LIFE CYCLE MANAGEMENT OF AGRICULTURAL AND ANIMAL WASTES THROUGH INTEGRATED ENERGY SYSTEMS FOR A PARTICULAR REGION

by

Figen Şişman Nayal

BS. in Env.E. Marmara University, 2002

M.S. in E.Sc., Boğaziçi University, 2004

Submitted to the Institute of Environmental Sciences in partial fulfillment of

the requirements for the degree of

Doctor

of

Philosophy

Boğaziçi University

2011

ACKNOWLEDGEMENTS

Special thanks to Assoc. Prof. Dr. Nilgün Cılız by whom the preparation of this study was guided. I am very grateful for her scientific guidance, support and encouragement during my PhD thesis study.

I would like to express my sincere gratitude to the jury members; Prof. Dr. Işıl Balcıoğlu, Prof. Dr. Turgut Tüzün Onay, Prof. Dr. Ayşen Erdinçler and Assoc. Prof. Dr. Mustafa Tırıs, for their valuable time and suggestions.

Thanks also to the Pilot Plant Project team whose extended input over a considerable period of time is much appreciated. I am grateful for their help, time, suggestions and kindness during my study. They were;

Assoc. Prof. Dr. Fehmi Akgün: Deputy Director, TUBITAK MRC Energy Institute
Dr. Ahmet Baban: Vice Director, TUBITAK MRC Environment Institute
Mr. Volkan Çoban: Senior Researcher, TUBITAK MRC Energy Institute.
Mr. E. Alptekin Yağmur: Senior Researcher, TUBITAK MRC Energy Institute.
Assoc.Prof. Dr. Durmuş Kaya: Instructor, Karaelmas University

Finally, I would like to express my gratitude to my dear husband Z. Murat Nayal, my family, my managers Dr. Argun Olcayto Erdoğan, Mr. Murat Ersoy Bulutlar, Mr. Tolga Afşin, Mr. Ömer Semih Oydaşık and my colleague Ms. Didem Eler at Siemens Water Technologies division, and many thanks to all my friends for their contributions, encouragement and support.

This project has been financially supported by Turkish Scientific and Technological Research Council (TUBITAK) and coordinated by TUBITAK Marmara Research Center (MRC), and the reference no. of the project is 106G112.

LIFE CYCLE MANAGEMENT OF AGRICULTURAL AND ANIMAL WASTES THROUGH INTEGRATED ENERGY SYSTEMS FOR A PARTICULAR REGION

Life cycle management is very essential to sustainable development which aims a balance between environmental, social and economic dimensions over products' life cycle. Life cycle management consists of methods to quantify and compare the environmental, social and economical analysis of providing goods and services. While Life Cycle Assessment (LCA) is used for estimating the potential environmental impacts of a product; Life Cycle Costing, LCC, is used to assess the total cost of that product during its life cycle. In this study, GaBi4 software is used as the LCA & LCC tool and EDIP 2003 is used as the LCA methodology.

The proposed thesis has been prepared as an application of life cycle management to succeed integrated waste minimization and energy conservation for a specific region in Turkey. The thesis covers the environmental and economical evaluation of a pilot scale anaerobic digestion (AD) and biogas recovery system which has been built in Kocaeli, Turkey. The waste recipe which is utilized for biogas production consists of cattle manures, poultry manures, slaughterhouse wastes, vegetable wastes and grass as raw material. The environmental evaluation is made according to the category indicators which are global warming, acidification, aquatic eutrophication, terrestrial eutrophication, photochemical ozone formation (impact on vegetation), stratospheric ozone depletion and the results are compared with six other scenarios including AD of only cattle manure, fossil fuel resources (coal power plant (PP), natural gas PP) and other renewable energy sources (hydro PP, wind PP, Integrated gasification combined cycle (IGCC)). With a different point of view, these energy production scenarios were evaluated in broad system boundaries and it is determined with this study that if the animal and agricultural wastes are not utilised in anaerobic digestion and biogas recovery system, even the renewable energy systems will be less environmentally friendly. It is determined that only an integrated interpretation of the scenarios can conclude the potential environmental impacts.

BELİRLİ BİR BÖLGE İÇİN TARIMSAL VE HAYVANSAL ATIKLARIN ENTEGRE ENERJİ SİSTEMLERİNDE YAŞAM DÖNGÜ YÖNETİMİ

Bir ürünün yaşam döngüsü boyunca çevresel, sosyal ve ekonomik yönleri arasında bir denge sağlanmasını amaçlayan sürdürülebilir gelişme için yaşam döngüsü yönetimi çok önemlidir. Bir ürünün yaşam döngüsü boyunca çevreye olan potansiyel etkilerini öngörmek için Yaşam Döngüsü Değerlendirmesi (YDD) kullanılırken; toplam maliyetini değerlendirmek için Yaşam Döngüsü Maliyetlendirmesi (YDM) kullanılır. Bu çalışmada, YDD & YDM aracı olarak GaBi4 yazılımı ve YDM yöntem bilimi olarak da EDIP 2003 kullanılmıştır.

Önerilen tez, Türkiye'de belirli bir bölge için entegre atık azaltımı ve enerji tasarrufu sağlamak üzere yaşam döngüsü yönetimi uygulanması amacıyla hazırlanmıştır. Bu tez, Kocaeli, Türkiye'de kurulmuş olan pilot ölçekli bir anaerobik çürütme ve biyogaz geri kazanım tesisi için çevresel ve ekonomik değerlendirmeyi kapsamaktadır. Biyogaz üretimi için kullanılan atık reçetesi hammadde olarak; büyükbaş hayvan gübresi, kümes hayvanları gübresi ile kesimhane atıkları, yiyecek atıkları ve çimenden oluşur. Çevresel değerlendirme, kategori göstergeleri olan küresel ısınma, asidifikasyon, sulak alan ötrofikasyonu, kara ötrofikasyonu, fotokimyasal ozon oluşumu (bitki örtüsü üzerindeki etkileri), stratosferik ozon azalmasına göre yapılmış ve sonuçlar sadece büyükbaş hayvan gübresinin anaerobik çürütülmesi, fosil bazlı enerji kaynakları (termik santral, doğalgaz santralı) ve diğer yenilenebilir enerji kaynaklarını (hidroelektrik santralı, rüzgar enerjisi santralı, entegre gazlaştırma kombine santralı) ele alan diğer altı senaryo ile karşılaştırılmıştır. Farklı bir bakış açısıyla, bu enerji üretim senaryoları geniş sistem sınırları içerisinde değerlendirilmiş; hayvansal ve bitkisel atıkların anaerobik çürütme ve biyogaz üretim sistemlerinde değerlendirilmemesi durumunda yenilenebilir enerji kaynaklarının bile daha az çevre dostu olacağı belirlenmiştir. Sonuçlar olarak; sadece senaryoların entegre değerlendirilmesi ile potansiyel çevresel etkilerinin ortaya koyulabileceği belirlenmiştir.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS/ABBREVIATIONS

Symbol	Explanation	Units used
AD	AD	
ADP	Abiotic depletion potential	
AETP	Aquatic ecotoxicity potential	
AN	Ammonium Nitrate	
AP	Acidification potential	
BOD_5	5-day Biochemical Oxygen Demand	(mg/L)
CFC's	Chlorofluorocarbons	
CH_4	Methane	
CO_2	Carbon dioxide	
DDOCm	Decomposable Degradable Organic Carbon	
DOC	Degradable Organic Carbon	
DOC_f	Fraction of the DOC that Decomposes under Anaerobic Conditions	
DS	Dry Solids	
EP	Eutrophication potential	
LCA	Life Cycle Assessment	
LCC	Life Cycle Costing	
LCI	Life Cycle Inventory	
LCIA	Life Cycle Impact Assessment	
ISO	International Organisation for Standardisation	
FAO	Food and Agriculture Organization	
GHG	Greenhouse gas	
GWP	Global Warming Potential	(kg CO_2^- eq.)
HTP	Human toxicity potential	
MCF	Methane conversion or correction factor	
MRC	Marmara Research Center	
MSW	Municipal Solid Wastes	
NMVOC	Non-methane volatile organic compounds	
NO	Nitric oxide	

Symbol	Explanation	Units used
NO_x	Nitrogen oxides	
N_2O	Nitrous oxide	
ODP	Ozone depletion potential	
ODS	Ozone depleting substance	
POCP	Photochemical ozone creation potential	
PP	Power plant	
ppm	Parts per million	
ROG	Reactive organic gas	
SETAC	Society of Environmental Toxicology and Chemistry	
SWDS	Solid Waste Disposal Site	
TETP	Terrestrial ecotoxicity potential	
TS	Total Solids	
TUBITAK	Turkish Scientific and Technological Research Council	
UN	United Nations	
UNEP	United Nations Environment Programme	
VS	Volatile Solids	
W	Waste Amount	
kg $CO_2^-{}_{eq}$.	kg CO_2 Carbon dioxide equivalents. Unit for potential contribution to global warming	
kg $NO_3^-{}_{eq.}$	kg NO_3 Nitrate equivalents. Unit for potential contribution to nutrient enrichment Unit for potential contribution to aquatic eutrophication	
m^2 UES	m^2 Unprotected ecosystem. Unit for potential contribution to acidification potential, and Unit for potential contribution to terrestrial eutrophication	

1. INTRODUCTION

Achieving ‘‘sustainable development’’ requires methods and tools to help quantify and compare the environmental impacts of providing goods and services to our societies. Life cycle assessment (LCA) is a methodological framework for estimating and assessing the environmental impacts attributable to the life cycle of a product, such as climate change, stratospheric ozone depletion, eutrophication, acidification, toxicological stress on human health and ecosystems, the depletion of resources [Rebitzer et al., 2004]. LCA consists of four phases, which are goal & scope definition, inventory analysis, impact assessment, and interpretation.

LCA is a very useful tool for the integral comparison of alternative systems on the basis of a similar function or service that is fulfilled by these systems. As basis for this comparison, a so-called functional unit is defined and all economic and environmental inputs and outputs are modelled in a linear way to this functional unit [Guinée et al., 2006]. The functional unit of this LCA study is “the benefits of 10,680 ton/year agricultural and animal wastes including the primary service of electricity production for at least 850 houses each with four (4)-family members” and the potential impacts of these wastes are evaluated in terms of human health, ecosystem health and material welfare.

Life cycle costing, LCC, is the process of economic analysis to assess the total cost of acquisition and ownership of a product. This analysis provides important inputs in the decision making process in the product design, development and use [Ravemark, 2004].

In this study, GaBi4 software is used as the LCA & LCC tool and EDIP 2003 is used as the LCA methodology to measure, evaluate and describe the possible environmental consequences of the systems.

For sustainable energy production, biomass can be converted to electricity, heat, and chemicals by using thermal, biological, and mechanical conversion processes.

LCA part of the thesis covers integrated LCA approach of biomass utilization with special emphasize on global carbon cycle. Integration of anaerobic digestion (AD) in LCA highlights the potential benefits of renewable energy to offset any conventional energy inputs and assessment of greenhouse gas emission reduction.

The proposed thesis covers the environmental and economical evaluation of a pilot scale AD and biogas recovery system which has been built in Kocaeli, Turkey. The waste recipe which is utilized for biogas production consists of cattle manures, poultry manures, slaughterhouse wastes, vegetable wastes and grass as raw material and as a result of this utilization; their potential environmental pollution is decreased dramatically. The laboratory scale anaerobic digester provided the initial data to determine the process conditions for the pilot scale reactor. The biological conversion of the waste recipe in AD and biogas recovery system is the main scenario, so called Scenario A and it is compared with six other scenarios according to five environmental category indicators which are global warming, acidification, aquatic eutrophication, terrestrial eutrophication, and photochemical ozone formation (impact on vegetation).

The second scenario utilises only cattle manure instead of the same amount of waste recipe (Scenario B). Since it is a clean and efficient thermal biomass conversion process, gasification receives growing interest nowadays. This study also covers Scenario G including biomass integrated gasification combined cycle of the waste recipe. Besides these biological and thermal conversion processes, there are scenarios including other renewable energy production methods such as hydropower plants (Scenario E) and wind power plants (Scenario F). And all these scenarios are compared with conventional energy production methods of coal power plant (Scenario C) and natural gas power plants (Scenario D). Since the agricultural and animal wastes can not be utilised for organic fertiliser production in scenarios other than Scenario A and Scenario B, those scenarios also include the production and application of Ammonium Nitrate as mineral fertiliser. In addition, Scenario C, D, E and F cover the conventional management of agricultural and animal wastes.

The findings in this LCA study reveal that renewable energy resources are more important in terms of sustainable energy development and environmental pollution prevention in Turkey. While the AD of the waste recipe appears to be the most environmentally friendly among the renewable energy resources according to the LCA study, the LCC part of the thesis points out its economical feasibility.

As a conclusion, it is proved with LCA and LCC methodologies that biomass utilisation via AD is more advantageous with respect to fossil fuel utilisation and other renewable energy production ways. Additionally, agricultural and animal wastes should be utilised for biogas production via AD and the digestate should be spread as organic fertiliser instead of mineral fertilisers, which will provide both environmental and economical advantages resulting in sustainable region development.

2. REVIEW OF THE LITERATURE

2.1. Life Cycle Assessment (LCA)

2.1.1. Introduction

The basis for achieving more sustainable products and services is the integrated assessment of all environmental impacts from cradle to grave. One of the assessment tools widely used for this is environmental Life Cycle Assessment, abbreviated LCA [Guinée et al., 2006]. A product's life cycle includes all stages of a product system, from raw material acquisition or natural resource production to the disposal of the product at the end of its life, including extracting and processing of raw materials; manufacturing; distribution; use; re-use; maintenance; recycling; and final disposal (i.e., cradle-to-grave) [UNEP/SETAC, 2009]. By LCA approach, a full picture of a product's impacts can be taken in order to find best solutions for their improvement without shifting impacts to other fields [Guinée et al., 2006].

The International Organisation for Standardisation (ISO) has played and still is playing a role in the formal task of methodology standardisation [ISO 14040 (1997)]. As a means of consolidating LCA procedures and methods, standards were developed as part of ISO's standards on environmental management. Four ISO standards (ISO 14040-14043) were published in the years 1997-2000, all of which were replaced in 2006 with two standards, ISO 14040 (2006) and ISO 14044 (2006). These standards describe the required and recommended elements of LCAs [UNEP/SETAC, 2009].

Current impact assessment methodologies have been developed to evaluate emission inventories for specific regions such as Europe (IMPACT 2002, Eco-indicator 95, Eco-indicator 99, CML, EDIP97, EDIP 2003), the US (TRACI), Canada (LUCAS), and Japan (LIME). The lack of current impact assessment models adapted to other regions is considered as a political and scientific limitation of the current impact assessment practices [Sedlbauer et al., 2007].

The Environmental Development of Industrial Products (EDIP) method is a nationally as well as internationally recognized impact assessment method developed by the Institute for Product Development (IPU) at the Technical University of Denmark. EDIP 2003 is the update version of the EDIP 1997 impact assessment methodology and both of versions are in compliance with the methodological requirements of the IS0 14040 standard [Wenzel et al., 1997].

In this study, EDIP 2003 methodology is used as the LCA procedure.

2.1.2. Phases of an LCA

According to ISO 14040, life cycle assessment shall include;

- goal and scope definition;
- inventory analysis;
- impact assessment; and
- interpretation of results as illustrated in Figure 2.1.

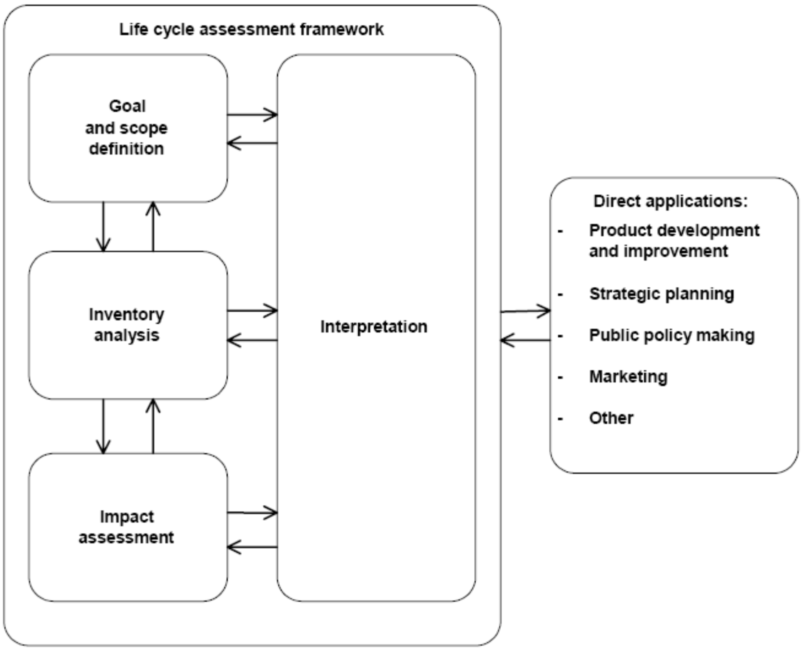


Figure 2.1. LCA framework [ISO 14040 (1997)].

2.1.3. Goal and Scope Definition

The goal and scope definition phase is the first phase of an LCA, where the reasons for carrying out the study and its intended use are described and where details are given on the approach taken to conduct the study. Notably, it is in this phase of the study that the description of the product system in terms of the system boundaries and a functional unit, and the breadth and depth of the study in relation to the stated goal are defined [ISO 14040 (1997); Guinée et al., 2006; ISO 14040 (2006)].

2.1.3.1. The Product System. The complete life cycle, together with its associated material and energy flows, is called the product system [Rebitzer et al., 2004].

2.1.3.2. Function and Functional Unit. The functional unit is the important basis that enables alternative goods, or services, to be compared and analysed [Rebitzer et al., 2004]. The primary purpose of the functional unit is to provide a reference to which the inputs and outputs are related. This reference is necessary to ensure comparability of LCA results which are particularly critical when different systems are being assessed to ensure that such comparisons are made on a common basis [ISO 14040 (1997)].

2.1.3.3. System Boundaries. The system boundaries determine which unit processes shall be included within the LCA [ISO 14040 (1997)]. The system boundaries have to be defined between the product system and the environment. It has to be defined which flows cross this boundary and are environmental interventions (i.e. resources extractions, emissions and land use) [Guinée et al., 2006].

2.1.3.4. Flow Diagram. A next step concerns drawing the flow diagram of the system studied. It constitutes the basis for the whole analysis and it identifies all relevant processes of the product system with their interconnections [Guinée et al., 2006].

2.1.4. Inventory Analysis

Life cycle inventory (LCI), is a methodology for estimating the consumption of resources and the quantities of waste flows and emissions caused by or otherwise attributable to a product's life cycle [Rebitzer et al., 2004]. The amounts of elementary flows exchanged by the product system (inputs from nature, e.g. extracted raw materials, land used) and the environment (outputs to nature, e.g. emissions to air, water and soil) are in reference to one functional unit, as defined in the Goal and Scope phase. In the inventory analysis, the life-cycle of the product (alternatives) analysed is determined, first qualitatively and then quantitatively. The basis of the inventory analysis is the unit process as shown in Figure 2.2 [Guinée et al., 2006].

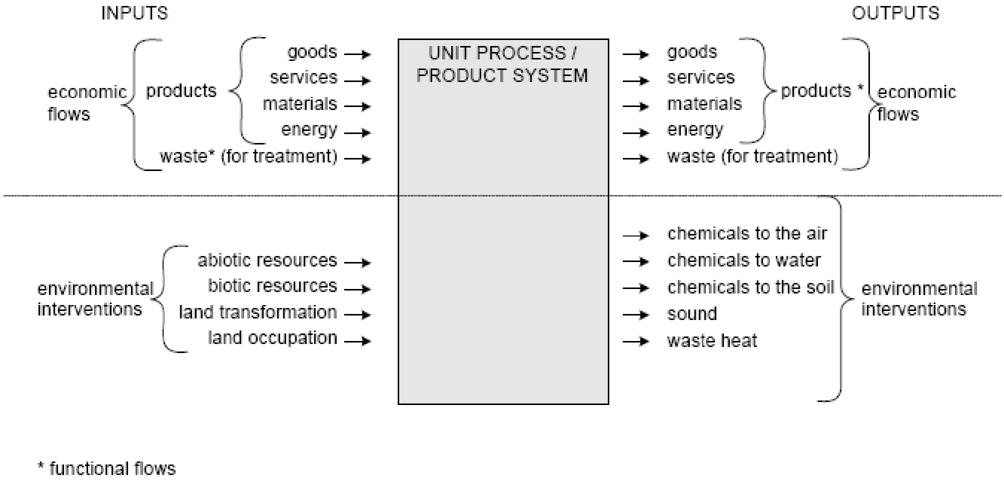


Figure 2.2. A unit process [Guinée et al., 2006].

For the quantification of the flow diagram, two types of data need to be collected for each unit process of the flow diagram: environmental flows and economic flows.

The meaning of the term "economic" has no connection with the value or price of the commodity, and it only indicates that this flow connects two unit processes: it is an inflow for one process and an outflow for another process. This is in contrast with the situation for environmental flows that are only connected to one unit process: environmental inflows flow from the environment to the unit process, and environmental outflows flow from the unit process to the environment [Guinée et al., 2006].

2.1.5. Impact Assessment

According to ISO 14040, impact assessment is a “phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of the product system”. The Life Cycle Impact Assessment (LCIA) should address ecological and human health effects and also resource depletion [SAIC, 2006].

For the environmental part of the impact assessment, the ambition is to interpret the emissions into their potential effects on the protection areas (human health, ecosystem health and the resource database) through the environmental causability web illustrated in Figure A.1. The result of the LCIA is an evaluation of a product life cycle, on a functional unit basis, in terms of several impacts categories (such as climate change, toxicological stress, noise, land use, etc.) [Rebitzer et al., 2004]. Within the impact assessment phase, several steps may be distinguished:

- selection of impact categories;
- selection of characterisation methods: category indicators, characterisation models and factors;
- classification;
- characterisation;
- normalisation;
- grouping;
- weighting.

According to ISO, the first four steps are mandatory and the last three are optional [Guinée et al., 2006; ISO 14042, 2000].

<u>2.1.5.1. Impact Categories.</u> The first step in an LCIA is to select the impact categories that will be considered as part of the overall LCA. For an LCIA, impacts are defined as the consequences that could be caused by the input and output streams of a system on human health, plants, and animals, or the future availability of natural resources. Typically, LCIAs focus on the potential impacts to three main categories: human health, ecological health,

and resource depletion. Table 2.1 shows some of the more commonly used impact categories [SAIC, 2006].

The impact categories chosen for this study are described below to give an overview of how each category affect the environment and which human activities contributes to this category.

Global Warming. Warming of the atmosphere, which causes climate changes [LCA Food Database, 2010], such as changes in seasonal temperatures and wind velocity, and the amount of precipitation and humidity for a given area or region.

Three major gases facilitate climate change: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). In naturally occurring quantities, these gases are not harmful; their presence in the atmosphere helps to sustain life on the planet by trapping some heat near the Earth's surface [Humane Society, 2009]. This natural greenhouse effect can be said with certainty to have been increased over the past few centuries by human activities [Hauschild and Potting, 2005]. Some of the biggest human contributors to global warming are the combustion of fossil fuels like oil, coal and natural gas [LCA Food Database, 2010; Hauschild and Potting, 2005].

While most of the concern about GHGs tends to focus on carbon dioxide, methane and nitrous oxide are also extremely potent gases. The global warming potential (GWP), or power, of each of these gases differs.

CO_2 has been assigned a value of one GWP, and the warming potentials of other gases are expressed relative to its power on a CO_2-equivalent basis. For example, one metric tonne of methane has the warming effect of around 23 tonnes of CO_2, while one tonne of nitrous oxide has the warming effect of around 296 tonnes of CO_2 [Humane Society, 2009].

Altering the atmosphere by trapping more heat has been modeled to have a wide variety of effects on the earth's climate, including longer growing seasons, droughts, floods, increased glaciation, and loss of the polar ice caps, sea level rise and other displacements, including direct effects on human health through biological agents. The speeds of these projected effects, coupled with their widespread nature, imply a devastating effect on the entire biosphere [U.S.EPA, 2000].

Acidification, or Acid Rain. It occurs when emissions of sulfur dioxide (SO_2) and oxides of nitrogen (NO_x) react in the atmosphere with water, oxygen, and oxidants to form various acidic compounds. This mixture forms a mild solution of sulfuric acid and nitric acid. Sunlight increases the rate of most of these reactions [U.S.EPA, 2000]. The most significant man made sources of acidification are combustion processes in electricity and heating production, and transport [LCA Food Database, 2010].

The main acidifying substances are transported more than several hundred to thousand kilometres. The deposition of acidifying substances may lead to an increase of acidity (i.e. decrease of pH) in the water or soil matrix [Hauschild and Potting, 2005]. Acid rain causes acidification of lakes and streams and contributes to damage of trees at high elevations [U.S.EPA, 2000]. When the pH falls to a critical level, toxic aluminium becomes mobile in harmful amounts. The aluminium affects the hair roots and thereby nutrition and water uptake of vegetation. The resulting decrease in health lowers the ability of trees and other vegetation to cope with stress. The aluminium ions are also toxic to aquatic life in freshwater systems [Hauschild and Potting, 2005]. In addition, acid rain accelerates the decay of building materials and paints, including irreplaceable buildings, statues, and sculptures that are part of our nation's cultural heritage. Prior to falling to the earth, SO_2 and NO_x gases and their particulate matter derivatives, sulfates and nitrates, contribute to visibility degradation and impact public health [U.S.EPA, 2000].

Eutrophication. It is called nutrient enrichment [Hauschild and Potting, 2005] and causes algal bloom in inlets and springs resulting in oxygen depletion and death of fish [LCA Food Database, 2010]. The nutrients, which normally limit biological growth in aquatic ecosystems, are nitrogen and phosphorus. For a compound to be regarded as contributing to aquatic eutrophication, it must thus contain biologically available nitrogen or phosphorus. Free nitrogen (N_2) is not regarded as a contributor to aquatic eutrophication, even if it is available for certain bacteria and algae. This is because emission of N_2 has no additional eutrophying effect.

Table 2.1. Common impact categories and subcategories [SAIC, 2006].

Impact Category	Scale	Examples of LCI Data (i.e. classification)	Common Possible Characterization Factor	Description of Characterization Factor
Global Warming	Global	Carbon Dioxide (CO_2) Nitrogen Dioxide (NO_2) Methane (CH_4) Chlorofluorocarbons (CFCs) Hydrochlorofluorocarbons (HCFCs) Methyl Bromide (CH_3Br)	Global Warming Potential	Converts LCI data to carbon dioxide (CO_2) equivalents Note: global warming potentials can be 50, 100, or 500 year potentials.
Stratospheric Ozone Depletion	Global	Chlorofluorocarbons (CFCs) Hydrochlorofluorocarbons (HCFCs) Halons Methyl Bromide (CH_3Br)	Ozone Depleting Potential	Converts LCI data to trichlorofluoromethane (CFC-11) equivalents.
Acidification	Regional Local	Sulfur Oxides (SOx) Nitrogen Oxides (NOx) Hydrochloric Acid (HCL) Hydroflouric Acid (HF) Ammonia (NH_4)	Acidification Potential	Converts LCI data to hydrogen (H+) ion equivalents.
Eutrophication	Local	Phosphate (PO_4) Nitrogen Oxide (NO) Nitrogen Dioxide (NO_2) Nitrates Ammonia (NH_4)	Eutrophication Potential	Converts LCI data to phosphate (PO_4) equivalents.
Photochemical Smog	Local	Non-methane hydrocarbon (NMHC)	Photochemical Oxident Creation Potential	Converts LCI data to ethane (C_2H_6) equivalents.
Terrestrial Toxicity	Local	Toxic chemicals with a reported lethal concentration to rodents	LC_{50}	Converts LC_{50} data to equivalents; uses multi-media modeling, exposure pathways.
Aquatic Toxicity	Local	Toxic chemicals with a reported lethal concentration to fish	LC_{50}	Converts LC_{50} data to equivalents; uses multi-media modeling, exposure pathways.
Human Health	Global Regional Local	Total releases to air, water, and soil.	LC_{50}	Converts LC_{50} data to equivalents; uses multi-media modeling, exposure pathways.
Resource Depletion	Global Regional Local	Quantity of minerals used Quantity of fossil fuels used	Resource Depletion Potential	Converts LCI data to a ratio of quantity of resource used versus quantity of resource left in reserve.
Land Use	Global Regional Local	Quantity disposed of in a landfill or other land modifications	Land Availability	Converts mass of solid waste into volume using an estimated density.
Water Use	Regional Local	Water used or consumed	Water Shortage Potential	Converts LCI data to a ratio of quantity of water used versus quantity of resource left in reserve.

Aquatic eutrophication can be caused by emissions to air, water and soil [Hauschild and Potting, 2005]. Emissions of nitrogen to the aquatic environment, especially fertilizers from agriculture contribute to eutrophication. Also oxides of nitrogen from combustion processes are of significance [LCA Food Database, 2010].

Photochemical Ozone Formation. The substances contributing to photochemical ozone formation are non-methane volatile organic compounds (NMVOC), methane (CH_4), nitrogen oxides (NO_x), and carbon monoxide (CO) [Hauschild and Potting, 2005]. It occurs when Volatile Organic Compounds (VOC's) are released in the atmosphere and oxidized in the presence of oxides of nitrogen (NO_x) [LCA Food Database, 2010]. Since the process is initiated by sunlight, it is called photochemical ozone formation [Hauschild and Potting, 2005].

When fossil fuels (e.g., gasoline) are burned, a variety of pollutants are emitted into the earth's troposphere [U.S.EPA, 2000]. The most significant VOC's emissions are released from unburnt petrol and diesel and the use of organic solvents, like paints [LCA Food Database, 2010]. The advent of increased automobile use in the last sixty years has led to increased levels of reactive organic gases (ROG's) and oxides of nitrogen (NO_x) in the air. Under certain conditions these gases, in the presence of sunlight, can undergo complex chemical reactions that create ground-level ozone. Two of the pollutants that are emitted are hydrocarbons (e.g., unburned fuel) and nitric oxide (NO). When these pollutants build up to sufficiently high levels, a chain reaction occurs from their interaction with sunlight in which the NO is converted to nitrogen dioxide (NO_2). NO_2 is a brown gas and at sufficiently high levels can contribute to urban haze.

However, a more serious problem is that NO_2 can absorb sunlight and break apart to produce oxygen atoms that combine with the O_2 in the air to produce ozone (O_3). Ozone is a powerful oxidizing agent, and a toxic gas.

Ground-level ozone causes a variety of short-term and long term health effects, such as eye and respiratory irritation, and pre-cancerous lesions. The oxidative ability of ozone causes damage to forests, agricultural products and personal property (i.e., items using paint, rubber or plastics) [U.S.EPA, 2000]. For agriculture it causes a reduction in yield [LCA Food Database, 2010; Hauschild and Potting, 2005].

Stratospheric Ozone Depletion. Stratospheric ozone is constantly being created and destroyed through natural cycle [U.S.EPA, 2000]. Various ozone-depleting substances (ODS's) from man-made emissions such as halocarbons, i.e., CFCs, HCFCs, halons and other longlived gases containing chlorine and bromine [LCA Food Database, 2010; Hauschild and Potting, 2005], however, accelerate the destruction processes, decreasing and thinning of ozone layer, often referred to as the ozone hole [LCA Food Database, 2010]. For example, when a particular type of ODS known as chlorofluorocarbons (CFC's) reach the stratosphere, the ultraviolet radiation from the sun causes them to break apart and release chlorine atoms which react with ozone, starting chemical cycles of ozone destruction that deplete the ozone layer [U.S.EPA, 2000].

Reductions in ozone levels will lead to higher levels of UVB (a kind of ultraviolet light from the sun) reaching the Earth's surface. UVB causes nonmelanoma skin cancer, plays a major role in malignant melanoma development and has been linked to cataracts. UVB also harms some crops, plastics and other materials, and certain types of marine life [U.S.EPA, 2000].

2.1.5.2. Classification. The classification is made through addressing different environmental impacts to impact categories. If the aim of a study is to evaluate the total environmental burden, all impact categories should be considered [Tidaker, 2003].

CH_4 and CO_2 are for example assigned to climate change. A possible double-counting may occur, e.g. for a chemical like NO_x that reacts to contribute to acidification and is then not available anymore to cause toxic impacts [Guinée et al., 2006].

2.1.5.3. Characterization. Characterization provides a way to directly compare the LCI results within each impact category. The interventions recorded in the inventory table are quantified in terms of a common category indicator. The factors translating emissions into contributions to impact categories are called characterisation factors. These are often based on complex environmental models comprising of transport processes through the environment, degradation, intake and impacts of substances.

The resulting number for one particular impact category is referred to as a category indicator result, and the complete set of category indicator results as the environmental profile [Guinée et al., 2006].

Generally expressed, if the emission of a substance (i) has the magnitude Q_i, and if the substance's characterization factor for the impact category (j) is EF $(j)_i$, the emission's potential contribution $EP(j)_i$, to the impact category is calculated as;

$$EP(j)_i = Q_i \,.\, EF(j)_i \tag{2.1}$$

Since the characterization expresses all contributions to an impact category relative to the same reference substance, the total contribution seen over the entire product system can be calculated simply by adding the contributions of all individual emissions [Wenzel and Hauschild, 2000]:

$$EP(j)_i = Q_i \,.\, EF(j)_i \tag{2.2}$$

$$EP(j) = \sum EP(j)_i = \sum (Q_i \,.\, EF(j)_i) \tag{2.3}$$

The characterization factors (commonly referred to as equivalency factors) of some substances and their impact categories are given in APPENDIX B.

In the characterization step, the indicator results are expressed each in their own units; so, a further weighting of these scores is thus difficult without a prior processing, the so-called normalisation [Guinée et al., 2006].

<u>2.1.5.4. Normalization.</u> Normalisation is the calculation of the magnitude of the category indicator results relative to reference values where the different indicator results and consumption of resources are expressed on a common scale through relating them to a common reference, in order to facilitate comparisons across impact categories [Hauschild

and Potting, 2005]. Global impacts, such as global warming is normalised with the impact from a global average person, while regional or local impacts, such as nutrient enrichment and acidification, the reference is an average person from the region of where the emission occurs [Kirkeby, 2005].

The normalization consists in dividing the impact potentials or resource consumptions by the corresponding normalization references. According to the EDIP method, the normalized environmental impact potentials, NEP(j), are thus calculated as shown below:

$$NEP(j) = EP(j) / (ER(j) \, . \, T) \tag{2.4}$$

If the functional unit defines the duration of service as T years, the normalization reference is expressed as $T \cdot ER(j)$, where ER(j) denotes the normalization reference for one year for an impact category j. When the impact potentials are normalized using EDIP normalization reference, they are expressed in person equivalents (PE) [Wenzel and Hauschild, 2000].

The normalization stage does not give much information about the importance and seriousness of environmental impacts of the LCA system. But, it is a leading stage for the weighting phase where the normalization results will be assessed according to the importance of the impact potentials.

2.1.5.5. Weighting. Even if the contributions to two different impact categories are equally large on normalization, this does not mean that the impact potentials are equally serious.

The mutual seriousness of impact categories is expressed in a set of weighting factors with one factor per impact category. The weighting is performed by multiplying the normalized impact potential, by this weighting factor as given below.

$$WP(j) = WF(j) \times NP(j) \tag{2.5}$$

where WP(j) is the weighted impact potential, WF(j) is the weighting factor for impact category j, and NP(j) is the normalized impact potential [Wenzel and Hauschild, 2000].

2.1.6. Interpretation

Life cycle interpretation, the last phase of the LCA process, is a systematic technique to identify, quantify, check, and evaluate information from the results of the LCI and the LCIA, and communicate them effectively. [SAIC, 2006].

The objectives of life cycle interpretation are to analyse results, reach conclusions, explain limitations and provide recommendations based on findings of the preceding phases of the LCA and to report the results of the life cycle interpretation in a transparetnt manner. Life cycle interpretation is also intended to provide a readily understandable, complete and consistent presentation of the results of an LCA study, in accordance with the goal and scope definition of the study [ISO 14043, 2000].

2.2. Life Cycle Costing (LCC)

Life Cycle Costing (LCC) is an economic evaluation tool in which all costs arising from creating, owning, operating, maintaining, and disposing of an asset are quantified. LCC is particularly suited to the evaluation of alternative designs that equally satisfy a required performance level but have different investment, operating, maintenance, or repair cost profiles as well as life spans. [BEC, 2005].

The LCC approach identifies all future costs and benefits and reduces them to their present value by the use of the discounting techniques through which the economic worth of a project or series of project options can be assessed. In order to achieve these objectives the following elements of LCC have been identified:

- initial capital costs;
- life of the asset;
- the discount rate;

- operating and maintenance costs;
- disposal cost.

LCC is concerned with optimising value for money in the ownership of physical assets, but its achievement depends upon the supply of accurate, relevant and speedy information from the operation of current assets, suppliers and other users of similar assets, and by application of appropriate statistical techniques to forecast future costs of ownership [Woodward, 1997].

2.3. LCA & LCC Software Tool – GaBi4

In order to execute an LCA and LCC study, computers and software tools are needed to manage a huge amount of data, structure the scenarios, display the process chains, analyze and present the results.

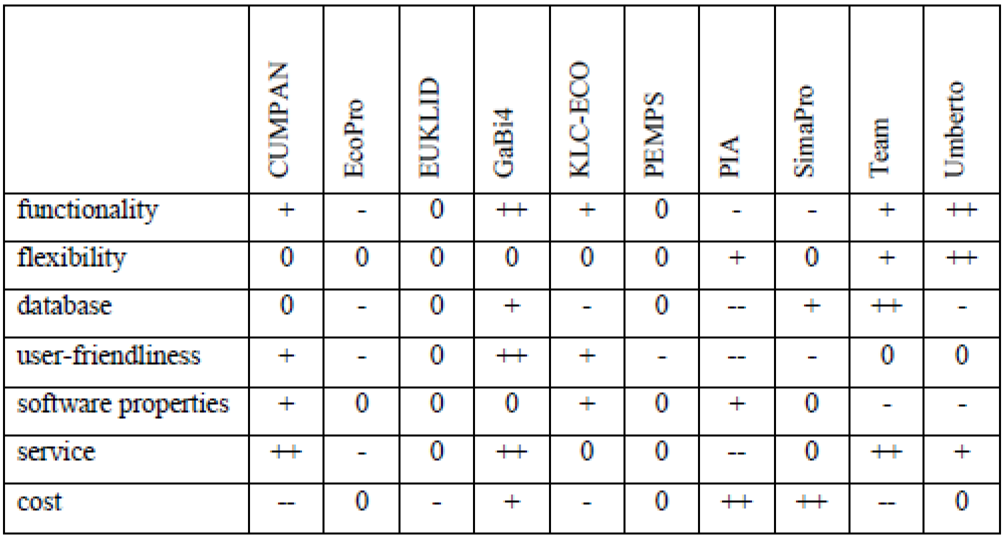
There are different LCA softwares in the market which are developed to evaluate the potential impacts of the products. Some of them were compared according to their functionality, flexibility, database, user friendliness, properties, service and cost. According to the comparison, GaBi4 software was found to be the best available software as shown in Table 2.2 [Dunmade, 2007]. Some of the scientific research studies which are based on GaBi4 software in order to execute LCA methodology are given in APPENDIX N.

GaBi4 software is developed by the Institute for Polymer Testing and Polymer Sciences (IKP) of the University of Stuttgart in collaboration with PE Europe Gmbh.

As a method for the assessment of the technical, economic and environment impacts of products, services and systems, comprehensive balances can be used to fulfill ecobalance (or Life Cycle Assessment) methods. GaBi4 is different from these methods because of its analysis method, which has been expanded to include technical, environmental, as well as socio-economic aspects.

The procedure of GaBi4 is standardized in compliance with the ISO 14040 series. The GaBi4 databases is derived from industry sources, scientific knowledge, technical literature, and internal patent information creating a solid foundation for assessing materials, products, services and processes (PE, 2010).

Table 2.2. Comparison of LCA softwares [Dunmade, 2007].



	CUMPAN	EcoPro	EUKLID	GaBi4	KLC-ECO	PEMPS	PIA	SimaPro	Team	Umberto
functionality	+	-	0	++	+	0	-	-	+	++
flexibility	0	0	0	0	0	0	+	0	+	++
database	0	-	0	+	-	0	--	+	++	-
user-friendliness	+	-	0	++	+	-	--	-	0	0
software properties	+	0	0	0	+	0	+	0	-	-
service	++	-	0	++	0	0	--	0	++	+
cost	--	0	-	+	-	0	++	++	--	0

GaBi4 software is a comprehensive tool to create life cycle balances. A balance includes a list of inputs and outputs generating from the life cycle of a product. Inputs and outputs are defined in GaBi4 software as flows.

With GaBi4, process related cost categories can be analyzed related to the life cycle of a product or a system. GaBi4 automatically calculates process and flow-related costs based on cost factors. In combination with categorization filters, the costs of different life cycle phases can be modeled. Internal or external company costs can be displayed separately and analyzed in the balance [GaBi4, 2003].

GaBi4 is a modular system and plans, processes and flows as well as their functions form modular units. It provides the user with the modular display of a product life cycle. Individual life-cycle phases can be grouped in categories and can be processed separately from each other. Simultaneously, balances are calculated based on individual or multiple processes and plans. The transparency of balance results is the major advantage of the GaBi4 [IKP, 2003].

2.4. Energy Situation and Potential in Turkey

Turkey's demand for energy and electricity is increasing rapidly. Turkey's annual electric energy demand in 2015 and 2020 is predicted that it goes up to 410 TWh and 571 TWh, respectively. Turkey's energy production meets nearly 28% of its total primary energy consumption [Yuksel, 2010].

Turkey presently has considerable renewable energy sources. The most important renewable sources are hydropower, biomass, geothermal, solar and wind [Yuksel, 2010]. Renewable energy sources, such as hydroelectric and wind energy, are cleaner, but can also carry limited environmental risks of their own [Kaygusuz, 2010].

The diagram below shows the energy sources for the gross national electricity production in Turkey for 2007. The small pie chart on the right shows the share in production of each form of renewable electricity in detail [PWC, 2009].

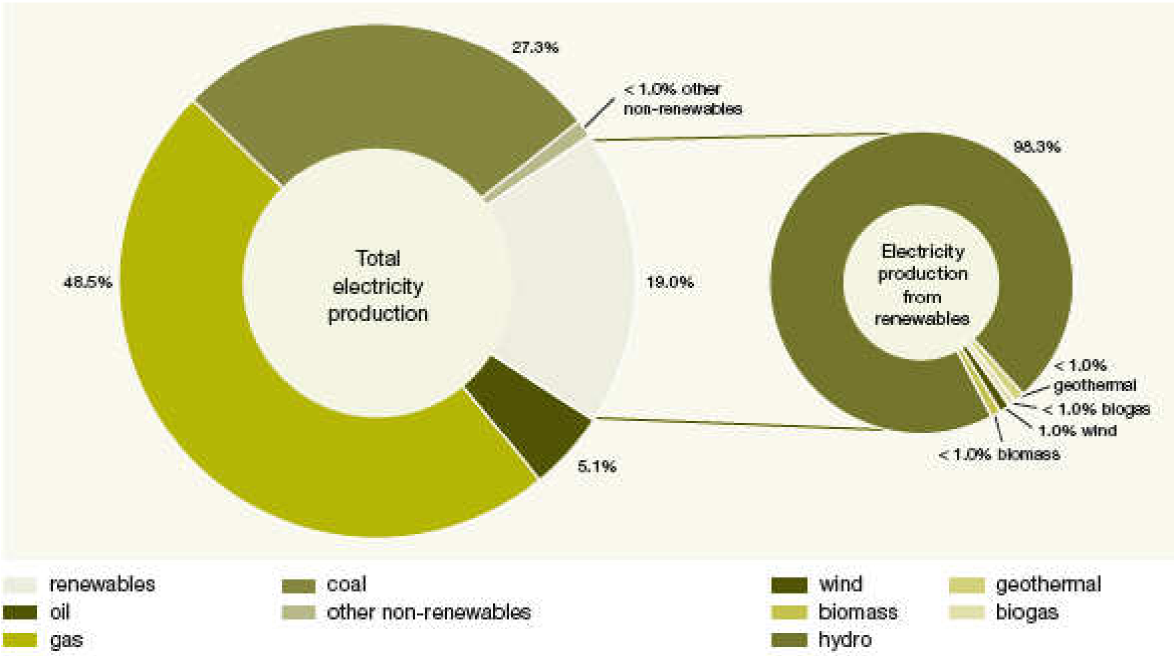


Figure 2.3. National electricity production of Turkey [PWC, 2009].

2.4.1. Hydropower

Hydropower is obtained by allowing water to fall on a turbine to turn a shaft. Electricity is produced from the kinetic energy of falling water. [Akpinar et al., 2008]. Hydropower plants are often subdivided into "large" hydro that usually involve dams, and small hydro that are normally run-of river systems. Small run-of-river hydropower systems generally have lower environmental and social impacts, and therefore are often preferred to larger plants that involve the construction of dams [Pembina Institute, 2011].

Hydropower is a complementary power source to more intermittent renewable energy power sources such as wind and solar because the flow can be regulated to reserve generating capacity during periods of peak demand or when the generating capacity of other renewable energy sources is limited [Pembina Institute, 2011]. On the other hand, large-scale hydroelectric dams can be a significant source of CH_4 emissions when they cause deforestation and alter natural river flow, with a range of cascading ecological impacts [Kaygusuz, 2010].

19% of the total electricity production in Turkey is provided by renewable energy resources. Among these renewable energy resources, 98.3% is provided by hydropower meaning that hydropower is the major renewable energy source in Turkey [PWC, 2009]. Turkey’s hydro electric potential can meet 33–46% of its electric energy demand in 2020 and this potential may easily and economically be developed [Yuksel, 2010].

2.4.2. Wind Energy

Because air has mass, moving air in the form of wind carries with it kinetic energy. A wind turbine converts this kinetic energy into electricity [Akpinar et al., 2008]. Wind energy has had a slow start in Turkey. However, as the country is preparing to join the European Union and considering ratifying the Kyoto Protocol (as an Annex I country), there are early indications of promising future developments [Kaygusuz, 2010]. It is estimated that the usable wind energy potential in Turkey is at around 8000 MW [Yuksel, 2010].

As well as the visual impacts, wind energy is associated with other environmental issues such as noise, land use and impacts during the construction phase. Some impacts, such as those on birds and flickering can be measured quantitatively; others, such as visual intrusion and noise require more subjective and qualitative criteria [Akpinar et al., 2008]. Wind energy also alters the landscape [Kaygusuz, 2010].

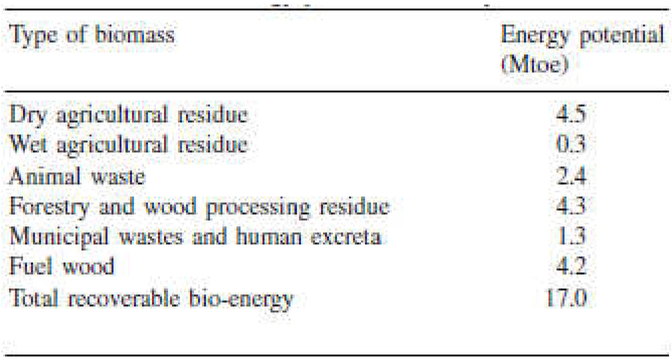
The consumption of conventional fossil energy sources (coal, petroleum and natural gas) on one hand results in serious environmental pollution problems, and on the other hand faces with the danger of exhaustion. In addition, Turkey should increase the proportion of renewable energy sources in the total energy budget because Turkey is an importing country. Therefore, the use of renewable energy resources shows a promising prospect in Turkey in the future as an alternative to the conventional energy [Akpinar et al., 2008].

2.4.3. Biomass

The importance of agriculture is also increasing because of biomass energy being one of the major resources in Turkey. Turkey has great agricultural potential and this makes energy production from biomass sources necessary [Gokcol et al., 2009].

The available agricultural and animal residues in Turkey have been estimated to be roughly equal to 22–27% of energy consumption in Turkey [Demirbas, 2008]. Table 2.3 shows the total recoverable bio-energy potential of Turkey which is estimated to be about 17 Mtoe [Demirbas et al., 2006].

Table 2.3. Total recoverable bio-energy potential in Turkey [Demirbas et al., 2006].



Type of biomass	Energy potential (Mtoe)
Dry agricultural residue	4.5
Wet agricultural residue	0.3
Animal waste	2.4
Forestry and wood processing residue	4.3
Municipal wastes and human excreta	1.3
Fuel wood	4.2
Total recoverable bio-energy	17.0

Since animal husbandry is highly developed in Turkey, a significant amount of animal wastes are produced each year. Table 2.4 shows the total amount of animal wastes, available dry manure and biogas in Turkey.

Table 2.4. Total amount of animal wastes, available dry manure and biogas in Turkey [Demirbas, 2008].

Animal waste	Waste quantity (tons/year)	Total dry manure (tons/year)	Available dry manure (tons/year)	Available biogas (m^3/year)	Heating value (MJ/m^3)	Total heating value (× 10^5 GJ)
Cow	127,654,932	16,211,033	10,535,172	2,107,434,345	22.7	478.4
Sheep	24,558,323	6,139,581	758,146	159,629,101	22.7	36.2
Poultry	7,731,694	1,932,924	1,913,594	382,718,866	22.7	36.9

Two sources of biomass result from agricultural production. The first is the residue left on the fields after harvesting and the second is the waste produced during processing of the agricultural products into industrial products. Cereals and oily seeds residues (shell, husk, stalk, pressed oily cake, bagasse, straw, etc.) are among the most widespread in Turkey. In addition, the highest estimated amounts of residues are from wheat and barley, followed by maize and cotton. The total annual amount of agricultural residues in the country is about 50–65 Mtons with a total calorific value of 228 PJ. The main residues that take place in the ratio of total calorific value are maize 33.4%, wheat 27.6%, and cotton 18.1%. The Table 2.5 presents the production and energy potential of crop residues in Turkey in 2003 [Gokcol et al., 2009].

Table 2.5. Production of crop residues in Turkey in 2003 [Gokcol et al., 2009].

Crop	Residue	Production (dry tons)		Available residue (dry tons)	Available residue ratio (%)	Heating value (MJ/kg)	Total heating value (× 10^5 GJ)
		Theoretic	Actual				
Wheat	Straw	29,170,755	23,429,907	3,514,486	15	17.9	629.1
Barley	Straw	9,992,948	8,963,012	1,344,452	15	17.5	235.3
Rye	Straw	405,188	358,040	53,706	15	17.5	9.4
Oats	Straw	419,678	321,236	48,185	15	17.4	8.4
Maize	Stalk	5,911,902	4,970,259	2,982,155	60	18.5	551.7
	Cob	596,592	1,907,307	1,144,384	60	18.4	210.6
Rice	Straw	582,555	209,532	125,719	60	16.7	21.0
	Husk	88,527	77,742	62,198	81	12.98	8.1
Tobacco	Stalk	362,763	410,778	246,467	60	16.1	39.7
Cotton	Stalk	6,317,181	2,520,281	1,512,169	60	18.2	275.2
	Ginning	481,527	732,220	585,776	80	15.65	91.7
Sunflower	Stalk	2,341,554	2,259,121	1,355,472	60	14.2	192.5
Groundnut	Straw	127,054					
	Shell	27,621	28,638	22,910	79	20.74	4.8
Soybean	Straw	60,468	21,872	13,123	62	19.4	2.5

The overall pollution prevention targets, the objectives of the Kyoto agreement as well important issues related to human and animal health and food safety require increasingly sustainable solutions for handling and recycling of animal manure and organic wastes. The large amounts of animal manure and slurries produced today by the animal breeding sector as well as the wet organic waste streams represent a constant pollution risk with a potential negative impact on the environment, if not managed optimally. To prevent emissions of greenhouse gases (GHG) and leaching of nutrients and organic matter to the natural environment it is necessary to close the loops from production to utilization by optimal recycling measures [Holm-Nielsen et al., 2009]. For that purpose, AD can be utilised as the biological conversion process and integrated gasification combined cycle can be used as thermal conversion process.

Following the environmental relevance of the animal and agricultural wastes, these biological and thermal conversion processes are explained below.

2.5. Environmental Relevance of the Agriculture

Animal production is increasing rapidly in the World and tends to be concentrated on larger production units, which also implies changes in animal production technology (feeding, housing etc.). This trend increases the risk of air, water and soil pollution [Vu et al., 2007].

The concentrated waste product from decomposing livestock manure can be environmentally detrimental if it enters rivers, streams, or groundwater supplies. Decomposing manure also causes air quality concerns associated with odor, ammonia emissions, and the contribution of methane emissions to global climate change [U.S.EPA, 2002]. The problems associated with the animal manure emissions can be summarized as follows:

- Emissions of ammonia (NH_3) and nitrogen oxides (NO) contribute to acidification and terrestrial eutrophication,
- Nitrate (NO_3) and phosphate (PO_4) emissions drive aquatic eutrophication,

- Nitrogen oxides (NO), particulate matter (PM_{10}) and ($PM_{2.5}$) emissions give rise to human toxicity and
- Methane (CH_4) and nitrous oxide (NO) emissions contribute to global warming [Havlikova et al., 2008].

2.5.1. Nitrogen Losses because of Agriculture

Nearly all of the crops grown in the industrialized world, including corn and soybeans, are nitrogen-saturated, meaning they are exposed to more nitrogen than they can use. Overuse of nitrogen for crops, its subsequent runoff into rivers and other bodies of water, and the millions of tonnes of nitrogen found in farm animal manure are growing threats to the environment and public health.

Nitrogen pollution can adversely affect land, water, air, and, consequently, quality of life for residents of communities located near animal production facilities. The odors emanating from some factory farm manure lagoons—the pools that hold and store farm animal manure and urine—are among the most noticeable effects of nitrogen pollution. Additionally, lagoons can be fragile, leaking waste into groundwater and overflowing during rainstorms [Humane Society, 2009].

Agriculture, including both crop and animal production, contributes considerably to total NH_3, NO_3, and N_2O emissions. Especially for ammonia, agriculture is by far the main source of emissions. Table 2.6 provides information about the contribution of agricultural production on the different total nitrogen emissions at different spatial scales [Brentrup et al., 2000].

Table 2.6. The share of agriculture on total global, European and German N emissions [Brentrup et al., 2000].

	Globe	**Europe**	**Germany**
NO_3	-	-	50%
NH_3	87%	97%	96%
N_2O	47%	48%	33%

2.5.1.1. Ammonia Losses. As shown in Table 2.6, nearly 90% of the global emissions of the volatile gas ammonia (NH_3) are related to agriculture. Within agriculture, animal husbandry has by far the greatest share on ammonia released to the environment.

Ammonia volatilization occurs during and after the production, storage and application of organic fertilizers [Brentrup et al., 2000].

The amount of ammonia lost during application of slurry or solid manure to land, depends on many factors including: percentage of dry matter in the slurry or manure, temperature, time of the year and method of application.

Manure applied to land contains a considerable amount of nitrogen, perhaps up to seven kg [N] t [freshweight]$^{-1}$, even after discounting the ammonia lost shortly after it is applied.

In the first year, the amount of this nitrogen available to the crop ranges from about 50% for pig slurry, 30% for cattle slurry to 10–49% for broiler litter. The actual amount varies because of the variable content of manures, the handling and processing that has been applied to the manure between production and spreading, and the rate of bacterial activity in the soil, which is a function of moisture and temperature [Sandars et al., 2003].

2.5.1.2. Nitrous Oxide Emissions. Agriculture has a considerable share on the anthropogenic N_2O emissions, whereas N_2O itself contributes to 5% to the total global warming potential. – Nearly 80% of the N_2O emissions because of agriculture are related to the use of mineral and organic fertilizers. Biomass burning (e.g. shifting cultivation, deforestation) is responsible for about 20%. Denitrification and nitrification are the two microbial processes in soil that are responsible for most of the N_2O emissions in agriculture [Brentrup et al., 2000].

2.5.1.3. Nitrate Leaching. The mineral nitrogen in the soil is mainly nitrate (NO_3^-) and to a lower extent ammonium (NH_4^+). As nitrate is hardly adsorbed by soil particles, it can be easily leached into the groundwater. During the vegetation period, the risk of NO_3^- leaching is low because large amounts of nitrate are taken up by the plants. Furthermore, almost no downward water movement occurs during the vegetation period mainly because of high evapotranspiration rates. During the vegetation-free period from late autumn to early spring precipitation often exceeds evapotranspiration so that the mobile NO_3^- anion can be leached downwards in the soil [Brentrup et al., 2000].

2.5.2. The Impact of Agriculture on Global Warming and Climate Change

When untreated or poorly managed, animal manure becomes a major source of air and water pollution. Nutrient leaching, mainly nitrogen and phosphorus, ammonia evaporation and pathogen contamination are some of the major threats.

The animal production sector is responsible for 18% of the overall green house gas emissions, measured in CO_2 equivalent and for 37% of the anthropogenic methane, which has 23 times the global warming potential of CO_2.

Furthermore, 65% of anthropogenic nitrous oxide and 64% of anthropogenic ammonia emission originates from the worldwide animal production sector [Holm-Nielsen et al., 2009].

2.5.2.1. Global Warming because of Carbondioxide caused by Fertilizer and Feed Production. A main input in modern meat, egg, and dairy production is artificial nitrogenous fertilizer, vast amounts of which are used in the cultivation of farm animal feed, primarily a combination of corn and soybeans. Most of that fertilizer is produced in factories dependent on fossil-fuel energy. Manufacturing fertilizer uses roughly 1% of the world’s total energy, and an estimated 41 million tonnes of CO_2 is emitted from fertilizer production exclusively for feed crops [Humane Society, 2009].

2.5.2.2. Global Warming because of Nitrous Oxide. In addition to its GWP, N_2O is involved in the depletion of the ozone layer. Ruminants, including cattle, goats, buffalo, and sheep, produce nitrous oxide emissions when their manure and urine are deposited.

Seventy per cent of anthropogenic N_2O emissions come from crop and farm animal production, with animal agriculture accounting for 65% of global N_2O emissions [Humane Society, 2009].

2.5.2.3. Global Warming because of Methane. Storing and disposing vast quantities of manure can produce anthropogenic methane. Globally, farm animals are the most significant source of anthropogenic methane, responsible for 35-40% of methane emissions worldwide [Humane Society, 2009].

2.6. Anaerobic Digestion (AD) and Biogas Recovery Systems

Anaerobic digestion (AD) is a process that is applied to manure both on farm and in centralised plants. The process is interesting to study in an LCA because it has the potential benefits of renewable energy to offset any energy inputs and environmental impacts because of the modification of the manure.

2.6.1. Overview of the AD Process

AD is a microbial process that occurs in the absence of oxygen. In the process, a community of microbial species breaks down both complex and simple organic materials, ultimately producing methane and carbon dioxide. AD can occur over a wide range of environmental conditions, although narrower ranges are needed for optimum operation as shown in Table 2.7 [Engler et al., 1999].

Carbon and nitrogen are the most important elements undergoing change inside the anaerobic digester. It is assumed that there is an 85% reduction in biological oxygen demand (BOD) because of converting carbon to biogas, most of which is used to generate electrical energy with an emission of carbon dioxide. A fugitive loss of 13.5% of the biogas is not unreasonable for a small-scale farm based digester where energy supply and demand rarely balances. The digestion process converts some of the nitrogen from the relatively stable organic form to the volatile ammoniacal nitrogen form, thus increasing the potency of the nitrogen [Sandars et al., 2003].

Table 2.7. Operating conditions for AD process [Engler et al., 1999].

Operating Parameter	**Typical Value**
Temperature	
Mesophilic	35°C
Termophilic	54°C
pH	7 – 8
Alkalinity	2500 mg/L minimum
Retention time	10 – 30 days
Loading rate	2.4 – 5.6 kg VS/m^3/d
Biogas yield	0.2 – 0.5 m^3/kg VS
Methane content	60 – 70%

The schematic process description of the AD can be explained as follows:

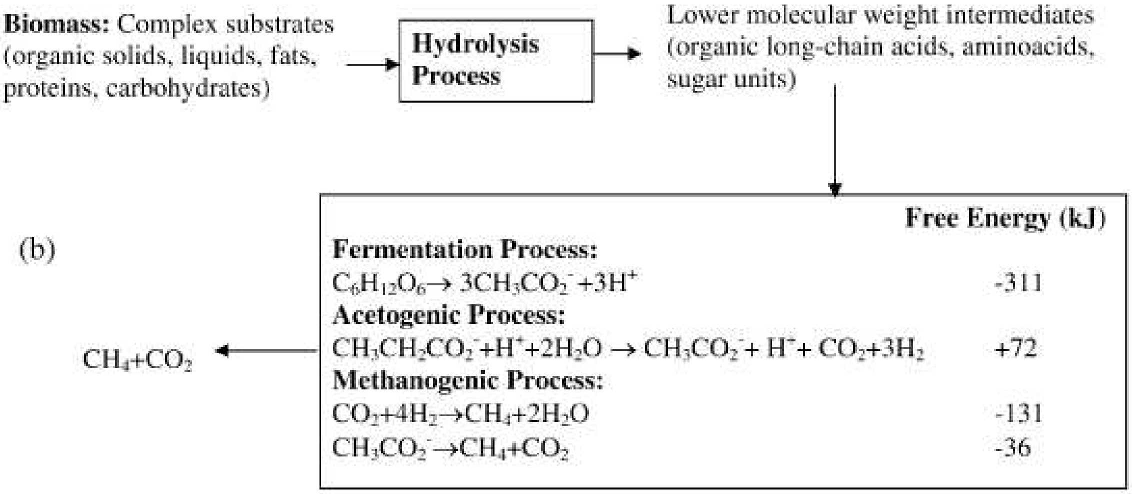


Figure 2.4. Certain details from the process of AD [Batzias et al., 2005].

Biogas digester systems can accommodate manure handled as a liquid, slurry, or semisolid (with little or no bedding added). The total solids content of the manure—a measure of manure thickness—determines these classifications.

Figure 2.5 shows the manure characteristics and handling systems that are appropriate for specific types of biogas digester systems [U.S.EPA, 2002].

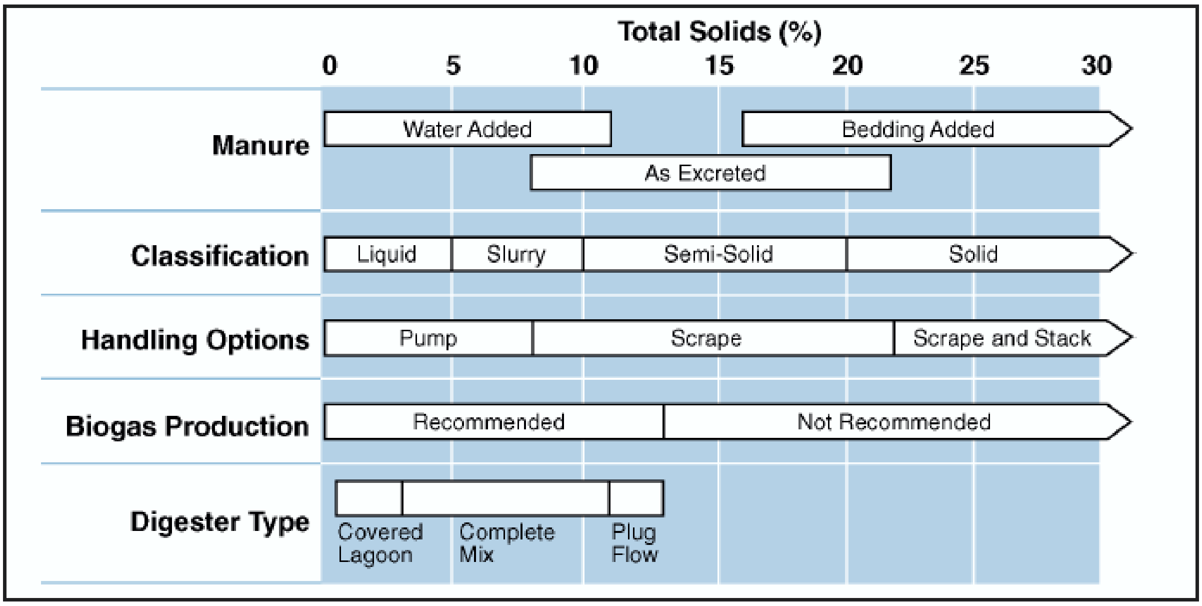


Figure 2.5. Appropriate manure characteristics and handling systems for specific types of biogas digester systems [U.S.EPA, 2002].

The conversion of animal waste to biogas through AD processes can provide added value to farm livestock manure as an energy resource, while the operation of the corresponding agro-industrial AD-units will significantly contribute to regional development. As a matter of fact, when used in a fully engineered system, AD-technology not only prevents pollution, but also allows for sustainable energy production, as well as for compost and nutrient recovery [U.S.EPA, 2002].

2.6.2. Overview of the Biogas Recovery Systems

Biogas can be produced from nearly all kind of biological feedstock types, within these from the primary agricultural sectors and from various organic waste streams from the overall society. The largest resource is represented by animal manure and slurries from cattle and pig production units as well as from poultry, fish, fur, etc. Another agricultural substrate suitable for AD is represented by energy crops, of which most common are grain crops, grass crops, and maize [Holm-Nielsen et al., 2009].

The natural product of the AD, biogas, typically contains between 60 to 70 per cent methane, 30 to 40 per cent carbon dioxide, and trace amounts of other gases.

When biogas is captured, it can be used to generate heat, hot water, or electricity—significantly reducing the cost of electricity and other farm fuels such as natural gas, propane, and fuel oil [U.S.EPA, 2002].

Biogas is a renewable source of energy with much lower environmental impacts than conventional fossil fuel. The methane generated from AD provides rural electric cooperatives and utilities with a source of "green power" to sell to customers who wish to purchase power from renewable sources. Biogas recovery also provides rural energy benefits such as distributed generation and voltage support [U.S.EPA, 2002].

2.6.3. Benefits of the AD Process and Biogas Recovery Systems

The environmental benefits provided by AD process and biogas recovery systems far exceed those supplied by "conventional" liquid and slurry manure management systems (e.g., storage tanks, storage ponds, lagoons). These benefits include odor control, improved air and water quality, improved nutrient management flexibility, and the opportunity to reduce greenhouse gas emissions and capture biogas—a useful source of energy [U.S.EPA, 2002].

2.6.3.1. Odor control. The effluent odor from anaerobic digesters is significantly less than odors from conventional manure management systems. Odor reduction using AD can be very cost-effective when compared to other alternatives such as aeration [U.S.EPA, 2002].

2.6.3.2. Greenhouse Gas Reduction. Conventional liquid and slurry manure management practices emit large amounts of methane, a greenhouse gas that contributes to global warming. Biogas recovery systems capture and combust methane, thus reducing greenhouse gas emissions [U.S.EPA, 2002].

Biogas from manure stands out as having very high reduction in greenhouse gas emissions and very high fossil fuel savings compared to the conventional storage and soil application of the manure [Thyø and Wenzel, 2007; U.S.EPA, 2002].

2.6.3.3. Water Quality Protection. AD provides several water quality benefits. When an anaerobic digester system, is properly managed, phosphorous and metals, such as copper and zinc, will settle out in the process cells, thus reducing phosphorous and metals loadings to surface waters when manure is land-applied. Digester systems, especially heated digesters, isolate and destroy disease causing organisms that might otherwise enter surface waters and pose a risk to human and animal health. The concrete or steel tanks used in plug flow and complete mix digesters also effectively prevent untreated manure from reaching ground water [U.S.EPA, 2002].

2.6.3.4. High-quality Fertilizer and Soil Amendment. Key by-products of AD include digested solids and liquids, which may be used as soil amendments or liquid fertilizers [Balsam and Ryan, 2006]. Because AD reduces ammonia losses, digested manure can contain more valuable nitrogen for crop production. Also, the fiber in digested dairy manure can be used on the farm as animal bedding or recovered for sale as a high-quality potting soil conditioner or mulch [U.S.EPA, 2002; Turnbull and Kamthunzi, 2005]. Another benefit of manure is saving the fossil energy required in the industrial production of mineral fertilizers [Ceotto, 2005].

2.6.3.5. Destruction of Harmful Organisms. Coliform bacteria, other pathogens, insect eggs and internal parasites also are destroyed or reduced to acceptable levels by anaerobic treatment [Engler et al., 1999].

2.6.3.6. Financial Benefit. Biogas production is an advantageous solution, with regard to the opportunity of selling the electricity and heat produced and thereby gaining a financial benefit [Thyø and Wenzel, 2007].

2.6.4. Co-Digestion of Animal Wastes

Co-digestion is the simultaneous digestion of a homogenous mixture of two or more substrates. Co-digestion offers several ecological, technological and economic advantages. Some of the merits of co-digestion are as follows:

- It provides improved nutrient balance from a variety of substrates which helps to maintain a stable and reliable digestion performance and produce a good fertilizer quality of the digestate.
- Provides for optimization of rheological qualities when wastes with poor fluid dynamics, aggregating wastes, particulate or bulking materials and floating wastes can be much easier digested after homogenization with dilute substrate such as sewage sludge or liquid manure.
- Agricultural biogas production from manure alone (which has a relatively low gas yield) is economically not viable at current oil prices. Addition of co-substrates with a high-methane potential increases gas yields [Braun and Wellinger, 2003]:

Co-digestion provides an opportunity to optimize biogas production, particularly in rural areas where quantities of animal manure might not be enough for sustained production throughout the year. The possibility to use energy crops as co-substrates offers a viable option [Jingura and Matengaifa, 2009]. A schematic representation of the sustainable cycle of anaerobic co-digestion of animal manure and organic wastes are shown in Figure 2.6.

Farm manures contain concentrations of ammonia which are greater than that necessary for microbial growth and may be inhibitory to AD. A high concentration of ammonia can be advantageous when used with other feedstocks which have low nitrogen concentrations [Ward et al., 2008].

A particularly strong reason for co-digestion of feedstocks is the adjustment of the carbon-to-nitrogen (C:N) ratio.

Microorganisms generally utilise carbon and nitrogen in the ratio of 25–30:1, but C:N ratios can often be considerably lower than this ideal [Ward et al., 2008]. It is often suggested that an optimum ratio of C/N is between 20/1 and 30/1, although it has been reported that for one series of experiments, there was a minimum C/N ratio of 16/1 and increasing the nitrogen content did not improve digestion [Hammad et al., 1999].

