Feasibility Study of Use of Renewable Energy to Power Greenfield Eco-Industrial Park

by

Vaibhav Gupta

A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science

Approved August 2014 by the
Graduate Supervisory Committee:

Ronald Calhoun, Chair
Kevin Dooley
Patrick Phelan

ARIZONA STATE UNIVERSITY

August 2014

ABSTRACT

An eco-industrial park (EIP) is an industrial ecosystem in which a group of co-located firms are involved in collective resource optimization with each other and with the local community through physical exchanges of energy, water, materials, byproducts and services – referenced in the industrial ecology literature as “industrial symbiosis”. EIPs, when compared with standard industrial resource sharing networks, prove to be of greater public advantage as they offer improved environmental and economic benefits, and higher operational efficiencies both upstream and downstream in their supply chain.

Although there have been many attempts to adapt EIP methodology to existing industrial sharing networks, most of them have failed for various factors: geographic restrictions by governmental organizations on use of technology, cost of technology, the inability of industries to effectively communicate their upstream and downstream resource usage, and to diminishing natural resources such as water, land and non-renewable energy (NRE) sources for energy production.

This paper presents a feasibility study conducted to evaluate the comparative environmental, economic, and geographic impacts arising from the use of renewable energy (RE) and NRE to power EIPs. Life Cycle Assessment (LCA) methodology, which is used in a variety of sectors to evaluate the environmental merits and demerits of different kinds of products and processes, was employed for comparison between these two energy production methods based on factors such as greenhouse gas emission, acidification potential, eutrophication potential, human toxicity potential, fresh water usage and land usage. To complement the environmental LCA analysis, levelized cost of electricity was used to evaluate the economic impact. This model was analyzed for two different geographic locations; United States and Europe, for 12 different energy production technologies.

The outcome of this study points out the environmental, economic and geographic superiority of one energy source over the other, including the total carbon dioxide equivalent emissions, which can then be related to the total number of carbon credits that can be earned or used to mitigate the overall carbon emission and move closer towards a net zero carbon footprint goal thus making the EIPs truly sustainable.

I dedicate this thesis to my Parents (Akhil and Usha) and my Aunt (Manju) for their continuous encouragement and guidance for hard work and excellence during my studies. I also dedicate this to my brother and family who are an ever-present source of strength and inspiration in my life.

ACKNOWLEDGMENTS

I would like to express my deep hearted gratitude and special thanks to Dr. Kevin Dooley and Dr. Ronald J. Calhoun for their invaluable thoughts, advice, support and patience.

I would like to thanks my committee member Dr. Patrick Phelan for support and advice. And lastly I would like to thank The Sustainability Consortium and Dr. Carole Mars for providing me the resources necessary to have this great learning experience.

TABLE OF CONTENTS

Page

CHAPTER

CHAPTER Page

APPENDIX

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

LIST OF SYMBOLS

1. IS – Industrial Symbiosis
2. IE – Industrial Ecosystem
3. EIP – Eco Industrial Park
4. RE – Renewable Energy
5. NRE – Non Renewable Energy
6. CSR – Corporate Social Responsibility
7. CO_2 – Carbon Dioxide
8. CC – Carbon Credits
9. GHG – Greenhouse Gas
10. GWP – Global Warming Potential
11. AP – Acidification Potential
12. EP – Eutrophication Potential
13. FAETP – Freshwater Aquatic Ecotoxicity Potential
14. HTP – Human Toxicity Potential
15. ODP – Ozone Depletion Potential
16. GaBi – Lifecycle Assessment Software
18. Gantt Chart – Bar Chart illustrating Project Schedule
19. MFA – Material Flow Analysis
20. LCOE – Levelized Cost of Electricity

CHAPTER 1

INTRODUCTION

Human activities from the birth of industrial revolution have contributed to environmental pollution and have affected the natural environment at an unprecedented rate. Environmental factors such as global warming potential, acidification potential, eutrophication potential, human toxicity potential, fresh water usage, land usage and resource depletion are some of the critical issues associated with industrial growth as emphasized by United Nations Environmental Programme (UNEP, 2008). With industrialization and globalization of markets, increasing pressure is faced by multiple stakeholders to reduce the environmental impacts associated with global consumption (TSC, 2009). As a result, supply-chain optimization and improvement of operational efficiency have taken a new urgency.

Since the early 90's, industries have faced challenges of balancing operations with environmental sustainability and economic stability because of diminishing critical resources such as water, land, and raw materials, and increasing price of commodities. Global efforts have been made to understand the nature of inter-firm resource sharing in the form of industrial symbiosis (IS), and adapt it to plan eco-industrial parks (EIP) for improved environmental and economic benefits, and higher resource sharing efficiency (Chertow, 2007). An eco-industrial park (EIP) is an industrial ecosystem in which a group of co-located firms are involved in "collective resource optimization with each other and with the local community through physical exchanges of energy, water, materials, byproducts and services" (Chertow & Lombardi, 2005). Industries located inside the EIP not only share basic resources: water, land, and electricity, they also share the collective responsibility for mitigating the environmental effects arising from the use of nonrenewable energy (NRE) sources for providing these resources. Analyzing the feasibility of replacing NRE producing technologies with renewable energy (RE) one's, will not only help reduce environmental degradation, but will also help improve the overall sustainability of the eco-industrial park. Below is a proposed design of an EIP with NRE generation grid replaced with RE grid and depicting the flow of resources within the ecosphere.

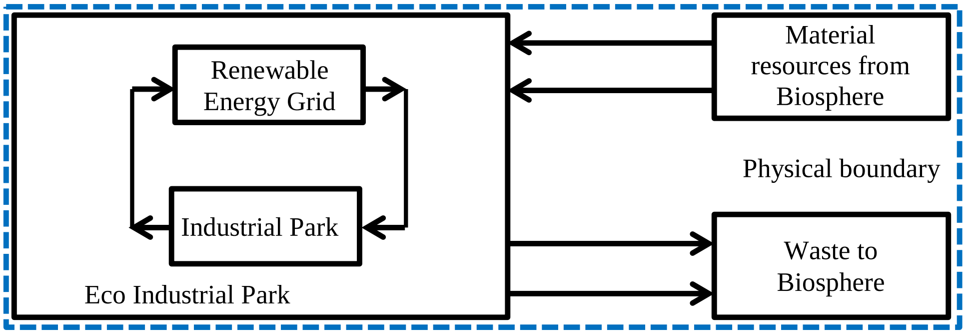


Figure 1: Proposed System Boundary Diagram

1.1 Research Question

This project investigates the comparative anthropogenic impacts arising from use of NRE sources and RE sources for providing electricity to EIPs. Three research questions are ansewered through this thesis:

- What are the individual comparative environmental merits and demerits of different energy production technologies evaluated using comprehensive lifecycle assessment methodology?

- What is the economics behind energy production, what are the different costs associated with mitigation of environmental impacts, and how can levelized cost of electricity (LCOE) of these technologies be used to analyze their individual economic impacts?
- How can the substitution from NRE to RE technology improve the net carbon neutrality of the EIP?

1.2 Motivation

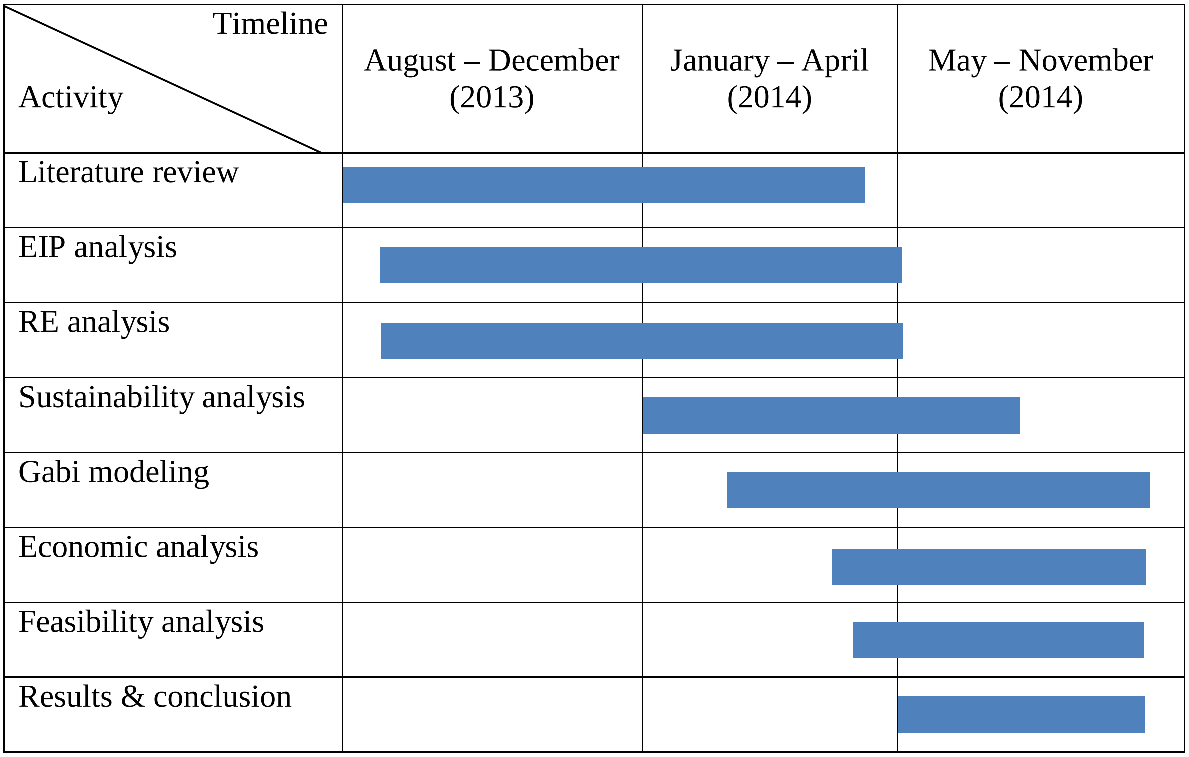
With the global decrease in critical (fresh water, land, etc.) resources, increasing prices of nonrenewable resources, and the increase in demand for electricity; new avenues and technologies exercising renewable resources for energy production are gaining traction. A number of modeling approaches to evaluate the lifecycle impacts of RE producing technologies exists (Pehnt, 2006), (Hung, 2010), but none of these compare both renewable and non-renewable energy technology directly for a baseline criteria; using a comprehensive life cycle analysis (LCA) software such as GaBi we can directly compare these technologies for a baseline criteria (i.e. total energy requied for a black box scenario), and perform an indepth environmental analysis. Environmental impacts factors evaluated from LCA such as feshwater consumption and land transformation, can be specifically used and compared with geological data to evaluate geographic preferences for planning greenfield EIPs based on their global availability.

Comparative results of different technologies with an emphasis on their environmental and economic impacts, and the total carbon credits expended could be used during the initial design and planning stage of an EIP, to evaluate the overall return on investment on a number of factors: geographic location across the globe; total carbon neutrality of the project; environmental impacts and total economic cost of the project.

1.3 Organization of the Report and Project Timeline

Chapter 1 introduces the research background, the research problem, and motivation for carrying out this thesis project. Chapter 2 presents a background review of EIPs, different energy technologies, and LCA methodology. Chapter 3 elaborates on the research methodology and explains in detail how research procedures were conducted. Chapter 4 presents the results and discusses the research findings. Chapter 5 presents the conclusions and recommendations for future works. Below is a project timeline Gantt chart describing the time taken during the course of the project for individual activity:-

Table 1: Project Timeline Gantt Chart



Timeline Activity	August – December (2013)	January – April (2014)	May – November (2014)
Literature review	■	■	
EIP analysis	■	■	
RE analysis	■	■	
Sustainability analysis		■	■
Gabi modeling		■	■
Economic analysis		■	■
Feasibility analysis		■	■
Results & conclusion			■

CHAPTER 2

BACKGROUND

2.1 Eco Industrial Park – An Overview

Corporate regulations in the form of corporate social responsibility (CSR) have always stimulated sustainable business strategies such as efficient resource management, improved operational efficiency, and have created the need to continuously innovate and improve inter-firm resource sharing, and waste management practices. Robust CSR in the past have not only helped plan EIP's, but they have also exhibited the way for different industries to work collaboratively for the greater good of the environment and its inhabitant. "Despite much rhetoric concerning the implementation of sustainable development within local and regional economic development strategies, very few concrete examples exist of projects that combine economic, social and environmental aims. However, recently, a number of developments have occurred, based around ideas drawn from industrial ecology" (Gibbs, 2003).

Kalundborg an example of near perfect industrial resource sharing network emerged in a similar sense when surrounding industries felt the need to effectively manage diminishing embedded resources such as water. Eco-industrial parks rely upon creating networks of material and by-product flows between participating firms. However, it is frequently assumed that the trust and cooperation between firms that this involves will arise automatically (Gibbs, 2003).

Embedded resources are those underlying materials and resources exchanged, without which the overall functionality and existence of the system would not be possible, as their availability is commonly taken for granted (like water, energy etc.); in future these resources will become scarce and will be budgeted for the successful and long term sustainable working. In my system there are many embedded resources like water, energy, land, air, etc., however the most important embedded resource of all is the energy derived from NRE source like crude oil, coal, nuclear etc.

Governments at both national and international level have initiated various policies and, rules and regulation for the promotion of eco-industrial parks:

- The President's Council on Sustainable Development (PCSD) was established by President Clinton in June 1993 to advise him on sustainable development and develop bold and new approaches to achieve our economic, environmental, and equity goals (PCSD, 2013).
- United State Business Council for Sustainable Development (USBCSD) is a non-profit business association that provides opportunities for its members to work on authentic sustainability projects with industry, governmental and other key stakeholders who might not otherwise have the chance to collaborate and network (WBCSD, 2013).

Kalundborg: Industrial symbiosis in Kalundborg really begun in the early 70's when a project to use surface water from a nearby lake for a new oil refinery was initiated, in order to save the limited supplies of ground water. The administration of Kalundborg city took the responsibility for the construction of the pipeline with the finances provided by the refinery management. Starting from this initial collaboration, a number of other inter-firm sharing projects were subsequently introduced and the number of participating members progressively increased. By the start of the 90's, the members realized that they had effectively "self-organized" themselves into what is probably the best-known example of a working IS (UNEP, 1999), (Christensen, 1999).

Some of the biggest participants in Kalundborg:

- Asnaes power station providing 782MW of electricity from its coal fired power plant.
- Statoil oil refinery
- Novo Nordisk multinational biotechnology company, largest producer of insulin and industrial enzymes
- Gyproc plasterboard producing company
- Kalundborg town that receives excess heat from Asnaes power plant

It is important to mention that water is scarce in Kalundborg and therefore systematically budgeted. Because of the IS in Kalundborg the reduction in groundwater use has been estimated at close to 2 million cubic meters per year in addition to the 1 million cubic meters of water per year saved by Statoil refinery by reusing cooling water and then supplying purified waste water to Asnaes power plant (Chertow, 2007), (Chertow & Lombardi, 2005).

Other planned (under development examples):

- Devene in north central Massachusetts, a highly successful redevelopment of a closed army base. It has become a model for successfully organizing a light industrial area and for involving small to medium-sized enterprises as well as larger firms, totaling over 90 firms (Lowitt, 2008).

- Rantasalmi in Finland is an eco-industrial park that involves mainly wood processing companies, altogether 7 firms (Saikku, 2006).

Two fundamental conclusions can be drawn from Kalundborg IS and related to failure of planning or governmental persuasion for setting up EIPs.

- Firstly, we can see that Kalundborg IS emerged from self-organization initiated by the private sector to achieve targets, such as cost reduction, business expansion, and safeguarding long-term access to embedded resources, and not from scientific planning or a multi stakeholder process. This implies that the IS emerged because of individual needs of the industries and not from any kind government involvement.
- Secondly, after the success of first exchanges, a coordinative function was found to be helpful in establishing additional exchanges and moving them forward. With respect to awareness on the environmental benefits gained from IS, they were uncovered after the exchanges were established, which is why attempts at creating such an inter-firm sharing network have failed (Chertow, 2007).

Below are the diagrams highlighting my understanding of an EIP with RE group, indicating inter-firm resource, energy and services sharing network. The diagram will be explained in the subsequent sections.

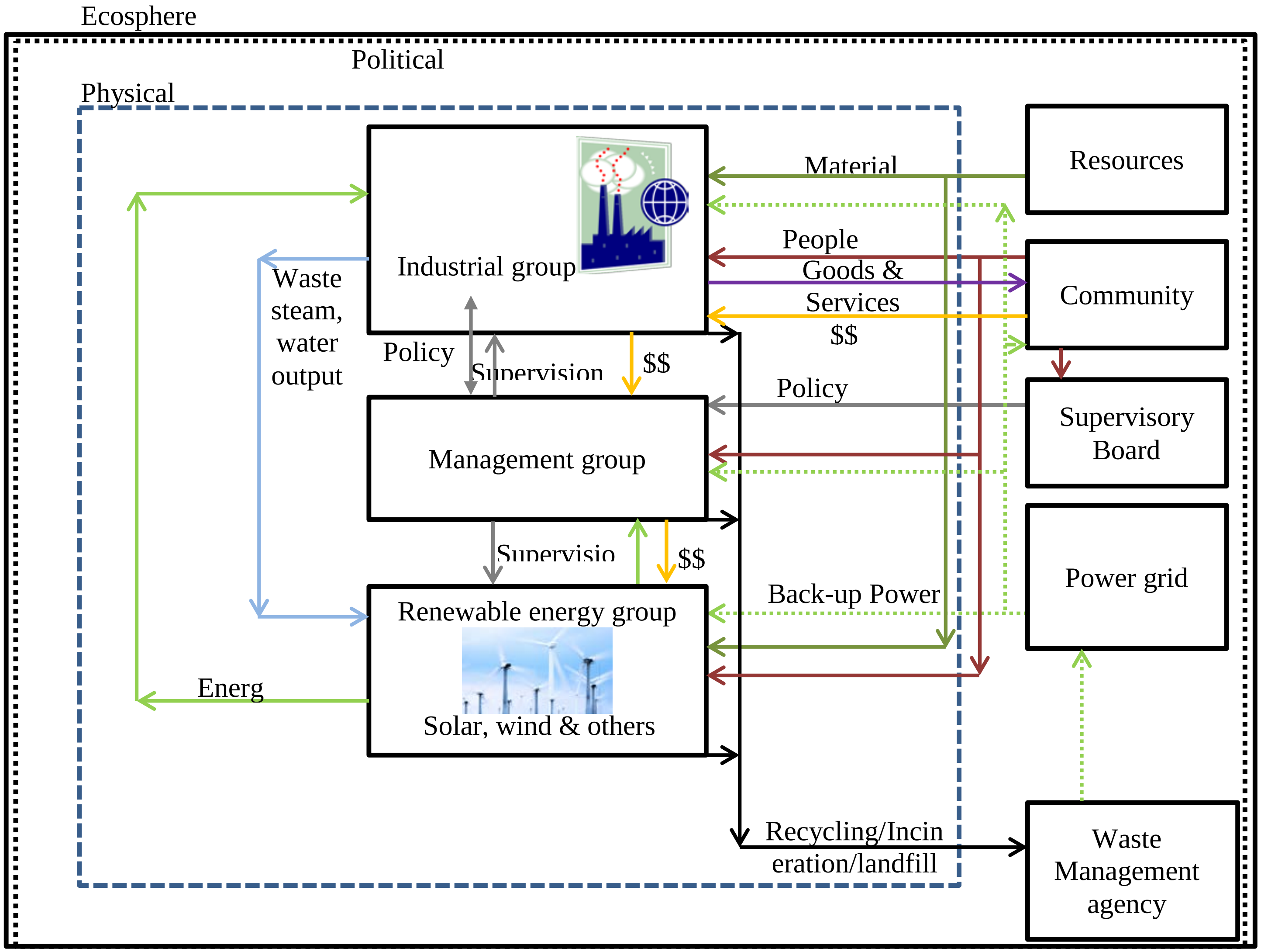


Figure 2: Eco Industrial Park: With different interfaces and flows originating from different value chain actors

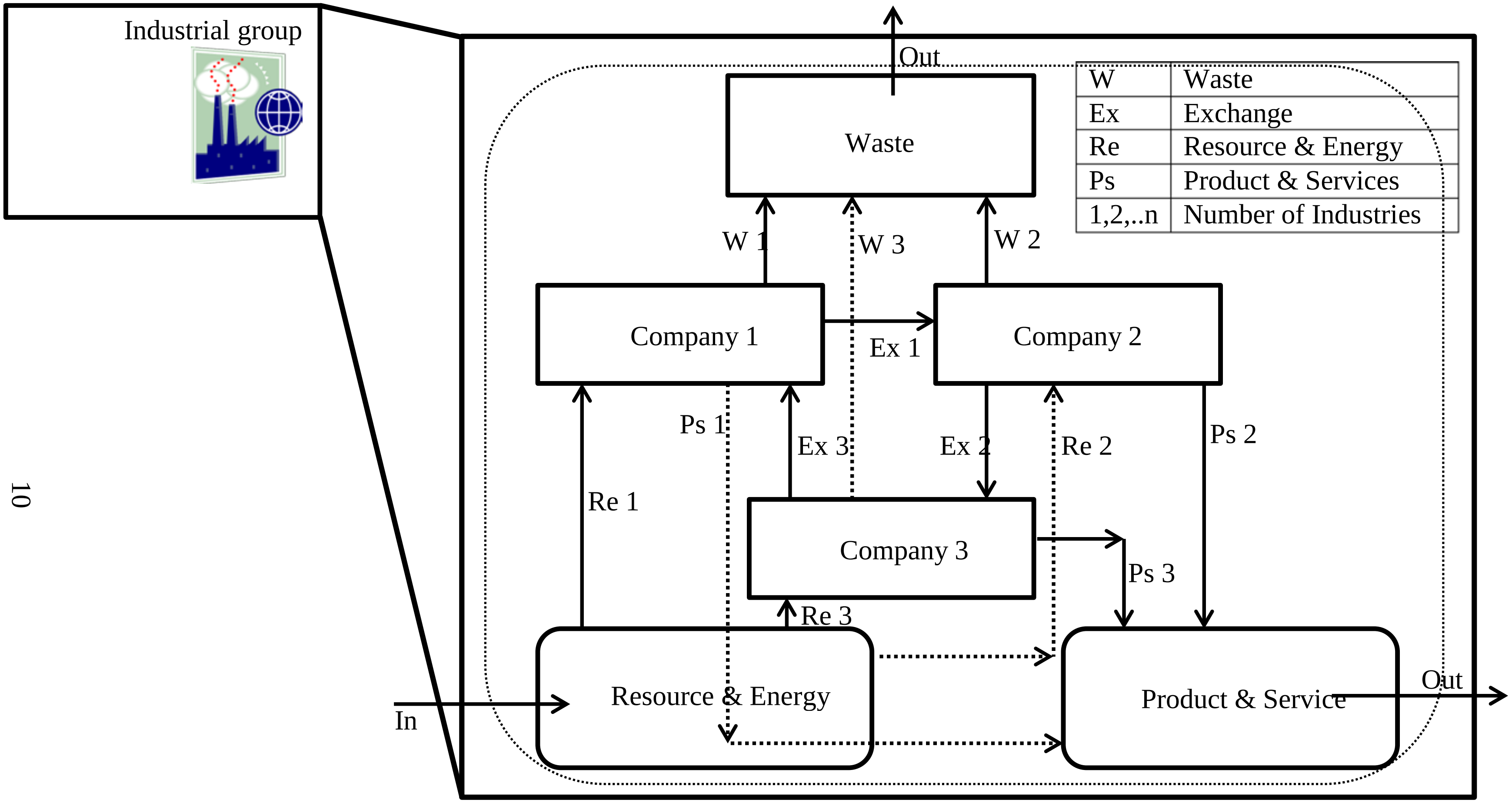


Figure 3: Exploded view of the internal operations and working of the industrial group. Any group of 3 or more industries can be considered as an Industrial Symbiosis (Chertow, 2007)

