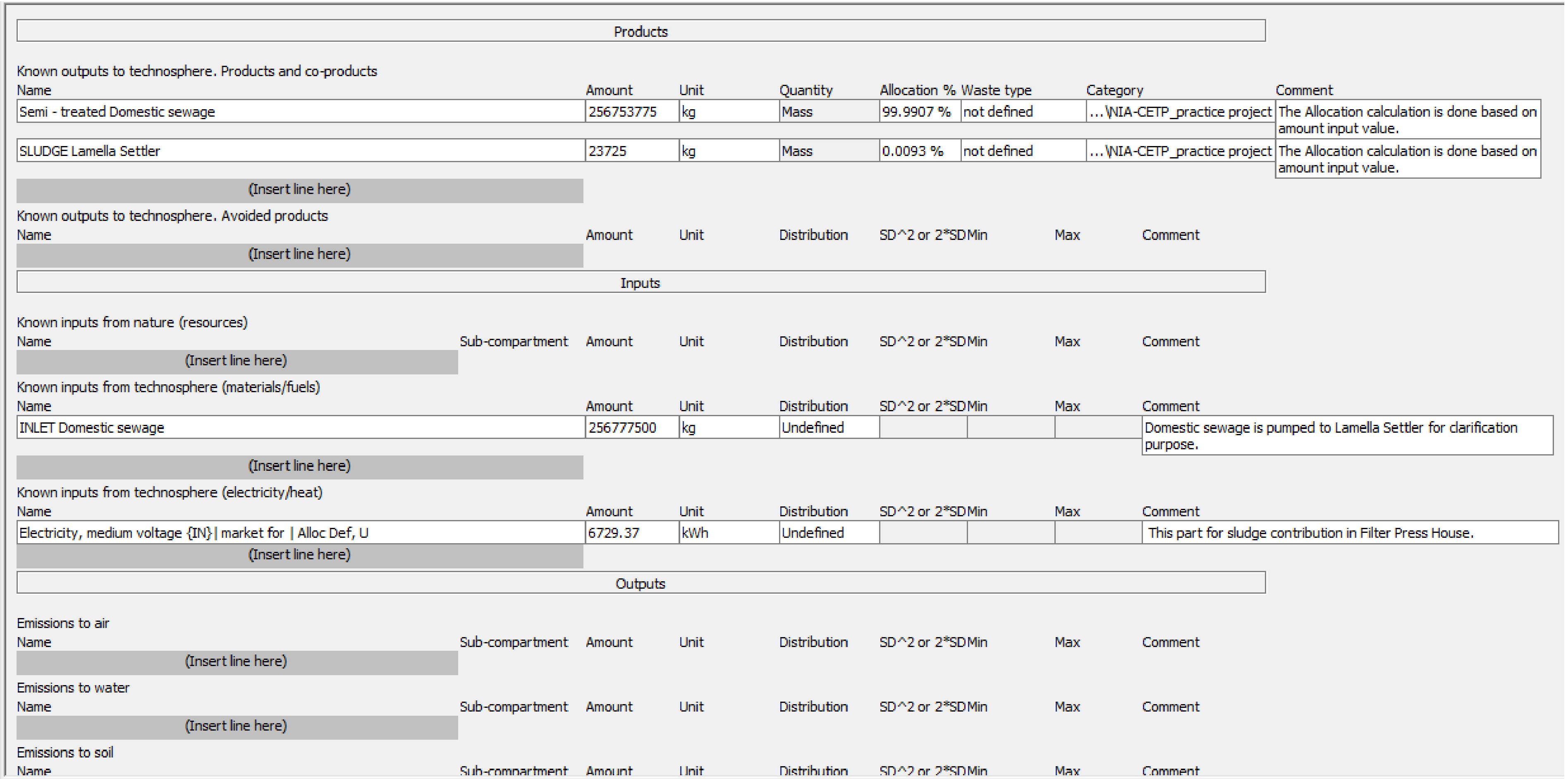
Emissions to water

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Emissions to soil

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Fig. : "Inlet Domestic Sewage" process made in SimaPro