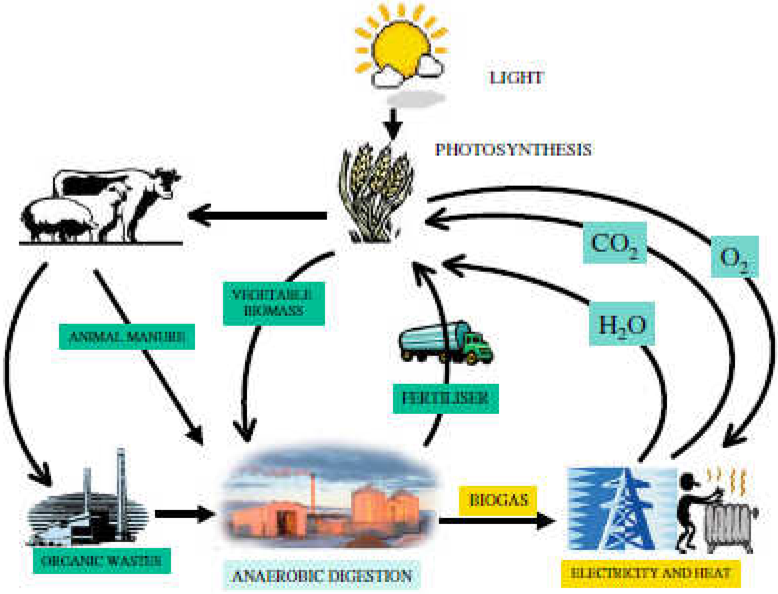


Figure 2.6. Schematic representation of the sustainable cycle of anaerobic co-digestion of animal manure and organic wastes [Holm-Nielsen et al., 2009].

Agricultural residues contain low nitrogen and have carbon-to-nitrogen ratios (C/N) around 60–90. Therefore, nitrogen needs to be supplemented to enhance the AD of agricultural solid residues. Nitrogen can be added in inorganic form such as ammonia or in organic form such as livestock manure, urea, or food wastes. Once nitrogen is released from the organic matter, it becomes ammonium which is water soluble. Recycling nitrogen in the digested liquid reduces the amount of nitrogen needed [Demirbas et al., 2006].

2.7. Carbon Sequestration

Carbon sequestration is the process through which agricultural and forestry practices remove carbon dioxide (CO_2) from the atmosphere. Sequestration activities can help prevent global climate change by enhancing carbon storage in trees and soils, preserving existing tree and soil carbon, and by reducing emissions of CO_2, methane (CH_4) and nitrous oxide (N_2O). Carbon sequestration rates vary by tree species, soil type, regional climate, topography and management practice. [U.S.EPA, 2011].

During photosynthesis, atmospheric CO_2 enters the leaf through stomata, combines with water, and is converted into cellulose, sugars, and other materials in a chemical reaction catalyzed by sunlight. Most of these materials become fixed as wood, although some are respired back as CO_2 or used to make leaves that are eventually shed by the tree [McPherson, 2008].

The total area of Turkey is 78 million and 26.9% of this area, which is an area 20.7 million hectare is forests. The main species groups in Turkish forests are Coniferous with 53.65% and Broadleaved trees with 46.35% of the total forests. Among Coniferous group, the highest amount of trees belongs to Pine trees with 41.53%. While the urban forests sequestrate 4-8 ton/ha CO_2, the rural forests, because of the higher density of trees, sequestrate double the amount of CO_2 sequestrated by the urban forests [Gul et al., 2009].

The carbon sequestration of pine trees over 25 years is 7.5 kg of carbon / m^2 . When the tree density is assumed as an average of one trees per six m^2, then the carbon sequestration can be defined as 6.4 kg CO_2/tree/year for 25-year forest tree [Tufts University, 2011].

According to the “Method for Calculating Carbon Sequestration by Trees in Urban and Suburban Settings”, the total carbon sequestration over 25 years is found as 29.3 kg CO_2 for fast growing pine trees. This method is appropriate only for carbon sequestration by individual (“open grown”) trees, such as trees typically planted along streets, in yards, and in parks and not used for calculating carbon sequestration by densely planted trees [U.S. DOE, EIA, 1998].

2.8. Integrated Gasification Combined Cycle (IGCC)

Gasification of biomass is based on the partial oxidation of material in a restricted supply of air or oxygen [EECA, 2001]. It is a well-known technology that can be classified depending on the gasifying agent: air, steam, steam–oxygen, air–steam, oxygen-enriched air, etc. Gasification is carried out at high temperatures in order to optimize the gas production. It yields a product gas from thermal decomposition composed of CO, CO_2, H_2O, H_2, CH_4, other gaseous hydrocarbons (CHs), tars, char, inorganic constituents, and ash. Gas composition of product from the biomass gasification depends heavily on the gasification process, the gasifying agent, and the feedstock composition [Balat, 2009].

In principle, biomass gasification can be divided into two stages. Assuming a gasification process using biomass as a feedstock, the first step of the process is pyrolysis that is a thermochemical decomposition of the cellulose, hemicelluloses and lignin compounds with production of char and volatiles, leaving carbon residues behind. Second stage is the gasification of char and some other equilibrium reactions of the carbon residues with the gasification reagents [Balat, 2009; Gibson et al., 2007].

The three principal types of gasifiers are fluidized bed, entrained flow, and fixed bed gasifiers. The main difference between these reactors is concerned with how the biomass and oxidizer are moved in the reactor. For large-scale operations the preferred and most reliable systems are fluidized bed and entrained bed gasifiers, while for small scale applications, a fixed bed gasifier is well suited [Gordillo and Annamalai, 2010]. There are many types of gasifiers including updraft, downdraft and a full range of circulating fluidised bed gasifiers ranging from 30 kW to 300 MW, though biomass gasifiers tend to be below 70 MW [EECA, 2001].

Gasification is capable of readily converting all major biomass components including refractory lignin to usable product gases [Gibson et al., 2007]. The efficient operation of a gasifier involves careful management of the ratio of biomass to oxidant (air or oxygen) to obtain complete conversion of the char while avoiding excessive combustion which would dilute the fuel gas with unreacted carbon dioxide [EECA, 2001].

If air is used as the gasification reagent, the product gas called producer gas is N_2 rich [Gibson et al., 2007] and it has a low calorific value (four to 10 MJ/Nm^3).

This gas can be used as a fuel in boilers, internal combustion engines or gas turbines [IEA, 1998]. Gasification using oxygen or steam as the gasification reagent will yield syngas [Gibson et al., 2007]. When not using ait, the resulting gas, synthesis gas, will have a higher calorific value with typically 10-15 MJ/Nm3 [IEA, 1998].

One advantage of gasification is that using the generated synthetic gas or liquid fuel, such as diesel, is more efficient than the direct combustion of the original fuel. This process extracts more of the energy contained in the original fuel [Vcore, 2011].

The carbon conversion efficiency could be as high as ~98%. The overall efficiency of converting biomass to electricity based on biomass gasification could reach around 40%, being much higher than traditional biomass combustion (25-30%) [Gibson et al., 2007].

Regardless of the final fuel form, gasification itself and subsequent processing neither directly emits nor traps greenhouse gases such as carbon dioxide. Power consumption in the gasification and syngas conversion processes may be significant though, and may indirectly cause CO_2 emissions [Gibson et al., 2007].

Because of the endothermic characteristic of biomass gasification, external heat is required for driving gasification. There exist two distinct manners (direct or indirect) by which heat can be introduced into gasifiers. Direct gasification occurs when gasification reagents containing oxidants (air or pure oxygen) are used to partially combust biomass to provide thermal energy for driving gasification. In indirect gasification additional processes that take place outside gasifiers are employed to provide the thermal energy, followed by transferring the heat into gasifiers. Steam is the most commonly used in indirect gasification because it is easy and cheap to produce and is able to increase the hydrogen content.

Slag is the primary solid byproduct of gasification and the quantity produced is a function of how much mineral matter is present in the gasifier feeds. The slag containes mineral matter associated with the feed in a vitrified form, a hard glassy substance.

It is not a good substrate for binding organic compunds so it is usually found to be nonhazardous and thus may be disposed of in a landfill [Wetherold et al., 2000].

The product gases from the gasifier contain a variety of pollutants (particulates, alkali metals, tars, and SOx) that are able to cause serious troubles to downstream utilization. Consequently, gas conditioning and cleanup units involving tar cracker, gas cooler, desulfurization ZnO bed, and water scrubber follow the gasifier to ensure the product gases are clean [Gibson et al., 2007]. The fine particulate matter often contains a high percentage of carbon, so the material is often recycled to the gasifier to recover the energy value of this material [Wetherold et al., 2000]. The range of products immediately obtainable from synthesis gas extends from bulk chemicals like ammonia and methanol, through industrial gases, to utilities such as clean fuel gas and electricity. Furthermore, there are interesting by-products, such as CO_2 and steam. Many of these direct products are only intermediates toward products closer to the consumer market, such as acetates and polyurethanes [Higman and Van der Burgt, 2003].

Direct combustion of product gases from biomass gasification in heat engines is a traditional approach for electricity generation, which is associated with a huge amount of energy waste that might be two or more times as much as the electricity generated. To avoid such a substantial energy waste, much effort has been dedicated to developing IGCC that has been widely regarded as the most efficient and environmetally friendly technology to utilize biomass for power generation. It is a concept of burning product gases obtained from biomass gasification in a gas turbine, followed by recoverying the thermal energy in exhaust gases derived from the gas turbine to produce steam to power steam turbines. The importance of this technology relies on the fact that it can take advantage of advanced turbine designs and heat-recovery steam generators to achieve high overall efficiency exceeding 40%. Moreover, with advanced technologies for gasification, turbines, gas separation and cleaning becoming available, each of these can be readily integrated into IGCC to improve the efficiency.

The temperature inside the gas turbine is fairly high (~1200°C), and the output temperature of flue gases is relatively high (~600°C) as well.

It can be seen that the flue gases exhausted from the gas turbine contain abundant thermal energy. If this thermal energy is not efficiently utilized, the energy waste will substantially decrease the overall efficiency of biomass utilization. In a combined cycle, a heat recovery steam generator (HRSG) recovers this thermal energy to produce steam that can be used to generate electricity via a steam turbine. The efficient utilization of biomass via the combined cycle leads IGCC to have many environmental benefits such as extremely low SO_x, NO_x and particulate emissions [Gibson et al., 2007].

3. LIFE CYCLE ASSESSMENT (LCA) METHODOLOGY

3.1. Introduction

The objective of this study is to increase the usage capacity of the agricultural and animal waste, and to increase the environmental, economical and social benefits in the selected pilot area, Kocaeli – Turkey, by following a sustainable method.

This project is an on-field application project and it includes the construction of a pilot plant in Kocaeli which consists of an AD plant and biogas recovery system. The raw materials to be used as feed are cattle manure, poultry manure, slaughterhouse wastes, vegetable wastes and grass. The impacts of these wastes that are anaerobically digested in the pilot plant are evaluated in the categories such as human health, ecosystem health and material welfare by Life Cycle Assessment (LCA) procedure.

As a result of the utilization of these wastes, their potential environmental pollution is decreased dramatically. The laboratory scale anaerobic digester provided the initial data to determine the process conditions for the pilot scale reactor.

Life Cycle Assessment is a method of accounting for the environmental benefits and burdens of the production of goods and services including consequential burdens generated elsewhere. LCA methods systematically follow the process from ‘cradle to grave’ to ensure that improvements at one stage correspond to an overall improvement and do not simply move problems up or down the chain [Sandars et al., 2003].

Life Cycle Assessment studies stress the importance of expressing impacts per unit of function and considering the whole chain.

The functional unit of the LCA study will be “benefits of 10,680 ton/year agricultural and animal wastes” where the primary service provided by, and equal for, all systems is “the electricity production for at least 850 houses each with four (4)-family members”.

The pilot plant will be fed with the following waste recipe including the agricultural and animal wastes of which types and quantities are given in Table 3.1.

Table 3.1. Waste recipe of the pilot plant in Kocaeli.

Material	**Amount (kg/day)**	**Amount (ton/year)**
Grass	16,164	5,900
Vegetable wastes	5,616	2,050
Slaughterhouse wastes	1,178	430
Poultry manure	5,342	1,950
Cattle manure	959	350
Total	29,260	10,680

LCA part of the project covers integrated LCA approach of biomass utilization with special emphasize on global carbon cycle. Integration of AD in LCA highlights the potential benefits of renewable energy to offset any conventional energy inputs and assessment of greenhouse gas emission reduction. The LCA study covers the following work packages;

- Determination of the air emissions of the pilot plant,
- Comparison of the emissions of the pilot plant in case of different feed characterization,
- Comparison of the environmental effects of the pilot plant with that of the conventional fossil fuel systems (hard coal power plant and natural gas power plant) to produce same amount of electricity, heat and fertilizer.
- Comparison of the environmental effects of the pilot plant with that of other renewable energy systems (hydropower plant, wind energy, and biomass integrated gasification combined cycle plant) to produce same amount of electricity and fertiliser.

In addition to the above work packages, the techniques for managing agricultural and animal wastes and their environmental impacts have been compared in this study.

The alternatives subject to comparative evaluation should provide equivalent services to society, not just regarding the primary service, which in this case is power production, but also secondary services.

Secondary services are defined as products/services arising e.g. as co-products from processes in the studied systems, and in this case, the secondary service is the production of fertilizer.

It can be concluded that utilizing animal and agricultural wastes by AD plant and biogas recovery system will provide real benefits in terms of environmental effects when compared to other energy production systems. Especially, the reduction of greenhouse gas emissions should be highlighted which provide a decrease in global warming and open doors for a better environment.

3.2. Goal and Scope Definition

The purpose of this study is to increase knowledge about the environmental impacts of different waste types and to illustrate the environmental benefits of using an AD plant and biogas recovery system resulting in sustainable region development.

Within the frame of this study, the environmental pollution because of the animal and agricultural wastes will be decreased providing a healthy environment for the residents. The usage capacity of the agricultural and animal wastes will be raised and the economical and social benefits will be increased in the selected pilot area by following a sustainable method.

Not only the use of agricultural and animal wastes to produce heat and power, but also the use of agricultural and animal wastes to produce organic fertilizer will be demonstrated which will totally provide environmental benefits including human health, ecosystem health and material welfare.

The study includes the illustration of the benefits of a pilot plant in Kocaeli which consists of an AD plant and biogas recovery system in which the animal and agricultural wastes will be used as raw materials. The raw materials to be used as feed are cattle manure, poultry manure, slaughterhouse wastes, vegetable wastes, and grass.

The impacts of these wastes that are anaerobically digested in the pilot plant are evaluated in the categories such as human health, ecosystem health and material welfare.

In addition, this plant will provide energy production from the agricultural and animal wastes. Biogas will be produced and used as an energy source among which electricity is the primary service. Besides, the wastes will be used to produce heat and organic fertilizer which are the secondary services. So, it will be advantageous in terms of the environmental pollution and will be a solution for the energy crisis occurring because of the decrease in the fossil fuel quantities. All of this can be accomplished in an economical manner while reducing greenhouse gas emissions and causing sustainable region development. Specific goals for the project are summarized in Table 3.2.

It is possible for the residents in the pilot area to get direct benefits from this AD and biogas recovery plant. The farmers and related institutions can be trained on the use of utilization of the animal manure and agricultural wastes in order to maintain the sustainability.

Completion of this study will facilitate the widespread adoption of this LCA strategy for managing agricultural and animal wastes and could lead to acceptance throughout areas in Turkey as an energy resource. As a result, the environmental pollution caused by these wastes will be decreased dramatically.

Table 3.2. Specific goals of the LCA study.

Goal Definition	Minimum Goal
Meeting part of the electricity need of the neighbouring village	≥10%
Decrease in Global Warming Potential (GWP)	≥60%
Saving urban trees compared to fossil fuel utilization	≥500,000 pcs.
GWP saving equal to yearly emissions of a considerable amount of average World Citizens	≥150 citizens
GWP Saving equal to a considerable amount of TVs running for a year	≥30,000 pcs.
GWP Saving equal to the extraction and refinery of crude oil to make a considerable amount of petrol	≥1,000 tonne
GWP Saving equal to manufacturing of a considerable amount cell phone	≥10,000 pcs.
GWP Saving equal to flying a considerable distance in economy class (long distance flight, emissions per passenger)	≥3,000,000 kilometres
GWP Saving equal to manufacturing a considerable amount of computers and monitors	≥2,500 pcs.
GWP Saving equal to producing a considerable amount of steel	≥300 tonne
GWP Saving equal to driving a considerable distance with an average European car	≥ 4,500,000 kilometre
GWP Saving equal to producing a considerable amount of sugar	≥900 tonne
Decrease in acidification potential	≥25%
Decrease in aquatic eutrophication potential	≥40%
Decrease in photochemical ozone formation - impact on vegetation	≥70%
Decrease in stratospheric ozone depletion	≥75%
Decrease in Terrestrial eutrophication	≥20%

3.2.1. Primary Service and Functional Unit

The functional unit of the LCA study will be “benefits of 10,680 ton/year agricultural and animal wastes” where the primary service provided by, and equal for, all systems is “the electricity production for at least 850 houses each with four (4)-family members”.

The LCA study covers the following work packages;

- Determination of the air emissions of the pilot plant,
- Comparison of the emissions of the pilot plant in case of different feed characterization,
- Comparison of the environmental effects of the pilot plant with that of the conventional fossil fuel systems (hard coal power plant and natural gas power plant) to produce same amount of electricity, heat and fertilizer.
- Comparison of the environmental effects of the pilot plant with that of other renewable energy systems (hydropower plant, wind energy, and biomass integrated gasification combined cycle plant) to produce same amount of electricity and fertiliser.

There are numerous scenarios of which life cycle analyses and comparisons were conducted within this study. The system in the main scenario (Scenario A) includes processes directly related to the AD and biogas recovery system of the waste recipe given in Table 3.1. In addition to the results of the laboratory scale studies provided by the Energy Institute Team of Turkish Scientific and Technological Research Council (TUBITAK) Marmara Research Center (MRC), some inventory data for the AD and biogas recovery system in Scenario A are gathered from the literature and the GaBi4 database. The results of these laboratory scale studies can be found in the interim report named “IP No: 5 (Laboratory Scale Biogas System Studies)” included in the TUBITAK project with reference no. of 106G112.

Only cattle waste is considered as the feed to the anaerobic digester in Scenario B instead of the same amount of waste recipe which is given in Figure 3.1. The inventory data for the AD and biogas recovery system in Scenario B are also gathered not only from the Energy Institute Team of TUBITAK MRC, but also from the literature and the GaBi4 database.

The third and fourth scenarios compare the environmental effects of the pilot plant with that of the conventional fossil fuel systems in order to produce the same amount of electricity and heat which will be connected to the grid systems. In addition to the electricity and heat production from some fossil fuel resources, these scenarios, Scenario C and Scenario D, also include the disposal of agricultural and animal wastes in conventional methods besides the production and usage of chemical fertiliser for wheat production.

These two scenarios are mainly the electricity and heat production from;

- hard coal burned in a power plant (Scenario C),
- natural gas burned in a power plant (Scenario D).

The fifth and sixth scenarios include the renewable energy systems in order to produce the same amount of electricity that will be connected to the grid system. In addition to the electricity production from renewable sources, these scenarios, Scenario E and Scenario F, also include the disposal of agricultural and animal wastes in conventional methods besides the production and usage of chemical fertiliser for wheat production.

These two scenarios are mainly the electricity production from

- hydropower plant (Scenario E),
- wind power plant (Scenario F).

The seventh scenario (Scenario G) includes biomass integrated gasification combined cycle of the waste recipe given in Table 3.1 and also the production and usage of chemical fertiliser for wheat production. The inventory for the biomass integrated gasification combined cycle is gathered from the literature and the GaBi4 database.

The system boundaries for each scenario are explained below. The selected processes are analysed with the method EDIP 2003 and evaluated according to the following impact categories: global warming, acidification, terrestrial and aquatic eutrophication, photochemical ozone formation - impact on vegetation and stratospheric ozone depletion.

3.2.2. System Boundaries and Flow Charts

The processes defined in the system boundaries of the main scenario, Scenario A, is used to evaluate the potential environmental and health impact of the pilot plant in which the waste recipe is anaerobically digested, the produced biogas is utilized to produce electricity and heat, and the digestate is used in agriculture as organic fertiliser. The difference between Scenario A and Scenario B is only the waste to be digested. While the input waste is the waste recipe defined in Table 3.1 for Scenario A, Scenario B utilises only the same amount of cattle manure as input waste. The system boundaries of Scenario A and Scenario B can be explained as follows:

- The wastes are assumed to be transported for 15 km-distance to the pilot plant.
- The production, transport and disposal of the main materials for the agricultural biogas plant are included.
- Spreading of the digested matter as fertiliser is taken into account, while the transport of the digestate from the pilot plant to the farms is ignored.
- All concrete units such as the anaerobic digester, primary storage and mixing unit and final storage unit are considered to have a service life time of 30 years.
- The gas engine used as cogeneration unit has a service life time of 60,000 hours which is equal to 7.5 years.
- The processes excluded from the system boundaries are;

    - The processes related to the production of the wastes in recipe,
    - The feed type and production of the feed for the animals,
    - The transport, grit connection and final use of the excess electricity and heat,
    - Leaching of digester supernatant or digester liquor into water supplies.

Supernatant commonly refers to the liquid between the sludge in the lower portion and the scum on the surface of an anaerobic digester or the liquid material left after separation of the slurry [Marchaim, 1992]. In Scenario A and Scenario B, the digestate is combined of both fibrous and liquor fractions since the anaerobic digesters are completely mixed, so the supernatant between the sludge in the lower portion and the scum on the surface of the anaerobic digester is not considered. The two fractions combined in the digestate are separated in further processing as to produce solid and liquid digestates.

It is known that direct discharge of digester liquor after anaerobic fermentation is detrimental to receiving waters as it contains high concentrations of organic carbon, nitrogen and phosphorus. In particular, the presence of high nitrogen concentrations in the digester liquor can cause adverse impacts, such as toxicity to fish and other aquatic organisms, dissolved oxygen (DO) depletion, eutrophication and potential public health hazard [Qiao et al., 2010].

Because of high nutrient content, the liquor produced by the AD process can be used as a liquid fertilizer on the farms. However, the unavailability of land area to which this liquor can be applied may not enable effective application of the liquid effluent. Therefore, in order to avoid adverse environmental consequences, through overapplication of AD liquor on limited land or leaching of effluent into water supplies, the nutrients must be completely or partially removed.

Furthermore, recovery of these nutrients from the anaerobically digested material is a potential source of revenue, partially offsetting the costs of treatment. This is why control over the point sources of N and P recently shifted from removal to recovery, with a particular emphasis on improving the sustainability of agricultural activities. This was mainly because of the increasing global demand for the nitrogenous fertilizer. Therefore, the current attempts are not only to protect the water resources, but also to extract the maximum amounts of N and P from the recoverable sources [Demirer and Othman, 2009].

In Scenario A and Scenario B, the digestate, which is separated in further processing as to produce solid and liquid digestates, is used in agriculture as organic fertiliser. The completely or partially removal of nutrients that are applied in case of the overapplication of AD liquor on limited land or leaching of effluent into water supplies are not taken into consideration within the system boundaries.

The flowchart of Scenario A and Scenarios B are shown below.

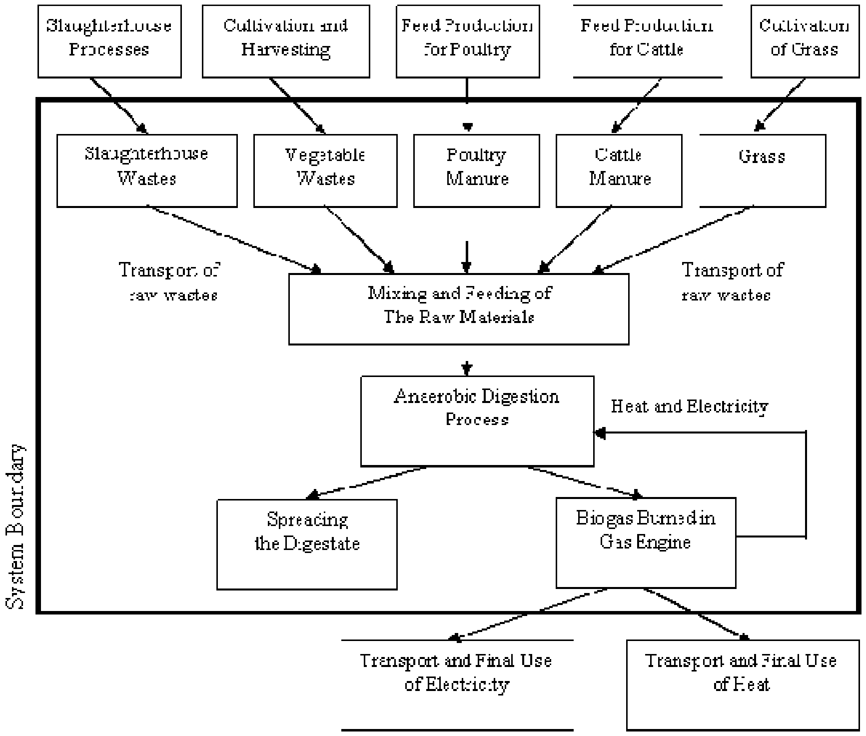


Figure 3.1. System boundary of the Main Scenario (Scenario A).

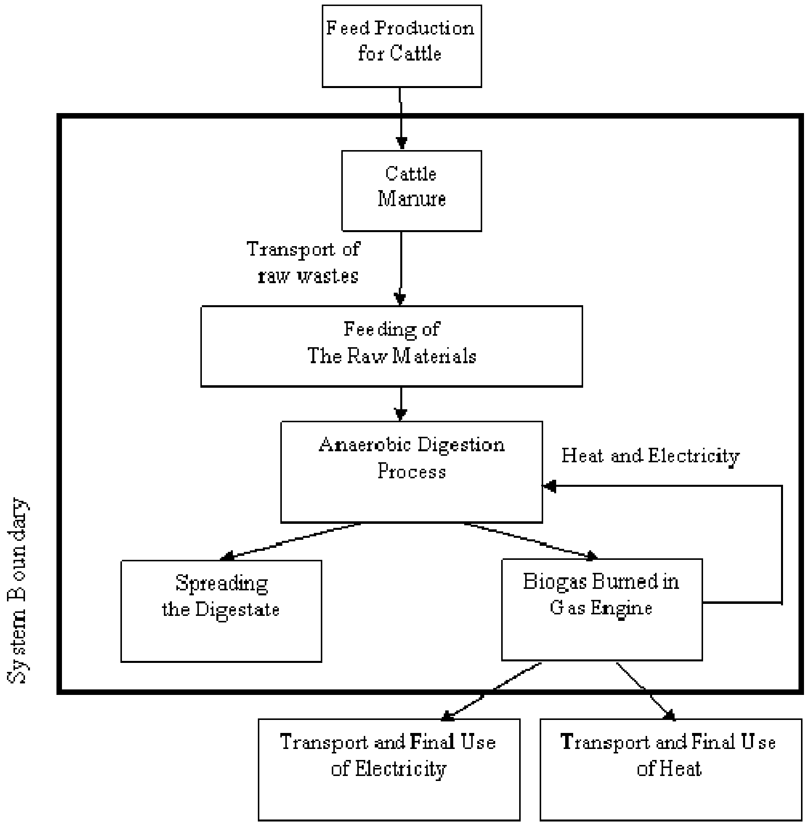


Figure 3.2. System boundary of the Scenario B.

The Scenario C is created in order to compare the environmental effects of energy production from coal power plant with that of the pilot plant. The system boundaries of Scenario C can be explained as follows:

- The system focuses on the electricity production from hard coal burning in a power plant, in addition to the heat production.
- The hard coal power plant is used for middle load with 4,000 hours operation at a full capacity per year. The plant is assumed to operate 1,500,000 hours during its lifetime.
- The electricity output is at busbar.

The Scenario D is created in order to compare the environmental effects of energy production from natural gas power plant with that of the pilot plant. The system boundaries of Scenario D can be explained as follows:

- The system includes not only the electricity production from natural gas burning in a power plant, but also includes the heat production.
- The system boundary covers the fuel input from high pressure network, infrastructure, emissions, and substances needed for operation of the natural gas power plant.

The Scenario E is created in order to compare the environmental effects of energy production from hydro power plant with that of the pilot plant. The system boundaries of the Scenario E cover the following processes:

- Electricity production from a conventional (dam) hydropower plant at the same amount of the excess electricity produced in Scenario A,
  The inventory of the hydropower plant includes;
- The most important materials used for the construction: cement, gravel, water, steel, explosives. Also includes transports and energy used for the construction. Included direct burdens to the environment are particle emissions caused by the construction and the disposal of the dam.

- Lifetime is assumed to be 150 years for the dam and 80 years for rest of the materials. The data refers to plant construction of a mix of types of dams built between 1945 and 1970, therefore they might not be representative for more modern construction, nor for an individual type.
- Net average efficiency, including pipe losses, is 78% (best efficiency can be 84%).
- Not only the construction, but also the average operation of the dam is included in the inventory. It includes the area occupied; a preliminary estimation of greenhouse gas emissions out of the water reservoir; lubricant oil; volume of the reservoir; mass of water passing through the turbines [GaBi4, 2003].

The Scenario F is created in order to compare the environmental effects of energy production from wind power plant with that of the pilot plant. The Scenario F covers the following processes:

- Electricity production from an onshore windpower plant with the same amount of the excess electricity produced in Scenario A.
- The inventory for the windpower plant includes materials used for moving parts: rotor, nacelle, electric parts, and their disposal. Also includes the processing, the energy requirements for assembling, the transports needed, and the connection to the grid. Lifetime is assumed to be 20 years.
- The inventory for the windpower plant also includes materials used for fixed parts: tower and base, and their disposal. Also includes the processing, the transports needed, and the area that is needed for installation and the energy requirements for the installation itself. Lifetime is assumed to be 40 years.
- The foundation (concrete and reinforcing steel) is assumed to be remaining in the ground after the demolition of the power plant.
- Not only the moving and fixed parts of the windpower plant, but also its operation with the necessary change of gear oil are included in the inventory. In addition, the capacity factor, concerning the wind conditions is considered. The capacity factor is assumed to be 10.5 %. Gear oil has to be changed every second year.

In addition to the electricity and heat production from the fossil fuel resources, hydropower and wind energy explained above, the system boundary of Scenario C, Scenario D, Scenario E and Scenario F also include the below processes:

- Conventional management of cattle manure (Pasture/range/paddock, Daily Spread, Solid Storage, Liquid / Slurry)
- Conventional management of poultry manure (without bedding waste management system),
- Landfilling of vegetable wastes, slaughterhouse wastes and grass. The system boundary covers the infrastructure materials for landfill construction (including access road), operation and aftercare. The landfill is considered as an anaerobic managed solid waste disposal site and its service lifetime is considered as 30 years. The landfill has a controlled placement of waste, and includes mechanical compacting. Besides landfill gas and leachate collection system, the recultivation and monitoring for 150 years after closure are also considered within the system boundaries.
- The production and spreading of the chemical fertiliser (Ammonium Nitrate) to the soil to be used for the winter wheat production. Since the system boundary of these scenarios cover also the production of mineral fertiliser, the inputs and outputs data of the ammonium nitrate production from ammonia and nitric acid are also considered. Transports of intermediate products to the fertiliser plant as well as the transport of fertiliser from the factory to the regional storehouse are also included. Production of waste treatment of catalysts, coating and packaging of the final fertiliser products are not included. The ammonium nitrate is assumed to be transported 10 km from the regional storehouse to the farm where winter wheat is produced. The inventory also takes into account the diesel fuel consumption and the amount of agricultural machinery and of the shed, which has to be attributed to the fertilising. Also taken into consideration is the amount of emissions to the air from combustion and the emission to the soil from tyre abrasion during the work process. The following activities where considered part of the work process: preliminary work at the farm, like attaching the adequate machine to the tractor; transfer to field (with an assumed distance of one km); field work (for a parcel of land of one ha surface);

transfer to farm and concluding work, like uncoupling the machine. The overlapping during the field work is considered.

- The processes considered out of the system boundaries of Scenario C, D, E and F are;

    - The infiltration of landfill leachate to groundwater,
    - The landfill leachate treatment prior to discharge to surface water bodies.

Landfill leachate is generated by the infiltration and percolation of rainfall, groundwater, runoff or flood water into and through the waste layers of a landfillsite. A combination of physical, chemical and microbial processes in the waste transfers pollutants from the waste material to the percolating water, creating a water-based solution that maybe harmful to a class of organisms, including human, ortoenvironmental receptors. It has been reported that small amounts of leachate could pollute large volume of groundwater, rendering them unusable for domestic and many other purposes. In fact, chemical pollutants contained in the leachate could be assimilated by any aquatic species, and may pass through the food chain and bioaccumulate over long-term exposure [Baderna et al., 2011].

Measures to prevent leachate infiltration to groundwater should be carefully planned to last long. Results show that even when leachate is collected and treated properly for the first 40 years, the impact on spoiled groundwater resources is significant if the leachate collection system loses its efficiency. However, the importance of spoiled groundwater resources depends on whether groundwater is used as a water resource in the region.

It is crucially important to ensure the highest collection efficiency of landfill leachate since a poor capture compromises the overall environmental performance. Once leachate is collected and treated, the potential impacts in the standard environmental categories and on spoiled groundwater resources significantly decrease.

Measures should be taken to prevent leachate infiltration to groundwater and it is essential to collect and treat the generated leachate. [Manfredi and Christensen, 2009].

Impact potentials for acidification and nutrient enrichment are related to leachate problem, and the main substances of importance here, is the leaching of phosphate and ammonia to surface water (marine or fresh).

Leachate controlling measures (bottom-liner and collection) lead to increased toxicity to the water ecosystem (from 0.007 PE to 0.012 PE per tonne waste). This is because of the fact that the leachate is treated at a wastewater plant, and the treated water is discharged into surface waters. There will though still be a minor amount of contaminants left in the treated water that will lead to an increased impact of eco-toxicity in water. The reason this impact is not as high in the not lined systems is that the leachate here will end in the groundwater resource and thereby will not be accredited to the surface water.

The unlined systems cause the largest impact, and the burdens are just shifted when controlling the leachate. It is to be noted that the main contributor to spoiled groundwater resources is ammonia, and the contribution and fate of this substance should be further studied to establish its importance [Damgaard et al., 2011].

The landfill in the Scenarios of this study is considered as a well-designed landfill with efficient leachate control; so the several risks that can occur because of the release of landfill leachate to groundwater are not considered in the system boundaries. In addition, the landfill leachate treatment prior to discharge to surface water bodies, is considered out of the system boundaries as well.

The Scenario G is created in order to compare the environmental effects of energy production from Integrated Gasification Combined Cycle (IGCC) with that of the pilot plant. The system boundaries of Scenario G can be explained as follows:

- The wastes are assumed to be transported for 15 km-distance to the pilot plant.
- Electricity production from the IGCC of the waste recipe with an amount equal to the excess energy produced in the Scenario A. The infrastructure process includes land use, buildings and facilities (including dismantling) of a typical biomass gasifier. Process includes the dryer, the comminution equipment, the gasifier and the gas treatment and conditioning facility. Lifetime is assumed to be 50 years. The ash

produced from the gasifier is sent to the sanitary landfill and the synthesis gas is utilised for electricity production. The life time for operation of the combined cycle unit is assumed 180,000 h which is equal to approximately 22.5 years.

- Since the output ash of the gasification has no fertilizer value, the system boundary of this scenario covers also the production of mineral fertiliser (Ammonium nitrate) as well as the transportation of fertiliser from the factory to the regional storehouse and its field application for the winter wheat production.
- The processes excluded from the system boundaries are;

    - The processes related to the production of the wastes in recipe,
    - The feed type and production of the feed for the animals,
    - The transport, grit connection and final use of the excess electricity and heat,

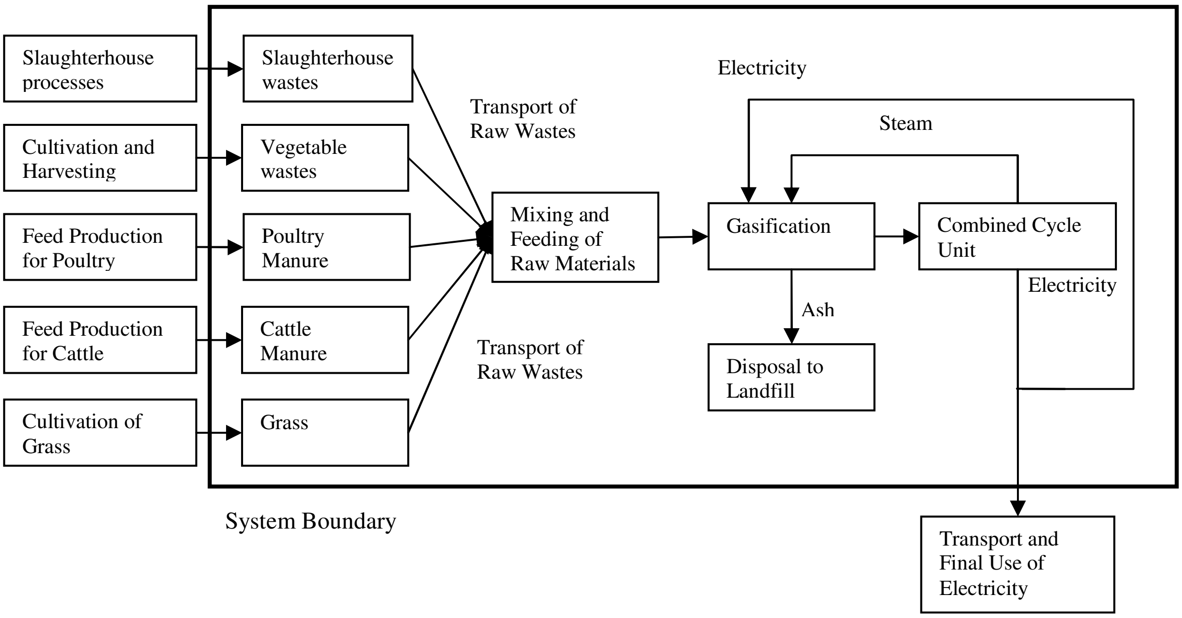


Figure 3.3. System boundary of the Scenario G.

All the scenarios considered in this LCA study can be summarized as follows:

Table 3.3. Summary of the scenarios in the LCA study.

	A	B	C	D	E	F	G
Raw Materials	Recipe	Cattle Manure	-	-	-	-	Recipe
Energy Source	Biogas	Biogas	Hard Coal	Natural Gas	Water	Wind	Syngas
Electricity Production	Gas Engine	Gas Engine	Power Plant	Power Plant	Power Plant	Power Plant	Combined Cycle
Cattle Manure Management	AD	AD	Conventional	Conventional	Conventional	Conventional	Gasification
Poultry Manure Management	AD	N.A.	Conventional	Conventional	Conventional	Conventional	Gasification
Vegetable Waste Management	AD	N.A.	Landfilling	Landfilling	Landfilling	Landfilling	Gasification
Slaughterhouse Waste Management	AD	N.A.	Landfilling	Landfilling	Landfilling	Landfilling	Gasification
Grass&Silage Management	AD	N.A.	Landfilling	Landfilling	Landfilling	Landfilling	Gasification
Fertiliser Type	Digestate (Organic)	Digestate (Organic)	Chemical (AN)	Chemical (AN)	Chemical (AN)	Chemical (AN)	Chemical (AN)

3.3. Inventory Analysis

In the inventory part of the study, data on inputs and outputs from the processes included in the study are collected. The results are summarised in an inventory of resource uses, emissions to air, water and soil (solid waste) induced and avoided per unit of transportation and energy service aggregated over the entire system.

In this study, the inventory data regarding the Pilot Plant in Kocaeli was gathered from the laboratory scale analysis results provided by the Energy Institute Team of TUBITAK MRC. The design and operational conditions of the pilot plant were determined by the Energy Institute Team of TUBITAK MRC according to the literature and the results of those laboratory scale studies.

3.3.1. Raw Material Quantity and Characteristics

The feed material used in this study is composed of five different wastes which are;

- Cattle manure
- Poultry manure
- Vegetable wastes
- Slaughterhouse wastes
- Grass and grass silage

While determining the feed recipe, the maximum utilization of poultry manure is considered since it is one of the biggest problem of Kocaeli Greater Municipality.

The daily and yearly amount of wastes to be utilised in the pilot plant are as given in Table 3.1. The characteristics of those wastes gathered from the interim report named “IP No: 5 (Laboratory Scale Biogas System Studies)” included in the TUBITAK project with reference no. of 106G112.are given in Table 3.4 and Table 3.5.

Table 3.4. Laboratory analysis results of the wastes comprised in the recipe[1].

Material	**Total Solids (TS)** (%)	**Volatile Solids (VS)** (%)	**Carbon** (%)	**Hydrogen** (%)	**Nitrogen** (%)	**NH_4** (%)
Grass	26.01	81.0	2.37	14.63	0.102	0.0005
Vegetable Wastes	8.97	85.0	5.23	11.71	0.155	0.0157
Slaughterhouse Wastes	16.81	85.0	8.17	9.94	0.462	0.0303
Poultry Manure	71.92	73.1	33.77	7.30	2.871	0.4437
Cattle Manue	16.44	75.0	9.09	9.74	0.469	0.0594

[1] The results of laboratory analysis are consistent with the literature information from [Baban et al; 2001; Hoffmann, 2010; ISAT and GTZ, 1999; Ozturk, 2005; Steffen et al., 1998; Werner et al., 1989].

The concentration of the trace elements is acceptable in terms of an efficient AD process. They are under the maximum allowable trace element concentration for the AD given in the literature [ISAT and GTZ, 1999; Ozturk, 2005; Werner et al., 1989].

Table 3.5. Trace element composition of the wastes comprised in the recipe.

	Grass	**Vegetable Wastes**	**Slaughterhouse Wastes**	**Poultry Manure**	**Cattle Manure**
Ca [ppm]	742.11	228.79	3,431.73	15,339.97	2,817,67
K [ppm]	888.13	3,609.54	2,760.21	23,091.60	2,719.29
Na [ppm]	103.73	128.08	827.15	3,863.81	861.13
Cr [ppm]	0.08	0.27	0.45	1.44	0.19
Cu [ppm]	0.25		11.32	33.78	5.22
Mn [ppm]	17.57	94.21		406.76	224.21
Ni [ppm]	2.42	15.77	42.31	322.98	35.96
Pb [ppm]	0.40	0.45	1.21	5.15	0.81
Zn [ppm]			0.20		
Al [ppm]	2.48	9.51	38.20	314.89	31.24

3.3.2. Main Scenario (Scenario A) – AD of the Waste Recipe

The pilot plant constructed for the AD of the waste recipe consists of four main units which are;

- Pretreament Units
    - Primary Storage and Mixing
    - Grinding and Mixing
- Anaerobic Digesters
- Separation Unit and Final Storage
- Cogeneration Unit.

The flow diagram of the pilot plant for the main scenario is given in Figure G.1. The reference quantities are given for “one(1)-year period of operation of the digester utilizing an amount of 10,680 ton/year recipe”.

The average distance between the waste production sites and the pilot plant is considered as 15 km. Energy consumption and related emissions for the transportation of wastes by a "Truck 7.5 t - 12 t total cap. / five t payload / Euro 3 PE" are gathered from the GaBi4 database.

The wastes will first be transported to the separate primary storage pits from where they will be fed to the common pretreatment units.

3.3.2.1. Pretreatment Units. Pre-treatment of feedstocks can increase biogas production and volatile solids reduction and increased solubilisation. The use of pre-treatment is particularly useful in the digestion of biomass feedstocks, as these tend to be high in cellulose or lignin. Pre-treatment can break down these recalcitrant polymers physically, thermally, or chemically [Ward et al., 2008].

Primary Storage and Mixing. Slaughterhouse wastes, cattle manure and poultry manure will be collected in a concrete primary storage unit of which volume is 100 m^3. There is a mixer inside the primary storage basin. The mixed animal wastes will then be sent to the anaerobic digesters via a pump. The service lifetime of the primary storage and mixing unit is considered as 30 years. The inventory of the primary storage and mixing unit takes into account the use of construction materials and building machines for construction, repair and replacement including waste disposal and the transportation of the materials to the building site [GaBi4, 2003]. The Table G.1 provides input and output data for the primary storage and mixing unit.

Grinding and Mixing. Grass and vegetable wastes are collected in a grinding unit where they are shredded and mixed. In this unit, there is a hydraulic moving part by which the grass and vegetable wastes are moved forward towards the screw shredders. The wastes are torn to pieces by vertical screws and then transported to a pump via a horizontal screw. The grinded grass and vegetable wastes are then subjected to AD process.

3.3.2.2. Anaerobic Digesters. Following the pretreatment, the agricultural and animal wastes are subjected to AD process.

During the laboratory scale studies, the organic material removal rate and biogas production rate of the laboratory scale digesters were determined. The detention time at which 70% of the biogas production observed gives the most efficient detention time of the anaerobic digesters [Kishore et al., 1987]. The laboratory studies made by the Energy Institute Team of TUBITAK MRC show that the proper detention time for the AD of the waste recipe in a completely mixed mesophilic digester is 47 days.

Considering the laboratory scale studies, two concrete anaerobic digesters each with 2089 m^3 net volume and 2400 m^3 gross volume have been constructed in the Kocaeli pilot plant. The digesters can be operated either in series or paralel. Each digester is equipped with two submersible mixers in order to provide homogeneous mixture inside the digesters. The digesters will be operated in mesophilic range (35-40°C) which will be provided by the heat exchangers and the heat will be retained by the isolation material. The digesters are also equipped with one double membrane gas holding units each with 700 m^3 effective volume.

The dimensions of the anaerobic digesters are as follows:
Diameter of each digester: 19,5 m
Cylindirical height of each digester: 8 m
Wall thickness of each digester: 0,3 m

According to the laboratory analysis made by the Energy Institute Team of TUBITAK MRC, the average biogas production of the waste recipe was 452 lt biogas/kg VSS at an organic loading rate of approximately two kg VSS/m^3 reactor.day. When the organic loading rate is evaluated, it is seen that the organic loading rate of two kg VS/m^3 reactor.day is a safe value when compared with the acceptable operational conditions at mesophilic range (2.4- 5.6 kg VS/m^3/d) [Engler et al., 1999; Ozturk, 2005].

The laboratory scale studies proved a volatile solids removal of approximately 50% which is consistent with the literature information [Burke and Dennis, 2001; Ozturk, 2005; Tjalfe, 2003].

The 50% destruction of volatile solids will result in 3832 m^3/day of total biogas production for 10,680 ton/year waste recipe digested at a 47-day detention time and at 35°C operational temperature in Kocaeli pilot plant.

Another proof of the effective digestion during the laboratory scale studies was the amount of methane inside the produced biogas. The average methane concentration of the biogas was 55% which is in the acceptable range for an effective digestion process [Ozturk, 2005].

The amount of H_2S inside the biogas was measured as to be not higher than 50 ppm which means that the waste recipe will not cause a problem in the cogeneration unit consisting of a gas engine [Ozturk, 2005].

The pH value inside the reactor was between 7.02-7.29 which proved that the AD proceeded effectively at the appropriate detention time and organic loading rate [ISAT and GTZ, 1999; Ozturk, 2005; Tjalfe, 2003]. These findings show that the selected detention time and organic loading rates are safe for the pilot anaerobic digesters.

The majority of the existing biogas plants treating organic wastes and animal manure are operating at dry matter concentrations of three to twelve per cent. The reason is that this material can be directly pumped without any special equipment and it is easier to ensure proper mixing in the reactor [Ozturk, 2005; Tjalfe, 2003].

In order to adjust the dry matter concentration inside the digester as nine per cent, water will added to the anaerobic digesters in Kocaeli pilot plant. The daily amount of fresh water added to the anaerobic digesters will be 9.8 m^3/day in addition to the recycled liquid digestate of 51.5 m^3/day with three-six per cent dry matter concentration in Kocaeli pilot plant.

The process flow diagram of the anaerobic digesters is given in Figure G.2. The process includes the production, transport and disposal of the main materials for an agricultural biogas plant. The lifetime of the industrial plants are generally between 25 and

49 years [Bekem et al., 2009] and so the service lifetime of the digesters is considered as 30 years.

The input and output data of the digesters are given in Table G.3.

The heat requirement of the digester is calculated by the sum of the heat requirement of the waste recipe and heat loss of the digester itself. Specific heat capacity of the recipe is determined as c: 1.45 kj/kg= 0.347 kcal/kg. Assuming that the minimum temperature of the recipe at the inlet of the anaerobic digester will be 15°C and that the maximum operating temperature will be 37°C inside the anaerobic digester, the temperature change is calculated as 37 – 15 = 22°C.

The mass of the recipe daily loaded to the anaerobic digester is 39,060 kg/day including 29,260 t/day mixed waste and 9,800 kg/day water. So, the heat requirement of the digester is calculated as;

Heat requirement of the waste recipe= m x c x ΔT= (39,060 kg/day recipe x 0.347 kcal/kg) x (37-15°C)= 298,184 kcal/day = 347 kWh/day

As shown in APPENDIX F, the heat loss of two digesters will be 2,221 kWh/day resulting in a total heating requirement of 2,568 kWh/day. The heating requirement of the digesters will be met by the hot water received from the cooling circuit of the gas engine inside the cogeneration unit. Following the digestion process, the digested recipe is pumped to the separation unit.

3.3.2.3. Separation and Final Storage Unit. In the separation unit, the digested recipe is separated into two forms, solid and liquid phases. The solid phase will have a dry solids (DS) content of 25-30%, whereas the liquid phase will have a DS content of three to six per cent. The solid phase will be stored in an open concrete based area and the liquid phase will be collected in a concrete basin of which volume is 1000 m^3. Both the solid and liquid phases can be used as organic fertiliser.

In order to adjust the dry solids content and nitrogen content of the anaerobic digesters, approximately 51.5 m^3/day liquid product is returned to the digesters via the submersible pump inside the final storage basin.

When the digestate is subjected to separation process, most of the consituents of anaerobic digester are collected in the liquid phase. Separation of coarse solids after AD reduces the mass of nitrogen and phosphorus in the remaining liquid fraction by about 18 and 38 per cent, respectively.

.

Table 3.6. Distributions of the constituents of anaerobic digester effluent following separation, % by weight [Martin, 2005].

Parameter	Liquid fraction	Solid fraction
Total solids	52.5	47.5
Total volatile solids	51.0	49.0
Fixed solids	62.3	37.7
Total Kjeldahl nitrogen	82.3	17.7
Organic nitrogen	73.4	26.6
Ammonia nitrogen	89.1	10.9
Total phosphorus	62.2	37.8

As indicated in the Table 3.6, the concentrations of TS and TVS in the separated liquid and solid fractions are similar. Conversely, the liquid fraction contains more than 75 per cent of the TKN and NH_4-N and almost two-thirds of the phosphorus and fixed solids originally present in the digester effluent [Martin, 2005].

The input and output data of the Separation and Final Storage unit are given in Table G.4.

According the distribution of the constituents of the digester effluent, the available amount of nitrogen in both the liquid and solid phase are expected to be 188 kg/day for the AD of the waste recipe.

3.3.2.4. Cogeneration Unit. The cogeneration unit consisting of a gas engine is used to produce electricity and heat from the biogas produced in the anaerobic digesters. The volumetric content of the biogas is given below:

Methane content : 50-65%
CO_2 content: 35-45 %
H_2S content: $\leq$ 50 ppm

In addition to these gases, little amount of other gases and moisture is also included in the biogas. The H_2S content of the biogas may cause corrosion problems inside the gas engine and pipelines. In order to protect the mechanical equipment, the H_2S and moisture should be avoided before being sent to the gas engine unit.

Even the H_2S concentration of the biogas is low, a biological sulphur removal system is used in order to remove H_2S problem in the pilot plant. A special wooden unit is installed at the top of the anaerobic digesters for that purpose. That wooden part of the digesters are fed with air (O_2) and the biogas of which H_2S content is removed biologically is sent to the gas engine unit to produce electricity and heat.

The electricity and heat requirement of the anaerobic digesters are provided from the cogeneration unit. The remaning electricity will be fed to the electricity grid and the remaining heat will be used for building heating. The technical data regarding the cogeneration unit which will be installed in the Pilot Plant is as follows:

Table 3.7. Technical data of the cogeneration unit [GE Power, 2010].

	Data at Full Load (100%)	
Energy Input	851	kW
Electrical Output	330	kWe
Total Recoverable Thermal Output	395	kWe
Specific Fuel Consumption of Engine	2,49	kWh/kWh
Lube Oil Consumption	0,10	kg/h
Specific Lube Oil Consumption	0,30	g/kWh
Dry exhaust gas flowrate	1294	Nm^3/hr

The flow chart of the cogeneration unit is given in Figure G.3.

As it can be seen from Figure G.1, the net annual electrical output of the cogeneration unit is 8599 GJ whereas the net annual heat output is 9079 GJ.

The minimum monthly electricity consumption of a house with four (4)-family members is approximately 230 kWh [Güven and Terzioğlu, 2010]. Since the yearly electricity production is 8599 GJ/year = 2,388,682 kWh/year, it means that the monthly electricity available to be used at houses is 199,057 kWh/month. By considering the minimum monthly electricity consumption as 230 kWh/month, it is seen that the electricity need of 865 houses can be met by utilising the waste recipe in AD and biogas recovery system.

The pilot plant is located in İzaydaş Area, in Alikahya village of Kocaeli and the population of Alikahya village is 34,500 people [Izmit Ziraat Odası Başkanlığı, 2011]. When the population is considered to consist of 4-member families, the quantity of houses of which electricity need will be met by the pilot plant is calculated to be 10% of the neigbouring village, Alikahya.

Considering that the heat requirement of a 90-m^2 house is 40 kcal/hr/m^3 [Kaya, 2011], it is determined that 25 houses can meet their heating requirement from the secondary service of the pilot plant.

The gas engine emissions in Scenario A are based on the emission data derived from the GaBi4 database.

3.3.2.5. Digestate Application to Agriculture. The digested matter application in agriculture is also considered in the LCA study. The emissions to soil because of the use of hydraulic loader and spreader and the emissions from the digested matter when used as a fertiliser in agriculture are taken into account.

The output of the liquid separated fraction and the solids digestate replaces mineral fertilisers. Not only the mineral fertilisers, but also the digested material gives emissions to the surrounding environment when applied on the field.

The emissions to soil because of the use of hydraulic loader and spreader are based on the GaBi4 database and summarised in Table G.6 and Table G.7.

The emissions produced because of the field application of the digestate as fertiliser for winter wheat production are calculated as follows:

Ammonia Volatilization because of Field Application of the Digestate. Ammonia losses during and after application of organic fertiliser ranges from one to 100% of the applied NH_4-N. This clearly indicates the need to estimate the NH_3 emissions both site specific and dependent on agricultural practices. The ammonia losses are determined by considering the following parameters:

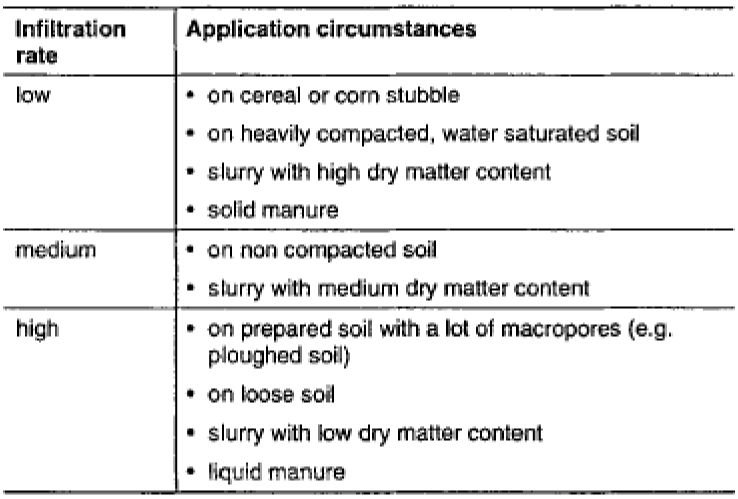
- Average air temperature
- Infiltration rate
- Time between application and incorporation or rainfall
- Precipitation or incorporation after application [Brentrup et al., 2000].

Environmental factors impact ammonia losses because weather elements provide the energy and the driving force for the soil-air gas exchange. Ammonia volatilization is increased by higher air temperature and increased wind speeds [Meisinger and Jokela, 2000]. While the temperature class of Kocaeli is chosen as 10-15 °C according to the meteorological statistics, the wind speed change is neglected [DMI, 2010].

The infiltration rate describes the capability of the soil to take up the NH_3/NH_4^+ [Brentrup et al., 2000]. The infiltration of NH_3/NH_4^+ into the soil reduces the volatilization rate [Brentrup et al., 2000; Meisinger and Jokela, 2000]. Rainfall reduces the volatilization of NH_3 considerably because of the increased solution of NH_3/NH_4^+ and an increased infiltration into the soil [Huijsmans, 2003] The extent of this reduction depends on the amount of rainfall [Brentrup et al., 2000]. Cultivating before application can also reduce ammonia emissions because of increased infiltration into the soil [Meisinger and Jokela, 2000].

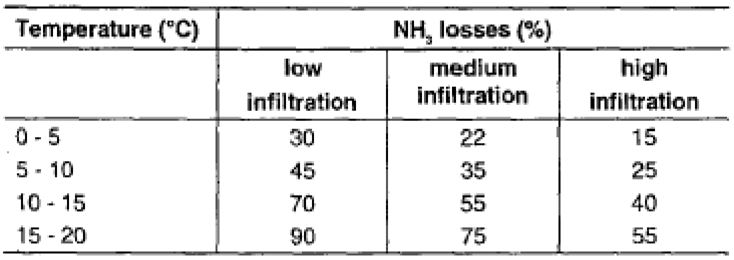
In the estimation method, the infiltration rate is evaluated according to Table 3.8 and the maximum potential ammonia losses are calculated as a percentage of the total NH_4-N applied according to Table 3.9.

Table 3.8. Evaluation of the infiltration rate [Brentrup et al., 2000].



Infiltration rate	Application circumstances
low	• on cereal or corn stubble • on heavily compacted, water saturated soil • slurry with high dry matter content • solid manure
medium	• on non compacted soil • slurry with medium dry matter content
high	• on prepared soil with a lot of macropores (e.g. ploughed soil) • on loose soil • slurry with low dry matter content • liquid manure

Table 3.9. Maximum potential ammonia loss in % of the applied NH_4-N dependent on temperature and infiltration rate into the soil [Brentrup et al., 2000].



Temperature (°C)	NH_3 losses (%)		
	low infiltration	medium infiltration	high infiltration
0 - 5	30	22	15
5 - 10	45	35	25
10 - 15	70	55	40
15 - 20	90	75	55

According to the tables in Table 3.8 and Table 3.9, the maximum potential ammonia loss is chosen as 70% for the solid digestate and 40% for the liquid digestate.

The amount of volatilized ammonia depends of course on the time the NH_3 is present on the soil surface. Thus, the time between the application and the disappearance of the NH_3/NH_4^+ deeper into the soil profile has to be considered in the estimation. The longer the time period between the application of an organic fertiliser and its incorporation or rainfall, the higher is the ammonia loss. This is considered by multiplying the maximum potential NH_3 loss by a time factor given in Table 3.10 [Brentrup et al., 2000], which are derived from field experiments and considered as 0.15 for the calculations in this project.

Table 3.10. Time factors for different temperature classes [Brentrup et al., 2000].

Temperature (°C)	Time between application and precipitation / incorporation											
	1h	2h	4h	8h	12h	1d	2d	3d	4d	6d	8d	12d
0 - 5	0.04	0.07	0.10	0.15	0.19	0.25	0.35	0.45	0.54	0.60	0.80	1.00
5 - 10	0.06	0.10	0.14	0.20	0.25	0.35	0.50	0.65	0.73	0.85	1.00	
10 - 15	0.15	0.25	0.35	0.50	0.60	0.73	0.83	0.92	1.00			
15 - 20	0.20	0.30	0.45	0.65	0.75	0.85	0.95	1.00				

Further NH_3 loss depends on the amount of rainfall. This is taken into account by introducing a rain factor (Table 3.11), which is again based on field experiments. The remaining potential ammonia loss, i.e. the maximum potential loss minus the loss between application of organic fertilizers and rainfall, is multiplied by this rain factor. The resulting figure gives the NH_3 loss after rainfall [Brentrup et al., 2000].

The rain factor for Kocaeli is determined according to precipitation of 5-10 mm and temperature of 10-15°C and found as 0.20 from Table 3.11.

Table 3.11. Rain factors for different temperature classes (precipitation after application and before total potential volatilization) [Brentrup et al., 2000].

Temperature (°C)	Precipitation			
	0 - 2mm	2 - 5mm	5 - 10mm	> 10mm
0 - 5	0.30	0.15	0.05	0
5 - 10	0.40	0.20	0.10	0
10 - 15	0.60	0.40	0.20	0
15 - 20	0.80	0.50	0.30	0

In the light of the above mentioned factors and according to the ammonia content of solid and liquid digestate, the ammonia volatilization because of organic fertilizer application is calculated as follows:

Table 3.12. Ammonia volatilization because of digestate application in agriculture.

	SOLID	**LIQUID**	**TOTAL**	
Amount of Digested Manure	14,210.79	20,404.53	34,615.33	kg/day
Ammonia content of organic fertiliser *	2.79	22.84	25.64	kg NH_4-N/day
NH_3 losses	70%	40%	55%	
Max potential ammonia loss	1.96	9.14	11.08	kg NH_3-N/day
Time between application and precipitation/incorporation	0.15	0.15	0.15	
Actual ammonia loss	0.29	1.37	1.66	kg NH_3-N/day
Remaining potential ammonia loss	1.66	7.77	9.42	kg NH_3-N/day
Rain factor	0.2	0.2	0.2	
Ammonia loss after incorporation	0.33	1.55	1.88	kg NH_3-N/day
TOTAL Ammonia loss	0.63	2.92	3.55	kg NH_3-N/day

* calculated according to the total NH_4-N concentration (0,074%) of the digestate. This is consistent with the literature information as there is significant decrease in the concentration of ON and concurrent increase in NH_4-N concentration reflecting the mineralization of ON during digestion. The distribution of ammonia between solid and liquid phases are taken from Table 3.6 [Martin, 2005].

According the distribution of the constituents of the digester effluent in Scenario A, the available amount of nitrogen in both the liquid and solid phase is expected to be 188 kg/day for the AD of the waste recipe.

According to the researches made by the Trakya Agricultural Research Institute, the amount of pure nitrogen needed for wheat production is 12-14 kg/da [Suzer, 2010]. By considering the amount of nitrogen applied for wheat production is 125.6 kg/ha, the daily digestate can be used for fertilising approximately 15 da= 1.5 ha field.

According to the above table, total ammonia loss because of both solid and liquid digestate is 3.55 kg NH_3-N/day, which is equal to 2.36 kg NH_3-N/ha.

Nitrous Oxide Emissions because of Field Application of the Digestate. Nearly 80% of the N_20 emissions because of agriculture are related to the use of mineral and organic fertilizers. The emission factor for N_2O emissions from organic fertilizers are derived from the following formula:

$$N_2O \text{ emission [kg } N_2O\text{-N/ha]} = 0.0125 * \text{N application [kg N/ha]} \qquad (3.1)$$

The applied N rate should be corrected for NH_3 emissions, as these predominantly occur earlier than the N_2O emissions [Brentrup et al., 2000].

So, the nitrous oxide emissions are calculated as (125.6 – 2.36) x 0.0125 = 1.54 kg N_2O-N/ha. According to the total available nitrogen content of the daily digestate applied to1.5 ha area, the total nitrous oxide emissions will be 2.31 N_2O-N/day.

<u>N_2-N Emissions because of Field Application of the Digestate</u>. N_2 is not of environmental relevance, but N_2 rates emitted to the air should be included in the nitrogen balance, which is a prerequisite for the calculation of the nitrate leaching rate. For practical reasons, the N_2-N emissions related to fertilizer application (corrected for NH_3-N volatilization) may be regarded as 9%, taking into account the IPCC emission factor of 1.25% for N_2O-N [Brentrup et al., 2000].

So, the N_2-N emissions are calculated as (125.6 – 2.36) x 0.09 = 11.09 kg N_2-N/ha. According to the total available nitrogen content of the daily digestate applied to 1.5 ha area, the total N_2-N emissions will be 16.63 N_2-N/day.

So, the total emissions (NH_3-N, N_2O-N, N_2-N) are 2.36+ 1.54 + 11.09 = 15.00 kg N/ha resulting in 22.50 kg N/day when applied to1.5 ha area.

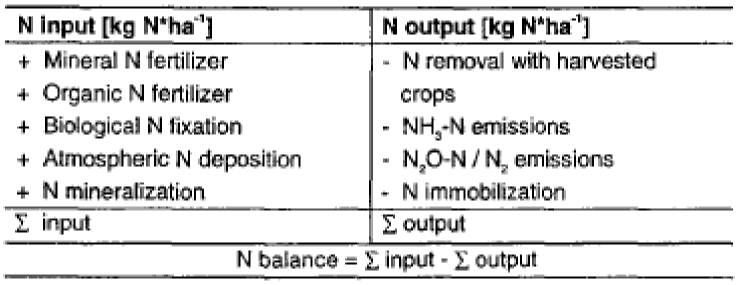
<u>Nitrate Leaching because of Field Application of the Digestate</u>. For LCA purposes it is important to be able to predict the potential NO_3 leaching rate related to an agricultural product or production process. The level of nitrate leaching depends strongly on different parameters. The most important parameters determining the nitrate leaching rate are:

- Agriculture-related: nitrogen balance [kg N/ha/a]
- Soil-related: field capacity in the effective rooting zone (FC_{Rze}) [mm]

- Climate-related: drainage water rate (W_{drain}) [mm/a]

The nitrogen balance can be used as a measure for the amount of nitrate-N in the soil susceptible to leaching after the vegetation period in autumn. The nitrogen balance can be calculated as described in the following table [Brentrup et al., 2000].

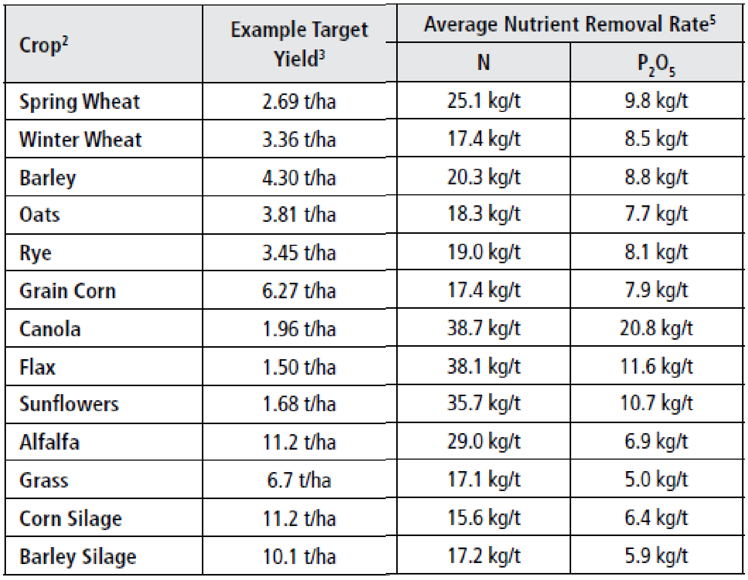
Table 3.13. Calculation of the nitrogen balance in autumn [Brentrup et al., 2000].



N input [kg N*ha^{-1}]	N output [kg N*ha^{-1}]
+ Mineral N fertilizer + Organic N fertilizer + Biological N fixation + Atmospheric N deposition + N mineralization	- N removal with harvested crops - NH_3-N emissions - N_2O-N / N_2 emissions - N immobilization
Σ input	Σ output
N balance = Σ input - Σ output	

The amount of winter wheat production for 2008-2009 years in Turkey is known as 2,198 ton/ha [TUIK, 2010]. And, the average nutrient removal rate for the winter wheat is known as 17.4 kg/t as given in the following table. So, the N removal with harvested crops are calculated as 2,198 x 17.4 = 38.25 kg N/ha.

Table 3.14. Crop removal rates for N and P_2O_5 [Canadian Fertiliser Institute, 2001].



Crop[2]	Example Target Yield[3]	Average Nutrient Removal Rate[5]	
		N	P_2O_5
Spring Wheat	2.69 t/ha	25.1 kg/t	9.8 kg/t
Winter Wheat	3.36 t/ha	17.4 kg/t	8.5 kg/t
Barley	4.30 t/ha	20.3 kg/t	8.8 kg/t
Oats	3.81 t/ha	18.3 kg/t	7.7 kg/t
Rye	3.45 t/ha	19.0 kg/t	8.1 kg/t
Grain Corn	6.27 t/ha	17.4 kg/t	7.9 kg/t
Canola	1.96 t/ha	38.7 kg/t	20.8 kg/t
Flax	1.50 t/ha	38.1 kg/t	11.6 kg/t
Sunflowers	1.68 t/ha	35.7 kg/t	10.7 kg/t
Alfalfa	11.2 t/ha	29.0 kg/t	6.9 kg/t
Grass	6.7 t/ha	17.1 kg/t	5.0 kg/t
Corn Silage	11.2 t/ha	15.6 kg/t	6.4 kg/t
Barley Silage	10.1 t/ha	17.2 kg/t	5.9 kg/t

The deposited nitrogen may enter the system as it can be taken up by the plants, similar to mineral fertilizers. From Figure 3.4, which provides information about the N deposition rate in Europe, it can be considered that the atmospheric N deposition in Turkey is 10 kg N/ha.

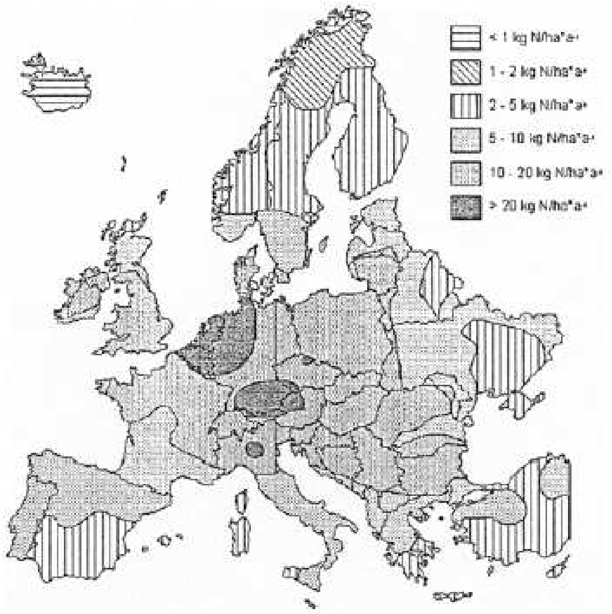


Figure 3.4. Total nitrogen deposition in Europe in 1993 [Brentrup et al., 2000].

Based on the assumption that an agricultural production system is relatively constant long term, i.e. for more than one crop rotation, and that the N fertilizer input is adjusted to the requirements of the plants, it can be assumed that the nitrogen mineralization and immobilization rates more or less equal each other. Based on the above findings, the nitrogen balance is calculated as 82.35 kg N/ha.

That part of the nitrate-N present in the soil in autumn that is actually lost via leaching depends on soil and climate parameters.

Table 3.15. Nitrogen Balance.

Nitrate leaching	
N inputs	
Mineral fertiliser	125.59 kg N/ha
Biological N fixation	0.00 kg N/ha
Atmospheric N deposition	10.00 kg N/ha
N net mineralization	0.00 kg N/ha
N outputs	
N removal with harvested crop	38.25 kg N/ha
Emissions	15.00 kg N/ha
Nitrogen balance	82.35 kg N/ha

The field capacity in the effective rooting zone (FC_{Rze}) describes the capacity of the soil to adsorb water within that part of the soil in which the roots are able to take up water. The FC_{Rze} can be calculated by multiplying the available field capacity (F_{Ca}) by the effective rooting zone (R_{Ze}).

$$FC_{Rz\,e}\ [mm] = F_{Ca}\ [mm/dm] * R_{Ze}\ [dm] \tag{3.2}$$

The available field capacity as well as the effective rooting zone strongly depends on the soil texture.