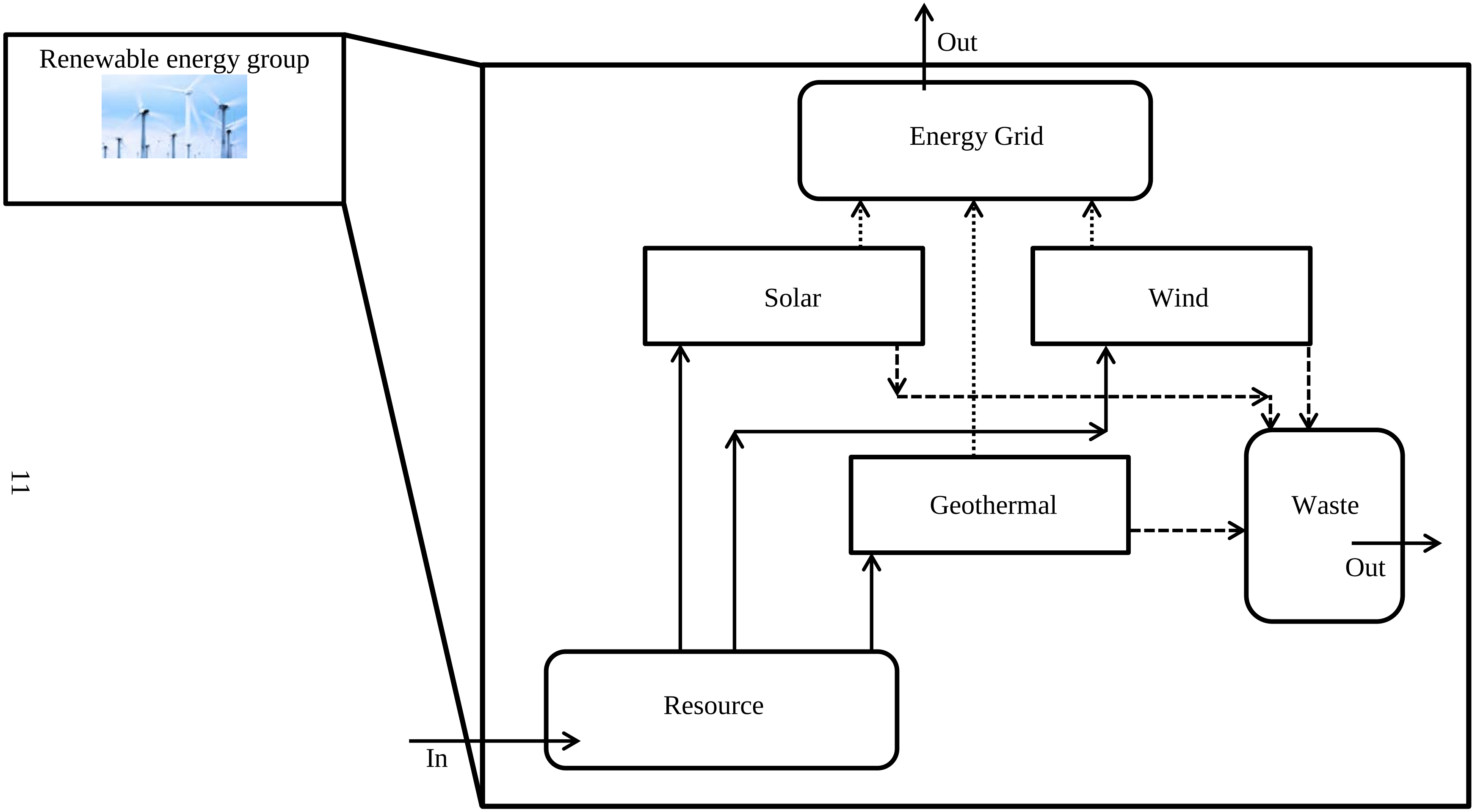


Figure 4: Exploded view of the RE Ggrid Scenario: Solar, Wind and Geotherm

Using material flow analysis (MFAs) technique to track inputs, outputs, and accumulated amounts of material throughout a product supply chain we can have a better understanding of the inter-firm resource sharing network. They typically include flows of material resources from: cradle, through product manufacture, to product use, to end of life, and disposal to the environment. MFAs can be of many types, and can be constructed at many spatial levels. The basic elements of the analysis are the classification of the reservoirs (i.e. companies, industries, states, etc.) and of the exchange of resources among them (e.g., within an industrial ecosystem, as in my case). MFAs have been used to drive policy making and to influence public decisions in several arenas (Graedel, Allen, Johnson, & Roigh, 2006).

Different material flows and their account in my system are discussed below:

⟶ Color indicates the **Information Flow** within the EIP. From governance standpoint, there is an outside supervisory board that provides the rules and regulation for the EIP's internal management board and subject to those rules the internal board further supervises the functioning of industrial and energy groups, and it defines the policies for fair exchanges among them. The main difference in supervisory and management board lies in their level of power, management board only observes the effective functioning of EIP and supplies its feedback to the supervisory board; which is also responsible for the communications between that regional government and EIP members (for functions like lobbying, policy amendments etc.).

⟶ Color indicates the transfer of **Virgin Materials** or **Fresh Resources** from the ecosphere across the physical boundary to different stakeholders. These materials can be processed or unprocessed depending on the requirements. Resource can be considered as fresh directly from the environment or an output from another industry outside the EIP.

⟶ Color indicates the flow of **Waste Resources** that cannot be utilized within the EIPs physical boundary, to an outside waste management agency or another industry which can properly and efficiently reuse, dispose, recycle, incinerate or landfill waste depending on its type, quality or other defining parameters.

⟶ Color indicates the movement of **Human Capital** from local communities across the physical boundary, to perform activities such as manufacturing, maintenance, gatekeeping, etc. to general management. People bring in skills and move out with financial gains, which in turn can be used to provide for the goods and services supplied by the EIP. Community here can be defined as a collection of individuals, market etc.

⟶ Color indicates the flow of **Energy** from the RE energy group with a backup external source (in the case of emergency) like a near-by power grid.

⟶ Color indicates the flow of **Waste** mainly in the form of excess heat, steam or waste water that can be reused with different renewable energy producing technologies.

⟶ Color indicates the flow of **Money** or **Finances** between different stakeholders and industries primarily in exchange for the materials and resources shared.

In order to develop a sustainable society, tools are required to analyze the relationship between the environment and human activities; and to estimate the overall carrying capacity of the natural resource base. Energy flow analysis can be used as a useful tool in this regards, it is a lot similar tool like material flow analysis except it only tracks the energy generation, transmission and use, and thus we can extrapolate its related environmental impacts. In my proposed system where the energy derived from RE sources will be replacing the energy derived from NRE sources, a baseline total energy requirement for the EIP will be estimated and will be used to back calculate the amount of different resources required and related environmental impacts.

2.2 Energy Production Technologies, Rewards and Challenges

In my proposed EIP energy grid a total to 12 different energy production technologies are considered, they consist of almost all the types of technologies that are currently used across the globe for electricity production.

Renewable Energy Technologies include:

- Biogas (BG)
- Biomass (solid) (BM)
- Geothermal (GEO)
- Hydro Power (HP)
- Photovoltaic (PV)
- Wind Power (WP)

Nonrenewable energy Technologies include:

- Coal Gases (CG)
- Hard Coal (HC)
- Heavy Fuel Oil (HFO)
- Lignite (type of coal most abundantly used for steam electric power generation)
- Natural Gas (NG)
- Nuclear

Biogas: Composed of a mixture of gases released due to anaerobic digestion of organic matter. It has mainly methane and carbon dioxide with small amounts of sulphur related gases. It is considered as a renewable source of energy and can be produced locally from organic recycled waste.

Biomass (solid): Consist of organic biological materials such as plants or plant based matter, and can be used directly as a fuel to produce energy, or can be converted into different forms of biofuel by thermal, chemical or biochemical methods.

Geothermal Power: Produces electricity from the thermal energy generated by utilizing the thermal gradient between the core of the planet and its surface. It is one of the most cost effective and sustainable forms of energy.

Hydro Power: It is the energy generated from the potential or the kinetic energy of water, and can be used with a variety of applications.

Photovoltaic: Radiant heat and light from the sun can be harnessed and converted directly into useable form of energy, using a solar photovoltaic device.

Wind Power: It is derived from the kinetic energy of the wind with the help of wind turbines. There are large wind farms both onshore and offshore, which consist of hundreds of individual wind turbines connected with an electrical power transmission network.

Coal Based Power: Derived from gaseous and solid form of coal based energy source such as coal gas (manufactured gaseous fuel), hard coal and lignite (can be used directly to produce energy).

Heavy Fuel Oil: It is among one of the fraction generated during petroleum distillation and can be directly used as a source of energy.

Natural Gas: Is a form of fossil fuel readily available across the globe and can be used in a variety of applications as a source of energy.

Nuclear: Can be used to create heat and electricity from the nuclear exothermic process occurring during a nuclear decay, in fission or a fusion reaction.

Rewards:

Governments at both national and international level have tried to initiate different policies, rules and regulation for the promotion of RE producing technologies.

PURPA: The public utility regulatory policies act is a United States act of congress passed as a part of national energy act in 1978, it is meant to promote greater use of domestic renewable energy. The law forced electric utilities to buy power from other more efficient producers like solar and wind (Clean Energy, 2013).

Investment Tax Credit (ITC): This investment tax credit varies depending on the type of renewable energy project; solar, fuel cells ($1500/0.5 kW) and small wind (< 100 kW) are eligible for credit of 30% of the cost of development, with no maximum credit limit; there is a 10% credit for geothermal, micro-turbines (< 2 MW) and combined heat and power plants (< 50 MW). The ITC is generated at the time the qualifying facility is placed in service. Benefits are derived from the ITC, accelerated depreciation, and cash flow over a 6-8 year period (US DOE ITC, 2013).

Production Tax Credits (PTCs): Under present law, an income tax credit of 2.3 cents/kilowatt-hour is allowed for the production of electricity from utility-scale wind turbines, geothermal, solar, hydropower, biomass, and marine and hydrokinetic renewable energy plants. This incentive, the renewable energy Production Tax Credit (PTC), was created under the Energy Policy Act of 1992 (at the value of 1.5 cents/kilowatt-hour, which has since been adjusted annually for inflation) (US DOE PTC, 2013).

Renewable Energy Certificate (RECs): A RE credit (occasionally referred to as a RE certificate) is an environmental commodity that represents the added value, environmental benefits and cost of renewable energy above conventional methods of producing electricity. RECs help RE facilities grow by improving financial viability, thereby incentivizing development. Purchasing/exchanging these credits is the widely accepted way to reduce the environmental footprint of your electricity consumption and help fund renewable energy development. (Renewable Energy Choice, 2013).

Challenges

NIMBY Issues: NIMBY is an acronym used for the phrase ‘Not in my backyard’ is a representation of opposition by residents of a community to a proposal for a new development project in their community. These issues are specifically related to wind energy farms and solar power plants. In my system NIMBY issues will be tackled as RE power plants will be a part of the EIP and thus it will create a more sustainable and environment friendly community.

2.3 Sustainability and LCA

What is Sustainability and can it be measured either qualitatively or quantitatively, if yes then how do we measure it? Does it depend on the constraints of the surroundings or can it simply be defined on the lines of what we want from it?

Sustainability in everyday life implies that we perform our day to day work in a manner that will require minimum fresh resources, work at optimum operational efficiencies, produce the most efficient output, generate the least amount of waste, and not diminish the future generation’s needs for maintaining their standard of living with minimum required resources and the available technology. Sustainability has three pillars on which we can depend for our framework: environmental, social and economic.

Life Cycle Analysis: Life cycle analysis (LCA) is a technique used to assess environmental impacts associated throughout a products lifecycle from cradle to grave. Performing an LCA study can be divided into four parts as stated by the ISO (ISO, 2006):

- Goal and Scope Definition
- Inventory Analysis
- Impact Assessment
- Interpretation

An LCA study begins with an exact definition of the goal and scope of the study. This provides the context to the audience to whom the results are communicated. It also describes the boundary for the assessment, defines the functional unit that forms the basis for comparison and states any assumptions and/or limitations. The goal and scope of this study is to compare the relative environmental impacts associated with energy production technologies, including their life cycle impacts and impacts associated with use for a one year period. The functional unit in this analysis is “amount of environmental impact/1000MW of electricity generation/year”. The factors associated with the variability in RE are addressed in subsequent section.

The inventory analysis step involves creating an input/output flow diagram of the product system being studied. Energy and raw materials are considered as inputs, emissions to air, water and soil are considered as outputs. Flow quantities are based on an appropriate functional unit and represent all the activities in the ecosphere depending on the goal and scope of the study. The inventory analysis step in this analysis is explained in the next chapter.

The next stage is the life cycle impact assessment (LCIA). According to ISO 14040, impact assessment is a “phase of LCA aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of the product system” (Guinee & Heijungs, 2005). The various environmental impacts categories and their description are explained in the following section. The impacts evaluated from this analysis and their related mitigation cost is used to evaluate total economic value for a technology from an economic and environmental point of view.

Interpretation stage is the last stage wherein the results of the inventory analysis and the LCIA are quantified and summarized. These results highlight the environmental issues from the study and conclusions from these results can be related in a way that business decision makers or stakeholders can understand (Guinee & Heijungs, 2005).

2.4 Environmental Impact Categories

As described above, impact assessment is one of the most important phases in an LCA. For the purpose of this thesis, 9 key impact categories are selected for this analysis. A brief description of each of those is given below.

Global Warming Potential is an index to measure the contribution of a substance released to the atmosphere towards global warming. It is impacted mainly by the emission of greenhouse gases such as CO_2 and methane. It is measured in terms of kg CO_2 equivalents for a time period of 100 years.

Acidification Potential refers to the increase in acidity of the soil and associated ecosystems due to chemical emissions. It is measured in terms of kg SO2 equivalents.

Eutrophication Potential is an abnormal increase in concentration of chemical nutrients resulting in hindered productivity due to reduction of available oxygen. It is expressed in terms of kg PO4 equivalents.

Freshwater Aquatic Ecotoxicity Potential refers to the impact on freshwater ecosystems due to the addition of toxic substances to air, water and soil. It is expressed in terms of kg 1,4-dichlorobenzene equivalents.

Human Toxicity Potential is the impact on humans due to toxic emissions to the environment. This however does not include occupational exposure to toxic chemicals. These by-products are mainly caused from electricity production from fossil sources. It is expressed in terms of kg 1,4-dichlorobenzene equivalents.

Ozone Depletion Potential refers to the relative impact on the ozone layer due to emission of chlorofluorocarbons in the atmosphere. It is expressed in terms of kg R-11 or kg CFC- 11 equivalents.

Resource Consumption refers to the total consumption or emission of materials both upstream and downstream during a products life cycle. It is expressed in terms of kg of consumption or emission (OSRAM, 2014).

Land Transformation Indicator refers to the amount of land converted due to change in land use from one type to another, e.g. transformation of forest area to an industrial area. It is expressed in terms of square meters (sqm).

Total Freshwater Consumption refers to the total amount of freshwater consumed during different industrial processes such as evaporation and transpiration from plants, freshwater integration into products, and release of freshwater into sea. It is expressed in kg of consumption of water.

2.5 Economics of Energy Production

Cost of electricity generation at the point of connection to an electricity grid, includes capital expenditures, operations and maintenance costs, fuels costs, and discounts rates. While calculating costs, various factors have to be considered for the entire life cycle of the project, for this reason “levelized cost of electricity (LCOE)” is used as the main economic indicator.

LCOE is the price at which electricity must be generated from a specific source to break even over the lifetime of the project. It measures the overall competiveness of different generating technologies; actual investments vary with specific technological requirements and regional characteristics (US EIA, 2014).

- LCOE = per kilowatt-hour cost ($) of building and operating a power plant over an assumed financial and operational life.
- Variable required to calculate LCOE:
    - Capital cost
    - Fuel cost
    - Fixed and variable operations and maintenance (O&M) cost
    - Financing cost
    - Assumed utilization rate (each plant type)

Economic burden from mitigation of environmental impacts such as cost associated with mitigation of GHG, AP, EP, HTP; associated with individual technologies is added to the LCOE to evaluate the overall economic comparison of these technologies (Sims, Rogner, & Gregory, 2003), (TUDelft, 2014).

CHAPTER 3

METHODOLOGY AND CALCULATIONS

3.1 LCA Methodology - GaBi

The work developed herein adds value to the existing LCA studies by characterizing 12 different energy production technologies (as mentioned previously) and 11 different technology combination scenarios (described below) for two different geographic locations: US and Europe.

Table 2: Different Energy Combination Scenarios for Gabi LCA Scenario Analysis

Scenarios	Technology Combinations
1	Energy derived from a combination of 50% Biogas and 50% Biomass (solid) sources
2	Energy derived from 100% Geothermal sources
3	Energy derived from 100% Hydro Power sources
4	Energy derived from 100% Wind Power sources
5	Energy derived from 100% Photovoltaic sources
6	Energy derived from a combination of 33.33% Coal Gases and 33.33% Hard Coal, and 33.33% Lignite sources
7	Energy derived from a combination of 50% Heavy Fuel Oil and 50% Natural Gas sources
8	Energy derived from 100% Nuclear sources
9	Energy derived from a combination of 16.67% Coal Gases, 16.67% Hard Coal, 16.67% Lignite, 16.67% Heavy Fuel Oil, 16.67% Natural Gas and 16.67% Nuclear sources
10	Energy derived from a combination of 50% Photovoltaic and 50% Wind Power sources
11	Energy derived from a combination of 16.67% Biogas, 16.67% Biomass, 16.67% Geothermal, 16.67% Hydro Power, 16.67% Wind Power and 16.67% Photovoltaic

As described in the previous section the goal of my problem statement is to analyze the environmental superiority of one technology over the other, and to identify which combination scenario will result in minimum environmental impacts. LCA analysis software GaBi’s inbuilt PE International database was used for evaluating the environmental impacts associated with different technologies. 1000MW energy grid capacity requirement at the point of connection to a load was used as the baseline quantity for comparing the related environmental impacts.

Calculating the total energy output from a 1000MW power plant operating continuously for duration of 1 year, at 60% of the overall rated capacity:

- For a 1000MW rated capacity Power Plant calculation for total energy output for 1 year.
- Power Plant Energy Efficiency

$$= \frac{Energy\ output\ from\ the\ power\ plant\ for\ a\ period}{Heat\ supplied\ to\ the\ power\ plant\ during\ the\ same\ period}$$

- Rated capacity = 1000 MW
- Total number of days in a year = 365
- Total number of hours in a day = 24
- Total number of seconds in a hour = 3600
- % efficiency of the plant at rated capacity = 60%
- Total energy output = $1000\ MW\ X\ 365\ X\ 24\ X\ 3600\ Sec\ X\ 60\%$

  $= 1.89216\ \mathrm{X}\ 10^{10}\ MJ$

  $= 5.256\ \mathrm{X}\ 10^{6}\ MWh$

Using the above calculated total energy as the final requirement in Gabi LCA model for 12 different technologies, we calculate the associated upstream and downstream environmental impacts (as mentioned previously in the environmental impacts category). Similarly total energy requirement was used in GaBi LCA model for 11 different combination scenarios, and the results described in chapter 4 of this document, were used to deduce the environmental superiority of one technology/scenario over the other. Figures below represents four different GaBi interfaces with input and output energy flows.