Products

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Waste type	Category	Comment
Semi - treated Domestic sewage	256753775	kg	Mass	99.9907 %	not defined	...\NIA-CETP_practice project	The Allocation calculation is done based on amount input value.
SLUDGE Lamella Settler	23725	kg	Mass	0.0093 %	not defined	...\NIA-CETP_practice project	The Allocation calculation is done based on amount input value.
(Insert line here)							

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
INLET Domestic sewage	256777500	kg	Undefined				Domestic sewage is pumped to Lamella Settler for clarification purpose.
(Insert line here)							

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Electricity, medium voltage {IN}| market for | Alloc Def, U	6729.37	kWh	Undefined				This part for sludge contribution in Filter Press House.
(Insert line here)							

Outputs

Emissions to air

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Emissions to water

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Emissions to soil

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment

Fig. : “Lamella Settler” process made in SimaPro

Products

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Waste type	Category	Comment
INLET Total Wastewater	2597312625	kg	Mass	100 %	not defined	...\NIA-CETP_practice project	This process is used to compile all the inlet wastewater processes.
(Insert line here)							

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
INLET Inorganic Effluent	762736850	kg	Undefined				Inorganic effluent is pumped to NIA-CETP.
INLET Organic Effluent	1577822000	kg	Undefined				Organic effluent is tranported via tankers to NIA-CETP.
Semi - treated Domestic sewage	256753775	kg	Undefined				Domestic sewage is pumped to NIA-CETP and then passed through Lamella Settler for clarification purpose.
(Insert line here)							

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Outputs

Emissions to air

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Emissions to water

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Emissions to soil

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Fig. : “Inlet Total Wastewater” process made in SimaPro

Products

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Waste type	Category	Comment
WASTEWATER Collection tank	2597311081	kg	Mass	99.99405 %	not defined	...\NIA-CETP_practice project	The Allocation calculation is done based on amount input value.
SLUDGE Collection tank	1544	kg	Mass	0.00595 %	not defined	...\NIA-CETP_practice project	The Allocation calculation is done based on amount input value.
(Insert line here)							

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
INLET Total Wastewater	2597312625	kg	Undefined				Wastewater from all industries is discharged in 8 collection tanks.
(Insert line here)							

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Electricity, medium voltage {IN}| market for | Alloc Def, U	2991909.4	kWh	Undefined				This part of electricity is used for pumping wastewater from collection tank to equalization tank.
Electricity, medium voltage {IN}| market for | Alloc Def, U	437.962	kWh	Undefined				This part for sludge contribution in Filter Press House.
(Insert line here)							

Outputs

Emissions to air

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Emissions to water

Fig. : "Collection tanks" process made in SimaPro

Products

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Waste type	Category	Comment
WASTEWATER Equalization tank	2597310309	kg	Mass	99.99997 %	not defined	...\NIA-CETP_practice project	The Allocation calculation is done based on amount input value.
SLUDGE Equalization tank	772	kg	Mass	0.00003 %	not defined	...\NIA-CETP_practice project	The Allocation calculation is done based on amount input value.
(Insert line here)							

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
WASTEWATER Collection tank	2597311081	kg	Undefined				Wastewater from 8 collection tanks is discharged in 2 equalization tanks in batch mode.
(Insert line here)							

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Electricity, medium voltage {IN}| market for | Alloc Def, U	944813.49	kWh	Undefined				This part of electricity is used for pumping wastewater from equalization tank to 9 HC reactor Sumps.
Electricity, medium voltage {IN}| market for | Alloc Def, U	236203.3	kWh	Undefined				This part of electricity is used for pumping Sludge from equalization tank to Filter Press House.
Electricity, medium voltage {IN}| market for | Alloc Def, U	217.203	kWh	Undefined				This part for sludge contribution in Filter Press House.
(Insert line here)							