The classes of available field capacity are given in Table 3.16 and the classes of effective rooting zone are given in Table 3.17 [Brentrup et al., 2000].

According to the information in the below tables and with the assumption that the soil texture is loamy silt (lU); The FC_{Rze} is calculated as;

FCRz e [mm] = FCa [mm/dm] * RZe [dm] = 24 [mm/dm] * 10 [dm] = 240 mm

Table 3.16. Assignment of soil textures to six classes of available field capacity [Brentrup et al., 2000].

Class	Soil texture*	FCa (mm*dm⁻¹)	
(evaluation)		range	average
1 (very low)	S	< 10	8
2 (low)	lT	10 – 14	12
3 (medium)	lS, tS, sL, tL, uT, T	14 – 18	16
4 (high)	uS, sU, uL	18 – 22	20
5 (very high)	lU, tU, U	> 22	24
6 (swamp)	Hh, Hn		60

(a) S = sand, s = sandy, U = silt, u = silty, T = clay, t = clayey, L = loam, l = loamy, H = swamp, h = swampy, n = half-swampy

Table 3.17. Assignment of soil textures to five classes of effective rooting zone [Brentrup et al., 2000].

Class	Soil texture*	RZe (dm)	
(evaluation)		range	average
1 (very low)	Hn	< 3	2
2 (low)	S, Hn	3 – 5	4
3 (medium)	lS, uS	5 – 7	6
4 (high)	tS, lS	7 – 9	8
5 (very high)	U, sU, lU, tU, sL, uL, tL, lT, T	> 9	10

(a) S = sand, s = sandy, U = silt, u = silty, T = clay, t = clayey, L = loam, l = loamy, H = swamp, h = swampy, n = half-swampy

The rate of drainage water (W_{drain}) is mainly determined by the precipitation rate (W_{precip}), its distribution through the year and the evapotranspiration rate according to the following equation.

$$W_{drain}[mm] = 0.86*W_{precip\_year}[mm] - 11.6*(W_{precip\_summer}/ W_{precip\_winter})[mm] - 241.4 \quad (3.3)$$

According to the information gathered from the Turkish State Meteorological Service, the average precipitation per year is 817.8 mm, the average precipitation for summer is 238 mm, and the average precipitation for winter is 579.8 mm [DMI, 2010].

So, the rate of drainage water (W_{drain}) is = 0.86 * 817.8 - 11.6 * (238/ 579.8) - 241.4 = 457 mm/year

The nitrate leaching rate is mainly dependent on the quantity of water that percolates through the soil profile into the groundwater. A measure for this quantity is the exchange frequency of the drainage water per year. This can be calculated using FC_{Rze} and W_{drain} as input parameters.

$$\text{exchange frequency / a} = W_{drain}\ [\text{mm/a}]\ /\ FC_{Rze}\ [\text{mm}] \tag{3.4}$$

$$\text{which results is Exchange frequency of } 457 / 240 = 1.90\ \text{year}^{-1} \tag{3.5}$$

Because of the fact that almost all NO_3 in the soil is dissolved in water, the whole amount of NO_3-N present in the soil at the beginning of the leaching period in autumn is supposed to be available for leaching. The exchange frequency of the drainage water directly reflects the share of nitrate lost via leaching. If the exchange frequency per year is equal or higher than 1, the whole amount of nitrate is supposed to be leached. Therefore, the maximum value for the exchange frequency per year used in the below equation is 1.

$$\text{leached } NO_3\text{-N [kg N/ha/a]} = NO_3\text{-N}_{in\_soil\_in\_autumn}\text{[kg N/ha]} * \text{exchange freq.}[a^{-1}] \tag{3.6}$$

So, the leached NO_3-N is calculated as 82.35 x 1 = 82.35 kg NO_3-N/ha/year.

According to the total available nitrogen content of the daily digestate applied to 1.5 ha area, the total leached NO_3-N will be 123.5 NO_3-N/year. According to the above calculations, the daily inputs and outputs data of the field application of the solid and liquid digestate for winter wheat production is given in Table G.8.

3.3.3. Scenario B – AD of Cattle Manure

The main difference of the Scenario B from the Scenario A, is the usage of only cattle manure instead of the same amount of waste recipe in the Pilot Plant.

According to the laboratory analysis made by the Energy Institute Team of TUBITAK MRC, the average biogas production of the waste recipe was 350 lt biogas/kg

VSS which is in the range of 200-500 lt/kg VS as given in the literature [Ozturk and Okumus, 2008; Engler et al., 1999].

The laboratory scale studies proved a volatile solids removal of approximately 40% which is consistent with the literature information [Burke and Dennis, 2001; Ozturk, 2005].

The 40% destruction of volatile solids will result in 1,572 m^3/day of total biogas production for 10,680 ton/year cattle manure digested at a 47-day detention time and at 35°C operational temperature in Kocaeli pilot plant.

According the distribution of the consituents of the digester effluent, the available amount of nitrogen in both the liquid and solid phase is expected to be 137 kg/day for the AD of the cattle manure.

As it can be seen from Figure G.4, the net annual electrical output of the cogeneration unit is 2,616 GJ whereas the net annual heat output is 1,734 GJ for Scenario B.

By considering that the minimum monthly electricity consumption of a house as 230 kWh/month, it is seen that the electricity need of 263 houses can be met by utilising the cattle manure in AD and biogas recovery system.

Considering that the heat requirement of a 90-m^2 house is 40 kcal/hr/m^3, it is determined that five houses can meet their heating requirement from the secondary service of the pilot plant if only cattle manure is utilized.

3.3.4. Scenario C (Hard Coal PP) and Scenario D (Natural Gas PP)

The Scenario C and Scenario D are created in order to compare the environmental effects of conventional energy production systems from fossil fuel resources, organic waste disposal systems and chemical fertilizer production & application with the waste to energy system provided with the Pilot Plant. The Scenario C and Scenario D cover the following processes:

- Electricity and heat production from fossil fuel resources with the same amount of the excess electricity and heat produced in Scenario A,
- Conventional management of cattle manure (Pasture/range/paddock, Daily Spread, Solid Storage, Liquid / Slurry),
- Conventional management of poultry manure (without bedding waste management system),
- Landfilling of vegetable wastes, slaughterhouse wastes and grass,
- The production and spreading of the chemical fertiliser (Ammonium nitrate) to the soil to be used for the winter wheat production.

The inventory data regarding the scenario, Scenario C and Scenario D are gathered from the GaBi4 database and from the literature.

The main difference between the two scenarios is that Scenario C utilizes hard coal, whereas the Scenario D utilizes natural gas as the fossil fuel source to produce heat and electricity. The amount of electricity and heat production is considered to be equal to the excess heat and electricity production of Scenario A which can be connected to the grid systems. The main processes and inventory data used in Scenario C are explained below.

3.3.4.1. Scenario C - Electricity and Heat Production. The Scenario C is created for the electricity and heat production from hard coal of which process summary is given in Figure G.5.

The inventory tables gathered from the GaBi4 database regarding the electricity production from hard coal is given in Table G.9. The inventory table gathered from GaBi4 regarding the heat production from hard coal is given in Table G.10.

3.3.4.2. Scenario D - Electricity and Heat Production. The Scenario D is created for the electricity and heat production from natural gas of which process summary is given in Figure G.6.

The inventory tables gathered from the GaBi4 database regarding the electricity production from natural gas is given in Table G.11.

The inventory tables gathered from the GaBi4 database regarding the heat production from natural gas is given in Table G.12.

3.3.4.3. Conventional Management of Cattle Manure

CH_4 Emissions from Cattle Manure Management. This section describes the calculation of CH_4 produced during the storage and treatment of manure, and from manure deposited on pasture. The term ‘manure’ is used here collectively to include both dung and urine (i.e., the solids and the liquids) produced by livestock.

The decomposition of manure under anaerobic conditions (i.e., in the absence of oxygen), during storage and treatment, produces CH_4. These conditions occur most readily when large numbers of animals are managed in a confined area (e.g., dairy farms, beef feedlots, and swine and poultry farms), and where manure is disposed of in liquid-based systems.

The main factors affecting CH_4 emissions are the amount of manure produced and the portion of the manure that decomposes anaerobically.

The former depends on the rate of waste production per animal and the number of animals, and the latter on how the manure is managed. When manure is stored or treated as a liquid (e.g., in lagoons, ponds, tanks, or pits), it decomposes anaerobically and can produce a significant quantity of CH_4. The temperature and the retention time of the storage unit greatly affect the amount of methane produced. When manure is handled as a solid (e.g., in stacks or piles) or when it is deposited on pastures and rangelands, it tends to decompose under more aerobic conditions and less CH_4 is produced [IPCC, 2006].

The amount of waste produced varies with the type of animal, but generally ranges from 60 to 85 kg (wet basis) per 1, 000 kg live animal mass per day in intensive production systems. The energy potential of these wastes is given by the volatile solids (organic matter) content, which ranges from 10 to 18% of the total wet waste or 75 to 85% of the dry weight [Engler et al., 1999].

The physical characteristics of animal manure are given in Table 3.18. The characteristics of the animal wastes differ according to various factors like the type, weight, feeding habits of the animal, season, etc. [Baban et al., 2001].

Table 3.18. Physical characteristics of animal wastes [Baban et al., 2001].

	Cattle (Dairy prod.)	Cattle (Meat prod.)	Poultry (Meat and egg)	Sheep
Animal weight, kg	636	431	2.0-2.3	45
Waste production, l/day	36.8	28.3	0.095-0.160	3.1
Waste density, t/m^3	0.99	0.96	0.96	1.04
Dry matter, %	15	15	15-85 (72)	23

Considering the dairy cattle weight as 636 kg/cattle and the manure production as 36.8 lt/day with 0.99 t/m^3 waste density; the daily manure production can be calculated as 36.4 kg/day/cattle.

Since the quantity of dairy cattle manure received to the Pilot Plant is 350 ton/year (~960 kg/day) that means that the quantity of animal of which manures are fed to the Pilot Plant is 26 cattles/day.

According to the laboratory analysis, the TS content of the dairy cattle is 16.44%; whereas the VS content is 75 % which means that the daily volatile solid amount fed to the pilot plant is 118.23 kg/day. Since the daily manure production is calculated as 36.4 kg/day/cattle, the VS content of each cattle is 4.49 kg VS/cattle/day.

Bedding materials (straw, sawdust, chippings, etc.) are not included in the VS modelled in these calculations. The type and use of these materials is highly variable from country to country. Since they typically are associated with solid storage systems, their contribution would not add significantly to overall methane production.

The other manure characteristic is the maximum amount of methane able to be produced from that manure (B_o) which is available in Table C.2 in APPENDIX C.

The dairy cattle characteristics are similar to that are given for the region, Eastern Europe, so the maximum amount of methane able to be produced from that manure (Bo) is considered as 0.24 m^3 CH_4/kg VS.

Manure management system characteristics include the types of systems used to manage manure and a system-specific methane conversion factor (MCF) that reflects the portion of B_o that is achieved. Regional assessments of manure management systems are used to estimate the portion of the manure that is handled with each manure management technique. A description of manure management systems is included in Table C.1 in APPENDIX C.

The system MCF varies with the manner in which the manure is managed and the climate, and can theoretically range from 0 to 100%. Both temperature and retention time play an important role in the calculation of the MCF.

Manure that is managed as a liquid under warm conditions for an extended period of time promotes methane formation. These manure management conditions can have high MCFs, of 65 to 80%. Manure managed as dry material in cold climates does not readily produce methane, and consequently has an MCF of about 1%.

Development of emission factors involves determining a weighted average MCF using the estimates of the manure managed by each waste system within each climate region.

The average MCF is then multiplied by the VS excretion rate and the B_o for the livestock categories. In equation form, the estimate is as follows:

$$EF_{(T)} = \left(VS_{(T)} \bullet 365\right) \bullet \left[B_{o(T)} \bullet 0{,}67\ kg/m^3 \bullet \sum_{S,k} \frac{MCF_{S,k}}{100} \bullet MS_{(T,S,k)}\right] \qquad (3.7)$$

where;

$EF_{(T)}$: annual CH_4 emission factor for livestock category *T*, kg CH_4/animal/yr

$VS_{(T)}$: daily volatile solid excreted for livestock category *T,* kg dry matter/animal/day

365: basis for calculating annual VS production, days/yr

$B_{o(T)}$: maximum methane producing capacity for manure produced by livestock category *T,* m^3 CH_4 / kg of VS excreted

0,67 : conversion factor of m^3 CH_4 to kilograms CH_4

$MCF_{(S,k)}$: methane conversion factors for each manure management system *S* by climate region *k*, %

$MS_{(T,S,k)}$: fraction of livestock category *T*'s manure handled using manure management system *S* in climate region *k*, dimensionless

[IPCC, 2006].

The $B_{o(T)}$, $MCF_{(S,k)}$, and $MS_{(T,S,k)}$ values are chosen from the Table C.2 in APPENDIX C for the Eastern Europe region at a temperature of 25°C.

The summary of annual methane emissions from dairy cattle manure management are given in the below table:

Table 3.19. Annual methane emission from the dairy cattle wastes.

	Animal weight	636	kg
	Manure volume produced	36.8	lt/day
	Manure density	0.99	t/m^3
	Daily manure production	36.4	kg/day
	Annual cattle manure received in pilot plant	350	ton/year
	Daily cattle manure received in pilot plant	958.9	kg/day
	Quantity of cattles	26	cattle/day
	Cattle manure TS%	16.44%	%
	Cattle manure VS%	75.00%	%
	Cattle manure VS amount	118.23	kg/day
	Assumed SIMILAR to Eastern Europe	for Temperature of 25 °C	
	<u>Chosen Manure Management Systems</u>	**<u>MS (T,S,k) *</u>**	**<u>MCF (S,k)</u>**
	Pasture / Range / Paddock	18.0%	1.5%
	Daily Spread	2.5%	0.5%
	Solid Storage	60.0%	4.,0%
	Liquid / Slurry	17.5%	65.0%
	Other	2.0%	1.0%
		100.0%	
VS (T)	Cattle manure VS amount/head	4.49	kg VS/head/day
Bo (T)	Max. Methane Producing capacity	0.24	m^3 CH_4/kg VS
EF (T)	Annual CH_4 emission factor	37.12	kg CH_4/animal/year
	Methane emission from cattles	976.88	kg CH_4/year

The below section describes how to estimate the N_2O produced, directly and indirectly, during the storage and treatment of manure.

Direct N_2O emissions occur via combined nitrification and denitrification of nitrogen contained in the manure. The emission of N_2O from manure during storage and treatment depends on the nitrogen and carbon content of manure, and on the duration of the storage and type of treatment.

Nitrification (the oxidation of ammonia nitrogen to nitrate nitrogen) is a necessary prerequisite for the emission of N_2O from stored animal manures. Nitrification is likely to occur in stored animal manures provided there is a sufficient supply of oxygen.

Nitrification does not occur under anaerobic conditions. Nitrites and nitrates are transformed to N_2O and dinitrogen (N_2) during the naturally occurring process of denitrification, an anaerobic process. There is general agreement in the scientific literature that the ratio of N_2O to N_2 increases with increasing acidity, nitrate concentration, and reduced moisture. In summary, the production and emission of N_2O from managed manures requires the presence of either nitrites or nitrates in an anaerobic environment preceded by aerobic conditions necessary for the formation of these oxidized forms of nitrogen. In addition, conditions preventing reduction of N_2O to N_2, such as a low pH or limited moisture, must be present.

Indirect emissions result from volatile nitrogen losses that occur primarily in the forms of ammonia and NO_x. The fraction of excreted organic nitrogen that is mineralized to ammonia nitrogen during manure collection and storage depends primarily on time, and to a lesser degree temperature. Simple forms of organic nitrogen such as urea (mammals) and uric acid (poultry) are rapidly mineralized to ammonia nitrogen, which is highly volatile and easily diffused into the surrounding air.

Nitrogen losses begin at the point of excretion in houses and other animal production areas (e.g., milk parlors) and continue through on-site management in storage and treatment systems (i.e., manure management systems).

Nitrogen is also lost through runoff and leaching into soils from the solid storage of manure at outdoor areas, in feedlots and where animals are grazing in pastures [IPCC, 2006].

Direct N_2O Emissions from Cattle Manure Management. The method entails multiplying the total amount of N excretion (from all livestock species/categories) in each type of manure management system by an emission factor for that type of manure management system (see the below Equation). Emissions are then summed over all manure management systems.

$$N_2O_{D(mm)} = \left[\sum_S \left[\sum_T \left(N_{(T)} \cdot Nex_{(T)} \cdot MS_{(T,S)} \right) \right] \cdot EF_{3(S)} \right] \cdot \frac{44}{28} \tag{3.8}$$

where;

$N_2O_{D(mm)}$: direct N_2O emissions from Manure Management in the country, kg N_2O/yr

$N_{(T)}$: number of head of livestock species/category *T* in the country

$Nex_{(T)}$: annual average N excretion per head of species/category *T* in the country, kg N/animal/yr

$MS_{(T,S)}$: fraction of total annual nitrogen excretion for each livestock species/category *T* that is managed in manure management system *S* in the country, dimensionless

$EF_{3(S)}$: emission factor for direct N_2O emissions from manure management system *S* in the country, kg, N_2O-N / kg N in manure management system *S*

S: manure management system

T: species/category of livestock

44/28: conversion of $(N_2O\text{-}N)_{(mm)}$ emissions to $N_2O_{(mm)}$ emissions

Manure management system usage (MS%) is as considered above for the methane emissions which was taken from Table C.2. The emission factor for direct N_2O emissions (EF_3) is taken from Table C.5 in APPENDIX C.

Annual Average Nitrogen Excretion Rates, $N_{ex(T)}$. The IPCC default nitrogen excretion rates are presented in Table C.4. These rates are presented in units of nitrogen excreted per 1000 kg of animal per day. These rates can be applied to livestock sub-categories of varying ages and growth stages using a typical average animal mass (TAM) for that population sub-category, as shown in the below equation.

$$Nex_{(T)} = N_{rate\,(T)} \cdot \frac{TAM}{1000} \cdot 365 \tag{3.9}$$

Where;

$Nex_{(T)}$: annual N excretion for livestock category *T,* kg N/animal/yr

$N_{rate(T)}$: default N excretion rate, kg N/1000 kg animal mass/day

$TAM_{(T)}$: typical animal mass for livestock category *T*, kg/animal

The N_2O emissions generated by manure in the system 'pasture, range, and paddock' occur directly and indirectly from the soil, and are therefore reported under the category 'N_2O Emissions from Managed Soils' [IPCC, 2006].

The annual direct N_2O–N emissions from managed soils because of urine and dung inputs to grazed soils are also considered. The emission factor for direct N_2O emissions from managed soils ($EF_{3PRP,CPP}$) is taken from Table C.8 in APPENDIX C.

According to the above equations, the direct N_2O emission from dairy cattle manure management and managed soils which is calculated only considering direct N_2O–N emissions because of urine and dung inputs to grazed soils are calculated as follows:

Table 3.20. Direct N_2O emissions from cattle manure management.

TAM (T) : Animal weight	636	Kg	
N (T) : Quantity of cattles	26	cattles/day	
Nrate (T) : Default N excretion rate	0.35	kg N/1000 kg animal/year	
Nex (T) : Annual N excretion rate	81.25	kg N/animal/year	
Chosen Manure Management Systems	**MS (T,S,k) ***	**EF 3,PRP, CPP**	**EF 3 (S)**
Pasture / Range / Paddock	18.0%	0.02	-
Daily Spread	2.5%	-	-
Solid Storage	60.0%	-	0.005
Liquid / Slurry	17.5%	-	0.005
Other	2.0%	-	-
N_2O D(mm) : Direct N_2O emissions	**25.1**	**kg N_2O/year**	

Indirect N_2O Emissions from Cattle Manure Management. The calculation of N volatilisation in forms of NH_3 and NO_x from manure management systems is based on multiplication of the amount of nitrogen excreted (from all livestock categories) and managed in each manure management system by a fraction of volatilised nitrogen (see Equation below). N losses are then summed over all manure management systems.

$$N_{volatilization-MMS} = \sum_{S}\left[\sum_{T}\left[\left(N_{(T)} \cdot Nex_{(T)} \cdot MS_{(T,S)}\right) \cdot \left(\frac{Frac_{GasMS}}{100}\right)_{(T,S)}\right]\right] \tag{3.10}$$

Where,

$N_{volatilisation-MMS}$: amount of manure nitrogen that is lost because of volatilisation of NH_3 and NO_x, kg N/yr

$N_{(T)}$: number of head of livestock species/category *T* in the country

$Nex_{(T)}$: annual average N excretion per head of species/category *T* in the country, kg N/animal/yr

$MS_{(T,S)}$: fraction of total annual nitrogen excretion for each livestock species/category *T* that is managed in manure management system *S* in the country, dimensionless

$Frac_{GasMS}$: per cent of managed manure nitrogen for livestock category *T* that volatilises as NH_3 and NO_x in the manure management system *S*, %

$Frac_{GasMS}$ which is the per cent of managed manure nitrogen that volatilises as NH_3 and NO_x in the manure management system can be found from Table C.6 in APPENDIX C.

The indirect N_2O emissions from volatilisation of N in forms of NH_3 and NO_x (N_2O_G(mm)) are estimated using the below equation:

$$N_2O_{G(mm)} = \left(N_{volatilisation-MMS} \cdot EF_4\right) \cdot \frac{44}{28} \tag{3.11}$$

Where;

$N_2O_{G(mm)}$: indirect N_2O emissions because of volatilisation of N from Manure Management in the country, kg N_2O/yr

EF_4 : emission factor for N_2O emissions from atmospheric deposition of nitrogen on soils and water surfaces, kg N_2O-N / (kg NH_3-N + NO_x-N volatilised); default value is 0.01 kg N_2O-N / (kg NH_3-N + NO_x-N volatilised)

EF_4 which is the emission factor for N_2O emissions from atmospheric deposition of nitrogen on soils and water surfaces is given in Table C.7 in APPENDIX C.

The annual amount of N_2O–N produced from atmospheric deposition of N volatilised from managed soils because of urine and dung inputs to grazed soils are also considered. The following factors for indirect N_2O emissions from managed soils ($Frac_{GASM}$) are provided in Table C.7 in APPENDIX C.

$Frac_{GASM}$ = volatilisation fraction from all applied organic N fertiliser materials and urine and dung N deposited by grazing animals that volatilises as NH_3 and NO_x, kg N volatilised / (kg of N applied or deposited) [IPCC, 2006].

According to the above equations, the indirect N_2O emission because of N volatilisation in forms of NH_3 and NO_x from dairy cattle manure management systems and from the managed soils because of the urine and dung inputs to grazed soils are calculated as follows:

Table 3.21. N_2O emissions due to volatilization during cattle manure management.

Chosen Manure Management Systems	**MS (T,S,k) ***	**Frac GasMS**
Pasture / Range / Paddock	18.0%	20.0%
Daily Spread	2.5%	7.0%
Solid Storage	60.0%	30.0%
Liquid / Slurry	17.5%	40.0%
Other	2.0%	0.0%
	100.0%	
N volatilization MMS	615.35	kg N/year
EF4: Emission factor	0.01	
N_2O emission due to volatilization	9.7	**kg N_2O/yr**

Nitrogen that leaches into soil and/or runs off during solid storage of manure at outdoor areas or in feedlots is derived as follows:

$$N_{leaching-MMS} = \sum_{S}\left[\sum_{T}\left[\left(N_{(T)} \cdot Nex_{(T)} \cdot MS_{(T,S)}\right) \cdot \left(\frac{Frac_{leachMS}}{100}\right)_{(T,S)}\right]\right] \qquad (3.12)$$

Where,

$N_{leaching-MMS}$: amount of manure nitrogen that leached from manure management system, kg N/yr.

$N_{(T)}$: number of head of livestock species/category T in the country

$Nex_{(T)}$: annual average N excretion per head of species/category T in the country, kg N/animal/yr

$MS_{(T,S)}$: fraction of total annual nitrogen excretion for each livestock species/category T that is managed in manure management system S in the country, dimensionless

$Frac_{leachMS}$: per cent of managed manure nitrogen losses for livestock category T because of runoff and leaching during solid and liquid storage of manure (typical range 1-20%) [IPCC, 2006].

The typical range of $Frac_{leachMS}$, which is the per cent of managed manure nitrogen losses for livestock category because of runoff and leaching during solid and liquid storage of manure, is given as 1-20%.

The indirect N_2O emissions from leaching and runoff of nitrogen from manure management systems ($N_2O_{L(mm)}$) are estimated using the below equation:

$$N_2O_{L(mm)} = \left(N_{leaching-MMS} \cdot EF_5\right) \cdot \frac{44}{28} \tag{3.13}$$

Where;

$N_2O_{L(mm)}$: indirect N_2O emissions because of leaching and runoff from Manure Management in the country, kg N_2O/y

EF_5 : emission factor for N_2O emissions from nitrogen leaching and runoff, kg N_2O-N/kg N leached and runoff (default value 0.0075 kg N_2O-N /kg N leaching and runoff)

The annual amount of N_2O–N produced because of runoff and leaching from managed soils because of urine and dung inputs to grazed soils are also considered. The following factor for indirect N_2O emissions from managed soils ($Frac_{LEACH-(H)}$) are provided in Table C.7 in APPENDIX C.

$Frac_{LEACH-(H)}$ = fraction of all N added to/mineralised in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff, kg N / kg of N additions [IPCC, 2006].

According to the above equations, the indirect N_2O emission because of nitrogen leaching and run off from dairy cattle manure management systems and from managed soils because of urine and dung inputs to grazed soils are calculated as follows:

Table 3.22. N_2O emissions due to leaching during cattle manure management.

Chosen Manure Management Systems	**MS (T,S,k) ***	**Frac LeachMS**
Pasture / Range / Paddock	18.0%	30.0%
Daily Spread	2.5%	10.0%
Solid Storage	60.0%	10.0%
Liquid / Slurry	17.5%	10.0%
Other	2.0%	10.0%
	100.0%	
N leaching MMS	290.84	kg N/year
EF5: Emission factor	0.0075	
N_2O L: N_2O emission due to leaching	3.4	**kg N_2O/yr**

From all the calculations above, it can be concluded that the total N_2O emissions from conventional dairy cattle manure management systems will be 38.2 kg N_2O/year.

Table 3.23. Total N_2O emissions from cattle manure management.

CATTLE MANURE - Direct + Indirect N_2O Emissions			
N_2O D(mm)	Direct N_2O emissions	25.1	kg N_2O/year
N_2O indirect	Indirect N_2O emissions	9.7	kg N_2O/year
N_2O indirect	Indirect N_2O emissions	3.4	kg N_2O/year
TOTAL N_2O EMISSIONS		38.2	**kg N_2O/year**

3.3.4.4. Conventional Management of Poultry Manure

CH_4 Emissions from Poultry Manure Management. Considering the poultry weight as 2.15 kg/poultry and the manure production as 0.1275 lt/day with 0.96 t/m^3 waste density; the daily manure production can be calculated as 0.12 kg/day/poultry.

Since the quantity of poultry manure received to the Pilot Plant is 1,950 ton/year (~5,342 kg/day) that means that the quantity of animal of which manures are fed to the Pilot Plant is 43,648 poultry/day. According to the laboratory analysis, the TS content of the poultry manure is 71.92%; whereas the VS content is 73.10% which means that the daily volatile solid amount fed to the pilot plant is 2,808.7 kg/day. Since the daily manure production is calculated as 0.12 kg/day/poultry, the VS content of each poultry is 0.064 kg VS/poultry/day.

The layers (dry) represent layers in a "without bedding" waste management system; so the maximum amount of methane able to be produced from that manure (Bo) is considered as 0.39 m^3 CH$_4$/kg VS. The Bo and MCF values are chosen from the Table C.3 in APPENDIX C for the “layers (dry)” manure mangement system. The summary of annual methane emissions from the poultry manure management are given in the below table:

Table 3.24. Annual methane emissions from the poultry manure management.

	Animal weight	2.15	kg
	Manure volume produced	0.1275	lt/day
	Manure density	0.96	t/m^3
	Daily manure production	0.12	kg/day
	Annual poultry manure received in pilot plant	1,950	ton/year
	Daily poultry manure received in pilot plant	5,342.5	kg/day
	Quantity of poultry	43,647.60	poultry/day
	Poultry manure TS%	71.92%	%
	Poultry manure VS%	73.10%	%
	Poultry manure VS amount	2,808.72	kg/day
	Chosen Manure Management Systems	**MS (T,S,k)**	**MCF (S,k)**
	Layers (dry)	100.0%	1.5%
	Layers (dry) represent layers in a "without bedding" waste management system;		
VS (T)	Poultry manure VS miktarı/head	0.064	kg VS/head/day
B0 (T)	Max. Methane Producing capacity	0.39	m^3 CH$_4$/kg VS
EF (T)	Annual CH4 emission factor	0.09	kg CH$_4$/animal/year
	Methane emission from poultry	4,018.2	kg CH$_4$/year

Direct N_2O Emissions from Poultry Manure Management. The direct N_2O emission from poultry manure management are calculated as follows:

Table 3.25. Direct N_2O emission from poultry manure management.

TAM (T): Animal weight	2.15	kg
N (T): Quantity of poultry	43,647.60	head/day
Nrate (T): Default N excretion rate	0.82	kg N/1000 kg animal/year
Nex (T): Annual N excretion rate	0.64	kg N/animal/year
Chosen Manure Management Systems	**MS (T,S,k) ***	**EF 3 (S)**
Layers (dry)	100.0%	0.001
Layers (dry) represent layers in a "without bedding" waste management system;		
N_2O D(mm): Direct N_2O emissions	**44.1**	**kg N_2O/year**

Indirect N_2O Emissions from Poultry Manure Management. The indirect N_2O emission because of N volatilisation in forms of NH_3 and NO_x from poultry manure management systems are calculated as follows:

Table 3.26. N_2O emissions due to volatilization during poultry manure management.

Chosen Manure Management Systems	**MS (T,S,k) ***	**Frac GasMS**
Layers (dry)	100.0%	55%
Layers (dry) represent layers in a "without bedding" waste management system		
N volatilization MMS	15,447.9	kg N/year
EF4: Emission factor	0.01	
N_2O emission due to volatilization	**242.8**	**kg N_2O/yr**

The indirect N_2O emission because of nitrogen leaching and run off from poultry manure management systems are calculated as follows:

Table 3.27. N_2O emission due to leaching during poultry manure management.

Chosen Manure Management Systems	**MS (T,S,k) ***	**Frac LeachMS**
Layers (dry)	100.0%	10%
Layers (dry) represent layers in a "without bedding" waste management system;		
N leaching MMS	2,808.7	kg N/year
EF5: Emission factor	0.01	
N_2O L: N_2O emission due to leaching	**33.1**	**kg N_2O/yr**

From all the calculations above, it can be concluded that the total N_2O emissions from conventional poultry manure management systems will be approximately 320 kg N_2O/year.

Table 3.28. Total N_2O emission from poultry manure management.

POULTRY MANURE - Direct + Indirect N_2O Emissions			
N_2O $_D$(mm)	Direct N_2O emissions	44.1	kg N_2O/year
N_2O indirect	Indirect N_2O emissions due to volatilization of N	242.8	kg N_2O/year
N_2O indirect	Indirect N_2O emissions due to leaching	33.1	kg N_2O/year
TOTAL N_2O EMISSIONS		320.0	**kg N_2O/year**

3.3.4.5. Landfilling of Vegetable Wastes, Slaughterhouse Wastes and Grass. The system boundary of Scenario C and Scenario D covers the landfilling of vegetable wastes, slaughterhouse wastes and grass&grass sillage. The process flow chart for the landfilling of the above mentioned wastes is given in Figure G.7.

The inputs and outputs data of the sanitary lanfill is given in Table G.13.

The CH_4 emissions from solid waste disposal for a single year can be estimated using the below equation. CH_4 is generated as a result of degradation of organic material under anaerobic conditions. Part of the CH_4 generated is oxidised in the cover of the SWDS. The CH_4 actually emitted from the SWDS will hence be smaller than the amount generated.

$$CH_4\ Emissions = \left[\sum_x CH_4\ generated_{x,T} - R_T\right] \cdot (1 - OX_T) \qquad (3.14)$$

Where;

CH_4 Emissions : CH_4 emitted in year *T*, Gg

T : inventory year

X : waste category or type/material

R_T : recovered CH_4 in year *T*, Gg

OX_T : oxidation factor in year *T*, (fraction)

The CH_4 recovered for energy or flaring must be subtracted from the amount CH_4 generated. Only the fraction of CH_4 that is not recovered will be subject to oxidation in the SWDS cover layer.

The CH_4 potential that is generated throughout the years can be estimated on the basis of the amounts and composition of the waste disposed into SWDS and the waste management practices at the disposal sites. The basis for the calculation is the amount of Decomposable Degradable Organic Carbon (DDOCm) as defined in the below equation. DDOCm is the part of the organic carbon that will degrade under the anaerobic conditions in SWDS. DDOCm equals the product of the waste amount (W), the fraction of degradable organic carbon in the waste (DOC), the fraction of the degradable organic carbon that decomposes under anaerobic conditions (DOCf), and the part of the waste that will decompose under aerobic conditions (prior to the conditions becoming anaerobic) in the SWDS, which is interpreted with the methane correction factor (MCF) [IPCC, 2006].

$$DDOCm = W \cdot DOC \cdot DOC_f \cdot MCF \qquad (3.15)$$

Where;

DDOCm : mass of decomposable DOC deposited, Gg

W : mass of waste deposited, Gg

DOC : degradable organic carbon in the year of deposition, fraction, Gg C/Gg waste

DOC_f : fraction of DOC that can decompose (fraction)

MCF : CH_4 correction factor for aerobic decomposition in the year of deposition (fraction)

With a first order reaction, the amount of product is always proportional to the amount of reactive material. This means that the year in which the waste material was deposited in the SWDS is irrelevant to the amount of CH_4 generated each year. It is only the total mass of decomposing material currently in the site that matters. This also means that when we know the amount of decomposing material in the SWDS at the start of the year, every year can be regarded as year "number 1" in the estimation method, and the basic first order calculations can be done by these two simple equations, with the decay reaction beginning on the 1st of January the year after deposition.

"DDOCm accumulated in the SWDS at the end of year T" is calculated as follows:

$$DDOCma_T = DDOCmd_T + \left(DDOCma_{T-1} \bullet e^{-k}\right) \tag{3.16}$$

"DDOCm decomposed at the end of year T" is calculated as below:

$$DDOCm\ decomp_T = DDOCma_{T-1} \bullet \left(1 - e^{-k}\right) \tag{3.17}$$

where;

T : inventory year

$DDOCma_T$: DDOCm accumulated in the SWDS at the end of year *T*, Gg

$DDOCma_{T-1}$: DDOCm accumulated in the SWDS at the end of year *(T-1)*, Gg

$DDOCmd_T$: DDOCm deposited into the SWDS in year *T*, Gg

$DDOCm\ decomp_T$: DDOCm decomposed in the SWDS in year *T*, Gg

k : reaction constant, $k = \ln(2)/t_{1/2}$ (y^{-1})

$t_{1/2}$: half-life time (y)

The amount of CH_4 formed from decomposable material is found by multiplying the CH_4 fraction in generated landfill gas and the CH_4 /C molecular weight ratio.

$$CH_4\ generated_T = DDOCm\ decomp_T \bullet F \bullet 16/12 \tag{3.18}$$

where;

CH_4 generated$_T$: amount of CH_4 generated from decomposable material

DDOCm decomp$_T$: DDOCm decomposed in year *T*, Gg

F: fraction of CH_4, by volume, in generated land fill gas (fraction)

16/12: molecular weight ratio CH_4/C (ratio)

The oxidation factor, the degradable organic carbon (DOC), methane correction factor (MCF) and methane generation rate (k) are given in APPENDIX D. The default value for oxidation factor (OX_T) is zero and the MCF value is considered as one (1) since the landfill is an anaerobic managed solid waste disposal site. Most waste in SWDS generates a gas with approximately 50 per cent CH_4. Only material including substantial amounts of fat or oil can generate gas with substantially more than 50 per cent CH_4. The use of the IPCC default value for the fraction of CH_4 in landfill gas (0.5) is therefore encouraged. The recommended default value for DOCf (F) is 0.5. The default value for CH_4 recovery (R_T) is zero.

In most solid waste disposal sites, waste is deposited continuously throughout the year, usually on a daily basis. However, there is evidence that production of CH_4 does not begin immediately after deposition of the waste. At first, decomposition is aerobic, which may last for some weeks, until all readily available oxygen has been used up. This is followed by the acidification stage, with production of hydrogen. The acidification stage is often said to last for several months. After which there is a transition period from acidic to neutral conditions, when CH_4 production starts. The period between deposition of the waste and full production of CH_4 is chemically complex and involves successive microbial reactions. Time estimates for the delay time are uncertain, and will probably vary with waste composition and climatic conditions. The IPCC provides a default value of six months for the time delay [IPCC, 2006].

According to the IPCC 2006 calculations summarized in Table G.14, the generated methane from landfilling of vegetable wastes, slaughterhouse wastes and grass are found to be 57 ton/year. Since the oxidation factor (OX_T) and CH_4 recovery (R_T) is considered as zero, the CH_4 actually emitted from the landfill will hence be equal to the amount generated.

3.3.4.6. Mineral Fertiliser Production and Application on Field. The digested recipe will be utilised as substitutes for mineral fertilizer. The substitution relation between the digested recipe and mineral fertilizer can be calculated based on the content of nitrogen in the digested recipe.

If ammonium nitrate (AN) is used as mineral fertiliser for the winter wheat production, which has a 35% N content, then in order to feed one kg N to the field, 2.86 kg AN would be required. That means that total nitrogen available in the digested recipe is equal to 188 x 2.86 = 538 kg/day mineral fertiliser in the form of ammonium nitrate.

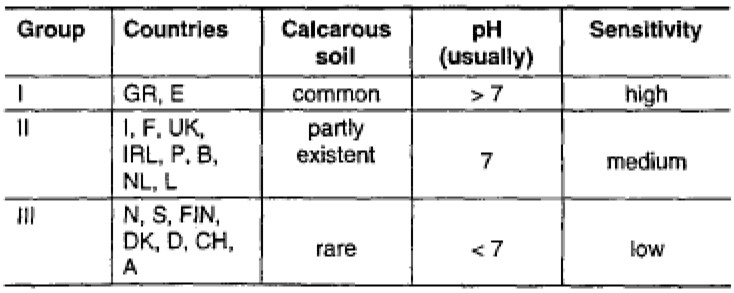
The flow chart of the fertiliser production, tranportation and field application is given in Figure G.8. The inputs and outputs data of the ammonium nitrate (AN) production which is gathered from the GaBi4 database are given in Table G.15.

The emissions produced because of the field application of the ammonium nitrate as fertiliser for winter wheat production are calculated as follows:

Ammonia Volatilization because of Field Application of Ammonium Nitrate. The ammonia emissions because of the application of mineral fertilizers are usually lower compared to slurry and manure. However, dependent on the ammonium and urea content of a mineral fertilizer, the climatic conditions and soil properties, considerable ammonia volatilization can also take place when applying mineral fertilizers. These emissions are estimated taking into account the different soil properties throughout Europe and the different NH_3 volatilization risk dependent on the fertilizer type.

Three classes of countries with different regional sensitivity to NH_3 volatilization are defined in the following table [Brentrup et al., 2000].

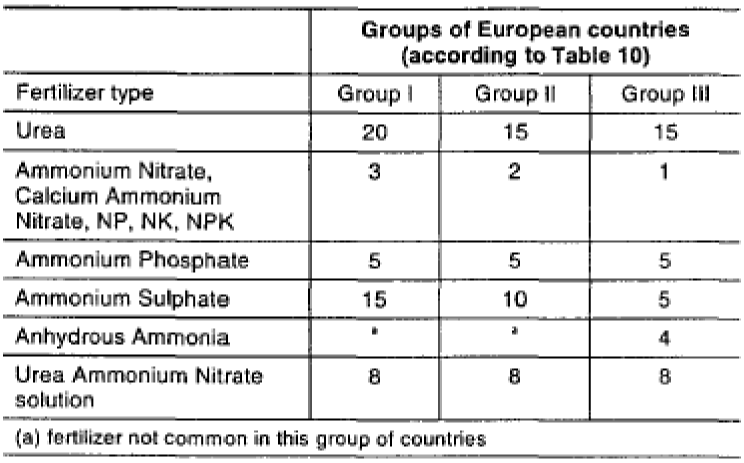
Table 3.29. European countries grouped according to their NH_3 volatilization [Brentrup et al., 2000].



Group	Countries	Calcarous soil	pH (usually)	Sensitivity
I	GR, E	common	> 7	high
II	I, F, UK, IRL, P, B, NL, L	partly existent	7	medium
III	N, S, FIN, DK, D, CH, A	rare	< 7	low

The NH_3 emission factors for six groups of mineral fertilizers taking into account the regional differences in NH_3 volatilization sensitivity are shown in the following table. [Brentrup et al., 2000]

Table 3.30. Emission factors (% NH_3-N loss of total applied mineral N) for different mineral fertilizers in Europe [Brentrup et al., 2000].



	Groups of European countries (according to Table 10)		
Fertilizer type	Group I	Group II	Group III
Urea	20	15	15
Ammonium Nitrate, Calcium Ammonium Nitrate, NP, NK, NPK	3	2	1
Ammonium Phosphate	5	5	5
Ammonium Sulphate	15	10	5
Anhydrous Ammonia	a	a	4
Urea Ammonium Nitrate solution	8	8	8

(a) fertilizer not common in this group of countries

According to the above tables; the below considerations are made.

The group is considered as “Group III” with the regional sensitivity to NH_3 volatilization as “low”. Since the mineral fertiliser to be used is Ammonium Nitrate, it is considered that the NH_3-N loss of total applied mineral N will be 1%.

Since the total available nitrogen content is 125.6 kg/ha, the total ammonia volatilization because of the application of Ammonium Nitrate is calculated to be 1% of 125.6 kg/ha which is equal to 1.26 kg NH_3-N/ha. According to the total available nitrogen content, the daily digestate is applied to 1.5 ha area in Scenario A. Since the mineral fertiliser will be applied to a similar area of 1.5 ha, the total NH_3 volatilization because of the application of Ammonium Nitrate will be 1.88 NH_3-N/day.

Nitrous Oxide Emissions because of Field Application of Ammonium Nitrate. The nitrous oxide emissions are calculated as (125.6 – 1.26) x 0.0125 = 1.55 kg N_2O-N/ha. When applied to 1.5 ha area, the total nitrous oxide emissions will be 2.33 N_2O-N/day.

N_2-N Emissions because of Field Application of Ammonium Nitrate. *T*he N_2-N emissions are calculated as (125.6– 1.26) x 0.09 = 11.19 kg N_2-N/ha. When applied to1.5 ha area, the total N_2-N emissions will be 16.78 N_2-N/day.

So, the total N emissions (NH_3-N, N_2O-N, N_2-N) are 1.26 + 1.55 + 11.19 = 14 kg N/ha resulting in 21 kg N/day when Ammonium Nitrate is applied to 1.5 ha area as mineral fertiliser.

Nitrate Leaching because of Field Application of Ammonium Nitrate.

The nitrogen balance for the field application of ammonium nitrate is calculated as 83.34 kg N/ha.

Table 3.31. Nitrogen balance.

Nitrate leaching	
N inputs	
Mineral fertiliser	125.59 kg N/ha
Biological N fixation	0.00 kg N/ha
Atmospheric N deposition	10.00 kg N/ha
N net mineralization	0.00 kg N/ha
N outputs	
N removal with harvested crop	38.25 kg N/ha
Emissions	14.00 kg N/ha
Nitrogen balance	83.34 kg N/ha

So, the leached NO_3-N is also calculated as 83.34 x 1 = 83.34 kg NO_3-N/ha/year. When applied to1.5 ha area, the total leached NO_3-N will be 125 NO_3-N/year.

According to the above calculations, the daily inputs and outputs data of the field application of ammonium nitrate for winter wheat production is given in Table G.16.

3.3.5. Scenario E – Hydropower Plant

The Scenario E is created in order to evaluate the environmental effects of energy production from a conventional (dam) hydropower plant and compare this renewable energy source with that of AD plant and the fossil fuel resources studied in other scenarios.

The inventory data regarding the Scenario E are gathered from the GaBi4 database and from the literature. The process flow chart of Scenario E is given in Figure G.9. The inventory tables gathered from the GaBi4 database regarding the electricity production from hydropower is given in Table G.17.

Similar to Scenario C and Scenario D, this scenario also covers the conventional organic waste disposal systems and chemical fertilizer production & application. The inventory data for the conventional management of cattle manure and poultry manure, landfilling of vegetable wastes, slaughterhouse wastes and grass, and the production and spreading of the chemical fertiliser (Ammonium nitrate) to the soil to be used for the winter wheat production, which are given in detail in Sections 3.3.4.3. , Sections 3.3.4.4. , Sections 3.3.4.5. and Section 3.3.4.6. respectively, are also valid for this scenario.

3.3.6. Scenario F – Windpower Plant

The Scenario F is created in order to evaluate the environmental effects of energy production from an onshore windpower plant and compare this renewable energy source with that of AD plant and the fossil fuel resources studied in other scenarios.

The inventory data regarding the Scenario F are gathered from GaBi4 and from the literature. The process flow chart of Scenario F is given in Figure G.10. The inventory tables gathered from the GaBi4 database regarding the electricity production from windpower plant is given in Table G.18.

Similar to Scenario C, D and E, this scenario also covers the conventional organic waste disposal systems and chemical fertilizer production & application. The inventory data for the conventional management of cattle manure (see Section 3.3.4.3.), conventional management of poultry manure (see Section 3.3.4.4.), landfilling of vegetable wastes, slaughterhouse wastes and grass (see Section 3.3.4.5.), and the production and spreading of the chemical fertiliser (Ammonium nitrate) to the soil to be used for the winter wheat production (see Section 3.3.4.6.) are also valid for this scenario.

3.3.7. Scenario G – Integrated Gasification Combined Cycle (IGCC) of the Waste Recipe

The Scenario G is created in order to evaluate the environmental effects of the gasification of the waste recipe, the ingredients of which are given in Table 3.1. The Scenario G covers the following processes:

- Electricity production from the IGCC of the waste recipe with an amount equal to the excess energy produced in the Scenario A,
- The production and spreading of the chemical fertiliser (Ammonium nitrate) to the soil to be used for the winter wheat production.

The inventory data regarding the Scenario G is gathered from the GaBi4 database and from the literature. The energy distribution of IGCC power plant is as shown in Figure 3.5.

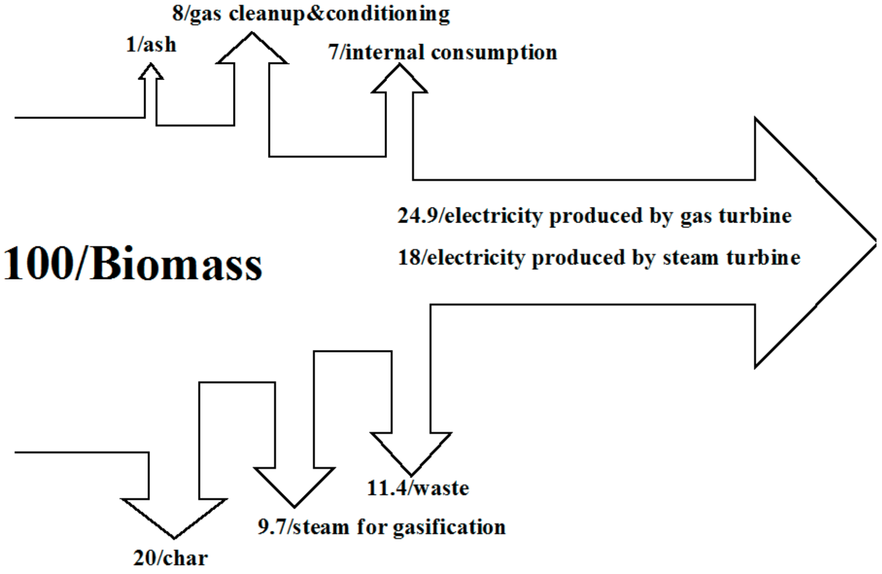


Figure 3.5. Energy distribution diagram of IGCC [Gibson et al., 2007].

The process summary of the Scenario G is given in Figure G.11.

3.3.7.1. Gasifier. Following the pretreatment, the agricultural and animal wastes are subjected to gasification. An indirectly heated steam-blown fluidized bed gasifier operated under atmospheric conditions is chosen for the biomass conversion. The process flow diagram of the gasifier is given in Figure G.12.

Since the output ash of the gasification has no fertilizer value, the system boundary of this scenario covers also the production of mineral fertiliser as well as the transportation of fertiliser from the factory to the regional storehouse and its field application. The flow chart of the fertiliser production, tranportation and field application are already provided in Section 3.3.4.6. The ash produced from the gasifier is sent to the sanitary landfill and the synthesis gas is utilised for electricity production.

3.3.7.2. Combined Cycle Unit. Following the gasification, the produced syngas is subjected to combined cycle unit for the production of electricity. The process flow diagram of the combined cycle unit is given in Figure G.13.

The inventory for the combined cycle unit includes the most important materials used for construction. It includes also the energy requirements for construction; transport is implicitly included in energy consumption [GaBi4, 2003].

The annual excess electrical output of the biomass integrated gasification combined cycle is equal to the amount produced in Scenario A which will be connected to the electrical grid.

The emissions from the IGCC power plant are CO_2 (46 g/KWh), NO_x (0.7 g/KWh), and SO_x (0.2 g/KWh) [Gibson et al., 2007].

3.4. Impact Assessment

The study, like any LCA, focuses on assessing the potential contributions to environmental impacts, and not the actual environmental effects. This is in accordance with both the ISO standards and international consensus, acknowledging that it is in practice impossible to know all sites of emissions to the environment and all actual exposure pathways of the emitted substances [Thyø and Wenzel, 2007].

While GaBi4 software is used as the LCA and LCC tool, the chosen methodology for the measurement, evaluation and description of the possible environmental consequences of the systems is EDIP 2003. Following the inventory phase, the data are interpreted through classification, characterization, normalization and weighting stages in the impact assessment phase.

3.4.1. Classification

At the first stage, named classification, the impact categories are selected according to the EDIP 2003 methodolgy. It has been decided to focus on global warming, since the main environmental concern with respect to energy recovery systems is global warming. However, data on other impact categories are also available, including:

- Stratospheric ozone depletion

- Photochemical ozone formation - impact on vegetation
- Aquatic eutrophication
- Terrestrial eutrophication
- Acidification

Contributions to photochemical ozone formation (impact on human health and materials) is considered insignificant in the studied systems and no assessment has been carried out on this impact category.

The emissions with their related impact categories and characterization units used in EDIP 2003 are given in Table 3.32.

Table 3.32. Classification of major emissions to impact categories.

Major Emissions	**Related Impact Categories**	**Unit**
CO_2, CH_4, N_2O, CO	Global warming	[kg CO_2-Equiv.]
NH_3, SO_2, NO_x	Acidification potential	[m^2 UES]
NH_3, NO_x, NO_3^-, PO_4^{-2}, NH_3/NH_4^+	Aquatic eutrophication	[kg NO_3-Equiv.]
NH_3, NO_x	Terrestrial eutrophication	[m^2 UES]
NMVOC, CH_4, NO_x, CO	Photochemical ozone formation - impact on vegetation	[m^2 UES*ppm*hours]
Halogenated organic substances (CCl4, Halon 1211, Halon 1301, R11, R114, R12, R22)	Stratospheric ozone depletion	[kg R11-Equiv.]

According to major emissions released to the environment from the entire life cycle of each scenario, the following results are obtained;

- The largest amount of emissions for Scenario A including AD plant utilising waste recipe is carbon dioxide, ammonia, nitrogen oxides, sulphur dioxide, nitrous oxide and carbon monoxide, respectively.

- The largest amount of emissions for Scenario B including AD plant utilising cattle manure is carbon dioxide, ammonia, nitrogen oxides, nitrous oxide, sulphur dioxide and carbon monoxide, respectively.
- The largest amount of emissions for Scenario C including coal PP is carbon dioxide, methane, nitrogen oxides, sulphur dioxide, carbon monoxide, NMVOC, nitrous oxide and ammonia, respectively.
- The largest amount of emissions for Scenario D including natural gas PP is carbon dioxide, methane, nitrogen oxides, carbon monoxide, NMVOC, sulphur dioxide, nitrous oxide and ammonia, respectively.
- The largest amount of emissions for Scenario E including hydro PP and Scenario F including wind PP is carbon dioxide, nitrogen oxides, methane, carbon monoxide, NMVOC, sulphur dioxide, nitrous oxide and ammonia, respectively.
- The largest amount of emissions for Scenario G including IGCC is carbon dioxide, nitrogen oxides, nitrous oxide, ammonia, sulphur dioxide, methane, and carbon monoxide, respectively. The gaseous emissions of carbon dioxide, nitrogen oxides, sulphur dioxide are associated mostly with the combined cycle process used for electricity production.

When all scenarios are compared in terms of each type of emission generated from their entire life cycle, the following results are gathered which are shown in the figures in APPENDIX H as well. In this comparison, Scenario B, which utilizes only cattle manure instead of the waste recipe used in Scenario A, has the lower emission results because of lower biogas production. The biogas produced in Scenario B can not meet the same net annual electricity production need as Scenario A. Scenario B is conducted just to compare the results with that of the main scenario and since the main scenario is Scenario A, the following comments about the comparison of the emissions are made ignoring the results of Scenario B.

- The mass of Carbon Dioxide, Carbon Monoxide, Nitrogen oxides, Nitrous Oxide, Sulphur dioxide, and Methane emitted to air from the scenarios can be ranked from highest as Scenario C, followed by Scenario D, F, E, G and to lowest Scenario A.
- The mass of Ammonia emitted to air from the scenarios can be ranked from highest as Scenario A, followed by Scenario C, F, D, E and to lowest Scenario G.

- The mass of Group NMVOC emissions to air from the scenarios can be ranked from highest as Scenario D, followed by Scenario C, F, E, A, and to lowest Scenario G.
- The mass of Halogenated organic emissions to air from the scenarios can be ranked from highest as Scenario D, followed by Scenario C, F, E, G, and to lowest Scenario A.
- The mass of Nitrate emitted to fresh water from the scenarios can be ranked from highest as Scenario C, followed by Scenario F, D, E, A, and to lowest Scenario G.
- The mass of Phosphate emitted to fresh water from the scenarios can be ranked from highest as Scenario C, followed by Scenario F, D, E, G, and to lowest Scenario A.
- The mass of Ammonium/Ammonia emitted to fresh water from the scenarios can be ranked from highest as Scenario F, followed by Scenario C, D, E, G and to lowest Scenario A.
- The mass of Phosphorus emitted to fresh water from the scenarios can be ranked from highest as Scenario F, followed by Scenario D, C, E, G and to lowest Scenario A.

The figures shown in APPENDIX H also compare each type of emission generated from their entire life cycle of all scenarios.

Following the classification, the characterization step is carried out to directly compare the LCI results within each impact category.

3.4.2. Characterisation

In the characterization step, the interventions recorded in the inventory table are quantified in terms of a common category indicator. The factors translating emissions into contributions to impact categories are called characterisation factors (equivalency factors).

APPENDIX B shows the equivalency factors used for the environmental quantities according to EDIP 2003 methodoloy. Characterization results of the selected impact categories are presented below.

3.4.2.1. Global Warming. The predicted consequences of the man-made greenhouse effect include higher global average temperatures, and changes in the global and regional climates. The world-wide network of meteorological researchers and atmospheric chemists, the IPCC (Intergovernmental Panel on Climate Change), is following the latest development in our knowledge of the greenhouse effect and issuing regular status reports. These status reports comprise the basis of the EDIP97 and EDIP2003 methodologies' assessment tool for the global warming [Hauschild and Potting, 2005].

In EDIP 2003 methodology, the contribution of the pollutants to the global warming potential (GWP) is given for the 20, 100 and 500 year time horizons as specified by ISO and SETAC. However, for this study, the time horizon 100 year is chosen, as this is the most widely used time period in LCA studies.

The overall GWP of Scenario A is determined as 401,074 kg CO_2-Equiv per year. As it can be seen from Figure I.1, the major GWP stage of the pilot plant in Scenario A is the agricultural application of the digestate followed by the cogeneration unit, and then the AD unit. The relative contribution of the agricultural application of the digestate to the GWP is 39.31% for the liquid fertilizer and 27.96% for the solid fertilizer, whereas it is 11.49% for the cogeneration unit and 7.37% for the anerobic digester itself.

The GWP of Scenario A is mostly caused by inorganic emissions to air. 73.76% of the GWP is caused by nitrous oxide and 91% of N_2O emissions come from the agricultural application of the digestate. N_2O is followed by carbon dioxide causing 25.10% of GWP and methane causing 0.95% of GWP.

It is obviously seen that the pretreatment of the recipe has low consideration to GWP.

When the carbon sequestration calculations are made, the forestration need of Kocaeli district for prevention of GWP which is 401,074 kg CO_2-Equiv per year for Scenarioa A are found as follows;

- The quantity of **individual urban trees** needed to prevent 401,074 kg CO_2-Equiv per year GWP is 342,352 pcs. fast growing, pine trees [U.S. DOE, EIA, 1998].

- The area of the **urban forest** needed to prevent 401,074 kg CO_2-Equiv per year GWP is 668,456 m^2 [Gul et al., 2009].
- The quantity of **rural trees** needed to prevent 401,074 kg CO_2-Equiv per year GWP is 62,987 fast growing, pine trees [Tufts University, 2011].

The Scenario B includes the AD of only cattle manure instead of the same amount of recipe included in Scenario A. As seen from the Figure I.2, lower amount of biogas and fertilizer produced in Scenario B when compared to Scenario A and this results in lower GWP (296,954 kg CO_2-Equiv.).

When the carbon sequestration calculations are made, the forestration need of Kocaeli district for prevention of GWP which is 296,954 kg CO_2-Equiv per year for Scenarioa B are found as follows;

- The quantity of **individual urban trees** needed to prevent 296,954 kg CO_2-Equiv per year GWP is 253,477 pcs. fast growing, pine trees [U.S. DOE, EIA, 1998].
- The area of the **urban forest** needed to prevent 296,954 kg CO_2-Equiv per year GWP is 494,923 m^2 [Gul et al., 2009].
- The quantity of **rural trees** needed to prevent 296,954 kg CO_2-Equiv per year GWP is 46,635 fast growing, pine trees [Tufts University, 2011].

As it can be seen from Figure I.3, the major GWP stage of the Scenario C is the electricity production from hard coal in a power plant, followed by the landfilling of the vegetable wastes, slaughterhouse wastes and grass. In addition to those processes, the thermal energy production from hard coal and mineral fertiliser production and application are also causing a considerable amount of global warming.

The relative contribution of the electricity production from hard coal to the GWP of Scenario C is 40.52%, whereas it is 26.92% for the landfilling process, 14.73% for the thermal energy production from hard coal and 14.12% for the mineral fertiliser production & application. Among the emissions; carbon dioxide, nitrous oxide and methane seems to be the biggest reason for the GWP, with 76.48%, 13.24 % and 10.11% contribution, respectively.

When the carbon sequestration calculations are made, the forestration need of Kocaeli district for prevention of GWP which is 6,452,091 kg CO_2-Equiv per year for Scenarioa C are found as follows;

- The quantity of **individual urban trees** needed to prevent 6,452,091 kg CO_2-Equiv per year GWP is 5,507,431 pcs. fast growing, pine trees [U.S. DOE, EIA, 1998].
- The area of the **urban forest** needed to prevent 6,452,091 kg CO_2-Equiv per year GWP is 10,753,485 m^2 [Gul et al., 2009].
- The quantity of **rural trees** needed to prevent 6,452,091 kg CO_2-Equiv per year GWP is 1,013,273 fast growing, pine trees [Tufts University, 2011].

As it can be seen from Figure I.4, the major GWP stage of the Scenario D is the landfilling of the vegetable wastes, slaughterhouse wastes and grass, followed by electricity production from natural in a power plant. In addition to those processes, the mineral fertiliser production and application and thermal energy production from natural gas are also causing a considerable amount of global warming. The relative contribution of the landfilling process to the GWP of Scenario D is 36.16%, whereas it is 27.99% for the electricity production from natural gas, 18.97% for the mineral fertiliser production & application and 11.91% for the thermal energy production from natural gas.

Among the emissions; carbondioxide, nitrous oxide and methane seems to be the biggest reason for the GWP, with 74.12%, 17.00% and 8.66%, respectively.

When the carbon sequestration calculations are made, the forestration need of Kocaeli district for prevention of GWP which is 4,803,495 kg CO_2-Equiv per year for Scenarioa D are found as follows;

- The quantity of **individual urban trees** needed to prevent 4,803,495 kg CO_2-Equiv per year GWP is 4,100,208 pcs. fast growing, pine trees [U.S. DOE, EIA, 1998].
- The area of the **urban forest** needed to prevent 4,803,495 kg CO_2-Equiv per year GWP is 8,005,825 m^2 [Gul et al., 2009].
- The quantity of **rural trees** needed to prevent 4,803,495 kg CO2-Equiv per year GWP is 754,368 fast growing, pine trees [Tufts University, 2011].

As it can be seen from Figure I.5, the major GWP stage of the Scenario E is the landfilling of the vegetable wastes, slaughterhouse wastes and grass, followed by the mineral fertiliser production and application. It is apparently seen that the GWP of the reservoir hydropower plant alone is almost negligible. The relative contribution of the landfilling process to the GWP of Scenario E is 59.96%, whereas it is 31.45% the mineral fertiliser production & application and just 0.33% for the hydropower plant.

Among the emissions; carbondioxide, nitrous oxide and methane seems to be the biggest reason for the GWP, with 61.39%, 27.99% and 10.28%, respectively.

When the carbon sequestration calculations are made, the forestration need of Kocaeli district for prevention of GWP which is 2,896,707 kg CO_2-Equiv per year for Scenario E are found as follows;

- The quantity of **individual urban trees** needed to prevent 2,896,707 kg CO_2-Equiv per year GWP is 2,472,596 pcs. fast growing, pine trees [U.S. DOE, EIA, 1998].
- The area of the **urban forest** needed to prevent 2,896,707 kg CO_2-Equiv per year GWP is 4,827,846 m^2 [Gul et al., 2009].
- The quantity of **rural trees** needed to prevent 2,896,707 kg CO_2-Equiv per year GWP is 454,915 fast growing, pine trees [Tufts University, 2011].

As it can be seen from Figure I.6, the major GWP stage of the Scenario F is the landfilling of the vegetable wastes, slaughterhouse wastes and grass, followed by the mineral fertiliser production and application. It is apparently seen that the GWP of the windpower plant alone is almost negligible. The relative contribution of the landfilling process to the GWP of Scenario F is 58.58%, whereas it is 30.73% the mineral fertiliser production & application and just 2.61% for the windpower plant.

Among the emissions; carbondioxide, nitrous oxide and methane seems to be the biggest reason for the GWP, with 62.06%, 27.37% and 10.21%, respectively.

When the carbon sequestration calculations are made, the forestration need of Kocaeli district for prevention of GWP which is 2,964,808 kg CO_2-Equiv per year for Scenario F are found as follows;

- The quantity of **individual urban trees** needed to prevent 2,964,808 kg CO_2-Equiv per year GWP is 2,530,726 pcs. fast growing, pine trees [U.S. DOE, EIA, 1998].
- The area of the **urban forest** needed to prevent 2,964,808 kg CO_2-Equiv per year GWP is 4,941,348 m^2 [Gul et al., 2009].
- The quantity of **rural trees** needed to prevent 2,964,808 kg CO_2-Equiv per year GWP is 465,610 fast growing, pine trees [Tufts University, 2011].

As it can be seen from Figure I.7, the major GWP stage of the Scenario G is the mineral fertiliser production and application, followed by the combined cycle unit and transportation of the raw materials.

The gasifier unit including the dryer and gas treatment unit has very low contribution to the GWP. The relative contribution of the mineral fertiliser production & application to the GWP of Scenario F is 82.22%, whereas it is 12.97% for the combined cycle unit and just 0.12% for the gasification unit itself.

Among the emissions; nitrous oxide, carbondioxide and methane seems to be the biggest reason for the GWP, with 62.10%, 36.68% and 1.14%, respectively.

When the carbon sequestration calculations are made, the forestration need of Kocaeli district for prevention of GWP which is 1,107,999 kg CO_2-Equiv per year for Scenario F are found as follows;

- The quantity of **individual urban trees** needed to prevent 1,107,999 kg CO_2-Equiv per year GWP is 945,776 pcs. fast growing, pine trees [U.S. DOE, EIA, 1998].
- The area of the **urban forest** needed to prevent 1,107,999 kg CO_2-Equiv per year GWP is 1,846,666 m^2 [Gul et al., 2009].
- The quantity of **rural trees** needed to prevent 1,107,999 kg CO_2-Equiv per year GWP is 174,007 fast growing, pine trees [Tufts University, 2011].

When all scenarios are compared side by side, it is apparent that the scenario which has the highest GWP is Scenario C; whereas the lowest GWP is caused by Scenario B. The biogas produced in Scenario B can not meet the same net annual electricity production need as Scenario A and actually, the GWP of Scenario B is low because of the lower production of biogas and lower nitrogen content of the digestate compared to Scenario A. It should also be noted that the pilot plant will be operated according to the recipe defined for Scenario A, so Scenario B is considered out of the comparisons made with other scenarios.

According to the findings of this study, the mineral fertiliser production and application which is included in Scenario C, D, E, F and G has a GWP of 166.40 g CO_2-Equiv per m^2 winter wheat production; whereas the spreading and application of the anerobic digestate has only a GWP of 53.69 g CO_2-Equiv per m^2 winter wheat produced.

The reduction of GWP achieved by using the anaerobic digestate instead of mineral fertiliser is 112.71 g CO_2-Equiv per m^2 winter wheat produced, or in other words 68% GWP saving occurs which makes the usage of the anaerobic digestate a more environmentally friendly product.

When the GWP of the conventional management of cattle and poultry manure is examined, it is seen that each cattle will cause a GWP of 3,815 g CO_2-Equiv per head which is very much higher than the GWP of a poultry which is approximately 13 g CO_2-Equiv per head.

When the AD is used for energy production from those cattle and poultry manure, it is apparent that 100% of GWP resulting from the conventional management of cattle and poultry manure will be prevented.

The GWP caused by the landfilling of the vegetable wastes, slaughterhouse wastes and grass is calculated as 207.25 g CO_2-Equiv per kg waste and this GWP is included in Scenario C, D, E and F. The landfilling of ash disposed from the gasification plant is also included in Scenario G of which GWP is calculated as 12.25 g CO_2-Equiv per kg ash. The comparison of these GWP values show us that Scenario G has 94% lower GWP because of the landfilling process, while Scenario A has 100% GWP saving since, instead of landfilling, those wastes are utilised for energy production.

Comparing only the electricity production stages of each scenario results in the following Figure I.8 and it shows that even the GWP of only the AD process of the waste recipe is lower than electricity production from hard coal PP itself (Scenario C). The same conclusion can be made for natural gas PP (Scenario D), or wind power plant (Scenario F) and the integrated gasification combined cycle plant itself (Scenario G). Only the hydropower plant itself has a lower GWP than the AD plant when only the electricity production stages are compared.

However, when all GWP figures resulting from mineral fertiliser usage, conventional cattle and poultry manure management and landfilling of wastes are combined with the power production stages, then GWP of all scenarios shown in Figure I.9 is obtained.

As a result of the findings mentioned above, the chosen pilot plant process for the utilization of the waste recipe, Scenario A, is the most environmentally friendly process when compared to conventional fossil fuel energy production and waste disposal systems in terms of GWP. This is valid even the conventional management of agricultural wastes and mineral fertiliser production and application are not considered for the fossil fuel scenarios.

When the Scenario A is compared with renewable energy sources such as hydropower plants, windpower plants and also with the thermochemical conversion technology of gasification, it still seems to be most environmentally friendly in terms of GWP. Even the environmental effects of hydropower plant is low when considered alone, the addition of environmental pollution potential because of the conventional management of the agricultural and animal wastes and usage of mineral fertiliser remove the advantage of this renewable energy source and it becomes less environmentally friendly when compared to the main scenario A.

The GWP reductions achieved by Scenario A with respect to other scenarios are given in the below table.

Table 3.33. Summary of GWP reductions achieved by Scenario A with respect to other scenarios.

	Reductions (%) of Scenario A compared to other Scenarios				
	C	**D**	**E**	**F**	**G**
Emissions to air	**94%**	**92%**	**86%**	**86%**	**64%**
Inorganic emissions to air	93%	91%	85%	85%	64%
Carbon dioxide	98%	97%	94%	95%	75%
Carbon monoxide	93%	93%	93%	93%	16%
Nitrous oxide (laughing gas)	65%	64%	64%	64%	57%
Organic emissions to air (group VOC)	99%	99%	99%	99%	70%
Methane	99%	99%	99%	99%	70%

In APPENDIX I, the results of Scenario A is compared with respect to other scenarios in terms of some different activities and goods which also point out the benefits of AD of the waste recipe with integrated energy recovery systems.

In conclusion, if the waste recipe is utilised in an AD plant with biogas recovery system instead of fossil fuel and other renewable energy sources mentioned in this study, at least 64% reductions will be achieved in terms of global warming potential.

3.4.2.2. Acidification Potential. Releases of nitrogen (NO_x and NH_3) and sulphur (SO_2) to air account in most countries for more than 95% of the total acidifying emissions. On a national level, acidifying emissions thus consist mainly of nitrogen and sulphur.

The site-generic as well as the site-dependent EDIP2003 acidification potentials of an emission from a functional unit are expressed as the area of ecosystem within the full deposition area which is brought to exceed the critical load of acidification as a consequence of the emission (area of unprotected ecosystem = m^2 UES/f.u.) [Hauschild and Potting, 2005].

The acidification potential of Scenario A is determined as 56,404 m^2 UES. As it can be seen from the Figure I.10, the major acidification potential of the pilot plant in Scenario

A comes from the agricultural application of the digestate followed by the cogeneration unit, and then the AD unit. The relative contribution of the agricultural application of the digestate to the acidification potential is 43.65% for the liquid fertiliser, whereas it is 35.62% for the cogeneration unit, 9.42% for the solid fertiliser and 3.13% for anaerobic digester itself. It is obviously seen that the pretreatment of the recipe and the transportation of the raw materials to and from the pilot plant have low consideration to acidification potential.

The acidification potential of Scenario A is caused by inorganic emissions to air. 53.26% of the acidification potential is caused by ammonia, followed by 31.08% of acidification potential because of sulphur dioxide and 15.67% of acidification potential because of nitrogen oxides.

The Scenario B includes the AD of only cattle manure instead of the same amount of recipe included in Scenario A. As seen from the Figure I.11, the lower nitrogen amount of the digestate and lower biogas production in Scenario B compared to Scenario A results in lower acidification potential (37,770 m^2 UES.).