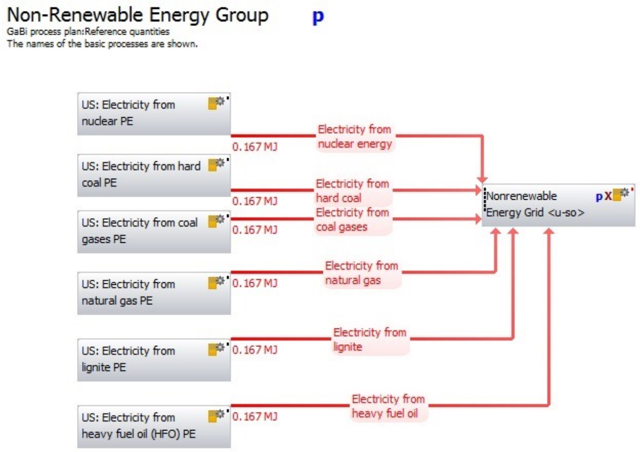


Figure 5: LCA Nonrenewable Electricity Grid Model

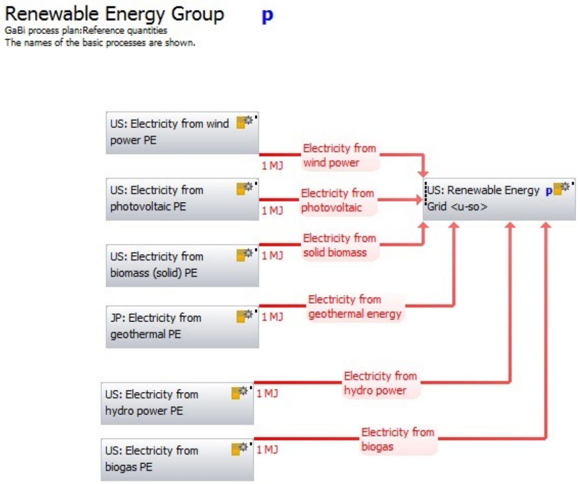


Figure 6: LCA Renewable Electricity Grid Model

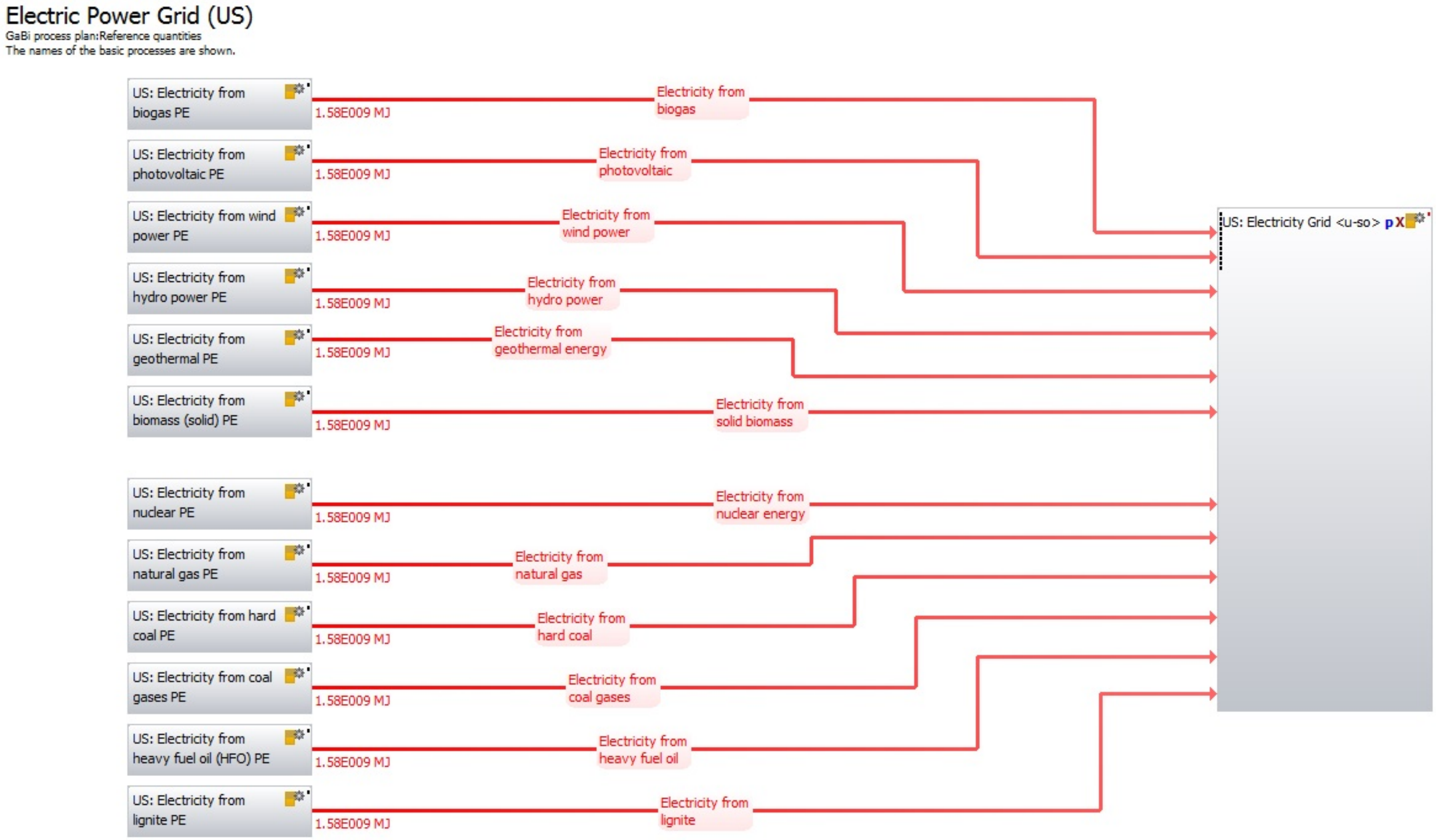


Figure 7: LCA Electricity Grid Model - US

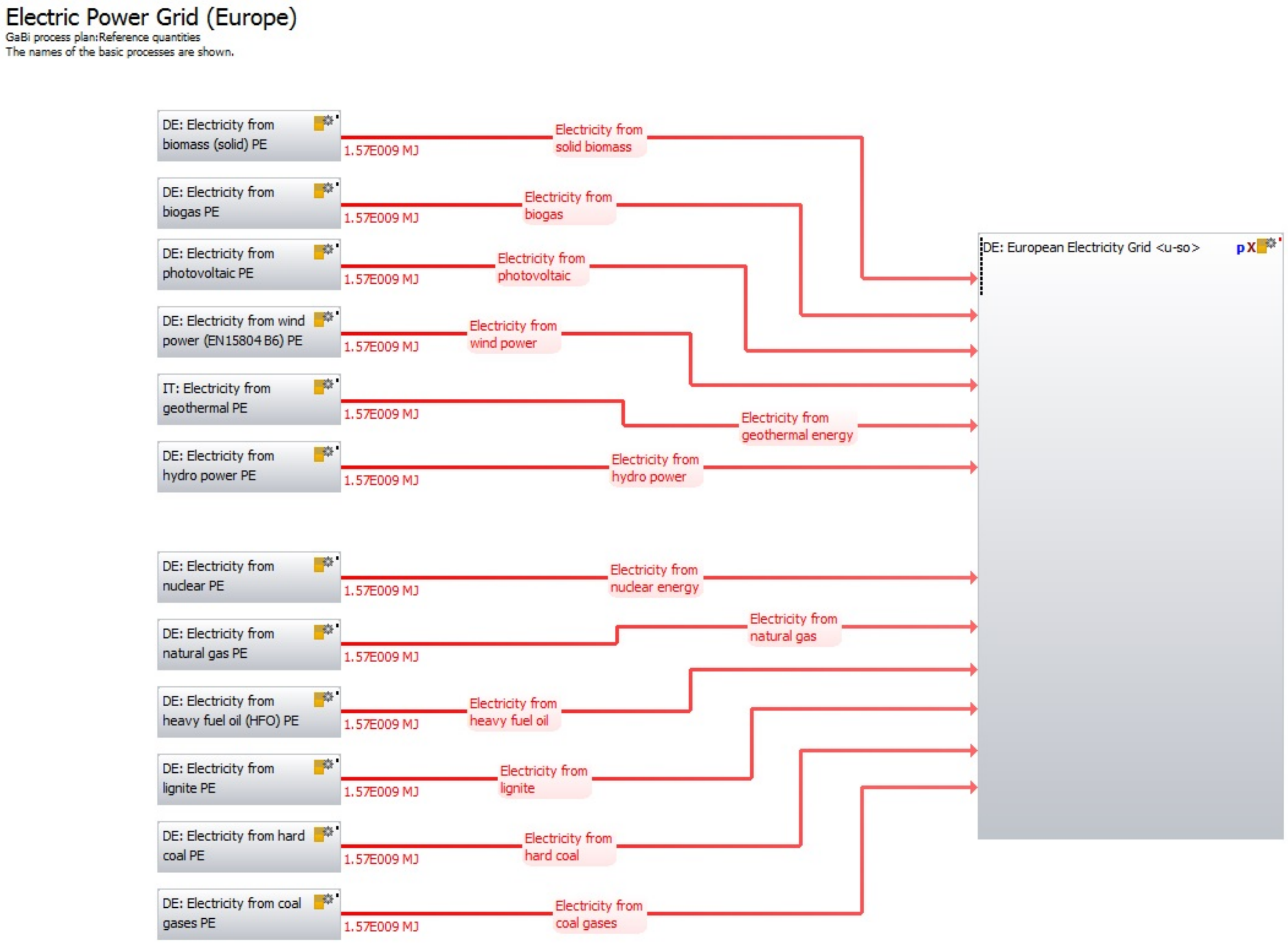


Figure 8: LCA Electricity Grid Model - Europe

3.2 Economic Modeling Methodology

Electricity generation cost at the point of connection to an electrical grid, is evaluated using LCOE for different technologies. LCOE is evaluated by incorporating the capacity factor of individual technologies in its calculation; we can also calculate the economic expenditure for the total MWh of energy requirement. The LCOE of individual technologies for US and Europe is listed in the table 3 below (World Energy Council, 2013).

Table 3: Comparison of Data for LCOE for Different Technologies

Levelized cost of electricity ($/MWh)	Capacity Factor	US		Europe	
		LL	HL	LL	HL
Coal	85%	77	78	119	172
Natural gas	80%	61	69	114	141
Nuclear	90%	94	94	147	147
Biomass	80%	50	210	50	210
Wind	35%	61	136	71	117
Photovoltaic	25%	139	449	90	397
Hydropower	80%	19	314	19	314
Geothermal	90%	60	276		

*LL - lower limit; HL - higher limit

Total levelized cost of electricity calculated from MWh energy requirement and listed in the table 4 below.

- MWh of energy required = $5.256X10^6\ MWh$ (evaluated in previous section)
- Total LCOE = $LCOE\ XMWh\ of\ energy\ required$

Table 4: Comparison of Data for Total LCOE based on MWh of Energy Required

Total LCOE ($)	US		Europe	
	LL	HL	LL	HL
Coal	4.05E+08	4.10E+08	6.25E+08	9.04E+08
Natural gas	3.21E+08	3.63E+08	5.99E+08	7.41E+08
Nuclear	4.94E+08	4.94E+08	7.73E+08	7.73E+08
Biomass	2.63E+08	1.10E+09	2.63E+08	1.10E+09
Wind	3.21E+08	7.15E+08	3.73E+08	6.15E+08
Photovoltaic	7.31E+08	2.36E+09	4.73E+08	2.09E+09
Hydropower	9.99E+07	1.65E+09	9.99E+07	1.65E+09
Geothermal	3.15E+08	1.45E+09		

*LL - lower limit; HL - higher limit

Economic burden in USD ($) from mitigation of environmental impacts evaluated using individual impact mitigation ($) value (TUDelft, 2014), and listed in the table 5 below.

Table 5: Comparison of Data for Environmental Impact Mitigation Costs

Environmental impact mitigation value	($/kg)
Eco cost of GWP	0.17
Eco cost of AP	10.23
Eco cost of EP	4.83
Eco cost of Ecotoxicity (ETP)	68.17
Eco cost of Human Toxicity (HTP)	44.62

Using the data from above table 5, data from inventory analysis results and the capacity factor for the individual technology, we can evaluate to economic burden associated with mitigation of environmental impacts of the said technology. To evaluate the total cost of the energy production along with mitigation we can add the environmental cost with LCOE for a baseline quantity of 1000 MW required for duration of one year for a power plant working at 60% capacity.

- Economic cost associated with mitigation of environmental impacts for a type of technology = $(Eco\ cost\ of\ GWP\ X\ kg\ GWP + Eco\ cost\ of\ GWP\ X\ kg\ AP + Eco\ cost\ of\ GWP\ X\ kg\ EP + Eco\ cost\ of\ GWP\ X\ kg\ HTP + Eco\ cost\ of\ GWP\ X\ kg\ ETP) X\ (60\%\ capacity)/(capacity\ factor)$
- Total Cost of energy production including mitigation cost for a type of technology = $Economic\ costs\ associated\ with\ mitigation + Total\ LCOE$

Total Cost ($) of energy production in table 6 is calculated using the above mentioned formulae and Total LCOE cost from table 4 and mitigation costs from table 5.

Table 6: Comparison of Data for Total Cost ($) of Energy Production

Technology	GWP	AP	EP	ETP	HTP	Total Cost
Coal	4.92E+08	2.04E+06	9.49E+04	1.94E+05	1.92E+07	6.88E+08
Natural gas	2.76E+08	1.42E+05	2.91E+04	6.93E+05	3.10E+06	1.76E+08
Nuclear	6.07E+06	3.49E+04	3.65E+03	6.27E+05	3.61E+06	1.37E+08
Biomass	2.28E+07	9.85E+05	1.42E+05	3.95E+05	3.82E+07	1.31E+09
Wind	3.72E+06	1.09E+04	1.18E+03	1.16E+04	4.17E+05	3.45E+07
Photovoltaic	1.50E+07	6.89E+04	5.30E+03	1.34E+05	2.24E+07	2.43E+09
Hydropower	3.21E+06	1.94E+03	2.80E+02	3.06E+03	-9.5E+04	-2.6E+06
Geothermal	2.76E+07	3.83E+06	4.28E+02	7.08E+02	6.15E+05	4.76E+07

Results from the analysis in this chapter are discussed in chapter 4.

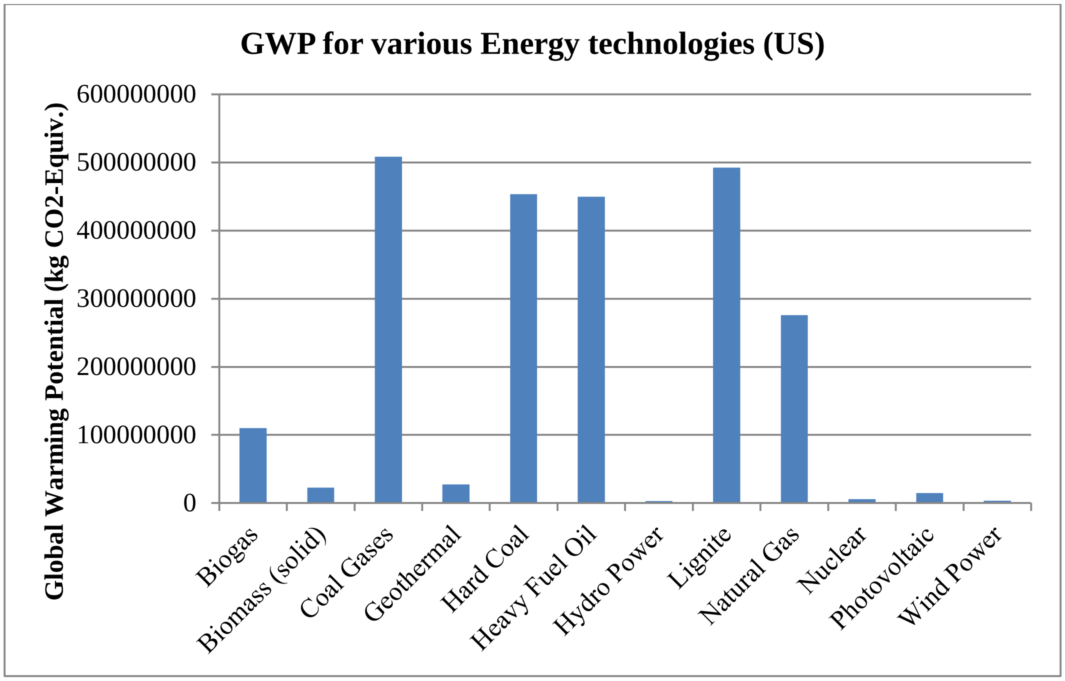
CHAPTER 4

RESULTS AND DISCUSSIONS

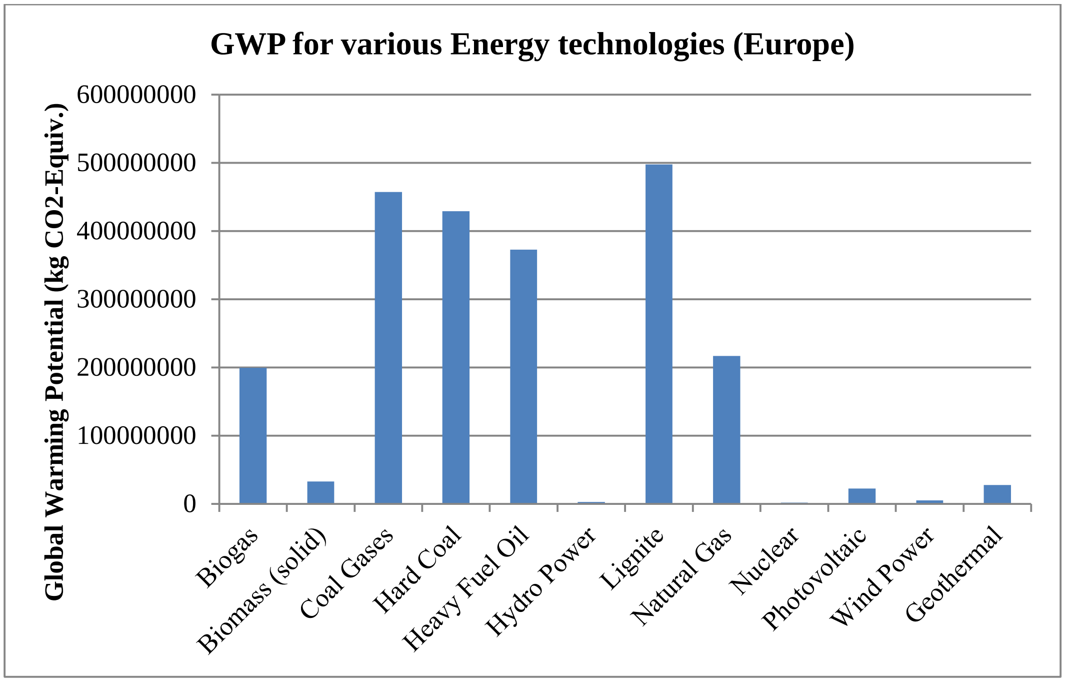
This chapter outlines the results obtained from GaBi LCA modeling and economic modeling, and discusses their variations and impacts. First, the detailed LCA inventory analysis results are plotted, with their data source attached in appendices A and B. Second, results from economic modeling of an energy production technology including their Total LCOE and economic costs associated with mitigation of environmental impacts is plotted for demonstrating the differences, with their data source discusses in table 6 in previous section..

4.1 GaBi - LCA Results

GaBi LCA model results for 12 different energy technologies compared simultaneously for two different geographic locations: US and Europe. This section presents in total 18 graphs displaying 9 different environmental impacts categories for different energy technologies.

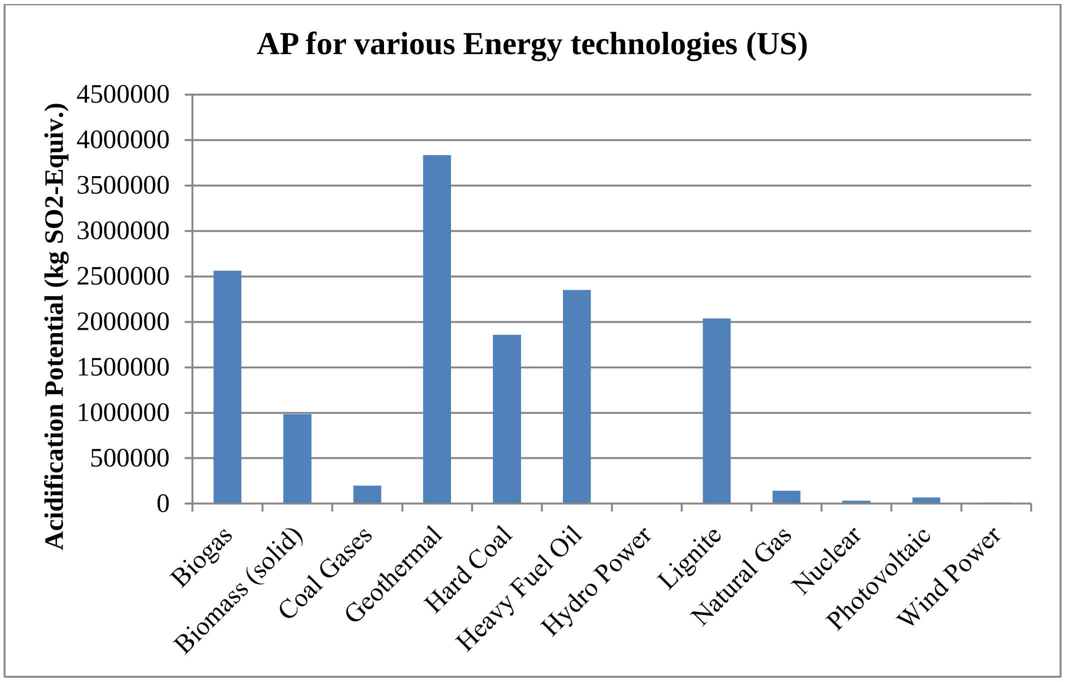


9 (a)

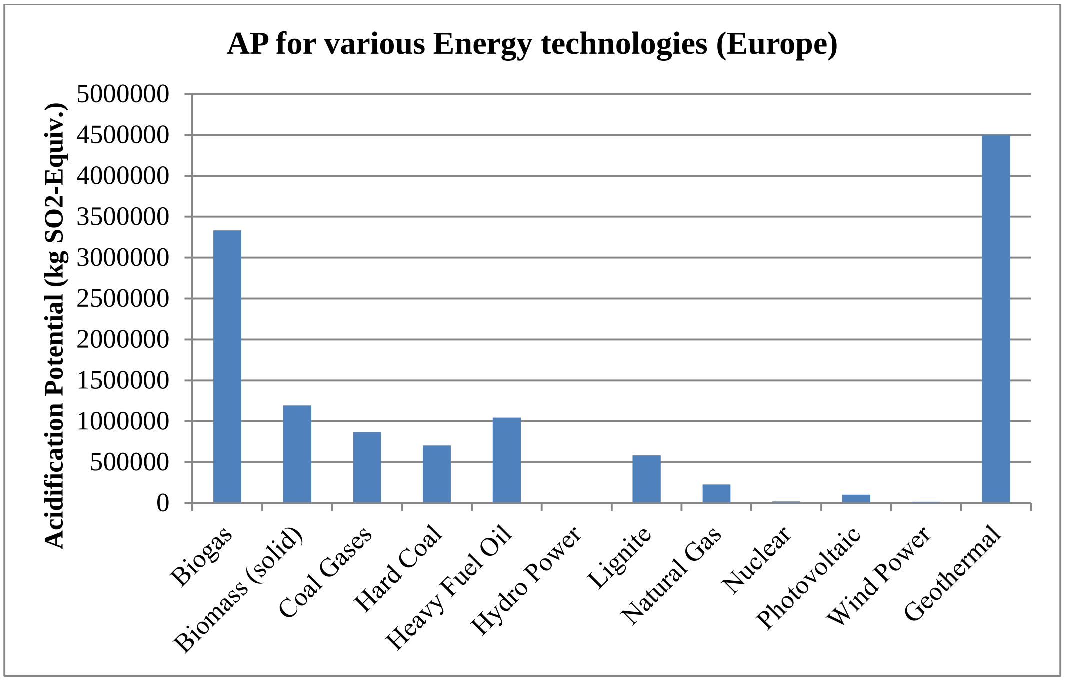


9 (b)

Figure 9: Comparison of Data for Global Warming Potential for Different Technologies

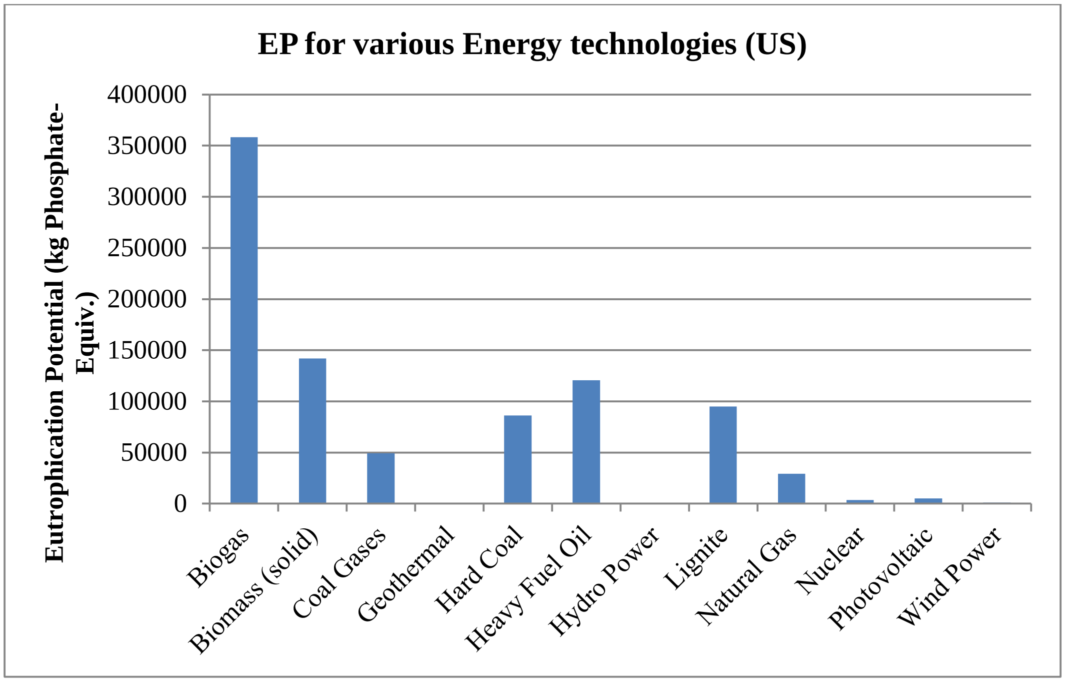


10 (a)

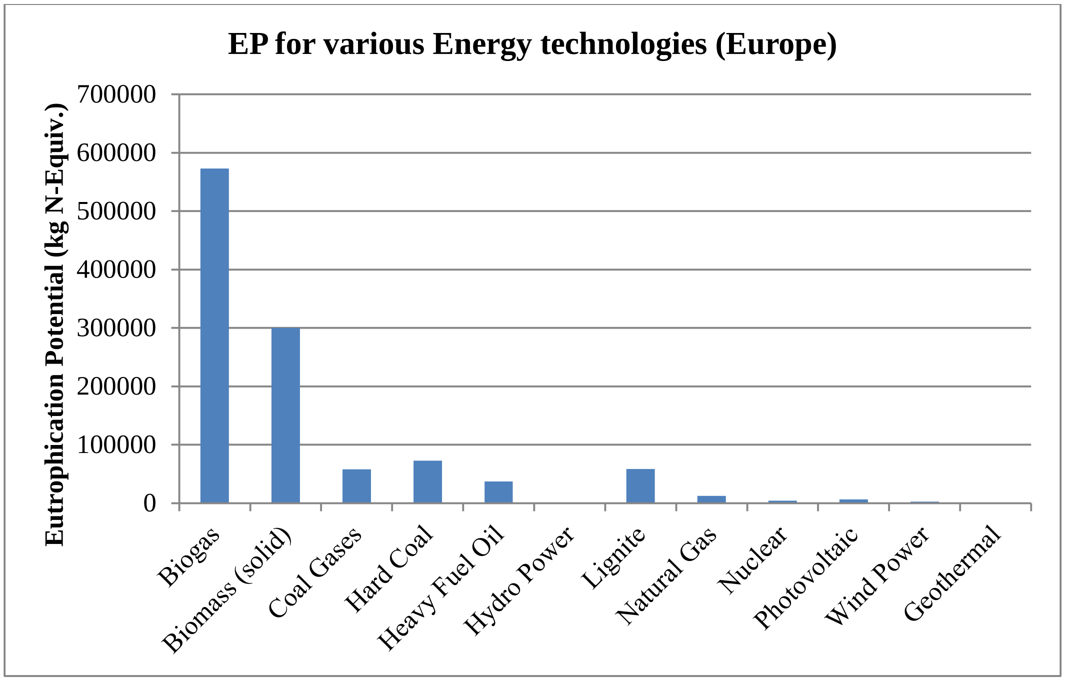


10 (b)

Figure 10: Comparison of Data for Acidification Potential for Different Technologies

