COMPARATIVE ANALYSIS OF NAPHTHA PRODUCTION FROM CRUDE OIL AT EUROPE AND SWITZERLAND REFINERY USING LIFE CYCLE ASSESSMENT

A Project Report Submitted in Partial Fulfillment of the
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DISASTER MANAGEMENT

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2015

INDIA GLYCOLS LIMITED

BONAFIDE CERTIFICATE

This is to certify that **Mr. VYOMESH KUMAR GUPTA,** a student of M. Tech. (Disaster Management) of **UNIVERSITY OF PETROLEUM AND ENERGY STUDIES, DHERADUN** has undergone his **Project Work** at **INDIAN GLYCOL LIMITED, KASHIPUR, UTTARAKHAND from 25/02/2015 to 17/04/2015.**

His study on **COMPARATIVE ANALYSIS OF NAPHTHA PRODUCTION FROM CRUDE OIL AT EUROPE AND SWITZERLAND REFINERY USING LIFE CYCLE ASSESSMENT** is noteworthy.

During the project period, he was found very punctual and disciplined. I wish him all success in life.

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Certified this titled "Comparative Analysis of NAPHTHA Production from Crude Oil at Europe and Switzerland Refinery Using Life Cycle Assessment" is the bonafide work of **VYOMESH KUMAR GUPTA (R107213017)** who carried out the work under my supervision. Certified further that to the best of my knowledge the work reported herein does not form part of any other thesis or dissertation on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

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Last but not least I wish to avail myself of this opportunity, express a sense of gratitude and love to my friends and beloved parents for their manual support, strength, and help for everything.

During my project I have learnt the peak tip for doing any project-

“A PROJECT IS COMPLETE WHEN IT STARTS WORKING FOR YOU, **RATHER THAN YOU WORKING FOR IT”**

With a heartfelt gratitude,

Vyomesh Kumar Gupta

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Chapter 1

INTRODUCTION

1.1 BACKGROUND

A life-cycle assessment is a technique to assess the environmental impact that is associated with all of the stages of a product's life, from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. According to the ISO 14040 and 14044 standards, a Life Cycle Assessment has four distinct phases. The first phase is 'Goal and scope', which requires an explicit statement of the goal and scope of the study. It establishes the context of the study and explains how and to whom the results are to be communicated. The second phase is a ‘Life cycle inventory (LCI)’, which involves the creation of an inventory of the flows from and to nature for a product system. Inventory flows include inputs of water, energy and raw materials, and releases to air, land and water. The third phase is a ‘Life cycle impact assessment (LCIA)’, which evaluates the significance of any potential environmental impact, based on the LCI flow results. A classical LCIA consists of the following mandatory elements: selection of impact categories, category indicators and characterization models. In the classification stage, the inventory parameters are sorted and assigned to specific impact categories. In impact measurement, the categorized LCI flows are characterized, using one of many possible LCIA methodologies, into common equivalence units that are then summed to provide an overall impact category total. The last phase is ‘Interpretation’, which is a systematic technique that identifies, quantifies, checks, and evaluates information from the results of the life cycle inventory and/or the life cycle impact assessment. The results of the inventory analysis and impact assessment are summarized during the interpretation phase.

The purpose of this work is to present an evaluation of life cycle inventory analysis and environmental impacts of naphtha produced from crude oil in refinery from Switzerland and Europe. The tool used for evaluation is Life Cycle Assessment. The comparative assessment has been done using the Eco-indicator 99 and IPCC 2013 GWP 100a V 1.00 methods.

1.2 GLOBAL SCENARIO FOR NAPHTHA

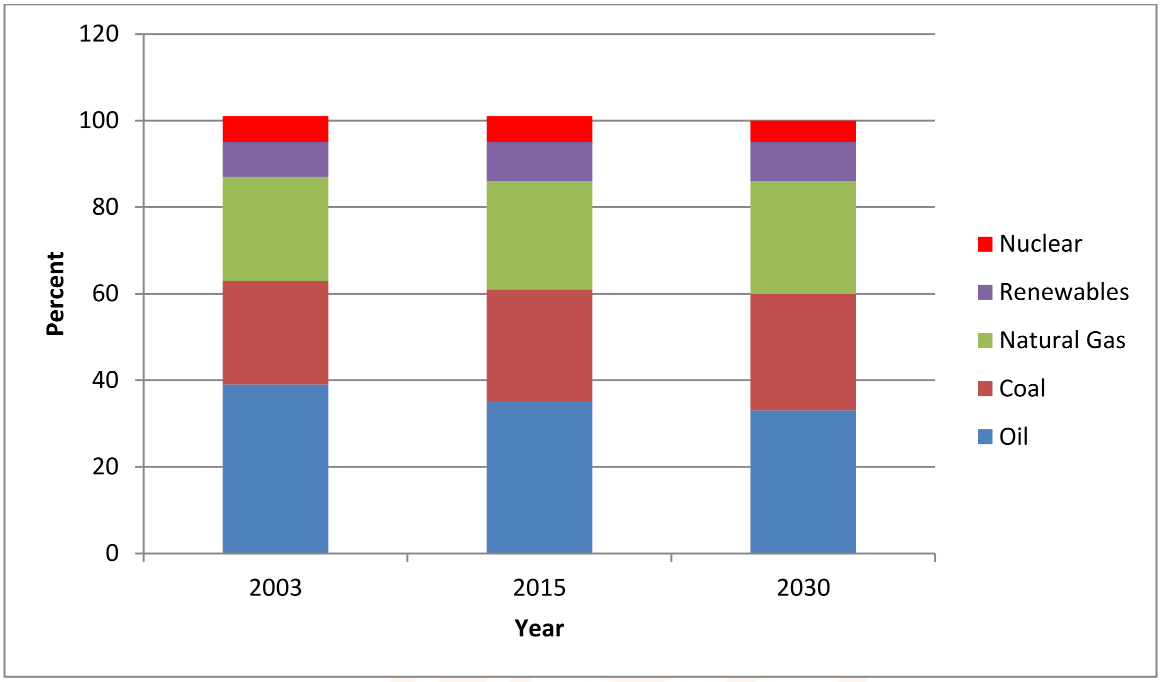


Figure 1-1 Energy consumption

Naphtha use is expected to grow from about 80 million barrels per day (mbpd) in 2003 to 98 mbpd in 2015 and 118 mbpd in 2030 as per Energy Information Administration (EIA), International Energy Outlook (IEO) 2006.

In the figure1.1 is shown the Energy Consumption worldwide. In the IEO 2006 reference case, world oil prices rise from $31 per barrel (in real 2004 dollars) in 2003 to $57 per barrel in 2030, and oil's share of total world energy use falls from 39 percent to 33 percent. Shift in energy mix over the period of time is shown in the chart.

To meet the projected increase in world naphtha demand, total petroleum supply in 2030 will need to be 38 mbpd higher than the 2003 level of 80 mbpd. Of this, China is projected to consume additional 9.4 mbpd, US 7.5 mbpd and Asia (other than China & India) 6 mbpd. The balance growth is expected in South America, Africa and Middle East. As per the same report India is expected to consume additional 2.2 mbpd 1. OPEC producers are expected to provide

14.6 mbpd of the increase. Higher oil prices cause a substantial increase in non-OPEC oil production—23.7 mbpd, which represents 62 percent of the increase in total world oil supplies over the projection period. In addition, unconventional resources (including biofuels, coal-to-liquids, and gas-to-liquids) are expected to become more competitive. In 2003, world production of unconventional resources totalled only 1.8 mbpd. Unconventional resource supplies are expected to rise to 11.5 mbpd and would account for nearly 10 per cent of total world energy supply in 2030.

1.3 OBJECTIVE

The life cycle assessment of NAPHTHA was done with the following objectives:

- To understand the Life Cycle Assessments (LCA) process.
- Identify processes/materials which contribute the most environmental impact.
- Identify opportunities to improve the environmental performance of products at various points in their life cycle.
- To do the comparative analysis of environmental impacts caused by the Naphtha production at Europe and Switzerland Refinery.
- To quantify environmental benefits and impacts of products.
- Understand relative contribution of processes and products.

CHAPTER 2

LITERATURE REVIEW

2.1 PREVIOUS RESEARCH WORK

The following standards have been studied & papers have reviewed and the methodology of the project **“COMPARATIVE ANALYSIS OF NAPHTHA PRODUCTION FROM CRUDE OIL AT EUROPE AND SWITZERLAND REFINERY USING LIFE CYCLE ASSESSMENT”** has been identified and followed:

Serial No	Title of Paper/Standard	Year	Author Name	Findings
1	ISO 14040: Environmental management	Geneve, 2006	International Organization for Standardization (ISO)	Life cycle assessment – Principles and framework
2	ISO 14044: Environmental management	Geneve, 2006	International Organization for Standardization (ISO)	Life cycle assessment – Requirements and guidelines
3	ISO 14042: Environmental management	Geneve, 2000	International Organization for Standardization (ISO)	Life cycle assessment – Life Cycle Impact Assessment
4	ISO 14043: Environmental management	Geneve, 2000	International Organization for Standardization (ISO)	Life cycle assessment – Life Cycle Interpretation
5	ISO 14041: Environmental management	Geneve, 1998	International Organization for Standardization (ISO)	Life cycle assessment – Goal and Scope definition and Inventory Analysis
6	The Propagation of Probabilistic and Possibilistic Uncertainty in a Life Cycle Assessment: A Case Study of a Naphtha Cracking Plant in Taiwan	Kevin Fong-Rey Liu, Si-Yu Chiu, Ming-Jui Hung, and Jong-Yih Kuo,	December 2013	Each phase of a LCA involves some simplifications, assumptions and choices.