The acidification potential of Scenario C is 267,932 m^2 UES. As it can be seen from Figure I.12, the major acidification potential stage of the Scenario C is the landfilling of the vegetable wastes, slaughterhouse wastes and grass, followed by electricity production from hard coal in a power plant. In addition to those processes, the mineral fertiliser production and application and the thermal energy production from hard coal are also causing a considerable amount of acidification potential. The relative contribution of the landfilling process to the acidification potential of Scenario C is 53.48%, whereas it is 22.39% for the electricity production from hard coal, 16.15% for the mineral fertiliser production & application and 7.98% for the thermal energy production from hard coal.

Among the emissions; nitrogen oxide, sulphur dioxide and ammonia seems to be the biggest reason for the acidification potential, with 52.72 %, 36.79% and 10.49% contribution, respectively.

The acidification potential of Scenario D is 216,666 m^2 UES. As it can be seen from Figure I.13, the major acidification potential stage of the Scenario D is the landfilling of the vegetable wastes, slaughterhouse wastes and grass, followed by mineral fertiliser production and application. In addition to those processes, the electricity production from natural gas in a power plant and thermal energy production from natural gas are also causing a considerable amount of acidification. The relative contribution of the landfilling process to the acidification potential is 66.13%, whereas it is 19.98% for the mineral fertiliser production & application, 10.64% for the electricity production from natural gas, and 3.25% for the thermal energy production from natural gas.

Among the emissions; nitrogen oxide, sulphur dioxide and ammonia seems to be the biggest reason for the acidification potential, with 58.70 %, 29.00% and 12.31% contribution, respectively.

The acidification potential of Scenario E is 187,007 m^2 UES. As it can be seen from Figure I.14, the major acidification potential stage of the Scenario E is the landfilling of the vegetable wastes, slaughterhouse wastes and grass, followed by mineral fertiliser production and application. The hydropower plant itself does not cause a considerable amount of acidification. The relative contribution of the landfilling process to the acidification potential 76.62%, whereas it is 23.15% for the mineral fertiliser production & application and just 0.23% for the hydropower plant.

Among the emissions; nitrogen oxide, sulphur dioxide and ammonia seems to be the biggest reason for the acidification potential, with 60.79 %, 24.98% and 14.24% contribution, respectively.

The acidification potential of Scenario F is 192,358 m^2 UES. As it can be seen from Figure I.15, the major acidification potential stage of the Scenario F is the landfilling of the vegetable wastes, slaughterhouse wastes and grass, followed by mineral fertiliser production and application. The windpower plant itself does not cause a considerable amount of acidification. The relative contribution of the landfilling process to the acidification potential 74.49%, whereas it is 22.50% for the mineral fertiliser production & application and just 3.01% for the windpower plant.

Among the emissions; nitrogen oxide, sulphur dioxide and ammonia seems to be the biggest reason for the acidification potential, with 59.78 %, 26.33% and 13.89% contribution, respectively.

The acidification potential of Scenario G is 76,621 m^2 UES. As it can be seen from Figure I.16, the major acidification potential stage of the Scenario G is the mineral fertiliser production and application, followed by the combined cycle unit. The gasification plant including the dryer, gasifier and the gas treatment unit does not cause a considerable amount of acidification. The relative contribution of the mineral fertiliser production & application to the acidification potential is 56.49%, whereas it is 38.64% for the combined cycle unit and just 0.12% for the gasifier, dryer and the gas treatment unit.

Among the emissions; nitrogen oxide, ammonia and sulphur dioxide seems to be the biggest reason for the acidification potential, with 41.51%, 33.67% and 24.82% contribution, respectively.

When all scenarios are compared side by side, it is apparent that the scenario which has the highest acidification potential is Scenario C; whereas the lowest acidification potential is caused by Scenario B. The biogas produced in Scenario B can not meet the same net annual electricity production need as Scenario A and actually, the acidification potential of Scenario B is low because of the lower production of biogas and lower nitrogen content of the digestate compared to Scenario A. It should be noted that the pilot plant will be operated according to the recipe defined for Scenario A. So; it can be concluded that the chosen pilot plant process for the utilization of the waste recipe, Scenario A, is the most environmentally process when compared to conventional energy production and waste disposal systems in terms of acidification potential.

When the Scenario A is compared with renewable energy sources such as hydropower plants, windpower plants and also with the thermochemical conversion technology of gasification, it still seems to be most environmentally friendly in terms of acidification potential.

Since the Scenario A includes utilization of waste recipe, the environmental pollution potential of the agricultural and animal wastes are prevented which can occur because of the conventional disposal methods and also the mineral fertiliser usage is prevented because of the fertiliser value of the digestate. Even the environmental effects of hydropower plant or windpower plant are negligible when they are considered alone, the addition of environmental pollution potential because of the conventional management of the agricultural and animal wastes and usage of mineral fertiliser remove that advantage of those renewable energy sources. Consequently, Scenario E, F and G become less environmentally friendly when compared to the main scenario A.

The acidification potential reductions achieved by Scenario A with respect to other scenarios can be summarised as; 79% reduction compared to Scenario C, 74% reduction compared to Scenario D, 70% reduction compared to Scenario E, 71% reduction compared to Scenario F and 26% reduction compared to Scenario G. In conclusion, if the waste recipe is utilised in an AD plant with biogas recovery system instead of fossil fuel and other renewable energy sources mentioned in this study, at least 26% reduction will be achieved in terms of acidification potential.

3.4.2.3. Aquatic Eutrophication Potential. Eutrophication literally means "the process of becoming rich of nutrients". The eutrophying impact typically characterised in life cycle impact assessment relates implicitly to eutrophication of aquatic ecosystems.

The EDIP2003 aquatic eutrophication potentials of a nutrient emission express the maximum exposure of aquatic systems that it can cause. In this respect, they are expressed as NO_{3-} equivalents [Hauschild and Potting, 2005].

The aquatic eutrophication potential of Scenario A is determined as 1,669 kg NO_3-Equiv. As it can be seen from the Figure I.18, the major aquatic eutrophication potential of the pilot plant in Scenario A comes from the digested matter application in agriculture, followed by the cogeneration unit. The relative contribution of the digested matter application in agriculture to the aquatic eutrophication potential is 56.16% for the liquid fertiliser and 13.21% for the solid fertiliser, whereas it is 14.28% for the cogeneration unit.

It is obviously seen that the pretreatment of the recipe and the transportation of the raw materials to and from the pilot plant and the AD unit has low consideration to aquatic eutrophication potential.

The aquatic eutrophication potential of Scenario A is caused mostly by inorganic emissions to air and fresh water. 65.22% of the aquatic eutrophication potential is caused by ammonia emmission to air, followed by 26.59% of aquatic eutrophication potential because of nitrogen oxides emitted to air. The emissions to fresh water that cause aquatic eutrophication are nitrate and phosphate with 4.46% and 3.66% of the aquatic eutrophication potential, respectively.

The Scenario B includes the AD of only cattle manure instead of the same amount of recipe included in Scenario A. As seen from the Figure I.19, the lower amount of fertilizer and biogas production in Scenario B compared to Scenario A results in lower aquatic eutrophication potential (1,262 kg NO_3-Equiv.).

The aquatic eutrophication potential of Scenario C is determined as 8,846 kg NO_3-Equiv. As it can be seen from Figure I.20, the major aquatic eutrophication potential stage of the Scenario C is the landfilling of the vegetable wastes, slaughterhouse wastes and grass, followed by the mineral fertiliser production and application. In addition to those processes, the electricity production from hard coal in a power plant and the thermal energy production from hard coal are also causing a considerable amount of aquatic eutrophication. The relative contribution of the landfilling process to the aquatic eutrophication potential of Scenario C is 62.73%, whereas it is 19.09% for the mineral fertiliser production & application, 13.54% for the electricity production from hard coal and 4.63% for the thermal energy production from hard coal.

The aquatic eutrophication potential of Scenario C is caused mostly by inorganic emissions to air and fresh water. 80.21% of the aquatic eutrophication potential is caused by nitrogen oxides emmission to air, followed by 11.51% of aquatic eutrophication potential because of ammonia emitted to air. The emissions to fresh water that cause aquatic eutrophication are phosphate, nitrate and ammonium/ammonia with 5.15%, 1.62 and 1.40% contribution, respectively.

The aquatic eutrophication potential of Scenario D is determined as 7,962 kg NO_3-Equiv. As it can be seen from Figure I.21, the major aquatic eutrophication potential stage of the Scenario D is the landfilling of the vegetable wastes, slaughterhouse wastes and grass, followed by mineral fertiliser production and application. In addition to those processes, the electricity production from natural gas in a power plant and thermal energy production from natural gas are also causing a considerable amount of aquatic eutrophication. The relative contribution of the landfilling process to the aquatic eutrophication potential is 69.71%, whereas it is 21.21% for the mineral fertiliser production & application, 6.83% for the electricity production from natural gas, and 2.25% for the thermal energy production.

Among the emissions; nitrogen oxide, ammonia and phosphate seems to be the biggest reason for the aquatic eutrophication potential, with 80.24%, 12.14% and 4.96% contribution, respectively.

The aquatic eutrophication potential of Scenario E is determined as 7,256 kg NO_3-Equiv. As it can be seen from Figure I.22, the major aquatic eutrophication potential stage of the Scenario E is the landfilling of the vegetable wastes, slaughterhouse wastes and grass, followed by mineral fertiliser production and application. The hydropower plant itself does not cause a considerable amount of aquatic eutrophication. The relative contribution of the landfilling process to the aquatic eutrophication potential is 76.49%, whereas it is 23.28% for the mineral fertiliser production & application and 0.24% for the hydropower plant.

Among the emissions; nitrogen oxide, ammonia and phosphate seems to be the biggest reason for the aquatic eutrophication potential, with 78.70%, 13.30% and 5.15% contribution, respectively.

The aquatic eutrophication potential of Scenario F is determined as 7,443 kg NO_3-Equiv. As it can be seen from Figure I.23, the major aquatic eutrophication potential stage of the Scenario F is the landfilling of the vegetable wastes, slaughterhouse wastes and grass, followed by mineral fertiliser production and application. The windpower plant itself does not cause a considerable amount of aquatic eutrophication. The relative contribution of the landfilling process to the aquatic eutrophication potential is 74.57%, whereas it is 22.69% for the mineral fertiliser production & application and 2.74% for the windpower plant.

Among the emissions; nitrogen oxide, ammonia and phosphate seems to be the biggest reason for the aquatic eutrophication potential, with 77.61%, 13.01% and 5.97% contribution, respectively.

The aquatic eutrophication potential of Scenario G is determined as 2,790 kg NO_3-Equiv. As it can be seen from Figure I.24, the major aquatic eutrophication potential stage of the Scenario G is the mineral fertiliser production and application, followed by the combined cycle unit. The gasification plant including the dryer, gasifier and the gas treatment unit does not cause a considerable amount of aquatic eutrophication. The relative contribution of the mineral fertiliser production & application to the aquatic eutrophication potential is 60.54%, whereas it is 33.53% for the combined cycle unit and 0.14% for the gasifier, dryer and the gas treatment unit.

Among the emissions; nitrogen oxide and ammonia emitted to air seem to be the biggest reason for the aquatic eutrophication potential, with 57.27% and 33.52% contribution, respectively. These emissions to air are followed by ammonium/ammonia and phosphorus release to fresh water with 3.91% and 2.65% contribution, respectively.

When all scenarios are compared side by side, it seems that the aquatic eutrophication of Scenario C is higher than the other scenarios. Almost all of the aquatic eutrophication potential of the scenarios comes from inorganic emissions to air. The lowest aquatic eutrophication potential is caused by Scenario B. The biogas produced in Scenario B can not meet the same net annual electricity production need as Scenario A and actually, the aquatic eutrophication potential of Scenario B is low because of the lower production of biogas and lower nitrogen content of the digestate compared to Scenario A.

It should be noted that the pilot plant will be operated according to the recipe defined for Scenario A. So; it can be concluded that the chosen pilot plant process for the utilization of the waste recipe, Scenario A, is the most environmentally process when compared to conventional energy production and waste disposal systems in terms of aquatic eutrophication potential.

When the Scenario A is compared with renewable energy sources such as hydropower plants, windpower plants and also with the thermochemical conversion technology of gasification, it still seems to be most environmentally friendly in terms of aquatic eutrophication potential. Since the Scenario A includes utilization of waste recipe, the environmental pollution potential of the agricultural and animal wastes are prevented which can occur because of the conventional disposal methods and also the mineral fertiliser usage is prevented because of the fertiliser value of the digestate. Even the environmental effects of hydropower plant or windpower plant are negligible when they are considered alone, the addition of environmental pollution potential because of the conventional management of the agricultural and animal wastes and usage of mineral fertiliser remove that advantage of those renewable energy sources. Consequently, Scenario E, F and G become less environmentally friendly when compared to the main scenario A.

The aquatic eutrophication potential reductions achieved by Scenario A with respect to other scenarios can be summarised as; 81% reduction compared to Scenario C, 79% reduction compared to Scenario D, 77% reduction compared to Scenario E, 78% reduction compared to Scenario F and 40% reduction compared to Scenario G. In conclusion, if the waste recipe is utilised in an AD plant with biogas recovery system instead of fossil fuel and other renewable energy sources mentioned in this study, at least 40% reductions will be achieved in terms of aquatic eutrophication potential.

3.4.2.4. Terrestrial Eutrophication Potential. Each ecosystem and each of its species has its own level of nutrients that relates to optimum growth. Availability of nutrients in excess of this optimum or critical load leads to a change of the species composition and hence to an unwanted change in the character of the given ecosystem. Normally, biological growth in terrestrial ecosystems is limited by nitrogen. In principle, most compounds containing nitrogen will thus contribute to terrestrial eutrophication. For natural soils, atmospheric deposition provides the main man-made supply of nitrogen (and other nutrients). In practice, only air-borne emissions will contribute to eutrophication of terrestrial natural ecosystems.

The site-generic, as well as the site-dependent, EDIP2003 eutrophication potentials of an emission are expressed as the area of terrestrial ecosystem within the full deposition area that is brought to exceed the critical load of eutrophication as a consequence of the emission (area of unprotected ecosystem = m^2 UES) [Hauschild and Potting, 2005].

The terrestrial eutrophication potential of Scenario A is 157,434 m^2 UES. As it can be seen from Figure I.26, the major terrestrial eutrophication potential of the pilot plant in Scenario A comes from the digested matter application in agriculture, followed by the cogeneration unit. The relative contribution of the digested matter application in agriculture is 68.37% for the liquid fertiliser and 14.75% for the solid fertiliser, whereas it is 8.26% for the cogeneration unit to the terrestrial eutrophication potential. It is obviously seen that the pretreatment of the recipe and the transportation of the raw materials to and from the pilot plant and the AD unit has low consideration to terrestrial eutrophication potential.

The terrestrial eutrophication potential of Scenario A is caused by inorganic emissions to air. 83.42% of the terrestrial eutrophication potential is caused by ammonia emitted to air, followed by 16.58% because of nitrogen oxides released to air.

The Scenario B includes the AD of only cattle manure instead of the same amount of recipe included in Scenario A. As seen from Figure I.27, the lower amount of digested matter and biogas production in Scenario B compared to Scenario A results in lower terrestrial eutrophication potential (120,927 m^2 UES).

The terrestrial eutrophication potential of Scenario C is 540,070 m^2 UES. As it can be seen from Figure I.28, the major terrestrial eutrophication potential stage of the Scenario C is the landfilling of the vegetable wastes, slaughterhouse wastes and grass, followed by the mineral fertiliser production and application. In addition to those processes, the electricity production from hard coal in a power plant and the thermal energy production from hard coal are also causing a considerable amount of terrestrial eutrophication. The relative contribution of the landfilling process to the terrestrial eutrophication potential of Scenario C is 57.18%, whereas it is 26.39% for the mineral fertiliser production & application, 12.12% for the electricity production from hard coal, and 4.31% for the thermal energy production from hard coal.

Among the emissions; nitrogen oxides and ammonia are the biggest reason for the terrestrial eutrophication potential, with 77.25% and 22.75% contribution, respectively.

The terrestrial eutrophication potential of Scenario D is 492,206 m^2 UES. As it can be seen from Figure I.29, the major terrestrial eutrophication potential stage of the Scenario D is the landfilling of the vegetable wastes, slaughterhouse wastes and grass, followed by mineral fertiliser production and application. In addition to those processes, the electricity production from natural gas in a power plant and thermal energy production from natural gas are also causing a considerable amount of terrestrial eutrophication. The relative contribution of the landfilling process to the terrestrial eutrophication potential is 62.74%, whereas it is 28.95% for the mineral fertiliser production & application, 6.20% for the electricity production from natural gas, and 2.11% for the thermal energy production.

Among the emissions; nitrogen oxide and ammonia are the biggest reason for the terrestrial eutrophication potential, with 76.31% and 23.69% contribution, respectively.

The terrestrial eutrophication potential of Scenario E is 452,135 m^2 UES. As it can be seen from Figure I.30, the major terrestrial eutrophication potential stage of the Scenario E is the landfilling of the vegetable wastes, slaughterhouse wastes and grass, followed by mineral fertiliser production and application. The hydropower plant itself does not cause a considerable amount of terrestrial eutrophication. The relative contribution of the landfilling process to the terrestrial eutrophication potential is 68.30%, whereas it is 31.52% for the mineral fertiliser production & application and 0.17% for the hydropower plant.

Among the emissions; nitrogen oxide and ammonia are the biggest reason for the terrestrial eutrophication potential, with 74.26% and 25.74% contribution, respectively.

The terrestrial eutrophication potential of Scenario F is 456,458 m^2 UES. As it can be seen from Figure I.31, the major terrestrial eutrophication potential stage of the Scenario F is the landfilling of the vegetable wastes, slaughterhouse wastes and grass, followed by mineral fertiliser production and application. The windpower plant itself does not cause a considerable amount of terrestrial eutrophication.

The relative contribution of the landfilling process to the terrestrial eutrophication potential is 67.66%, whereas it is 31.22% for the mineral fertiliser production & application, and 1.12% for the windpower plant.

Among the emissions; nitrogen oxide and ammonia are the biggest reason for the terrestrial eutrophication potential, with 74.41% and 25.59% contribution, respectively.

The terrestrial eutrophication potential of Scenario G is 206,735 m^2 UES. As it can be seen from Figure I.32, the major terrestrial eutrophication potential stage of the Scenario G is the mineral fertiliser production and application, followed by the combined cycle unit. The gasification plant including the dryer, gasifier and the gas treatment unit does not cause a considerable amount of terrestrial eutrophication. The relative contribution of the mineral fertiliser production & application to the terrestrial eutrophication potential is 68.94%, whereas it is 26.53% for the combined cycle unit and 0.07% for the gasifier, dryer and the gas treatment unit.

Among the emissions; ammonia and nitrogen oxide are the biggest reason for the terrestrial eutrophication potential, with 54.56% and 45.44% contribution, respectively.

When all scenarios are compared side by side, it is apparent that the scenario which has the highest terrestrial eutrophication potential is Scenario C; whereas the lowest terrestrial eutrophication potential is caused by Scenario B. The biogas produced in Scenario B can not meet the same net annual electricity production need as Scenario A and actually, the terrestrial eutrophication potential of Scenario B is low because of the lower nitrogen content of the digested matter and lower production of biogas compared to Scenario A. It should be noted that the pilot plant will be operated according to the recipe defined for Scenario A. So; it can be concluded that the chosen pilot plant process for the utilization of the waste recipe, Scenario A, is the most environmentally process when compared to conventional energy production and waste disposal systems in terms of terrestrial eutrophication potential.

When the Scenario A is compared with renewable energy sources such as hydropower plants, windpower plants and also with the thermochemical conversion technology of gasification, it still seems to be most environmentally friendly in terms of terrestrial eutrophication potential.

Since the Scenario A includes utilization of waste recipe, the environmental pollution potential of the agricultural and animal wastes are prevented which can occur because of the conventional disposal methods and also the mineral fertiliser usage is prevented because of the fertiliser value of the digestate. Even the environmental effects of hydropower plant or windpower plant are negligible when they are considered alone, the addition of environmental pollution potential because of the conventional management of the agricultural and animal wastes and usage of mineral fertiliser remove that advantage of those renewable energy sources. Consequently, Scenario E, F and G become less environmentally friendly when compared to the main Scenario A.

The terrestrial eutrophication potential reductions achieved by Scenario A with respect to other scenarios can be summarised as; 71% reduction compared to Scenario C, 68% reduction compared to Scenario D, 65% reduction compared to Scenario E, 66% reduction compared to Scenario F and 24% reduction compared to Scenario G.

In conclusion, if the waste recipe is utilised in an AD plant with biogas recovery system instead of fossil fuel and other renewable energy sources mentioned in this study, at least 24% reductions will be achieved in terms of terrestrial eutrophication potential.

3.4.2.5. Photochemical Ozone Formation - Impact on Vegetation. When solvents and other volatile organic compounds are released to the atmosphere, most of them are degraded within a few days to weeks. Initiated by sunlight, nitrogen oxides (NO_x) and volatile organic compounds (VOC_s) react to form ozone. Because of its high reactivity, ozone attacks organic substances present in plants and animals or materials exposed to air leading to an increased frequency of humans with problems in the respiratory tract and reduced agricultural yield.

For vegetation, the impact is expressed as the AOT40, the accumulated exposure (duration times exceedance of threshold) above the threshold of 40 ppb times the area that is exposed as a consequence of the emission. The threshold of 40 ppb is chosen as an exposure level below which no or only small effects occur. The unit for vegetation exposure is m^2 UES*ppm*hours [Hauschild and Potting, 2005].

The photochemical ozone formation - impact on vegetation potential of all scenarios are given and compared below.

The photochemical ozone formation - impact on vegetation potential of Scenario A is determined as 2,073,767 m^2 UES*ppm*hours. As it can be seen from Figure I.34, the major photochemical ozone formation - impact on vegetation potential of the pilot plant in Scenario A comes from the cogeneration unit, followed by the digested matter application in agriculture.

The relative contribution of the cogeneration unit to the photochemical ozone formation - impact on vegetation potential is 48.48%, whereas it is 14.25% for solid fertiliser spreading and 8.85% for liquid fertiliser spreading to the field and 10.13% for the digestion unit itself.

It is obviously seen that the pretreatment of the recipe and the transportation of the raw materials to and from the pilot plant and the AD unit has low consideration to photochemical ozone formation - impact on vegetation potential.

The photochemical ozone formation - impact on vegetation potential of Scenario A is caused mostly by inorganic (90.16%) and organic emissions (9.84%) to air. 89.18% of the photochemical ozone formation - impact on vegetation potential is caused by nitrogen oxides emitted to air, followed by 7.18% by NMVOCs, 2.65% by methane and 0.98% by carbon monoxide released to air.

The Scenario B includes the AD of only cattle manure instead of the same amount of recipe included in Scenario A. As seen from Figure I.35, the lower amount of digested matter and biogas production in Scenario B compared to Scenaro A results in lower photochemical ozone formation - impact on vegetation potential (1,438,700 m^2 UES*ppm*hours).

The photochemical ozone formation - impact on vegetation potential of Scenario C is determined as 43,176,680 m^2 UES*ppm*hours. As it can be seen from Figure I.36, the major photochemical ozone formation - impact on vegetation potential stage of the Scenario C is the landfilling of the vegetable wastes, slaughterhouse wastes and grass, followed by the electricity production from hard coal in a power plant. In addition to those processes, the thermal energy production from hard coal and the mineral fertiliser production and application are also causing a considerable amount of photochemical ozone formation - impact on vegetation.

The relative contribution of the landfilling process to the photochemical ozone formation - impact on vegetation potential of Scenario C is 64.48%, whereas it is 19.07% for the electricity production from hard coal, it is 6.74% for the thermal energy production from hard coal and 5.54% for the mineral fertiliser production & application.

Among the emissions; nitrogen oxides and methane are the biggest reason for the photochemical ozone formation - impact on vegetation potential, with 68.47% and 21.76% contribution respectively.

The photochemical ozone formation - impact on vegetation potential of Scenario D is determined as 37,243,079 m^2 UES*ppm*hours. As it can be seen from Figure I.37, the major photochemical ozone formation - impact on vegetation potential stage of the Scenario D is the landfilling of the vegetable wastes, slaughterhouse wastes and grass, followed by the electricity production from natural gas in a power plant. In addition to those processes, the mineral fertiliser production and application and the poultry manure management are also causing a considerable amount of photochemical ozone formation - impact on vegetation. The relative contribution of the landfilling process to the photochemical ozone formation - impact on vegetation potential is 74.75%, whereas it is

10.60% for the electricity production from natural gas, it is 6.42% for the mineral fertiliser production & application and 3.88% for the poultry manure management.

Among the emissions; nitrogen oxide, methane and NMVOCs are the biggest reason for the photochemical ozone formation - impact on vegetation potential, with 71.47%, 16.08% and 11.67% contribution, respectively.

The photochemical ozone formation - impact on vegetation potential of Scenario E is determined as 32,094,040 m^2 UES*ppm*hours. As it can be seen from Figure I.38, the major photochemical ozone formation - impact on vegetation potential stage of the Scenario E is the landfilling of the vegetable wastes, slaughterhouse wastes and grass, followed by the mineral fertiliser production and application. The poultry and cattle manure management are also causing a considerable amount of photochemical ozone formation - impact on vegetation.

However, the hydropower plant itself does not cause a considerable amount of chemical ozone formation - impact on vegetation. The relative contribution of the landfilling process to the photochemical ozone formation - impact on vegetation potential is 86.75%, whereas it is 7.45% for the mineral fertiliser production & application and 4.51% for the poultry manure management. The contribution of the hydropower plant is just 0.20% of the total photochemical ozone formation - impact on vegetation potential of Scenario E.

Among the emissions; nitrogen oxide, methane and NMVOCs are the biggest reason for the photochemical ozone formation - impact on vegetation potential, with 74.13%, 13.36% and 11.66% contribution, respectively.

The photochemical ozone formation - impact on vegetation potential of Scenario F is determined as 32,490,526 m^2 UES*ppm*hours. As it can be seen from Figure I.39, the major photochemical ozone formation - impact on vegetation potential stage of the Scenario F is the landfilling of the vegetable wastes, slaughterhouse wastes and grass, followed by the mineral fertiliser production and application. The poultry manure management is also causing a considerable amount of photochemical ozone formation -

impact on vegetation. However, the windpower plant itself does not cause a considerable amount of chemical ozone formation - impact on vegetation. The relative contribution of the landfilling process to the photochemical ozone formation - impact on vegetation potential is 85.69%, whereas it is 7.36% for the mineral fertiliser production & application and 4.45% for the poultry manure management. The contribution of the windpower plant is just 1.41% of the total photochemical ozone formation - impact on vegetation potential of Scenario F.

Among the emissions; nitrogen oxide, methane and NMVOCs are the biggest reason for the photochemical ozone formation - impact on vegetation potential, with 74.08%, 13.41% and 11.62% contribution, respectively.

The photochemical ozone formation - impact on vegetation potential of Scenario G is determined as 6,992,883 m^2 UES*ppm*hours. As it can be seen from Figure I.40, the major photochemical ozone formation - impact on vegetation potential stage of the Scenario G is the combined cycle unit, followed by mineral fertiliser production and application. The gasification plant including the dryer, gasifier and the gas treatment unit does not cause a considerable amount of photochemical ozone formation - impact on vegetation potential.

The relative contribution of the combined cycle unit to the photochemical ozone formation - impact on vegetation potential is 55.63%, whereas it is 34.21% for the mineral fertiliser production & application and 0.18% for the gasifier, dryer and the gas treatment unit.

Among the emissions; nitrogen oxide, methane and NMVOCs are the biggest reason for the photochemical ozone formation - impact on vegetation potential, with 95.20%, 2.60% and 1.86% contribution, respectively.

When all scenarios are compared side by side, it is apparent that the scenario which has the highest photochemical ozone formation - impact on vegetation potential is Scenario C; whereas the lowest photochemical ozone formation - impact on vegetation potential is caused by Scenario B. The biogas produced in Scenario B can not meet the same net annual electricity production need as Scenario A and actually, the photochemical ozone formation - impact on vegetation potential of Scenario B is low because of the lower production of biogas and lower nitrogen content of the digested matter compared to Scenario A. It should be noted that the pilot plant will be operated according to the recipe defined for Scenario A. So; it can be concluded that the chosen pilot plant process for the utilization of the waste recipe, Scenario A, is the most environmentally process when compared to conventional energy production and waste disposal systems in terms of photochemical ozone formation - impact on vegetation potential.

When the Scenario A is compared with renewable energy sources such as hydropower plants, windpower plants and also with the thermochemical conversion technology of gasification, it still seems to be most environmentally friendly in terms of photochemical ozone formation - impact on vegetation potential. Since the Scenario A includes utilization of waste recipe, the environmental pollution potential of the agricultural and animal wastes are prevented which can occur because of the conventional disposal methods and also the mineral fertiliser usage is prevented because of the fertiliser value of the digestate.

Even the environmental effects of hydropower plant or windpower plant are negligible when they are considered alone, the addition of environmental pollution potential because of the conventional management of the agricultural and animal wastes and usage of mineral fertiliser remove that advantage of those renewable energy sources.

Consequently, Scenario E, F and G become less environmentally friendly when compared to the main Scenario A.

The Photochemical ozone formation - impact on vegetation potential reductions achieved by Scenario A with respect to other scenarios are given in the below table.

Table 3.34. Photochemical ozone formation - impact on vegetation potential reductions achieved by Scenario A with respect to other scenarios.

	Reductions (%) of Scenario A Compared to Other Scenarios				
	C	**D**	**E**	**F**	**G**
Flows	**95%**	**94%**	**94%**	**94%**	**70%**
Inorganic emissions to air	94%	93%	92%	92%	72%
Carbon monoxide	93%	93%	93%	93%	16%
Nitrogen oxides	94%	93%	92%	92%	72%
Organic emissions to air (group VOC)	98%	98%	97%	97%	35%
Group NMVOC to air	96%	97%	96%	96%	-15%
Methane	99%	99%	99%	99%	70%

In conclusion, if the waste recipe is utilised in an AD plant with biogas recovery system instead of fossil fuel and other renewable energy sources mentioned in this study, at least 70% reductions will be achieved in terms of photochemical ozone formation - impact on vegetation potential.

3.4.2.6. Stratospheric Ozone Depletion. Manmade emissions of halocarbons, i.e., CFCs, HCFCs, halons and other longlived gases containing chlorine and bromine increase the breakdown of stratospheric ozone, and the ozone content of the stratosphere is therefore falling. As a consequence of the thinning of the ozone layer, the intensity of hazardous ultraviolet radiation at the earth’s surface has increased over parts of the southern and northern hemispheres. This can have dangerous consequences in the form of increased frequency of skin cancer in humans and damage to the plants [Hauschild and Potting, 2005].

The overall stratospheric ozone depletion potential of Scenario A is determined as 0.01 kg R11-Equiv. As it can be seen from Figure I.42, the major stratospheric ozone depleting stage of the pilot plant in Scenario A is the agricultural application of the digestate and then the cogeneration unit and the AD unit.

The relative contribution of the agricultural application of the digestate to the stratospheric ozone depletion is 32.47% for solid fertiliser spreading, whereas it is 30.96% for the cogeneration and 26.56 % for the anaerobic digester itself.

It is obviously seen that the transportation and pretreatment of the recipe has low consideration to stratospheric ozone depletion.

The stratospheric ozone depletion of Scenario A is mostly caused by halogenated organic emissions to air. 86.37% of the stratospheric ozone depletion is caused by Halon 1301, followed by 8.50% of stratospheric ozone depletion because of Halon 1211.

The Scenario B includes the AD of only cattle manure instead of the same amount of recipe included in Scenario A. As seen from Figure I.43, lower amount of biogas and solid fertilizer produced in Scenario B when compared to Scenario A and this result in lower stratospheric ozone depletion (0.004 kg R11-Equiv.).

The stratospheric ozone depletion potential of Scenario C is determined as 0.65 kg R11-Equiv. As it can be seen from Figure I.44, the major stratospheric ozone depleting stage of the Scenario C is the landfilling of the vegetable wastes, slaughterhouse wastes and grass, followed by mineral fertiliser production and application. The relative contribution of the landfilling process to the stratospheric ozone depletion of Scenario C is 94.96%, whereas it is 3.63% for the mineral fertiliser production & application, 1.25% for the electricity production from hard coal and 0.15% for the thermal energy production from hard coal.

Among the emissions; Halon 1301 and Halon 1211 seems to be the biggest reason for the stratospheric ozone depletion, with 96.87% and 2.05% contribution, respectively.

The stratospheric ozone depletion potential of Scenario D is determined as 0.76 kg R11-Equiv. As it can be seen from Figure I.45, the major stratospheric ozone depletion stage of the Scenario D is the landfilling of the vegetable wastes, slaughterhouse wastes and grass, followed by electricity production from natural gas in a power plant. In addition to those processes, the mineral fertiliser production and application is also causing a considerable amount of stratospheric ozone depletion. The relative contribution of the landfilling process to the stratospheric ozone depletion of Scenario D is 81.99%, whereas it is 14.76% for the electricity production from natural gas, 3.13% for the mineral fertiliser production & application and 0.11% for the thermal energy production from natural gas.

Among the emissions; Halon 1301 and Halon 1211 seems to be the biggest reason for the stratospheric ozone depletion, with 82.97% and 15.63%, respectively.

The stratospheric ozone depletion potential of Scenario E is determined as 0.64 kg R11-Equiv. As it can be seen from Figure I.46, the major stratospheric ozone depletion stage of the Scenario E is the landfilling of the vegetable wastes, slaughterhouse wastes and grass, followed by the mineral fertiliser production and application. The hydropower plant itself does not cause a considerable amount of stratospheric ozone depletion. The relative contribution of the landfilling process to the stratospheric ozone depletion of Scenario E is 96.23%, whereas it is 3.68% for the mineral fertiliser production & application and just 0.08% for the hydropower plant itself. Among the emissions; Halon 1301 and Halon 1211 seems to be the biggest reason for the stratospheric ozone depletion, with 97.30% and 1.95%, respectively.

According to Pascale et al., the total stratospheric ozone depletion potential of a hydropower including the weir, intake, canal and forebay, the penstock, the powerhouse, turbine and outflow, and the control house and control & conditioning equipment are $5x10^{-7}$ g R11/kWh which is higher than the result of the above mentioned 0.08% of Scenario E.

The stratospheric ozone depletion potential of Scenario F is determined as 0.65 kg R11-Equiv. As it can be seen from Figure I.47, the major stratospheric ozone depletion stage of the Scenario F is the landfilling of the vegetable wastes, slaughterhouse wastes and grass, followed by the mineral fertiliser production and application. The windpower plant itself does not cause a considerable amount of stratospheric ozone depletion. The relative contribution of the landfilling process to the stratospheric ozone depletion of Scenario F is 95.73%, whereas it is 3.66% for the mineral fertiliser production & application and just 0.61% for the windpower plant itself. Among the emissions; Halon 1301 and Halon 1211 seems to be the biggest reason for the stratospheric ozone depletion, with 96.95% and 2.04%, respectively.

The stratospheric ozone depletion potential of Scenario G is determined as 0.02 kg R11-Equiv. As it can be seen from Figure I.48, the major stratospheric ozone depletion stage of the Scenario G is the mineral fertiliser production and application followed by raw material tranportation, combined cycle unit and the gasification unit. The relative contribution of the mineral fertiliser production & application to the stratospheric ozone depletion of Scenario G is 96.42%, whereas it is 1.92% for the raw material transportation, 0.78% for the combined cycle unit and just 0.46% for the gasifier, dryer and the gas treatment unit. Among the emissions; Halon 1301 and Halon 1211 seems to be the biggest reason for the stratospheric ozone depletion, with 57.38% and 38.49%, respectively.

When all scenarios are compared side by side, it is apparent that the scenario which has the highest stratospheric ozone depletion is Scenario D; whereas the lowest stratospheric ozone depletion is caused by Scenario B. The biogas produced in Scenario B can not meet the same net annual electricity production need as Scenario A and actually, the stratospheric ozone depletion of Scenario B is low because of the lower production of biogas and lower nitrogen content of the digestate compared to Scenario A. It should be noted that the pilot plant will be operated according to the recipe defined for Scenario A. So; it can be concluded that the chosen pilot plant process for the utilization of the waste recipe, Scenario A, is the most environmentally process when compared to conventional energy production and waste disposal systems in terms of stratospheric ozone depletion.

When the Scenario A is compared with renewable energy sources such as hydropower plants, windpower plants and also with the thermochemical conversion technology of gasification, it still seems to be most environmentally friendly in terms of stratospheric ozone depletion potential. Since the Scenario A includes utilization of waste recipe, the environmental pollution potential of the agricultural and animal wastes are prevented which can occur because of the conventional disposal methods and also the mineral fertiliser usage is prevented because of the fertiliser value of the digestate. Even the environmental effects of hydropower plant or windpower plant are negligible when they are considered alone, the addition of environmental pollution potential because of the conventional management of the agricultural and animal wastes and usage of mineral fertiliser remove that advantage of those renewable energy sources.

Consequently, Scenario E, F and G become less environmentally friendly when compared to the main scenario A. The stratospheric ozone depletion potential reductions achieved by Scenario A with respect to other scenarios can be summarised as; 99%

reduction compared to Scenario C, 99% reduction compared to Scenario D, 99% reduction compared to Scenario E, 99% reduction compared to Scenario F and 75% reduction compared to Scenario G. In conclusion, if the waste recipe is utilised in an AD plant with biogas recovery system instead of fossil fuel and other renewable energy sources mentioned in this study, at least 75% reductions will be achieved in terms of stratospheric ozone depletion potential.

The below table summarizes the characterization of all scenarios.

Table 3.35 Characterization results of all scenarios.

EDIP 2003 Characterisation Results	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Acidification potential [m^2 UES]	56,404	37,770	267,932	216,666	187,007	192,358	76,621
Aquatic eutrophication [kg NO$_3$-Equiv.]	1,669	1,262	8,846	7,962	7,256	7,443	2,790
Global warming [kg CO$_2$-Equiv.]	401,549	297,261	6,464,471	4,817,238	2,908,725	2,976,947	1,108,398
Photochemical ozone formation - impact on vegetation [m^2 UES*ppm*hours]	2,073,767	1,438,701	43,176,680	37,243,026	32,094,040	32,490,526	6,992,884
Stratospheric ozone depletion , [kg R11-Equiv.]	0.006	0.004	0.653	0.756	0.644	0.648	0.025
Terrestrial eutrophication [m^2 UES]	157,435	120,927	540,070	492,205	452,135	456,458	206,735

According to the above table and Figure I.50, it seems as if the photochemical ozone formation – impact on vegetation has the biggest environmental concern for Scenario C.

However, the characterisation results are given for each impact category with a different unit and so the environmental impacts should be compared relative to a common scale. For that purpose, the normalization phase below is conducted.

3.4.3. Normalisation

In the normalization step, the impact categories are normalised with a common reference that resembles the impact from an average person [Kirkeby, 2005]. In Table B.8, the normalization factors used according to EDIP 2003 are illustrated.

The results from the scenarios were all calculated as normalised potential impacts according to the EDIP 2003 methodology. The resultant normalised impact potentials for all scenarios are given in Figure J.1. From this figure, it is apparent that the biggest environmental impact potential of Scenario A and Scenario B comes from terrestrial eutrophication, whereas it is global warming for other scenarios.

In terms of the normalized impact values of global warming, Scenario C has the highest contribution among the scenarios. This is valid also for the acidification potential, photochemical ozone formation and aquatic& terrestrial eutrophication categories. However, for the stratospheric ozone depletion, the highest normalized impact value is observed for Scenario D.

3.4.4. Weighting

In the weighting stage, weights are assigned to the different impact categories and resources reflecting the relative importance. ("how important is it?") [Hauschild and Potting, 2005].

The EDIP 2003 methodology applies weighting factors on the basis of political environmental targets set by the Danish Government or by various international protocols. The weighting factors applied in the assessment according to EDIP 2003 methodology is given in Table B.9. The results from the scenarios were all calculated as weighted potential impacts according to the EDIP 2003 methodology. The resultant weighted impact potentials for all scenarios are given in Figure K.8 and Table 3.36.

According to the overall weighted environmental impact potential results, Scenario C has the highest contribution to the environmental pollution. This is valid for the global warming, acidification potential, aquatic eutrophication, photochemical ozone formation, and terrestrial eutrophication categories. For the stratospheric ozone depletion, Scenario D has the highest weighted environmental impact potential.

Table 3.36. Comparison of the Weighted Environmental Impact Potential of Scenarios.

EDIP 2003, Env. imp. eval. (PET W, EU 2004)	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Env. imp. eval.	**234.36**	**173.18**	**2,296.66**	**2,015.34**	**1,597.00**	**1,621.15**	**447.24**
Acidification potential	32.56	21.80	154.67	125.08	107.95	111.04	44.23
Aquatic eutrophication	35.11	26.54	186.08	167.47	152.62	156.55	58.68
Global warming	51.69	38.27	832.21	620.15	374.46	383.24	142.69
Photochemical ozone formation - impact on human health and materials	0.02	0.01	0.41	0.35	0.30	0.30	0.06
Photochemical ozone formation - impact on vegetation	19.70	13.67	410.18	353.81	304.89	308.66	66.43
Stratospheric ozone depletion	3.81	2.63	399.37	462.54	394.10	396.17	15.04
Terrestrial eutrophication	91.46	70.25	313.76	285.95	262.67	265.18	120.10

For Scenario A, the highest weighted environmental impact potential comes from the terrestrial eutrophication followed by global warming with 39.03% and 22.06% contribution, respectively. The aquatic eutrophication contributes only 14.98% of the total weighted environmental impact potential of Scenario A.

In terms of the process stages in Scenario A, the biggest environmental impact potential results from on field emissions of the liquid fertiliser, cogeneration unit, solid fertiliser, digestion unit and raw material transportation with 49.82 %, 17.44%, 15.20%, 4.57% and 2.81% of the total weighted environmental impact potential of Scenario A, respectively.

For Scenario B, the highest weighted environmental impact potential comes from the terrestrial eutrophication followed by the global warming potential with 40.57% and 22.10% contribution, respectively. In terms of the process stages in Scenario B, the biggest environmental impact potential results from on field emissions of the liquid & solid fertiliser, cogeneration unit, manure transportation and digestion units with 55.00%, 12.75%, 9.68%, 6.76% and 6.18% of the total weighted environmental impact potential of Scenario B, respectively.

For Scenario C, the biggest portion of the environmental concern results from the global warming and the photochemical ozone formation - impact on vegetation impacts. 36.24% of the total weighted environmental impact potential comes from the global warming; whereas 17.86% comes from the photochemical ozone formation - impact on vegetation. In terms of the process stages in Scenario C, the biggest weighted environmental impact potential results from the landfilling of the vegetable wastes, slaughterhouse wastes, grass followed by electricity production from hard coal, mineral fertiliser production & application and then thermal energy production from hard coal with 54.34%, 22.54%, 12.97% and 8.06%, respectively.

For Scenario D, the biggest portion of the environmental concern results from the global warming and stratospheric ozone depletion impacts. 30.77% of the total weighted environmental impact potential comes from the global warming; whereas 22.95% comes from the stratospheric ozone depletion. In terms of the process stages in Scenario D, the biggest weighted environmental impact potential results from the landfilling of the vegetable wastes, slaughterhouse wastes, grass followed by electricity production from hard coal, mineral fertiliser production & application and then thermal energy production from hard coal with 61.92%, 15.96%, 14.78% and 4.96%, respectively.

For Scenario E, the biggest portion of the environmental concern results from the stratospheric ozone depletion and global warming impacts. 24.68% of the total weighted environmental impact potential comes from the stratospheric ozone depletion; whereas 23.45% comes from the global warming. In terms of the process stages in Scenario E, the biggest weighted environmental impact potential results from the landfilling of the vegetable wastes, slaughterhouse wastes, grass followed by mineral fertiliser production & application and then emissions from the conventional management of poultry and cattle manure with 78.14%, 18.65%, 2.50% and 0.50%, respectively. The weighted environmental impact potential of the reservoir hydropower plant is the lowest among the processes included in Scenario E representing just 0.20% of the total weighted impact potential.

For Scenario F, the biggest portion of the environmental concern results from the stratospheric ozone depletion and global warming impact categories. 24.44% of the total weighted environmental impact potential comes from the stratospheric ozone depletion; whereas 23.64% comes from the global warming. In terms of the process stages in Scenario F, the biggest weighted environmental impact potential results from the landfilling of the vegetable wastes, slaughterhouse wastes, grass followed by mineral fertiliser production & application and then emissions of conventional poultry manure management with 76.98%, 18.37% and 2.46%, respectively. The weighted environmental impact potential of the windpower plant follows the emissions of poultry manure conventional management with 1.69% of the total weighted impact.

For Scenario G, the biggest portion of the environmental concern results from the global warming and terrestrial eutrophication impact categories. 31.90% of the total weighted environmental impact potential comes from the global warming and the terrestrial eutrophication contributes 26.85% of the total weighted environmental impact potential of Scenario G. In terms of the process stages in Scenario G, the biggest weighted environmental impact potential results from the mineral fertiliser production & application, followed by the combined cycle unit and raw material transportation with 66.60%, 27.78% 5.37%, respectively. The weighted environmental impact potential of the gasification unit including the the dryer and gas treatment unit follows the emissions of material transportation with just 0.13 % of the total weighted impact.

The weighted results show that Scenario C has the biggest total weighted environmental impact potential (2,297 PET W, EU 2004) whereas Scenario B has the lowest potential. Since Scenario B has lower biogas production rate than Scenario A, the electricity production is not as high as Scenario A. So, it is not considered for the comparison made with the fossil fuel and renewable energy scenario results. In this respect, it can be stated that the Scenario A representing the pilot plant operated with the waste recipe has the lowest total weighted environmental impact potential when compared to other scenarios with the same primary service.

When the total weighted environmental impact potential of Scenario C is evaluated in detail, even the impact potential of only electricity production and thermal energy production from hard coal without the conventional management of agricultural and animal wastes is 702.89 PET W, EU 2004 which is already higher than the overall weighted impact potential of Scenario A (234.36 PET W, EU 2004). Among the fossil fuel resources, hard coal has more environmental impact potential than natural gas since the total weighted environmental impact potential values of Scenario C (2,297 PET W, EU 2004) is higher than Scenario D (2,015 PET W, EU 2004). In addition, the same conclusion for Scenario C in terms of only electricity production and thermal energy production from hard coal without the conventional management of agricultural and animal wastes is valid for Scenario D; since these processes have a total weighted environmental impact potential of 421.57 PET W, EU which is also higher than the overall weighted impact potential of Scenario A.

Among the renewable resources, Scenario G including gasification has the lowest environmental impact potential (447 PET W, EU 2004) followed by Scenario E including hydropower plant (1,597 PET W, EU 2004) and Scenario F including windpower plant (1,621 PET W, EU 2004). The reason for that is Scenario G utilizes the agricultural and animal wastes for energy production in the gasification unit while those wastes are managed in conventional methods in Scenario E and F.

The renewable energy production plants (Scenario E and F) are expected to have lower environmental impacts compared to the AD. However the conventional waste disposal systems included in those renewable energy scenarios caused the overall environmental impact potential to be higher than the AD scenario. The reason for that is the agricultural and animal wastes are utilized for both energy and organic fertiliser need in Scenario A. On the other hand, it should be emphasized that the internal energy need of the gasification unit is much higher than the AD resulting in more raw material need in order to produce same amount of excess electricity connected to grid.

This is one other reason why the overall weighted environmental impact potential of the Scenario G is higher than Scenario A. Even the agricultural and animal wastes are also utilised in the gasification process of Scenarios G, the remaining ash can not be used as organic fertiliser and so it is disposed to landfill and consequently the usage of mineral fertiliser is needed. This is also a reason for Scenario G to have additional environmental consequences. The below table summarizes the reductions achieved with Scenario A compared to other scenarios in terms of the weighted environmental potentials and also compares the the potential environmental benefits with the goals of the LCA study.

Table 3.37. Comparison of Scenario A with the other scenarios and with the goal of the study in terms of the Weighted Environmental Impact Potentials.

EDIP 2003, Env. imp. eval. (PET W, EU 2004)	**Minimum Goal**	**Reductions (%) of Scenario A compared to other scenarios**				
		C	**D**	**E**	**F**	**G**
Env. imp. eval.	45%	**90%**	**88%**	**85%**	**86%**	**48%**
Acidification potential	25%	79%	74%	70%	71%	26%
Aquatic eutrophication	40%	81%	79%	77%	78%	40%
Global warming	60%	94%	92%	86%	87%	64%
Photochemical ozone formation - impact on vegetation	70%	95%	94%	94%	94%	70%
Stratospheric ozone depletion	75%	99%	99%	99%	99%	75%
Terrestrial eutrophication	20%	71%	68%	65%	66%	24%

The environmental impact potential reductions show that choosing the AD for the treatment of the waste recipe lead to substantial environmental benefits compared to the energy production from fossil fuel resources and renewable energy production plants.

4. LIFE CYCLE COSTING (LCC) METHODOLOGY

4.1. Introduction

The purpose of this study is to determine if the AD plant and biogas recovery system can be economically beneficial. The project covers Life Cycle Costing Comparison of the two scenarios (Scenario A and Scenario B) including the AD plant and biogas recovery system which is the most environmentally friendly when compared with the energy production from fossil fuel resources, renewable energy sources with the conventional waste disposal systems (Scenario C, D, E, F and G).

The LCC analysis takes the investment costs and costs in operation of all phases into account. In general, LCC yields present value of current and future expenditures for procurement of building and operating and maintaining the building through its life. As the operational costs make up the main part of the total costs over the whole lifetime of a building, the LCC comparison of different scenarios creates the necessary transparency for the decision-making process. [Hunkeler et al., 2008].

Besides constructional and operational costs, revenues from the by-products of the AD plant and biogas recovery system are also considered for the LCC study. The expected incomes of the AD plant and biogas recovery system come from selling the produced heat and electricity and also the organic fertiliser.

In this study, it is shown that utilizing animal and agricultural wastes by the AD plant and biogas recovery system will not only provide real benefits in terms of the environmental effects, but also in terms of economic benefits.

4.2. Cost Analysis

The main items considered for the cost of an AD and biogas recovery system is the investment cost and operational costs. On the other hand, selling of the produced electricity and heat and also the organic fertiliser will provide an income during the operation of the plant which should be considered for the life cycle costing of the pilot plant.

4.2.1. Investment Costs of the Pilot Plant

First of all, the projection and design of the AD and biogas recovery system can be considered as the investment cost. Not only the construction of the plant units and provision and installation of the electromechanical equipment, but also the preparation, digging and filling of the ground is considered as part of the investment costs. Besides, the technical and legal permissions and the costs for the connection of the produced electricity to the power grid are also considered as the main investment costs. The main investment cost of the pilot plant will be 1,400,000.00 Euro including four main units which are;

- Pretreament Units
    - Primary Storage and Mixing
    - Grinding and Mixing
- Anaerobic Digesters
- Separation Unit and Final Storage
- 350 kW Cogeneration Unit

4.2.2. Operational Costs of the Pilot Plant

The operational costs of the pilot plant consist of the following items;

- *Operational personnel costs*: are calculated based on three (3) shifts each with one operating personnel. There will be three (3) employees in total each with 2000 Euro/month salary including annual social security and other social services.
- *Maintenance costs*: Assumed as 3% of the equipment cost [Kaya et al., 2009].
- *Insurance and taxes c*osts: Assumed as 7.5% of the investment cost and assigned as overhead cost [Kaya et al., 2009].
- *Transportation costs*: The supply of the raw materials is assumed as three Euro/ton including the transportation cost [Kaya et al., 2009].

4.2.3. Incomes from the Pilot Plant

The following items will provide an income during the operation of the Pilot Plant:

- *Electricity sales*: with a unit selling price of 0.094 €/kWh [Resmi Gazete, 2010]
- *Profit from Carbon Trade (Green Certificate)*: with a unit selling price of 0,020 €/kWh [Kaya et al., 2009]
- *Heat sales*: with a unit selling price of 0.030 €/kWh [Kaya et al., 2009]
- *Organic fertiliser sales*: with a unit selling price of 30 €/ton [Kaya et al., 2009]

AD is cost-competitive when compared to conventional waste management practices. These systems can also have financially attractive payback periods of three to seven years when energy gas uses are employed. Conventional waste systems, in contrast, do not provide this payback opportunity and become sunk costs to the farm enterprise [U.S.EPA, 2002].

The investment cost, operational cost and income of the Pilot Plant (Scenario A) that utilizes both agricultural and animal wastes are summarized in Table L.1; where it is shown that the pay back period of the Pilot Plant will be 5.3 years.

4.3. LCC Analysis with GaBi4

The above cost information is assigned to GaBi4 flows in order to make the LCC analysis of the Pilot Plant. The investment and operational costs are assigned as negative values, whereas the income values are considered as positive figures.

A basic distinction is made here between three different flow types, each also with a differing cost structure. In addition to the elementary flows generally used, which bear the material costs, there are also machines and people to which machine costs and personnel costs are assigned.

The inputs and outputs of a process with cost information are included in the flow costs table. In addition, machine and personnel costs are assigned to the process. The cogeneration unit process is shown in APPENDIX M as an example to flow costs, machine costs and personnel cost information. Cost Information for the Unit Process of Cogeneration Unit is given in Table M.1.

4.3.1. Flow Cost

Elementary flows are assigned to material cost information. The price, the costs and the overhead costs are important for the later assessment of material costs. The unit flow cost of the raw material, "cattle manure", is given in Table M.2 as an example. The cost is calculated in the following way:

$$\text{Price} = \text{Purchase price} + \text{Freight charges} + \text{Packaging} + \text{Insurance} - \text{Discounts} \qquad (4.1)$$

$$\text{Overhead Ratio} = \text{Direct cost per period} / \text{overhead costs per period} \qquad (4.2)$$

$$\text{Overhead costs} = \text{price} * \text{overhead ratio} \qquad (4.3)$$

When all cost information for the flows are assigned to GaBi4, the Figure M.1 is obtained showing the total of all input and output flows of the pilot plant in Scenario A and Scenario B.

4.3.2. Machine Cost

The cost information for the machines is assigned to machine flow objects in GaBi4. The hourly machine ratio, the overhead costs and the total costs are important for the later assessment of material costs. The following scheme is used to calculate these values. Here, the utilization period is assigned for each equipment/unit with an annual nominal working period of 8,000 hrs/yr. The interest rate is assumed as 5%, while the overhead ratio (insurance and taxes) and the annual maintenance are considered as 7.5% and 3% of the equipment replacement value, respectively. The machine cost of the cogeneration unit is given as an example in Table M.3. The hourly machine ratio is calculated as follows:

$$\text{Calc. Depreciation} = \text{replacement value} / (\text{useful life} * \text{nominal hours}) \tag{4.4}$$

$$\text{Maintenance costs} = (\text{replacement value} * \text{total maintenance}) / \text{nominal hours} \tag{4.5}$$

$$\text{Calc. interest} = ((\text{replacement value} / 2) * \text{calc. interest rate}) / \text{nominal hours} \tag{4.6}$$

$$\text{Machine ratio} = \text{Calc. Depreciation} + \text{Maintenance costs} + \text{Calc. interest} + \text{Rent charges} + \text{Vehicle costs} \tag{4.7}$$

$$\text{Overhead ratio} = \text{Direct costs per period} / \text{overhead costs per period} \tag{4.8}$$

$$\text{Overhead costs} = \text{machine ratio} * \text{overhead ratio} \tag{4.9}$$

When all machine cost information is assigned to GaBi4, the Figure M.2 is obtained for the pilot plant units in Scenario A and Scenario B.

4.3.3. Personnel Cost

The cost information for the personnel is assigned to personnel flow objects in GaBi4. The hourly wage, the overhead cost ratio and the total costs are important for the later assessment of personnel costs. The below scheme is used to calculate these values. The personnel cost of the cogeneration unit is given as an example in Table M.4.

The hourly wage is calculated in the following way [GaBi4, 2003]:

$$\text{Wage costs} = \text{Gross pay} - \text{AG\_Ant.\_Soc. Sec} - \text{Other social sec. costs} \tag{4.10}$$

$$\text{Wage costs} = \text{Wage costs} / \text{annual nominal hours} \tag{4.11}$$

$$\text{Overhead ratio} = \text{Direct costs per period} / \text{overhead costs per period} \tag{4.12}$$

$$\text{Total costs} = \text{hourly wage} * \text{overhead ratio} \tag{4.13}$$

When all personnel cost information is assigned to GaBi4, the Figure M.3 is obtained for the pilot plant units in Scenario A and Scenario B. The personnel costs are same for both scenarios.

4.3.4. Evaluation of the Flow Cost, Machine Cost and Personnel Costs

When all cost information are gathered in a common figure and compared for both scenarios, it is obvious that even the Scenario A needs higher investment cost because of the higher capacity of the cogeneration unit and because of an additional grinding and mixing unit for the agricultural wastes, the income of Scenario A is much higher than Scenario B thanks to the higher amount of biogas produced.

Consequently, this comparison points out that the economical benefits of using the waste recipe in the Pilot Plant are much higher than utilizing only the cattle manure because of higher production of biogas resulting in higher income from electricity and heat sales.

When all flow, machine and personnel cost information are assigned to GaBi4, the Figure M.4 is obtained for the pilot plant units in Scenario A and Scenario B.

5. CONCLUSIONS

This study aims to make the environmental and economical assessment of the pilot plant which has been constructed in Kocaeli that consists of an AD plant and biogas recovery system where the animal and agricultural wastes will be used as raw materials. The raw materials to be used as feed are cattle manure, poultry manure, slaughterhouse wastes, vegetable wastes and grass.

The potential environmental impacts of these wastes that are anerobically digested in the pilot plant are evaluated with the implementation of Life Cycle Assessment (LCA); whereas the economical evaluation of the plant is carried out with Life Cycle Costing (LCC). GaBi4 software is used as the LCA & LCC tool and EDIP 2003 is used as the LCA methodology to measure, evaluate and describe the possible environmental consequences of the systems.

The functional unit of the LCA study is “benefits of 10,680 ton/year agricultural and animal wastes including the primary service of electricity production for at least 850 houses each with four (4)-family members”.

In addition to the determination of the emissions of the pilot plant, this study also covers the comparison of the emissions in case of different feed characterization and the comparison of the potential environmental impacts with that of the conventional fossil fuel systems and other renewable energy sources. For that purpose, seven scenarios are prepared.

The system in the main scenario (Scenario A) includes processes directly related to the AD and biogas recovery system of the waste recipe; in other words, the pilot plant itself. In Scenario B, only cattle waste with the same amount of the waste recipe is considered as the feed to the pilot plant.

The Scenario C and D are prepared in order to compare the potential environmental effects of the pilot plant with that of not only the conventional fossil fuel systems (hard coal PP and natural gas PP, respectively), but also the conventional waste management systems (conventional cattle and poultry manure management; landfilling of slaughterhouse wastes, vegetable wastes and grass) and the mineral fertiliser production & application in agriculture.

Scenario E and Scenario F include mainly the electricity production from hydropower plant (Scenario E) and wind power plant (Scenario F); on the other hand, these two scenarios also include the disposal of agricultural and animal wastes in conventional methods besides the production and agricultural application of the chemical fertiliser for wheat production. The last scenario (Scenario G) includes biomass integrated gasification combined cycle of the waste recipe and also the production and agricultural application of the mineral fertiliser.

The results of the LCA study are summarized according to five environmental category indicators which are global warming, acidification, aquatic eutrophication, terrestrial eutrophication, photochemical ozone formation (impact on vegetation) and stratospheric ozone depletion. The aggregated potential environmental impacts are normalized for person equivalent and then weighted according to political reduction targets.

The weighted results show that Scenario C has the biggest total weighted environmental impact potential (2,297 PET W, EU 2004) whereas Scenario B has the lowest potential. Since Scenario B has lower biogas production rate than Scenario A, the electricity production is not as high as Scenario A. So, it is not considered for the comparison made with the fossil fuel and renewable energy scenario results. In this respect, it can be stated that the Scenario A representing the pilot plant operated with the waste recipe has the lowest total weighted environmental impact potential when compared to other scenarios with the same primary service. If the scenarios are ranked from the most to less environmentally friendly one, the first rank will be of Scenario A (waste recipe digestion), followed by Scenario G (IGCC plant), Scenario E (hydro PP), Scenario F (wind PP), Scenario D (natural gas PP) and Scenario C (coal PP).

However, if the wastes other than the cattle manure included in the waste recipe were considered as conventionally managed in the system boundary of the Scenario B, the emissions due to the conventional management of poultry manure and landfilling of slaughterhouse wastes, vegetable wastes and grass would cause Scenario B to be less environmentally friendly and the scenario ranking from the most to less environmentally friendly, would be of Scenario A (waste recipe digestion), followed by Scenario G (IGCC plant), Scenario B (cattle manure digestion), Scenario E (hydro PP), Scenario F (wind PP), Scenario D (natural gas PP) and Scenario C (coal PP). Considering the conventional management of poultry manure and landfilling of slaughterhouse wastes, vegetable wastes and grass in Scenario B; Scenario A would have at least 84% saving in terms of weighted impact potentials when compared to Scenario B.

The use of fossil fuels for energy production causes many environmental pollution problems. The greenhouse gases emitted during the conventional energy production processes threaten our world in terms of global climate change. According to the potential impact evaluation results, Scenario C utilizing hard coal as the energy source has the highest contribution to the global warming, acidification potential, aquatic eutrophication, photochemical ozone formation, and terrestrial eutrophication categories. Only for the stratospheric ozone depletion, Scenario D utilizing natural gas as the energy source has the highest weighted environmental impact potential. Among the fossil fuel resources, hard coal has more environmental impact potential than natural gas. When the total weighted environmental impact potential of Scenario C and Scenario D are evaluated in detail, even the impact potential of only the electricity and thermal energy production from hard coal or natural gas without the conventional management of wastes and without the production & agricultural application of mineral fertiliser are higher than the overall weighted impact potential of Scenario A (234.36 PET W, EU 2004).

Biogas production through AD of agricultural and animal wastes results in high reduction of greenhouse gas emissions. In addition to the fossil fuel replacement by biogas, GWP is also decreased from the reduced methane and nitrous oxide emissions from conventional management of cattle and poultry manure. Besides, landfilling of vegetables wastes, slaughterhouse wastes and grass will be prevented resulting in reduced methane emissions.

The product of the AD of the agricultural and animal wastes which can be utilised as organic fertiliser also provides environmental benefits. Since the anaerobic digestate can be used instead of mineral fertiliser, carbondioxide emissions during the production and nitrous oxide emissions & nitrate leaching during the soil application of the mineral fertilisers will be reduced. In addition, plant availability of the nitrogen in the digested material will be higher which will also cause reduction of global warming potential. The reduction of GWP achieved by using the anaerobic digestate instead of mineral fertiliser is 112.71 g CO_2-Equiv per m^2 winter wheat produced, or in other words 68% GWP saving occurs which makes the usage of the anaerobic digestate a more environmentally friendly product. Besides its environmental advantages, usage of anaerobic digestate also saves costs resulting from the mineral fertilizer production.

The contribution of the AD to the environment is not only replacement of chemical fertilizers. Instead of conventional management or landfilling, the animal and agricultural wastes will also be recycled and processed via AD. By this way, harmful substances will not leach into the soil and drinking water sources. Besides, pathogenic microorganisms will be destroyed contributing to human health protection. In short, by using wastes as an input and resource, a closed loop process will be obtained resulting in resource efficiency and environmental protection.

From the LCA results, it is obviously seen that the performance of the renewable energy scenarios are better than the fossil fuel scenarios in terms of the weighted potential environmental impacts. The fossil fuels when used as energy source have big contribution to the global environmental pollution. These results point out that the key for a better future life is to use the existing resources efficiently and increase the usage of renewable energy sources.

Even the renewable energy resources are more environmentally friendly than the fossil fuel resources, they can also carry their own environmental risks. Among the renewable resources, Scenario G including gasification has the lowest environmental impact potential (447 PET W, EU 2004) followed by Scenario E including hydropower plant (1,597 PET W, EU 2004) and Scenario F including windpower plant (1,621 PET W, EU 2004). The reason for that is Scenario G utilizes the agricultural and animal wastes for energy production in the gasification unit while those wastes are managed in conventional methods in Scenario E and F.

The renewable energy production scenarios (Scenario E and F) are expected to have lower environmental impacts compared to the AD; however the conventional waste disposal systems and production & agricultural application of the mineral fertiliser included in those renewable energy scenarios caused the overall environmental impact potential to be higher than the AD scenario.

In order to manage high noise problems of windpower plants, they are generally constructed on open areas and so, access roads, foundations and cable ditches are needed to be constructed in those areas. In addition to the production of fixed parts and moving parts of the wind power plant, the other items constructed to access the open area also cause the wind power plant to have environmental impacts. The disadvantage of windpower is that it is not always available and it does not provide a continuous power generation. Because of that reason, complementary electricity production is needed for proper use of wind power. On the other hand, AD plant will operate continuously resulting in more steady energy generation than wind power.

Instead of requiring high amount of land and causing deforestation, hydropower with reservoir is more environmentally friendly when compared to fossil fuel resource scenarios and windpower plant. Although hydropower appeared to be more environmentally friendly than the wind power plant, there is just a slight difference due to longer lifetime of hydropower plant compared to windpower plant. However, if additional secondary benefits of hydropower were also included in the LCA study such as water supply, flood control, irrigation, prevention of soil erosion and operating flexibility, the overall benefits of hydropower could be even higher than the wind power plant.

Turkey has a great agricultural potential for energy production from biomass sources. For the defined waste recipe, AD is more suitable compared to gasification process, because it has moisture content of approximately 70%, and it needs to be dried before the gasifier in order to prevent the decrease in the thermal efficiency of the gasification process. On the other hand, it should be emphasized that the internal energy need of the gasification unit is higher than the AD resulting in more raw material need in order to produce same amount of excess electricity connected to grid. Energy consumed for the gasification itself and syngas conversion processes also cause CO_2 emissions indirectly. Even the agricultural and animal wastes are also utilised in the gasification process of Scenarios G, the remaining ash can not be used as organic fertiliser and so it is disposed to landfill and consequently the usage of mineral fertiliser is needed. These are reasons why the overall weighted environmental impact potential of the Scenario G is higher than Scenario A.

When the potential environmental impacts are compared, it is seen that Scenario A is a low emitting technology with reduced carbon footprint. The study reveals that if the animal and agricultural wastes are not utilized in the AD and biogas recovery system, their conventional waste management processes and the production & application of the mineral fertiliser will cause even the renewable energy scenarios to be less environmentally friendly.

The LCC study covers the economic evaluation of the two scenarios (Scenario A and Scenario B) related to the pilot plant which is more environmentally friendly when compared to the other scenarios. The economic evaluations indicate that the AD and biogas recovery system of the agricultural and animal wastes is a commercially beneficial technology with multiple benefits including by-product (organic fertilizer, electricity and heat) sales, and carbon credit value. Comparison of the by-products income with the system installation and operational costs shows that the AD and biogas recovery system of the agricultural and animal wastes is a cost-effective process leading to sustainable region development.

This study has been prepared as an application of life cycle management to succeed integrated waste minimization and energy conservation for a specific region in Turkey. The point of view in the scope of this study is that shifting environmental problems from one place to another should be avoided. With this different point of view, different energy production scenarios were evaluated in broad system boundaries and it is determined with this study that if the animal and agricultural wastes are not utilised in anaerobic digestion and biogas recovery system, even the renewable energy systems will be less environmentally friendly. That means only an integrated interpretation of the scenarios can conclude the potential environmental impacts.

The results of the study show that in terms of environmental protection, climate change reduction, and resource savings, agricultural and animal wastes should be utilised for energy production instead of fossil fuel or renewable energy resources and the digestate should be used in agricultural soils as organic fertiliser instead of the mineral fertilisers.

It can be concluded that if the utilization of agricultural and animal wastes through AD and biogas recovery systems dominate the renewable energy supply of Turkey, it will lead to sustainable development of the country through resource efficiency and reduction of emissions. Finally, doors will be opened for the improvement of Turkey in terms of the environmental and economic profile and socio-economic welfare of the country will be increased.

REFERENCES

Akpinar, A., Kömürcü, M. İ., Kankala, M., Özölçer, İ., H., Kaygusuz, K., 2008. Energy Situation and Renewables in Turkey and Environmental Effects of Energy Use. Renewable and Sustainable Energy Reviews, 12, 2013–2039.

Baban, A., Timur, H., Cılız, N., Olgun, H., Akgün, F, 2001. Kümes ve Ahır Gübrelerinin Geri Kazanılması ve Bertarafı Projesi Final Raporu. TÜBİTAK-MRC.

Baderna, D., Maggioni, S., Boriani, E., Gemmab, S., Molteni, M., Lombardo, A., Colombo, A., Bordonali, S., Rotella, G., Lodi, M., Benfenati, E., 2011. A Combined Approach to Investigate the Toxicity of an Industrial Landfill's Leachate: Chemical Analyses, Risk Assessment and In Vitro Assays. Environmental Research, 111, 603–613.

Balat, M., Balat, M., Kırtay, E., Balat H., 2009. Main Routes for the Thermo-Conversion of Biomass into Fuels and Chemicals. Part 2: Gasification Systems. Energy Conversion and Management 50, 3158–3168.

Balsam, J., Ryan, D., 2006. Anaerobic Digestion of Animal Wastes: Factors to Consider. ATTRA—National Sustainable Agriculture Information Service managed by the National Center for Appropriate Technology (NCAT). www.attra.ncat.org/attra-pub/PDF/anaerobic.pdf , IP219, Slot 218, Version 102506.

Batzias, F.A., Sidiras, D.K., Spyrou, E.K., 2005. Evaluating Livestock Manures for Biogas Production: a GIS Based Method. Renewable Energy, 30, 1161–1176.

BEC (Business Environment Council), 2005. Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) Study of Building Materials and Components for the Hong Kong Housing Authority. Agreement no. Cb20020024.

Bekem, İ., Gültekin, A., B., Dikmen, Ç., B., 2009. Examination of Construction Products within the Context of “Service Life”: Case Study of Reinforced Concrete. 5. Uluslararası İleri Teknolojiler Sempozyumu (IATS’09), 13-15 Mayıs 2009, Karabük, Türkiye.

Braun, R., Wellinger, A., 2003. Potential of Co-Digestion. IEA Bioenergy Task 37.

Brentrup, F., Küsters, J., Lammel, J., Kuhlmann, H., 2000. Methods to Estimate On-Field Nitrogen Emissions from Crop Production as an Input to LCA Studies in the Agricultural Sector. International Journal of LCA, 5, 349 - 357.

Burke, P.E., Dennis, A., 2001. Dairy Waste Anaerobic Digestion Handbook, Options for Recovering Beneficial Products from Dairy Manure. Environmental Energy Company. 6007 Hill Street Olympia, WA 98516. www.makingenergy.com.

Canadian Fertiliser Institute, 2001. Nutrient Uptake and Removal by Field Crops. Western Canada.