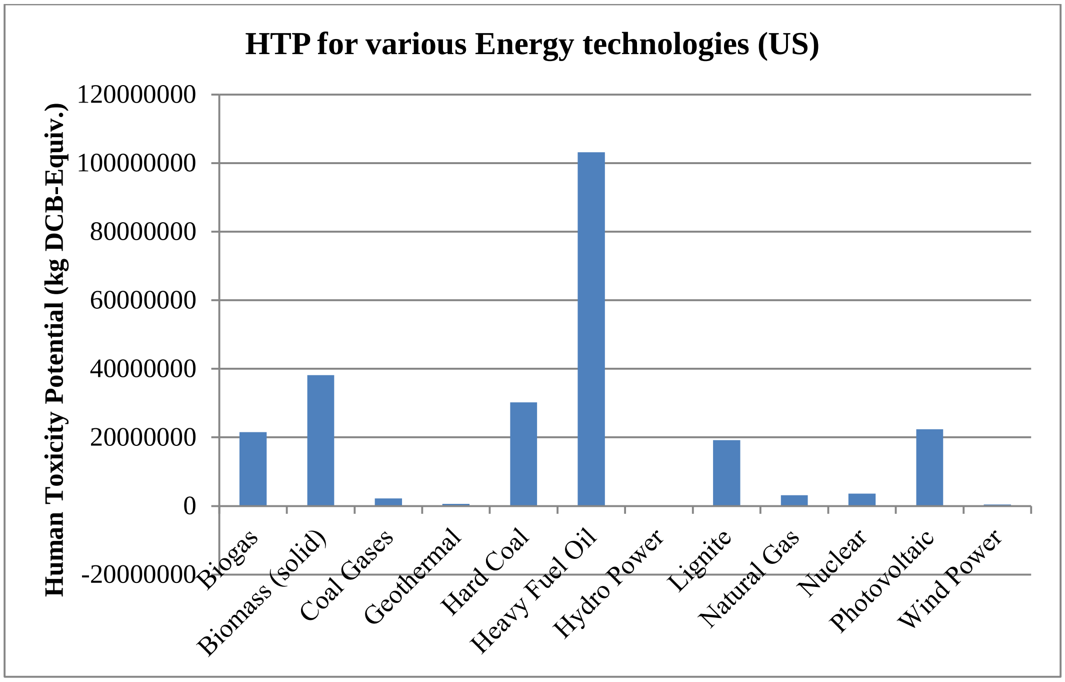


11 (a)

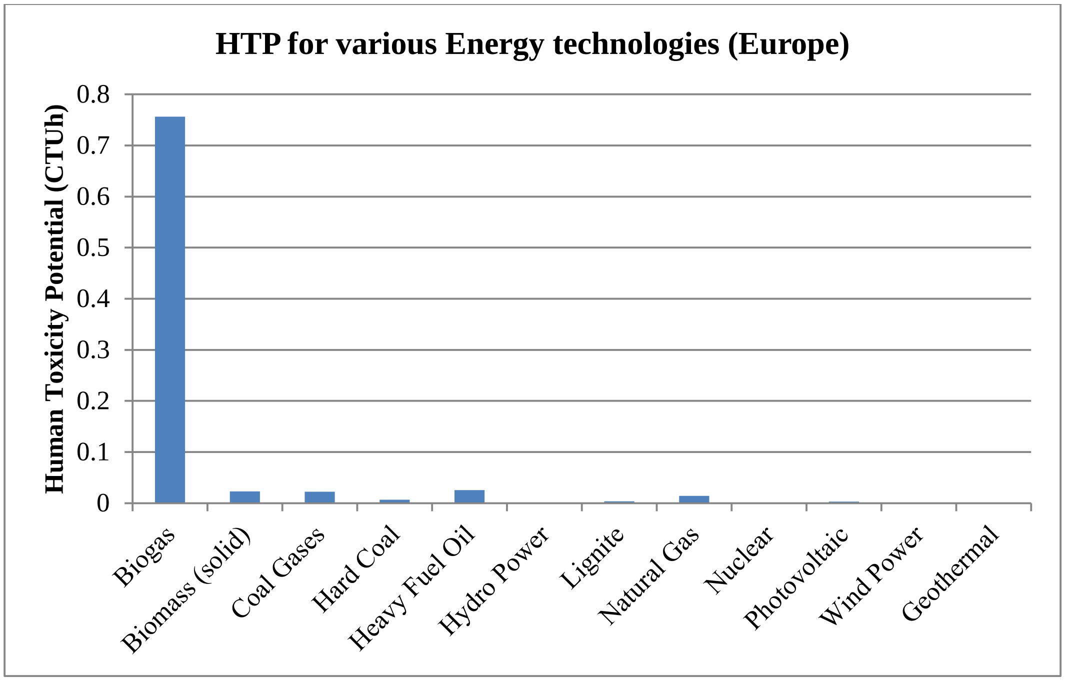


11 (b)

Figure 11: Comparison of Data for Eutrophication Potential for Different Technologies

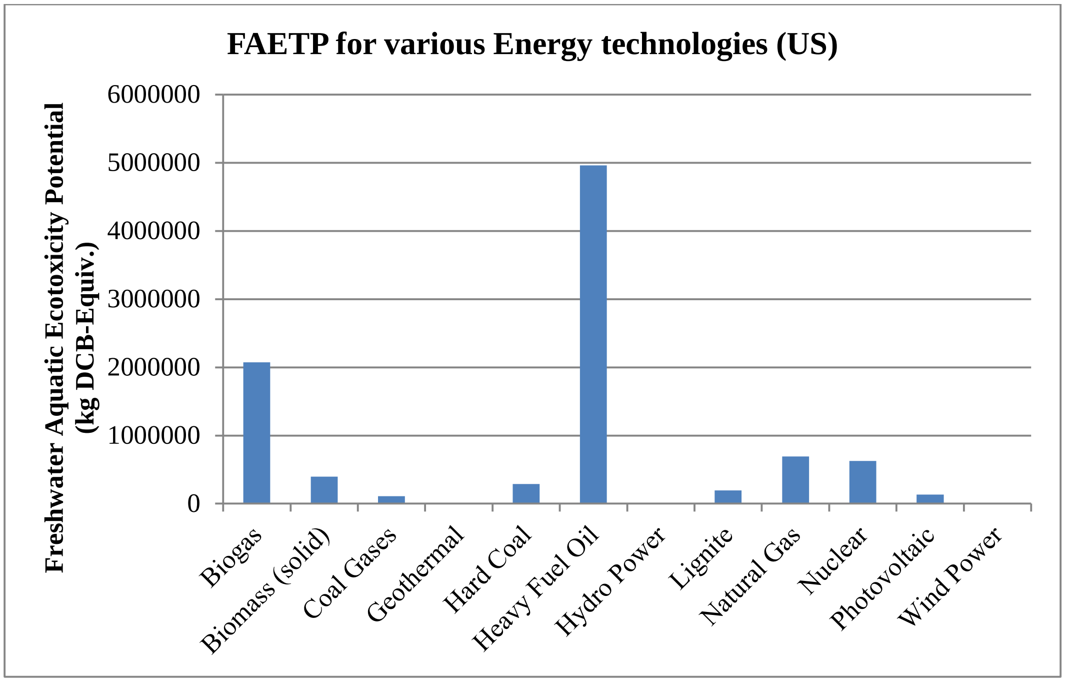


12 (a)

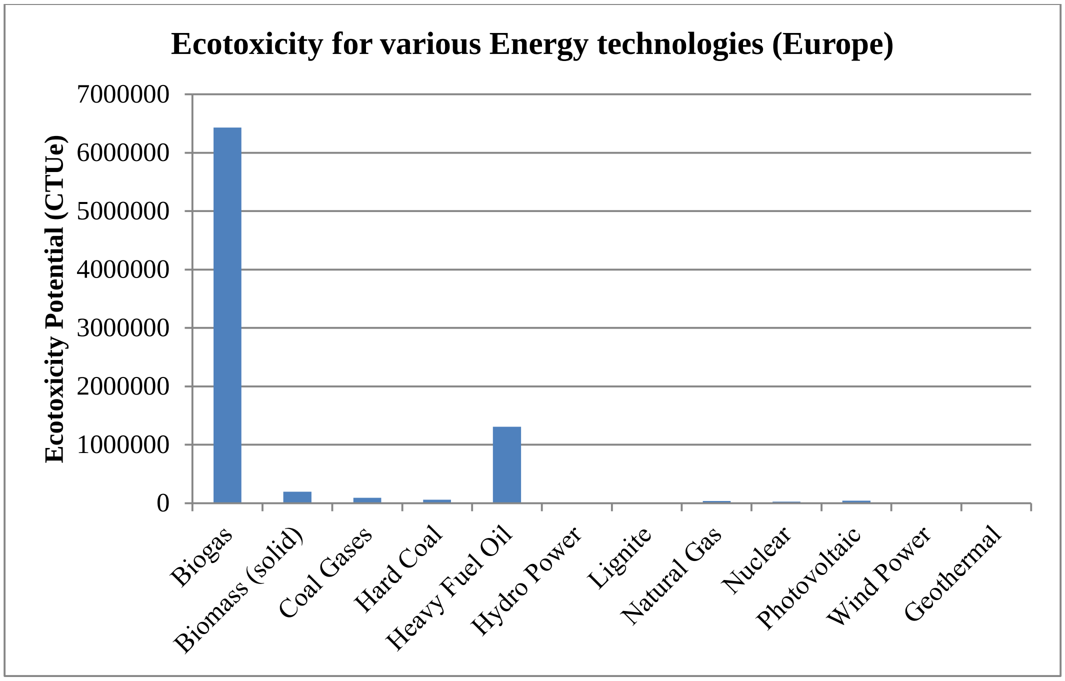


12 (b)

Figure 12: Comparison of Data for Human Toxicity Potential for Different Technologies

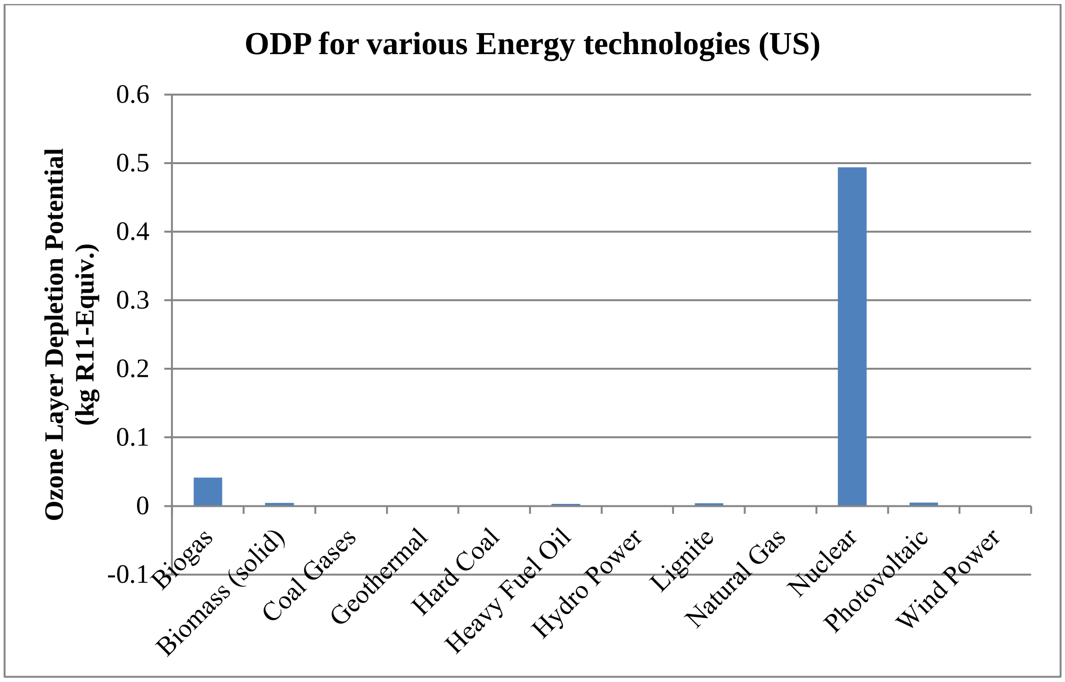


13 (a)

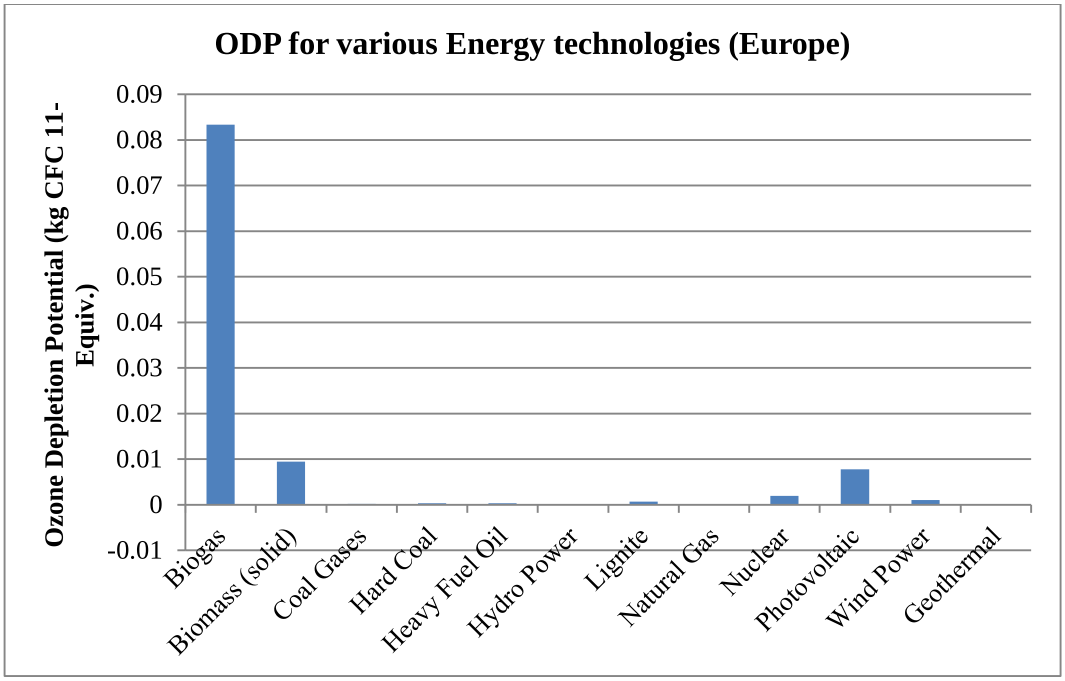


13 (b)

Figure 13: Comparison of Data for Ecotoxicity Potential for Different Technologies

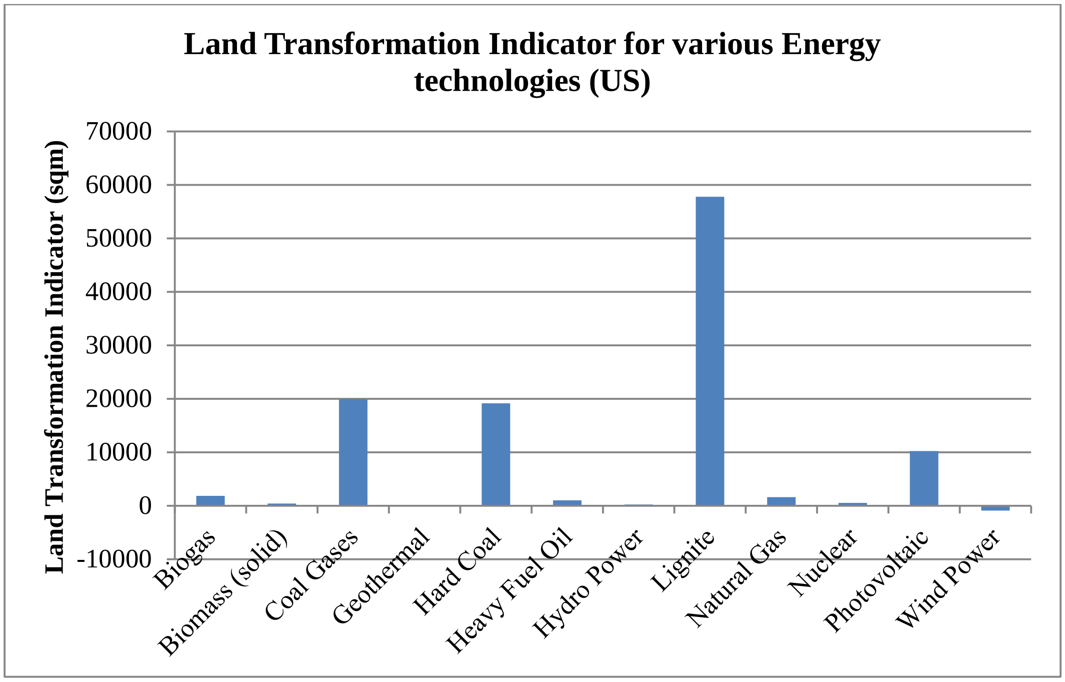


14 (a)

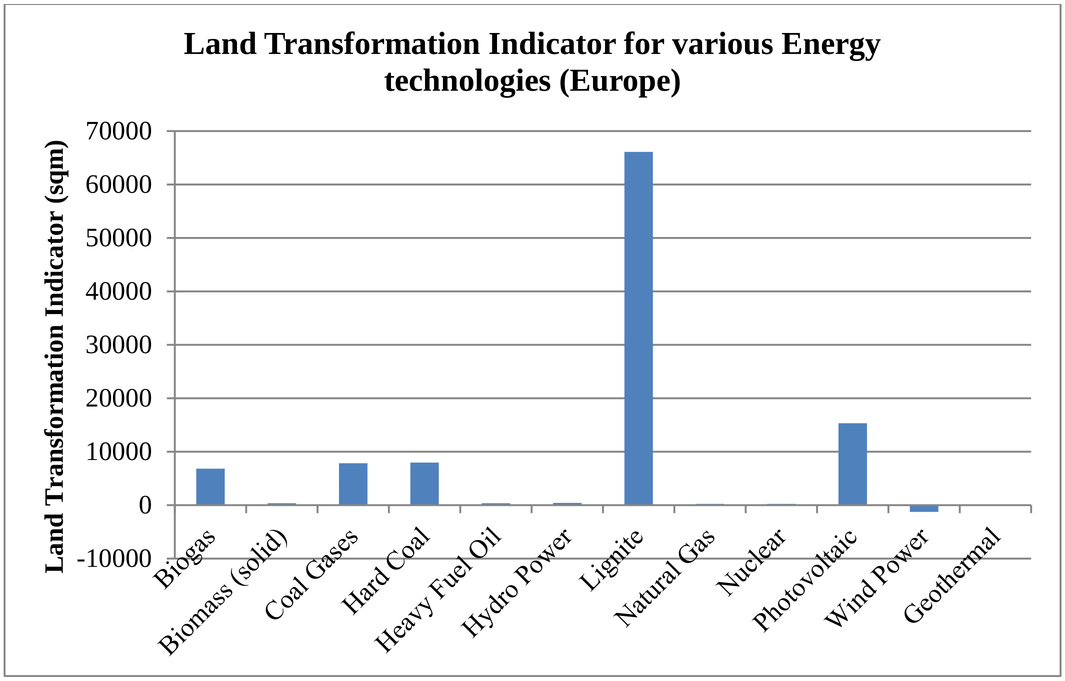


14 (b)

Figure 14: Comparison of Data for Ozone Depletion Potential for Different Technologies

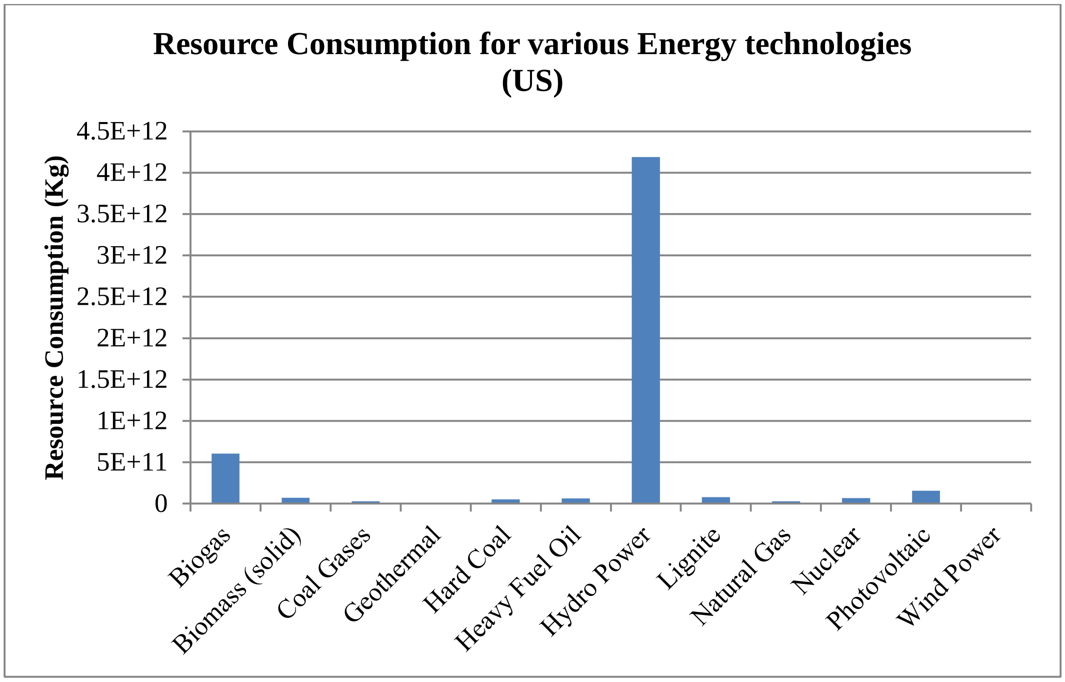


15 (a)

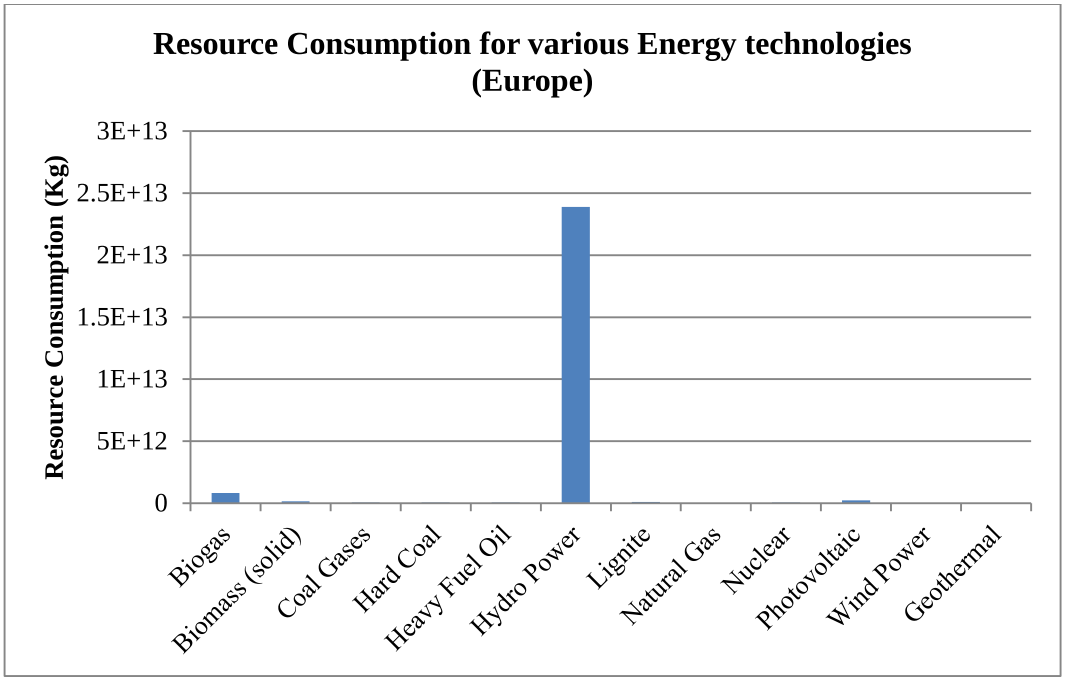


15 (b)