7	Life Cycle Assessment Of The Methanol Production From Sugarcane Bagasse Considering Two Different Alternatives Of Energy Supply	Maria Luiza Grillo Renó, Electo Eduardo Silva Lora	November2009	Evaluation of life cycle energy balance and environmental impacts of production of methanol from biomass.

2.2 SYSTEM DETAILS

Naphtha is a general term that has been used for over two thousand years to refer to flammable liquid hydrocarbon mixtures. Mixtures labeled naphtha have been produced from natural gas condensates, petroleum distillates, and the distillation of coal tar and peat. It is used differently in different industries and regions to refer to gross products like crude_oil or refined products such as kerosene.

Naphtha From Crude Oil

The crude oil distillation unit (CDU) is the first processing unit in virtually all petroleum refineries. The CDU distills the incoming crude oil into various fractions of different boiling ranges, each of which are then processed further in the other refinery processing units. The CDU is often referred to as the *atmospheric distillation unit* because it operates at slightly above atmospheric pressure.

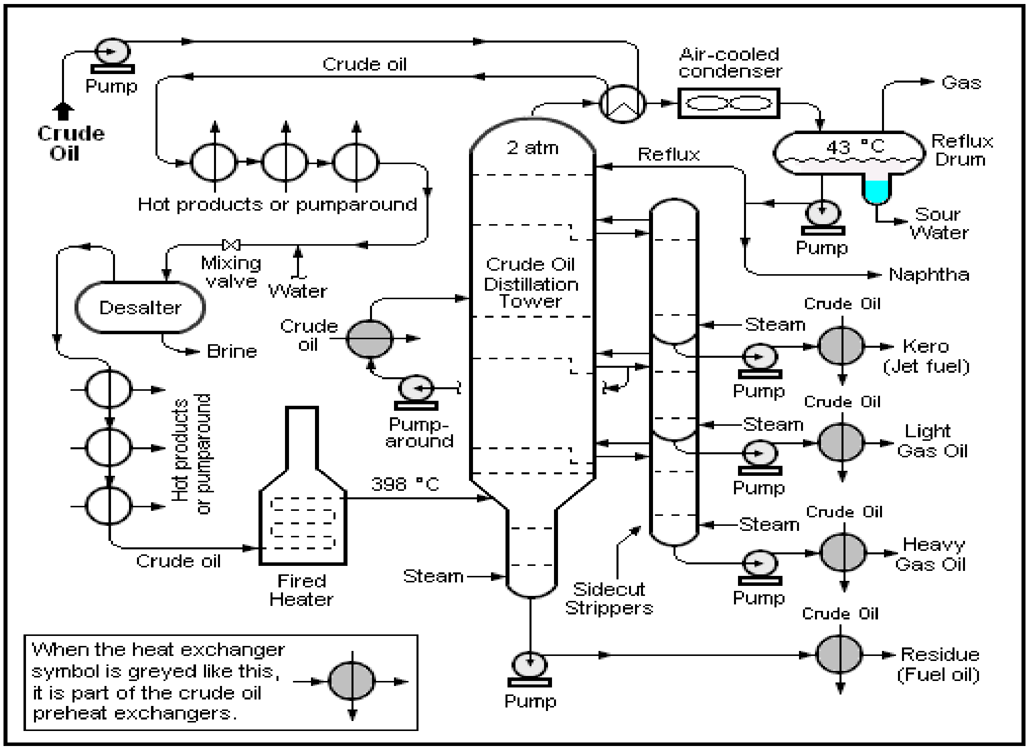


Figure 2-1 Atmospheric distillation unit

In figure2.1 is a schematic flow diagram of a typical crude oil distillation unit. The incoming crude oil is preheated by exchanging heat with some of the hot, distilled fractions and other streams. It is then desalted to remove inorganic salts (primarily sodium chloride).

Following the desalter, the crude oil is further heated by exchanging heat with some of the hot, distilled fractions and other streams. It is then heated in a fuel-fired furnace (fired heater) to a temperature of about 398 °C and routed into the bottom of the distillation unit.

The cooling and condensing of the distillation tower overhead is provided partially by exchanging heat with the incoming crude oil and partially by either an air-cooled or water-cooled condenser. Additional heat is removed from the distillation column by a pump around system as shown in the diagram below.

As shown in the flow diagram, the overhead distillate fraction from the distillation column is naphtha. The fractions removed from the side of the distillation column at various points between the column top and bottom is called *side cuts*.

CHAPTER 3

METHODOLOGY

3.1 LIFE CYCLE ASSESSMENT

Life Cycle Assessment (LCA) studies involve the collection, assessment and interpretation of data from an environmental perspective over a product's lifecycle (production, use, and end of life). Studies can evaluate entire product life cycle, often referred to as cradle-to-gate. The ISO 14040 series of standards contain the international standards for LCA. These series were developed by international experts on LCA from more than fifty countries over a period of more than 10 years. According to ISO 14040, the four phases of an LCA are (1) Goal and Scope Definition, (2) Life Cycle Inventory, (3) Impact Assessment, and (4) Interpretation.

Goal and scope definition is the phase of the LCA process that define the purpose and method of including life cycle environmental impacts into the decision-making process. In this phase, the following items must be determined: the type of information that is needed to add value to the decision-making process, how accurate the results must be add value, and how the results should be interpreted and displayed in order to be meaningful and usable.

Life Cycle Inventory (LCI) involves compiling data about relevant inputs and outputs of a product system that may contribute to multiple environmental issues. Material and energy balances are performed. The data collection is carried out for each process as defined in the goal and scope definition (e.g., air emissions, solid waste disposal, and waste water discharges).

One of the most important and frequent methodological problems to be tackled, when carrying out the life cycle inventory is the allocation of environmental loads in processes in which there are several useful products (co-products). The various allocation principles may be divided into five groups:

- Allocation based on natural causality. If there are natural identifiable causalities for environmental loads, allocation must be based on these.

- Allocation based on some physical parameter. Examples of physical quantities are: mass, volume, energy, number of moles, etc.

- Allocation based on social causes of the process. The justification for a process is that it produces value. These values may or may not be measurable in economic terms.

- Allocation based on an arbitrary number. This criterion should only be based in case there is no other possibility.

- Extension of system boundaries, avoiding the allocation problem.

Life Cycle Impact Assessment (LCIA) phase of an LCA is the evaluation of potential human health and environmental impacts of the environmental resources and releases identified during the LCI. So, Impact Assessment should address ecological and human health effects; it should also address resource depletion. A LCIA attempts to establish a linkage between the product or process and its potential environmental impacts.

According to ISO 14044, Life Cycle Impact Assessment proceeds through two mandatory and two optional steps:

1 – Selection of impact categories and classification, where the categories of environmental impacts, which are of relevance to the study, are defined by their impact pathway and impact indicator, and the elementary flows from the inventory are assigned to the impacts categories according to substances' ability to contribute to different environmental problems (mandatory).

2 – Characterization, where the impact from each emission is modeled quantitatively according to the underlying environmental mechanism. The impact is expressed as an impact score in a unit common to all contributions within the impact category applying characterization factors. A characterization factor is a substance-specific factor calculated with a characterization model for expressing the impact from the particular elementary flow in terms of the common unit of the category indicator (mandatory).

3 – Normalization, where the different characterized impact scores are related to a common reference, e.g. the impacts caused by one person during one year, in order to facilitate comparisons across impact categories (optional).

4 – Weighting, where a ranking and/or weighting are performed of the different environmental impact categories reflecting the relative importance that is assigned in the study (optional).

Interpretation is the final phase of an LCA. In the interpretation, an investigation of significant environmental aspects (energy use, greenhouse gases), significant contributions of stages in the life cycle. This step helps provide more certain conclusions, recommendations and sensitivity analysis.