Ceotto, E., 2005. The Issues of Energy and Carbon Cycle: New Perspectives for Assessing the Environmental Impact of Animal Waste Utilization. Bioresource Technology, 96, 191–196.

Damgaard, A., Manfredi, S., Merrild, H., Stensøe, S., Christensen, T., H., 2011. LCA and Economic Evaluation of Landfill Leachate and Gas Technologies. Waste Management, 31, 1532–1541.

Demirbas, A., Pehlivan, E., Altun, T., 2006. Potential Evolution of Turkish Agricultural Residues as Bio-gas, Bio-char and Bio-oil Sources. International Journal of Hydrogen Energy, 31, 613 – 620.

Demirbas, A., 2008. Importance of Biomass Energy Sources for Turkey. Energy Policy, 36, 834–842.

Demirer, S., U., Othman, M., 2009. Removal of Ammonium and Phosphate from the Supernatant of Anaerobically Digested Waste Activated Sludge by Chemical Precipitation. Bioresource Technology, 100, 3236–3244.

Devlet Meteoroloji İşleri Genel Müdürlüğü (DMI), 2010. “Average air temperature of Kocaeli”.http://www.dmi.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?m=KOCAELI, (accessed October 2010).

Devlet Meteoroloji İşleri Genel Müdürlüğü (DMI), 2010. “Average rainfall data for Kocaeli”.http://www.meteor.gov.tr/veridegerlendirme/yillik-toplam-yagisverileri.aspx?m=kocaeli. (accessed October 2010).

Dunmade, I., 2007. LCA Software Tools and Approaches. Life Cycle Assessment in Environmental Practice, AGM/Conference, Calgary, Canada.

Energy Efficiency and Conservation Authority (EECA), 2001. Energy from Woody Biomass in New Zealand. EECA PO Box 388 – Wellington, New Zealand. May.

Engler, C.R., Jordan, E.R., McFarland, M.J., Lacewell, R.D., 1999. Economics and Environmental Impact of Biogas Production as a Manure Management Strategy. In: Proceedings of the 1999 Texas Animal Manure Management Conference. Texas A & M University. College Station, TX, USA.

GaBi4 Software, 2003. Software and Database for Life Cycle Engineering, PE Europe GmbH and IKP University of Stuttgart, Germany.

GE Power, Jenbacher Gas Engines, 2010. Technical Description for the Cogeneration Unit, JMS 208 GS-B.L.

Gibson, L., Kugai, J., Winslow, C., Xie, C., 2007. Generating Electricity from Biomass in Centre County, Pennsylvania. The Biomass Group.

Gokcol, C., Dursun, B., Alboyaci, B., Sunan, E., 2009. Importance of Biomass Energy as Alternative to Other Sources in Turkey. Energy Policy, 37, 424–431.

Gordillo, G., Annamalai, K., 2010. Adiabatic Fixed Bed Gasification of Dairy Biomass with Air and Steam. Fuel, 89, 384–391.

Guinée, J.B., Oers, L., Koning, A., Tamis, W., 2006. Life Cycle Approaches for Conservation Agriculture. CML Institute of Environmental Sciences. CML Report 171.

Gül, A., Topay, M., Özaltin, O., 2009. The Important of Urban Forests toward to Global Warming Threat (Küresel Isınma Tehditine Karşı Kent Ormanlarının Önemi). International Davraz Congress on Social and Economic Issues Shaping The World's Future: New Global Dialogue, 24-27 September 2009 Isparta, s:221-234, 2009.

Güven, S., Terzioğlu, G., 2010.“Evde Enerji Tasarrufu Için Öneriler”. Available at; http://www.eeb.hacettepe.edu.tr/atbtasarruf.pdf. (accessed June 2010).

Hammad, M., Badarneh, D., Tahboub, K., 1999. Evaluating Variable Organic Waste to Produce Methane. Energy Conversion & Management, 40, 1463±1475.

Hauschild, M., Potting, J., 2005. Spatial Differentiation in Life Cycle Impact Assessment - The EDIP2003 Methodology. Environmental news No. 80, Institute for Product Development Technical University of Denmark.

Havlikova, M., Kroezea, C., Huijbregts, M.A.J., 2008. Environmental and Health Impact by Dairy Cattle Livestock and Manure Management in the Czech Republic. Science of the Total Environment, 396, 121 – 131.

Higman, C., Van der Burgt, M., 2003. Gasification. Elsevier Science (USA), 20 Wheeler Road, Burlington, MA 01803.

Hoffmann, G., Schingnitz, D., Schnapke, A., Bilitewski, B., 2010. Reduction of CO2-Emissions by Using Biomass in Combustion and Digestion Plants. Waste Management, 30, 893–901.

Holm-Nielsen, J.B., Al Seadi, T., Oleskowicz-Popiel, P., 2009. The Future of Anaerobic Digestion and Biogas Utilization. Bioresource Technology 100, 5478–5484.

Huijsmans, J.F.M., 2003. Manure Application and Ammonia Volatilization. No. 2003-20 of the Institute of Agricultural and Environmental Engineering (IMAG), PO Box 43, 6700 AA Wageningen, the Netherlands (ISBN 90-5406-236-3).

Humane Society of the United States. An HSUS Report: The Impact of Animal Agriculture on Global Warming and Climate Change. Available at http://www.humanesociety.org/assets/pdfs/farm/animal-agriculture-and-climate.pdf (accessed February 2009).

Hunkeler, D., Lichtenvort, K., and Rebitzer, G., 2008. Environmental Life Cycle Costing. Environmental Life Cycle Costing. CRC Press, isbn 978-1-4200-5470-5.

IEA Bioenergy and CADDET Renewable Energy Programmes, 1998. Advanced Thermal Conversion Technologies for Energy from Solid Waste. IEA CADDET Centre for Renewable Energy, ETSU, Harwell, Oxfordshire OX11 0RA, UK.

IKP, PE Europe GMBH, 2003. GaBi4 Manual. Institute for Polymer Testing and Polymer Science of the University of Stuttgart, PE Europe GMBH Life Cycle Engineering, Germany.

IPCC Guidelines for National Greenhouse Gas Inventories, 2006. “Chapter 10: Emissions from Livestock and Manure Management” and “Chapter 11: N_2O Emissions from Managed Soils, and CO_2 Emissions from Lime and Urea Application” of Volume 4: Agriculture, Forestry and Other Land Use.

IPCC Guidelines for National Greenhouse Gas Inventories. (2006). “Chapter 2: Waste Generation, Composition and Management Data” and “Chapter 3: Solid Waste Disposal” of Volume 5: Waste.

ISAT and GTZ, 1999. Biogas Digest Volume I Biogas Basics. Information and Advisory Service on Appropriate Technology (ISAT), GATE in Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), GmbH (German Agency for Technical Cooperation).

ISKI Water Unit Price List 2011 available at http://www.iski.gov.tr/Web/UserFiles/File/suBirimFiyatlari/2011_Su_Birim_Fiyatlari.pdf. (accessed July 2011).

ISO 14040, 1997. Environmental Management – Life Cycle Assessment – Principles and Framework. International Organization of Standardization

ISO 14040, 2006. Environmental Management – Life Cycle Assessment – Principles and Framework. International Organization of Standardization

ISO 14042, 2000. Environmental Management – Life Cycle Assessment – Life cycle impact assessment. International Organization of Standardization

ISO 14043, 2000. Environmental Management – Life Cycle Assessment – Life cycle interpretration. International Organization of Standardization

Izmit Ziraat Odası Başkanlığı, 2011. “İzmit Tanıtımı” http://www.izmitziraat.org/kocaeli.asp. (accessed April 2011).

Jingura, R., M., Matengaifa, R., 2009. Optimization of Biogas Production by Anaerobic Digestion for Sustainable Energy Development in Zimbabwe. Renewable and Sustainable Energy Reviews,13, 1116–1120

Kaya, D., Eyidoğan, M., Çoban, V., Çağman, S., Aydoner, C., Tırıs, M., 2009. Türkiye'nin Hayvansal Atık Kaynaklı Biyogaz Potansiyeli ve Ekonomisi. ICCI 2009 Proceedings Book.

Kaya, M., 2011. "Pratik Isı Kaybı Hesabı". ESOGU (Eskişehir Osmangazi Üniversitesi) http://www.ogu.edu.tr/images/birimduyuru/2009122394432.ppt#266,12, (accessed October 2011)

Kaygusuz, K., 2010. Sustainable Energy, Environmental and Agricultural Policies in Turkey. Energy Conversion and Management, 51, 1075–1084.

Kirby, A., 2008. Kick the Habit, A UN Guide to Climate Neutrality. UNEMG, UNEP/GRID-Arendal ISBN: 978-92-807-2926-9, Malta.

Kirkeby, J., 2005. Modelling of Life Cycle Assessment of Solid Waste Management Systems and Technologies, Ph.D. Thesis, Institute of Environment & Resources Technical University of Denmark.

Kishore, V.V.N., Raman, P., Rao, V.V.R., 1987. Fixed Dome Biogas Plants-A Design, Construction and Operation Manual, Tata Energy Research Institute, New Delhi.

LCA Food Database, 2010. "Life Cycle Assessment (LCA)" http://www.lcafood.dk/LCA/LCA.htm#word. (accessed August 2010).

Manfredi, S., Christensen, T. H., 2009. Environmental Assessment of Solid Waste Landfilling Technologies by means of LCA-modeling. Waste Management 29, 32–43.

Marchaim, U., 1992. Biogas Processes for Sustainable Development. Food and Agriculture Organization (FAO) of the United Nations, M-09 ISBN 92-5-103126-6.

Martin, J., H., 2005. An Evaluation of a Mesophilic, Modified Plug Flow Anaerobic Digester for Dairy Cattle Manure. EPA Contract No. GS 10F-0036K Work Assignment/Task Order No. 9.

McPherson, E., G., 2008. Urban Forestry and Carbon, What the Reporting Protocol Means to You. The Center for Urban Forest Research, Pacific Southwest Research Station, U.S. Forest Service, Davis, California. http://www.fs.fed.us/psw/programs/uesd/uep/products/CUFR_778_UrbanFor_ArbNews_2008_12.pdf (accessed June 2011)

Meisinger, J., J., Jokela, W., E., 2000. Ammonia Volatilization from Dairy and Poultry Manure. Managing Nutrients and Pathogens from Animal Agriculture (NRAES-130). Natural Resource, Agriculture and Engineering Service, PO Box 4557, Ithaca NY 14852-4557.

Ozturk, B., Okumus, E., 2008. Biyogaz Üretimi ve Yakıt Kalitesinin Yükseltilmesi. VII. Ulusal Temiz Enerji Sempozyumu, UTES’2008, 17-19 Aralık 2008, İstanbul.

Ozturk, M., 2005. Hayvan Gübresinden Biyogaz Üretimi. Çevre ve Orman Bakanlığı, Ankara.

Pascale, A., Urmee, T., Moore, A., 2011. Life Cycle Assessment of a Community Hydroelectric Power System in Rural Thailand. Renewable Energy 36, 2799-2808.

PE., 2010. PE International, GaBi Software. http://www.gabi-software.com

Pembina Institute, Sustainable Energy Solutions, 2011. “Energy Source: Hydropower”. http://www.pembina.org/re/sources/hydro-power. (accessed August 2011).

PWC (Price Water House Coopers), 2009. Green Electricity Making a Difference - An International Survey of Renewable Electricity Labels.

Qiao, S., Yamamoto, T., Misaka, M. Isaka, K., Sumino, T., Bhatti, Z., Furukawa, K., 2010. High-rate Nitrogen Removal from Livestock Manure Digester Liquor by Combined Partial Nitritation–Anammox Process. Biodegradation, 21, 11–20.

Ravemark, D., 2004. LCC/LCA Experience - Developing and Working with LCC Tools. ABB, DANTES Project, EU Life Environment Program.

Rebitzer, G., Ekvall, T., Frischknecht, R., Hunkeler, D., Norris, G., Rydberg, T., Schmidt, W., P., Suh, S., Weidema, B.P., Pennington, D.W., 2004. Life Cycle Assessment Part 1: Framework, Goal and Scope Definition, Inventory Analysis, and Applications. Environment International 30, 701– 720.

Resmi Gazete, 2010. Kanun No. 6094 "Yenilenebilir Enerji Kaynaklarının Elektrik Enerjisi Üretimi Amaçlı Kullanımına Ilişkin Kanunda Değişiklik Yapılmasına Dair Kanun". Sayı : 27809. Kabul tarihi 29.12.2010.

SAIC, 2006. Life Cycle Assessment: Principles and Practice. Scientific Applications International Corporation (SAIC) 11251 Roger Bacon Drive Reston, VA 20190 Contract No. 68-C02-067, Work Assignment 3-15 funded by National Risk Management Research Laboratory Office of Research and Development U.S. Environmental Protection Agency (USEPA). EPA/600/R-06/060. May.

Sandars, D.L., Audsley, E., Canete, C., Cumby, T.R., Scotford, I. M., Williams, A.G., 2003. Environmental Benefits of Livestock Manure Management Practices and Technology by Life Cycle Assessment. Biosystems Engineering, 84 (3), 267–281.

Sedlbauer, K., Braune, A., Humbert,S., Margni, M., Schuller, O., Fischer M., 2007. Spatial Differentiation in LCA - Moving Forward to More Operational Sustainability. Technikfolgenabschätzung - Theorie und Praxis, 16, 24-31.

Steffen, R.; Szolar, O. and Braun, R., 1998. Feedstocks for Anaerobic Digestion. Institute for Agrobiotechnology Tulln, University of Agricultural Sciences, Vienna.

Suzer, S., 2010. "Buğday Tarımı" Trakya Agricultural Research Institute. Available at http://hayrabolutb.org.tr/media/ziraat/Bugday-Tarimi.pdf (accessed September 2010).

Thyø, K., A., Wenzel, H., 2007. Life Cycle Assessment of Biogas from Maize Silage and from Manure – for Transport and for Heat and Power Reduction under Displacement of Natural Gas Based Heat Works and Marginal Electricity in Northern Germany. Report for Xergi A/S by the Institute for Product Development.

Tidaker, P., 2003. Life Cycle Assessment of Grain Production Using Source-Separated Human Urine and Mineral Fertiliser. Swedish University of Agricultural Sciences Department of Agricultural Engineering (SLU), Report 251, ISSN 00283-0086, ISRN SLU-LT-R-251-SE.

Tjalfe G. P., 2003. Chapter 5: Anaerobic Digestion. Aalborg University.

Tufts University, Office of Sustainability, 2011. “Carbon Sequestration”
http://sustainability.tufts.edu/?pid=74#top, (accessed April 2011).

Türkiye İstatistik Kurumu, 2010.
http://www.tuik.gov.tr. (accessed August 2011).

Turnbull, J. H., Kamthunzi, W., 2005. Greenhouse Gas Benefits of an Anaerobic Digester in the USA. IEA Bioenergy: T38: 2005: 03.

UNEP/SETAC, 2009. Guidelines for Social Life Cycle Assessment of Products. UNEP/SETAC Life Cycle Initiative at UNEP, CIRAIG, FAQDD and the Belgium Federal Public Planning Service Sustainable Development. ISBN: 978-92-807-3021-0, DTI/1164/PA

U.S. DOE, EIA, 1998. Method for Calculating Carbon Sequestration by Trees in Urban and Suburban Settings. Voluntary Reporting of Greenhouse Gases Program, U.S. Department of Energy, Energy Information Administration, EI-81, 1000 Independence Avenue, S.W., Washington, DC 20585.

U.S.EPA (United States Environmental Protection Agency), 2000. Framework for Responsible Environmental Decision-Making (FRED): Using Life Cycle Assessment to Evaluate Preferability of Products. Office of Research and Development. Washington, DC. EPA/600/R-00/095. October.

U.S.EPA (United States Environmental Protection Agency), 2002. Managing Manure with Biogas Recovery Systems Improved Performance at Competitive Costs. Office of Air and Radiation, The AgStar Program. EPA-430-F-02-004. Winter.

U.S.EPA (United States Environmental Protection Agency), 2011. "Carbon Sequestration in Agriculture and Forestry"
http://www.epa.gov/sequestration/ (accessed April 2011).

Vcore, 2011. "Gasification / Biomass Technologies". 760.579.7356.
http://vcoreusa.com/pdf/VCORE_Gasification_Biomass.pdf. (accessed July 2011)

Vu, T.K.V., Tran, M.T., Dang, T.T.S., 2007. "A Survey of Manure Management on Pig Farms in Northern Vietnam". Livestock Science 112, 288–297.

Ward, A.J., Hobbs, P.J., Holliman, P.J., Jones, D.L., 2008. Optimisation of the Anaerobic Digestion of Agricultural Resources. Bioresource Technology 99, 7928–7940.

Werner, U., Stöhr, U., Hees, N., 1989. Biogas Plants in Animal Husbandry. A Publication of the Deutsches Zentrum für Entwicklungstechnologien, GATE, A Division of the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH.

Wenzel, H., Hauschild, M., Alting, L., 1997. Environmental Assessment of Products, Volume1, Methodology, Tools and Case Studies in Product Development. Chapman & Hall, United Kingdom, ISBN 0 412 80800 5.

Wenzel, H., Hauschild, M., 2000. Life Cycle Assessment – Environmental Assessment of Products, pp. 155-189, CRC Press LLC, Denmark.

Wetherold, B., Orr, D., Maxwell, D., 2000. A Comparison of Gasification and Incineration of Hazardous Wastes. U.S. Department of Energy, National Energy Technology Laboratory (NETL), 3610 Collins Ferry Road, Morgantown, West Virginia 26505. DCN 99.803931.02. March.

Woodward, D., G., 1997. Life Cycle Costing-Theory, Information Acquisition and Application. Internattonal Journal of Project Management, Vol. 15, No. 6, pp. 335-344.

Yuksel, I., 2010. Energy Production and Sustainable Energy Policies in Turkey. Renewable Energy 35, 1469–1476.

REFERENCES NOT CITED

Acar, E, Doğan, A., 2008. Potansiyeli ve Çevresel Etkilerinin Değerlendirilmesi. II. Ulusal Temiz Enerji Sempozyumu, UTES'2008, 17-19 Aralık 2008, İstanbul.

Alçiçek, A., Demiruluş, H., 1994. Çiftlik Gübrelerinin Biyogaz Teknolojisinde Kullanılması. Ekoloji Çevre Dergisi, Ekim-Kasım-Aralık, Sayı: 13, Sf. 5-9, 1994.

Allan, D., Katovich, E., Nelson, C., 2003. Fertilizer Value and Weed Seed Destruction Potential of Digested Manure Anaerobic Digester Technology Applications in Animal Agriculture: A National Summit, June 2-4, 2003, Raleigh, North Carolina.

Alvareza, R., Lidén, G., 2008. Semi-continuous Co-digestion of Solid Slaughterhouse Waste, Manure, and Fruit and Vegetable Waste. Renewable Energy 33, 726–734.

Balat, M., 2005. Use of Biomass Sources for Energy in Turkey and a View to Biomass Potential. Biomass and Bioenergy, 29, 32–41.

Banar, M., Cokaygil, Z., Ozkan, A., 2009. Life Cycle Assessment of Solid Waste Management Options for Eskisehir, Turkey. Waste Management 29, 54–62.

Başçetinçelik, A., Öztürk, H., Karaca, C., 2010. Türkiye'de Tarımsal Biyokütleden Enerji Üretimi Olanakları.
http://www.mmo.org.tr/resimler/dosya_ekler/32590c74a229a9f_ek.pdf?dergi=563
(accessed March 2010).

Berglund, M., Börjesson, P., 2006. Assessment of energy performance in the life-cycle of biogas production. Biomass and Bioenergy, 30, 254–266.

Boesch, D. F., 1999. Causes and Consequences of Nutrient Overenrichment of Coastal Waters. Proceedings of 24th Annual Seminar on World Planetary Emergencies, Erice, Italy.

Callaghan, F.J., Wase, D.A.J., Thayanithy, K., Forster, C.F., 2002. Continuous Co-digestion of Cattle Slurry with Fruit and Vegetable Wastes and Chicken Manure. Biomass and Bioenergy 27, 71–77.

Carpentieri, M., Corti, A., Lombardi, L., 2005. Life Cycle Assessment (LCA) of an Integrated Biomass Gasification Combined Cycle (IBGCC) with CO_2 Removal. Energy Conversion and Management 46, 1790–1808.

Chadwick, D., Sommer, S., Thorman, R., Fangueiro, D., Cardenas, L., Amon, B., Misselbrook, T., 2011. Manure management: Implications for Greenhouse Gas Emissions. Animal Feed Science and Technology 166– 167, 514– 531.

Clemens, J., Trimborn, M., Weiland, P. Amon, B., 2006. Mitigation of Greenhouse Gas Emissions by Anaerobic Digestion of Cattle Slurry. Agriculture, Ecosystems and Environment 112, 171–177.

Comino, E., Rosso, M, Riggio, V., 2010. Investigation of Increasing Organic Loading Rate in the Co-digestion of Energy Crops and Cow Manure Mix. Bioresource Technology 101, 3013–3019.

Converse, J., C., 2001. Fundamentals of Biogas Production from Dairy Manure. Wisconsin Ad Hoc Anaerobic Digestion Committee Meeting, DATCP. May 3, 2001.

Corti, A., Lombardi, L., 2004. Biomass Integrated Gasification Combined Cycle with Reduced CO_2 Emissions: Performance Analysis and Life Cycle Assessment (LCA). Energy 29, 2109-2124.

El-Mashad, H. M., Zhang, R., 2010. Biogas Production from Co-digestion of Dairy Manure and Food Waste. Bioresource Technology 10, 4021–4028.

Gagnona, L., Bélangerb, C., Uchiyama, Y., 2002. Life-Cycle Assessment of Electricity Generation Options: The status of Research in Year 2001. Energy Policy 30, 1267–1278.

Goodrich, P., R., 2005. Anaerobic Digester Systems for Mid-Sized Dairy Farms. The Minnesota Project. AgStar Fund for Rural America. http://www.mnproject.org/pdf/agstar%20report%20full%20update.pdf (accessed April 2010).

Gorokhov, V., Manfredo, L., Ratafia-Brown, J., Ramezan, M., Stiegel, G, J., 2000. Life Cycle Assessment of Gasification-Based Power Cycles. Proceedings of 2000 International Joint Power Generation Conference, Miami Beach, Florida, July 23-26, 2000.

Hall, D., O., Scrase, J., I., 1998. Will Biomass Be the Environmetally Friendly Fuel for the Future? Biomass and Bioenergy, Vol. 15, Nos. 4/5, 357-367.

Haren, V. M., Fleming, R., 2005. Electricity and Heat Production Using Biogas from the Anaerobic Digestion of Livestock Manure - Literature Review. Ridgetown College – University of Guelph Ridgetown, Ontario, Canada N0P 2C0, Prepared for: Ontario Ministry of Agriculture, Food and Rural Affairs October 2005.

Hashimoto, A. G., Varel, H., Chen, Y. R., 1981. Ultimate Methane Yield from Beef Cattle Manure: Effect of Temperature, Ration Constituents, Antibiotics and Manure Age. Agrwuhural Wastes 3, 241-256.

Hejnfelt, A., Angelidaki, I., 2009. Anaerobic Digestion of Slaughterhouse By-products. Biomass and Bioenergy 33, 1046–1054.

Hellebrand, H., J., Scholz, V., Kern, J., Kavdir, Y., 2005. N_2O Release During Cultivation of Energy Crops. Agrartechnische Forschung 11, Heft 5, S. E 114-E 124.

Ishikawa, S., Hoshiba, S., Hinata, T., Hishinuma, T., Morita, S., 2006. Evaluation of a Biogas Plant from Life Cycle Assessment (LCA). International Congress Series 1293, 230–233.

J.M. de Boer, I., 2003. Environmental impact assessment of conventional and organic milk production. Livestock Production Science 80, 69–77.

Karim, K., Klasson, T., Hoffmann, R., Drescher, S. R., DePaoli, D. W., Al-Dahhan, M. H., 2005. Anaerobic Digestion of Animal Waste: Effect of Mixing. Bioresource Technology 96, 1607–1612.

Kaygusuz, K., Turker, M. F., 2002. Biomass Energy Potential in Turkey. Renewable Energy 26, 661–678.

Keener, K. M., Shook, R., Anderson, K., Parrish, C. R., 2002. Characterization of Poultry Manure for Potential Co-Combustion with Coal in an Electricity Generation Plant. Paper number 026058, 2002.

Klass, D. L., 1998. Biomass for Renewable Energy, Fuels, and Chemicals. Academic Press, London.

LCA Food Database, 2010. “Slaughtering of cattle”
http://www.lcafood.dk/processes/industry/slaughteringofcattle.htm
(accessed March 2010).

Macias-Corral, M., Samani, Z., Hanson, A., Smith, G., Funk, P., Yu, H., Longworth, J., 2008. Anaerobic Digestion of Municipal Solid Waste and Agricultural Waste and the Effect of Co-digestion with Dairy Cow Manure. Bioresource Technology 99, 8288–8293.

Martin, J., H., 2005. A Comparison of Dairy Cattle Manure Management with and without Anaerobic Digestion and Biogas Utilization. EPA Contract No. 68-W7-0068, Work Assignment/Task Order No. 400.

Miller, V. B., Landis, A. E., Schaefer, L. A., 2011. A Benchmark for Life Cycle Air Emissions and Life Cycle Impact Assessment of Hydrokinetic Energy Extraction Using Life Cycle Assessment. Renewable Energy 36, 1040-1046.

Moller, H.B., Sommer, S.G., Ahring, B.K, 2004. Methane Productivity of Manure, Straw and Solid Fractions of Manure. Biomass and Bioenergy 26, 485 – 495.

Ocak, M., Ocak, Z., Bilgen, S., Keleş, S., Kaygusuz, K., 2004. Energy Utilization, Environmental Pollution and Renewable Energy Sources in Turkey. Energy Conservation and Management, 45, 845-864.

∅rtenblad, H., 2000. Anaerobic Digestion: Making Energy and Solving Modern Waste Problems. Herning Municipal Utilities, Ad-Nett Report 2000.

Özön, N. N., Kılıçaslan, İ., 2010. Kocaeli Ilinde Rüzgar Çiftliği Için Yer Seçimi. Kocaeli Üniversitesi Teknik Eğitim Fakültesi Makine Eğitimi Bölümü. http://www.emo.org.tr/ekler/97dfe4d6bab44f3_ek.doc (accessed June 2010).

Potting, J., Hauschild, M., 2005. Background for Spatial Differentiation in Life Cycle Impact Assessment - The EDIP2003 Methodology. Environmental Project No. 996 2005, Institute for Product Development Technical University of Denmark.

Quiroga, G., Castrillón, L., Fernández-Nava, Y., Marañón, E., 2010. Physico-chemical Analysis and Calorific Values of Poultry Manure. Waste Management 30, 880–884.

Ratafia-Brown, J. A., Manfredo, L. M., Hoffmann, J. W., Ramezan, M., Stiegel, G. J., 2002. An Environmental Assessment of IGCC Power Systems. Nineteenth Annual Pittsburgh Coal Conference, September 23 – 27, 2002.

Salminen, E., Rintala, J., 2002. Anaerobic Digestion of Organic Solid Poultry Slaughterhouse Waste – A Review. Bioresource Technology 83, 13–26.

Türker, M., 2008. Anaerobik Biyoteknoloji ve Biyogaz Üretimi, Dünya'da ve Türkiye'de Eğilimler. VII. Uluslararası Temiz Enerji Sempozyumu, UTES' 2008. 17-19 Aralık, 2008, Istanbul.

UNEP, 2003. Evaluation of Environmental Impacts in Life Cycle Assessment. Meeting report Brussels, 29-30 November 1998, and Brighton, 25-26 May 2000. ISBN: 92-807-2144-5.

UNEP, 2007. Life Cycle Management, A Business Guide to Sustainability. United Nations Programme, ISBN: 978-92-807-2772-2, DTI/0889/PA.

Voća, N., Krička, T., Ćosić, T., Rupić, V., Jukić, Ž., Kalambura, S., 2005. Digested Residue as a Fertilizer after the Mesophilic Process of Anaerobic Digestion. Plant Soil Environ., 51, 6,: 262–266.

Voss, A., 2001. LCA and External Costs in Comparative Assessment of Electricity Chains, Decision Support for Sustainable Electiricity Provision. IEA Conference - Energy Policy and Externalities: The Life Cycle Analysis Approach, Paris, November, 15th – 16th, 2001.

Wellinger, A., 2005. Biogas Production and Utilization. IEA Bioenergy Task 37:2005:01.

Williams, R. B., Jenkins, B. M., Nguyen, D., 2003. Solid Waste Conversion: A Review and Database of Current and Emerging Technologies. University of California Davis Department of Biological and Agricultural Engineering, One Shields Avenue Davis, CA 95616. Interagency Agreement – IWM-C0172. California Integrated Waste Management Board

Wood, S., Cowie, A., 2004. A Review of Greenhouse Gas Emission Factors for Fertiliser Production. Research and Development Division, State Forests of New South Wales. Cooperative Research Centre for Greenhouse Accounting For IEA Bioenergy Task 38, June 2004.

Yaldız, O., 1997. Organik Atıklardan Biyogaz Üretim Tekniği. Akdeniz Üniversitesi Ziraat Fakültesi Tarım Makinaları Bölümü, Antalya. Available at; http://www.biyogazder.org/yazi_ve_makaleler.htm (accessed May 2010).

Young, L., Pian, C. C. P., 2003. High-temperature, Air-blown Gasification of Dairy-farm Wastes for Energy Production. Energy 28, 655–672.

Zhang, R., McGarvey, J. A., Ma, Y., Mitloehner, F. M., 2008. Effects of anaerobic digestion and aerobic treatment on the reduction of gaseous emissions from dairy manure storages. International Journal of Agricultural and Biological Engineering, Vol. 1, No.2, 15-20.

APPENDIX A

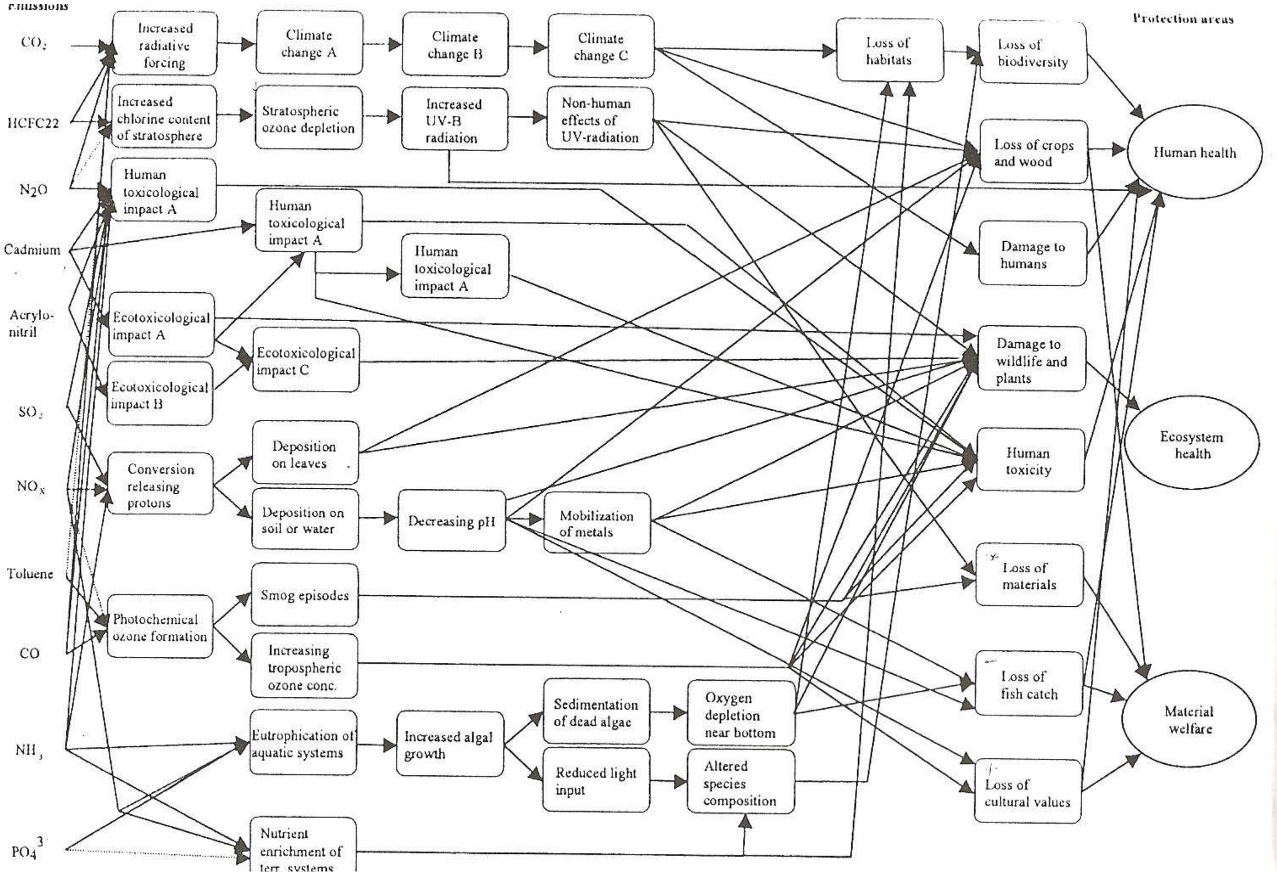
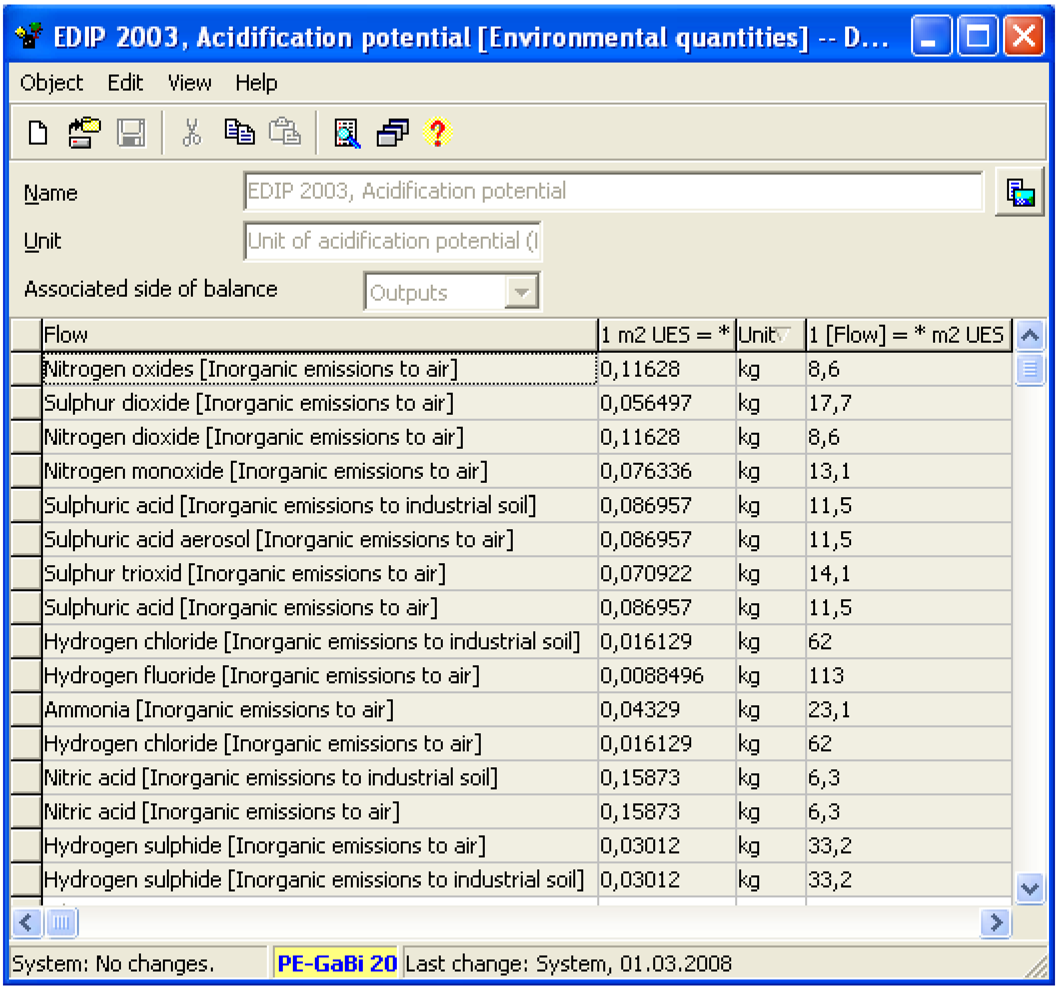


Figure A.1. The causability web or cause-impact network for environmental emissions [Wenzel and Hauschild, 2000].

APPENDIX B - EQUIVALENCY, NORMALISATION AND WEIGHTING FACTORS

Table B.1. Equivalency factors for acidification [GaBi4, 2003].



Name: EDIP 2003, Acidification potential

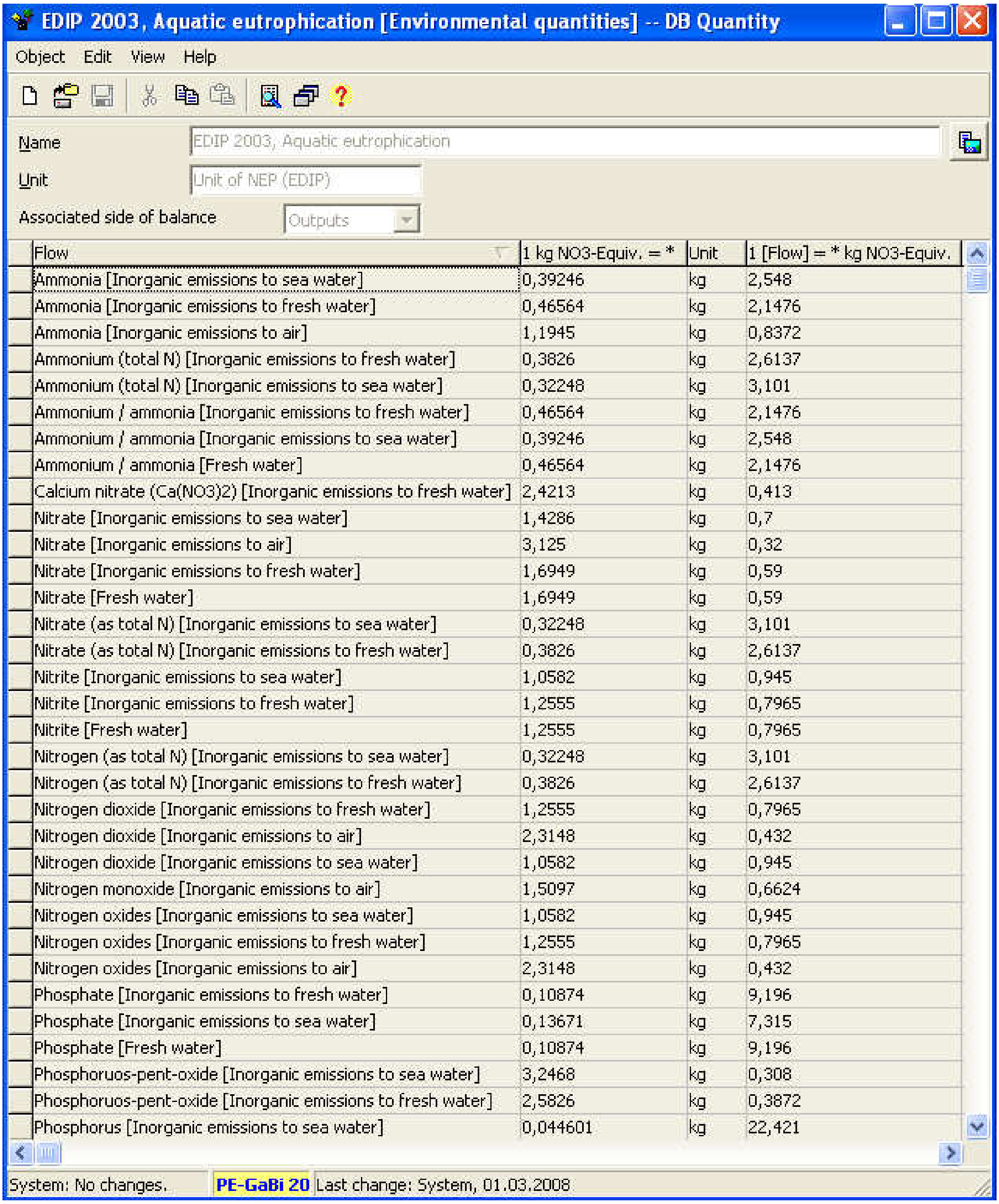
Unit: Unit of acidification potential (I

Associated side of balance: Outputs

Flow	1 m2 UES = *	Unit	1 [Flow] = * m2 UES
Nitrogen oxides [Inorganic emissions to air]	0,11628	kg	8,6
Sulphur dioxide [Inorganic emissions to air]	0,056497	kg	17,7
Nitrogen dioxide [Inorganic emissions to air]	0,11628	kg	8,6
Nitrogen monoxide [Inorganic emissions to air]	0,076336	kg	13,1
Sulphuric acid [Inorganic emissions to industrial soil]	0,086957	kg	11,5
Sulphuric acid aerosol [Inorganic emissions to air]	0,086957	kg	11,5
Sulphur trioxid [Inorganic emissions to air]	0,070922	kg	14,1
Sulphuric acid [Inorganic emissions to air]	0,086957	kg	11,5
Hydrogen chloride [Inorganic emissions to industrial soil]	0,016129	kg	62
Hydrogen fluoride [Inorganic emissions to air]	0,0088496	kg	113
Ammonia [Inorganic emissions to air]	0,04329	kg	23,1
Hydrogen chloride [Inorganic emissions to air]	0,016129	kg	62
Nitric acid [Inorganic emissions to industrial soil]	0,15873	kg	6,3
Nitric acid [Inorganic emissions to air]	0,15873	kg	6,3
Hydrogen sulphide [Inorganic emissions to air]	0,03012	kg	33,2
Hydrogen sulphide [Inorganic emissions to industrial soil]	0,03012	kg	33,2

System: No changes. PE-GaBi 20 Last change: System, 01.03.2008

Table B.2. Aquatic eutrophication potential equivalency factors [GaBi4, 2003].



Name: EDIP 2003, Aquatic eutrophication

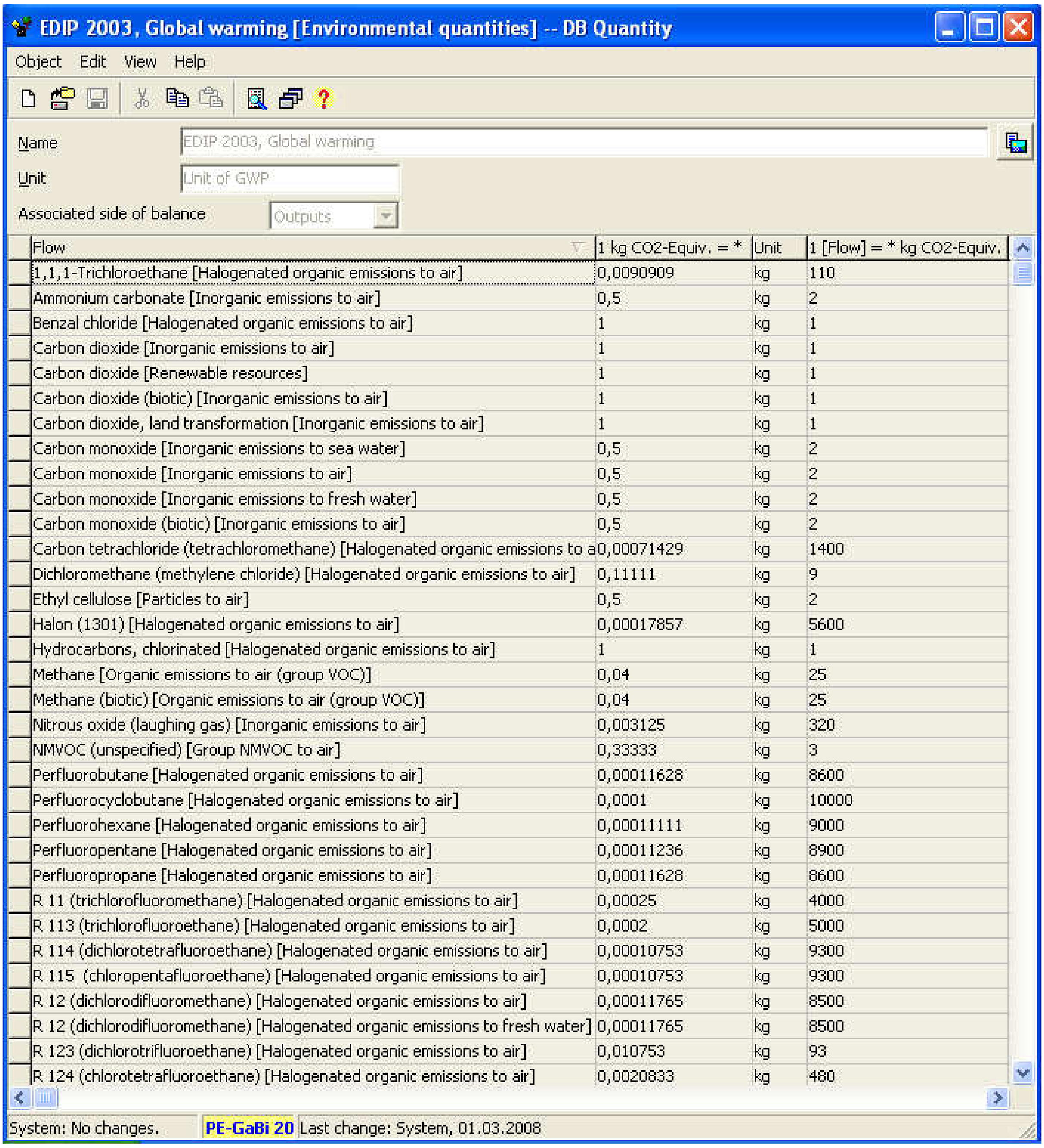
Unit: Unit of NEP (EDIP)

Associated side of balance: Outputs

Flow	1 kg NO3-Equiv. = *	Unit	1 [Flow] = * kg NO3-Equiv.
Ammonia [Inorganic emissions to sea water]	0,39246	kg	2,548
Ammonia [Inorganic emissions to fresh water]	0,46564	kg	2,1476
Ammonia [Inorganic emissions to air]	1,1945	kg	0,8372
Ammonium (total N) [Inorganic emissions to fresh water]	0,3826	kg	2,6137
Ammonium (total N) [Inorganic emissions to sea water]	0,32248	kg	3,101
Ammonium / ammonia [Inorganic emissions to fresh water]	0,46564	kg	2,1476
Ammonium / ammonia [Inorganic emissions to sea water]	0,39246	kg	2,548
Ammonium / ammonia [Fresh water]	0,46564	kg	2,1476
Calcium nitrate (Ca(NO3)2) [Inorganic emissions to fresh water]	2,4213	kg	0,413
Nitrate [Inorganic emissions to sea water]	1,4286	kg	0,7
Nitrate [Inorganic emissions to air]	3,125	kg	0,32
Nitrate [Inorganic emissions to fresh water]	1,6949	kg	0,59
Nitrate [Fresh water]	1,6949	kg	0,59
Nitrate (as total N) [Inorganic emissions to sea water]	0,32248	kg	3,101
Nitrate (as total N) [Inorganic emissions to fresh water]	0,3826	kg	2,6137
Nitrite [Inorganic emissions to sea water]	1,0582	kg	0,945
Nitrite [Inorganic emissions to fresh water]	1,2555	kg	0,7965
Nitrite [Fresh water]	1,2555	kg	0,7965
Nitrogen (as total N) [Inorganic emissions to sea water]	0,32248	kg	3,101
Nitrogen (as total N) [Inorganic emissions to fresh water]	0,3826	kg	2,6137
Nitrogen dioxide [Inorganic emissions to fresh water]	1,2555	kg	0,7965
Nitrogen dioxide [Inorganic emissions to air]	2,3148	kg	0,432
Nitrogen dioxide [Inorganic emissions to sea water]	1,0582	kg	0,945
Nitrogen monoxide [Inorganic emissions to air]	1,5097	kg	0,6624
Nitrogen oxides [Inorganic emissions to sea water]	1,0582	kg	0,945
Nitrogen oxides [Inorganic emissions to fresh water]	1,2555	kg	0,7965
Nitrogen oxides [Inorganic emissions to air]	2,3148	kg	0,432
Phosphate [Inorganic emissions to fresh water]	0,10874	kg	9,196
Phosphate [Inorganic emissions to sea water]	0,13671	kg	7,315
Phosphate [Fresh water]	0,10874	kg	9,196
Phosphoruos-pent-oxide [Inorganic emissions to sea water]	3,2468	kg	0,308
Phosphoruos-pent-oxide [Inorganic emissions to fresh water]	2,5826	kg	0,3872
Phosphorus [Inorganic emissions to sea water]	0,044601	kg	22,421

System: No changes. PE-GaBi 20 Last change: System, 01.03.2008

Table B.3. Global warming potential equivalency factors [GaBi4, 2003].



Name: EDIP 2003, Global warming

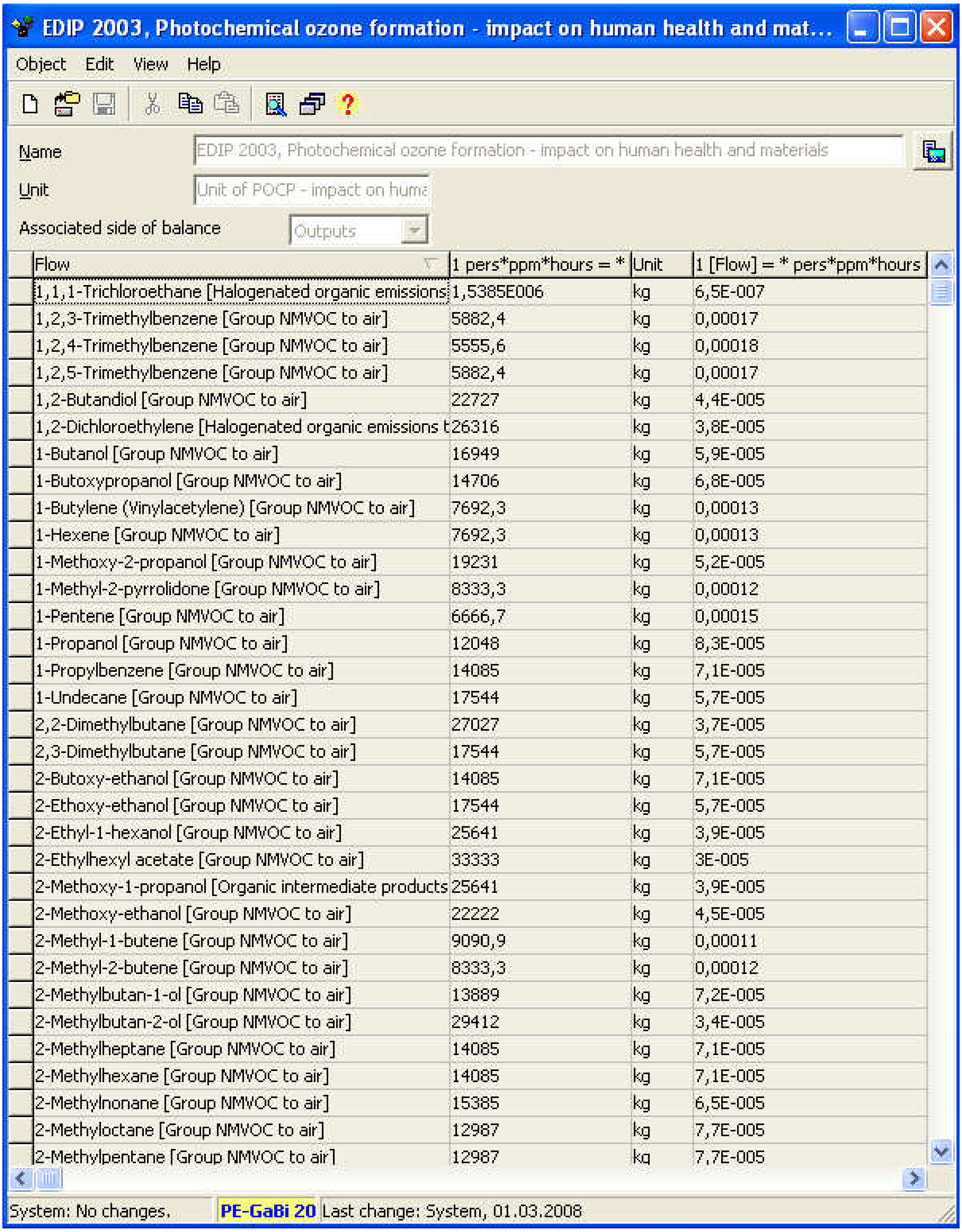
Unit: Unit of GWP

Associated side of balance: Outputs

Flow	1 kg CO2-Equiv. = *	Unit	1 [Flow] = * kg CO2-Equiv.
1,1,1-Trichloroethane [Halogenated organic emissions to air]	0,0090909	kg	110
Ammonium carbonate [Inorganic emissions to air]	0,5	kg	2
Benzal chloride [Halogenated organic emissions to air]	1	kg	1
Carbon dioxide [Inorganic emissions to air]	1	kg	1
Carbon dioxide [Renewable resources]	1	kg	1
Carbon dioxide (biotic) [Inorganic emissions to air]	1	kg	1
Carbon dioxide, land transformation [Inorganic emissions to air]	1	kg	1
Carbon monoxide [Inorganic emissions to sea water]	0,5	kg	2
Carbon monoxide [Inorganic emissions to air]	0,5	kg	2
Carbon monoxide [Inorganic emissions to fresh water]	0,5	kg	2
Carbon monoxide (biotic) [Inorganic emissions to air]	0,5	kg	2
Carbon tetrachloride (tetrachloromethane) [Halogenated organic emissions to a	0,00071429	kg	1400
Dichloromethane (methylene chloride) [Halogenated organic emissions to air]	0,11111	kg	9
Ethyl cellulose [Particles to air]	0,5	kg	2
Halon (1301) [Halogenated organic emissions to air]	0,00017857	kg	5600
Hydrocarbons, chlorinated [Halogenated organic emissions to air]	1	kg	1
Methane [Organic emissions to air (group VOC)]	0,04	kg	25
Methane (biotic) [Organic emissions to air (group VOC)]	0,04	kg	25
Nitrous oxide (laughing gas) [Inorganic emissions to air]	0,003125	kg	320
NMVOC (unspecified) [Group NMVOC to air]	0,33333	kg	3
Perfluorobutane [Halogenated organic emissions to air]	0,00011628	kg	8600
Perfluorocyclobutane [Halogenated organic emissions to air]	0,0001	kg	10000
Perfluorohexane [Halogenated organic emissions to air]	0,00011111	kg	9000
Perfluoropentane [Halogenated organic emissions to air]	0,00011236	kg	8900
Perfluoropropane [Halogenated organic emissions to air]	0,00011628	kg	8600
R 11 (trichlorofluoromethane) [Halogenated organic emissions to air]	0,00025	kg	4000
R 113 (trichlorofluoroethane) [Halogenated organic emissions to air]	0,0002	kg	5000
R 114 (dichlorotetrafluoroethane) [Halogenated organic emissions to air]	0,00010753	kg	9300
R 115 (chloropentafluoroethane) [Halogenated organic emissions to air]	0,00010753	kg	9300
R 12 (dichlorodifluoromethane) [Halogenated organic emissions to air]	0,00011765	kg	8500
R 12 (dichlorodifluoromethane) [Halogenated organic emissions to fresh water]	0,00011765	kg	8500
R 123 (dichlorotrifluoroethane) [Halogenated organic emissions to air]	0,010753	kg	93
R 124 (chlorotetrafluoroethane) [Halogenated organic emissions to air]	0,0020833	kg	480

System: No changes. PE-GaBi 20 Last change: System, 01.03.2008

Table B.4. Photochemical ozone formation – impact on human health and materials potential equivalency factors [GaBi4, 2003].



Name: EDIP 2003, Photochemical ozone formation - impact on human health and materials

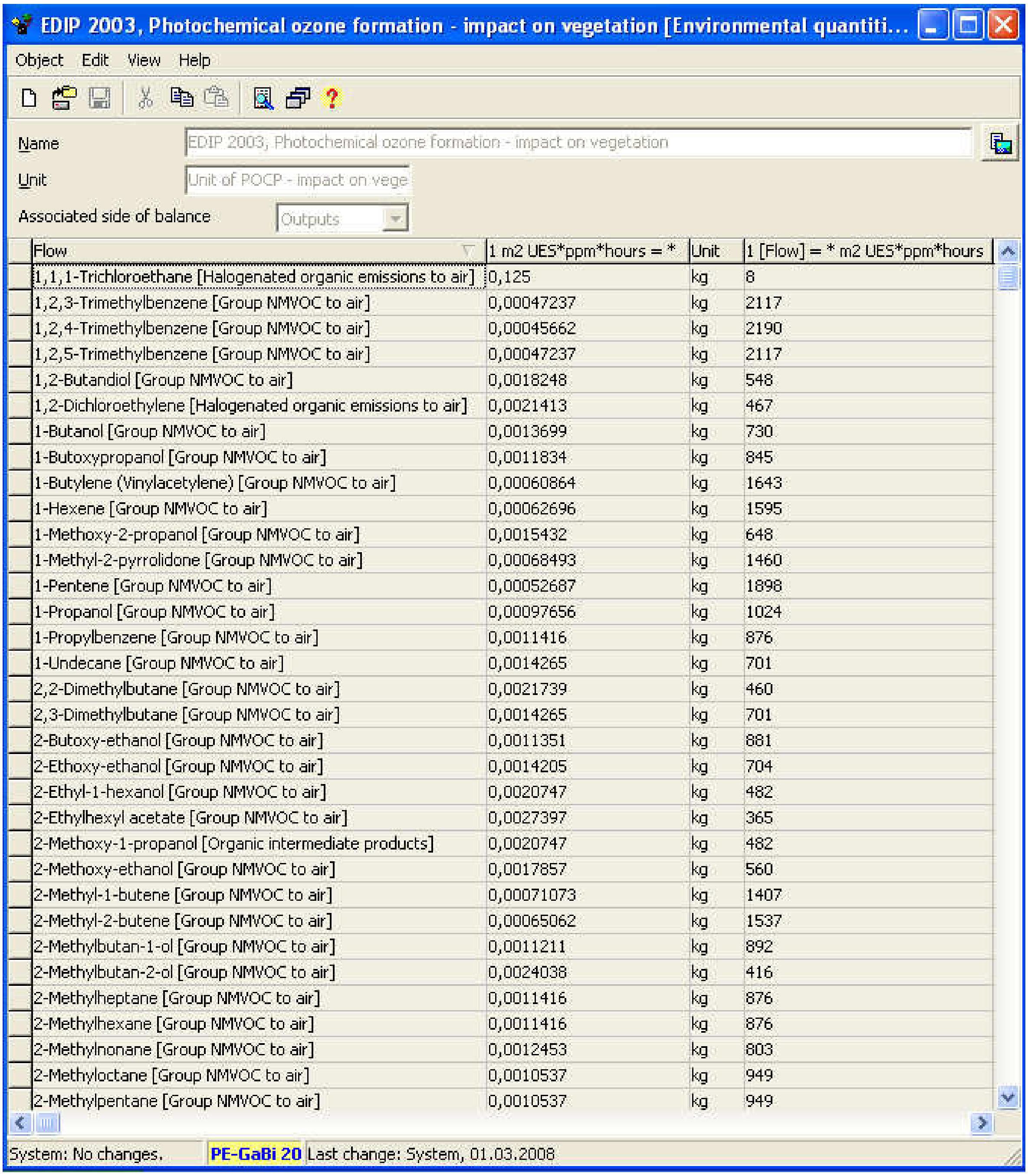
Unit: Unit of POCP - impact on huma

Associated side of balance: Outputs

Flow	1 pers*ppm*hours = *	Unit	1 [Flow] = * pers*ppm*hours
1,1,1-Trichloroethane [Halogenated organic emissions	1,5385E006	kg	6,5E-007
1,2,3-Trimethylbenzene [Group NMVOC to air]	5882,4	kg	0,00017
1,2,4-Trimethylbenzene [Group NMVOC to air]	5555,6	kg	0,00018
1,2,5-Trimethylbenzene [Group NMVOC to air]	5882,4	kg	0,00017
1,2-Butandiol [Group NMVOC to air]	22727	kg	4,4E-005
1,2-Dichloroethylene [Halogenated organic emissions t	26316	kg	3,8E-005
1-Butanol [Group NMVOC to air]	16949	kg	5,9E-005
1-Butoxypropanol [Group NMVOC to air]	14706	kg	6,8E-005
1-Butylene (Vinylacetylene) [Group NMVOC to air]	7692,3	kg	0,00013
1-Hexene [Group NMVOC to air]	7692,3	kg	0,00013
1-Methoxy-2-propanol [Group NMVOC to air]	19231	kg	5,2E-005
1-Methyl-2-pyrrolidone [Group NMVOC to air]	8333,3	kg	0,00012
1-Pentene [Group NMVOC to air]	6666,7	kg	0,00015
1-Propanol [Group NMVOC to air]	12048	kg	8,3E-005
1-Propylbenzene [Group NMVOC to air]	14085	kg	7,1E-005
1-Undecane [Group NMVOC to air]	17544	kg	5,7E-005
2,2-Dimethylbutane [Group NMVOC to air]	27027	kg	3,7E-005
2,3-Dimethylbutane [Group NMVOC to air]	17544	kg	5,7E-005
2-Butoxy-ethanol [Group NMVOC to air]	14085	kg	7,1E-005
2-Ethoxy-ethanol [Group NMVOC to air]	17544	kg	5,7E-005
2-Ethyl-1-hexanol [Group NMVOC to air]	25641	kg	3,9E-005
2-Ethylhexyl acetate [Group NMVOC to air]	33333	kg	3E-005
2-Methoxy-1-propanol [Organic intermediate products	25641	kg	3,9E-005
2-Methoxy-ethanol [Group NMVOC to air]	22222	kg	4,5E-005
2-Methyl-1-butene [Group NMVOC to air]	9090,9	kg	0,00011
2-Methyl-2-butene [Group NMVOC to air]	8333,3	kg	0,00012
2-Methylbutan-1-ol [Group NMVOC to air]	13889	kg	7,2E-005
2-Methylbutan-2-ol [Group NMVOC to air]	29412	kg	3,4E-005
2-Methylheptane [Group NMVOC to air]	14085	kg	7,1E-005
2-Methylhexane [Group NMVOC to air]	14085	kg	7,1E-005
2-Methylnonane [Group NMVOC to air]	15385	kg	6,5E-005
2-Methyloctane [Group NMVOC to air]	12987	kg	7,7E-005
2-Methylpentane [Group NMVOC to air]	12987	kg	7,7E-005

System: No changes. PE-GaBi 20 Last change: System, 01.03.2008

Table B.5. Photochemical ozone formation – impact on vegetation potential equivalency factors [GaBi4, 2003].

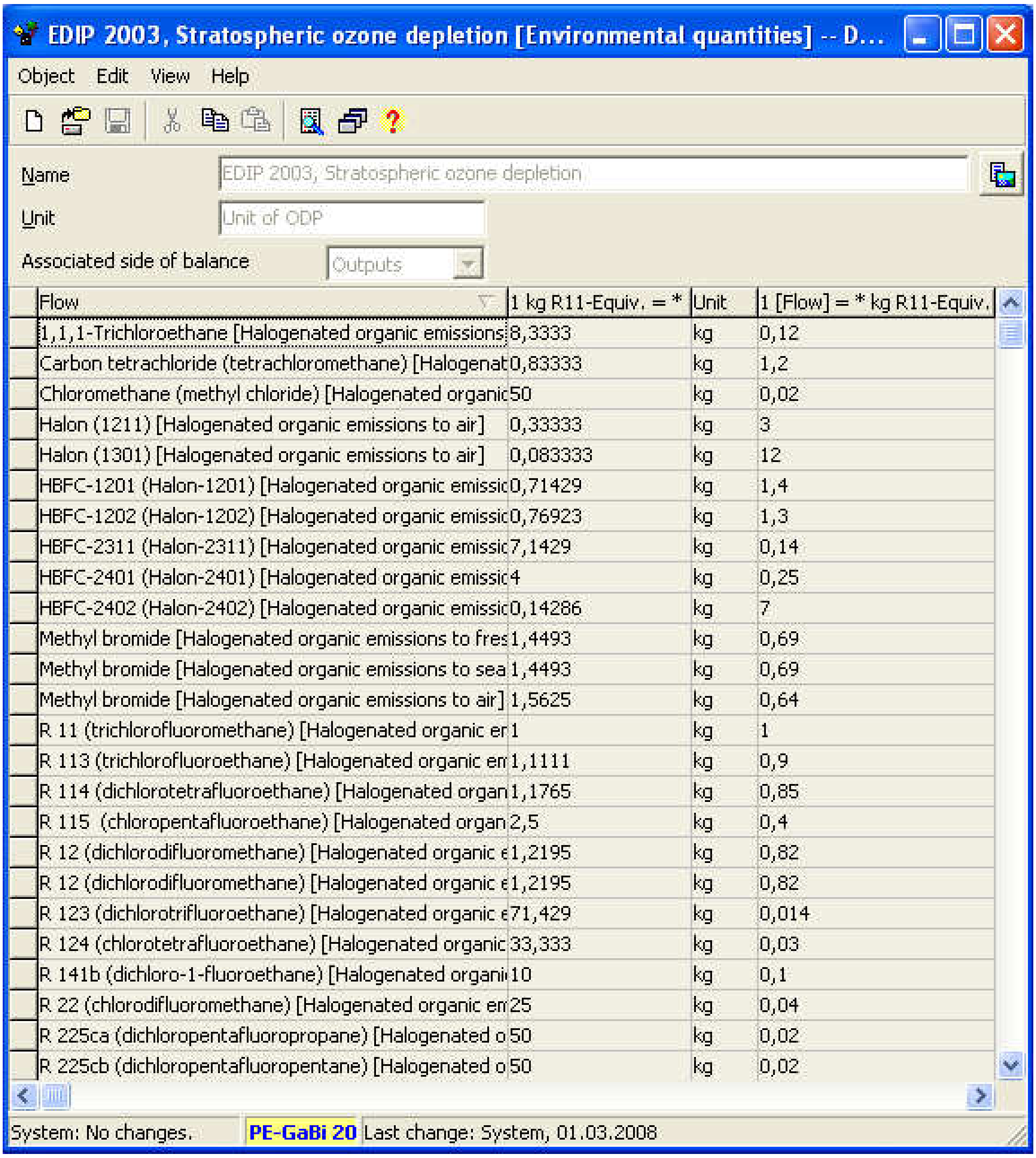


Name: EDIP 2003, Photochemical ozone formation - impact on vegetation
Unit: Unit of POCP - impact on vege
Associated side of balance: Outputs

Flow	1 m2 UES*ppm*hours = *	Unit	1 [Flow] = * m2 UES*ppm*hours
1,1,1-Trichloroethane [Halogenated organic emissions to air]	0,125	kg	8
1,2,3-Trimethylbenzene [Group NMVOC to air]	0,00047237	kg	2117
1,2,4-Trimethylbenzene [Group NMVOC to air]	0,00045662	kg	2190
1,2,5-Trimethylbenzene [Group NMVOC to air]	0,00047237	kg	2117
1,2-Butandiol [Group NMVOC to air]	0,0018248	kg	548
1,2-Dichloroethylene [Halogenated organic emissions to air]	0,0021413	kg	467
1-Butanol [Group NMVOC to air]	0,0013699	kg	730
1-Butoxypropanol [Group NMVOC to air]	0,0011834	kg	845
1-Butylene (Vinylacetylene) [Group NMVOC to air]	0,00060864	kg	1643
1-Hexene [Group NMVOC to air]	0,00062696	kg	1595
1-Methoxy-2-propanol [Group NMVOC to air]	0,0015432	kg	648
1-Methyl-2-pyrrolidone [Group NMVOC to air]	0,00068493	kg	1460
1-Pentene [Group NMVOC to air]	0,00052687	kg	1898
1-Propanol [Group NMVOC to air]	0,00097656	kg	1024
1-Propylbenzene [Group NMVOC to air]	0,0011416	kg	876
1-Undecane [Group NMVOC to air]	0,0014265	kg	701
2,2-Dimethylbutane [Group NMVOC to air]	0,0021739	kg	460
2,3-Dimethylbutane [Group NMVOC to air]	0,0014265	kg	701
2-Butoxy-ethanol [Group NMVOC to air]	0,0011351	kg	881
2-Ethoxy-ethanol [Group NMVOC to air]	0,0014205	kg	704
2-Ethyl-1-hexanol [Group NMVOC to air]	0,0020747	kg	482
2-Ethylhexyl acetate [Group NMVOC to air]	0,0027397	kg	365
2-Methoxy-1-propanol [Organic intermediate products]	0,0020747	kg	482
2-Methoxy-ethanol [Group NMVOC to air]	0,0017857	kg	560
2-Methyl-1-butene [Group NMVOC to air]	0,00071073	kg	1407
2-Methyl-2-butene [Group NMVOC to air]	0,00065062	kg	1537
2-Methylbutan-1-ol [Group NMVOC to air]	0,0011211	kg	892
2-Methylbutan-2-ol [Group NMVOC to air]	0,0024038	kg	416
2-Methylheptane [Group NMVOC to air]	0,0011416	kg	876
2-Methylhexane [Group NMVOC to air]	0,0011416	kg	876
2-Methylnonane [Group NMVOC to air]	0,0012453	kg	803
2-Methyloctane [Group NMVOC to air]	0,0010537	kg	949
2-Methylpentane [Group NMVOC to air]	0,0010537	kg	949

System: No changes. **PE-GaBi 20** Last change: System, 01.03.2008

Table B.6. Stratospheric ozone depletion potential equivalency factors [GaBi4, 2003].