Figure 15: Comparison of Data for Land Transformation for Different Technologies

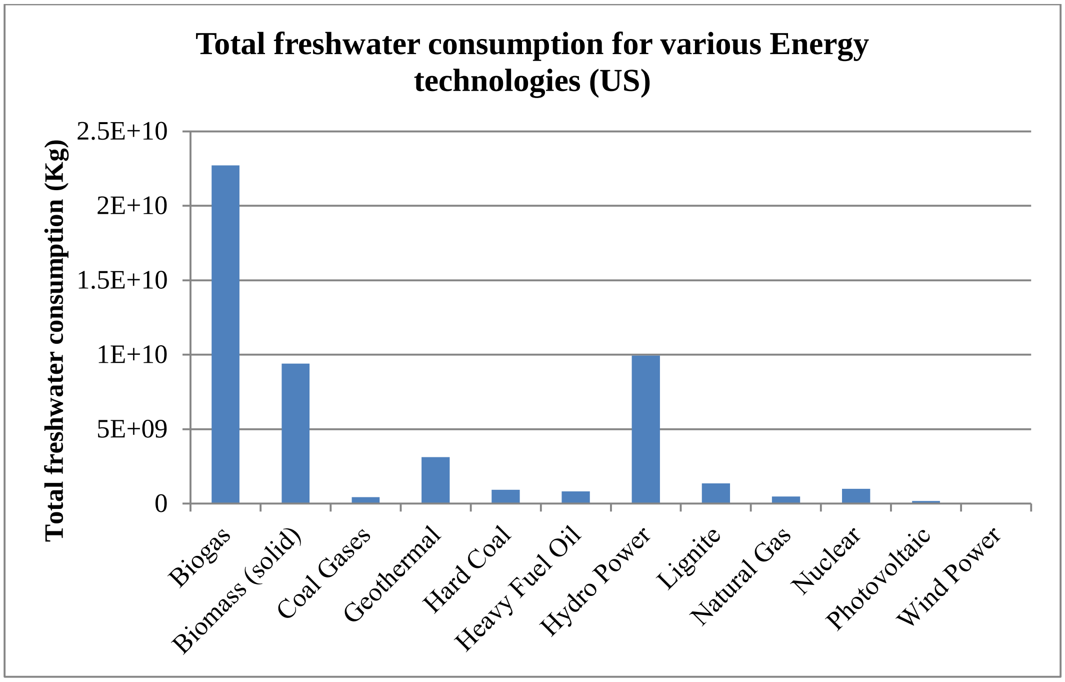


16 (a)

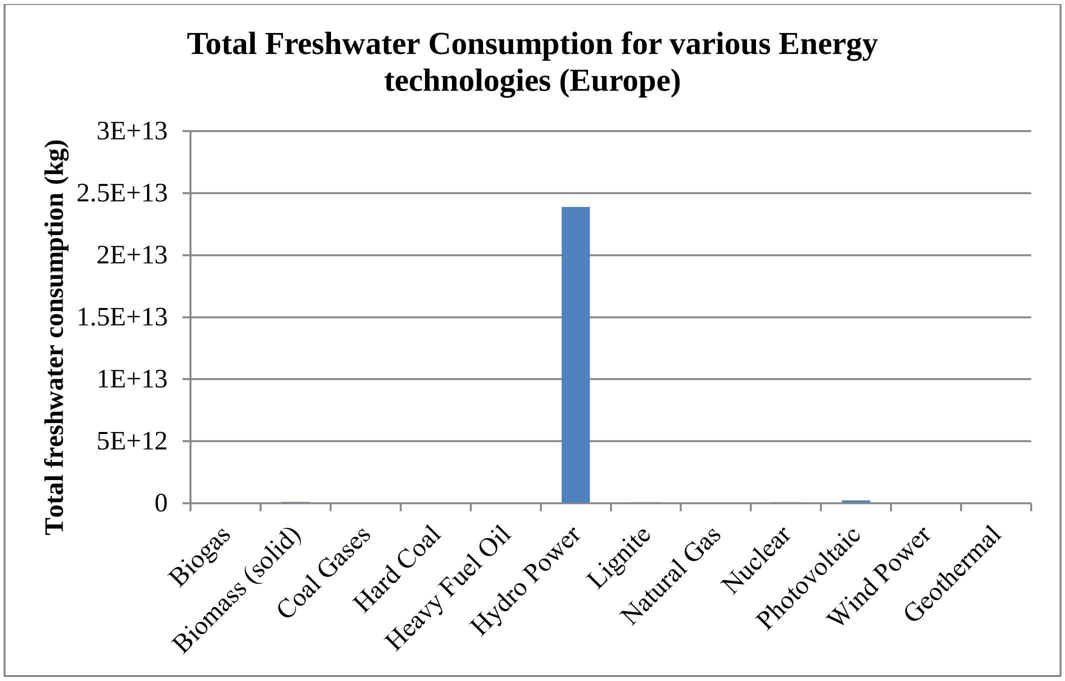


16 (b)

Figure 16: Comparison of Data for Resource Consumption for Different Technologies



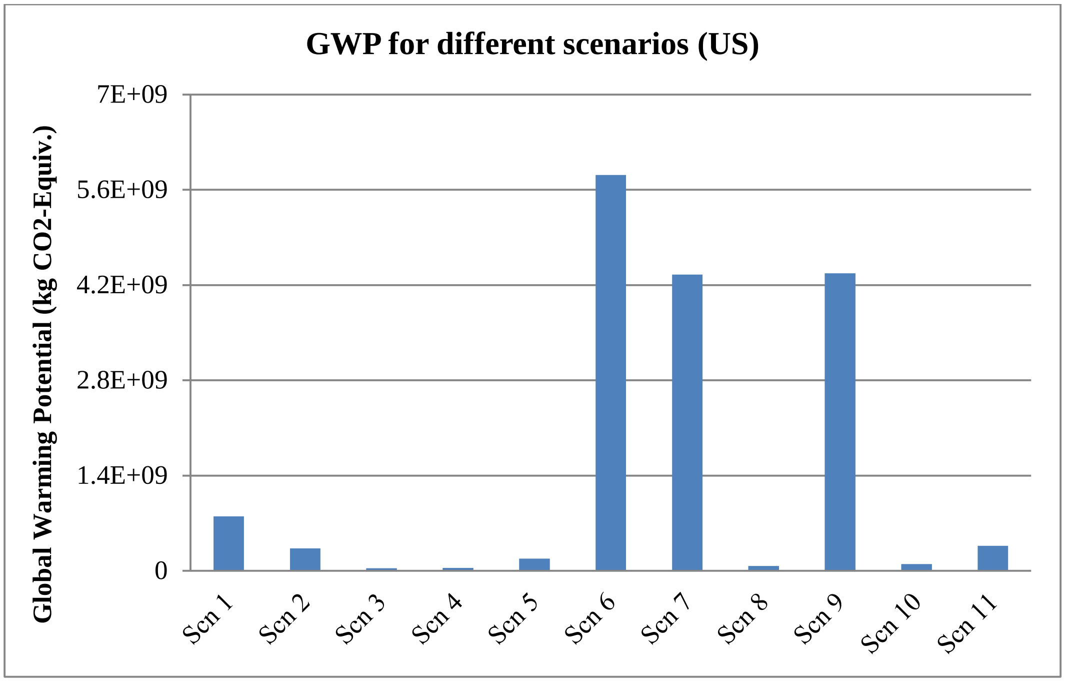
17 (a)



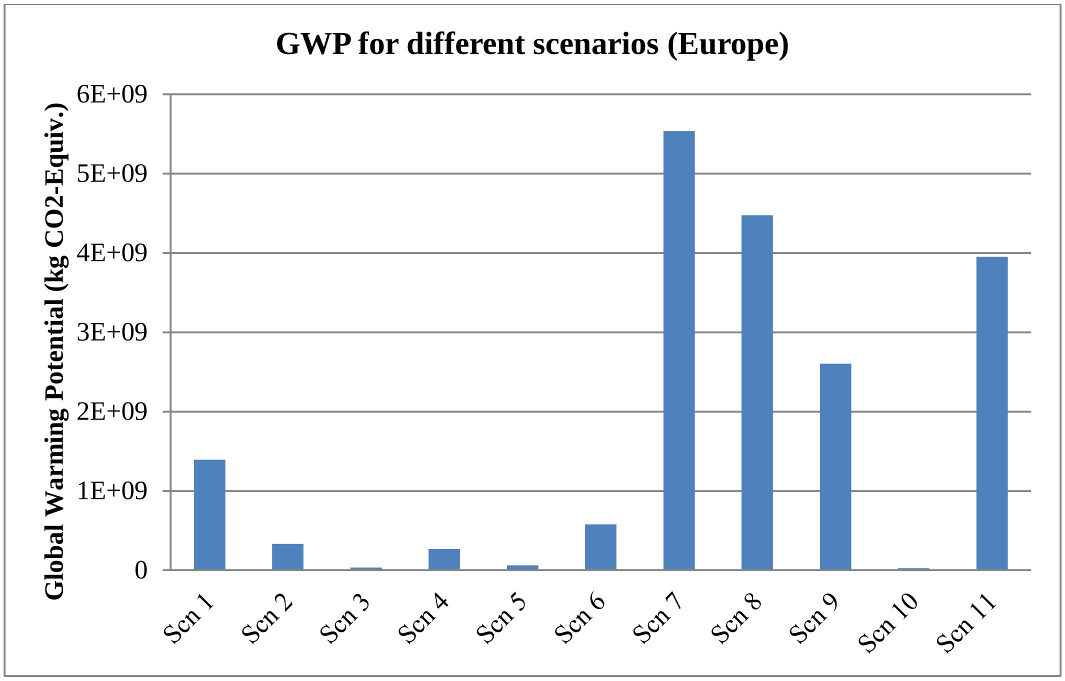
17 (b)

Figure 17: Comparison of Data for Freshwater Consumption for Different Technologies

GaBi LCA model result for 11 different scenario combinations compared simultaneously for two different geographic locations: US and Europe. This section presents in total 18 graphs displaying 9 different environmental impacts categories for different energy combination scenarios.

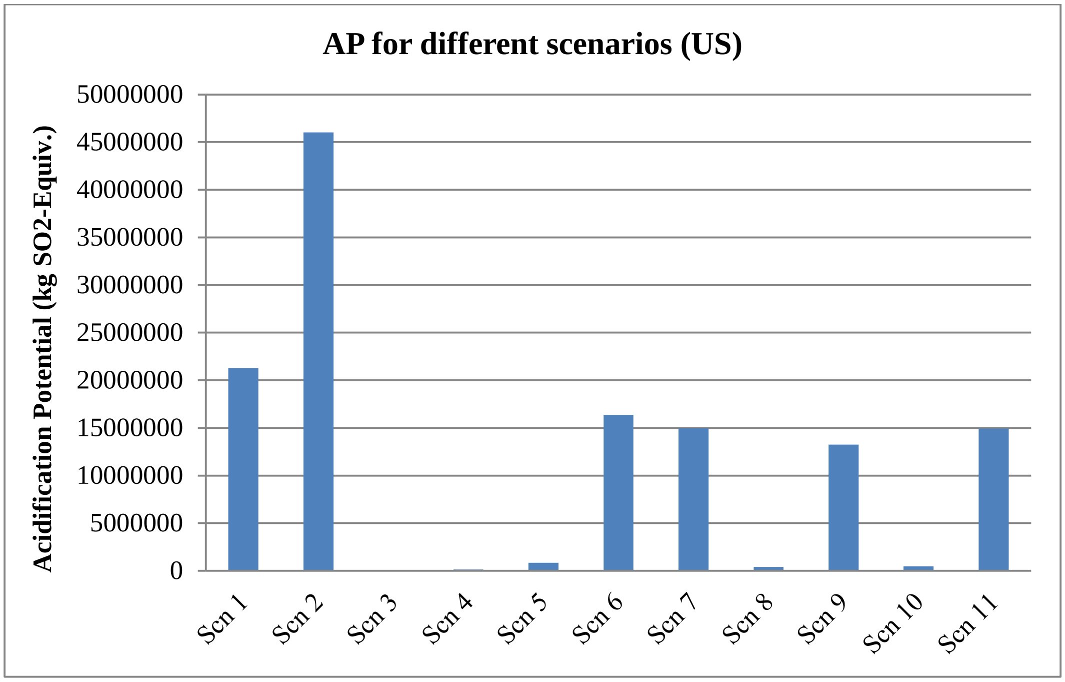


18 (a)

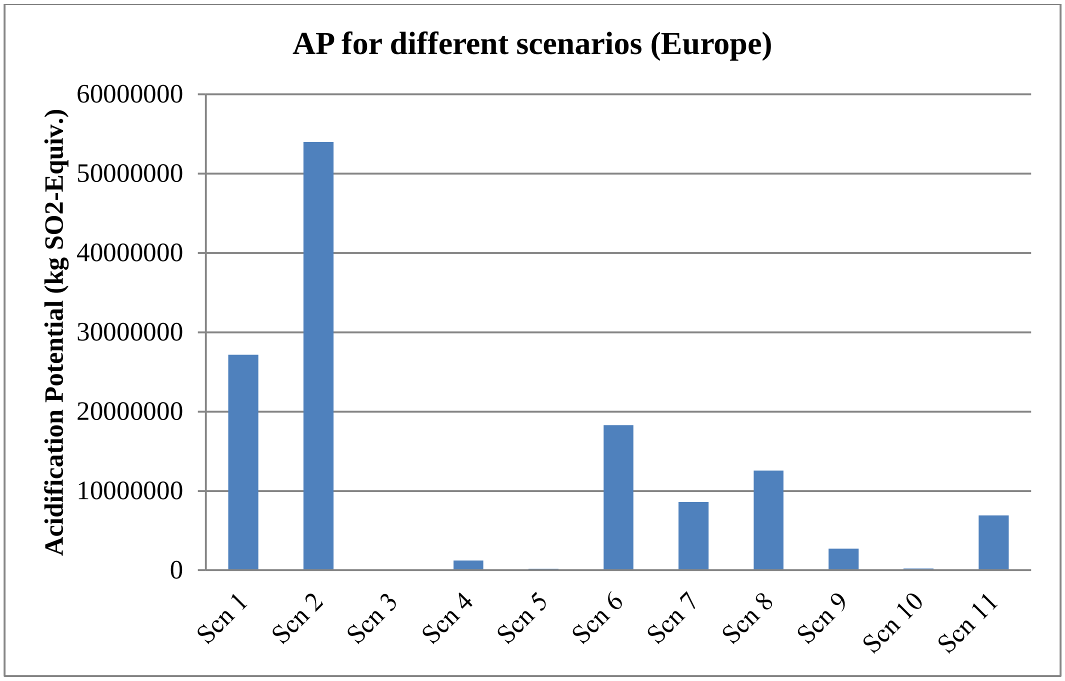


18 (b)

Figure 18: Comparison of Data for Global Warming Potential for Different Scenarios

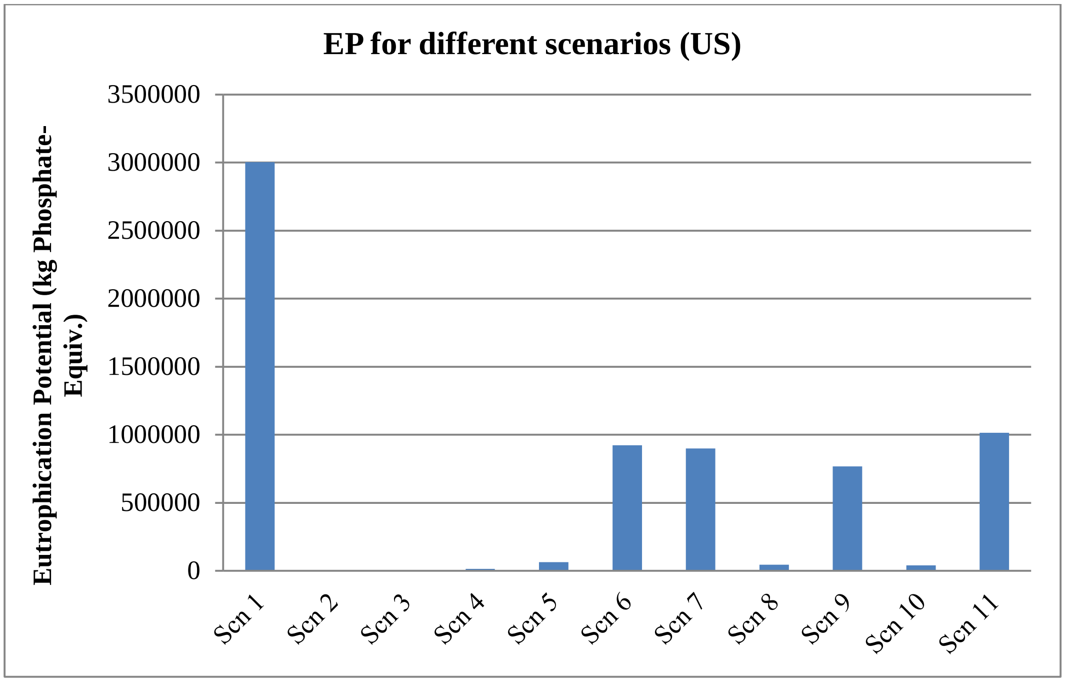


19 (a)

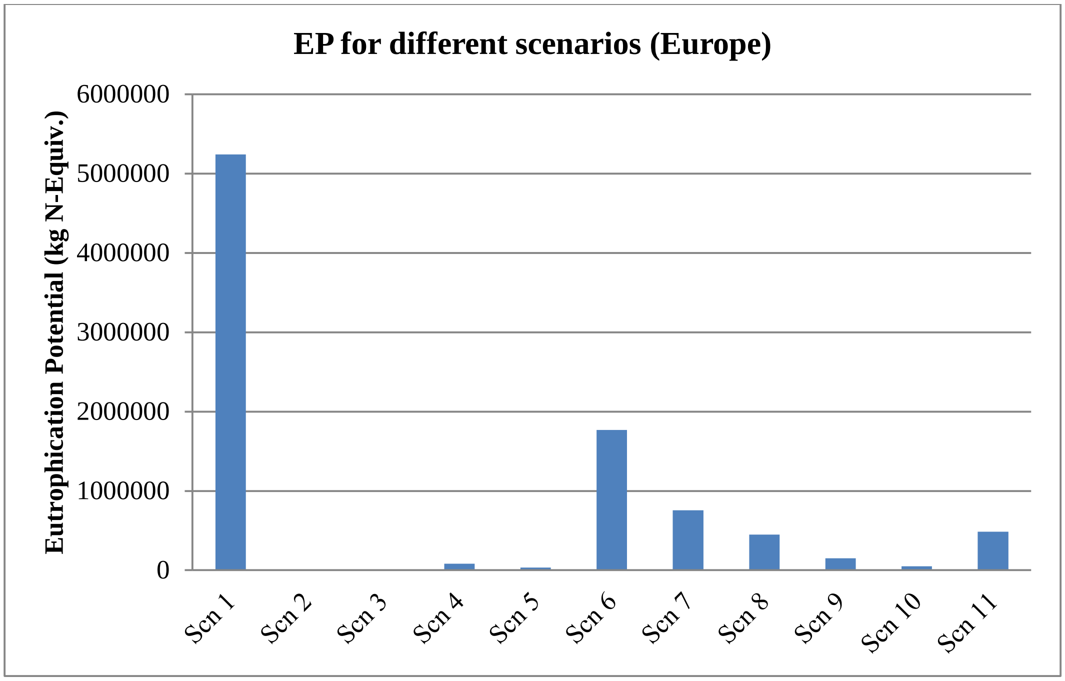


19 (b)

Figure 19: Comparison of Data for Acidification Potential for Different Scenarios

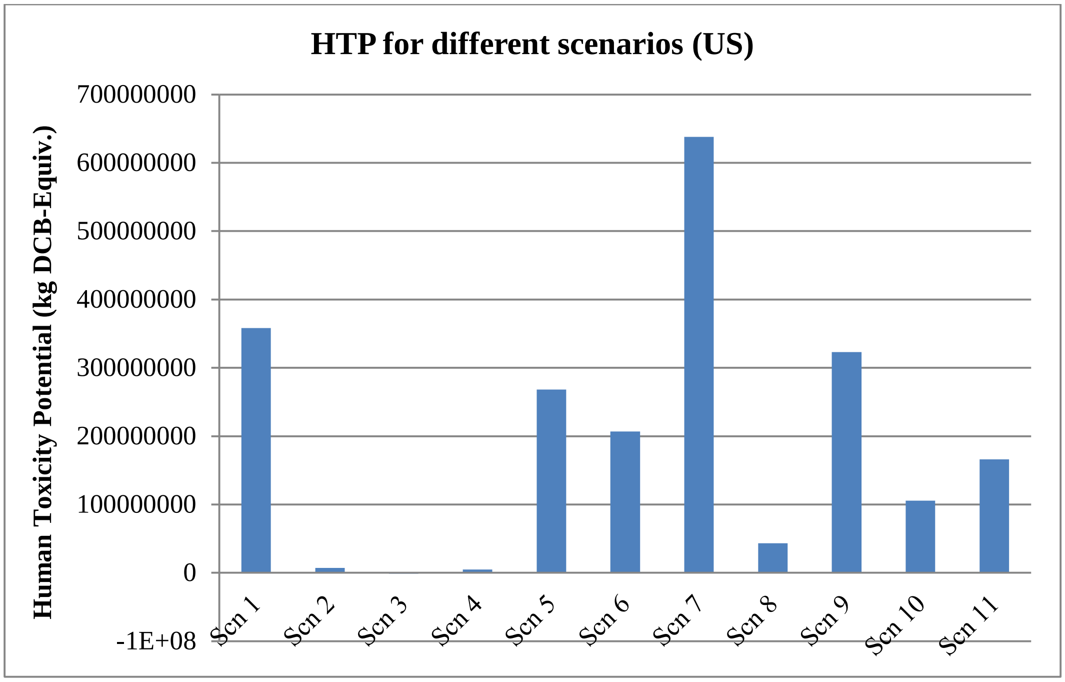


20 (a)

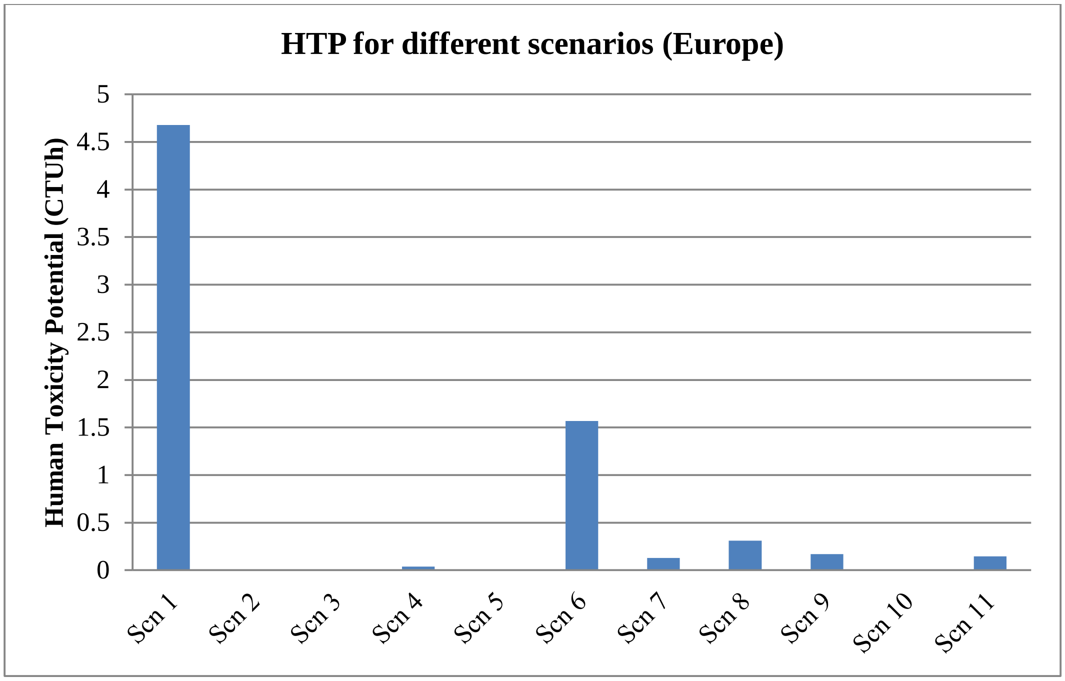


20 (b)

Figure 20: Comparison of Data for Eutrophication Potential for Different Scenarios