3.2 NAPHTHA LIFE CYCLE ASSESSMENT

The purpose of this study is to evaluate the life cycle inventory analysis and environmental impacts of naphtha production from crude oil. The scope of study involves the production of crude oil until to naphtha synthesis in the refinery. The system boundaries are presented in Fig. 3, and the functional unit used in this study was 1 kg of naphtha

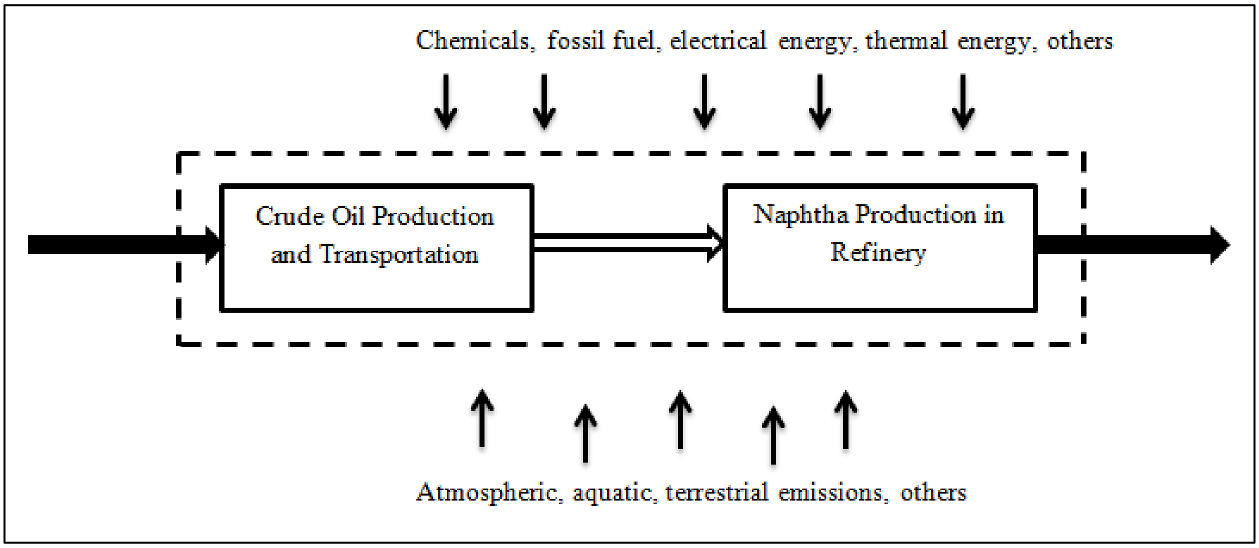


Figure 3-1 Boundaries system of naphtha production

In Figure 3.1 can be noted some input and output data, in this work the main inputs considered were: fossil fuel used in crude oil production and transport, chemicals, steam and water consumed in naphtha production; electricity and steam consumed during the whole LCA. The LCA ends at naphtha production, not including the stages of distribution and the final use.

In relation the outputs of naphtha process, these refer to emissions and residues generated in different stages of the process. They are generated in combustion of fossil fuel, transportation emissions, residues produced in distillation process and others. As input and output data are computed according to the functional unit (1 kg naphtha).

3.3 METHODS AND IMPACT CATEGORIES

There are many LCIA methodologies that apply essentially the same principles or minor variations for impact categories. In this work were selected Eco-Indicator 99 and IPCC 2013 GWP 100a V 1.00, Eco- Indicator 99 aims to provide best practice for midpoint indicators as well as endpoint indicators while IPCC 2013 GWP 100a V 1.00 tells about the global warming potential due to emissions.

3.3.1 Eco-Indicator 99

Eco-indicator 99 is probably still one of the most widely used impact assessment methods in LCA. It has replaced Eco-indicator 95, the first endpoint assessment method. It allowed the expression of the environmental impact in one single score.

This method analyses three different types of damage: human health, ecosystem quality and resources. Relevant information about Eco-indicator 99 is that the standard unit given in all the categories is point (Pt) or millipoint (mPt). Since the aim of this method is the comparison of products or components, the value itself is not most relevant but rather a comparison of values. The method distinguishes three different cultural perspectives or "Archetypes":

- H → Hierarchist (default)
- I → Individualist
- E → Egalitarian

The following tables show the impact categories in each of the sub-methods of Eco-indicator 99:

Table 3.1 Impact categories included in the methods eco-indicator 99 (E), (H) & (I)

Midpoint/Endpoint	Impact category group	Name of the impact category in the method
Midpoint	Eco toxicity	Ecosystem Quality - Land conversion (PDF·m^2)
	Eco toxicity	Ecosystem Quality - Land conversion (PDF·m^2·year)
	Eco toxicity	Ecosystems Quality - Acidification and Eutrophication
	Eco toxicity	Ecosystems Quality - Eco toxicity
	Human toxicity	Human Health - Carcinogenic
	Human toxicity	Human Health - Climate change
	Human toxicity	Human health - Ionizing radiation
	Human toxicity	Human health - Ozone layer depletion
	Human toxicity	Human Health - Respiratory effects caused by inorganic substances

	Human toxicity	Human Health - Respiratory effects caused by organic substances
	Depletion of abiotic	Resources - fossil fuels
	Depletion of abiotic	Resources - minerals
Endpoint	Depletion of abiotic Resources	Resources-total
	Human toxicity	Human Health-total
	Eco toxicity	Ecosystems-total

In table3.1 above are the midpoint/endpoint impact categories of the various environmental impacts. These intermediate endpoint categories are grouped into the three areas of protection: Human Health, Resources and Ecosystems. For calculating the ecosystem damage category, a factor of 0.1 is applied to the eco toxicity impact category. For the rest of the impact categories, a factor of 1 is used.

This model is used for the following impact categories:

- Carcinogens: carcinogenic affects due to the emission of carcinogenic substances to air, water and soil. Damage is expressed in Disability adjusted Life Years (DALY)/kg emitted.
- Respiratory organics: respiratory effects resulting from summer smog, due to the emission of organic substances to the air, which cause respiratory problems. Damage is expressed in DALY/kg emitted.
- Respiratory inorganics: respiratory effects resulting from winter smog, caused by the emission of dust, sulfur and nitrogen oxides to the air. Damage is expressed in DALY/kg emitted.
- Climate change: damage, expressed in DALY/kg emitted, resulting from an increase in diseases and death caused by climate change.
- Radiation: damage, expressed in DALY/kg emitted, resulting from radioactive radiation
- Ozone layer: damage, expressed in DALY/kg emitted, due to increased UV radiation as a result of the emission of ozone-depleting substances to the air.
- Eco toxicity: damage to the quality of the ecosystem as a result of the emission of eco toxic substances to the air, water and soil. Damage is expressed in Potentially Affected Fraction (PAF)*m^2*year/kg emitted.

- Acidification/ Eutrophication: damage to the quality of the ecosystem as a result of the emission of acidifying substances to the air. Damage is expressed in Potentially Disappeared Fraction (PDF)*m^2*year/kg emitted.
- Land use: damage as a result of either the conversion of land or the occupation of land. Damage is expressed in Potentially Disappeared Fraction (PDF)*m^2*year/m^2 or m^2a.
- Minerals: surplus energy per kg mineral or ore as a result of decreasing ore grades.

3.3.2 IPCC 2013 GWP 100a

Global-warming potential (GWP) is a relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of carbon dioxide. A GWP is calculated over a specific time interval, commonly 20, 100 or 500 years. GWP is expressed as a factor of carbon dioxide (whose GWP is standardized to 1). The Environmental Profiles characterisation model is based on factors developed by the UN's Intergovernmental Panel on Climate Change (IPCC). Factors are expressed as Global Warming Potential over the time horizon of different years, being the most common 100 years (GWP100), measured in the reference **unit, kg CO_2 equivalent.**

IPCC 2013 is a method developed by the International Panel on Climate Change. This method lists the climate change factors of IPCC with a timeframe of 20 and 100 years.

The GWP depends on the following factors:

- the absorption of infrared radiation by a given species
- the spectral location of its absorbing wavelengths
- the atmospheric lifetime of the species

Characterization

The IPCC characterization factors for the direct global warming potential of air emissions. They are:

- Not including indirect formation of di nitrogen monoxide from nitrogen emissions.

- Not accounting for radiative forcing due to emissions of NOx, water, sulphate, etc. in the lower stratosphere + upper troposphere.
- Not considering the range of indirect effects given by IPCC.
- Including CO2 formation from CO emissions.
- Considering biogenic CO2 uptake as negative impact.

Normalization and Weighting

Normalization and weighting are not a part of this method.

Table 3.2 GWP Values as Per IPCC 2013

GWP values and lifetimes from 2013 IPCC AR5 p714 (with climate-carbon feedbacks)	Lifetime (years)	GWP time horizon	
		20 years	100 years
Methane	12.4	86	34
HFC-134a (hydro fluorocarbon)	13.4	3790	1550
CFC-11 (chlorofluorocarbon)	45.0	7020	5350
Nitrous oxide (N_2O)	121.0	268	298
Carbon tetra fluoride (CF_4)	50000	4950	7350

In the table3.2 above are the GWP values of various pollutants as per IPCC 2013.

3.4 INVENTORY ANALAYASIS

In the Table 3.3 are presented the main collected inputs data for naphtha production at Switzerland Refinery and adjusted to unit functional used in this work.

Table 3.3 Input data of naphtha production at Switzerland Refinery

			References
Crude Oil Production & Transportation	**Crude oil production RAF**		Ecoinvent
	Crude Oil at Production(kg)	1	
	Transport		
	Transocean Tanker(tkm)	17	
	Crude Oil Pipeline(tkm)	1.3	
	Crude oil, production RME		
	Crude Oil at Production(kg)	1	
	Transport		
	Transocean Tanker(tkm)	1	
	Crude Oil Pipeline(tkm)	1.34	
Naphtha Production in Refinery	Tap Water(kg)	0.015037	Ecoinvent
	Crude Oil RME(kg)	0.448538	
	Crude Oil RAF(kg)	0.55266	
	Electricity(kWh)	0.028375	
	Refinery Gas(MJ)	0.791701	
	Heavy Fuel Oil(MJ)	0.17646	
	Chlorine Liquid(kg)	0.00016369	
	Chemicals Organics(kg)	0.00034684	
	Propylene Glycol(kg)	0.000022741	
	Catalyst(kg)	6.55529E-07	
	Calcium Chloride(kg)	0.000016026	
	Lime(kg)	0.000034625	
	Sulphuric Acid(kg)	0.000011772	

In the Table 3.3 is possible to observe the high demand of electrical energy (0.028375 kWh), refinery gas (0.791701 MJ), and heavy oil (0.17646MJ) for producing 1 kg of naphtha. The refinery gas and heavy oil demand is high because it is necessary for heating the crude oil at slightly above atmospheric pressure.