Name EDIP 2003, Stratospheric ozone depletion

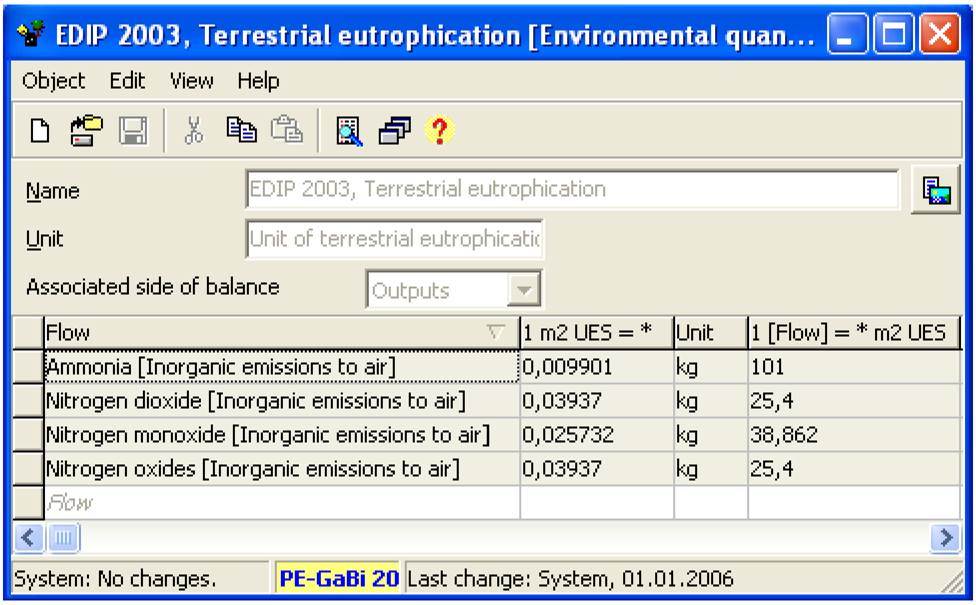
Unit Unit of ODP

Associated side of balance Outputs

Flow	1 kg R11-Equiv. = *	Unit	1 [Flow] = * kg R11-Equiv.
1,1,1-Trichloroethane [Halogenated organic emissions	8,3333	kg	0,12
Carbon tetrachloride (tetrachloromethane) [Halogenat	0,83333	kg	1,2
Chloromethane (methyl chloride) [Halogenated organic	50	kg	0,02
Halon (1211) [Halogenated organic emissions to air]	0,33333	kg	3
Halon (1301) [Halogenated organic emissions to air]	0,083333	kg	12
HBFC-1201 (Halon-1201) [Halogenated organic emissic	0,71429	kg	1,4
HBFC-1202 (Halon-1202) [Halogenated organic emissic	0,76923	kg	1,3
HBFC-2311 (Halon-2311) [Halogenated organic emissic	7,1429	kg	0,14
HBFC-2401 (Halon-2401) [Halogenated organic emissic	4	kg	0,25
HBFC-2402 (Halon-2402) [Halogenated organic emissic	0,14286	kg	7
Methyl bromide [Halogenated organic emissions to fres	1,4493	kg	0,69
Methyl bromide [Halogenated organic emissions to sea	1,4493	kg	0,69
Methyl bromide [Halogenated organic emissions to air]	1,5625	kg	0,64
R 11 (trichlorofluoromethane) [Halogenated organic er	1	kg	1
R 113 (trichlorofluoroethane) [Halogenated organic em	1,1111	kg	0,9
R 114 (dichlorotetrafluoroethane) [Halogenated organ	1,1765	kg	0,85
R 115 (chloropentafluoroethane) [Halogenated organ	2,5	kg	0,4
R 12 (dichlorodifluoromethane) [Halogenated organic e	1,2195	kg	0,82
R 12 (dichlorodifluoromethane) [Halogenated organic e	1,2195	kg	0,82
R 123 (dichlorotrifluoroethane) [Halogenated organic e	71,429	kg	0,014
R 124 (chlorotetrafluoroethane) [Halogenated organic	33,333	kg	0,03
R 141b (dichloro-1-fluoroethane) [Halogenated organi	10	kg	0,1
R 22 (chlorodifluoromethane) [Halogenated organic em	25	kg	0,04
R 225ca (dichloropentafluoropropane) [Halogenated o	50	kg	0,02
R 225cb (dichloropentafluoropentane) [Halogenated o	50	kg	0,02

System: No changes. PE-GaBi 20 Last change: System, 01.03.2008

Table B.7. Terrestrial eutrophication potential equivalency factors [GaBi4, 2003].



Name: EDIP 2003, Terrestrial eutrophication

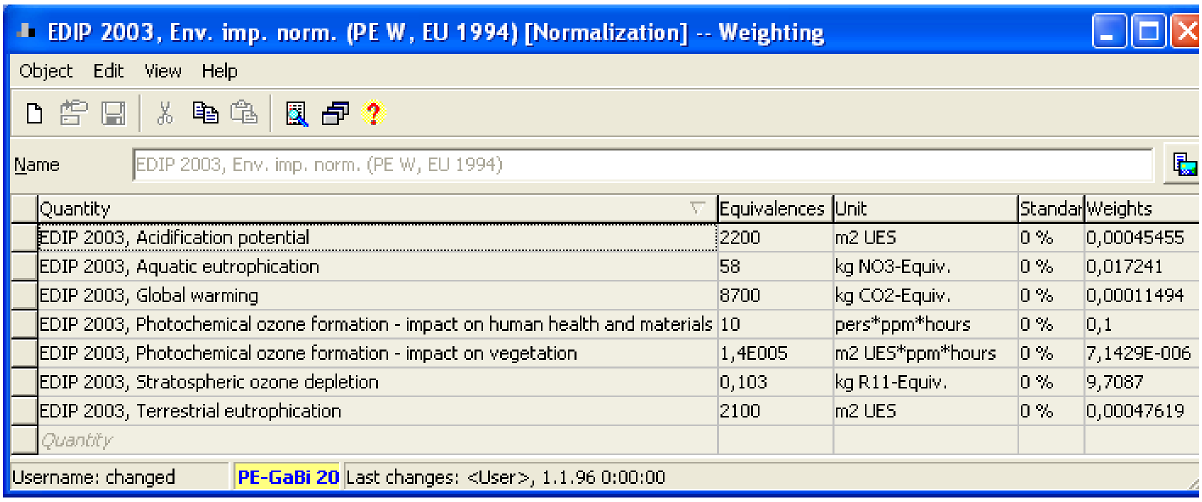
Unit: Unit of terrestrial eutrophicati

Associated side of balance: Outputs

Flow	1 m2 UES = *	Unit	1 [Flow] = * m2 UES
Ammonia [Inorganic emissions to air]	0,009901	kg	101
Nitrogen dioxide [Inorganic emissions to air]	0,03937	kg	25,4
Nitrogen monoxide [Inorganic emissions to air]	0,025732	kg	38,862
Nitrogen oxides [Inorganic emissions to air]	0,03937	kg	25,4
Flow			

System: No changes. **PE-GaBi 20** Last change: System, 01.01.2006

Table B.8. Normalization factors according to EDIP 2003 [GaBi4, 2003].

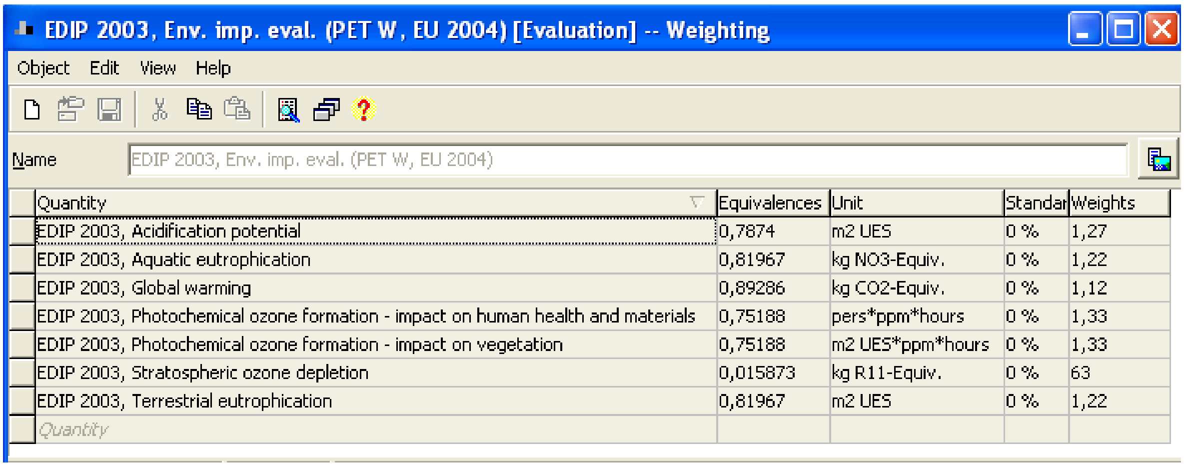


Name: EDIP 2003, Env. imp. norm. (PE W, EU 1994)

Quantity	Equivalences	Unit	Standar	Weights
EDIP 2003, Acidification potential	2200	m2 UES	0 %	0,00045455
EDIP 2003, Aquatic eutrophication	58	kg NO3-Equiv.	0 %	0,017241
EDIP 2003, Global warming	8700	kg CO2-Equiv.	0 %	0,00011494
EDIP 2003, Photochemical ozone formation - impact on human health and materials	10	pers*ppm*hours	0 %	0,1
EDIP 2003, Photochemical ozone formation - impact on vegetation	1,4E005	m2 UES*ppm*hours	0 %	7,1429E-006
EDIP 2003, Stratospheric ozone depletion	0,103	kg R11-Equiv.	0 %	9,7087
EDIP 2003, Terrestrial eutrophication	2100	m2 UES	0 %	0,00047619
Quantity				

Username: changed **PE-GaBi 20** Last changes: <User>, 1.1.96 0:00:00

Table B.9. Weighting factors according to EDIP 2003 [GaBi4, 2003].

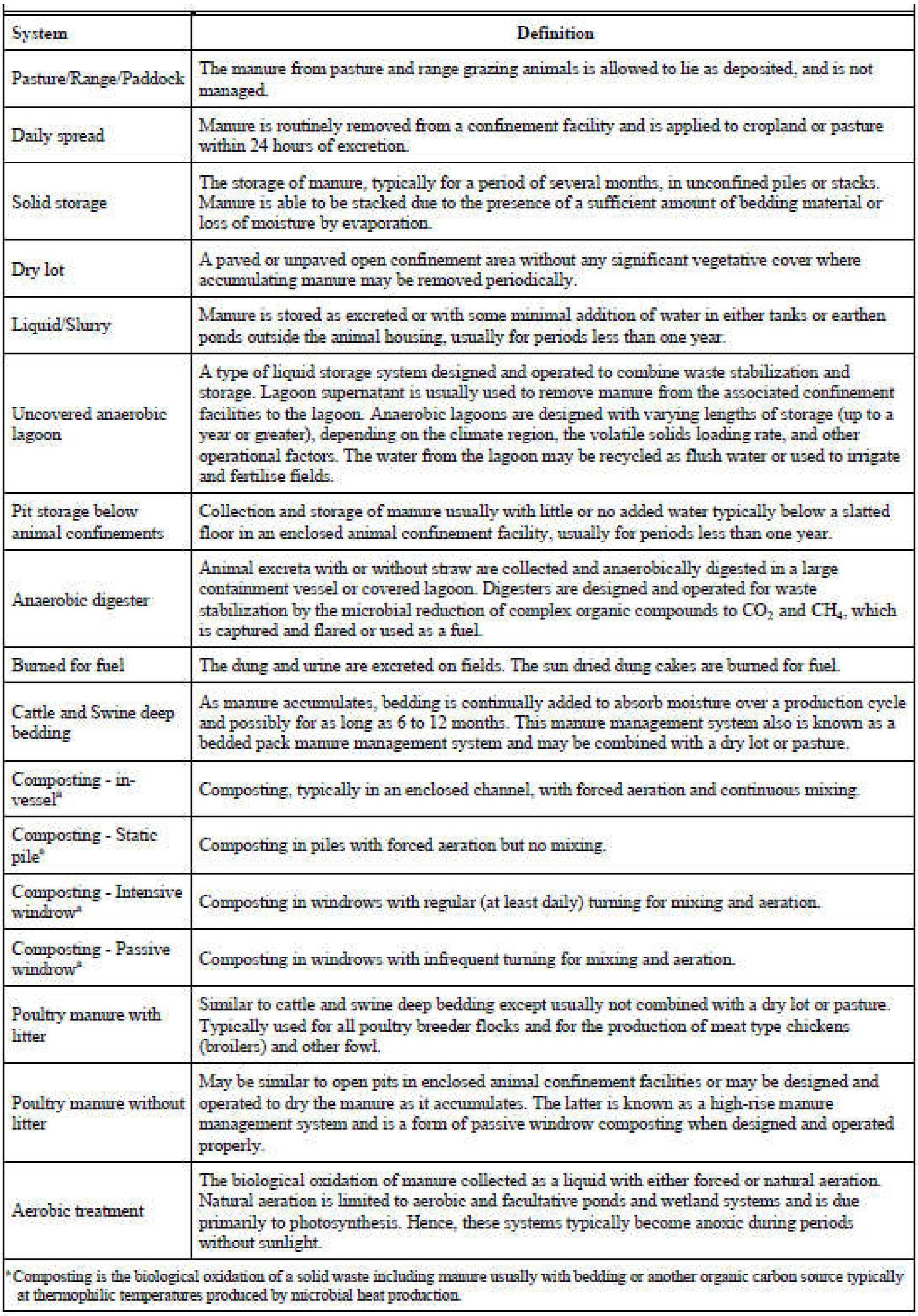


Name: EDIP 2003, Env. imp. eval. (PET W, EU 2004)

Quantity	Equivalences	Unit	Standar	Weights
EDIP 2003, Acidification potential	0,7874	m2 UES	0 %	1,27
EDIP 2003, Aquatic eutrophication	0,81967	kg NO3-Equiv.	0 %	1,22
EDIP 2003, Global warming	0,89286	kg CO2-Equiv.	0 %	1,12
EDIP 2003, Photochemical ozone formation - impact on human health and materials	0,75188	pers*ppm*hours	0 %	1,33
EDIP 2003, Photochemical ozone formation - impact on vegetation	0,75188	m2 UES*ppm*hours	0 %	1,33
EDIP 2003, Stratospheric ozone depletion	0,015873	kg R11-Equiv.	0 %	63
EDIP 2003, Terrestrial eutrophication	0,81967	m2 UES	0 %	1,22
Quantity				

APPENDIX C– DATA TABLES REGARDING THE MANURE MANAGEMENT SYSTEMS AND MANAGED SOILS

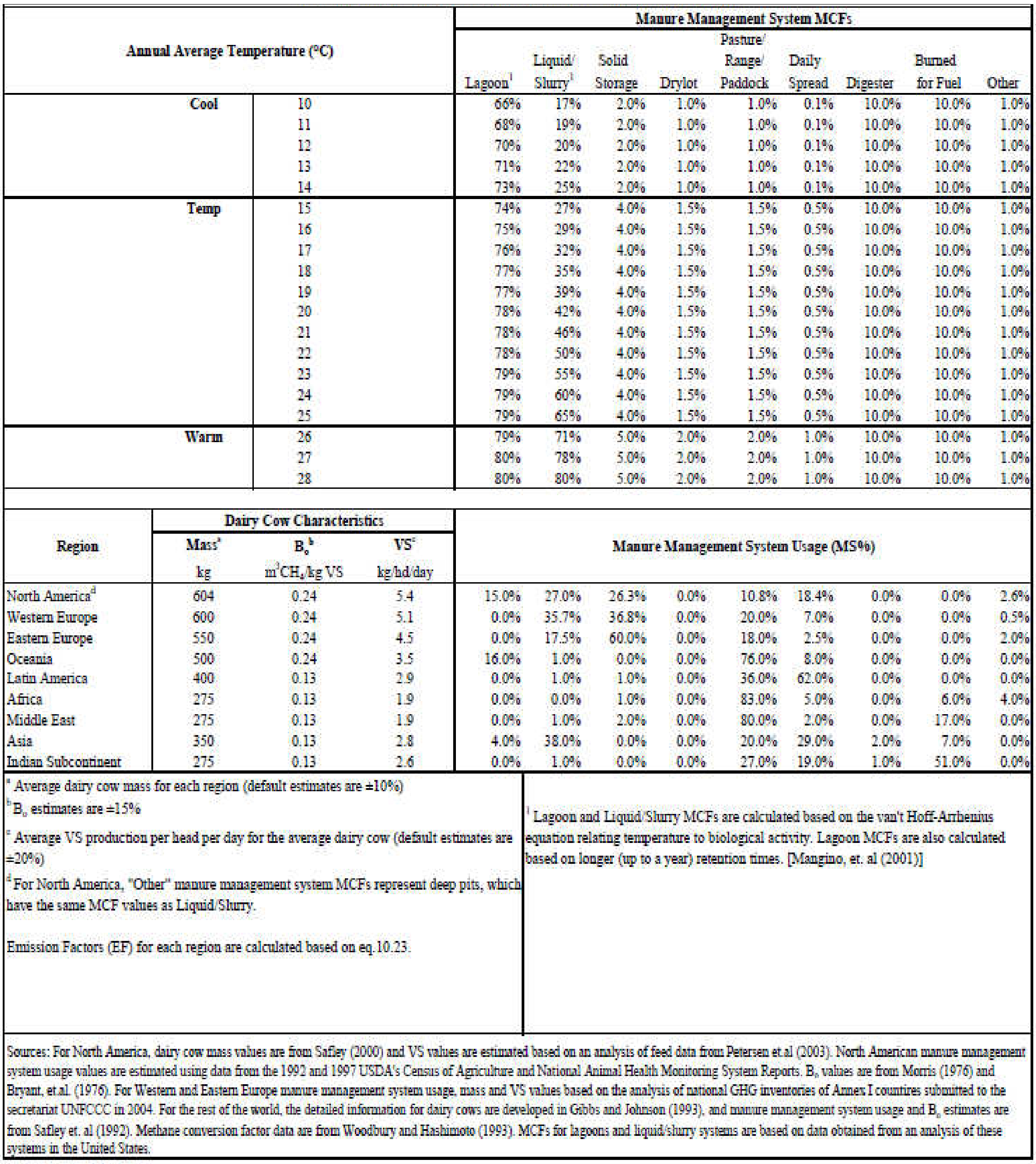
Table C.1. Definitions of manure management systems [IPCC, 2006].



System	Definition
Pasture/Range/Paddock	The manure from pasture and range grazing animals is allowed to lie as deposited, and is not managed.
Daily spread	Manure is routinely removed from a confinement facility and is applied to cropland or pasture within 24 hours of excretion.
Solid storage	The storage of manure, typically for a period of several months, in unconfined piles or stacks. Manure is able to be stacked due to the presence of a sufficient amount of bedding material or loss of moisture by evaporation.
Dry lot	A paved or unpaved open confinement area without any significant vegetative cover where accumulating manure may be removed periodically.
Liquid/Slurry	Manure is stored as excreted or with some minimal addition of water in either tanks or earthen ponds outside the animal housing, usually for periods less than one year.
Uncovered anaerobic lagoon	A type of liquid storage system designed and operated to combine waste stabilization and storage. Lagoon supernatant is usually used to remove manure from the associated confinement facilities to the lagoon. Anaerobic lagoons are designed with varying lengths of storage (up to a year or greater), depending on the climate region, the volatile solids loading rate, and other operational factors. The water from the lagoon may be recycled as flush water or used to irrigate and fertilise fields.
Pit storage below animal confinements	Collection and storage of manure usually with little or no added water typically below a slatted floor in an enclosed animal confinement facility, usually for periods less than one year.
Anaerobic digester	Animal excreta with or without straw are collected and anaerobically digested in a large containment vessel or covered lagoon. Digesters are designed and operated for waste stabilization by the microbial reduction of complex organic compounds to CO_2 and CH_4, which is captured and flared or used as a fuel.
Burned for fuel	The dung and urine are excreted on fields. The sun dried dung cakes are burned for fuel.
Cattle and Swine deep bedding	As manure accumulates, bedding is continually added to absorb moisture over a production cycle and possibly for as long as 6 to 12 months. This manure management system also is known as a bedded pack manure management system and may be combined with a dry lot or pasture.
Composting - in-vessel[a]	Composting, typically in an enclosed channel, with forced aeration and continuous mixing.
Composting - Static pile[a]	Composting in piles with forced aeration but no mixing.
Composting - Intensive windrow[a]	Composting in windrows with regular (at least daily) turning for mixing and aeration.
Composting - Passive windrow[a]	Composting in windrows with infrequent turning for mixing and aeration.
Poultry manure with litter	Similar to cattle and swine deep bedding except usually not combined with a dry lot or pasture. Typically used for all poultry breeder flocks and for the production of meat type chickens (broilers) and other fowl.
Poultry manure without litter	May be similar to open pits in enclosed animal confinement facilities or may be designed and operated to dry the manure as it accumulates. The latter is known as a high-rise manure management system and is a form of passive windrow composting when designed and operated properly.
Aerobic treatment	The biological oxidation of manure collected as a liquid with either forced or natural aeration. Natural aeration is limited to aerobic and facultative ponds and wetland systems and is due primarily to photosynthesis. Hence, these systems typically become anoxic during periods without sunlight.

[a] Composting is the biological oxidation of a solid waste including manure usually with bedding or another organic carbon source typically at thermophilic temperatures produced by microbial heat production.

Table C.2. Manure management methane emission factors for dairy cows [IPCC, 2006].



Annual Average Temperature (°C)		Manure Management System MCFs: Lagoon[1]	Liquid/ Slurry[1]	Solid Storage	Drylot	Pasture/ Range/ Paddock	Daily Spread	Digester	Burned for Fuel	Other
Cool	10	66%	17%	2.0%	1.0%	1.0%	0.1%	10.0%	10.0%	1.0%
	11	68%	19%	2.0%	1.0%	1.0%	0.1%	10.0%	10.0%	1.0%
	12	70%	20%	2.0%	1.0%	1.0%	0.1%	10.0%	10.0%	1.0%
	13	71%	22%	2.0%	1.0%	1.0%	0.1%	10.0%	10.0%	1.0%
	14	73%	25%	2.0%	1.0%	1.0%	0.1%	10.0%	10.0%	1.0%
Temp	15	74%	27%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	16	75%	29%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	17	76%	32%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	18	77%	35%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	19	77%	39%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	20	78%	42%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	21	78%	46%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	22	78%	50%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	23	79%	55%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	24	79%	60%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	25	79%	65%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
Warm	26	79%	71%	5.0%	2.0%	2.0%	1.0%	10.0%	10.0%	1.0%
	27	80%	78%	5.0%	2.0%	2.0%	1.0%	10.0%	10.0%	1.0%
	28	80%	80%	5.0%	2.0%	2.0%	1.0%	10.0%	10.0%	1.0%

Region	Dairy Cow Characteristics: Mass[a] kg	B_o[b] m^3CH_4/kg VS	VS[c] kg/hd/day	Manure Management System Usage (MS%)								
North America[d]	604	0.24	5.4	15.0%	27.0%	26.3%	0.0%	10.8%	18.4%	0.0%	0.0%	2.6%
Western Europe	600	0.24	5.1	0.0%	35.7%	36.8%	0.0%	20.0%	7.0%	0.0%	0.0%	0.5%
Eastern Europe	550	0.24	4.5	0.0%	17.5%	60.0%	0.0%	18.0%	2.5%	0.0%	0.0%	2.0%
Oceania	500	0.24	3.5	16.0%	1.0%	0.0%	0.0%	76.0%	8.0%	0.0%	0.0%	0.0%
Latin America	400	0.13	2.9	0.0%	1.0%	1.0%	0.0%	36.0%	62.0%	0.0%	0.0%	0.0%
Africa	275	0.13	1.9	0.0%	0.0%	1.0%	0.0%	83.0%	5.0%	0.0%	6.0%	4.0%
Middle East	275	0.13	1.9	0.0%	1.0%	2.0%	0.0%	80.0%	2.0%	0.0%	17.0%	0.0%
Asia	350	0.13	2.8	4.0%	38.0%	0.0%	0.0%	20.0%	29.0%	2.0%	7.0%	0.0%
Indian Subcontinent	275	0.13	2.6	0.0%	1.0%	0.0%	0.0%	27.0%	19.0%	1.0%	51.0%	0.0%

[a] Average dairy cow mass for each region (default estimates are ±10%)

[b] B_o estimates are ±15%

[c] Average VS production per head per day for the average dairy cow (default estimates are ±20%)

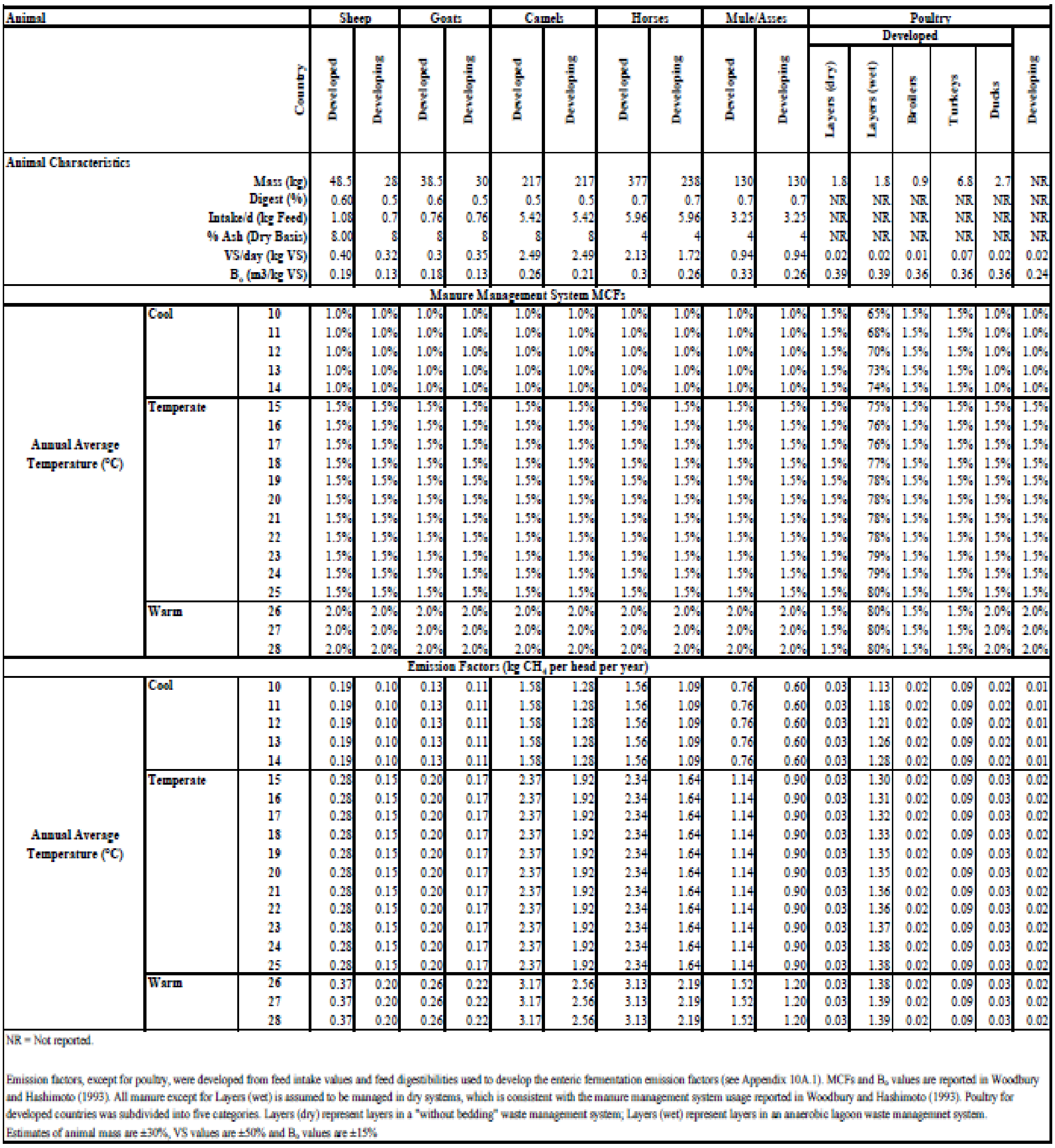
[d] For North America, "Other" manure management system MCFs represent deep pits, which have the same MCF values as Liquid/Slurry.

Emission Factors (EF) for each region are calculated based on eq.10.23.

[1] Lagoon and Liquid/Slurry MCFs are calculated based on the van't Hoff-Arrhenius equation relating temperature to biological activity. Lagoon MCFs are also calculated based on longer (up to a year) retention times. [Mangino, et. al (2001)]

Sources: For North America, dairy cow mass values are from Safley (2000) and VS values are estimated based on an analysis of feed data from Petersen et.al (2003). North American manure management system usage values are estimated using data from the 1992 and 1997 USDA's Census of Agriculture and National Animal Health Monitoring System Reports. B_o values are from Morris (1976) and Bryant, et.al. (1976). For Western and Eastern Europe manure management system usage, mass and VS values based on the analysis of national GHG inventories of Annex I countires submitted to the secretariat UNFCCC in 2004. For the rest of the world, the detailed information for dairy cows are developed in Gibbs and Johnson (1993), and manure management system usage and B_o estimates are from Safley et. al (1992). Methane conversion factor data are from Woodbury and Hashimoto (1993). MCFs for lagoons and liquid/slurry systems are based on data obtained from an analysis of these systems in the United States.

Table C.3. Manure mangement methane emission factor derivation for poultry wastes [IPCC, 2006].



Animal			Sheep		Goats		Camels		Horses		Mule/Asses		Poultry					
													Developed					
		Country	Developed	Developing	Developed	Developing	Developed	Developing	Developed	Developing	Developed	Developing	Layers (dry)	Layers (wet)	Broilers	Turkeys	Ducks	Developing
Animal Characteristics																		
		Mass (kg)	48.5	28	38.5	30	217	217	377	238	130	130	1.8	1.8	0.9	6.8	2.7	NR
		Digest (%)	0.60	0.5	0.6	0.5	0.5	0.5	0.7	0.7	0.7	0.7	NR	NR	NR	NR	NR	NR
		Intake/d (kg Feed)	1.08	0.7	0.76	0.76	5.42	5.42	5.96	5.96	3.25	3.25	NR	NR	NR	NR	NR	NR
		% Ash (Dry Basis)	8.00	8	8	8	8	8	4	4	4	4	NR	NR	NR	NR	NR	NR
		VS/day (kg VS)	0.40	0.32	0.3	0.35	2.49	2.49	2.13	1.72	0.94	0.94	0.02	0.02	0.01	0.07	0.02	0.02
		B_o (m3/kg VS)	0.19	0.13	0.18	0.13	0.26	0.21	0.3	0.26	0.33	0.26	0.39	0.39	0.36	0.36	0.36	0.24
Manure Management System MCFs																		
Annual Average Temperature (°C)	Cool	10	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.5%	65%	1.5%	1.5%	1.0%	1.0%
		11	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.5%	68%	1.5%	1.5%	1.0%	1.0%
		12	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.5%	70%	1.5%	1.5%	1.0%	1.0%
		13	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.5%	73%	1.5%	1.5%	1.0%	1.0%
		14	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.5%	74%	1.5%	1.5%	1.0%	1.0%
	Temperate	15	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	75%	1.5%	1.5%	1.5%	1.5%
		16	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	76%	1.5%	1.5%	1.5%	1.5%
		17	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	76%	1.5%	1.5%	1.5%	1.5%
		18	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	77%	1.5%	1.5%	1.5%	1.5%
		19	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	78%	1.5%	1.5%	1.5%	1.5%
		20	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	78%	1.5%	1.5%	1.5%	1.5%
		21	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	78%	1.5%	1.5%	1.5%	1.5%
		22	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	78%	1.5%	1.5%	1.5%	1.5%
		23	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	79%	1.5%	1.5%	1.5%	1.5%
		24	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	79%	1.5%	1.5%	1.5%	1.5%
		25	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	80%	1.5%	1.5%	1.5%	1.5%
	Warm	26	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	1.5%	80%	1.5%	1.5%	2.0%	2.0%
		27	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	1.5%	80%	1.5%	1.5%	2.0%	2.0%
		28	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	1.5%	80%	1.5%	1.5%	2.0%	2.0%
Emission Factors (kg CH_4 per head per year)																		
Annual Average Temperature (°C)	Cool	10	0.19	0.10	0.13	0.11	1.58	1.28	1.56	1.09	0.76	0.60	0.03	1.13	0.02	0.09	0.02	0.01
		11	0.19	0.10	0.13	0.11	1.58	1.28	1.56	1.09	0.76	0.60	0.03	1.18	0.02	0.09	0.02	0.01
		12	0.19	0.10	0.13	0.11	1.58	1.28	1.56	1.09	0.76	0.60	0.03	1.21	0.02	0.09	0.02	0.01
		13	0.19	0.10	0.13	0.11	1.58	1.28	1.56	1.09	0.76	0.60	0.03	1.26	0.02	0.09	0.02	0.01
		14	0.19	0.10	0.13	0.11	1.58	1.28	1.56	1.09	0.76	0.60	0.03	1.28	0.02	0.09	0.02	0.01
	Temperate	15	0.28	0.15	0.20	0.17	2.37	1.92	2.34	1.64	1.14	0.90	0.03	1.30	0.02	0.09	0.03	0.02
		16	0.28	0.15	0.20	0.17	2.37	1.92	2.34	1.64	1.14	0.90	0.03	1.31	0.02	0.09	0.03	0.02
		17	0.28	0.15	0.20	0.17	2.37	1.92	2.34	1.64	1.14	0.90	0.03	1.32	0.02	0.09	0.03	0.02
		18	0.28	0.15	0.20	0.17	2.37	1.92	2.34	1.64	1.14	0.90	0.03	1.33	0.02	0.09	0.03	0.02
		19	0.28	0.15	0.20	0.17	2.37	1.92	2.34	1.64	1.14	0.90	0.03	1.35	0.02	0.09	0.03	0.02
		20	0.28	0.15	0.20	0.17	2.37	1.92	2.34	1.64	1.14	0.90	0.03	1.35	0.02	0.09	0.03	0.02
		21	0.28	0.15	0.20	0.17	2.37	1.92	2.34	1.64	1.14	0.90	0.03	1.36	0.02	0.09	0.03	0.02
		22	0.28	0.15	0.20	0.17	2.37	1.92	2.34	1.64	1.14	0.90	0.03	1.36	0.02	0.09	0.03	0.02
		23	0.28	0.15	0.20	0.17	2.37	1.92	2.34	1.64	1.14	0.90	0.03	1.37	0.02	0.09	0.03	0.02
		24	0.28	0.15	0.20	0.17	2.37	1.92	2.34	1.64	1.14	0.90	0.03	1.38	0.02	0.09	0.03	0.02
		25	0.28	0.15	0.20	0.17	2.37	1.92	2.34	1.64	1.14	0.90	0.03	1.38	0.02	0.09	0.03	0.02
	Warm	26	0.37	0.20	0.26	0.22	3.17	2.56	3.13	2.19	1.52	1.20	0.03	1.38	0.02	0.09	0.03	0.02
		27	0.37	0.20	0.26	0.22	3.17	2.56	3.13	2.19	1.52	1.20	0.03	1.39	0.02	0.09	0.03	0.02
		28	0.37	0.20	0.26	0.22	3.17	2.56	3.13	2.19	1.52	1.20	0.03	1.39	0.02	0.09	0.03	0.02

NR = Not reported.

Emission factors, except for poultry, were developed from feed intake values and feed digestibilities used to develop the enteric fermentation emission factors (see Appendix 10A.1). MCFs and B_o values are reported in Woodbury and Hashimoto (1993). All manure except for Layers (wet) is assumed to be managed in dry systems, which is consistent with the manure management system usage reported in Woodbury and Hashimoto (1993). Poultry for developed countries was subdivided into five categories. Layers (dry) represent layers in a "without bedding" waste management system; Layers (wet) represent layers in an anaerobic lagoon waste managemnet system.
Estimates of animal mass are ±30%, VS values are ±50% and B_o values are ±15%

Table C.4. Default values for nitrogen excretion rate (kg N (1000 kg animal mass)$^{-1}$day^{-1}) [IPCC, 2006].

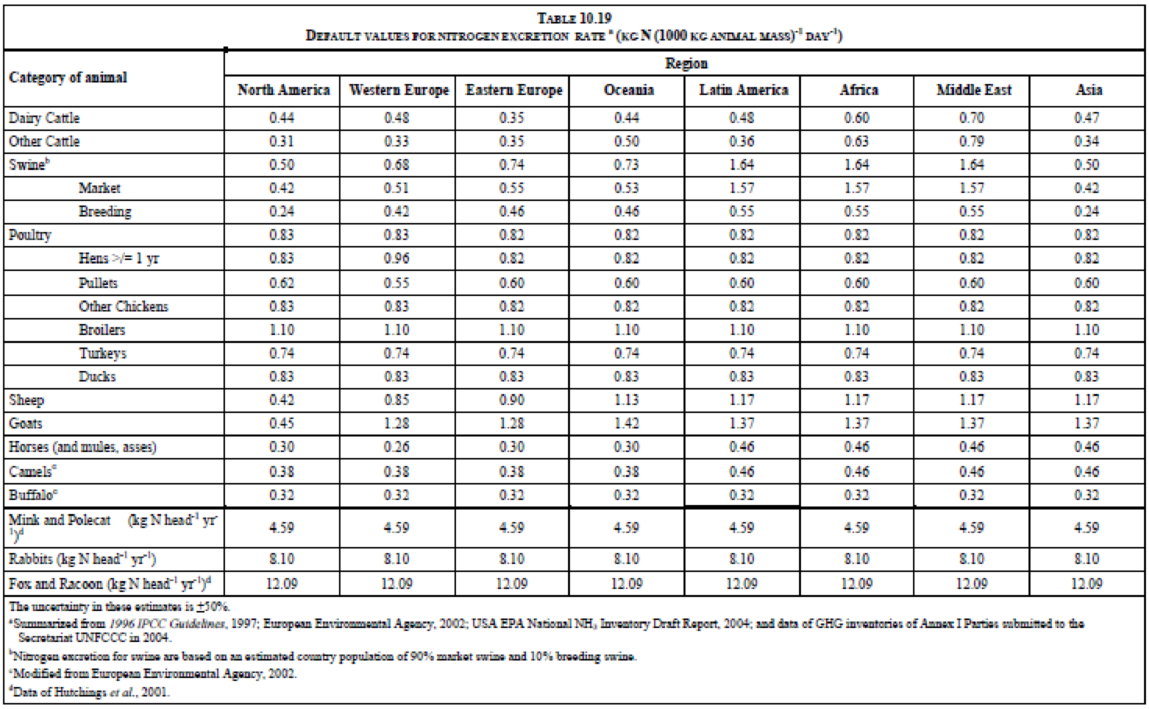


TABLE 10.19
DEFAULT VALUES FOR NITROGEN EXCRETION RATE [a] (KG N (1000 KG ANIMAL MASS)$^{-1}$ DAY^{-1})

Category of animal	**Region**							
	North America	**Western Europe**	**Eastern Europe**	**Oceania**	**Latin America**	**Africa**	**Middle East**	**Asia**
Dairy Cattle	0.44	0.48	0.35	0.44	0.48	0.60	0.70	0.47
Other Cattle	0.31	0.33	0.35	0.50	0.36	0.63	0.79	0.34
Swine[b]	0.50	0.68	0.74	0.73	1.64	1.64	1.64	0.50
Market	0.42	0.51	0.55	0.53	1.57	1.57	1.57	0.42
Breeding	0.24	0.42	0.46	0.46	0.55	0.55	0.55	0.24
Poultry	0.83	0.83	0.82	0.82	0.82	0.82	0.82	0.82
Hens >/= 1 yr	0.83	0.96	0.82	0.82	0.82	0.82	0.82	0.82
Pullets	0.62	0.55	0.60	0.60	0.60	0.60	0.60	0.60
Other Chickens	0.83	0.83	0.82	0.82	0.82	0.82	0.82	0.82
Broilers	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Turkeys	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74
Ducks	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83
Sheep	0.42	0.85	0.90	1.13	1.17	1.17	1.17	1.17
Goats	0.45	1.28	1.28	1.42	1.37	1.37	1.37	1.37
Horses (and mules, asses)	0.30	0.26	0.30	0.30	0.46	0.46	0.46	0.46
Camels[c]	0.38	0.38	0.38	0.38	0.46	0.46	0.46	0.46
Buffalo[c]	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
Mink and Polecat (kg N head^{-1} yr^{-1})[d]	4.59	4.59	4.59	4.59	4.59	4.59	4.59	4.59
Rabbits (kg N head^{-1} yr^{-1})	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10
Fox and Racoon (kg N head^{-1} yr^{-1})[d]	12.09	12.09	12.09	12.09	12.09	12.09	12.09	12.09

The uncertainty in these estimates is ±50%.

[a] Summarized from *1996 IPCC Guidelines*, 1997; European Environmental Agency, 2002; USA EPA National NH$_3$ Inventory Draft Report, 2004; and data of GHG inventories of Annex I Parties submitted to the Secretariat UNFCCC in 2004.

[b] Nitrogen excretion for swine are based on an estimated country population of 90% market swine and 10% breeding swine.

[c] Modified from European Environmental Agency, 2002.

[d] Data of Hutchings *et al.*, 2001.

Table C.5. Default emission factors for direct N_2O emissions from manure management [IPCC, 2006].

System	Definition		EF_3 [kg N_2O-N (kg Nitrogen excreted)$^{-1}$]	Uncertainty ranges of EF_3	Source[a]
Pasture/Range/ Paddock	The manure from pasture and range grazing animals is allowed to lie as is, and is not managed.		Direct and indirect N_2O emissions associated with the manure deposited on agricultural soils and pasture, range, paddock systems are treated in Chapter 11, Section 11.2, N_2O emissions from managed soils.		
Daily spread	Manure is routinely removed from a confinement facility and is applied to cropland or pasture within 24 hours of excretion. N_2O emissions during storage and treatment are assumed to be zero. N_2O emissions from land application are covered under the Agricultural Soils category.		0	Not applicable	Judgement by IPCC Expert Group (see Co-chairs, Editors and Experts; N_2O emissions from Manure Management).
Solid storage[b]	The storage of manure, typically for a period of several months, in unconfined piles or stacks. Manure is able to be stacked due to the presence of a sufficient amount of bedding material or loss of moisture by evaporation.		0.005	Factor of 2	Judgement of IPCC Expert Group in combination with Amon *et al.* (2001), which shows emissions ranging from 0.0027 to 0.01 kg N_2O-N (kg N)$^{-1}$.
Dry lot	A paved or unpaved open confinement area without any significant vegetative cover where accumulating manure may be removed periodically. Dry lots are most typically found in dry climates but also are used in humid climates.		0.02	Factor of 2	Judgement of IPCC Expert Group in combination with Kulling (2003).
Liquid/Slurry	Manure is stored as excreted or with some minimal addition of water to facilitate handling and is stored in either tanks or earthen ponds.	With natural crust cover	0.005	Factor of 2	Judgement of IPCC Expert Group in combination with Sommer *et al.* (2000).
		Without natural crust cover	0	Not applicable	Judgement of IPCC Expert Group in combination with the following studies: Harper *et al.* (2000), Lague *et al.* (2004), Monteny *et al.* (2001), and Wagner-Riddle and Marinier (2003). Emissions are believed negligible based on the absence of oxidized forms of nitrogen entering systems in combination with low potential for nitrification and denitrification in the system.
Uncovered anaerobic lagoon	Anaerobic lagoons are designed and operated to combine waste stabilization and storage. Lagoon supernatant is usually used to remove manure from the associated confinement facilities to the lagoon. Anaerobic lagoons are designed with varying lengths of storage (up to a year or greater), depending on the climate region, the volatile solids loading rate, and other operational factors. The water from the lagoon may be recycled as flush water or used to irrigate and fertilise fields.		0	Not applicable	Judgement of IPCC Expert Group in combination with the following studies: Harper *et al.* (2000), Lague *et al.* (2004), Monteny *et al.* (2001), and Wagner-Riddle and Marinier (2003). Emissions are believed negligible based on the absence of oxidized forms of nitrogen entering systems in combination with low potential for nitrification and denitrification in the system.
Pit storage below animal confinements	Collection and storage of manure usually with little or no added water typically below a slatted floor in an enclosed animal confinement facility.		0.002	Factor of 2	Judgement of IPCC Expert Group in combination with the following studies: Amon *et al.* (2001), Kulling (2003), and Sneath *et al.* (1997).

System	Definition		EF_3 [kg N_2O-N (kg Nitrogen excreted)$^{-1}$]	Uncertainty ranges of EF_3	Source[a]
Anaerobic digester	Anaerobic digesters are designed and operated for waste stabilization by the microbial reduction of complex organic compounds to CH_4 and CO_2, which is captured and flared or used as a fuel.		0	Not applicable	Judgement of IPCC Expert Group in combination with the following studies: Harper *et al.* (2000), Lague *et al.* (2004) Monteny *et al.* (2001), and Wagner-Riddle and Marinier (2003). Emissions are believed negligible based on the absence of oxidized forms of nitrogen entering systems in combination with low potential for nitrification and denitrification in the system.
Burned for fuel or as waste	The dung is excreted on fields. The sun dried dung cakes are burned for fuel.		The emissions associated with the burning of the dung are to be reported under the IPCC category 'Fuel Combustion' if the dung is used as fuel and under the IPCC category 'Waste Incineration' if the dung is burned without energy recovery.		
	Urine N deposited on pasture and paddock		Direct and indirect N_2O emissions associated with the urine deposited on agricultural soils and pasture, range, paddock systems are treated in Chapter 11, Section 11.2, N_2O emissions from managed soils.		
Cattle and swine deep bedding	As manure accumulates, bedding is continually added to absorb moisture over a production cycle and possibly for as long as 6 to 12 months. This manure management system also is known as a bedded pack manure management system and may be combined with a dry lot or pasture.	No mixing	0.01	Factor of 2	Average value based on Sommer and Moller (2000), Sommer (2000), Amon *et al.* (1998), and Nicks *et al.* (2003).
		Active mixing	0.07	Factor of 2	Average value based on Nicks *et al.* (2003) and Moller *et al.* (2000). Some literature cites higher values to 20% for well maintained, active mixing, but those systems included treatment for ammonia which is not typical.
Composting - In-Vessel[c]	Composting, typically in an enclosed channel, with forced aeration and continuous mixing.		0.006	Factor of 2	Judgement of IPCC Expert Group. Expected to be similar to static piles.
Composting - Static Pile[c]	Composting in piles with forced aeration but no mixing.		0.006	Factor of 2	Hao *et al.* (2001).
Composting - Intensive Windrow[c]	Composting in windrows with regular turning for mixing and aeration.		0.1	Factor of 2	Judgement of IPCC Expert Group. Expected to be greater than passive windrows and intensive composting operations, as emissions are a function of the turning frequency.
Composting - Passive Windrow[c]	Composting in windrows with infrequent turning for mixing and aeration.		0.01	Factor of 2	Hao *et al.* (2001).
Poultry manure with litter	Similar to deep bedding systems. Typically used for all poultry breeder flocks and for the production of meat type chickens (broilers) and other fowl.		0.001	Factor of 2	Judgement of IPCC Expert Group based on the high loss of ammonia from these systems, which limits the availability of nitrogen for nitrification/denitrification.
Poultry manure without litter	May be similar to open pits in enclosed animal confinement facilities or may be designed and operated to dry the manure as it accumulates. The latter is known as a high-rise manure management system and is a form of passive windrow composting when designed and operated properly.		0.001	Factor of 2	Judgement of IPCC Expert Group based on the high loss of ammonia from these systems, which limits the availability of nitrogen for nitrification/denitrification.

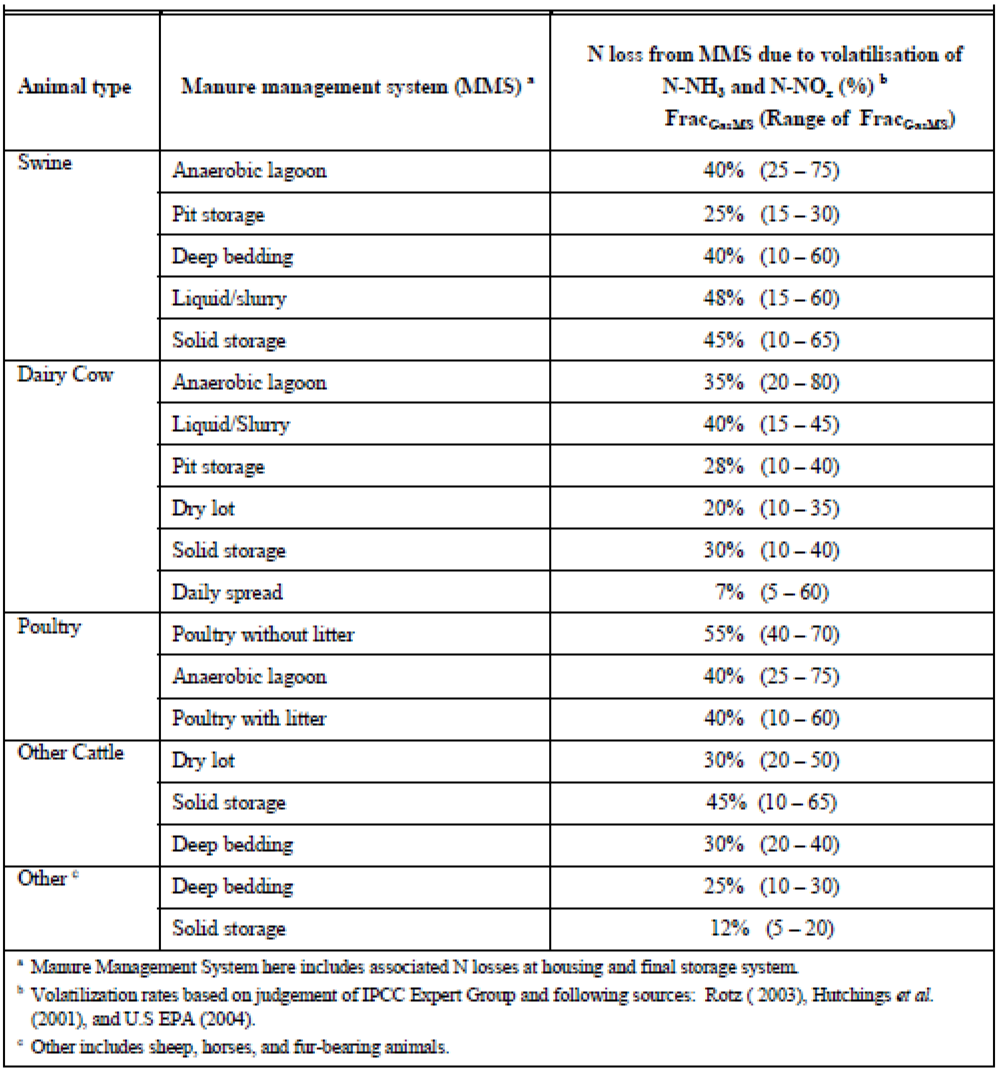
System	**Definition**		**EF$_3$ [kg N$_2$O-N (kg Nitrogen excreted)$^{-1}$]**	**Uncertainty ranges of EF$_3$**	**Source[a]**
Aerobic treatment	The biological oxidation of manure collected as a liquid with either forced or natural aeration. Natural aeration is limited to aerobic and facultative ponds and wetland systems and is due primarily to photosynthesis. Hence, these systems typically become anoxic during periods without sunlight.	Natural aeration systems	0.01	Factor of 2	Judgement of IPCC Expert Group. Nitrification-denitrification is used widely for the removal of nitrogen in the biological treatment of municipal and industrial wastewaters with negligible N$_2$O emissions. Limited oxidation may increase emissions compared to forced aeration systems.
		Forced aeration systems	0.005	Factor of 2	Judgement of IPCC Expert Group. Nitrification-denitrification is used widely for the removal of nitrogen in the biological treatment of municipal and industrial wastewaters with negligible N$_2$O emissions.

[a] Also see Dustan (2002), which compiled information from some of the original references cited.

[b] Quantitative data should be used to distinguish whether the system is judged to be a solid storage or liquid/slurry. The borderline between dry and liquid can be drawn at 20% dry matter content.

[c] Composting is the biological oxidation of a solid waste including manure usually with bedding or another organic carbon source typically at thermophilic temperatures produced by microbial heat production.

Table C.6. Default values for nitrogen loss because of volatilization of NH_3 and NO_X from manure management [IPCC, 2006].



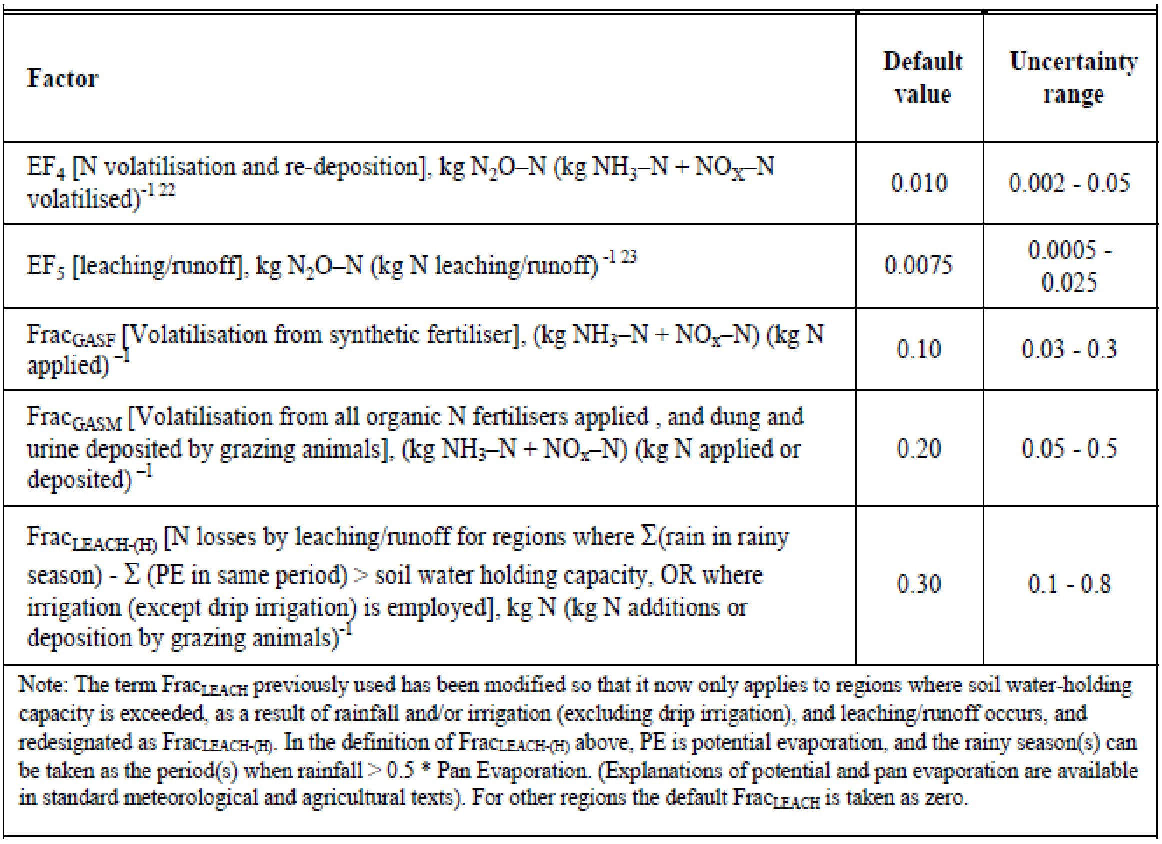
Animal type	**Manure management system (MMS)** [a]	**N loss from MMS due to volatilisation of N-NH_3 and N-NO_x (%)** [b] **$Frac_{GasMS}$ (Range of $Frac_{GasMS}$)**
Swine	Anaerobic lagoon	40% (25 – 75)
	Pit storage	25% (15 – 30)
	Deep bedding	40% (10 – 60)
	Liquid/slurry	48% (15 – 60)
	Solid storage	45% (10 – 65)
Dairy Cow	Anaerobic lagoon	35% (20 – 80)
	Liquid/Slurry	40% (15 – 45)
	Pit storage	28% (10 – 40)
	Dry lot	20% (10 – 35)
	Solid storage	30% (10 – 40)
	Daily spread	7% (5 – 60)
Poultry	Poultry without litter	55% (40 – 70)
	Anaerobic lagoon	40% (25 – 75)
	Poultry with litter	40% (10 – 60)
Other Cattle	Dry lot	30% (20 – 50)
	Solid storage	45% (10 – 65)
	Deep bedding	30% (20 – 40)
Other [c]	Deep bedding	25% (10 – 30)
	Solid storage	12% (5 – 20)

[a] Manure Management System here includes associated N losses at housing and final storage system.

[b] Volatilization rates based on judgement of IPCC Expert Group and following sources: Rotz (2003), Hutchings *et al.* (2001), and U.S EPA (2004).

[c] Other includes sheep, horses, and fur-bearing animals.

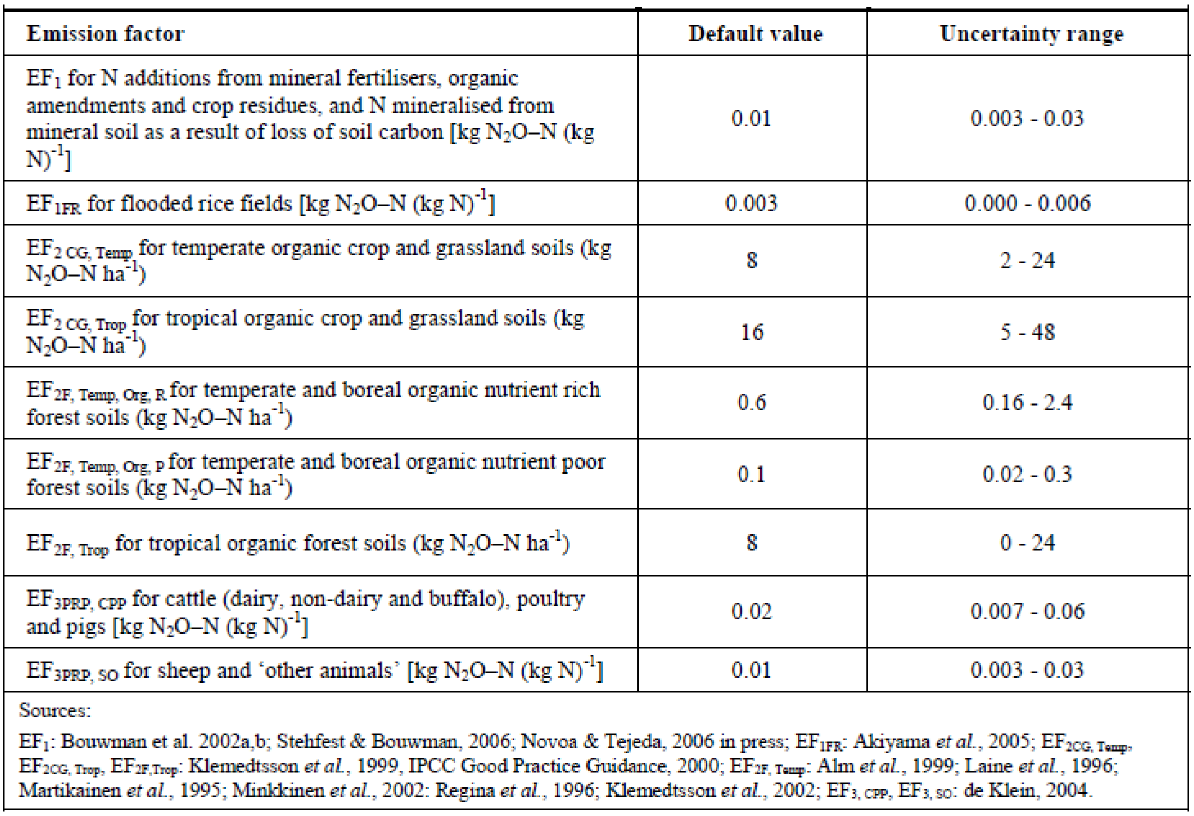
Table C.7. Default emission, volatilization and leaching factors for indirect soil N_2O emissions [IPCC, 2006].



Factor	**Default value**	**Uncertainty range**
EF_4 [N volatilisation and re-deposition], kg N_2O–N (kg NH_3–N + NO_X–N volatilised)$^{-1}$[22]	0.010	0.002 - 0.05
EF_5 [leaching/runoff], kg N_2O–N (kg N leaching/runoff)$^{-1}$[23]	0.0075	0.0005 - 0.025
$Frac_{GASF}$ [Volatilisation from synthetic fertiliser], (kg NH_3–N + NO_x–N) (kg N applied)$^{-1}$	0.10	0.03 - 0.3
$Frac_{GASM}$ [Volatilisation from all organic N fertilisers applied , and dung and urine deposited by grazing animals], (kg NH_3–N + NO_x–N) (kg N applied or deposited)$^{-1}$	0.20	0.05 - 0.5
$Frac_{LEACH-(H)}$ [N losses by leaching/runoff for regions where Σ(rain in rainy season) - Σ (PE in same period) > soil water holding capacity, OR where irrigation (except drip irrigation) is employed], kg N (kg N additions or deposition by grazing animals)$^{-1}$	0.30	0.1 - 0.8

Note: The term $Frac_{LEACH}$ previously used has been modified so that it now only applies to regions where soil water-holding capacity is exceeded, as a result of rainfall and/or irrigation (excluding drip irrigation), and leaching/runoff occurs, and redesignated as $Frac_{LEACH-(H)}$. In the definition of $Frac_{LEACH-(H)}$ above, PE is potential evaporation, and the rainy season(s) can be taken as the period(s) when rainfall > 0.5 * Pan Evaporation. (Explanations of potential and pan evaporation are available in standard meteorological and agricultural texts). For other regions the default $Frac_{LEACH}$ is taken as zero.

Table C.8. Default emission factors to estimate direct N_2O emissions from managed soils [IPCC, 2006].



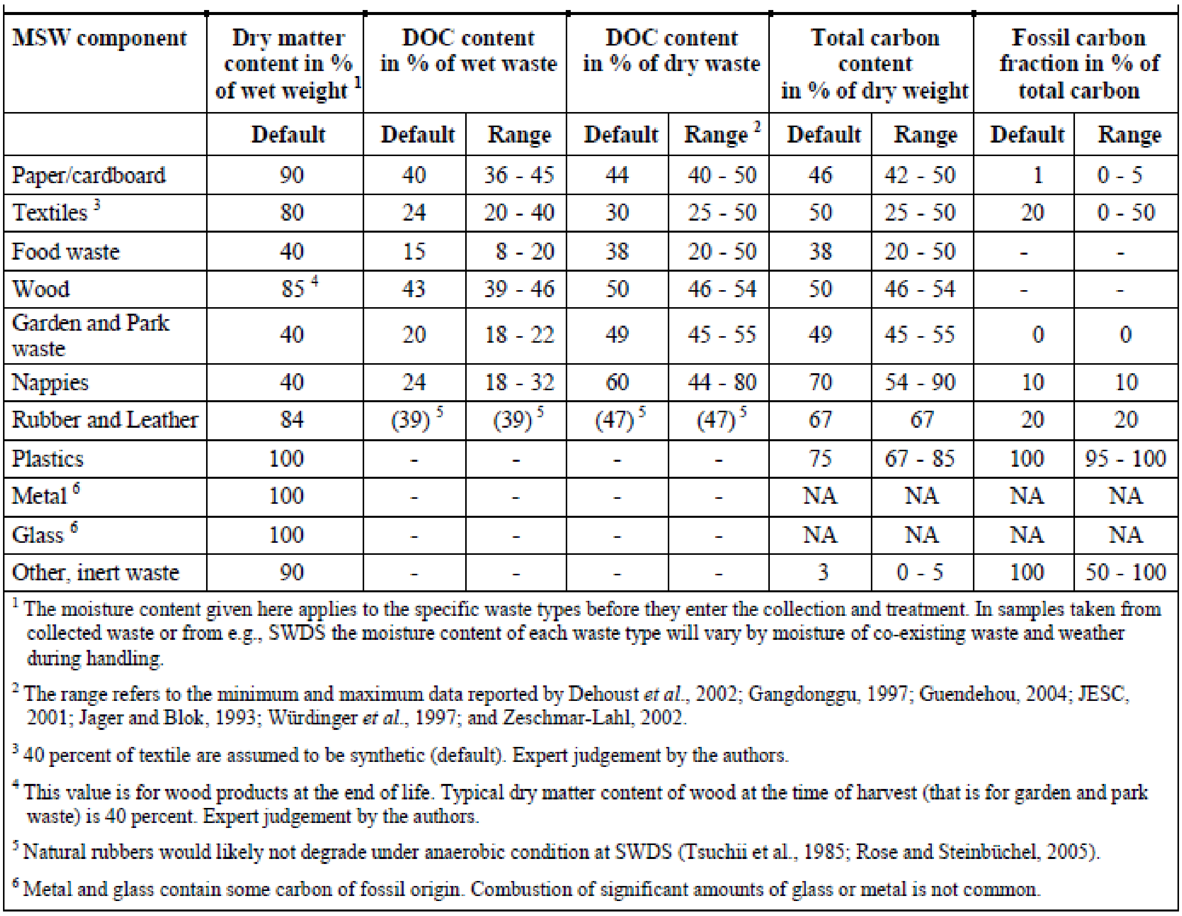
Emission factor	**Default value**	**Uncertainty range**
EF_1 for N additions from mineral fertilisers, organic amendments and crop residues, and N mineralised from mineral soil as a result of loss of soil carbon [kg N_2O–N (kg N)$^{-1}$]	0.01	0.003 - 0.03
EF_{1FR} for flooded rice fields [kg N_2O–N (kg N)$^{-1}$]	0.003	0.000 - 0.006
$EF_{2\,CG,\,Temp}$ for temperate organic crop and grassland soils (kg N_2O–N ha^{-1})	8	2 - 24
$EF_{2\,CG,\,Trop}$ for tropical organic crop and grassland soils (kg N_2O–N ha^{-1})	16	5 - 48
$EF_{2F,\,Temp,\,Org,\,R}$ for temperate and boreal organic nutrient rich forest soils (kg N_2O–N ha^{-1})	0.6	0.16 - 2.4
$EF_{2F,\,Temp,\,Org,\,P}$ for temperate and boreal organic nutrient poor forest soils (kg N_2O–N ha^{-1})	0.1	0.02 - 0.3
$EF_{2F,\,Trop}$ for tropical organic forest soils (kg N_2O–N ha^{-1})	8	0 - 24
$EF_{3PRP,\,CPP}$ for cattle (dairy, non-dairy and buffalo), poultry and pigs [kg N_2O–N (kg N)$^{-1}$]	0.02	0.007 - 0.06
$EF_{3PRP,\,SO}$ for sheep and 'other animals' [kg N_2O–N (kg N)$^{-1}$]	0.01	0.003 - 0.03

Sources:

EF_1: Bouwman et al. 2002a,b; Stehfest & Bouwman, 2006; Novoa & Tejeda, 2006 in press; EF_{1FR}: Akiyama *et al.*, 2005; $EF_{2CG,\,Temp}$, $EF_{2CG,\,Trop}$, $EF_{2F,Trop}$: Klemedtsson *et al.*, 1999, IPCC Good Practice Guidance, 2000; $EF_{2F,\,Temp}$: Alm *et al.*, 1999; Laine *et al.*, 1996; Martikainen *et al.*, 1995; Minkkinen *et al.*, 2002: Regina *et al.*, 1996; Klemedtsson *et al.*, 2002; $EF_{3,\,CPP}$, $EF_{3,\,SO}$: de Klein, 2004.

APPENDIX D– DATA TABLES REGARDING THE LANDFILLING OF SOLID WASTES

Table D.1. Default dry matter content, DOC content, total carbon content and fossil carbon fraction of different MSW components [IPCC, 2006].



MSW component	Dry matter content in % of wet weight [1]	DOC content in % of wet waste		DOC content in % of dry waste		Total carbon content in % of dry weight		Fossil carbon fraction in % of total carbon	
	Default	Default	Range	Default	Range [2]	Default	Range	Default	Range
Paper/cardboard	90	40	36 - 45	44	40 - 50	46	42 - 50	1	0 - 5
Textiles [3]	80	24	20 - 40	30	25 - 50	50	25 - 50	20	0 - 50
Food waste	40	15	8 - 20	38	20 - 50	38	20 - 50	-	-
Wood	85 [4]	43	39 - 46	50	46 - 54	50	46 - 54	-	-
Garden and Park waste	40	20	18 - 22	49	45 - 55	49	45 - 55	0	0
Nappies	40	24	18 - 32	60	44 - 80	70	54 - 90	10	10
Rubber and Leather	84	(39) [5]	(39) [5]	(47) [5]	(47) [5]	67	67	20	20
Plastics	100	-	-	-	-	75	67 - 85	100	95 - 100
Metal [6]	100	-	-	-	-	NA	NA	NA	NA
Glass [6]	100	-	-	-	-	NA	NA	NA	NA
Other, inert waste	90	-	-	-	-	3	0 - 5	100	50 - 100

[1] The moisture content given here applies to the specific waste types before they enter the collection and treatment. In samples taken from collected waste or from e.g., SWDS the moisture content of each waste type will vary by moisture of co-existing waste and weather during handling.

[2] The range refers to the minimum and maximum data reported by Dehoust *et al.*, 2002; Gangdonggu, 1997; Guendehou, 2004; JESC, 2001; Jager and Blok, 1993; Würdinger *et al.*, 1997; and Zeschmar-Lahl, 2002.

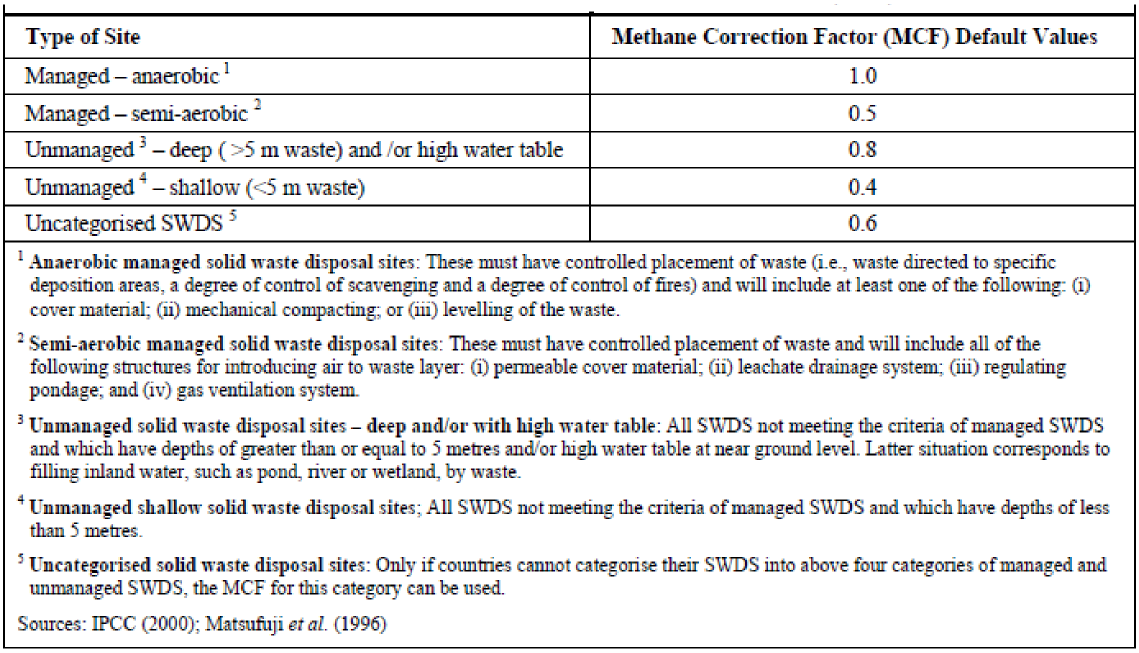
[3] 40 percent of textile are assumed to be synthetic (default). Expert judgement by the authors.

[4] This value is for wood products at the end of life. Typical dry matter content of wood at the time of harvest (that is for garden and park waste) is 40 percent. Expert judgement by the authors.