Outputs

Emissions to air

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment

Fig. : “Equalization tanks” process made in SimaPro

Products

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Waste type	Category	Comment
CHEMICAL PREPARATION Steam	2190000	kg	Mass	100 %	not defined	...\NIA-CETP_practice project	The Allocation calculation is done based on amount input value.
(Insert line here)							

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Water, unspecified natural origin, IN	in water	2190	m3	Undefined				Demineralized water is purchased from outside and used for production of Steam.
(Insert line here)								

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Natural gas, high pressure {RoW}| market for | Alloc Def, U	68531	m3	Undefined				PNG is used as fuel to burn inside the boiler to produce heat.
Water, ultrapure {RoW}| production | Alloc Def, U	1460000	kg	Undefined				Condensed water from vaporizer is also fed to hot water boiler.
(Insert line here)							

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Electricity, medium voltage {IN}| market for | Alloc Def, U	15746.89	kWh	Undefined				This part of electricity is used to pump demineralized water to the hot water boiler.
(Insert line here)							

Outputs

Emissions to air

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Emissions to water

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Emissions to soil

Fig. : “Hot Water Boiler” process made in SimaPro

Products

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Waste type	Category	Comment
CHEMICAL PREPARATION Chlorine Gas	2942100	kg	Mass	100 %	not defined	...\NIA-CETP_practice project	The Allocation calculation is done based on amount input value.

(Insert line here)

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Water, ultrapure {RoW}| production | Alloc Def, U	1460000	kg	Undefined				Some amount of condensed steam is tranported back to hot water boiler to reduce the fresh water requirement by boiler.

(Insert line here)

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment

(Insert line here)

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Chlorine, liquid {GLO}| production | Alloc Def, U	2942100	kg	Undefined				Liquid Chlorine is purchased from nearby chemical industry in Tonners.
CHEMICAL PREPARATION Steam	2190000	kg	Undefined				Steam prepared in the hot water boiler is tranported to Vaporizer via insulated pipe.

(Insert line here)

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment

(Insert line here)

Outputs

Emissions to air

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment

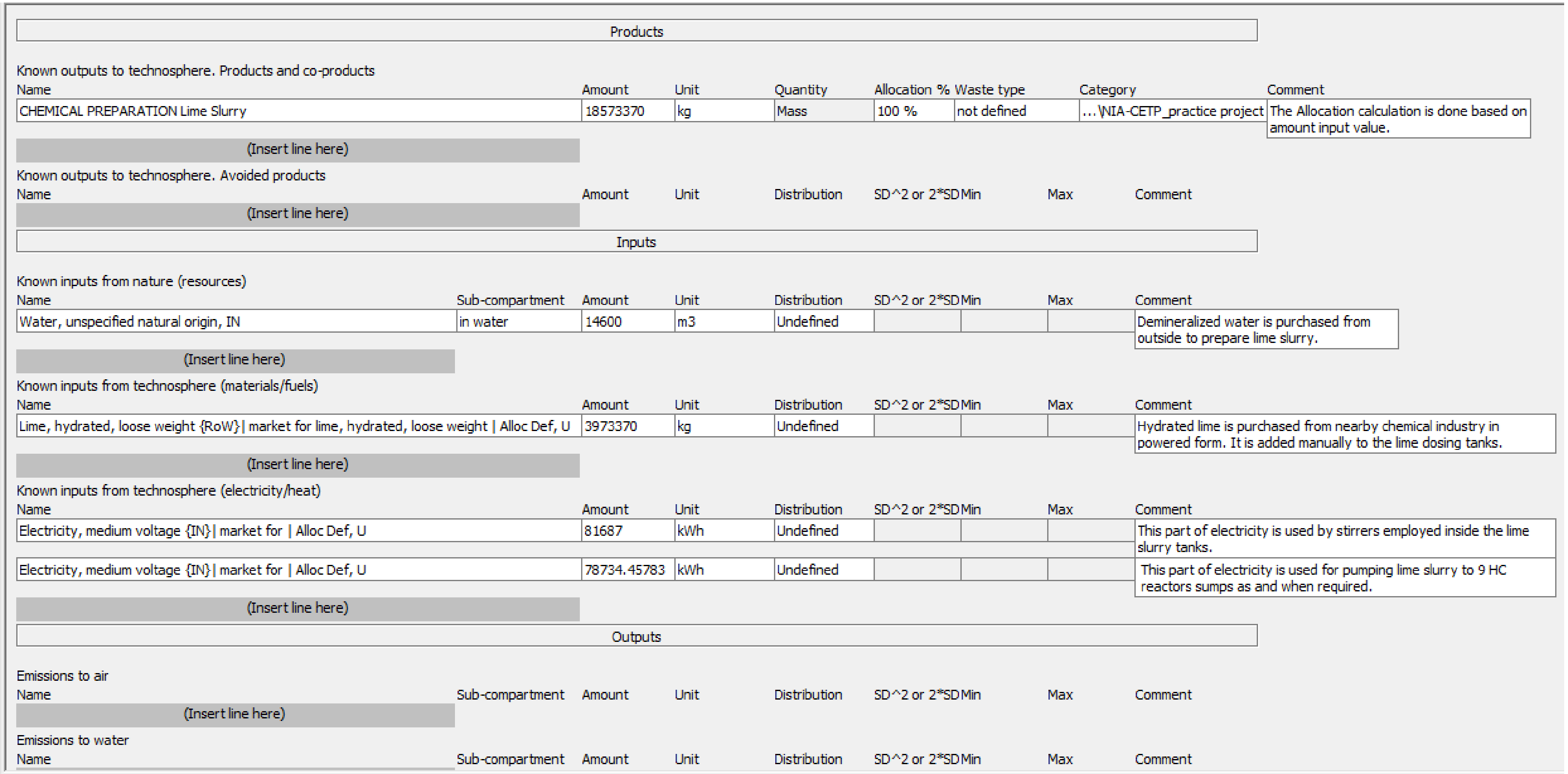
(Insert line here)