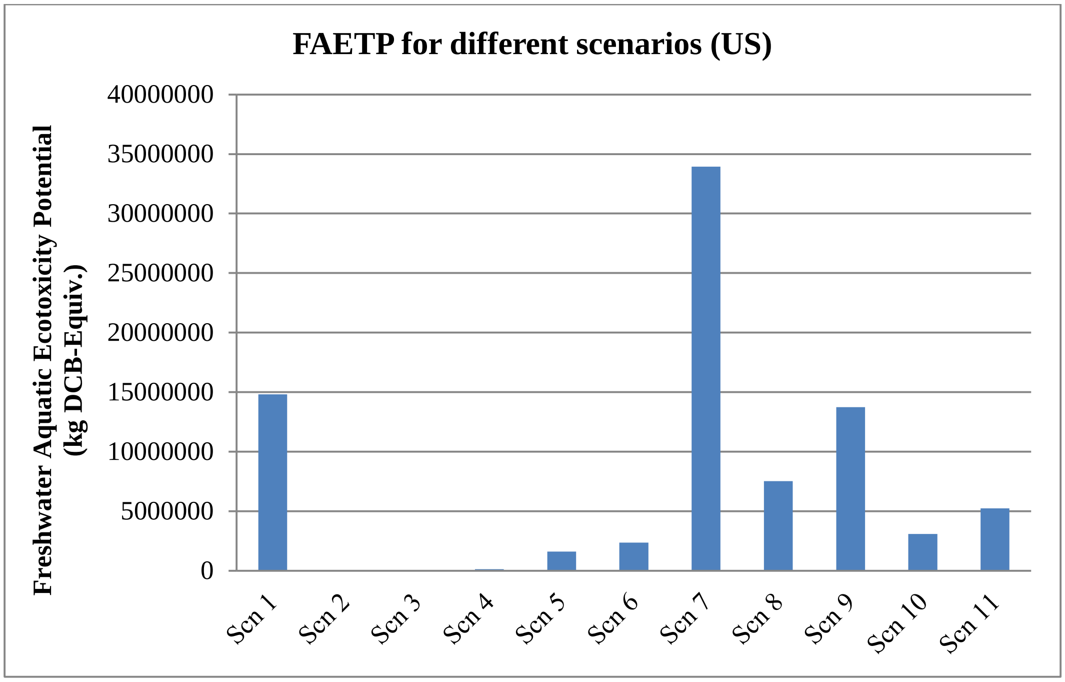


21 (a)

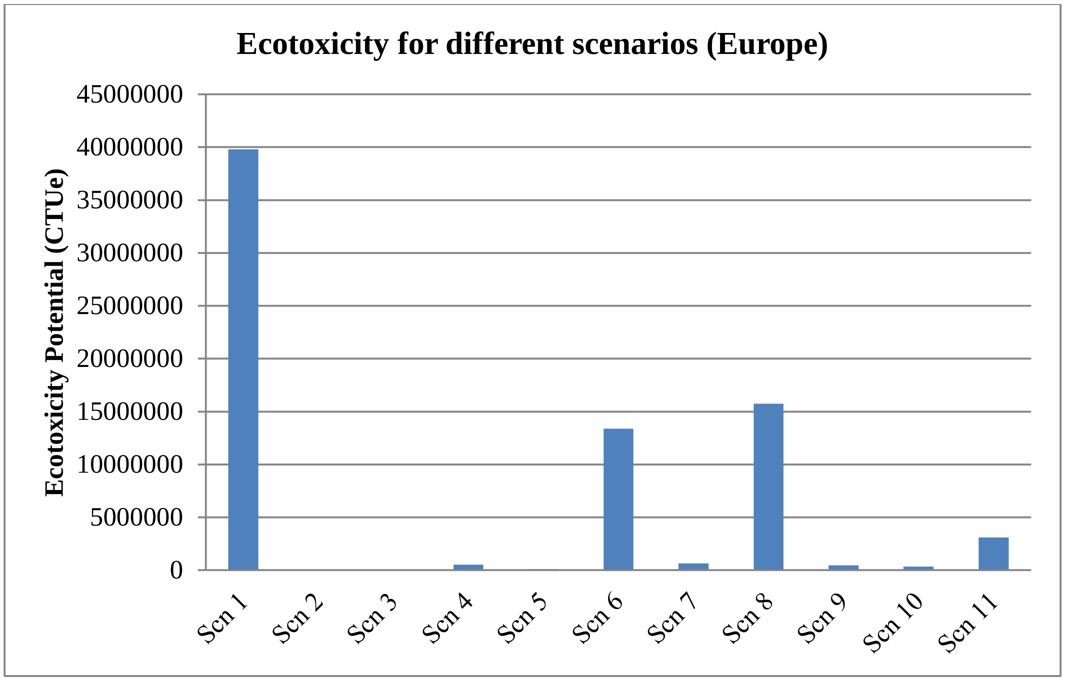


21 (b)

Figure 21: Comparison of Data for Human Toxicity Potential for Different Scenarios

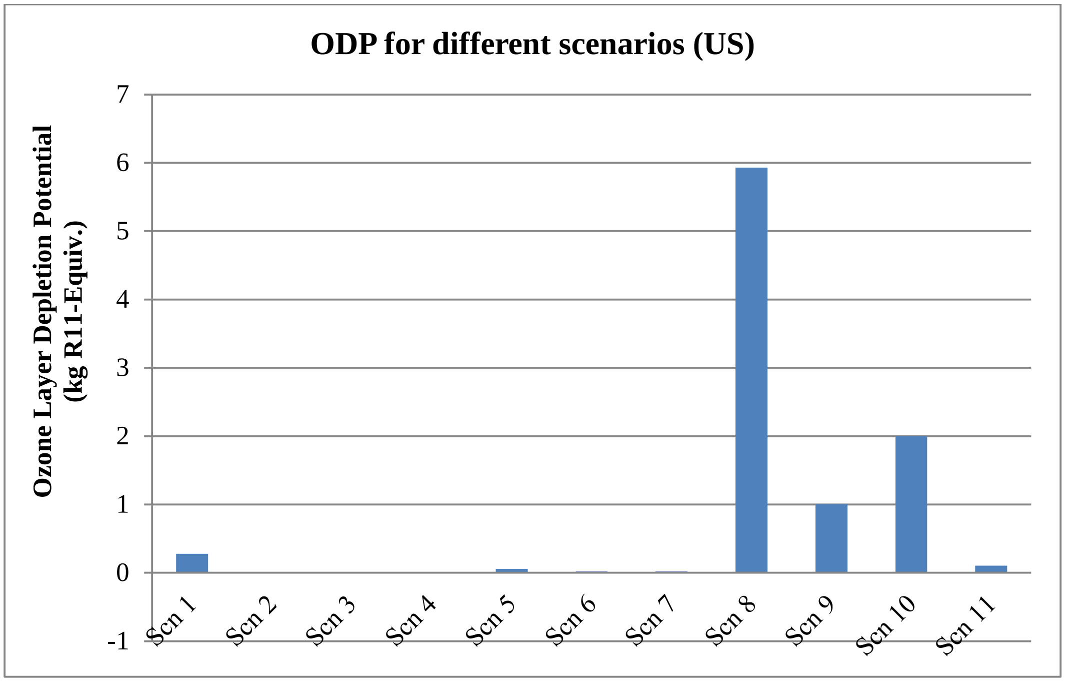


22 (a)

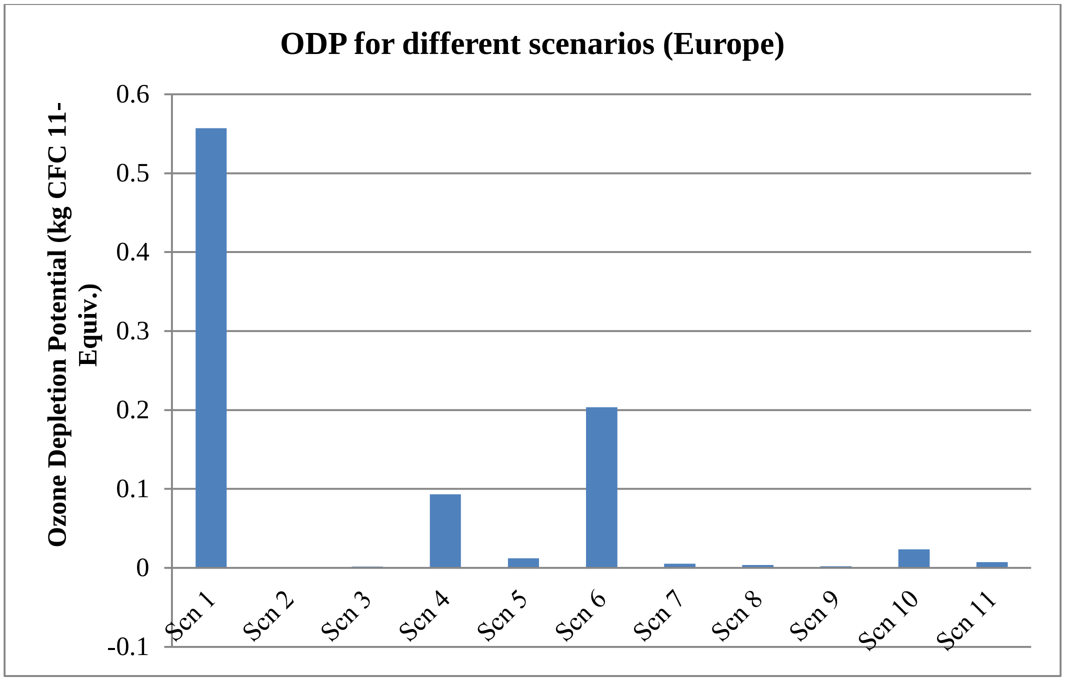


22 (b)

Figure 22: Comparison of Data for Ecotoxicity Potential for Different Scenarios

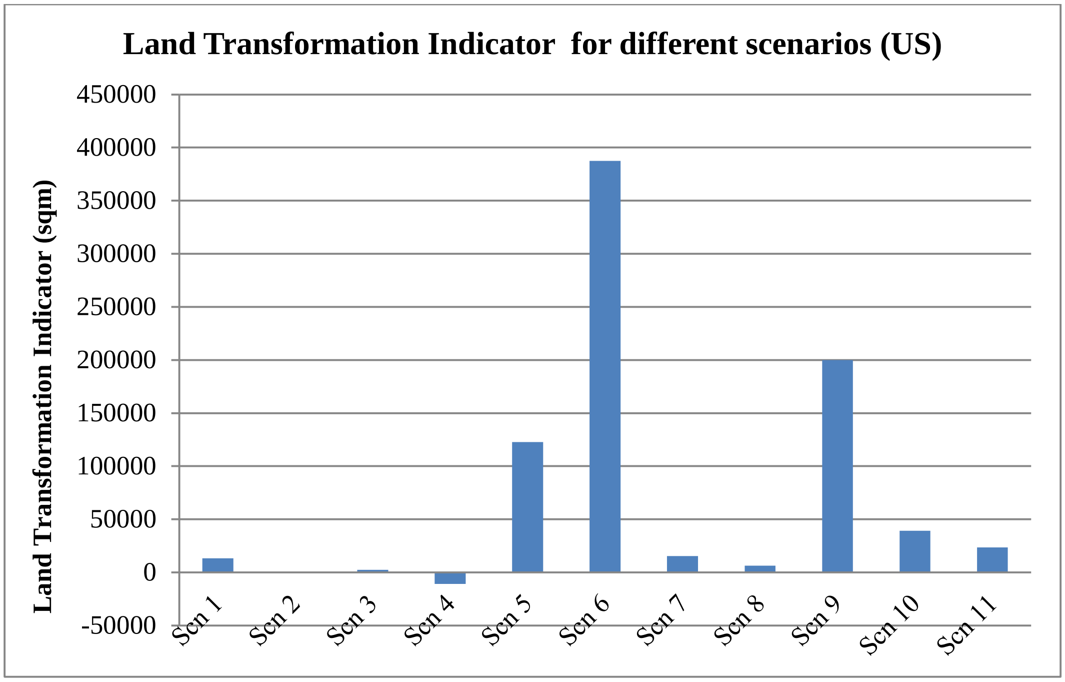


23 (a)

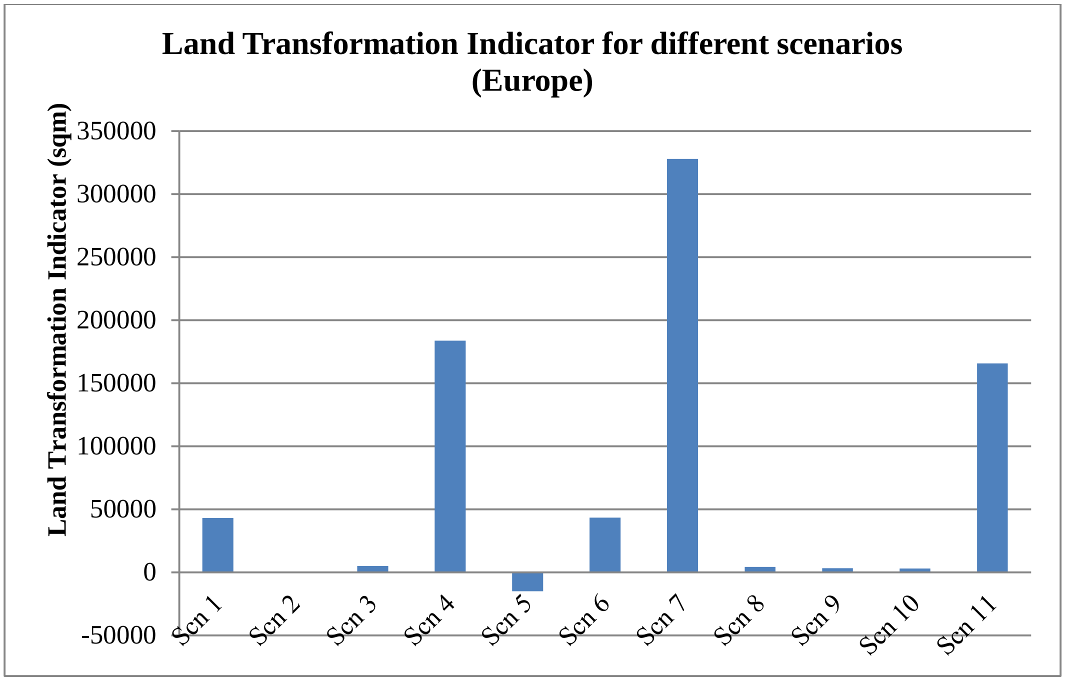


23 (b)

Figure 23: Comparison of Data for Ozone Depletion Potential for Different Scenarios

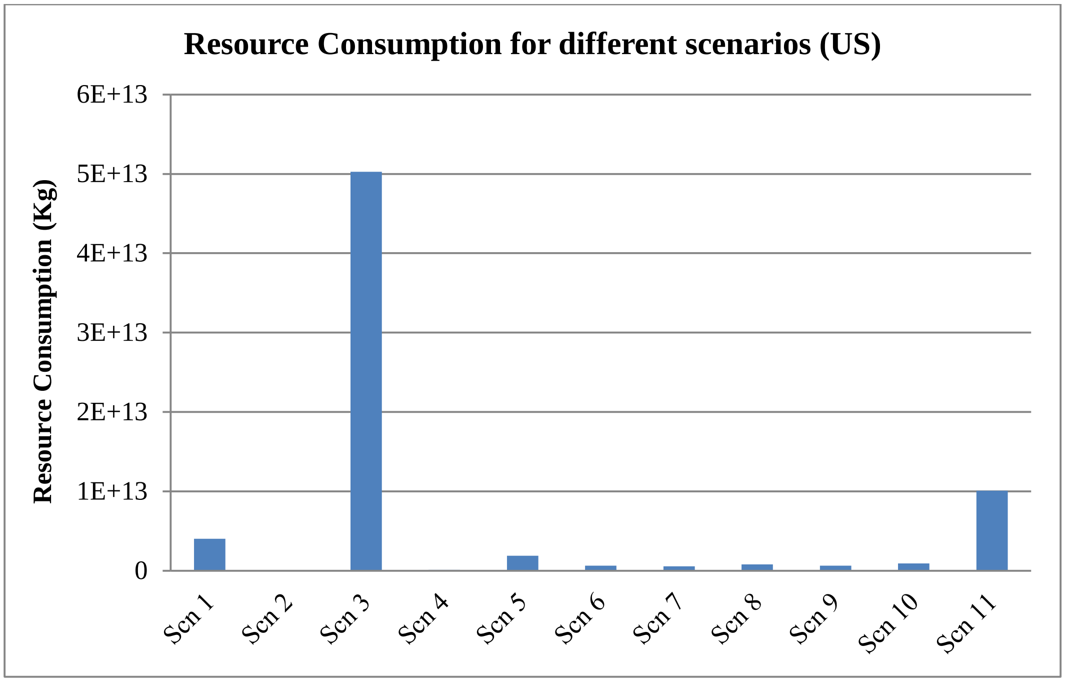


24 (a)

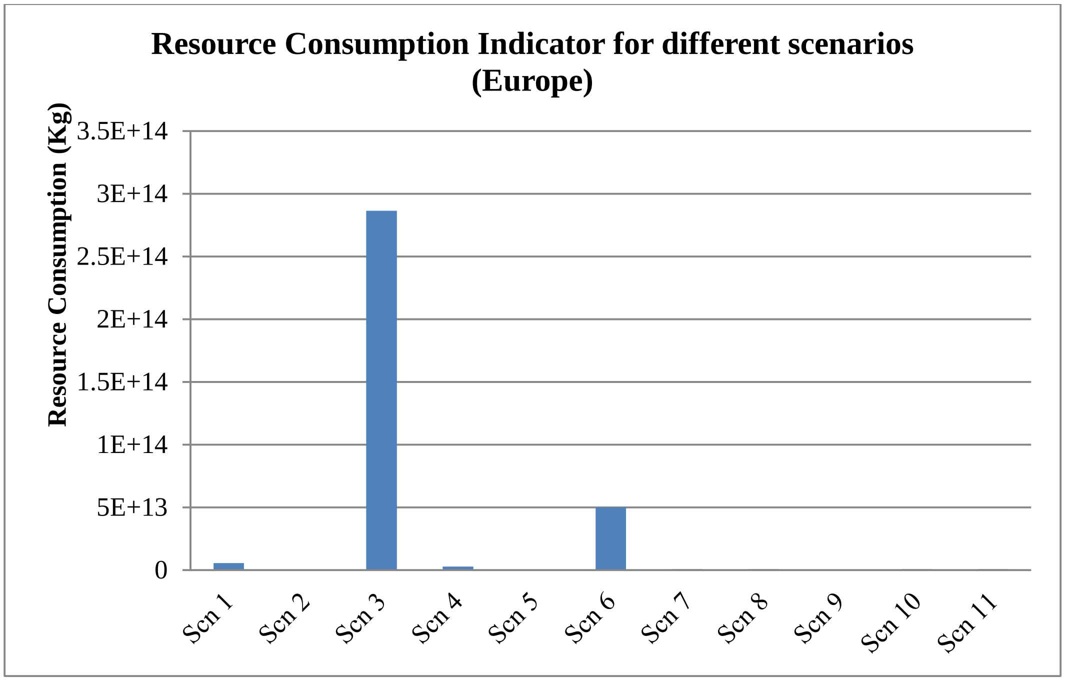


24 (b)

Figure 24: Comparison of Data for Land Transformation Indicator for different scenarios

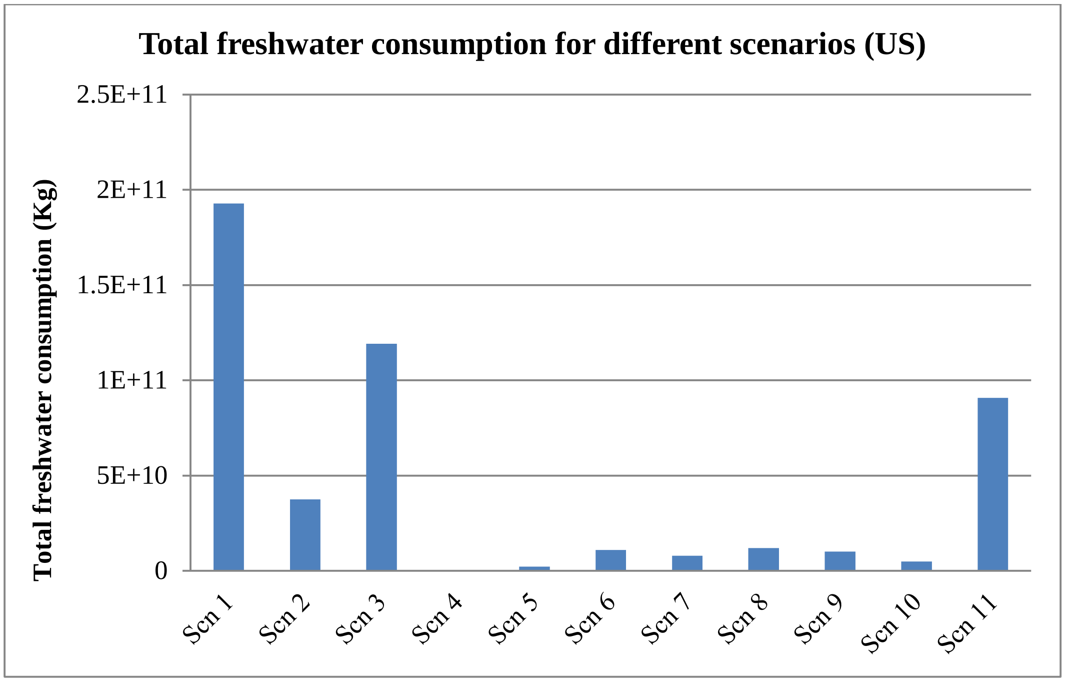


25 (a)

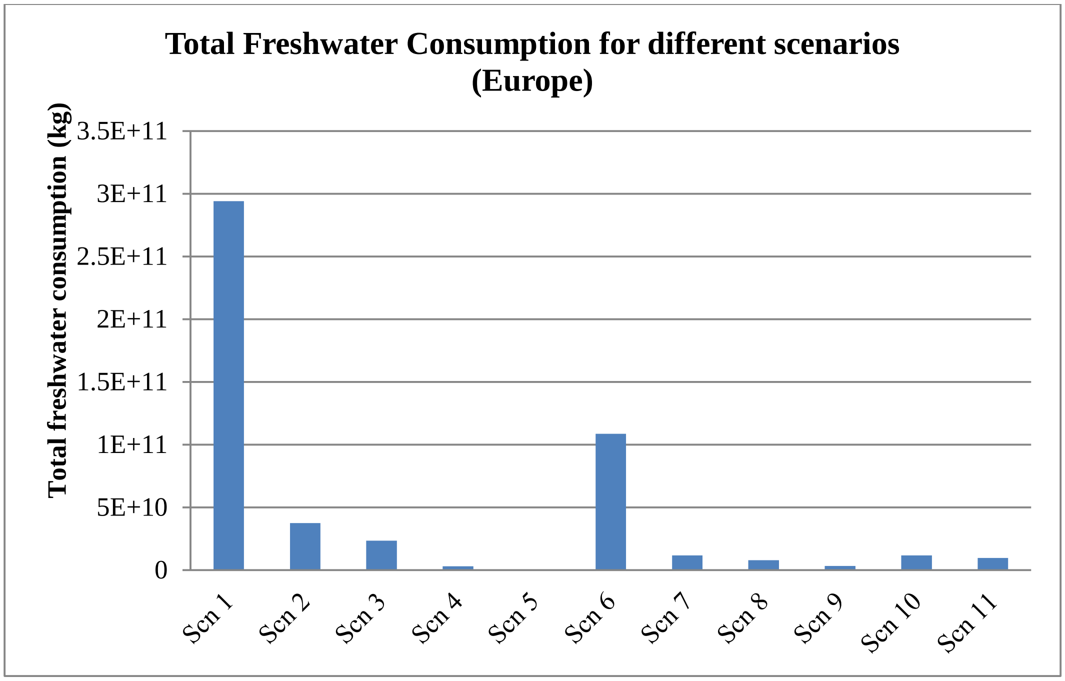


25 (b)

Figure 25: Comparison of Data for Resource Consumption for Different Scenarios



26 (a)



26 (b)

Figure 26: Comparison of data for Total Freshwater Consumption for different scenarios

GaBi LCA results for total carbon credits mitigated compared simultaneously for two different geographic locations: US and Europe.