[5] Natural rubbers would likely not degrade under anaerobic condition at SWDS (Tsuchii et al., 1985; Rose and Steinbüchel, 2005).

[6] Metal and glass contain some carbon of fossil origin. Combustion of significant amounts of glass or metal is not common.

Table D.2. SWDS classification and methane correction factors (MCF) [IPCC, 2006].



Type of Site	Methane Correction Factor (MCF) Default Values
Managed – anaerobic [1]	1.0
Managed – semi-aerobic [2]	0.5
Unmanaged [3] – deep (>5 m waste) and /or high water table	0.8
Unmanaged [4] – shallow (<5 m waste)	0.4
Uncategorised SWDS [5]	0.6

[1] **Anaerobic managed solid waste disposal sites**: These must have controlled placement of waste (i.e., waste directed to specific deposition areas, a degree of control of scavenging and a degree of control of fires) and will include at least one of the following: (i) cover material; (ii) mechanical compacting; or (iii) levelling of the waste.

[2] **Semi-aerobic managed solid waste disposal sites**: These must have controlled placement of waste and will include all of the following structures for introducing air to waste layer: (i) permeable cover material; (ii) leachate drainage system; (iii) regulating pondage; and (iv) gas ventilation system.

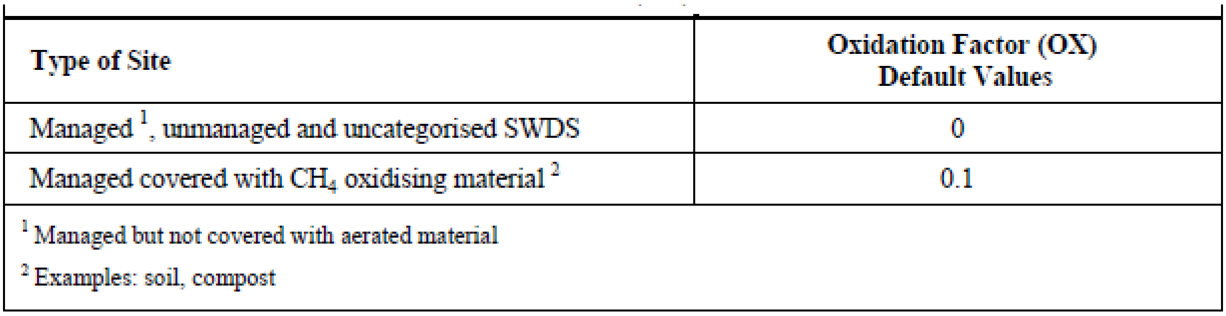
[3] **Unmanaged solid waste disposal sites – deep and/or with high water table**: All SWDS not meeting the criteria of managed SWDS and which have depths of greater than or equal to 5 metres and/or high water table at near ground level. Latter situation corresponds to filling inland water, such as pond, river or wetland, by waste.

[4] **Unmanaged shallow solid waste disposal sites**; All SWDS not meeting the criteria of managed SWDS and which have depths of less than 5 metres.

[5] **Uncategorised solid waste disposal sites**: Only if countries cannot categorise their SWDS into above four categories of managed and unmanaged SWDS, the MCF for this category can be used.

Sources: IPCC (2000); Matsufuji *et al.* (1996)

Table D.3. Oxidation factor (OX) for SWDS [IPCC, 2006].

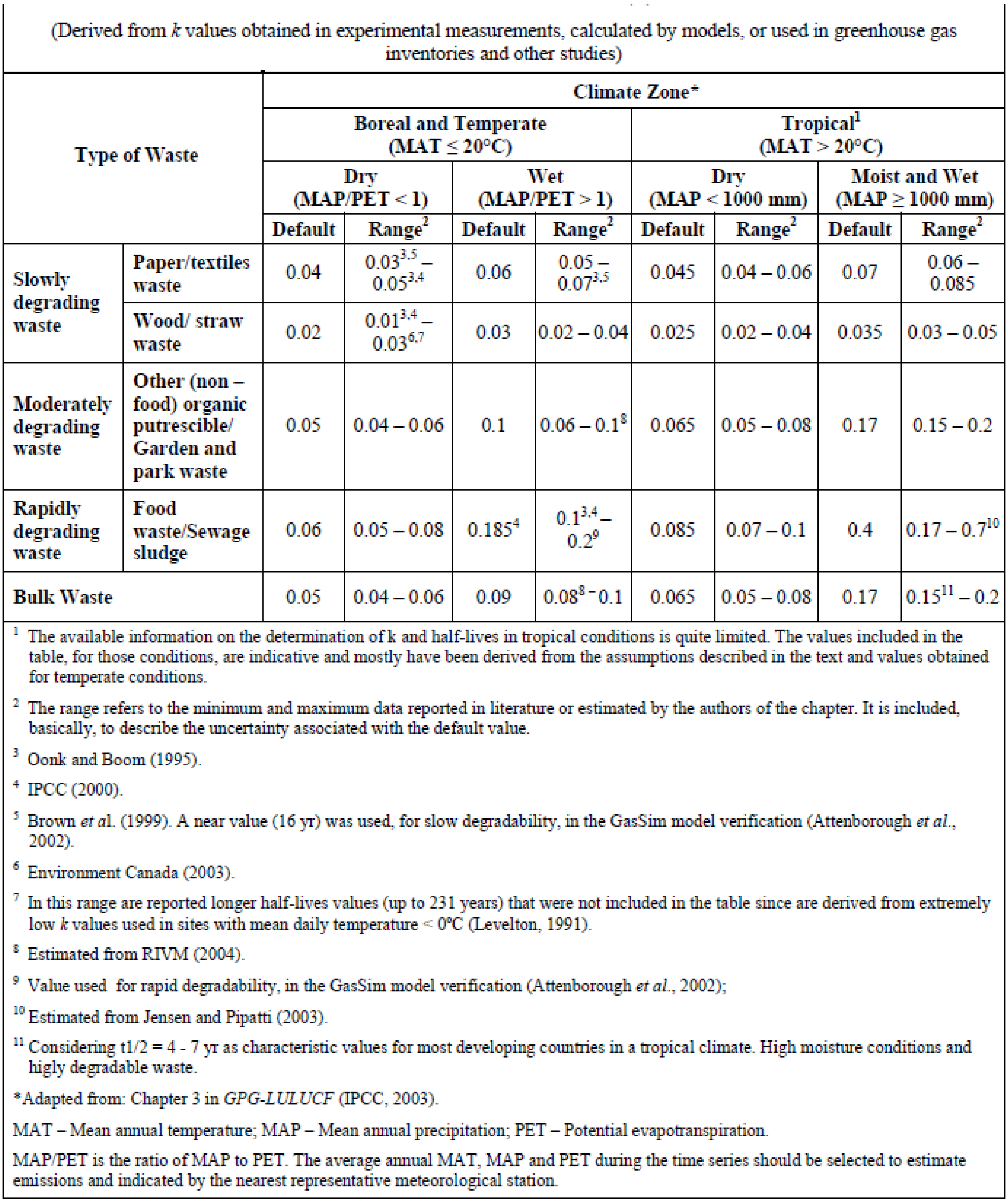


Type of Site	Oxidation Factor (OX) Default Values
Managed [1], unmanaged and uncategorised SWDS	0
Managed covered with CH_4 oxidising material [2]	0.1

[1] Managed but not covered with aerated material

[2] Examples: soil, compost

Table D.4. Recommended default methane generation rate (k) values [IPCC, 2006].



(Derived from *k* values obtained in experimental measurements, calculated by models, or used in greenhouse gas inventories and other studies)

Type of Waste		Climate Zone*							
		Boreal and Temperate (MAT ≤ 20°C)				Tropical[1] (MAT > 20°C)			
		Dry (MAP/PET < 1)		Wet (MAP/PET > 1)		Dry (MAP < 1000 mm)		Moist and Wet (MAP ≥ 1000 mm)	
		Default	Range[2]	Default	Range[2]	Default	Range[2]	Default	Range[2]
Slowly degrading waste	**Paper/textiles waste**	0.04	0.03[3,5] – 0.05[3,4]	0.06	0.05 – 0.07[3,5]	0.045	0.04 – 0.06	0.07	0.06 – 0.085
	Wood/ straw waste	0.02	0.01[3,4] – 0.03[6,7]	0.03	0.02 – 0.04	0.025	0.02 – 0.04	0.035	0.03 – 0.05
Moderately degrading waste	**Other (non – food) organic putrescible/ Garden and park waste**	0.05	0.04 – 0.06	0.1	0.06 – 0.1[8]	0.065	0.05 – 0.08	0.17	0.15 – 0.2
Rapidly degrading waste	**Food waste/Sewage sludge**	0.06	0.05 – 0.08	0.185[4]	0.1[3,4] – 0.2[9]	0.085	0.07 – 0.1	0.4	0.17 – 0.7[10]
Bulk Waste		0.05	0.04 – 0.06	0.09	0.08[8] – 0.1	0.065	0.05 – 0.08	0.17	0.15[11] – 0.2

[1] The available information on the determination of k and half-lives in tropical conditions is quite limited. The values included in the table, for those conditions, are indicative and mostly have been derived from the assumptions described in the text and values obtained for temperate conditions.

[2] The range refers to the minimum and maximum data reported in literature or estimated by the authors of the chapter. It is included, basically, to describe the uncertainty associated with the default value.

[3] Oonk and Boom (1995).

[4] IPCC (2000).

[5] Brown *et al*. (1999). A near value (16 yr) was used, for slow degradability, in the GasSim model verification (Attenborough *et al.*, 2002).

[6] Environment Canada (2003).

[7] In this range are reported longer half-lives values (up to 231 years) that were not included in the table since are derived from extremely low *k* values used in sites with mean daily temperature < 0°C (Levelton, 1991).

[8] Estimated from RIVM (2004).

[9] Value used for rapid degradability, in the GasSim model verification (Attenborough *et al.*, 2002);

[10] Estimated from Jensen and Pipatti (2003).

[11] Considering t1/2 = 4 - 7 yr as characteristic values for most developing countries in a tropical climate. High moisture conditions and higly degradable waste.

*Adapted from: Chapter 3 in *GPG-LULUCF* (IPCC, 2003).

MAT – Mean annual temperature; MAP – Mean annual precipitation; PET – Potential evapotranspiration.

MAP/PET is the ratio of MAP to PET. The average annual MAT, MAP and PET during the time series should be selected to estimate emissions and indicated by the nearest representative meteorological station.

APPENDIX E– INSTALLED POWER AND ENERGY CONSUMPTION OF THE PILOT PLANT

Table E.1. Installed power and energy consumption of the pilot plant units.

	EQUIPMENT NAME	Installed Power (kW)	Working Duration (hr)
1	**PRIMARY STORAGE UNIT**		
	Mixer	11	2
	Pump	11	2
	Atex Fan	1	24
2	**FEEDING UNIT – PASCO**		
	Hydraulic agregate	3	4
	Dosage Unit (6 x 2,2 kW+ 5,5 kW)	18.7	4
	Snail	6.8	4
	Darn snail	5	4
3	**GRINDER**		
	Electric Motor (2 x 11 kW)	22	2
4	**FERMENTER 30A**		
	Mixer	7.5	18
	Mixer	7.5	18
	Sulphide Removal	0.13	24
5	**FERMENTER 30B**		
	Mixer	7.5	18
	Mixer	7.5	18
	Sulphide Removal	0.13	24
	Pump	3	24
6	**CHP UNIT**		
	CHP Auxiliary Unit	30	24
	Central Heating	3	4
	Flair	1	0.5
7	**ALL SENSOR and GAS ANALYSIS SYSTEM**	10	24
8	**RAW MATERIAL DISTRIBUTION**		
	Raw Material Distribution Pump	7.5	7
	Compressor	3	3
9	**FINAL STORAGE**		
	Seperator	5.5	10
	Pump	11	10
10	**GUARD HOUSE and LIGTHING**	**3**	8

APPENDIX F– HEAT LOSS CALCULATIONS FOR THE ANAEROBIC DIGESTER

Table F.1. Heat loss of the anaerobic digesters.

DIGESTER HEATING REQUIREMENT		
Daily Sludge Intake	4	m^3/h
Inlet Temperature	15	Celcius
Operating Temperature	37	Celcius
Minimum Hava Sıcaklığı	14.7	Celcius
Bottom Part Soil Temperature	10	Celcius
Side Part Soil Temperature	10	Celcius
THE COEFFICIENTS OF HEATING TRANSFER		
Concrete Surfaces	**1.8**	Kcal/mhC
Isolation Material (Glass Wool)	**0.035**	Kcal/mhC
Aluminium Surface Coating	**172.0**	Kcal/mhC
THE COEFFICIENTS OF MEDIA		
External Part (Air - Walls)	**20.0**	$Kcal/m^2hC$
Water	**166.0**	$Kcal/m^2hC$
Gas	**5.3**	$Kcal/m^2hC$
Digester Information		
Digester Volume	**2,400**	m^3
Diameter	19.5	m
Total cylindiric height	8.0	m
Cylindiric height above ground level	5.3	m
Cylindiric height under ground level	2.7	m
Upper cross sectional diamater of conic base	19.5	m
Lower cross sectional diamater of conic base	19.5	m
Net height on conic base	0.00	m
Upper cross sectional diamater of conic ceiling	19.5	m
Upper cross sectional diamater of conic ceiling (at maximum sludge level)	19.5	m
Lower cross sectional diamater of conic ceiling	19.5	m
Net height on conic ceiling (Gas part only)	1.04	m
Net height on conic ceiling (Sludge part only)	0.00	m
Side wall surface area above ground level	327	m^2

Side wall surface area under ground level	163	m^2
Ceiling surface area in contact with the sludge	0	m^2
Ceiling surface area in contact with the gas	362	m^2
Lower part surface area in contact with the sludge	298	m^2
TOTAL DIGESTER AREA	**1,151**	m^2
Wall thickness of base	**0.90**	**m**
Wall thickness of ceiling	**0.40**	**m**
Wall thickness of side walls	**0.50**	**m**
Thickness of glass wool	**0.10**	**m**
Coating thickness of Al surface	**0.001**	**m**
Heating transfer coefficient of cylindiric side walls above ground level	0.313	Kcal/m^2hC
Heating transfer coefficient of cylindiric side walls under ground level	3.524	Kcal/m^2hC
Heating transfer coefficient of lower parts under ground level	1.976	Kcal/m^2hC
Heating transfer coefficient of ceiling part for sludge	0.319	Kcal/m^2hC
Heating transfer coefficient of ceiling part for gas	0.301	Kcal/m^2hC
HEATING LOSS		
Ceiling in contact with gas	2,432	Kcal/h
Ceiling in contact with with sludge	0	Kcal/h
Side walls above ground level	2,280	Kcal/h
Side walls under ground level	15,534	Kcal/h
Lower part	15,927	Kcal/h
Pipes and Manholes (Estimation value 10%)	3,617	Kcal/h
Total Loss	39,790	Kcal/h
Heating for raw sludge / (Calculated on the next page)	0	Kcal/h
Total	39,790	Kcal/h
	46.3	Kw/h
	1,110	**Kw-h/d**
	3.9	Kg Fuel Oil / h
	94.3	Kg Fuel Oil / day
Heating Requirements		
Heating requirement of the waste recipe	12,424.34	kcal/hr
Heating requirement of the waste recipe	14.45	kWh/hr
Heating requirement of the waste recipe	346.73	kWh/day
Max. Digester Heating Loss	**2,220.85**	kWh/day
Max. Digester Heating Loss	92.54	kWh/hr

Max. Digester Heating Loss	79,580.33	kcal/hr
Total heating requirement (daily heating duration: 24 hours)	**2,567.57**	**kWh/day**
Total heating requirement	**106.98**	**kWh/hr**
Total heating requirement	**92,004.66**	**kcal/hr**

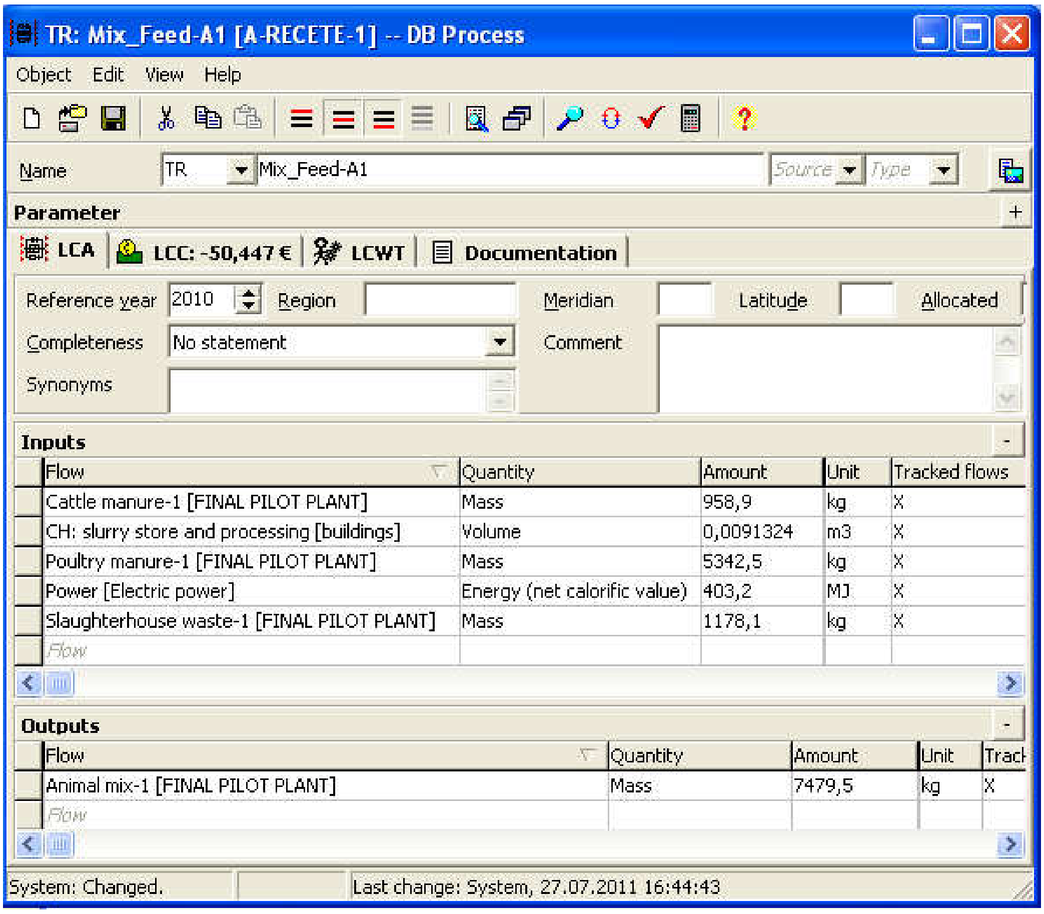
APPENDIX G– PROCESS PLANS AND INPUT&OUTPUT TABLES OF THE SCENARIOS (INVENTORY ANALYSIS RESULTS)

SCENARIO A

The flow diagram of the pilot plant for the main scenario is given in Figure G.1. The reference quantities are given for "one(1)-year period of operation of the digester utilizing an amount of 10,680 ton/year recipe".

The Table G.1 provides input and output data for the primary storage and mixing unit.

Table G.1. Input and output data of primary storage and mixing unit.



TR: Mix_Feed-A1 [A-RECETE-1] -- DB Process

Name: TR Mix_Feed-A1

LCC: -50,447 €

Reference year: 2010

Completeness: No statement

Synonyms:

Inputs

Flow	Quantity	Amount	Unit	Tracked flows
Cattle manure-1 [FINAL PILOT PLANT]	Mass	958,9	kg	X
CH: slurry store and processing [buildings]	Volume	0,0091324	m3	X
Poultry manure-1 [FINAL PILOT PLANT]	Mass	5342,5	kg	X
Power [Electric power]	Energy (net calorific value)	403,2	MJ	X
Slaughterhouse waste-1 [FINAL PILOT PLANT]	Mass	1178,1	kg	X
Flow				

Outputs

Flow	Quantity	Amount	Unit	Trac
Animal mix-1 [FINAL PILOT PLANT]	Mass	7479,5	kg	X
Flow				

System: Changed.

Last change: System, 27.07.2011 16:44:43

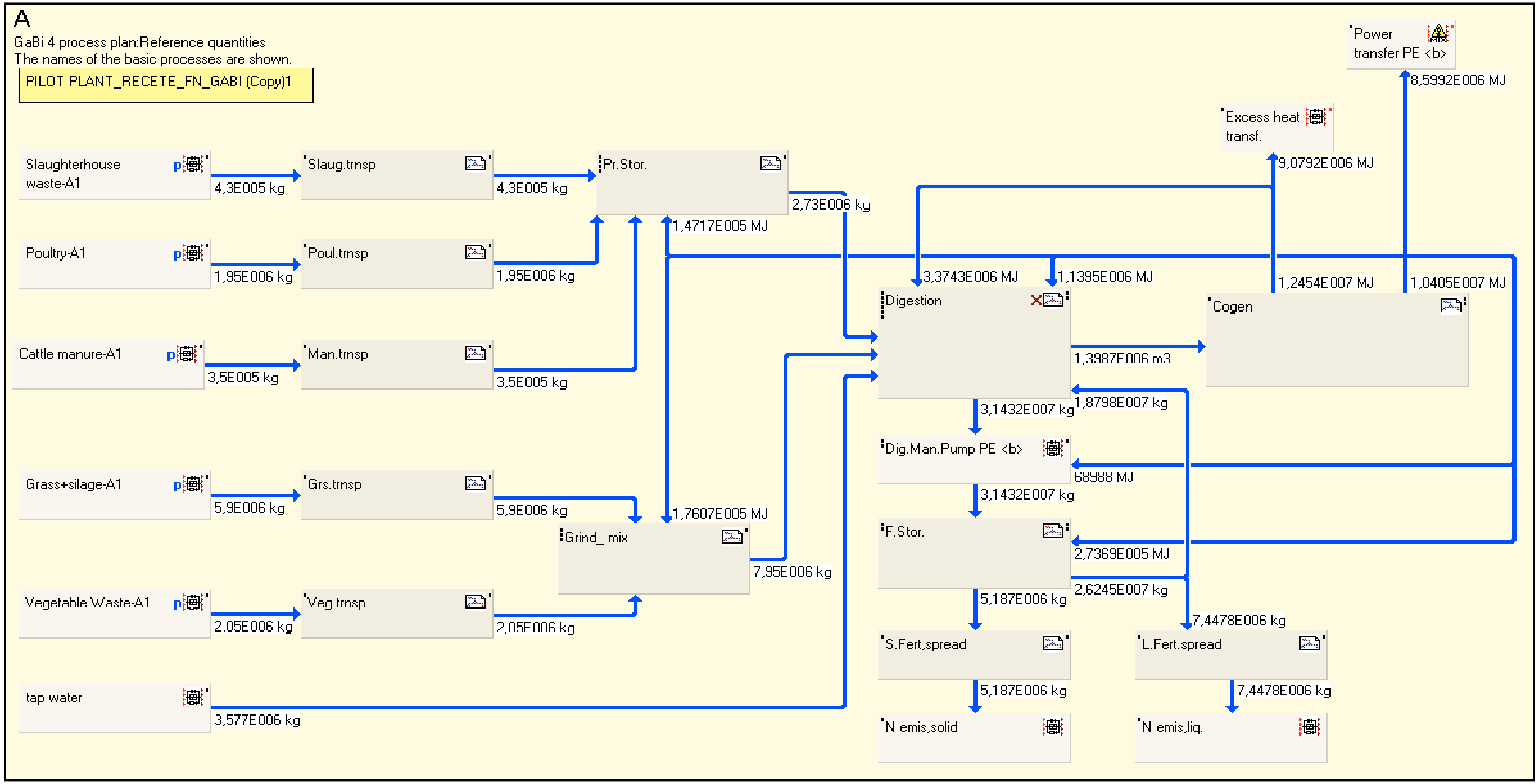
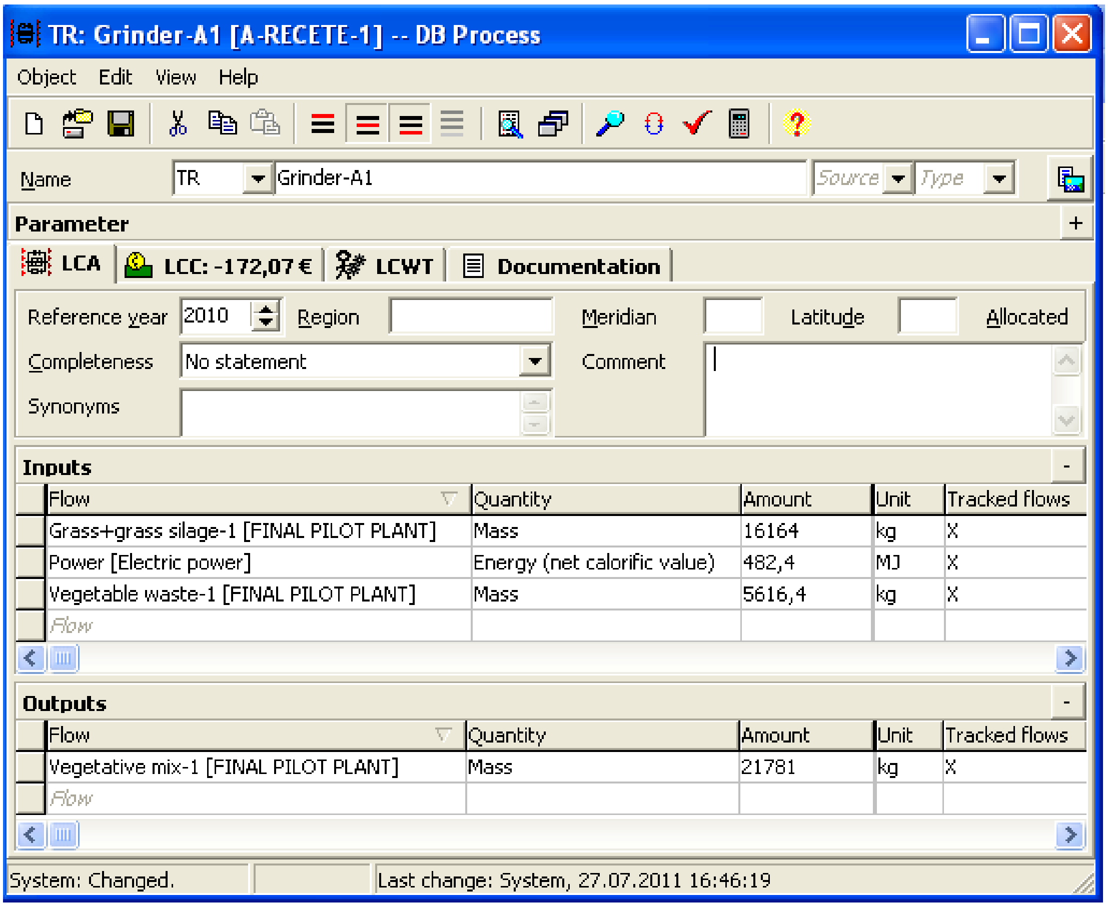


Figure G.1. Flow chart of the pilot plant (main scenario – Scenario A).

The Table G.2 provides input and output data for the the grinding and mixing unit.

Table G.2. Input and output data of grinding and mixing unit.



Name: TR Grinder-A1

Reference year: 2010

Completeness: No statement

Inputs

Flow	Quantity	Amount	Unit	Tracked flows
Grass+grass silage-1 [FINAL PILOT PLANT]	Mass	16164	kg	X
Power [Electric power]	Energy (net calorific value)	482,4	MJ	X
Vegetable waste-1 [FINAL PILOT PLANT]	Mass	5616,4	kg	X
Flow				

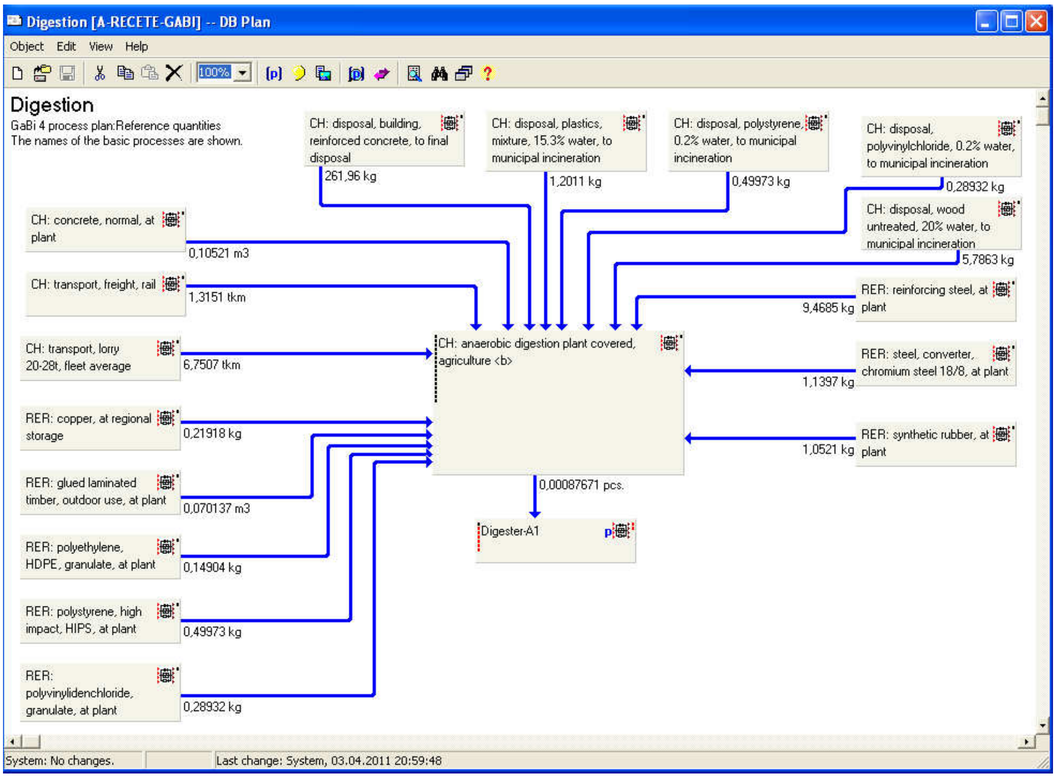
Outputs

Flow	Quantity	Amount	Unit	Tracked flows
Vegetative mix-1 [FINAL PILOT PLANT]	Mass	21781	kg	X
Flow				

System: Changed.

Last change: System, 27.07.2011 16:46:19

The process flow diagram of the anaerobic digesters is given in Figure G.2.



Digestion [A-RECETE-GABI] -- DB Plan

Digestion

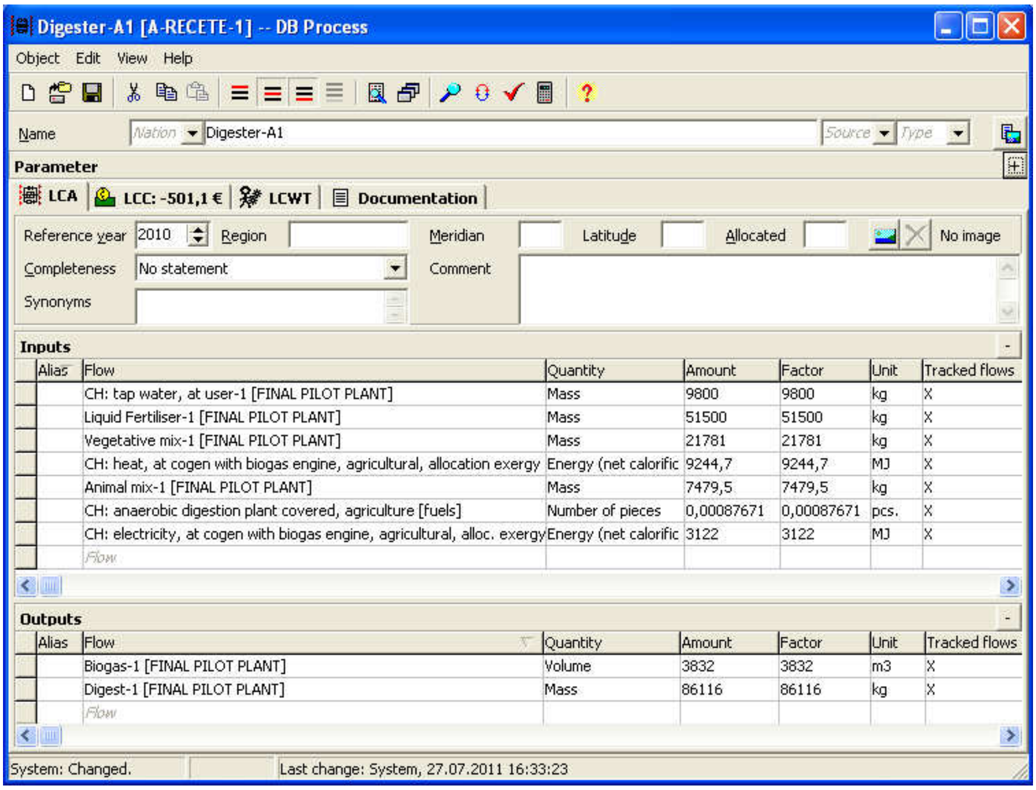
GaBi 4 process plan:Reference quantities
The names of the basic processes are shown.

System: No changes.

Last change: System, 03.04.2011 20:59:48

Figure G.2. Process flow diagram of the anaerobic digesters.

Table G.3. Input and output data of the anaerobic digesters.



Digester-A1 [A-RECETE-1] -- DB Process

Name: Digester-A1

Reference year: 2010

Region:

Meridian:

Latitude:

Allocated:

Completeness: No statement

Comment:

Synonyms:

Inputs

Alias	Flow	Quantity	Amount	Factor	Unit	Tracked flows
	CH: tap water, at user-1 [FINAL PILOT PLANT]	Mass	9800	9800	kg	X
	Liquid Fertiliser-1 [FINAL PILOT PLANT]	Mass	51500	51500	kg	X
	Vegetative mix-1 [FINAL PILOT PLANT]	Mass	21781	21781	kg	X
	CH: heat, at cogen with biogas engine, agricultural, allocation exergy	Energy (net calorific	9244,7	9244,7	MJ	X
	Animal mix-1 [FINAL PILOT PLANT]	Mass	7479,5	7479,5	kg	X
	CH: anaerobic digestion plant covered, agriculture [fuels]	Number of pieces	0,00087671	0,00087671	pcs.	X
	CH: electricity, at cogen with biogas engine, agricultural, alloc. exergy	Energy (net calorific	3122	3122	MJ	X
	Flow					

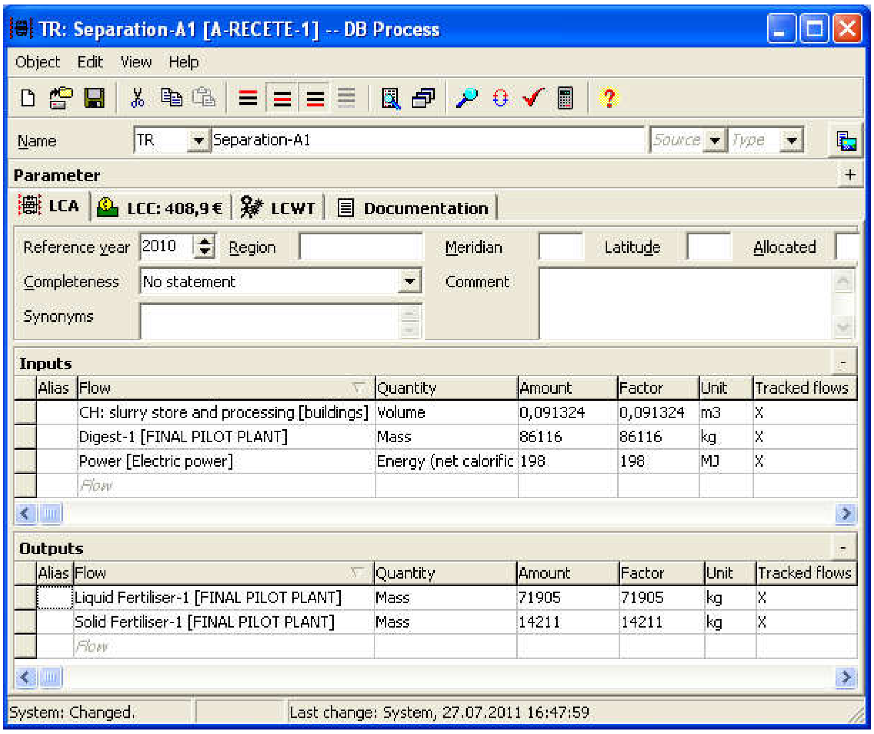
Outputs

Alias	Flow	Quantity	Amount	Factor	Unit	Tracked flows
	Biogas-1 [FINAL PILOT PLANT]	Volume	3832	3832	m3	X
	Digest-1 [FINAL PILOT PLANT]	Mass	86116	86116	kg	X
	Flow					

System: Changed.

Last change: System, 27.07.2011 16:33:23

Table G.4. Input and output data of the separation and final storage unit.



TR: Separation-A1 [A-RECETE-1] -- DB Process

Name: TR | Separation-A1

Parameter

LCA | LCC: 408,9 € | LCWT | Documentation

Reference year: 2010

Completeness: No statement

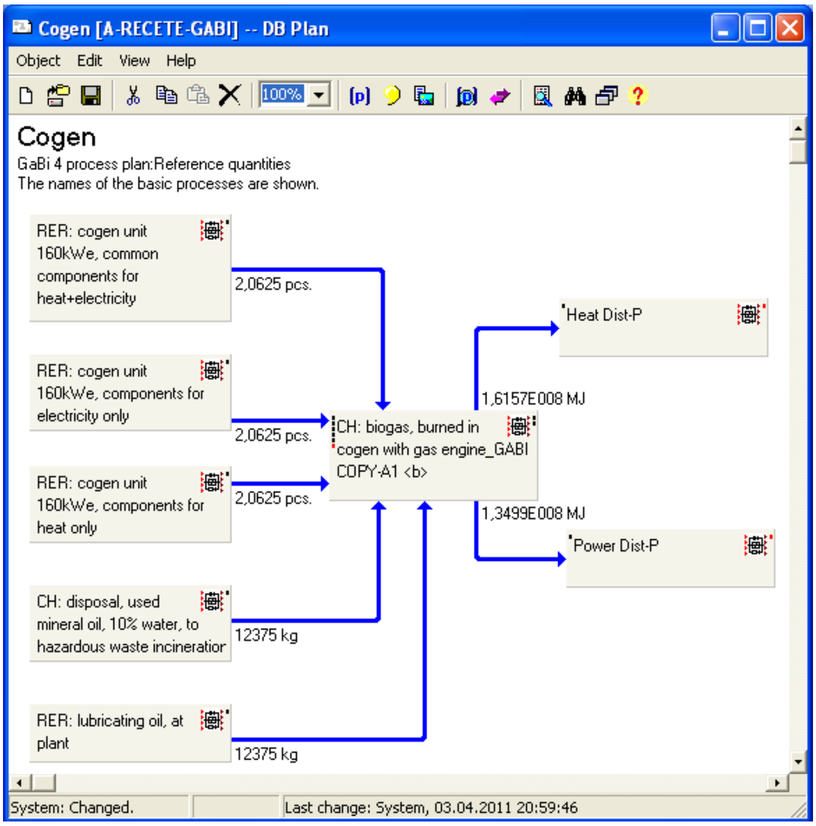
Inputs

Alias	Flow	Quantity	Amount	Factor	Unit	Tracked flows
	CH: slurry store and processing [buildings]	Volume	0,091324	0,091324	m3	X
	Digest-1 [FINAL PILOT PLANT]	Mass	86116	86116	kg	X
	Power [Electric power]	Energy (net calorific	198	198	MJ	X

Outputs

Alias	Flow	Quantity	Amount	Factor	Unit	Tracked flows
	Liquid Fertiliser-1 [FINAL PILOT PLANT]	Mass	71905	71905	kg	X
	Solid Fertiliser-1 [FINAL PILOT PLANT]	Mass	14211	14211	kg	X

System: Changed. Last change: System, 27.07.2011 16:47:59



Cogen [A-RECETE-GABI] -- DB Plan

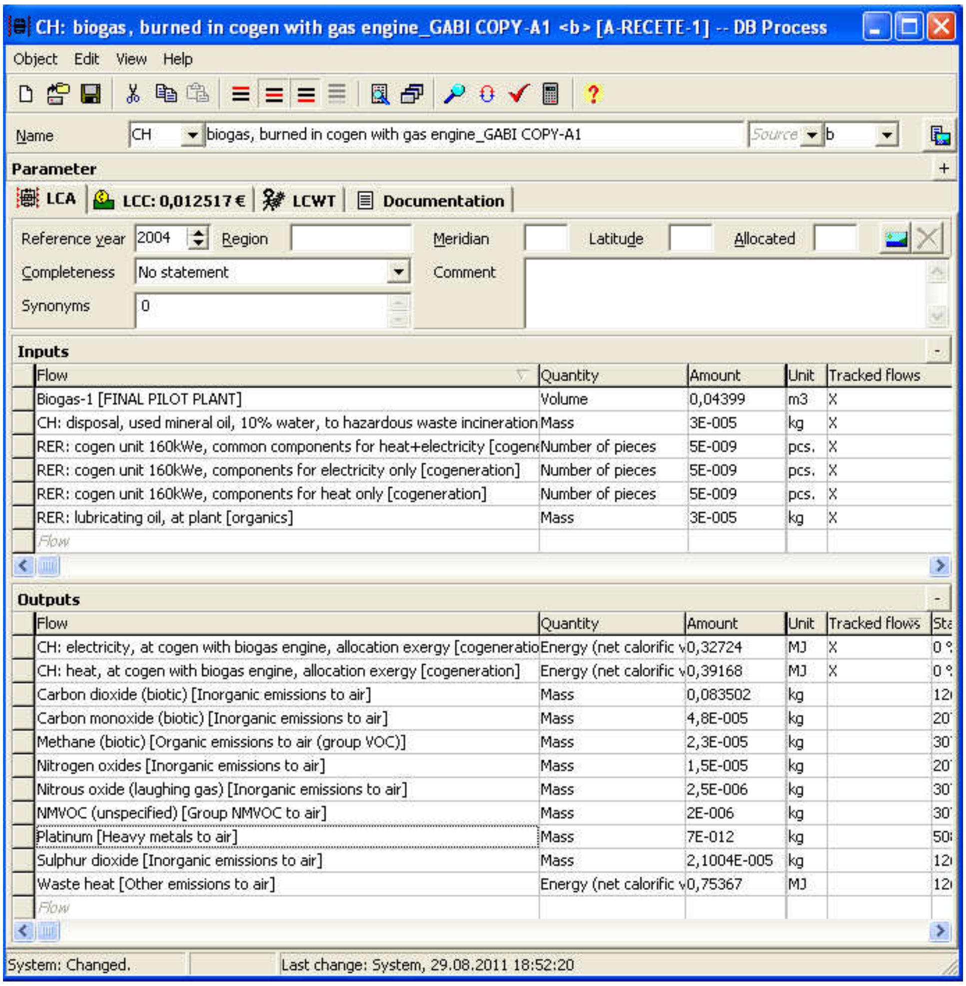
Cogen

GaBi 4 process plan:Reference quantities
The names of the basic processes are shown.

System: Changed. Last change: System, 03.04.2011 20:59:46

Figure G.3. Flow chart of the cogeneration unit.

Table G.5. Input and output data of the cogeneration unit [GaBi4, 2003].



CH: biogas, burned in cogen with gas engine_GABI COPY-A1 <b> [A-RECETE-1] -- DB Process

Name: CH biogas, burned in cogen with gas engine_GABI COPY-A1 Source b

LCC: 0,012517 €

Reference year: 2004
Region:
Meridian:
Latitude:
Allocated:
Completeness: No statement
Comment:
Synonyms: 0

Inputs

Flow	Quantity	Amount	Unit	Tracked flows
Biogas-1 [FINAL PILOT PLANT]	Volume	0,04399	m3	X
CH: disposal, used mineral oil, 10% water, to hazardous waste incineration	Mass	3E-005	kg	X
RER: cogen unit 160kWe, common components for heat+electricity [cogene	Number of pieces	5E-009	pcs.	X
RER: cogen unit 160kWe, components for electricity only [cogeneration]	Number of pieces	5E-009	pcs.	X
RER: cogen unit 160kWe, components for heat only [cogeneration]	Number of pieces	5E-009	pcs.	X
RER: lubricating oil, at plant [organics]	Mass	3E-005	kg	X
Flow				

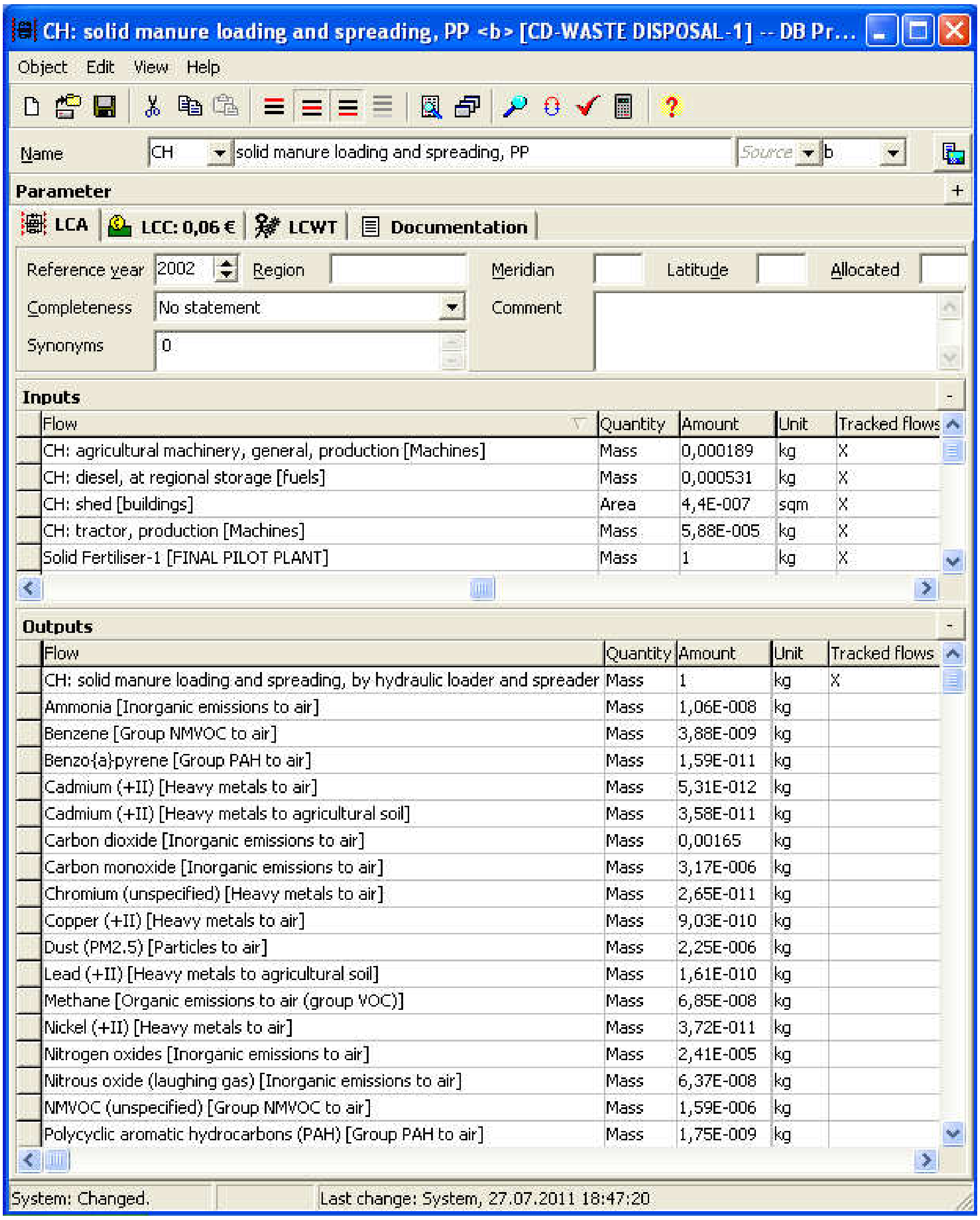
Outputs

Flow	Quantity	Amount	Unit	Tracked flows	Sta
CH: electricity, at cogen with biogas engine, allocation exergy [cogeneratio	Energy (net calorific v	0,32724	MJ	X	0
CH: heat, at cogen with biogas engine, allocation exergy [cogeneration]	Energy (net calorific v	0,39168	MJ	X	0
Carbon dioxide (biotic) [Inorganic emissions to air]	Mass	0,083502	kg		12
Carbon monoxide (biotic) [Inorganic emissions to air]	Mass	4,8E-005	kg		20
Methane (biotic) [Organic emissions to air (group VOC)]	Mass	2,3E-005	kg		30
Nitrogen oxides [Inorganic emissions to air]	Mass	1,5E-005	kg		20
Nitrous oxide (laughing gas) [Inorganic emissions to air]	Mass	2,5E-006	kg		30
NMVOC (unspecified) [Group NMVOC to air]	Mass	2E-006	kg		30
Platinum [Heavy metals to air]	Mass	7E-012	kg		50
Sulphur dioxide [Inorganic emissions to air]	Mass	2,1004E-005	kg		12
Waste heat [Other emissions to air]	Energy (net calorific v	0,75367	MJ		12
Flow					

System: Changed.
Last change: System, 29.08.2011 18:52:20

The emissions to soil because of the use of hydraulic loader and spreader are based on the GaBi4 database and summarised in Table G.6 and Table G.7.

Table G.6. Input and output data of the spreading of the solid fertiliser [GaBi4, 2003].



Name: CH | solid manure loading and spreading, PP | Source | b

Reference year: 2002

Region:

Meridian:

Latitude:

Allocated:

Completeness: No statement

Comment:

Synonyms: 0

Inputs

Flow	Quantity	Amount	Unit	Tracked flows
CH: agricultural machinery, general, production [Machines]	Mass	0,000189	kg	X
CH: diesel, at regional storage [fuels]	Mass	0,000531	kg	X
CH: shed [buildings]	Area	4,4E-007	sqm	X
CH: tractor, production [Machines]	Mass	5,88E-005	kg	X
Solid Fertiliser-1 [FINAL PILOT PLANT]	Mass	1	kg	X

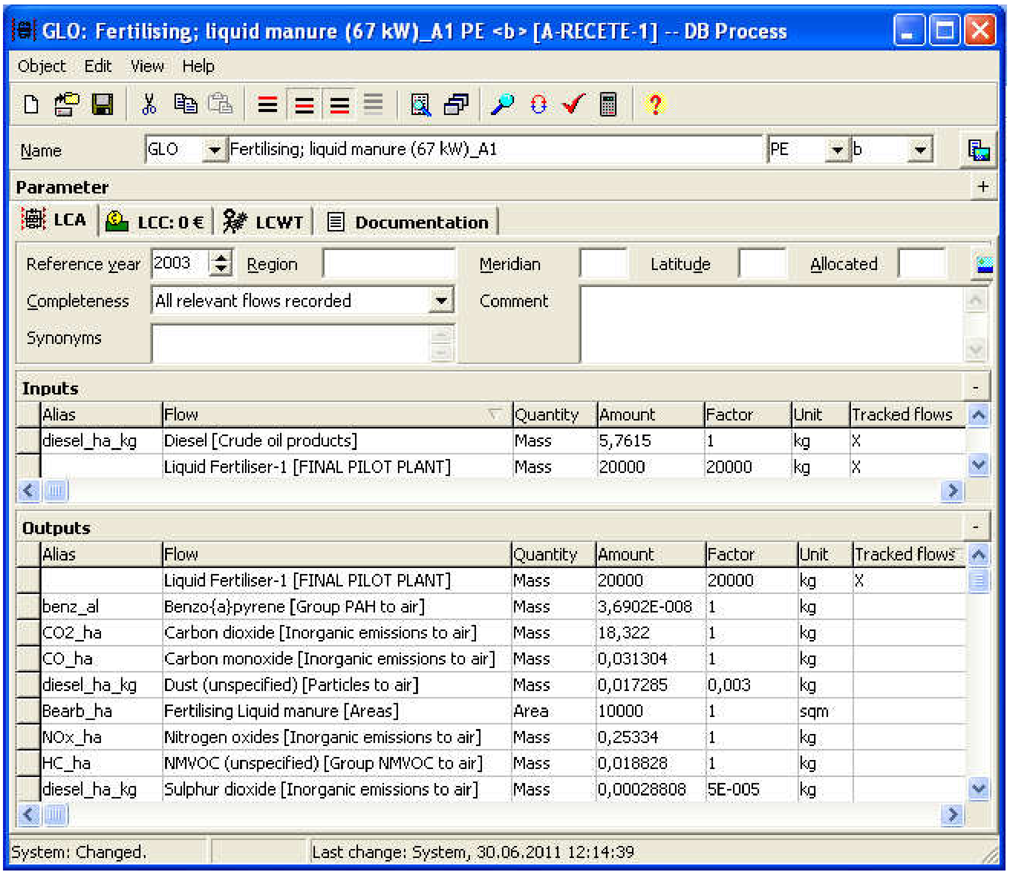
Outputs

Flow	Quantity	Amount	Unit	Tracked flows
CH: solid manure loading and spreading, by hydraulic loader and spreader	Mass	1	kg	X
Ammonia [Inorganic emissions to air]	Mass	1,06E-008	kg	
Benzene [Group NMVOC to air]	Mass	3,88E-009	kg	
Benzo{a}pyrene [Group PAH to air]	Mass	1,59E-011	kg	
Cadmium (+II) [Heavy metals to air]	Mass	5,31E-012	kg	
Cadmium (+II) [Heavy metals to agricultural soil]	Mass	3,58E-011	kg	
Carbon dioxide [Inorganic emissions to air]	Mass	0,00165	kg	
Carbon monoxide [Inorganic emissions to air]	Mass	3,17E-006	kg	
Chromium (unspecified) [Heavy metals to air]	Mass	2,65E-011	kg	
Copper (+II) [Heavy metals to air]	Mass	9,03E-010	kg	
Dust (PM2.5) [Particles to air]	Mass	2,25E-006	kg	
Lead (+II) [Heavy metals to agricultural soil]	Mass	1,61E-010	kg	
Methane [Organic emissions to air (group VOC)]	Mass	6,85E-008	kg	
Nickel (+II) [Heavy metals to air]	Mass	3,72E-011	kg	
Nitrogen oxides [Inorganic emissions to air]	Mass	2,41E-005	kg	
Nitrous oxide (laughing gas) [Inorganic emissions to air]	Mass	6,37E-008	kg	
NMVOC (unspecified) [Group NMVOC to air]	Mass	1,59E-006	kg	
Polycyclic aromatic hydrocarbons (PAH) [Group PAH to air]	Mass	1,75E-009	kg	

System: Changed.

Last change: System, 27.07.2011 18:47:20

Table G.7. Input and output data of the spreading of the liquid fertiliser [GaBi4, 2003].



GLO: Fertilising; liquid manure (67 kW)_A1 PE <b> [A-RECETE-1] -- DB Process

Name: GLO | Fertilising; liquid manure (67 kW)_A1 | PE | b

Reference year: 2003
Region:
Meridian:
Latitude:
Allocated:
Completeness: All relevant flows recorded
Comment:
Synonyms:

Inputs

Alias	Flow	Quantity	Amount	Factor	Unit	Tracked flows
diesel_ha_kg	Diesel [Crude oil products]	Mass	5,7615	1	kg	X
	Liquid Fertiliser-1 [FINAL PILOT PLANT]	Mass	20000	20000	kg	X

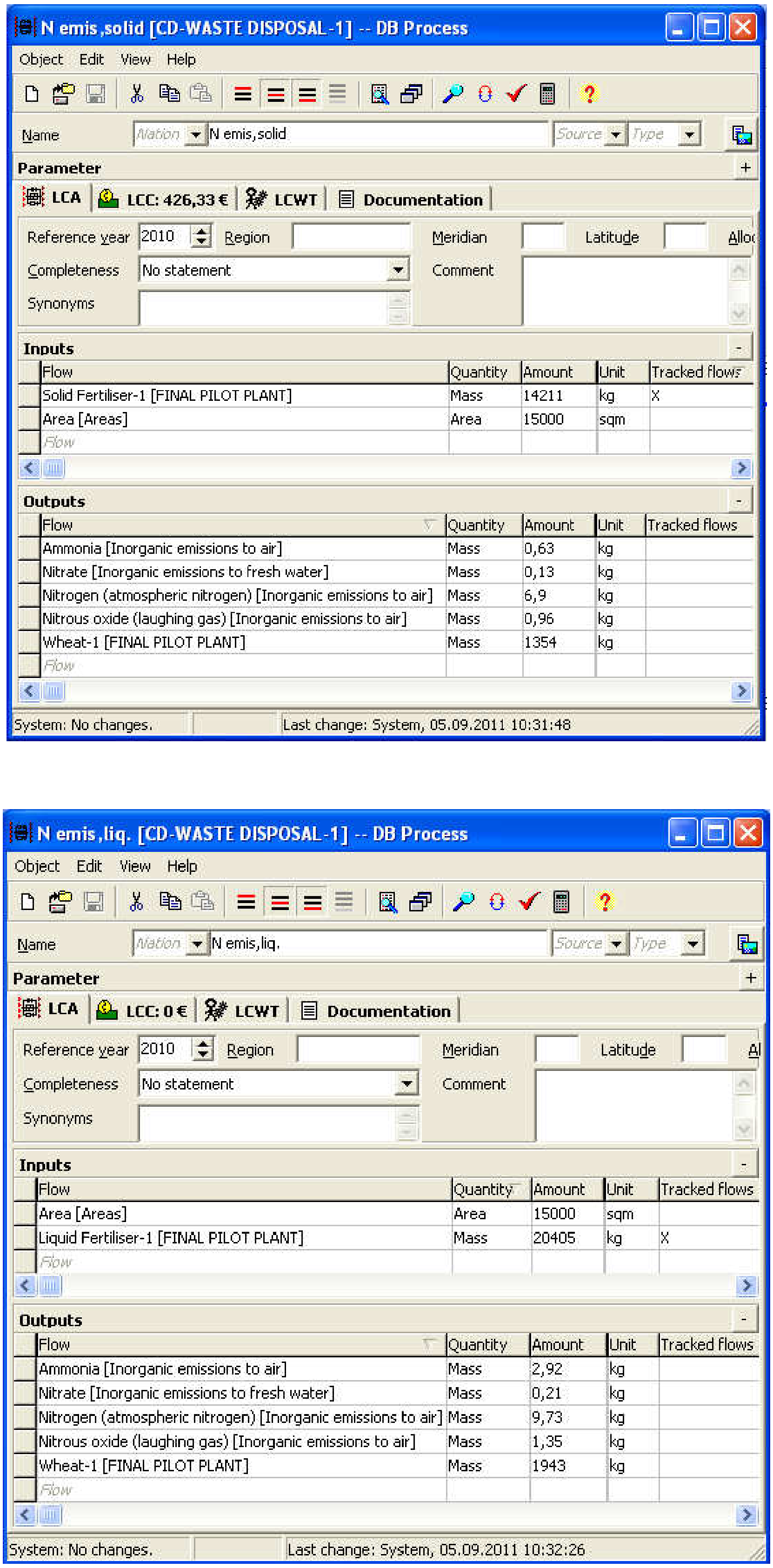
Outputs

Alias	Flow	Quantity	Amount	Factor	Unit	Tracked flows
	Liquid Fertiliser-1 [FINAL PILOT PLANT]	Mass	20000	20000	kg	X
benz_al	Benzo{a}pyrene [Group PAH to air]	Mass	3,6902E-008	1	kg	
CO2_ha	Carbon dioxide [Inorganic emissions to air]	Mass	18,322	1	kg	
CO_ha	Carbon monoxide [Inorganic emissions to air]	Mass	0,031304	1	kg	
diesel_ha_kg	Dust (unspecified) [Particles to air]	Mass	0,017285	0,003	kg	
Bearb_ha	Fertilising Liquid manure [Areas]	Area	10000	1	sqm	
NOx_ha	Nitrogen oxides [Inorganic emissions to air]	Mass	0,25334	1	kg	
HC_ha	NMVOC (unspecified) [Group NMVOC to air]	Mass	0,018828	1	kg	
diesel_ha_kg	Sulphur dioxide [Inorganic emissions to air]	Mass	0,00028808	5E-005	kg	

System: Changed. Last change: System, 30.06.2011 12:14:39

The daily inputs and outputs data of the field application of the solid and liquid digestate for winter wheat production is given in Table G.8.

Table G.8. Emission data of the agricultural application of the digested recipe.



N emis,solid [CD-WASTE DISPOSAL-1] -- DB Process

Name: N emis,solid

LCC: 426,33 €

Reference year: 2010

Completeness: No statement

Inputs

Flow	Quantity	Amount	Unit	Tracked flows
Solid Fertiliser-1 [FINAL PILOT PLANT]	Mass	14211	kg	X
Area [Areas]	Area	15000	sqm	

Outputs

Flow	Quantity	Amount	Unit	Tracked flows
Ammonia [Inorganic emissions to air]	Mass	0,63	kg	
Nitrate [Inorganic emissions to fresh water]	Mass	0,13	kg	
Nitrogen (atmospheric nitrogen) [Inorganic emissions to air]	Mass	6,9	kg	
Nitrous oxide (laughing gas) [Inorganic emissions to air]	Mass	0,96	kg	
Wheat-1 [FINAL PILOT PLANT]	Mass	1354	kg	

System: No changes. Last change: System, 05.09.2011 10:31:48

N emis,liq. [CD-WASTE DISPOSAL-1] -- DB Process

Name: N emis,liq.

LCC: 0 €

Reference year: 2010

Completeness: No statement

Inputs

Flow	Quantity	Amount	Unit	Tracked flows
Area [Areas]	Area	15000	sqm	
Liquid Fertiliser-1 [FINAL PILOT PLANT]	Mass	20405	kg	X

Outputs

Flow	Quantity	Amount	Unit	Tracked flows
Ammonia [Inorganic emissions to air]	Mass	2,92	kg	
Nitrate [Inorganic emissions to fresh water]	Mass	0,21	kg	
Nitrogen (atmospheric nitrogen) [Inorganic emissions to air]	Mass	9,73	kg	
Nitrous oxide (laughing gas) [Inorganic emissions to air]	Mass	1,35	kg	
Wheat-1 [FINAL PILOT PLANT]	Mass	1943	kg	

System: No changes. Last change: System, 05.09.2011 10:32:26

SCENARIO B

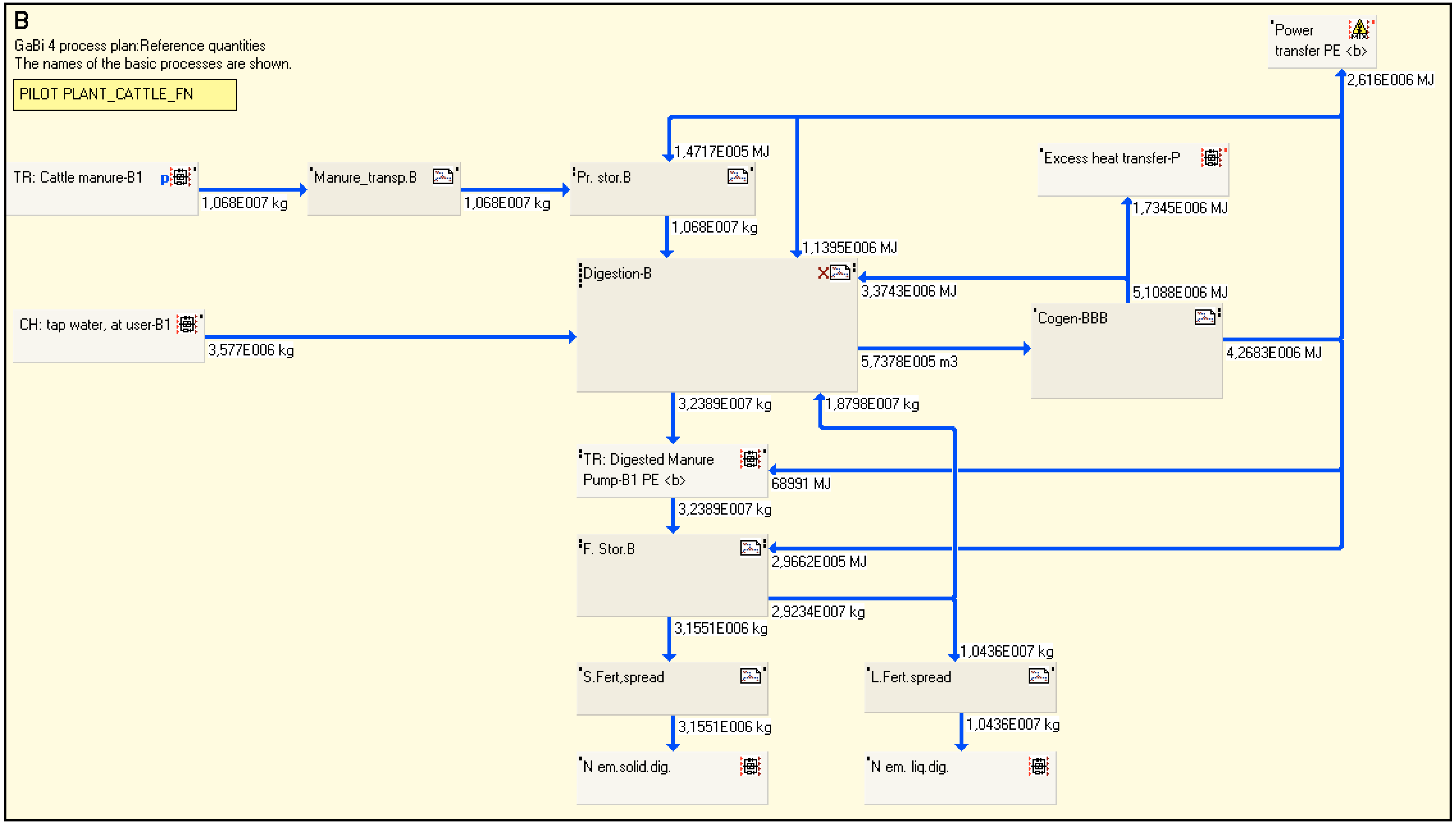


Figure G.4. Process flowchart of Scenario B.

SCENARIO C

The Scenario C is created for the electricity and heat production from hard coal of which process summary is given in Figure G.5.

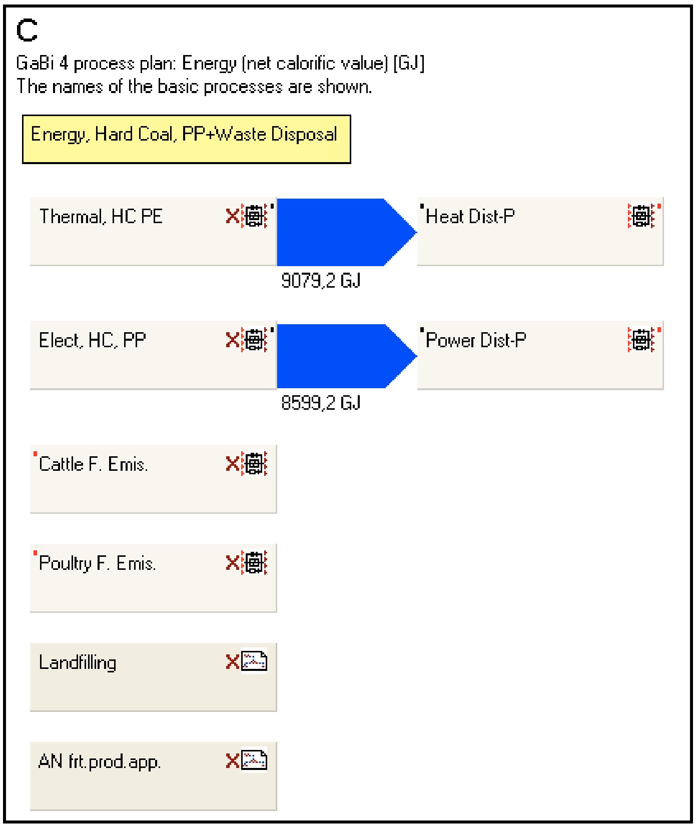
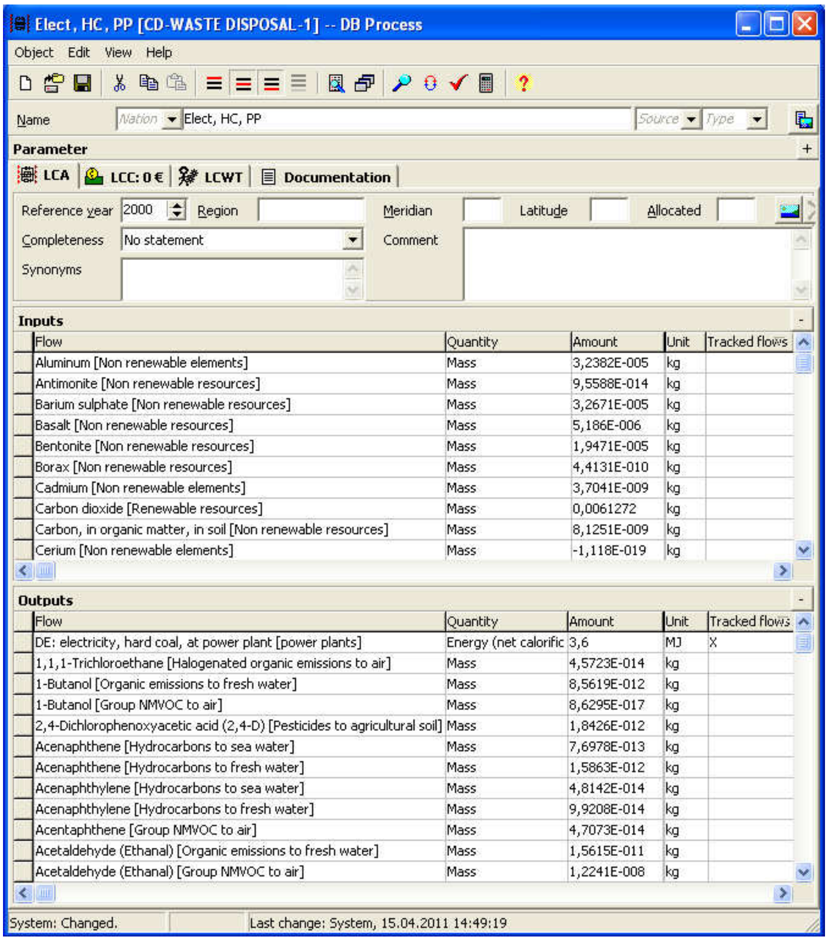


Figure G.5. Flow chart for Scenario C, the annual heat and electricity production from hard coal.

The inventory tables gathered from the GaBi4 database regarding the electricity production from hard coal is given in Table G.9.

Table G.9. Inputs and outputs for the electricity production from hard coal [GaBi4, 2003].