While main outputs from naphtha production, in Tab. 3.4 is presented the emissions, residues and others produced during all stages of naphtha production. They were adjusted to 1 kg of naphtha.

Table 3.4 Output data of naphtha production.at Switzerland Refinery

		References
Crude Oil Production & Transportation	**Crude oil, production RAF** Emissions to Air Hydrocarbons(kg) 0.0000014 Benzene(kg) 0.00000045 Butane(kg) 0.0000038 Methane(kg) 0.0000016 Ethane(kg) 0.00000045 Hexane(kg) 0.0000018 Pentane(kg) 0.0000054 Propane(kg) 0.0000029 Toluene(kg)0.00000027	Ecoinvent
	Crude oil, production RME Emissions to Air Hydrocarbons(kg) 0.0000014 Benzene(kg) 0.00000045 Butane(kg) 0.0000038 Methane(kg) 0.0000016 Ethane(kg) 0.00000045 Hexane(kg) 0.0000018 Pentane(kg) 0.0000054 Propane(kg) 0.0000029 Toluene(kg)0.00000027	
Naphtha Production in Refinery	Emissions to Air Ammonia(kg) 7.27E-08 Hydrocarbons(kg) 1.32957E-10 Benzene(kg) 5.83E-06 Butane(kg) 5.83E-05 Butene(kg)1.45E-06 Methane(kg) 1.63E-05 Ethene(kg) 2.91E-06 Ethane(kg) 1.45E-05 Hexane(kg) 2.91E-05 Pentane(kg) 7.28E-05 Propane(kg) 5.83E-05 Toluene(kg)8.74E-06 Particulates>10µm 9.89E-06 Nitrogen Oxides(kg) 9.43E-06 Xylene(kg) 5.83E-06 Heat, waste(MJ) 0.027095 Sulfur Dioxide(kg) 1.04E-05	Ecoinvent
	Emissions to Water Al(kg) 2.8E-08 Ba(kg) 5.6E-08 B(kg) 2.24E-07 Ca(kg) 2.8E-05 Fluoride(kg)2.5E-06 Cyanide(kg) 9.69E-08 Chloride(kg) 4.45E-05 Mg(kg) 1.39E-05 Mn(kg) 1.12E-07 Hg(kg) 5.6E-11 Nitrate(kg) 4.6E-06 K ion(kg) 5.6E-06 Phosphorous(kg) 2.17E-07 Na ion(kg) 0.000168 Sulfide(kg) 5.6E-08 Sulfate(kg) 0.000113 Suspended Solids(kg) 5.6E-06 Lead(kg) 1.75E-07 Oils(kg) 5.76E-07 No Emissions to Soil	

In the Table 3.4 can be observed the high emissions provide from crude oil transportation (tanker emissions), this is explained by diesel consumption of these vehicles. The opposite for distillation and naphtha production, these processes are “clear” technologies, because they emit to environment low atmospheric pollutants.

In the Table 3.5 are presented the main collected inputs data for naphtha production at Europe Refinery and adjusted to unit functional used in this work.

Table 3.5 Input data of naphtha production at Europe Refinery

			References
Crude Oil Production & Transportation	**Crude oil production RAF**		Ecoinvent
	Crude Oil at Production(kg)	1	
	Transport		
	Transocean Tanker(tkm)	17	
	Crude Oil Pipeline(tkm)	1.3	
	Crude oil, production RME		
	Crude Oil at Production(kg)	1	
	Transport		
	Transocean Tanker(tkm)	1	
	Crude Oil Pipeline(tkm)	1.34	
Naphtha Production in Refinery	Tap Water(kg)	0.014528	Ecoinvent
	Crude Oil RME(kg)	0.24443	
	Crude Oil RAF(kg)	0.293607	
	Electricity(kWh)	0.055459	
	Refinery Gas(MJ)	1.59249	
	Heavy Fuel Oil(MJ)	0.40689	
	Chlorine Liquid(kg)	0.00013089	
	Chemicals Organics(kg)	0.00036495	
	Propylene Glycol(kg)	0.000019758	
	Catalyst(kg)	5.51971E-07	
	Calcium Chloride(kg)	0.000015484	
	Lime(kg)	0.000033454	
	Sulphuric Acid(kg)	0.000011374	

In the Table 3.5 is possible to observe the high demand of electrical energy (0.055459 kWh), refinery gas (1.59249 MJ), and heavy oil (0.40689MJ) for producing 1 kg of naphtha. The refinery gas and electrical energy demand is high because it is necessary for heating the crude oil at slightly above atmospheric pressure.

While main outputs from naphtha production, in Tab. 3.6 is presented the emissions, residues and others produced during all stages of naphtha production. They were adjusted to 1 kg of naphtha.

Table 3.6 Output data of naphtha production.at Europe Refinery

	Crude oil, production RAF	**References**
Crude Oil Production & Transportation	**Crude oil, production RAF** Emissions to Air Hydrocarbons(kg) 0.0000014 Benzene(kg) 0.00000045 Butane(kg) 0.0000038 Methane(kg) 0.0000016 Ethane(kg) 0.00000045 Hexane(kg) 0.0000018 Pentane(kg) 0.0000054 Propane(kg) 0.0000029 Toluene(kg)0.00000027 **Crude oil, production RME** Emissions to Air Hydrocarbons(kg) 0.0000014 Benzene(kg) 0.00000045 Butane(kg) 0.0000038 Methane(kg) 0.0000016 Ethane(kg) 0.00000045 Hexane(kg) 0.0000018 Pentane(kg) 0.0000054 Propane(kg) 0.0000029 Toluene(kg)0.00000027	Ecoinvent
Naphtha Production in Refinery	Emissions to Air Ammonia(kg) 7.03E-08 Hydrocarbons(kg) 1.29255E-10 Benzene(kg) 5.15E-06 Butane(kg) 5.15E-05 Butene(kg)1.29E-06 Methane(kg) 3.85E-05 Ethene(kg) 2.58E-06 Ethane(kg) 1.29E-05 Hexane(kg) 2.58E-05 Pentane(kg) 6.44E-05 Propane(kg) 5.15E-05 Toluene(kg)7.73E-06 Particulates>10µm 9.62E-06 Nitrogen Oxides(kg) 1.32E-06 Xylene(kg) 5.83E-06 Heat, waste(MJ) 0.092969 Sulfur Dioxide(kg) 0.000101 Emissions to Water Al(kg) 1.22E-08 Ba(kg) 2.45E-08 B(kg) 9.75E-08 Ca(kg) 1.22E-05 Fluoride(kg)1.09E-06 Cyanide(kg) 4.23E-08 Chloride(kg) 1.94E-05 Mg(kg) 6.11E-06 Mn(kg) 4.88E-08 Hg(kg) 2.45E-11 Nitrate(kg) 2.01E-06 K ion(kg) 2.45E-06 Phosphorous(kg) 9.46E-08 Na ion(kg) 7.33E-05 Sulfide(kg) 2.45E-08 Sulfate(kg) 4.97E-05 Suspended Solids(kg) 2.45E-06 Lead(kg) 7.65E-08 Oils(kg) 2.4504E-06 No Emissions to Soil	Ecoinvent

In the Table 3.6 can be observed the high emissions provide from crude oil transportation (tanker emissions), this is explained by diesel consumption of these vehicles. The opposite for distillation and naphtha production, these processes are “clear” technologies, because they emit to environment low atmospheric pollutants.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 ANALYSIS OF NAPHTHA SWISS AND NAPHTHA EUROPE BY ECO-INDICATOR 99

The environmental impacts were computed with base in inputs data of Table 3.3 and Table 3.5, and outputs data of Table 3.4 and Table 3.6 as well as the software SIMAPRO 8.0.3.14 was applied for getting the main impact categories of naphtha production, with the Eco-indicator 99 method.

The results developed in SIMAPRO 8.0.3.14 with Eco-indicator 99 method are presented in Table 4.1, Table 4.2, Table 4.3, Table4.4, Figure 4.1 and Figure 4.2. It shows the order of magnitude of the environmental problems generated by the products' life cycle.