Table 7: Comparison of Carbon Credits consumed for Different Scenarios

Carbon credits tonne CO2-Equiv. (US) different combination scenarios (tonne GHG emitted)										
Scn 1	Scn 2	Scn 3	Scn 4	Scn 5	Scn 6	Scn 7	Scn 8	Scn 9	Scn 10	Scn 11
7.98E+05	3.31E+05	3.85E+04	4.46E+04	1.80E+05	5.82E+06	4.35E+06	7.29E+04	4.37E+06	9.90E+04	3.65E+05
Carbon credit consumed										
-8.0E+05	-3.3E+05	-3.8E+04	-4.5E+04	-1.8E+05	-5.8E+06	-4.4E+06	-7.3E+04	-4.4E+06	-9.9E+04	-3.7E+05
Carbon credits tonne CO2-Equiv. (Europe) different combination scenarios (tonne GHG emitted)										
Scn 1	Scn 2	Scn 3	Scn 4	Scn 5	Scn 6	Scn 7	Scn 8	Scn 9	Scn 10	Scn 11
1.39E+06	3.31E+05	3.23E+04	2.69E+05	6.17E+04	5.80E+05	5.54E+06	4.47E+06	2.60E+06	2.48E+04	3.95E+06
Carbon credit consumed										
-1.4E+06	-3.3E+05	-3.2E+04	-2.7E+05	-6.2E+04	-5.8E+05	-5.5E+06	-4.5E+06	-2.6E+06	-2.5E+04	-4.0E+06

Table 8: Comparison of Carbon Credits consumed for Different Technologies

Carbon credits tonne CO2-Equiv. (US) Different Energy Technologies (tonne GHG emitted)											
BG	BM	CG	GEO	HC	HFO	HP	Lignite	NG	Nuclear	PV	WP
1.10E+05	2.28E+04	5.08E+05	2.76E+04	4.53E+05	4.50E+05	3.21E+03	4.92E+05	2.76E+05	6.07E+03	1.50E+04	3.72E+03
Carbon credit consumed											
-1.1E+05	-2.3E+04	-5.1E+05	-2.8E+04	-4.5E+05	-4.5E+05	-3.2E+03	-4.9E+05	-2.8E+05	-6.1E+03	-1.5E+04	-3.7E+03
Carbon credits tonne CO2-Equiv. (Europe) Different Energy Technologies (tonne GHG emitted)											
BG	BM	CG	GEO	HC	HFO	HP	Lignite	NG	Nuclear	PV	WP
1.99E+05	3.29E+04	4.57E+05	4.29E+05	3.73E+05	2.69E+03	4.98E+05	2.17E+05	2.07E+03	2.24E+04	5.14E+03	2.76E+04
Carbon credit consumed											
-2.0E+05	-3.3E+04	-4.6E+05	-4.3E+05	-3.7E+05	-2.7E+03	-5.0E+05	-2.2E+05	-2.1E+03	-2.2E+04	-5.1E+03	-2.8E+04

4.2 Economic Assessment Results

This section presents the LCOE cost graph for different energy technologies; the data set for this graph is discussed in the previous section table 3.

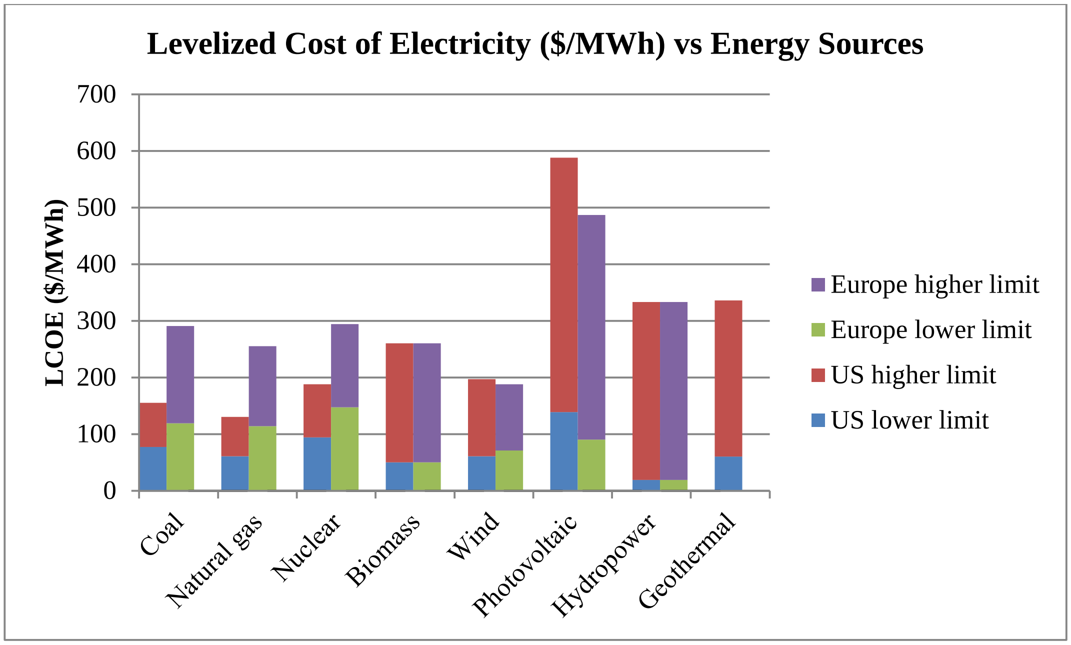


Figure 27: Comparison of Data for LCOE for Different Technologies

The graph below presents the Total LCOE evaluated for US and Europe for different energy production technologies, describing the variation and impacts in LCOE.

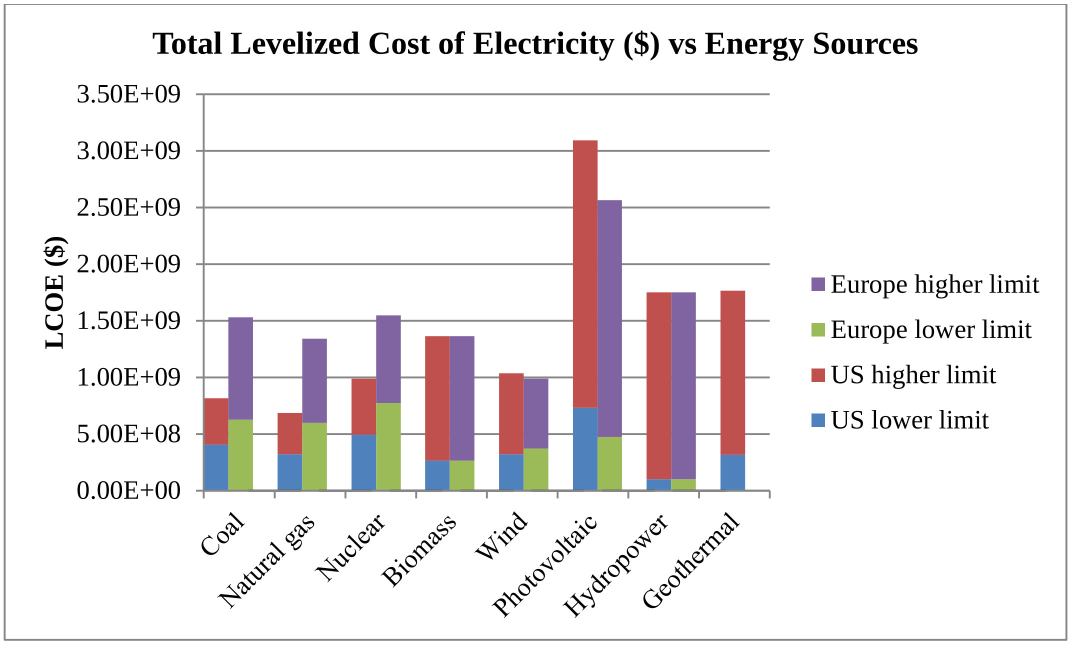


Figure 28: Comparison of Data for Total LCOE for Different Technologies

The graph below presents the Total Cost of energy production including mitigation costs and Total LCOE, evaluated for US and Europe.

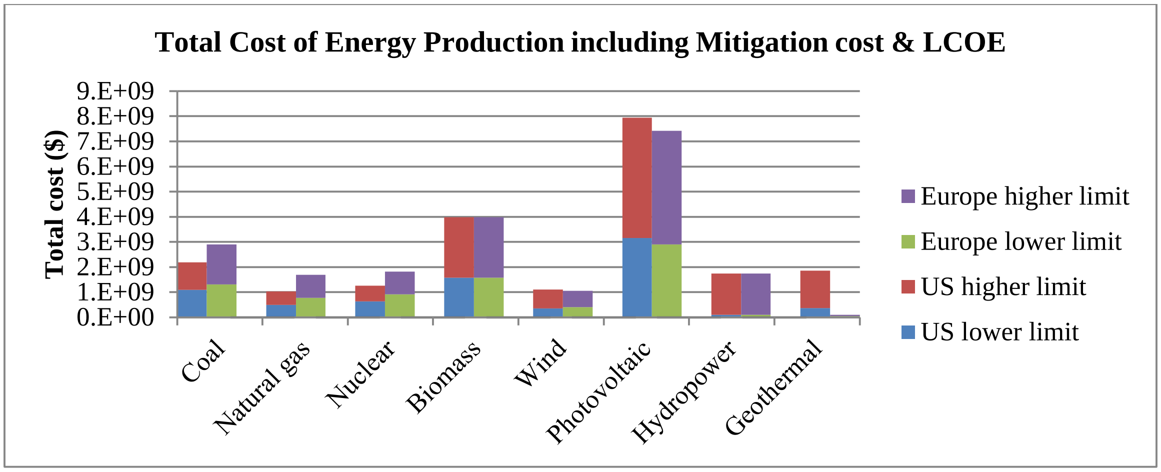


Figure 29: Comparison of Data for Total Cost of Energy Production

4.3 Discussions

GaBi LCA results:

- **GWP:** Biomass, Geothermal, Hydro Power, Nuclear, Photovoltaic , and Wind Power are the lowest greenhouse gas emission technologies, whereas Biogas, Coal Gases, Hard Coal, Lignite, Heavy Fuel Oil, and Natural Gas technologies emits more than five time as much greenhouse gases over a duration of one year for the same amount of energy required at the output energy grid.
- **AP:** Hydro Power, Natural Gas, Nuclear, Photovoltaic, and Wind Power clearly are the lowest acidification emission technologies, whereas Biogas, Biomass, Coal Gases, Hard Coal, Heavy Fuel Oil, and Lignite technologies emits more than six times as much acidification emissions, with Geothermal as the highest acidification emission technology with as much as 15 times more emissions.
- **EP:** Biogas and Biomass are the biggest eutrophication emission technologies, emitting three to 10 times as much emission than other technologies.
- **HTP:** Biogas, Biomass, Hard Coal, Lignite and Photovoltaic emits 15 times as much emissions than Coal Gases, Hydro Power, Natural Gas, Nuclear and Wind Power, with the exception of Heavy Fuel Oil, the single biggest emission technology with 50 times as much emissions. European graph displays a different trend because of the difference in units.
- **FAETP:** Biogas and Heavy Fuel Oil have the highest freshwater aquatic ecotoxicity emissions, as much as five to eight times higher than other technologies. European graph displays a different trend because of the difference in units.

- **ODP:** Nuclear and Biogas clearly have the highest emissions, as much as 10 to 100 times higher out of all the technologies. European graph displays a different trend because of the difference in units.
- **Land Transformation Indicator:** Lignite, Coal Gases, Hard Coal, Biogas and Photovoltaic have the biggest land transformation impacts, as much as 10 to 50 times higher than all the other technologies.
- **Resource Consumption:** Hydro Power and Biogas has the biggest resource consumption impacts on the environment, because of the extra infrastructural requirements as compared to all other technologies.
- **Freshwater Consumption:** Hydro Power, Biogas and Biomass clearly have the highest freshwater consumption impacts on the environment, followed by geothermal and other NRE technologies.
- **Carbon Credits:** Considering the results from carbon credit table, calculated from GWP data, by reversing the GWP data and calculating ton CO_2 equiv. emissions, we can evaluate the number of carbon credits that can be earned or needed to mitigate greenhouse gas emission arising from switching between different technologies or scenarios.

Different environmental impact categories take precedence across different geographic locations and thus during the initial planning and design stage Greenfield EIP management can decide on which impacts factor can affect the overall sustainability of their EIP. Similarly different energy technology combination scenarios, display variations based on the type of technologies comprising the associated scenario and related environmental impacts.

These results further solidifies the thought process, that when planning a Greenfield EIP management can overlook certain impacts as compared to other ones, such as when the EIP is located in a geographic location with abundant fresh water and land resources but delicate balance for environmental emissions, the technology or scenario with related results can be used as the energy source.

Economic Assessment Results:

Total Cost results evaluated for US and European from Total LCOE and mitigation costs associated with environmental impacts indicate that over the lifetime of the project with variations in lower and higher limits on cost, RE technologies are financially competitive with NRE technologies, especially wind energy technology which is financially and environmentally the most viable option. EIP management can thus decide on the corresponding technology, when calculating their return on investment for the lifetime of the EIP, depending on what degree of importance is given to Total Cost and LCA results.

CHAPTER 5

CONCLUSIONS AND FUTURE WORK

This chapter outlines the final conclusions drawn from this feasibility study and provides recommendation for future work that can be performed to refine the methodology used in this research.

5.1 Conclusion

This feasibility study points out a unique methodology comprising of environmental, economic and geographic factor that can be used during Greenfield EIP planning stage. EIP management can prioritize their preferences for addressing environmental and economic impacts, arising from use of specific energy production technologies, depending on their geographic location and the frailty of the ecosystem under consideration. The three research questions are answered as follows:

- The LCA study results points out the fact that RE technologies are far superior to NRE technologies with respect to their associated environmental impacts, and thus the overall sustainability of the EIP can be improved when switching from NRE to RE technology for energy production.
- Return on investment is always one of the major deciding factors for establishing a new project. Total Cost calculations assuming a baseline energy requirement at the point of connection to a grid, is the most justifiable factor to consider the overall economic impacts arising not only from the use of specific technology but also taking into considerations a variety of factors such as:

    - Mitigation costs associated with environmental impacts for individual technologies.
    - Diminishing NRE sources, thus forcing to adopt RE sources for energy production
    - New governmental regulation restricted to use of certain technologies, new tax deductions/benefits.
    - Geographic restrictions and cost of technology
- Total carbon credits evaluated in this report points out the clear merits associated with switching from NRE technologies to RE technologies for energy production. Carbon credits can also be traded as a commodity on the financial market to mitigate other types of environmental and economic impacts.

5.2 Future Work

Although the described methodology succeeds in painting a viable environmental and economic picture, but it currently limits in success due to non-availability of actual practical EIP environmental and economic data with NRE and RE technologies used for energy production, to justify its results. In future when the said limitations are overwhelmed and EIP data is readily available a more comprehensive look at comparing the modeling and data from EIP could help optimize the discussed methodology.

Fluctuations in Total Costs due to dynamic variations in commodities prices for NRE and RE sources could also be considered, to expand the current economic scope of this study. In an IS there are many other resource exchanges that exist between the NRE producing technology and other stakeholders, which are not considered in this study, when replacing the said NRE technology with RE, what will happen to those exchanges, could also be analyzed.

REFERENCES

1. Ashton, W. (2008). Understanding the Organization of Industrial Ecosystems. Journal of Industrial Ecology, 12: 34–51. doi: 10.1111/j.1530-9290.2008.00002.x

2. Behera, S. K., et al, (2011). Evolution of designed industrial symbiosis networks in the ULSAN eco-industrial park: research and development into business as the enabling framework. doi:10.1016/j.jclepro.2012.02.009

3. Clean Energy, (2013), Union of Concerned Scientist. Retrieved from http://www.ucsusa.org/clean_energy/clean_energy_101/

4. Chertow, M. R. (2007). “Uncovering” Industrial Symbiosis. Journal of Industrial Ecology, 11: 11–30. doi: 10.1162/jiec.2007.1110

5. Chertow, M. R., Lombardi, D. R. (2005). Quantifying Economic and Environmental Benefits of Co-Located Firms. Environmental Science & Technology, 39(17): 6535–6541. doi: 10.1021/es050050+

6. Christensen, J., (1999). Proceedings of industry and Environment Workshop, held at Indian Institute of Management Ahmedabad, India.

7. Folke et al. (2010). Resilience thinking: integrating resilience, adaptability and transformability. Ecology and Society 15(4): 20. Retrieved from http://www.ecologyandsociety.org/vol15/iss4/art20/

8. Gibbs, D., Deutz, P., & Proctor, A. (2005). Industrial Ecology and Eco-industrial Development: A Potential Paradigm for local and regional development? Taylor & Francis Group, 39(2), 171–183. Retrieved from: http://web.ebscohost.com.ezproxy1.lib.asu.edu/ehost/pdfviewer/pdfviewer?sid=7b700c0a-6864-4850-b621-688300b2a9dc%40sessionmgr4&vid=2&hid=26

9. Gibbs, (2003). Local Economy: Trust and Networking in Inter-firm Relations: the Case of Eco-Industrial Development, Retrieved from http://lec.sagepub.com/content/18/3/222

10. Graedel, T., Allen, F. D., Johnson, K. & Rogich, D. (2006). “A workshop on Data scope and Data structure for National Material accounts”. United States Environmental Protection Agency. Retrieved from http://www.yale.edu/jie/DSDSNMA.pdf

11. Guinee, J. B., & Heijungs, R. (2005). Kirk-Othmer Encyclopedia of Chemical Technology.John Wiley & Sons, Inc

12. Hung, C., (2010). Environmental Impacts of Renewable Energy - An Overview of Life Cycle Results. Masters in Industrial Ecology NTNU

13. ISO, I., (2006). 14040: Environmental Management - Lifecycle Assessment - Principals and Framework. London: British Standard Institute

14. Jacobsen, N. B. (2006). Industrial Symbiosis in Kalundborg, Denmark: A Quantitative Assessment of Economic and Environmental Aspects. Journal of Industrial Ecology, 10: 239–255. doi: 10.1162/108819806775545411

15. Lowitt, P. C., (2008). Devene redevelopment: The emergence of a successful eco-industrial park in the United States. doi: 10.1111/j.1530-9290.2008.00078.x

16. OSRAM, (2014). Environmental Impact Categories. Retrieved from: http://www.osram.com/osram_com/sustainability/sustainable-products/life-cycle-analysis/method-and-definitions/environmental-impact-categories/index.jsp

17. PCSD, (2013). President’s Council on Sustainable Development. Retrieved from http://clinton2.nara.gov/PCSD/Overview/index.html

18. Pehnt, M., (2006), Dynamic life cycle assessment (LCA) of renewable energy technologies. Journal of Renewable Energy, 31(1): 55-71. doi: 10.1016/j.renene.2005.03.002

19. Renewable Energy Choice, (2013), How Renewable Energy Credits Work. Retrieved from http://www.renewablechoice.com/business-about-renewable-energy.html

20. Saikku,L., (2006). Eco-industrial parks: A background report for the eco-industrial park project at Rantasalmi

21. Sims, R.E.H, Rogner, H.H., & Gregory, K., (2003). Carbon Emission and mitigation cost comparisons between fossil fuel, nuclear and renewable energy resources for electricity generation. Energy Policy, 31: 1315-1326

22. TSC, (2009). The Sustainability Consortium. Retrieved from http://www.sustainabilityconsortium.org/

23. TUDelft, (2014). The model of the Eco costs / Value Ratio (EVR). Retrieved from TUDelft university website for information on sustainability: http://www.ecocostsvalue.com/EVR/model/theory/subject/2-eco-costs.html

24. USBCSD, (2013). United States Business Council for Sustainable Development. Retrieved from http://usbcsd.org/

25. UNEP, (1999). Case study Kalundborg. Retrieved from http://www.iisbe.org/iisbe/gbpn/documents/policies/instruments/UNEP-green-ind-zones/UNEP-GIZ-ppt-kalundborg%20case.pdf

26. UNEP. (2008). United Nations Environmental Program Annual Report 2007. Retrieved from http://www.unep.org/PDF/AnnualReport/2007/AnnualReport2007_en_web.pdf

27. US DOE ITC, (2013). United States Department of Energy, Business Energy Investment Tax Credit. Retrieved from: http://dsireusa.org/incentives/incentive.cfm?Incentive_Code=US02F

28. US DOE PTC, (2013). United States Department of Energy, Renewable Energy Production Tax Credit. Retrieved from: http://dsireusa.org/incentives/incentive.cfm?Incentive_Code=US13F

29. US EIA, (2014). Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2014. Independent Statistics & Analysis. Retrieved from: http://www.eia.gov/forecasts/aeo/pdf/electricity_generation.pdf

30. World Energy Council, (2013). World energy Perspective - Cost of energy technologies. Retrieved from: http://www.worldenergy.org/wp-content/uploads/2013/09/WEC_J1143_CostofTECHNOLOGIES_021013_WEB_Final.pdf

APPENDIX A

GABI - LIFECYCLE ASSESSMENT RESULTS FOR 12 DIFFERENT TECHNOLOGIES

1. ***Data set for global warming potential (GWP):***

US - GWP (Kg CO2 equiv.)												
	BG	BM	CG	GEO	HC	HFO	HP	Lignite	NG	Nuclear	PV	WP
Input Flow	7.13E+8	5.38E+8	2.46E+5	9.98E+2	2.60E+5	3.81E+5	3.50E+4	4.06E+5	1.35E+5	1.62E+5	1.67E+6	2.35E+5
Output flow	8.23E+8	5.61E+8	5.09E+8	2.76E+7	4.54E+8	4.50E+8	3.24E+6	4.93E+8	2.76E+8	6.23E+6	1.66E+7	3.95E+6
Net emission	1.10E+8	2.28E+7	5.08E+8	2.76E+7	4.53E+8	4.50E+8	3.21E+6	4.92E+8	2.76E+8	6.07E+6	1.50E+7	3.72E+6
Europe - GWP (Kg CO2 equiv.)												
	BG	BM	CG	HC	HFO	HP	Lignite	NG	Nuclear	PV	WP	GEO
Input Flow	9.04E+8	6.34E+8	5.56E+5	5.91E+5	5.13E+5	7.05E+4	1.10E+6	2.95E+5	5.48E+4	2.50E+6	3.26E+05	9.95E+2
Output flow	1.10E+9	6.67E+8	4.58E+8	4.30E+8	3.73E+8	2.76E+6	4.99E+8	2.17E+8	2.12E+6	2.49E+7	5.47E+06	2.76E+7
Net emission	1.99E+8	3.29E+7	4.57E+8	4.29E+8	3.73E+8	2.69E+6	4.98E+8	2.17E+8	2.07E+6	2.24E+7	5.14E+06	2.76E+7

Table A1: Global Warming Potential US vs Europe

2. ***Data set for acidification potential (AP):***

US - AP (Kg SO2 equiv.)												
	BG	BM	CG	GEO	HC	HFO	HP	Lignite	NG	Nuclear	PV	WP
Input Flow	0	0	0	0	0	0	0	0	0	0	0	0
Output flow	2.56E+6	9.85E+5	1.97E+5	3.83E+6	1.86E+6	2.35E+6	1.94E+3	2.04E+6	1.42E+5	3.49E+4	6.89E+4	1.09E+4
Net emission	2.56E+6	9.85E+5	1.97E+5	3.83E+6	1.86E+6	2.35E+6	1.94E+3	2.04E+6	1.42E+5	3.49E+4	6.89E+4	1.09E+4
Europe - AP (Kg SO2 equiv.)												
	BG	BM	CG	HC	HFO	HP	Lignite	NG	Nuclear	PV	WP	GEO
Input Flow	0	0	0	0	0	0	0	0	0	0	0	0
Output flow	3.33E+6	1.19E+6	8.68E+5	7.06E+5	1.05E+6	4.49E+3	5.83E+5	2.28E+5	1.89E+4	1.03E+5	1.57E+4	4.50E+6
Net emission	3.33E+6	1.19E+6	8.68E+5	7.06E+5	1.05E+6	4.49E+3	5.83E+5	2.28E+5	1.89E+4	1.03E+5	1.57E+4	4.50E+6