Emissions to water

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment

(Insert line here)

Fig. : “Vaporizer” process made in SimaPro



Products

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Waste type	Category	Comment
CHEMICAL PREPARATION Lime Slurry	18573370	kg	Mass	100 %	not defined	...\NIA-CETP_practice project	The Allocation calculation is done based on amount input value.

(Insert line here)

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment

(Insert line here)

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Water, unspecified natural origin, IN	in water	14600	m3	Undefined				Demineralized water is purchased from outside to prepare lime slurry.

(Insert line here)

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Lime, hydrated, loose weight {RoW}| market for lime, hydrated, loose weight | Alloc Def, U	3973370	kg	Undefined				Hydrated lime is purchased from nearby chemical industry in powered form. It is added manually to the lime dosing tanks.

(Insert line here)

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Electricity, medium voltage {IN}| market for | Alloc Def, U	81687	kWh	Undefined				This part of electricity is used by stirrers employed inside the lime slurry tanks.
Electricity, medium voltage {IN}| market for | Alloc Def, U	78734.45783	kWh	Undefined				This part of electricity is used for pumping lime slurry to 9 HC reactors sumps as and when required.

(Insert line here)

Outputs

Emissions to air

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment

(Insert line here)

Emissions to water

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment

Fig. : “Lime Slurry Preparation tanks” process made in SimaPro

Products

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Waste type	Category	Comment
WASTEWATER HC reactor sumps	2611890779	kg	Mass	99.735 %	not defined	...\NIA-CETP_practice project	The Allocation calculation is done based on amount input value.
SLUDGE HC reactor sumps	6935000	kg	Mass	0.265 %	not defined	...\NIA-CETP_practice project	The Allocation calculation is done based on amount input value.
(Insert line here)							

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
CHEMICAL PREPARATION Chlorine Gas	2942100	kg	Undefined				Chlorine Gas is transported by vaporizer to HC reactors sumps via insulated pipe.
CHEMICAL PREPARATION Lime Slurry	18573370	kg	Undefined				Lime Slurry is dosed to HC reactors sumps as and when required to maintain pH above 11.
WASTEWATER Equalization tank	2597310309	kg	Undefined				Wastewater from Equalization tanks is pumped to 9 HC reacors sumps in batch mode.
(Insert line here)							