Table 4.1 Method: Eco-indicator 99 (H) V2.09 / Europe EI 99 H/H / Characterization Unit used: % & analyzing 1 ton 'Naptha, at Switzerland refinery/CH U'

Label	Naphtha, at refinery/CH U	Tap water, at user/CH U	Calcium chloride, CaCl2, at plant/RER U	Hydrochloric acid, 30% in H2O, at plant/RER U	Lime, hydrated, packed, at plant/CH U	Lubricating oil, at plant/RER U	Sulphuric acid, liquid, at plant/RER U	Crude oil, production RME, at long distance transport/CH U	Crude oil, production RAF, at long distance transport/CH U	Electricity, medium voltage, at grid/CH U	Refinery gas, burned in furnace/MJ/CH U	Heavy fuel oil, burned in refinery furnace/MJ/CH U	Chlorine, liquid, production mix, at plant/RER U	Chemicals organic, at plant/GLO U	Propylene glycol, liquid
Carcinogens	0.8849	0.0009	0.0097	0.061	0.0007	0.0146	0.0025	5.913	51.5008	0.992	3.0312	21.4652	0.0933	0.1487	0.0844
Resp. organics	5.3699	3.91E-05	0.0001	0.0008	0.0003	0.009	2.55E-05	1.2325	20.6618	0.0262	1.6838	0.4552	0.0013	0.0286	0.0031
Resp. inorganics	0.4235	0.0005	0.0038	0.0158	0.0013	0.0067	0.0038	5.5737	41.8198	0.3512	3.5437	3.4013	0.031	0.0783	0.014
Climate change	0.1538	0.0004	0.0025	0.014	0.0047	0.0047	0.0003	2.4922	33.0206	0.5981	9.5365	2.9269	0.0317	0.1129	0.0168
Radiation	0	0.0083	0.004	0.0785	0.0021	0.0107	0.0006	3.6495	49.0458	32.5882	1.3564	0.3634	0.2127	0.1147	0.0767
Ozone layer	0	2.42E-05	4.71E-05	0.0167	0.0003	0.0022	2.11E-05	7.2836	54.1503	0.0532	1.5621	0.4283	0.0625	0.0084	0.0093
Ecotoxicity	0.0296	0.0013	0.009	0.0616	0.0006	0.014	0.0024	6.4707	46.5428	1.3025	1.9572	16.7956	0.09	0.2634	0.0396
Acidification/ Eutrophication	0.529	0.0003	0.0047	0.0097	0.0009	0.0047	0.0021	4.5947	41.1965	0.2692	3.4026	2.4673	0.0204	0.065	0.0095
Land use	0	0.0018	0.0023	0.0095	0.0022	0.0118	0.0004	4.6206	57.5668	0.2359	1.5756	0.4273	0.016	0.026	0.0069
Minerals	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Fossil fuels	**0**	**0.0033**	**0.0389**	**0.105**	**0.0008**	**0.0158**	**0.0015**	**5.8235**	**65.0328**	**5.393**	**1.5249**	**0.4126**	**0.2598**	**0.1687**	**0.0964**

Table 4.2 Method: Eco-indicator 99 (H) V2.09 / Europe EI 99 H/H / Characterization Analyzing 1 ton 'Naphtha, at Switzerland refinery/CH U'

Impact category	Unit	Total	Naphtha, at refinery/CH U	Tap water, at user/CH U	Calcium chloride, CaCl2, at plant/RER U	Lime, hydrated, packed, at plant/CH U	Lubricating oil, at plant/RER U	Sulphuric acid, liquid, at plant/RER U	Crude oil, production RME, at long distance transport/CH U	Crude oil, production RAF, at long distance transport/CH U	Electricity, medium voltage, at grid/CH U	Refinery gas, burned in furnace/MJ/CH U	Heavy fuel oil, burned in refinery furnace/MJ/CH U	Refinery gas, burned in flare/GLO U	Chlorine, liquid, production mix, at plant/RER U	Chemicals organic, at plant/GLO U	Propylene glycol, liquid
Carcinogens	DALY	4.29E-06	3.79E-08	3.69E-11	4.16E-10	2.91E-11	6.27E-10	1.07E-10	2.53E-07	2.21E-06	4.25E-08	1.3E-07	9.2E-07	1.51E-09	4E-09	6.37E-09	3.62E-09
Resp. organics	DALY	4.18E-06	2.25E-07	1.64E-12	4.87E-12	1.28E-11	3.76E-10	1.07E-12	5.16E-08	8.64E-07	1.1E-09	7.04E-08	1.9E-08	1.81E-10	5.37E-11	1.2E-09	1.31E-10
Resp. inorganics	DALY	0.000334	1.41E-06	1.64E-09	1.28E-08	4.36E-09	2.22E-08	1.26E-08	1.86E-05	0.00014	1.17E-06	1.18E-05	1.13E-05	1.72E-06	1.04E-07	2.61E-07	4.69E-08
Climate change	DALY	0.000117	1.79E-07	5.06E-10	2.97E-09	5.53E-09	5.45E-09	3.4E-10	2.91E-06	3.85E-05	6.97E-07	1.11E-05	3.41E-06	3.34E-07	3.7E-08	1.32E-07	1.96E-08
Radiation	DALY	1.24E-06	0	1.03E-10	5.07E-11	2.67E-11	1.33E-10	8.06E-12	4.54E-08	6.1E-07	4.05E-07	1.69E-08	4.52E-09	4.32E-12	2.64E-09	1.43E-09	9.54E-10
Ozone layer	DALY	7.61E-07	0	1.84E-13	3.58E-13	1.92E-12	1.66E-11	1.61E-13	5.54E-08	4.12E-07	4.05E-10	1.19E-08	3.26E-09	0	4.76E-10	6.42E-11	7.11E-11
Ecotoxicity	PAF *m2 yr	48.03118	0.014195	0.000607	0.0043	0.00287	0.006718	0.00116	3.107974	22.35506	0.625586	0.940061	8.067112	0.000326	0.043234	0.126519	0.019029
Acidification / Eutrophication	PDF *m2 yr	12.44977	0.065867	3.62E-05	0.000585	0.000117	0.000587	0.000265	0.572027	5.128866	0.033517	0.423617	0.30717	0.052502	0.002544	0.008087	0.001187
Land use	PDF *m2 yr	11.3401	0	0.000206	0.000262	0.000254	0.001337	4.2E-05	0.523982	6.528135	0.026753	0.178669	0.048459	0	0.001814	0.002955	0.000783
Minerals	MJ surplus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fossil fuels	MJ surplus	0.717075	0	2.4E-05	0.000279	5.55E-06	0.000113	1.09E-05	0.041759	0.466334	0.038672	0.010935	0.002959	0	0.001863	0.00121	0.000691

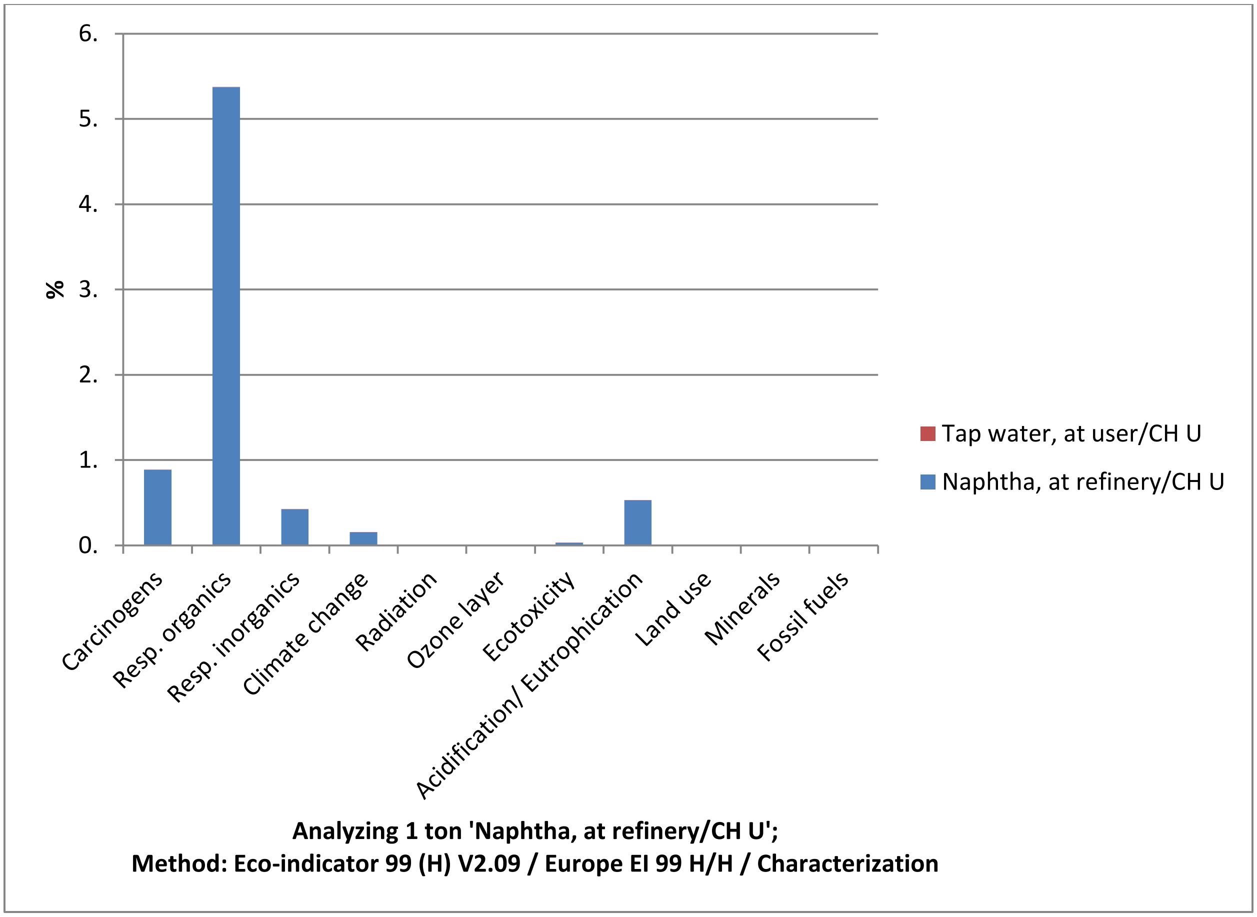


Figure 4-1 Main environmental impacts of naphtha production system at Swiss Refinery

In Table 4.1 can be observed that the major environmental impacts are mainly contributed by crude oil RAF, Crude Oil RME and Heavy oil.