Table A2: Acidification Potential US vs Europe

3. ***Data set for eutrophication potential (EP):***

US - EP (Kg Phosphate-Equiv.)												
	BG	BM	CG	GEO	HC	HFO	HP	Lignite	NG	Nuclear	PV	WP
Input Flow	0	0	0	0	0	0	0	0	0	0	0	0
Output flow	3.58E+5	1.42E+5	4.93E+4	4.28E+2	8.64E+4	1.21E+5	2.80E+2	9.49E+4	2.91E+4	3.65E+3	5.30E+3	1.18E+3
Net emission	3.58E+5	1.42E+5	4.93E+4	4.28E+2	8.64E+4	1.21E+5	2.80E+2	9.49E+4	2.91E+4	3.65E+3	5.30E+3	1.18E+3
Europe - EP (Kg N-Equiv.)												
	BG	BM	CG	HC	HFO	HP	Lignite	NG	Nuclear	PV	WP	GEO
Input Flow	0	0	0	0	0	0	0	0	0	0	0	0
Output flow	5.73E+5	3.00E+5	5.80E+4	7.27E+4	3.75E+4	2.90E+2	5.86E+4	1.28E+4	4.22E+3	6.81E+3	2.77E+3	2.00E+2
Net emission	5.73E+5	3.00E+5	5.80E+4	7.27E+4	3.75E+4	2.90E+2	5.86E+4	1.28E+4	4.22E+3	6.81E+3	2.77E+3	2.00E+2

Table A3: Eutrophication Potential US vs Europe

4. ***Data set for human toxicity potential (HTP):***

US - HTP (Kg DCB-Equiv.)												
	BG	BM	CG	GEO	HC	HFO	HP	Lignite	NG	Nuclear	PV	WP
Input Flow	0	0	0	0	0	0	0	0	0	0	0	0
Output flow	2.15E+7	3.82E+7	2.19E+6	6.15E+5	3.02E+7	1.03E+8	-9.5E+4	1.92E+7	3.10E+6	3.61E+6	2.24E+7	4.17E+5
Net emission	2.15E+7	3.82E+7	2.19E+6	6.15E+5	3.02E+7	1.03E+8	-9.5E+4	1.92E+7	3.10E+6	3.61E+6	2.24E+7	4.17E+5
Europe - HTP (CTUh)												
	BG	BM	CG	HC	HFO	HP	Lignite	NG	Nuclear	PV	WP	GEO
Input Flow	0	0	0	0	0	0	0	0	0	0	0	0
Output flow	7.56E-1	2.3E-2	2.22E-2	6.6E-3	2.6E-2	6.57E-5	3.8E-3	1.42E-2	4.98E-4	3.2E-3	5.00E-4	9.6E-5
Net emission	7.56E-1	2.3E-2	2.22E-2	6.6E-3	2.6E-2	6.57E-5	3.8E-3	1.42E-2	4.98E-4	3.2E-3	5.00E-4	9.6E-5

Table A4: Human Toxicity Potential US vs Europe

5. ***Data set for freshwater aquatic ecotoxicity potential (FEATP):***

US - FAETP (Kg DCB-Equiv.)												
	BG	BM	CG	GEO	HC	HFO	HP	Lignite	NG	Nuclear	PV	WP
Input Flow	0	0	0	0	0	0	0	0	0	0	0	0
Output flow	2.07E+6	3.95E+5	1.12E+5	7.08E+2	2.87E+5	4.96E+6	3.06E+3	1.94E+5	6.93E+5	6.27E+5	1.34E+5	1.16E+4
Net emission	2.07E+6	3.95E+5	1.12E+5	7.08E+2	2.87E+5	4.96E+6	3.06E+3	1.94E+5	6.93E+5	6.27E+5	1.34E+5	1.16E+4
Europe - FAETP (CTUe)												
	BG	BM	CG	HC	HFO	HP	Lignite	NG	Nuclear	PV	WP	GEO
Input Flow	0	0	0	0	0	0	0	0	0	0	0	0
Output flow	6.43E+6	1.97E+5	9.42E+4	5.99E+4	1.31E+6	2.58E+3	1.20E+4	3.82E+4	2.85E+4	4.50E+4	9.10E+3	5.17E+3
Net emission	6.43E+6	1.97E+5	9.42E+4	5.99E+4	1.31E+6	2.58E+3	1.20E+4	3.82E+4	2.85E+4	4.50E+4	9.10E+3	5.17E+3

Table A5: Ecotoxicity Potential US vs Europe

6. ***Data set for ozone layer depletion potential (ODP):***

US - ODP (Kg R11-Equiv.)												
	BG	BM	CG	GEO	HC	HFO	HP	Lignite	NG	Nuclear	PV	WP
Input Flow	0	0	0	0	0	0	0	0	0	0	0	0
Output flow	4.2E-2	4.4E-3	4.4E-4	-4.2E-8	4.3E-4	2.9E-3	6.9E-5	4.2E-3	1.2E-4	4.9E-1	4.9E-3	7.0E-4
Net emission	4.2E-2	4.4E-3	4.4E-4	-4.2E-8	4.3E-4	2.9E-3	6.9E-5	4.2E-3	1.2E-4	4.9E-1	4.9E-3	7.0E-4
Europe - ODP (Kg CFC-Equiv.)												
	BG	BM	CG	HC	HFO	HP	Lignite	NG	Nuclear	PV	WP	GEO
Input Flow	0	0	0	0	0	0	0	0	0	0	0	0
Output flow	8.3E-2	9.4E-3	2.4E-4	3.7E-4	3.2E-4	1.4E-4	6.9E-4	1.7E-4	2.0E-3	7.8E-3	1.0E-3	-4.7E-7
Net emission	8.3E-2	9.4E-3	2.4E-4	3.7E-4	3.2E-4	1.4E-4	6.9E-4	1.7E-4	2.0E-3	7.8E-3	1.0E-3	-4.7E-7

Table A6: Ozone Depletion Potential US vs Europe

7. ***Data set for land transformation indicator:***

US - Land Transformation Indicator (sqm)												
	BG	BM	CG	GEO	HC	HFO	HP	Lignite	NG	Nuclear	PV	WP
Input Flow	1.83E+3	3.95E+2	1.99E+4	7.06E+0	1.91E+4	9.76E+2	1.97E+2	5.78E+4	1.60E+3	5.27E+2	1.02E+4	-9.1E+2
Output flow	0	0	0	0	0	0	0	0	0	0	0	0
Net emission	1.8E+3	3.9E+2	2.0E+4	7.1E+0	1.9E+4	9.8E+2	2.0E+2	5.8E+4	1.6E+3	5.3E+2	1.0E+4	-9.1E+2
Europe - Land Transformation Indicator (sqm)												
	BG	BM	CG	HC	HFO	HP	Lignite	NG	Nuclear	PV	WP	GEO
Input Flow	6.83E+3	3.54E+2	7.89E+3	7.97E+3	3.53E+2	4.23E+2	6.61E+4	2.63E+2	2.58E+2	1.53E+4	-1.3E+3	7.05E+0
Output flow	0	0	0	0	0	0	0	0	0	0	0	0
Net emission	6.8E+3	3.5E+2	7.9E+3	8.0E+3	3.5E+2	4.2E+2	6.6E+4	2.6E+2	2.6E+2	1.5E+4	-1.3E+3	7.0E+0

Table A7: Land Transformation Indicator US vs Europe

8. ***Data set for mass for all inputs and outputs:***

US - Mass of all the inputs and outputs (Kg)												
	BG	BM	CG	GEO	HC	HFO	HP	Lignite	NG	Nuclear	PV	WP
Input Flow	3.0E+11	3.6E+10	1.3E+10	3.1E+09	2.6E+10	3.1E+10	2.1E+12	3.9E+10	1.4E+10	3.4E+10	7.9E+10	5.3E+09
Output flow	3.0E+11	3.6E+10	1.4E+10	3.2E+09	2.6E+10	3.2E+10	2.1E+12	3.9E+10	1.4E+10	3.4E+10	7.9E+10	5.3E+09
Net emission	6.0E+11	7.2E+10	2.7E+10	6.3E+09	5.2E+10	6.3E+10	4.2E+12	7.8E+10	2.8E+10	6.7E+10	1.6E+11	1.1E+10
Europe - Mass of all the inputs and outputs (Kg)												
	BG	BM	CG	HC	HFO	HP	Lignite	NG	Nuclear	PV	WP	GEO
Input Flow	4.2E+11	7.3E+10	3.4E+10	3.2E+10	3.2E+10	1.2E+13	4.7E+10	1.3E+10	3.4E+10	1.2E+11	7.3E+09	3.1E+09
Output flow	4.1E+11	7.9E+10	3.5E+10	3.2E+10	3.2E+10	1.2E+13	4.7E+10	1.3E+10	3.4E+10	1.2E+11	7.3E+09	3.2E+09
Net emission	8.2E+11	1.4E+11	6.9E+10	6.4E+10	6.5E+10	2.4E+13	9.4E+10	2.7E+10	6.7E+10	2.4E+11	1.5E+10	6.3E+09

Table A8: Resource Consumption US vs Europe

9. ***Data set for total freshwater consumption:***

US - Total Freshwater Consumption (including rainwater - Kg)												
	BG	BM	CG	GEO	HC	HFO	HP	Lignite	NG	Nuclear	PV	WP
Input Flow	2.8E+11	2.7E+10	7.9E+09	3.1E+09	1.7E+10	2.3E+10	2.1E+12	2.6E+10	9.2E+09	2.5E+10	7.9E+10	5.2E+09
Output flow	2.6E+11	1.7E+10	7.5E+09	1.1E+07	1.6E+10	2.3E+10	2.1E+12	2.4E+10	8.7E+09	2.4E+10	7.8E+10	5.2E+09
Net emission	2.3E+10	9.4E+09	4.3E+08	3.1E+09	9.3E+08	8.2E+08	9.9E+09	1.4E+09	4.9E+08	9.9E+08	1.8E+08	2.6E+07
Europe - Total Freshwater Consumption (including rainwater - Kg)												
	BG	BM	CG	HC	HFO	HP	Lignite	NG	Nuclear	PV	WP	GEO
Input Flow	4.0E+11	6.3E+10	3.1E+10	2.9E+10	3.0E+10	1.2E+13	3.9E+10	1.2E+10	3.3E+10	1.2E+11	7.2E+09	3.1E+09
Output flow	3.7E+11	4.3E+10	3.1E+10	2.8E+10	2.9E+10	1.2E+13	3.7E+10	1.1E+10	3.2E+10	1.2E+11	7.2E+09	1.1E+07
Net emission	2.9E+10	2.0E+10	8.5E+08	7.9E+08	6.8E+08	2.0E+09	1.3E+09	2.8E+08	9.9E+08	2.7E+08	3.6E+07	3.1E+09

Table A9: Total Freshwater Consumption US vs Europe

APPENDIX B

GABI - LIFECYCLE ASSESSMENT RESULTS FOR 11 DIFFERENT COMBINATION SCENARIOS

1. ***Data set for global warming potential (GWP):***

US - GWP (Kg CO2 equiv.)											
	Scn 1	Scn 2	Scn 3	Scn 4	Scn 5	Scn 6	Scn 7	Scn 8	Scn 9	Scn 10	Scn 11
Input Flow	7.51E+9	1.20E+4	4.20E+5	2.83E+6	2.00E+7	3.65E+6	3.10E+6	1.95E+6	3.18E+6	8.27E+6	2.51E+9
Output flow	8.31E+9	3.31E+8	3.89E+7	4.75E+7	2.00E+8	5.82E+9	4.36E+9	7.48E+7	4.37E+9	1.07E+8	2.87E+9
Net emission	7.98E+8	3.31E+8	3.85E+7	4.46E+7	1.80E+8	5.82E+9	4.35E+9	7.29E+7	4.37E+9	9.90E+7	3.65E+8
Europe - GWP (Kg CO2 equiv.)											
	Scn 1	Scn 2	Scn 3	Scn 4	Scn 5	Scn 6	Scn 7	Scn 8	Scn 9	Scn 10	Scn 11
Input Flow	9.23E+9	1.19E+4	8.46E+5	3.00E+7	3.91E+6	3.08E+9	9.00E+6	6.16E+6	3.54E+6	6.58E+5	6.22E+6
Output flow	1.1E+10	3.31E+8	3.31E+7	2.99E+8	6.56E+7	3.66E+9	5.55E+9	4.48E+9	2.61E+9	2.55E+7	3.96E+9
Net emission	1.4E+9	3.31E+8	3.23E+7	2.69E+8	6.17E+7	5.80E+8	5.54E+9	4.47E+9	2.60E+9	2.48E+7	3.95E+9

Table B1: Global Warming Potential US vs Europe

2. ***Data set for acidification potential (AP):***

US - AP (Kg SO2 equiv.)											
	Scn 1	Scn 2	Scn 3	Scn 4	Scn 5	Scn 6	Scn 7	Scn 8	Scn 9	Scn 10	Scn 11
Input Flow	0	0	0	0	0	0	0	0	0	0	0
Output flow	2.13E+7	4.60E+7	2.33E+4	1.31E+5	8.27E+5	1.64E+7	1.49E+7	4.18E+5	1.32E+7	4.59E+5	1.49E+7
Net emission	2.13E+7	4.60E+7	2.33E+4	1.31E+5	8.27E+5	1.64E+7	1.49E+7	4.18E+5	1.32E+7	4.59E+5	1.49E+7
Europe - AP (Kg SO2 equiv.)											
	Scn 1	Scn 2	Scn 3	Scn 4	Scn 5	Scn 6	Scn 7	Scn 8	Scn 9	Scn 10	Scn 11
Input Flow	0	0	0	0	0	0	0	0	0	0	0
Output flow	2.72E+7	5.40E+7	5.38E+4	1.23E+6	1.88E+5	1.83E+7	8.63E+6	1.26E+7	2.73E+6	2.27E+5	6.90E+6
Net emission	2.72E+7	5.40E+7	5.38E+4	1.23E+6	1.88E+5	1.83E+7	8.63E+6	1.26E+7	2.73E+6	2.27E+5	6.90E+6

Table B2: Acidification Potential US vs Europe

3. ***Data set for eutrophication potential (EP):***

US - EP (Kg Phosphate-Equiv.)											
	Scn 1	Scn 2	Scn 3	Scn 4	Scn 5	Scn 6	Scn 7	Scn 8	Scn 9	Scn 10	Scn 11
Input Flow	0	0	0	0	0	0	0	0	0	0	0
Output flow	3.00E+06	5.13E+03	3.36E+03	1.42E+04	6.36E+04	9.22E+05	8.98E+05	4.38E+04	7.68E+05	4.05E+04	1.01E+06
Net emission	3.00E+06	5.13E+03	3.36E+03	1.42E+04	6.36E+04	9.22E+05	8.98E+05	4.38E+04	7.68E+05	4.05E+04	1.01E+06
Europe - EP (Kg N-Equiv.)											
	Scn 1	Scn 2	Scn 3	Scn 4	Scn 5	Scn 6	Scn 7	Scn 8	Scn 9	Scn 10	Scn 11
Input Flow	0	0	0	0	0	0	0	0	0	0	0
Output flow	5.24E+06	2.40E+03	3.48E+03	8.17E+04	3.32E+04	1.77E+06	7.57E+05	4.50E+05	1.53E+05	5.07E+04	4.87E+05
Net emission	5.24E+06	2.40E+03	3.48E+03	8.17E+04	3.32E+04	1.77E+06	7.57E+05	4.50E+05	1.53E+05	5.07E+04	4.87E+05

Table B3: Eutrophication Potential US vs Europe

4. ***Data set for human toxicity potential (HTP):***

US - HTP (Kg DCB-Equiv.)											
	Scn 1	Scn 2	Scn 3	Scn 4	Scn 5	Scn 6	Scn 7	Scn 8	Scn 9	Scn 10	Scn 11
Input Flow	0	0	0	0	0	0	0	0	0	0	0
Output flow	3.58E+08	7.38E+06	-1.1E+06	5.00E+06	2.68E+08	2.07E+08	6.38E+08	4.33E+07	3.23E+08	1.06E+08	1.66E+08
Net emission	3.58E+08	7.38E+06	-1.1E+06	5.00E+06	2.68E+08	2.07E+08	6.38E+08	4.33E+07	3.23E+08	1.06E+08	1.66E+08
Europe - HTP (CTUh)											
	Scn 1	Scn 2	Scn 3	Scn 4	Scn 5	Scn 6	Scn 7	Scn 8	Scn 9	Scn 10	Scn 11
Input Flow	0	0	0	0	0	0	0	0	0	0	0
Output flow	4.68E+00	1.2E-03	7.88E-04	3.9E-02	6.00E-03	1.57E+00	1.3E-01	3.10E-01	1.70E-01	6E-03	1.46E-01
Net emission	4.68E+00	1.2E-03	7.88E-04	3.9E-02	6.00E-03	1.57E+00	1.3E-01	3.10E-01	1.70E-01	6E-03	1.46E-01

Table B4: Human Toxicity Potential US vs Europe

5. ***Data set for freshwater aquatic ecotoxicity potential (FEATP):***

US - FAETP (Kg DCB-Equiv.)											
	Scn 1	Scn 2	Scn 3	Scn 4	Scn 5	Scn 6	Scn 7	Scn 8	Scn 9	Scn 10	Scn 11
Input Flow	0	0	0	0	0	0	0	0	0	0	0
Output flow	1.48E+07	8.49E+03	3.67E+04	1.39E+05	1.61E+06	2.37E+06	3.39E+07	7.52E+06	1.38E+07	3.09E+06	5.24E+06
Net emission	1.48E+07	8.49E+03	3.67E+04	1.39E+05	1.61E+06	2.37E+06	3.39E+07	7.52E+06	1.38E+07	3.09E+06	5.24E+06
Europe - FAETP (CTUe)											
	Scn 1	Scn 2	Scn 3	Scn 4	Scn 5	Scn 6	Scn 7	Scn 8	Scn 9	Scn 10	Scn 11
Input Flow	0	0	0	0	0	0	0	0	0	0	0
Output flow	3.98E+07	6.21E+04	3.10E+04	5.40E+05	1.09E+05	1.34E+07	6.65E+05	1.57E+07	4.58E+05	3.41E+05	3.09E+06
Net emission	3.98E+07	6.21E+04	3.10E+04	5.40E+05	1.09E+05	1.34E+07	6.65E+05	1.57E+07	4.58E+05	3.41E+05	3.09E+06

Table B5: Ecotoxicity Potential US vs Europe

6. ***Data set for ozone layer depletion potential (ODP):***

US - ODP (Kg R11-Equiv.)											
	Scn 1	Scn 2	Scn 3	Scn 4	Scn 5	Scn 6	Scn 7	Scn 8	Scn 9	Scn 10	Scn 11
Input Flow	0	0	0	0	0	0	0	0	0	0	0
Output flow	2.8E-01	-5.0E-07	8.3E-04	8.4E-03	5.8E-02	2.0E-02	1.8E-02	5.9E+00	1.0E+00	2.0E+00	1.0E-01
Net emission	2.8E-01	-5.0E-07	8.3E-04	8.4E-03	5.8E-02	2.0E-02	1.8E-02	5.9E+00	1.0E+00	2.0E+00	1.0E-01
Europe - ODP (Kg CFC-Equiv.)											
	Scn 1	Scn 2	Scn 3	Scn 4	Scn 5	Scn 6	Scn 7	Scn 8	Scn 9	Scn 10	Scn 11
Input Flow	0	0	0	0	0	0	0	0	0	0	0
Output flow	5.6E-01	-5.6E-06	1.7E-03	9.3E-02	1.2E-02	2.0E-01	5.2E-03	3.9E-03	2.0E-03	2.3E-02	7.5E-03
Net emission	5.6E-01	-5.6E-06	1.7E-03	9.3E-02	1.2E-02	2.0E-01	5.2E-03	3.9E-03	2.0E-03	2.3E-02	7.5E-03

Table B6: Ozone Depletion Potential US vs Europe

7. ***Data set for land transformation indicator:***

US - Land Transformation Indicator (sqm)											
	Scn 1	Scn 2	Scn 3	Scn 4	Scn 5	Scn 6	Scn 7	Scn 8	Scn 9	Scn 10	Scn 11
Input Flow	1.3E+04	8.5E+01	2.4E+03	-1.1E+04	1.2E+05	3.9E+05	1.5E+04	6.3E+03	2.0E+05	3.9E+04	2.3E+04
Output flow	0	0	0	0	0	0	0	0	0	0	0
Net emission	1.3E+04	8.5E+01	2.4E+03	-1.1E+04	1.2E+05	3.9E+05	1.5E+04	6.3E+03	2.0E+05	3.9E+04	2.3E+04
Europe - Land Transformation Indicator (sqm)											
	Scn 1	Scn 2	Scn 3	Scn 4	Scn 5	Scn 6	Scn 7	Scn 8	Scn 9	Scn 10	Scn 11
Input Flow	4.3E+04	8.5E+01	5.1E+03	1.8E+05	-1.5E+04	4.3E+04	3.3E+05	4.2E+03	3.2E+03	3.1E+03	1.7E+05
Output flow	0	0	0	0	0	0	0	0	0	0	0
Net emission	4.3E+04	8.5E+01	5.1E+03	1.8E+05	-1.5E+04	4.3E+04	3.3E+05	4.2E+03	3.2E+03	3.1E+03	1.7E+05

Table B7: Land Transformation Indicator US vs Europe

8. ***Data set for mass of all inputs and outputs:***

US - Mass of all the inputs and outputs (Kg)											
	Scn 1	Scn 2	Scn 3	Scn 4	Scn 5	Scn 6	Scn 7	Scn 8	Scn 9	Scn 10	Scn 11
Input Flow	2.04E+12	3.77E+10	2.51E+13	6.35E+10	9.45E+11	3.14E+11	2.74E+11	4.03E+11	3.15E+11	4.71E+11	5.04E+12
Output flow	2.01E+12	3.81E+10	2.51E+13	6.33E+10	9.45E+11	3.15E+11	2.74E+11	4.03E+11	3.16E+11	4.70E+11	5.04E+12
Net emission	4.1E+12	7.6E+10	5.0E+13	1.3E+11	1.9E+12	6.3E+11	5.5E+11	8.1E+11	6.3E+11	9.4E+11	1.0E+13
Europe - Mass of all the inputs and outputs (Kg)											
	Scn 1	Scn 2	Scn 3	Scn 4	Scn 5	Scn 6	Scn 7	Scn 8	Scn 9	Scn 10	Scn 11
Input Flow	2.91E+12	3.77E+10	1.43E+14	1.42E+12	8.78E+10	2.51E+13	4.55E+11	3.88E+11	1.61E+11	4.03E+11	3.86E+11
Output flow	2.88E+12	3.80E+10	1.43E+14	1.42E+12	8.76E+10	2.51E+13	4.57E+11	3.88E+11	1.61E+11	4.03E+11	3.87E+11
Net emission	5.8E+12	7.6E+10	2.9E+14	2.8E+12	1.8E+11	5.0E+13	9.1E+11	7.8E+11	3.2E+11	8.1E+11	7.7E+11

Table B8: Resource Consumption US vs Europe

9. ***Data set for total freshwater consumption:***

US - Total Freshwater Consumption (including rainwater - Kg)											
	Scn 1	Scn 2	Scn 3	Scn 4	Scn 5	Scn 6	Scn 7	Scn 8	Scn 9	Scn 10	Scn 11
Input Flow	1.9E+12	3.8E+10	2.5E+13	6.3E+10	9.4E+11	2.0E+11	2.0E+11	3.0E+11	2.2E+11	4.4E+11	5.0E+12
Output flow	-1.7E+12	-1.3E+08	-2.5E+13	-6.3E+10	-9.4E+11	-1.9E+11	-1.9E+11	-2.9E+11	-2.1E+11	-4.3E+11	-4.9E+12
Net emission	1.9E+11	3.8E+10	1.2E+11	3.1E+08	2.2E+09	1.1E+10	7.8E+09	1.2E+10	1.0E+10	4.8E+09	9.1E+10
Europe - Total Freshwater Consumption (including rainwater - Kg)											
	Scn 1	Scn 2	Scn 3	Scn 4	Scn 5	Scn 6	Scn 7	Scn 8	Scn 9	Scn 10	Scn 11
Input Flow	2.8E+12	3.8E+10	1.4E+14	1.4E+12	8.7E+10	2.5E+13	4.0E+11	3.6E+11	1.4E+11	3.9E+11	3.5E+11
Output flow	-2.5E+12	-1.3E+08	-1.4E+14	-1.4E+12	-8.6E+10	-2.5E+13	-3.8E+11	-3.5E+11	-1.4E+11	-3.8E+11	-3.4E+11
Net emission	2.9E+11	3.8E+10	2.3E+10	3.3E+09	4.3E+08	1.1E+11	1.2E+10	8.2E+09	3.4E+09	1.2E+10	9.8E+09

Table B9: Total Freshwater Consumption US vs Europe