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Electricity, medium voltage {IN}| market for | Alloc Def, U	2204564.8	kWh	Undefined				This part of electricity is used for pumping wastewater from HC reactor sumps to Intermediate holding tank.
Electricity, medium voltage {IN}| market for | Alloc Def, U	2834440.48	kWh	Undefined				This part of electricity is used for working of HC reactors.
Electricity, medium voltage {IN}| market for | Alloc Def, U	1417220.2	kWh	Undefined				This part of electricity is used for pumping Sludge from HC reactor sumps to Filter Press House.
Electricity, medium voltage {IN}| market for | Alloc Def, U	1967176.62	kWh	Undefined				This part for sludge contribution in Filter Press House.
(Insert line here)							

Outputs

Fig. : “HC Reactors Sumps” process made in SimaPro

Products

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Waste type	Category	Comment
SLUDGE Final dried to Landfill	3020530	kg	Mass	43.391 %	not defined	...\NIA-CETP_practice project	The Allocation calculation is done based on amount input value.
Semi-treated Filterate	3940562	kg	Mass	56.609 %	not defined	...\NIA-CETP_practice project	The Allocation calculation is done based on amount input value.
(Insert line here)							

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
SLUDGE Lamella Settler	23725	kg	Undefined				Lamella settler sludge is generated when bottom value of lamella settler is opened. It is mixed with other unit's sludge for dewatering in filter press house.
SLUDGE Collection tank	1544	kg	Undefined				Collection tank sludge is pumped to filter press regularly.
SLUDGE Equalization tank	772	kg	Undefined				Equalization tank sludge is pumped to filter press regulary.
SLUDGE HC reactor sumps	6935000	kg	Undefined				HC reactors sumps' sludge is pumped to filter press house regulary.
SLUDGE Intermediate Holding tank	51	kg	Undefined				Intermediate holding tank sludge is generated when it is cleaned It is mixed with other unit's sludge for dewatering in filter press house.
(Insert line here)							

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Electricity, medium voltage {IN}| market for | Alloc Def, U	1889626.9	kWh	Undefined				This part of electricity is used for pumping sludge to all filter presses.
Electricity, medium voltage {IN}| market for | Alloc Def, U	19604.8	kWh	Undefined				This part of electricity is used inside filter press by Clamping Mechanisms.
Electricity, medium voltage {IN}| market for | Alloc Def, U	65349.6	kWh	Undefined				This part of electricity is used when cleaning of filter presses is done by Pressure Jet.
(Insert line here)							

Fig. : "Filter Press house" process made in SimaPro

Products

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Waste type	Category	Comment
WASTEWATER Intermediate holding tank	2615831290	kg	Mass	99.999998 °	not defined	...\NIA-CETP_practice project	The Allocation calculation is done based on amount input value.
SLUDGE Intermediate Holding tank	51	kg	Mass	0.000002 %	not defined	...\NIA-CETP_practice project	The Allocation calculation is done based on amount input value.
(Insert line here)							

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
WASTEWATER HC reactor sumps	2611890779	kg	Undefined				Wastewater from all HC reactors sumps is discharged in intermediate holding tank.
Semi-treated Filterate	3940562	kg	Undefined				Filterate comes from Filter press house for storage purpose only.
(Insert line here)							

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Electricity, medium voltage {IN}| market for | Alloc Def, U	314937.8	kWh	Undefined				This part of electricity is used for pumping wastewater from intermedaite holding tank to final holding tank.
Electricity, medium voltage {IN}| market for | Alloc Def, U	13.822	kWh	Undefined				This part for sludge contribution in Filter Press House.
(Insert line here)							

Outputs

Emissions to air

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)								

Emissions to water

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment

Fig. : “Intermediate Holding Tank” process made in SimaPro