In Tab 4.2 can be observed eco toxicity environmental impacts is maximum (48.0311824319958 PAF*m2yr) by naphtha production. The ozone layer depletion contribution by naphtha is zero. Crude oil RAF gives the major Acidification/Eutrophication environmental impact of 5.12886631608101 PDF*m2yr.

In figure4.1 can be observed that the respiratory organics 5.3699% is the major environmental impact by naphtha production by the atmospheric distillation unit followed by carcinogens, Acidification/Eutrophication, respiratory inorganics, and then climate change. The rest environmental impacts are almost zero.

Table 4.3 Method: Eco-indicator 99 (H) V2.09 / Europe EI 99 H/H / Characterization Unit used: % & analyzing 1 ton 'Naphtha, at Europe refinery/RER U'

Label	**Naphtha, at refinery/RER U**
Carcinogens	100
Resp. organics	100
Resp. inorganics	100
Climate change	100
Radiation	100
Ozone layer	100
Eco toxicity	100
Acidification/ Eutrophication	100
Land use	100
Minerals	0
Fossil fuels	100

In Table 4.3 can be observed that the major environmental impacts are mainly contributed by naphtha production in all impact categories while zero in minerals category as naphtha is produced from the fossil fuels.

Table 4.4 Method: Eco-indicator 99 (H) V2.09 / Europe EI 99 H/H / Characterization Analyzing 1 ton 'Naphtha, at Europe refinery/RER U'

Impact category	Unit	Naphtha, at refinery/RER U
Carcinogens	DALY	7.61045E-06
Resp. organics	DALY	1.72865E-06
Resp. inorganics	DALY	0.00049499
Climate change	DALY	8.69933E-05
Radiation	DALY	1.50374E-06
Ozone layer	DALY	4.71167E-07
Eco toxicity	PAF*m2yr	79.41522151
Acidification/ Eutrophication	PDF*m2yr	13.44068224
Land use	PDF*m2yr	34.3695748
Minerals	MJ surplus	0
Fossil fuels	MJ surplus	1.250332955

In Tab 4.4 can be observed eco toxicity environmental impacts is maximum (79.41522151PAF*m2yr) by naphtha production. The damage to minerals by naphtha is zero.

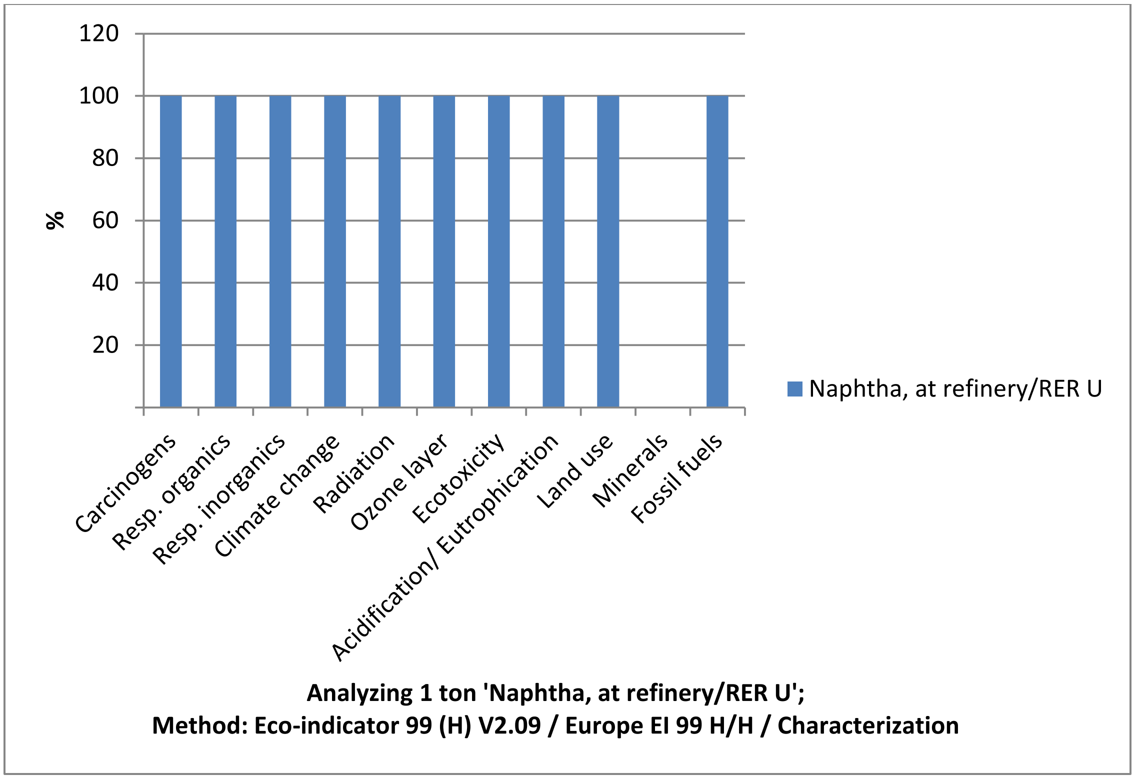


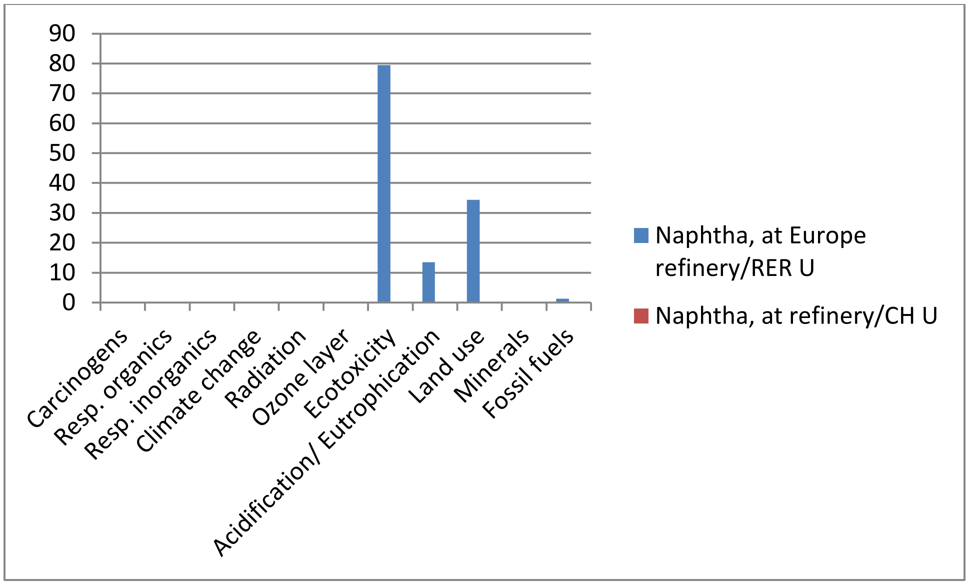
Figure 4-2 Main environmental impacts of naphtha production system at Europe Refinery

In figure4.2 can be observed that the major environmental impacts by naphtha production are 100% in all impact categories. The minerals environmental impact is zero.

4.2 Comparison as Per Eco-Indicator 99

Table 4.5 Method: Eco-indicator 99 (H) V2.09 / Europe EI 99 H/H / Characterization Unit used: % & analyzing1 ton 'Naphtha, at Europe refinery/RER U' and at Swiss Refinery/CH U'

	Unit	Naphtha, at Europe refinery/RER U	Naphtha, at Switzerland refinery/CH U
Carcinogens	DALY	7.61045E-06	3.79172E-08
Resp. organics	DALY	1.72865E-06	2.24662E-07
Resp. inorganics	DALY	0.00049499	1.41273E-06
Climate change	DALY	8.69933E-05	1.79375E-07
Radiation	DALY	1.50374E-06	0
Ozone layer	DALY	4.71167E-07	0
Eco toxicity	PAF*m2yr	79.41522151	0.014195283
Acidification/ Eutrophication	PDF*m2yr	13.44068224	0.065866964
Land use	PDF*m2yr	34.3695748	0
Minerals	MJ surplus	0	0
Fossil fuels	MJ surplus	1.250332955	0



Method: Eco-indicator 99 (H) V2.09 / Europe EI 99 H/H / Characterization
Unit used: % & analyzing1 ton 'Naphtha, at Europe refinery/RER U' and at Swiss Refinery/CH U'

Figure 4-3 Main environmental impacts of naphtha production system at Europe Refinery/RER U and Swiss Refinery/CH U'

In Table 4.5 can be observed that the major environmental impacts are mainly contributed by naphtha production at European Refinery while zero in minerals category as naphtha is produced from the fossil fuels.

In figure4.2 can be observed that the major environmental impact by naphtha production at Europe refinery is eco toxicity. The minerals environmental impact is zero at both refineries. While the radiation, ozone layer and land use environmental impacts by naphtha production at Swiss refinery are zero.

4.3 ANALYSIS OF NAPHTHA SWISS & NAPHTHA EUROPE BY IPCC 2013 GWP 100A V 1.00

The environmental impacts were computed with base in inputs data of Table 3.3 and Table 3.5, and outputs data of Table 3.4 and Table 3.6 as well as the software SIMAPRO 8.0.3.14 was applied for getting the main impact categories of naphtha production, with the IPCC 2013 GWP 100A V 1.00 method.

The results gotten in SIMAPRO 8.0.3.14 with IPCC 2013 GWP 100A V 1.00 method are presented in Table 4.6, Table 4.7, Table 4.8, Table4.9, Figure 4.4 and Figure 4.5. It shows the order of magnitude of the climate change/ global warming potential generated by the products' life cycle.

Table 4.6 Method: IPCC 2013 GWP 100a V1.00/ Characterization Unit used: Kg CO2 eq & Analyzing 1 ton 'Naphtha, at Switzerland refinery/CH U'

Impact category	IPCC GWP 100a
Unit	kg CO2 eq
Total	601.5387432
Naphtha, at refinery/CH U	0.5885953
Tap water, at user/CH U	0.002440272
Ammonia, liquid, at regional storehouse/RER U	0.004213229
Calcium chloride, CaCl2, at plant/RER U	0.014316826
Hydrochloric acid, 30% in H2O, at plant/RER U	0.079108706
Iron sulphate, at plant/RER U	0.00941494
Lime, hydrated, packed, at plant/CH U	0.026270424
Lubricating oil, at plant/RER U	0.026483592
Nitrogen, liquid, at plant/RER U	0.354667468
Soap, at plant/RER U	0.004530828
Sodium hypochlorite, 15% in H2O, at plant/RER U	0.04587367
Sulphuric acid, liquid, at plant/RER U	0.001628559
Transport, lorry >16t, fleet average/RER U	0.166529487
Transport, freight, rail/RER U	0.314566881
Crude oil, production RME, at long distance transport/CH U	14.40918106
Crude oil, production RAF, at long distance transport/CH U	193.4375076
Crude oil, production NG, at long distance transport/CH U	314.3849181
Electricity, medium voltage, at grid/CH U	3.347943533
Refinery gas, burned in furnace/MJ/CH U	53.68679682
Heavy fuel oil, burned in refinery furnace/MJ/CH U	16.45275921
Refinery gas, burned in flare/GLO U	1.590293692
Refinery/RER/I U	0.223186319
Chlorine, liquid, production mix, at plant/RER U	0.178634422
Chemicals organic, at plant/GLO U	0.651515396
Propylene glycol, liquid, at plant/RER U	0.095388429
Molybdenum, at regional storage/RER U	0.000956869
Nickel, 99.5%, at plant/GLO U	0.000164032
Palladium, at regional storage/RER U	0.965620906
Platinum, at regional storage/RER U	0.04682825
Rhodium, at regional storage/RER U	0.091609675
Zeolite, powder, at plant/RER U	0.087966982
Zinc, primary, at regional storage/RER U	0.000747982
Disposal, refinery sludge, 89.5% water, to hazardous waste incineration/CH U	0.247710073
Disposal, catalytic converter NOx reduction, 0% water, to underground deposit/DE U	0.000373691

Table 4.7 Method: IPCC 2013 GWP 100a V1.00/Characterization Unit used: % & analyzing 1 ton 'Naphtha, at Switzerland refinery/CH U'

Label	IPCC GWP 100a
Naphtha, at refinery/CH U	0.0978
Tap water, at user/CH U	0.0004
Ammonia, liquid, at regional storehouse/RER U	0.0007
Calcium chloride, CaCl2, at plant/RER U	0.0024
Hydrochloric acid, 30% in H2O, at plant/RER U	0.0132
Iron sulphate, at plant/RER U	0.0016
Lime, hydrated, packed, at plant/CH U	0.0044
Lubricating oil, at plant/RER U	0.0044
Nitrogen, liquid, at plant/RER U	0.059
Soap, at plant/RER U	0.0008
Sodium hypochlorite, 15% in H2O, at plant/RER U	0.0076
Sulphuric acid, liquid, at plant/RER U	0.0003
Transport, lorry >16t, fleet average/RER U	0.0277
Transport, freight, rail/RER U	0.0523
Crude oil, production RME, at long distance transport/CH U	2.3954
Crude oil, production RAF, at long distance transport/CH U	32.1571
Crude oil, production NG, at long distance transport/CH U	52.2635
Electricity, medium voltage, at grid/CH U	0.5566
Refinery gas, burned in furnace/MJ/CH U	8.9249
Heavy fuel oil, burned in refinery furnace/MJ/CH U	2.7351
Refinery gas, burned in flare/GLO U	0.2644
Refinery/RER/I U	0.0371
Chlorine, liquid, production mix, at plant/RER U	0.0297
Chemicals organic, at plant/GLO U	0.1083
Propylene glycol, liquid, at plant/RER U	0.0159
Molybdenum, at regional storage/RER U	0.0002
Nickel, 99.5%, at plant/GLO U	2.73E-05
Palladium, at regional storage/RER U	0.1605
Platinum, at regional storage/RER U	0.0078
Rhodium, at regional storage/RER U	0.0152
Zeolite, powder, at plant/RER U	0.0146
Zinc, primary, at regional storage/RER U	0.0001
Disposal, refinery sludge, 89.5% water, to hazardous waste incineration/CH U	0.0412
Disposal, catalytic converter NOx reduction, 0% water, to underground deposit/DE U	6.21E-05

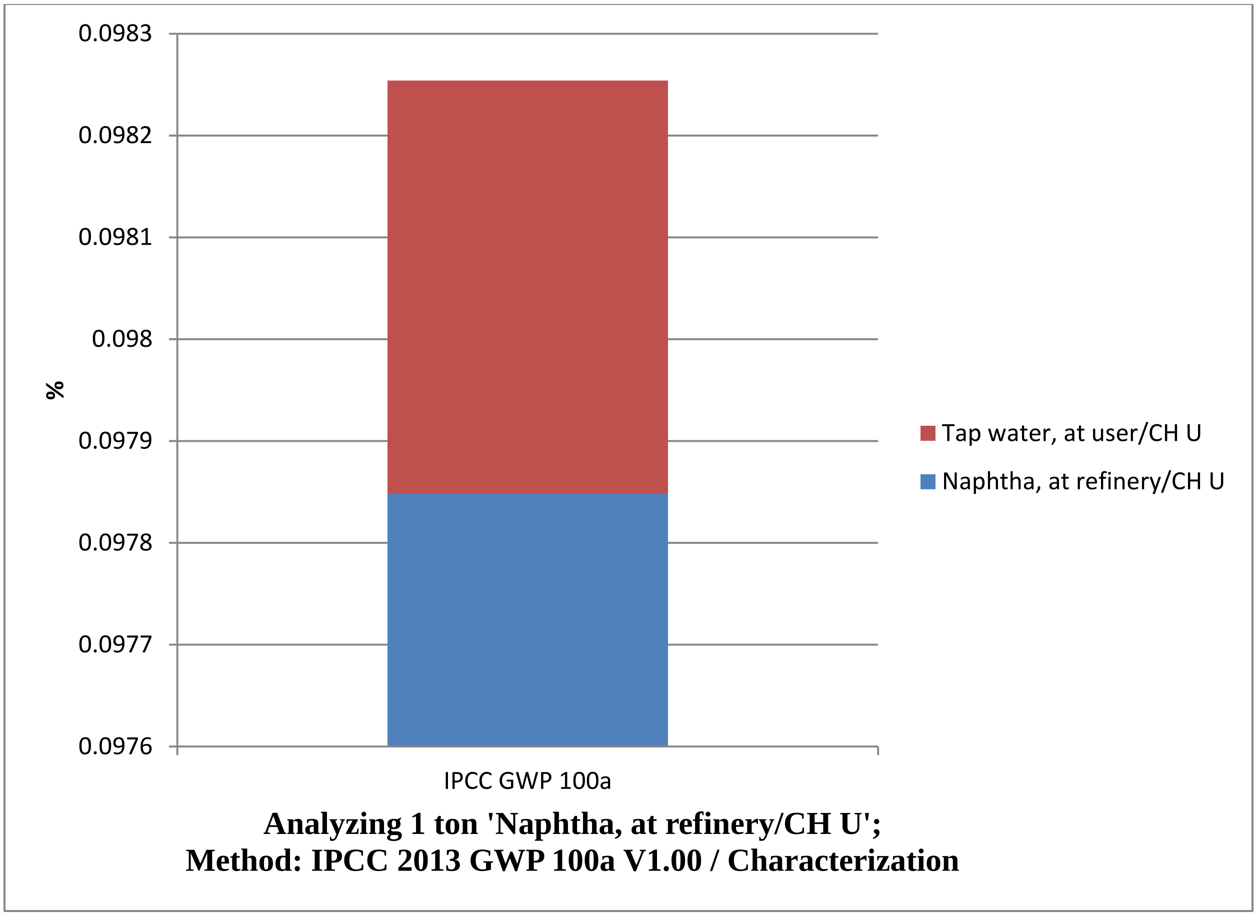


Figure 4-4 : Global Warming Potential of Naphtha Production System at Swiss Refinery

In Table 4.6 can be observed that the total Global Warming Potential (GWP) is 601.5387432kg CO_2 eq, out of which maximum GWP is by crude oil long distance transportation followed by refinery gas burned in flare and heavy oil burned in refinery furnace.

In Tab 4.7 can be observed the maximum 52% GWP 100a is by crude oil long distance transportation and the minimum 6.21E-05 % by the catalytic converter NO_x reduction.

In figure4.4 can be observed that the global warming potential by naphtha production is 0.0978% only.

Table 4.8 Method: IPCC 2013 GWP 100a V1.00/ Characterization Unit used: Kg CO2 eq & Analyzing 1 ton 'Naphtha, at Europe refinery/RER U'

Impact category	Unit	Naphtha, at refinery/RER U
IPCC GWP 100a	kg CO2 eq	426.6443387

In Table 4.8 can be observed that the total Global Warming Potential (GWP) is 426.6443387kg CO_2 eq.

Table 4.9 Method: IPCC 2013 GWP 20a V1.00/ Characterization Unit used: % & analyzing 1 ton 'Naphtha, at Europe refinery/RER U'

Label	Naphtha, at refinery/RER U
IPCC GWP 20a	100

In Tab 4.9 can be observed the maximum GWP 20a is by naphtha production only.

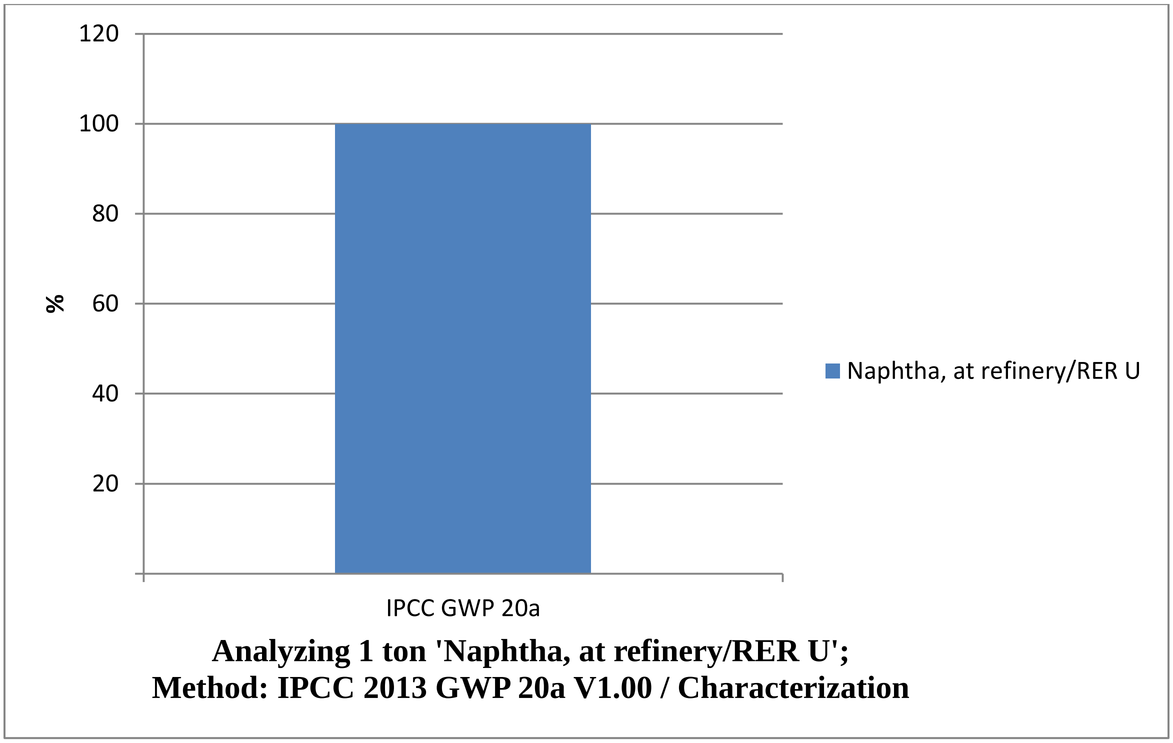


Figure 4-5 Global Warming Potential of Naphtha Production System at Europe Refinery

In figure4.5 can be observed that the global warming potential by naphtha production is 100%.

4.4 Comparison as Per IPCC 2013 GWP 100A V 1.00

Table 4.10 Method: IPCC 2013 GWP 100a V1.00/ Characterization Unit used: Kg CO2 eq, Analyzing 1 ton 'Naphtha, at Europe refinery/RER U' & at Switzerland refinery/CH U'

Impact category	Unit	Naphtha, at Europe refinery/RER U	Naphtha, at Swiss refinery/CH U
IPCC GWP 100a	kg CO2 eq	426.6443387	601.5387432

In Table 4.10 can be observed that the total Global Warming Potential (GWP) by naphtha production at Swiss refinery is highest of both the naphtha production system.

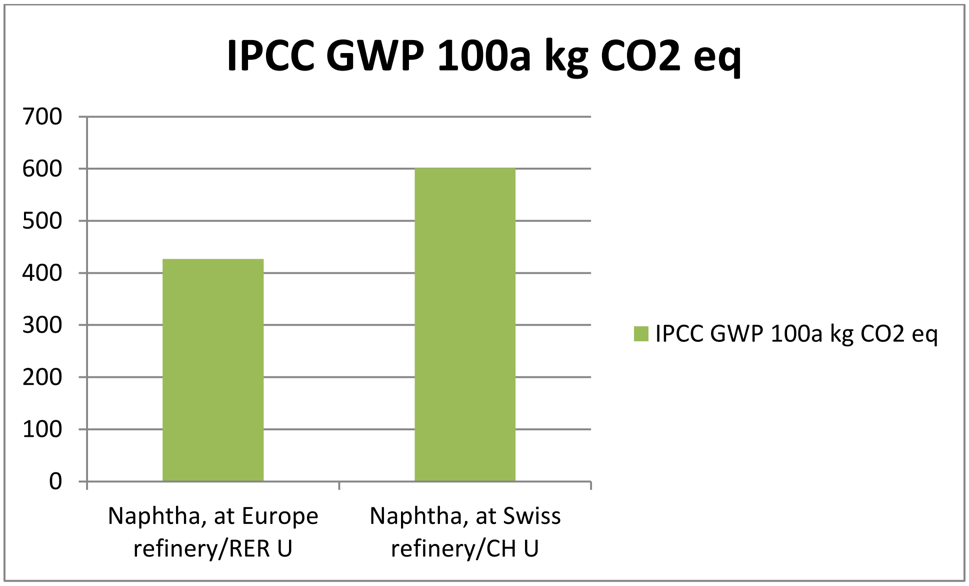


Figure 4-6 Global Warming Potential of Naphtha Production System at Europe Refinery & at Swiss Refinery

In figure4.6 can be observed that the global warming potential by naphtha production at Swiss refinery is 601.5387432kg CO_2 eq.

CHAPTER 5

SUMMARY AND CONCLUSION

5.1 SUMMARY

A Life Cycle Assessment study involves the collection, assessment and interpretation of data from an environmental perspective over a product's life cycle (production, use, and end of life). Studies can evaluate entire product life cycle, often referred to as cradle-to-gate. The ISO 14040 series of standards contain the international standards for LCA. This work presents an evaluation of life cycle energy balance and net environmental impacts of naphtha production using Life Cycle Assessment as a tool. In this study the naphtha is produced from crude oil at Switzerland refinery AND Europe refinery. In this study, the impact assessment method Eco-Indicator 99 and IPCC 2013 GWP 100a V 1.00 are used to model the results. The results obtained allowed to characterize the main environment impacts associated with naphtha production from crude oil and then analyzing the results. A comparative assessment has been done for the both methods used for the result analysis.

5.2 CONCLUSION

This work was presented an evaluation of life cycle inventory analysis and environmental impacts of production of naphtha from crude oil at Swiss and Europe refineries. The crude oil selected was RAF & RME and the tool for evaluation environmental was Life Cycle Assessment.

- The reduction of the fossil energy demand of fuel production will decrease the environmental impacts.
- The use of electricity is more expressive in naphtha production by the distillation unit system, so this naphtha production route using electricity as fuel is more viable when it is whished high global energy efficiency and low environmental impacts.
- The integration of naphtha production unit adjacent to crude oil production will minimize the environmental impacts due to transportation fuel consumption in Europe.
- The Global Warming Potential is mainly caused by the crude oil transportation during the naphtha production.
- The Global Warming Potential 20a is highest (100%) by the naphtha production at Europe

Refinery.

- The damage to minerals environmental impact category is zero at both the naphtha production sites as fossil fuel is used for the naphtha production.

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