Elect, HC, PP [CD-WASTE DISPOSAL-1] -- DB Process

Name: Elect, HC, PP

Reference year: 2000

Completeness: No statement

Inputs

Flow	Quantity	Amount	Unit	Tracked flows
Aluminum [Non renewable elements]	Mass	3,2382E-005	kg	
Antimonite [Non renewable resources]	Mass	9,5588E-014	kg	
Barium sulphate [Non renewable resources]	Mass	3,2671E-005	kg	
Basalt [Non renewable resources]	Mass	5,186E-006	kg	
Bentonite [Non renewable resources]	Mass	1,9471E-005	kg	
Borax [Non renewable resources]	Mass	4,4131E-010	kg	
Cadmium [Non renewable elements]	Mass	3,7041E-009	kg	
Carbon dioxide [Renewable resources]	Mass	0,0061272	kg	
Carbon, in organic matter, in soil [Non renewable resources]	Mass	8,1251E-009	kg	
Cerium [Non renewable elements]	Mass	-1,118E-019	kg	

Outputs

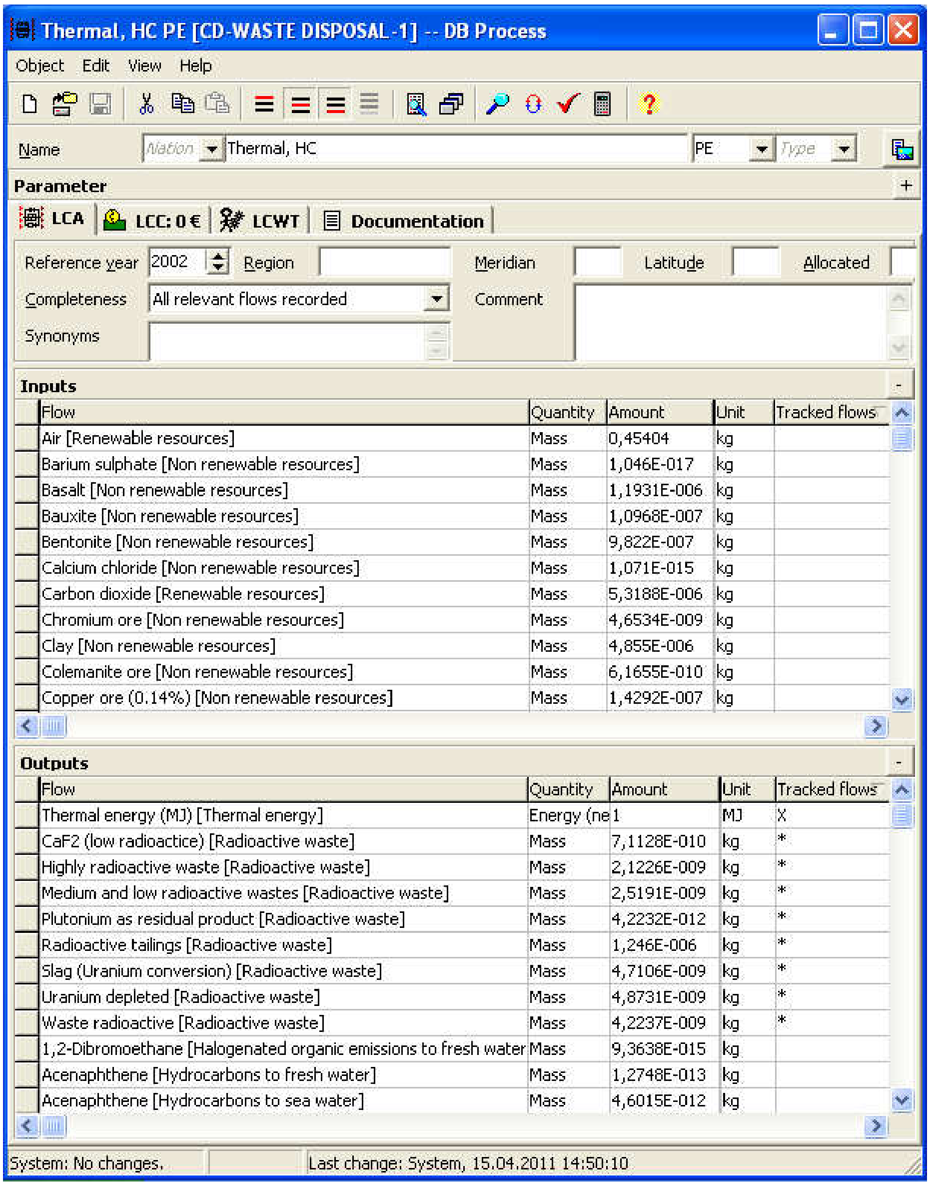
Flow	Quantity	Amount	Unit	Tracked flows
DE: electricity, hard coal, at power plant [power plants]	Energy (net calorific	3,6	MJ	X
1,1,1-Trichloroethane [Halogenated organic emissions to air]	Mass	4,5723E-014	kg	
1-Butanol [Organic emissions to fresh water]	Mass	8,5619E-012	kg	
1-Butanol [Group NMVOC to air]	Mass	8,6295E-017	kg	
2,4-Dichlorophenoxyacetic acid (2,4-D) [Pesticides to agricultural soil]	Mass	1,8426E-012	kg	
Acenaphthene [Hydrocarbons to sea water]	Mass	7,6978E-013	kg	
Acenaphthene [Hydrocarbons to fresh water]	Mass	1,5863E-012	kg	
Acenaphthylene [Hydrocarbons to sea water]	Mass	4,8142E-014	kg	
Acenaphthylene [Hydrocarbons to fresh water]	Mass	9,9208E-014	kg	
Acentaphthene [Group NMVOC to air]	Mass	4,7073E-014	kg	
Acetaldehyde (Ethanal) [Organic emissions to fresh water]	Mass	1,5615E-011	kg	
Acetaldehyde (Ethanal) [Group NMVOC to air]	Mass	1,2241E-008	kg	

System: Changed.

Last change: System, 15.04.2011 14:49:19

The inventory table gathered from GaBi4 regarding the heat production from hard coal is given in Table G.10.

Table G.10. Inputs and outputs for the heat production from hard coal [GaBi4, 2003].



Thermal, HC PE [CD-WASTE DISPOSAL-1] -- DB Process

Name: Nation | Thermal, HC | PE | Type

Reference year: 2002
Region:
Meridian:
Latitude:
Allocated:
Completeness: All relevant flows recorded
Comment:
Synonyms:

Inputs

Flow	Quantity	Amount	Unit	Tracked flows
Air [Renewable resources]	Mass	0,45404	kg	
Barium sulphate [Non renewable resources]	Mass	1,046E-017	kg	
Basalt [Non renewable resources]	Mass	1,1931E-006	kg	
Bauxite [Non renewable resources]	Mass	1,0968E-007	kg	
Bentonite [Non renewable resources]	Mass	9,822E-007	kg	
Calcium chloride [Non renewable resources]	Mass	1,071E-015	kg	
Carbon dioxide [Renewable resources]	Mass	5,3188E-006	kg	
Chromium ore [Non renewable resources]	Mass	4,6534E-009	kg	
Clay [Non renewable resources]	Mass	4,855E-006	kg	
Colemanite ore [Non renewable resources]	Mass	6,1655E-010	kg	
Copper ore (0.14%) [Non renewable resources]	Mass	1,4292E-007	kg	

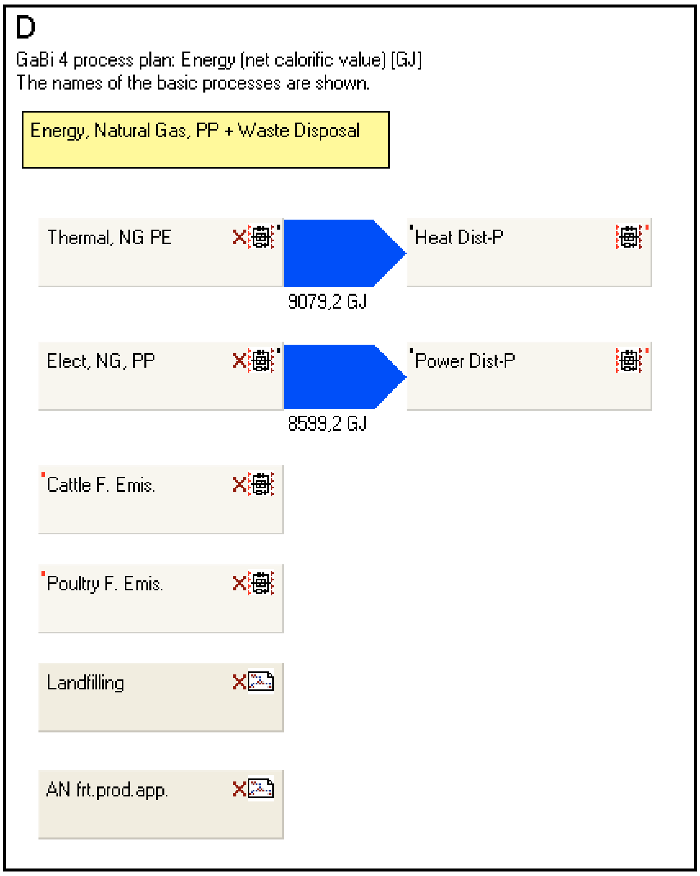
Outputs

Flow	Quantity	Amount	Unit	Tracked flows
Thermal energy (MJ) [Thermal energy]	Energy (ne	1	MJ	X
CaF2 (low radioactice) [Radioactive waste]	Mass	7,1128E-010	kg	*
Highly radioactive waste [Radioactive waste]	Mass	2,1226E-009	kg	*
Medium and low radioactive wastes [Radioactive waste]	Mass	2,5191E-009	kg	*
Plutonium as residual product [Radioactive waste]	Mass	4,2232E-012	kg	*
Radioactive tailings [Radioactive waste]	Mass	1,246E-006	kg	*
Slag (Uranium conversion) [Radioactive waste]	Mass	4,7106E-009	kg	*
Uranium depleted [Radioactive waste]	Mass	4,8731E-009	kg	*
Waste radioactive [Radioactive waste]	Mass	4,2237E-009	kg	*
1,2-Dibromoethane [Halogenated organic emissions to fresh water	Mass	9,3638E-015	kg	
Acenaphthene [Hydrocarbons to fresh water]	Mass	1,2748E-013	kg	
Acenaphthene [Hydrocarbons to sea water]	Mass	4,6015E-012	kg	

System: No changes.
Last change: System, 15.04.2011 14:50:10

The Scenario D is created for the electricity and heat production from natural gas of which process summary is given in Figure G.6.

SCENARIO D



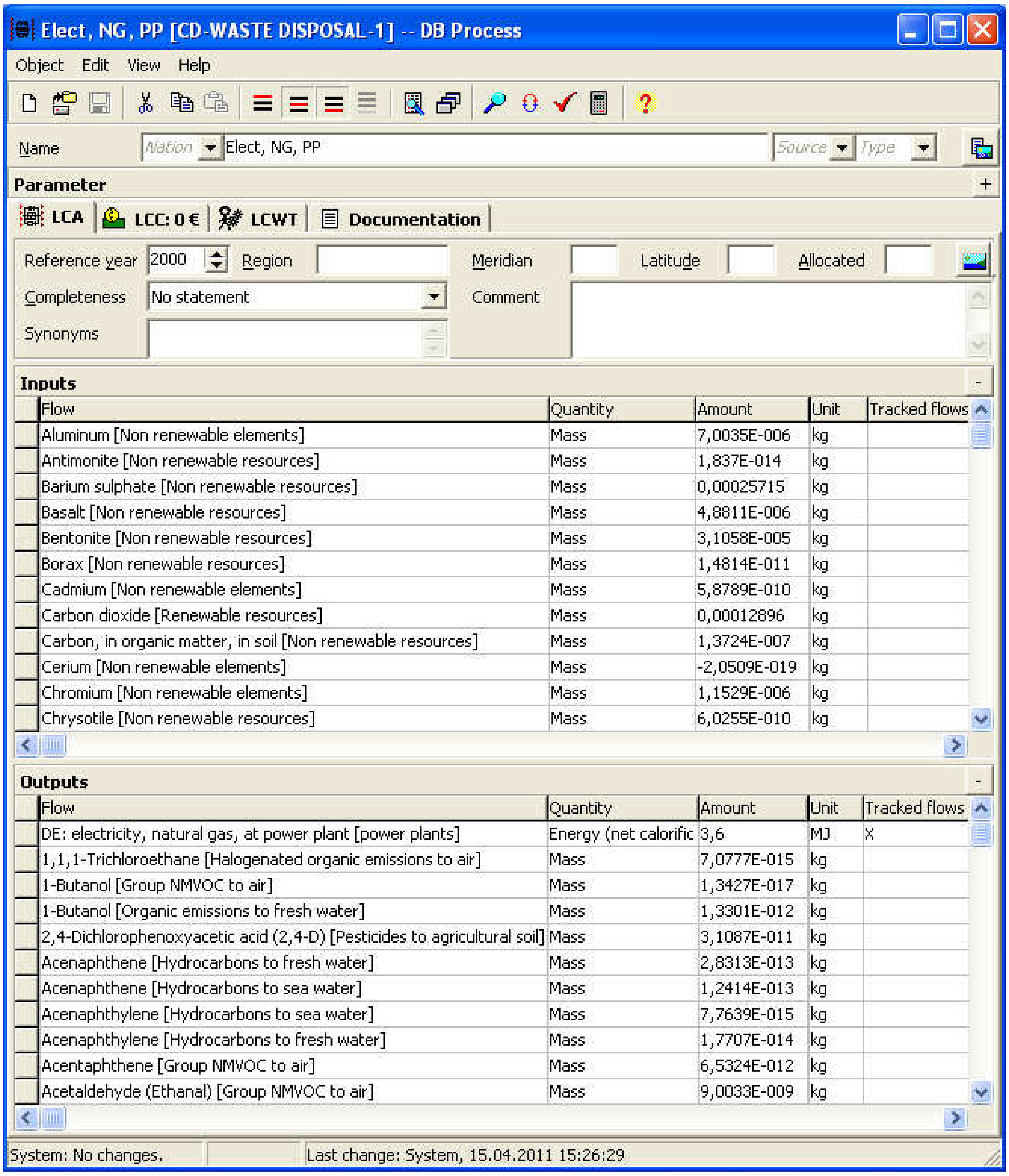
D

GaBi 4 process plan: Energy (net calorific value) [GJ]
The names of the basic processes are shown.

Figure G.6. Flow chart for Scenario D, the annual heat and electricity production from natural gas.

The inventory tables gathered from the GaBi4 database regarding the electricity production from natural is given in Table G.11.

Table G.11. Inputs and outputs for the electricity production from natural gas [GaBi4, 2003].



Elect, NG, PP [CD-WASTE DISPOSAL-1] -- DB Process

Name: Nation | Elect, NG, PP | Source | Type

Reference year: 2000
Region:
Meridian:
Latitude:
Allocated:
Completeness: No statement
Comment:
Synonyms:

Inputs

Flow	Quantity	Amount	Unit	Tracked flows
Aluminum [Non renewable elements]	Mass	7,0035E-006	kg	
Antimonite [Non renewable resources]	Mass	1,837E-014	kg	
Barium sulphate [Non renewable resources]	Mass	0,00025715	kg	
Basalt [Non renewable resources]	Mass	4,8811E-006	kg	
Bentonite [Non renewable resources]	Mass	3,1058E-005	kg	
Borax [Non renewable resources]	Mass	1,4814E-011	kg	
Cadmium [Non renewable elements]	Mass	5,8789E-010	kg	
Carbon dioxide [Renewable resources]	Mass	0,00012896	kg	
Carbon, in organic matter, in soil [Non renewable resources]	Mass	1,3724E-007	kg	
Cerium [Non renewable elements]	Mass	-2,0509E-019	kg	
Chromium [Non renewable elements]	Mass	1,1529E-006	kg	
Chrysotile [Non renewable resources]	Mass	6,0255E-010	kg	

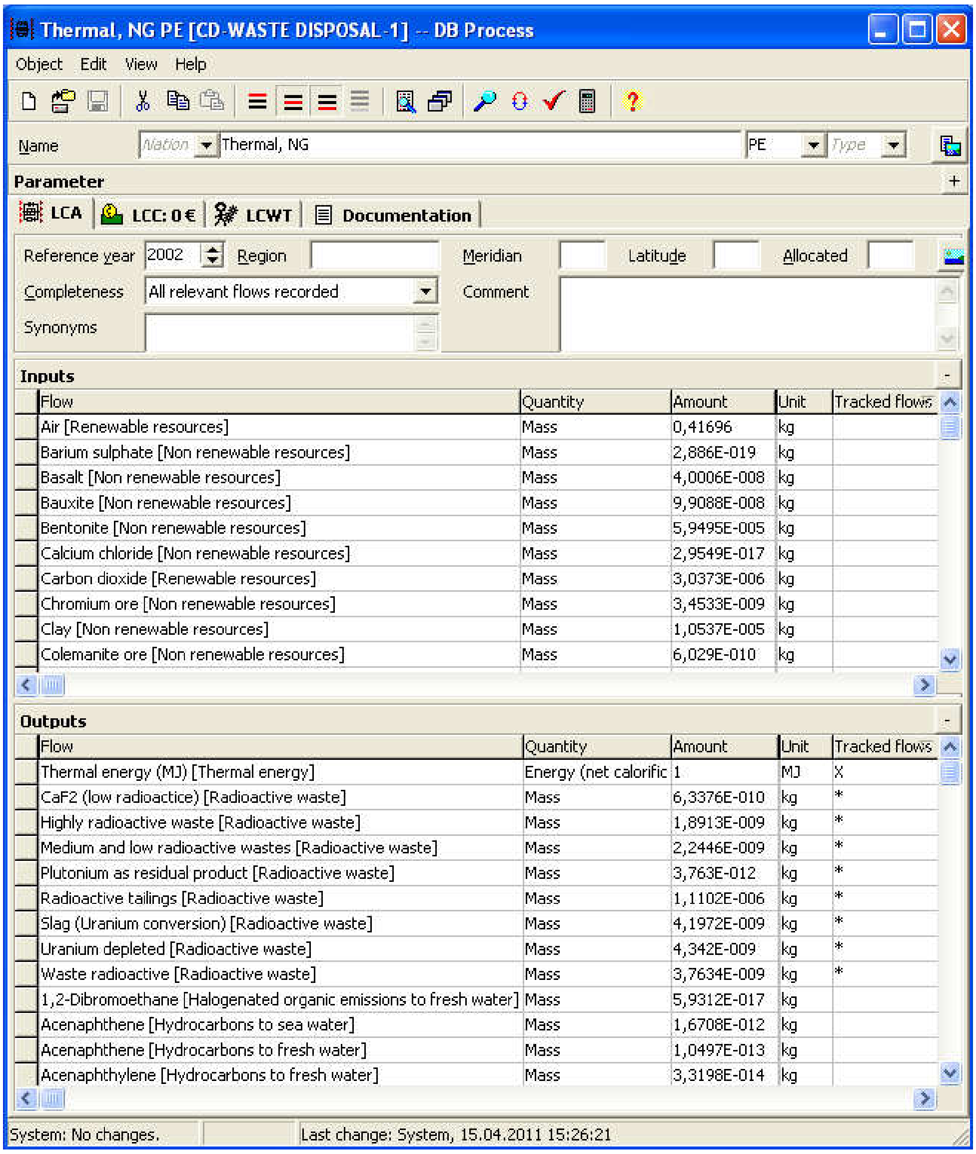
Outputs

Flow	Quantity	Amount	Unit	Tracked flows
DE: electricity, natural gas, at power plant [power plants]	Energy (net calorific	3,6	MJ	X
1,1,1-Trichloroethane [Halogenated organic emissions to air]	Mass	7,0777E-015	kg	
1-Butanol [Group NMVOC to air]	Mass	1,3427E-017	kg	
1-Butanol [Organic emissions to fresh water]	Mass	1,3301E-012	kg	
2,4-Dichlorophenoxyacetic acid (2,4-D) [Pesticides to agricultural soil]	Mass	3,1087E-011	kg	
Acenaphthene [Hydrocarbons to fresh water]	Mass	2,8313E-013	kg	
Acenaphthene [Hydrocarbons to sea water]	Mass	1,2414E-013	kg	
Acenaphthylene [Hydrocarbons to sea water]	Mass	7,7639E-015	kg	
Acenaphthylene [Hydrocarbons to fresh water]	Mass	1,7707E-014	kg	
Acentaphthene [Group NMVOC to air]	Mass	6,5324E-012	kg	
Acetaldehyde (Ethanal) [Group NMVOC to air]	Mass	9,0033E-009	kg	

System: No changes.
Last change: System, 15.04.2011 15:26:29

The inventory tables gathered from the GaBi4 database regarding the heat production from natural is given in Table G.12.

Table G.12. Inputs and outputs for the heat production from natural gas [GaBi4, 2003].



Name: Nation | Thermal, NG | PE | Type

Reference year: 2002

Region:

Meridian:

Latitude:

Allocated:

Completeness: All relevant flows recorded

Comment:

Synonyms:

Inputs

Flow	Quantity	Amount	Unit	Tracked flows
Air [Renewable resources]	Mass	0,41696	kg	
Barium sulphate [Non renewable resources]	Mass	2,886E-019	kg	
Basalt [Non renewable resources]	Mass	4,0006E-008	kg	
Bauxite [Non renewable resources]	Mass	9,9088E-008	kg	
Bentonite [Non renewable resources]	Mass	5,9495E-005	kg	
Calcium chloride [Non renewable resources]	Mass	2,9549E-017	kg	
Carbon dioxide [Renewable resources]	Mass	3,0373E-006	kg	
Chromium ore [Non renewable resources]	Mass	3,4533E-009	kg	
Clay [Non renewable resources]	Mass	1,0537E-005	kg	
Colemanite ore [Non renewable resources]	Mass	6,029E-010	kg	

Outputs

Flow	Quantity	Amount	Unit	Tracked flows
Thermal energy (MJ) [Thermal energy]	Energy (net calorific	1	MJ	X
CaF2 (low radioactice) [Radioactive waste]	Mass	6,3376E-010	kg	*
Highly radioactive waste [Radioactive waste]	Mass	1,8913E-009	kg	*
Medium and low radioactive wastes [Radioactive waste]	Mass	2,2446E-009	kg	*
Plutonium as residual product [Radioactive waste]	Mass	3,763E-012	kg	*
Radioactive tailings [Radioactive waste]	Mass	1,1102E-006	kg	*
Slag (Uranium conversion) [Radioactive waste]	Mass	4,1972E-009	kg	*
Uranium depleted [Radioactive waste]	Mass	4,342E-009	kg	*
Waste radioactive [Radioactive waste]	Mass	3,7634E-009	kg	*
1,2-Dibromoethane [Halogenated organic emissions to fresh water]	Mass	5,9312E-017	kg	
Acenaphthene [Hydrocarbons to sea water]	Mass	1,6708E-012	kg	
Acenaphthene [Hydrocarbons to fresh water]	Mass	1,0497E-013	kg	
Acenaphthylene [Hydrocarbons to fresh water]	Mass	3,3198E-014	kg	

System: No changes.

Last change: System, 15.04.2011 15:26:21

The process flow chart for the landfilling of the above mentioned wastes is given in Figure G.7.

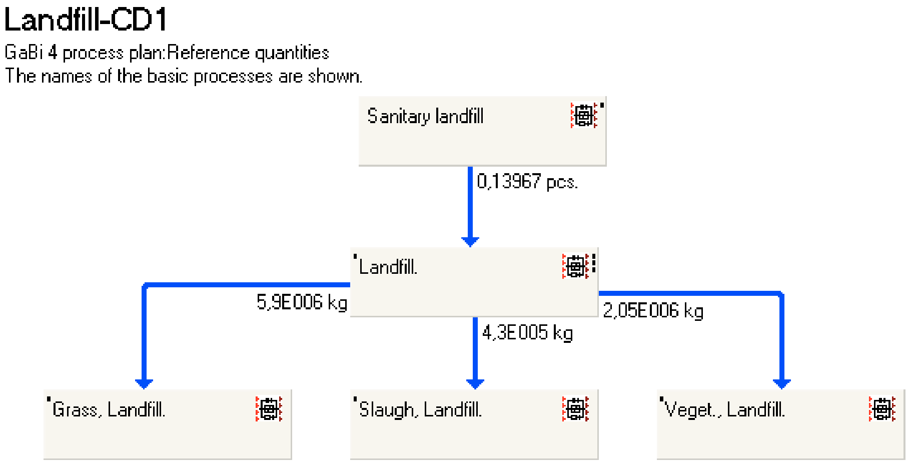
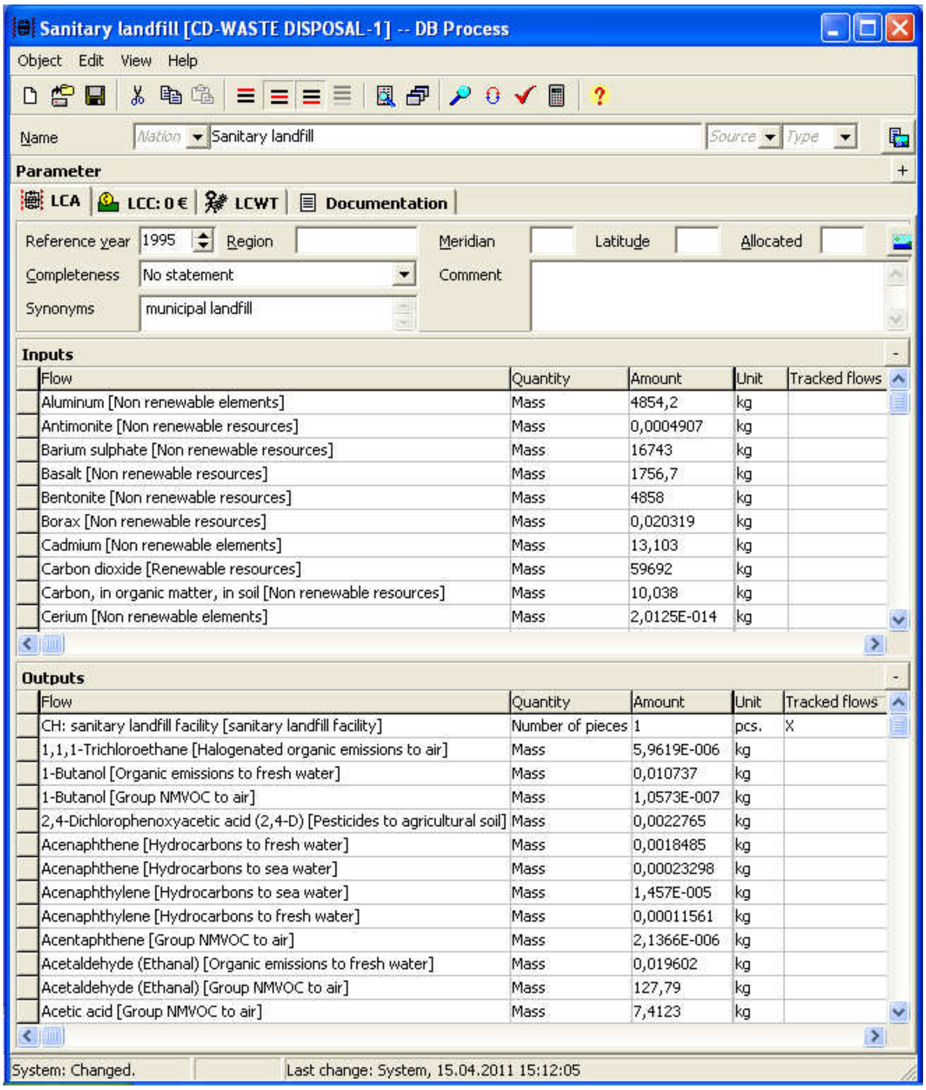


Figure G.7. Process flow chart of landfilling of vegetable waste, slaughterhouse wastes and grass.

The inputs and outputs data of the sanitary lanfill is given in Table G.13.

Table G.13. Inputs and outputs data for the sanitary landfill [GaBi4, 2003].



Sanitary landfill [CD-WASTE DISPOSAL-1] -- DB Process

Name: Sanitary landfill

Parameter

Reference year: 1995
Region:
Meridian:
Latitude:
Allocated:
Completeness: No statement
Comment:
Synonyms: municipal landfill

Inputs

Flow	Quantity	Amount	Unit	Tracked flows
Aluminum [Non renewable elements]	Mass	4854,2	kg	
Antimonite [Non renewable resources]	Mass	0,0004907	kg	
Barium sulphate [Non renewable resources]	Mass	16743	kg	
Basalt [Non renewable resources]	Mass	1756,7	kg	
Bentonite [Non renewable resources]	Mass	4858	kg	
Borax [Non renewable resources]	Mass	0,020319	kg	
Cadmium [Non renewable elements]	Mass	13,103	kg	
Carbon dioxide [Renewable resources]	Mass	59692	kg	
Carbon, in organic matter, in soil [Non renewable resources]	Mass	10,038	kg	
Cerium [Non renewable elements]	Mass	2,0125E-014	kg	

Outputs

Flow	Quantity	Amount	Unit	Tracked flows
CH: sanitary landfill facility [sanitary landfill facility]	Number of pieces	1	pcs.	X
1,1,1-Trichloroethane [Halogenated organic emissions to air]	Mass	5,9619E-006	kg	
1-Butanol [Organic emissions to fresh water]	Mass	0,010737	kg	
1-Butanol [Group NMVOC to air]	Mass	1,0573E-007	kg	
2,4-Dichlorophenoxyacetic acid (2,4-D) [Pesticides to agricultural soil]	Mass	0,0022765	kg	
Acenaphthene [Hydrocarbons to fresh water]	Mass	0,0018485	kg	
Acenaphthene [Hydrocarbons to sea water]	Mass	0,00023298	kg	
Acenaphthylene [Hydrocarbons to sea water]	Mass	1,457E-005	kg	
Acenaphthylene [Hydrocarbons to fresh water]	Mass	0,00011561	kg	
Acentaphthene [Group NMVOC to air]	Mass	2,1366E-006	kg	
Acetaldehyde (Ethanal) [Organic emissions to fresh water]	Mass	0,019602	kg	
Acetaldehyde (Ethanal) [Group NMVOC to air]	Mass	127,79	kg	
Acetic acid [Group NMVOC to air]	Mass	7,4123	kg	

System: Changed.

Last change: System, 15.04.2011 15:12:05

Table G.14. Methane emission calculations for landfilling of vegetable wastes, slaughterhouse wastes and grass & grass sillage.

VEGETABLE WASTE

Year	**Total MSW**	**% to SWDS**	**VEGETABLE WASTE**	DOC		Methane generation rate constant	Half-life time (t1/2, years):	exp1	Process start in deposition year. Month M	exp2	Fraction to CH4	Amount deposited	MCF	Decomposable DOC (DDOCm) deposited	DDOCm not reacted. Deposition year	DDOCm decomposed. Deposition year	DDOCm accumulated in SWDS end of year	DDOCm decomposed	CH4 generated
	ton	%	%	DOC	DOCf	k	h = ln(2)/k	exp(-k)	M	exp(-k*((13-M)/12))	F	W	MCF	D = W * DOC * DOCf * MCF	B = D * exp2	C = D * (1-exp2)	H = B + (Hlast year * exp1)	E = C + Hlast year * (1 - exp1)	Q = E * 16/12 * F
												ton	fraction	ton	ton	ton	ton	ton	ton
2010	2050	100%	100%	0.15	0.5	0.185	3.75	0.83	13	1.0	0.5	2050	1	153.75	153.75	0.00	153.75	0.00	0.00
2011	0	100%	100%	0.15	0.5	0.185	3.75	0.83	13	1.0	0.5	2050	1	153.75	153.75	0.00	281.53	25.97	17.31

GRASS+GRASS SILAGE

Year	**Total MSW**	**% to SWDS**	**GRASS+ GRASS SILAGE**	DOC		Methane generation rate constant	Half-life time (t1/2, years):	exp1	Process start in deposition year. Month M	exp2	Fraction to CH4	Amount deposited	MCF	Decomposable DOC (DDOCm) deposited	DDOCm not reacted. Deposition year	DDOCm decomposed. Deposition year	DDOCm accumulated in SWDS end of year	DDOCm decomposed	CH4 generated
	ton	%	%	DOC	DOCf	k	h = ln(2)/k	exp(-k)	M	exp(-k*((13-M)/12))	F	W	MCF	D = W * DOC * DOCf * MCF	B = D * exp2	C = D * (1-exp2)	H = B + (Hlast year * exp1)	E = C + Hlast year * (1 - exp1)	Q = E * 16/12 * F
												ton	fraction	ton	ton	ton	ton	ton	ton
2010	5900	100%	100%	0.2	0.5	0.1	6.93	0.90	13	1.0	0.5	5900	1	590.00	590.00	0.00	590.00	0.00	0.00
2011	0	100%	100%	0.2	0.5	0.1	6.93	0.90	13	1.0	0.5	5900	1	590.00	590.00	0.00	1123.85	56.15	37.43

SLAUGHTERHOUSE WASTE

Year	**Total MSW**	**% to SWDS**	**SLAUGHTER HOUSE WASTE**	DOC		Methane generation rate constant	Half-life time (t1/2, years):	exp1	Process start in deposition year. Month M	exp2	Fraction to CH4	Amount deposited	MCF	Decomposable DOC (DDOCm) deposited	DDOCm not reacted. Deposition year	DDOCm decomposed. Deposition year	DDOCm accumulated in SWDS end of year	DDOCm decomposed	CH4 generated
	ton	%	%	DOC	DOCf	k	h = ln(2)/k	exp(-k)	M	exp(-k*((13-M)/12))	F	W	MCF	D = W * DOC * DOCf * MCF	B = D * exp2	C = D * (1-exp2)	H = B + (Hlast year * exp1)	E = C + Hlast year * (1 - exp1)	Q = E * 16/12 * F
												ton	fraction	ton	ton	ton	ton	ton	ton
2010	430	100%	100%	0.2	0.5	0.1	6.93	0.90	13	1.0	0.5	430	1	43.00	43.00	0.00	43.00	0.00	0.00
2011	0	100%	100%	0.2	0.5	0.1	6.93	0.90	13	1.0	0.5	430	1	43.00	43.00	0.00	81.91	4.09	2.73

The flow chart of the fertiliser production, tranportation and field application is given in Figure G.8.

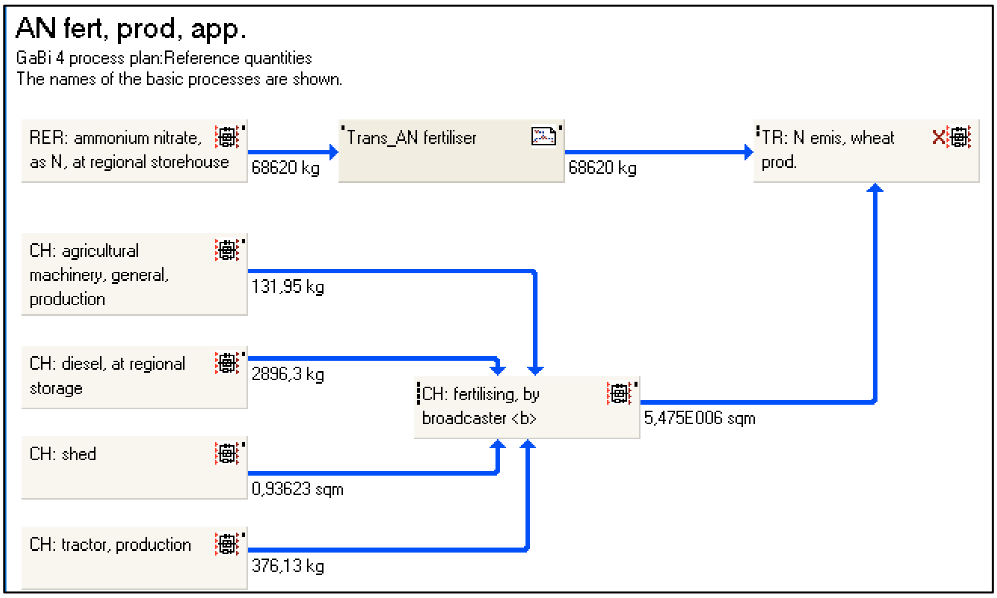
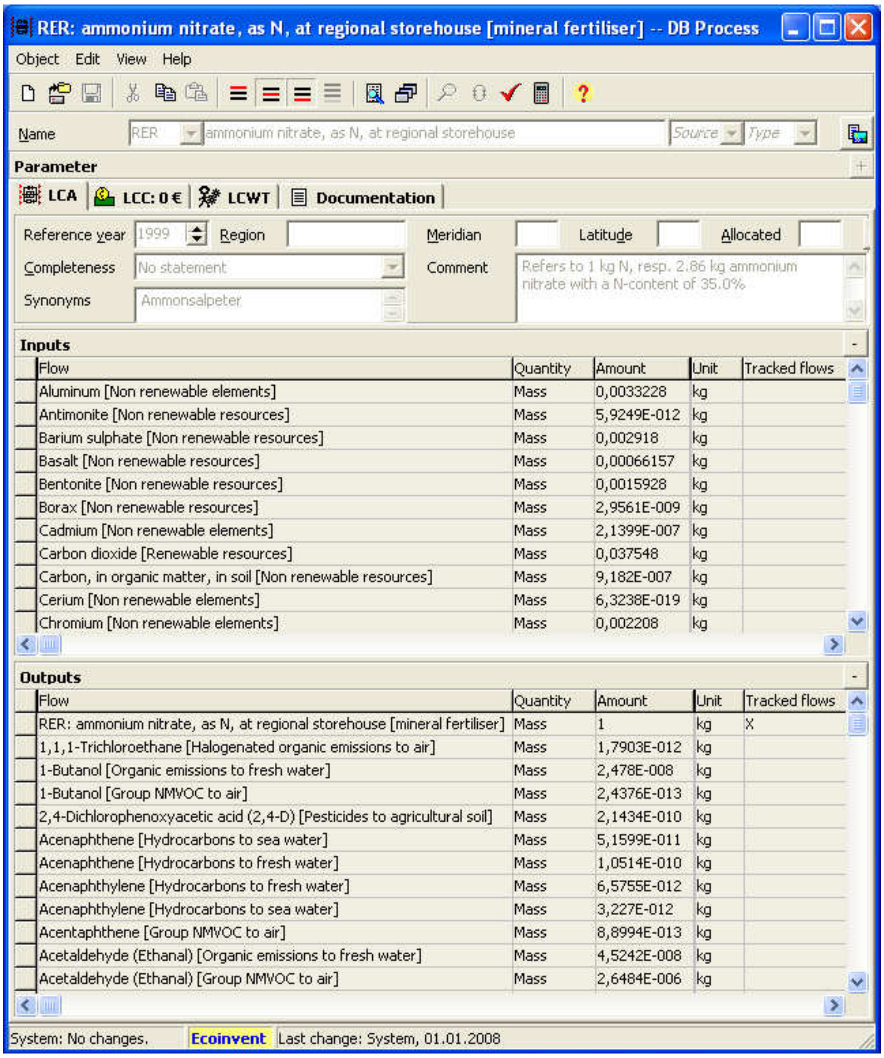


Figure G.8. Flowchart of annual mineral fertiliser production and application.

The inputs and outputs data of the ammonium nitrate (AN) production which is gathered from the GaBi4 database are given in Table G.15.

Table G.15. Input and output data of the ammonium nitrate production [GaBi4, 2003].



Name: RER | ammonium nitrate, as N, at regional storehouse | Source | Type

Reference year: 1999
Region:
Meridian:
Latitude:
Allocated:
Completeness: No statement
Comment: Refers to 1 kg N, resp. 2.86 kg ammonium nitrate with a N-content of 35.0%
Synonyms: Ammonsalpeter

Inputs

Flow	Quantity	Amount	Unit	Tracked flows
Aluminum [Non renewable elements]	Mass	0,0033228	kg	
Antimonite [Non renewable resources]	Mass	5,9249E-012	kg	
Barium sulphate [Non renewable resources]	Mass	0,002918	kg	
Basalt [Non renewable resources]	Mass	0,00066157	kg	
Bentonite [Non renewable resources]	Mass	0,0015928	kg	
Borax [Non renewable resources]	Mass	2,9561E-009	kg	
Cadmium [Non renewable elements]	Mass	2,1399E-007	kg	
Carbon dioxide [Renewable resources]	Mass	0,037548	kg	
Carbon, in organic matter, in soil [Non renewable resources]	Mass	9,182E-007	kg	
Cerium [Non renewable elements]	Mass	6,3238E-019	kg	
Chromium [Non renewable elements]	Mass	0,002208	kg	

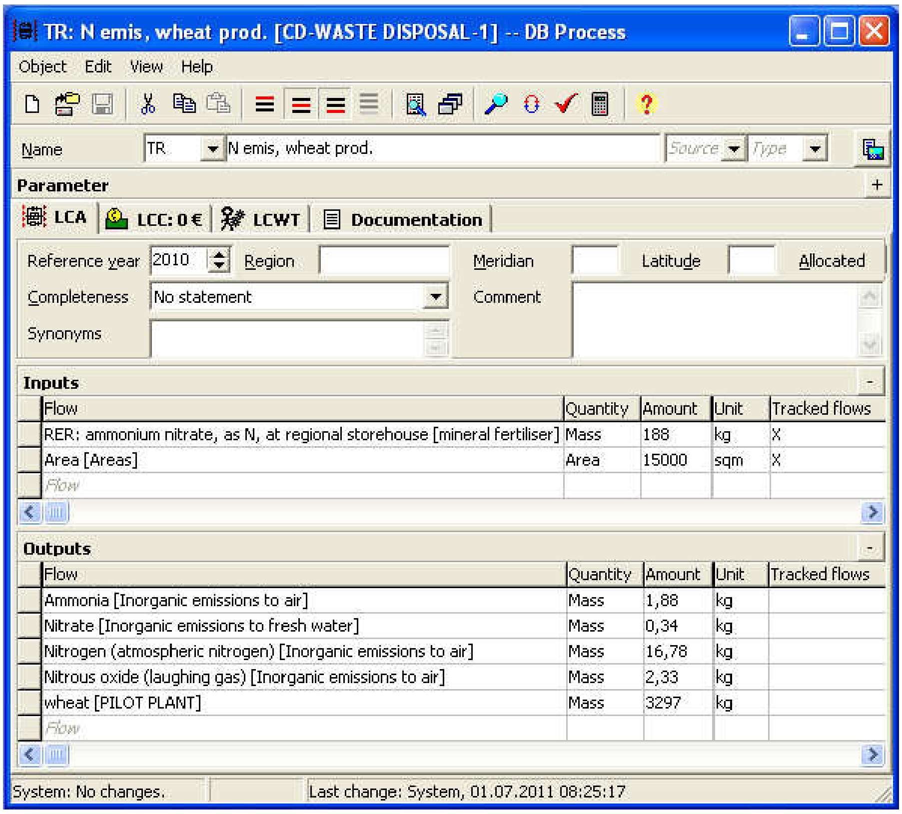
Outputs

Flow	Quantity	Amount	Unit	Tracked flows
RER: ammonium nitrate, as N, at regional storehouse [mineral fertiliser]	Mass	1	kg	X
1,1,1-Trichloroethane [Halogenated organic emissions to air]	Mass	1,7903E-012	kg	
1-Butanol [Organic emissions to fresh water]	Mass	2,478E-008	kg	
1-Butanol [Group NMVOC to air]	Mass	2,4376E-013	kg	
2,4-Dichlorophenoxyacetic acid (2,4-D) [Pesticides to agricultural soil]	Mass	2,1434E-010	kg	
Acenaphthene [Hydrocarbons to sea water]	Mass	5,1599E-011	kg	
Acenaphthene [Hydrocarbons to fresh water]	Mass	1,0514E-010	kg	
Acenaphthylene [Hydrocarbons to fresh water]	Mass	6,5755E-012	kg	
Acenaphthylene [Hydrocarbons to sea water]	Mass	3,227E-012	kg	
Acentaphthene [Group NMVOC to air]	Mass	8,8994E-013	kg	
Acetaldehyde (Ethanal) [Organic emissions to fresh water]	Mass	4,5242E-008	kg	
Acetaldehyde (Ethanal) [Group NMVOC to air]	Mass	2,6484E-006	kg	

System: No changes.
Ecoinvent
Last change: System, 01.01.2008

The daily inputs and outputs data of the field application of ammonium nitrate for winter wheat production is given in Table G.16.

Table G.16. Inputs and outputs data for the field application of ammonium nitrate as fertiliser.



Name: TR | N emis, wheat prod.

Reference year: 2010

Region:

Meridian:

Latitude:

Allocated:

Completeness: No statement

Comment:

Synonyms:

Inputs

Flow	Quantity	Amount	Unit	Tracked flows
RER: ammonium nitrate, as N, at regional storehouse [mineral fertiliser]	Mass	188	kg	X
Area [Areas]	Area	15000	sqm	X

Outputs

Flow	Quantity	Amount	Unit	Tracked flows
Ammonia [Inorganic emissions to air]	Mass	1,88	kg	
Nitrate [Inorganic emissions to fresh water]	Mass	0,34	kg	
Nitrogen (atmospheric nitrogen) [Inorganic emissions to air]	Mass	16,78	kg	
Nitrous oxide (laughing gas) [Inorganic emissions to air]	Mass	2,33	kg	
wheat [PILOT PLANT]	Mass	3297	kg	

System: No changes.

Last change: System, 01.07.2011 08:25:17

The process flow chart of Scenario E is given in Figure G.9.

SCENARIO E

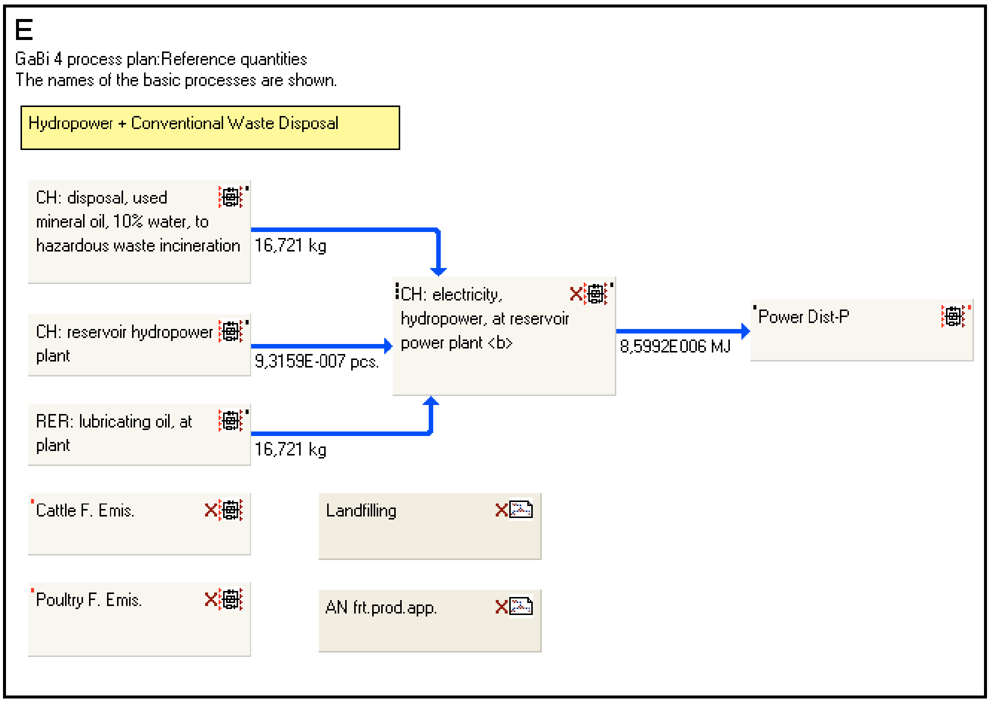
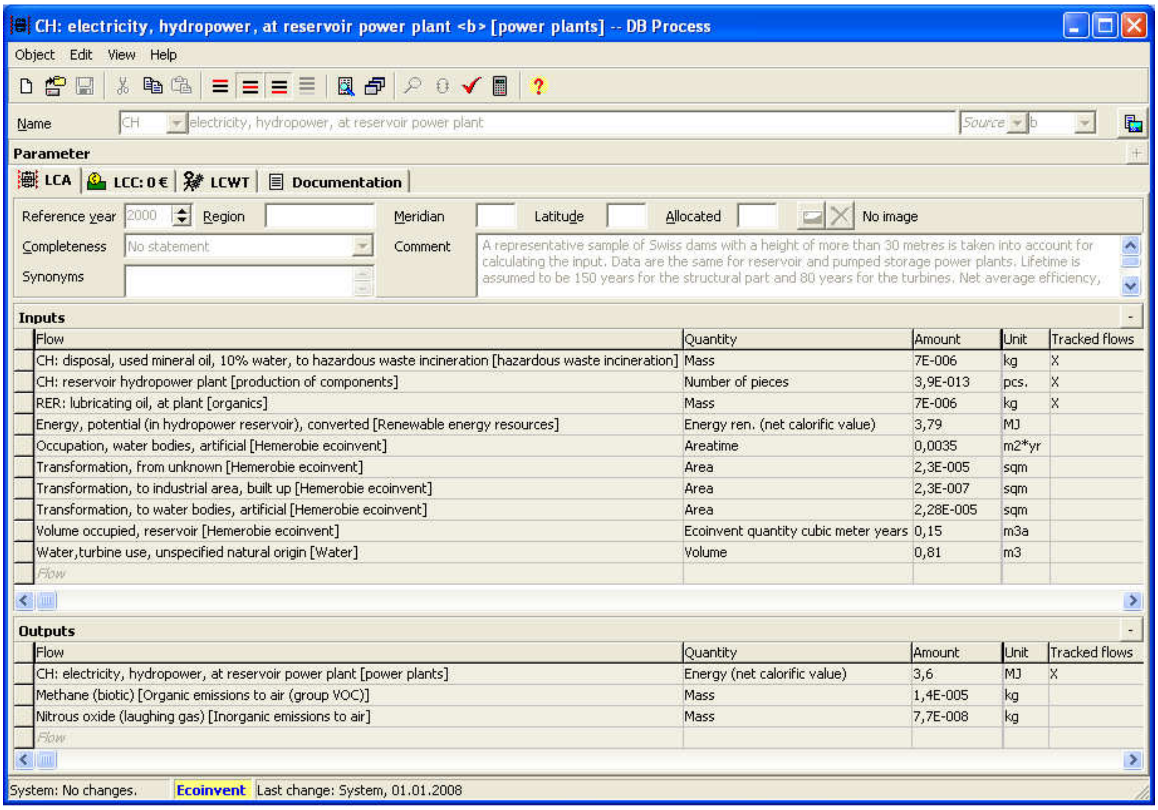


Figure G.9. Flow chart for Scenario E, the annual electricity production from hydropower.

The inventory tables gathered from the GaBi4 database regarding the electricity production from hydropower is given in Table G.17.

Table G.17. Inputs and outputs for the electricity production from hydropower [GaBi4, 2003].



Name: CH electricity, hydropower, at reservoir power plant Source b

Reference year: 2000
Region:
Meridian:
Latitude:
Allocated:
No image
Completeness: No statement
Synonyms:
Comment: A representative sample of Swiss dams with a height of more than 30 metres is taken into account for calculating the input. Data are the same for reservoir and pumped storage power plants. Lifetime is assumed to be 150 years for the structural part and 80 years for the turbines. Net average efficiency,

Inputs

Flow	Quantity	Amount	Unit	Tracked flows
CH: disposal, used mineral oil, 10% water, to hazardous waste incineration [hazardous waste incineration]	Mass	7E-006	kg	X
CH: reservoir hydropower plant [production of components]	Number of pieces	3,9E-013	pcs.	X
RER: lubricating oil, at plant [organics]	Mass	7E-006	kg	X
Energy, potential (in hydropower reservoir), converted [Renewable energy resources]	Energy ren. (net calorific value)	3,79	MJ	
Occupation, water bodies, artificial [Hemerobie ecoinvent]	Areatime	0,0035	m2*yr	
Transformation, from unknown [Hemerobie ecoinvent]	Area	2,3E-005	sqm	
Transformation, to industrial area, built up [Hemerobie ecoinvent]	Area	2,3E-007	sqm	
Transformation, to water bodies, artificial [Hemerobie ecoinvent]	Area	2,28E-005	sqm	
Volume occupied, reservoir [Hemerobie ecoinvent]	Ecoinvent quantity cubic meter years	0,15	m3a	
Water,turbine use, unspecified natural origin [Water]	Volume	0,81	m3	
Flow				

Outputs

Flow	Quantity	Amount	Unit	Tracked flows
CH: electricity, hydropower, at reservoir power plant [power plants]	Energy (net calorific value)	3,6	MJ	X
Methane (biotic) [Organic emissions to air (group VOC)]	Mass	1,4E-005	kg	
Nitrous oxide (laughing gas) [Inorganic emissions to air]	Mass	7,7E-008	kg	
Flow				

System: No changes. **Ecoinvent** Last change: System, 01.01.2008

The process flow chart of Scenario F is given in Figure G.10.

SCENARIO F

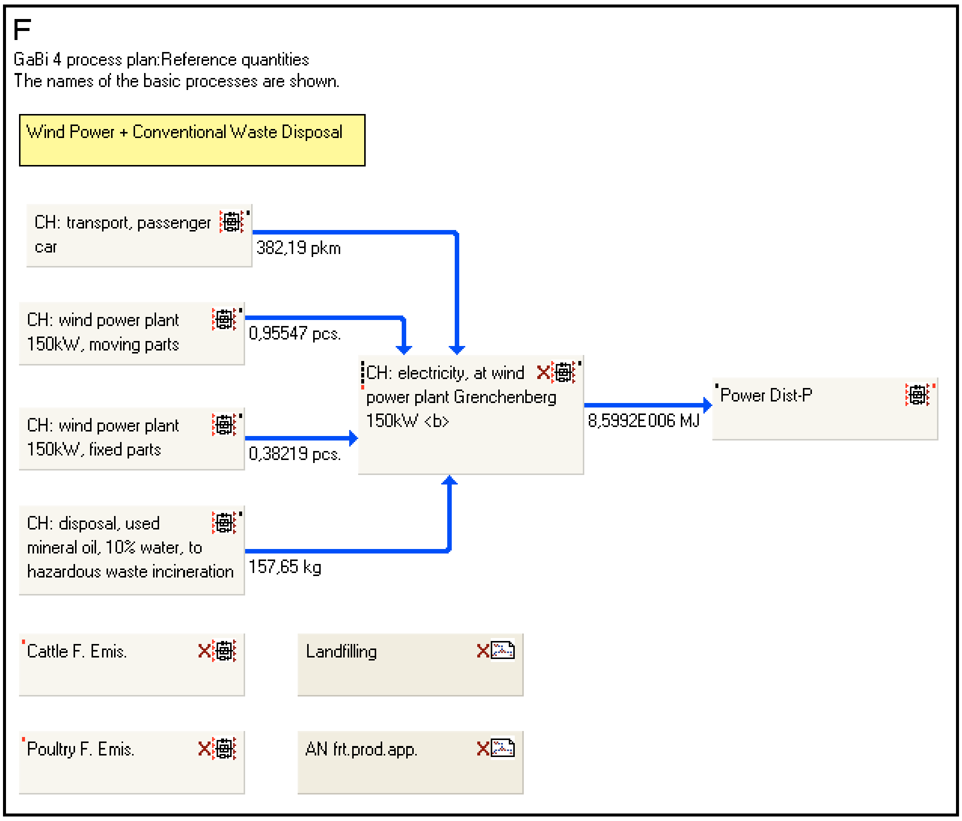
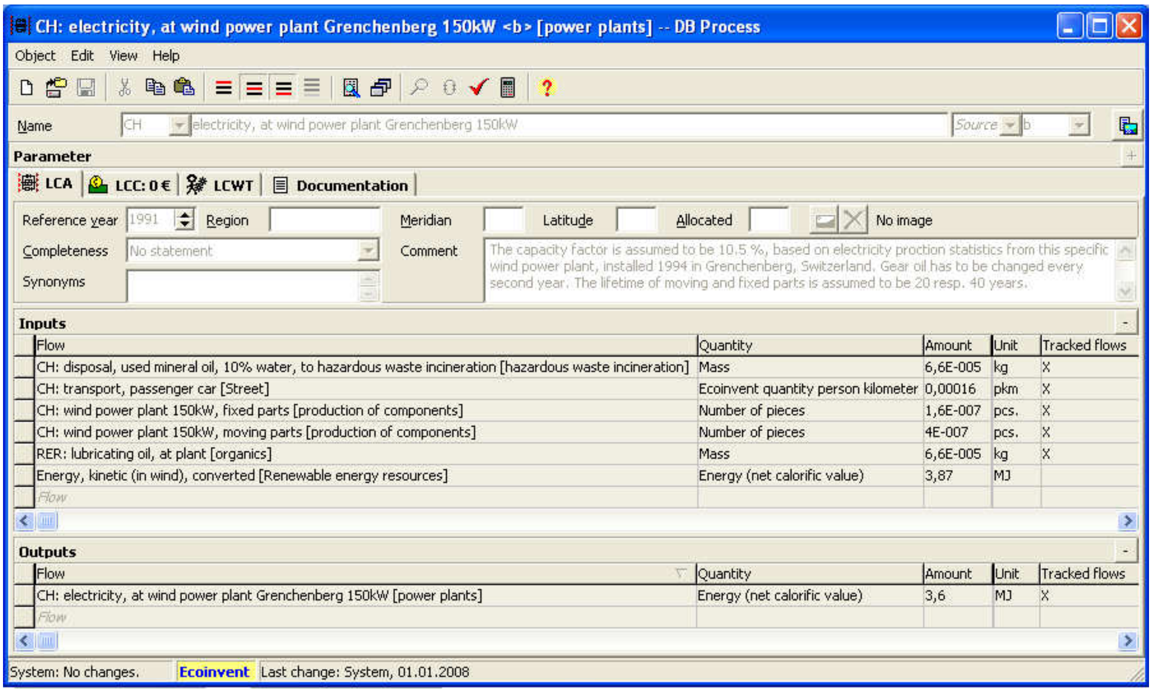


Figure G.10. Flow chart for Scenario F, the annual electricity production from windpower.

The inventory tables gathered from the GaBi4 database regarding the electricity production from windpower plant is given in Table G.18.

Table G.18. Inputs and outputs for the electricity production from windpower [GaBi4, 2003].



CH: electricity, at wind power plant Grenchenberg 150kW <b> [power plants] -- DB Process

Name: CH | electricity, at wind power plant Grenchenberg 150kW | Source | b

Reference year: 1991

Region:

Meridian:

Latitude:

Allocated:

Completeness: No statement

Synonyms:

Comment: The capacity factor is assumed to be 10.5 %, based on electricity proction statistics from this specific wind power plant, installed 1994 in Grenchenberg, Switzerland. Gear oil has to be changed every second year. The lifetime of moving and fixed parts is assumed to be 20 resp. 40 years.

Inputs

Flow	Quantity	Amount	Unit	Tracked flows
CH: disposal, used mineral oil, 10% water, to hazardous waste incineration [hazardous waste incineration]	Mass	6,6E-005	kg	X
CH: transport, passenger car [Street]	Ecoinvent quantity person kilometer	0,00016	pkm	X
CH: wind power plant 150kW, fixed parts [production of components]	Number of pieces	1,6E-007	pcs.	X
CH: wind power plant 150kW, moving parts [production of components]	Number of pieces	4E-007	pcs.	X
RER: lubricating oil, at plant [organics]	Mass	6,6E-005	kg	X
Energy, kinetic (in wind), converted [Renewable energy resources]	Energy (net calorific value)	3,87	MJ	
Flow				

Outputs

Flow	Quantity	Amount	Unit	Tracked flows
CH: electricity, at wind power plant Grenchenberg 150kW [power plants]	Energy (net calorific value)	3,6	MJ	X
Flow				

System: No changes. Ecoinvent Last change: System, 01.01.2008

The process summary of the Scenario G is given in Figure G.11.

SCENARIO G

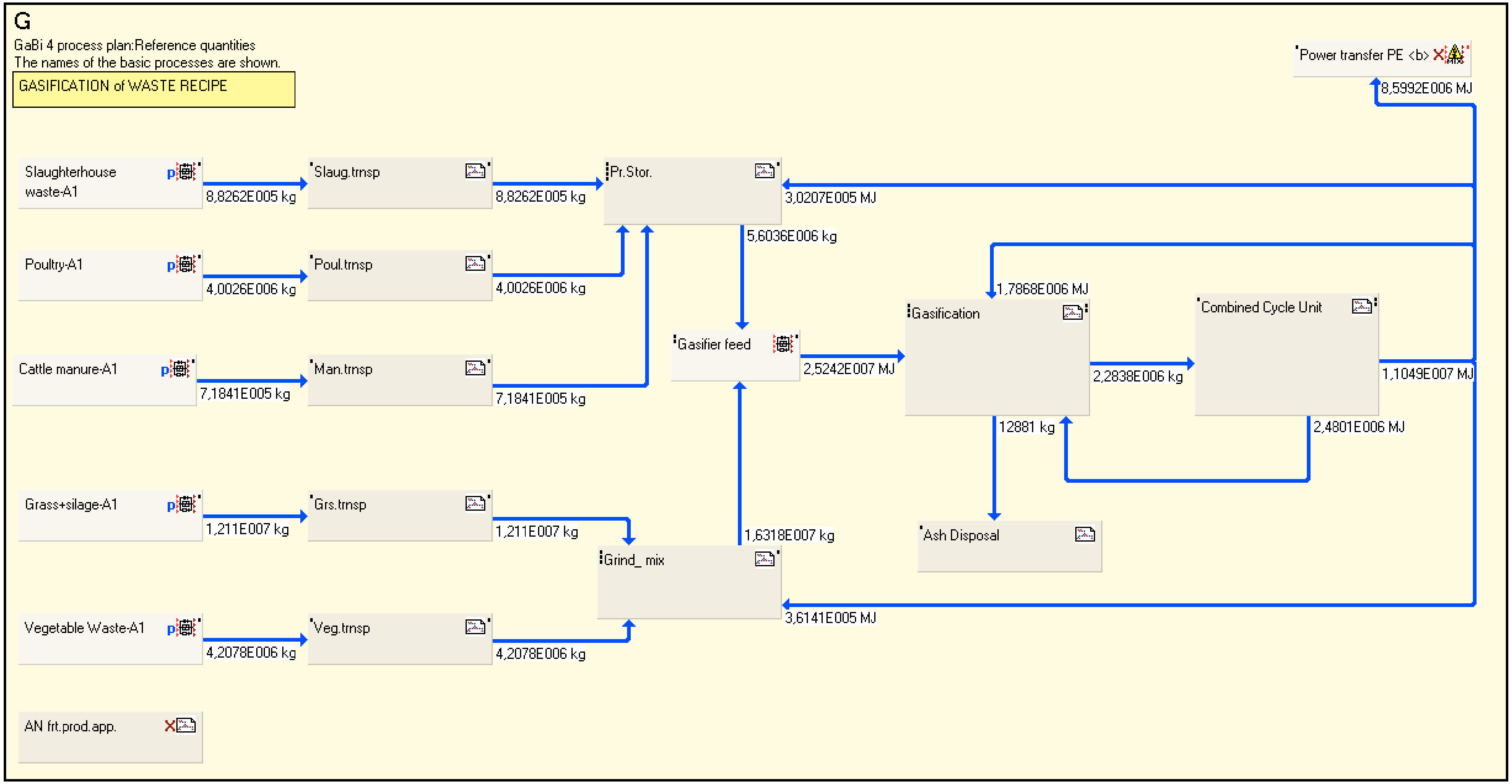


Figure G.11. Flow chart for Scenario G, the annual electricity production from the IGCC of the waste recipe.

The process flow diagram of the gasifier is given in Figure G.12.

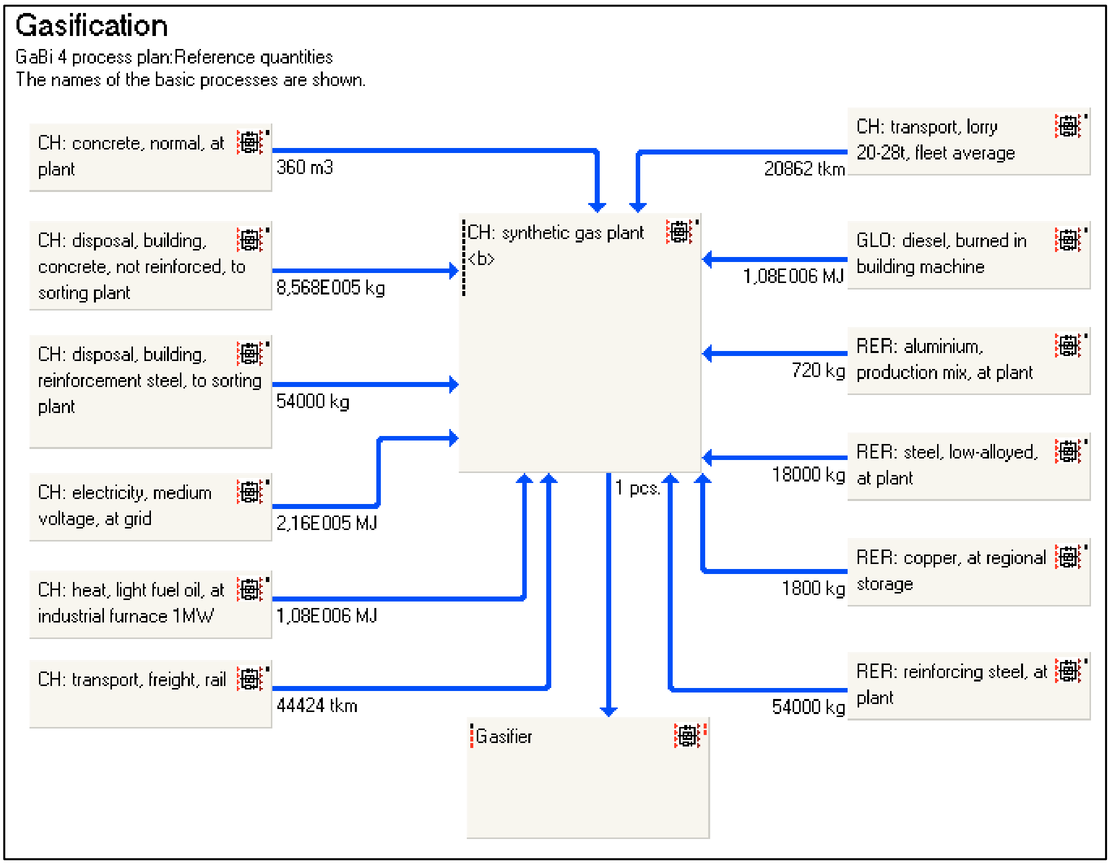
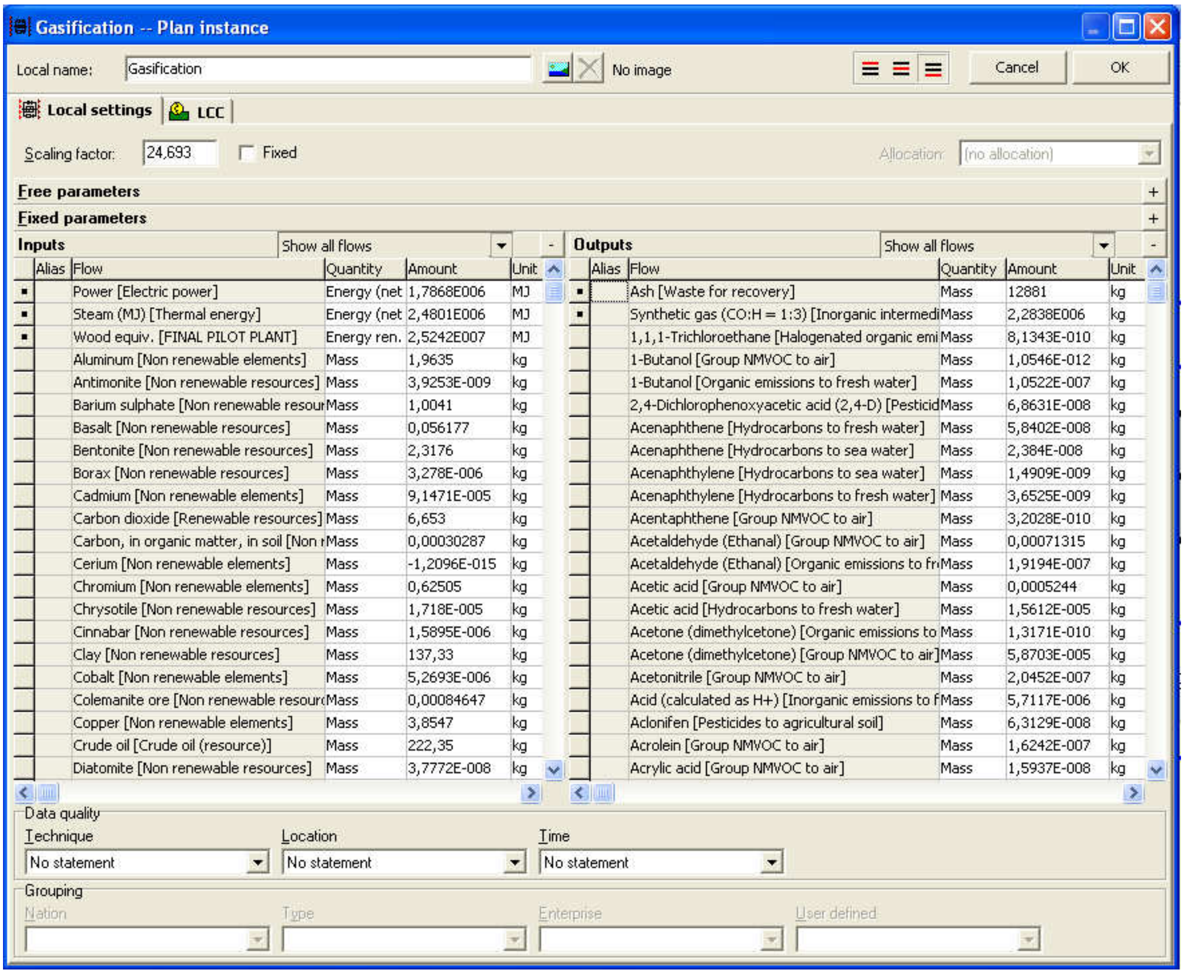


Figure G.12. Process flow diagram of the gasifier.

Table G.19. Input and output data of the gasifier.



Local name: Gasification

No image

Scaling factor: 24,693 ☐ Fixed

Allocation: (no allocation)

Free parameters

Fixed parameters

Inputs Show all flows

	Alias	Flow	Quantity	Amount	Unit
■		Power [Electric power]	Energy (net	1,7868E006	MJ
■		Steam (MJ) [Thermal energy]	Energy (net	2,4801E006	MJ
■		Wood equiv. [FINAL PILOT PLANT]	Energy ren.	2,5242E007	MJ
		Aluminum [Non renewable elements]	Mass	1,9635	kg
		Antimonite [Non renewable resources]	Mass	3,9253E-009	kg
		Barium sulphate [Non renewable resour	Mass	1,0041	kg
		Basalt [Non renewable resources]	Mass	0,056177	kg
		Bentonite [Non renewable resources]	Mass	2,3176	kg
		Borax [Non renewable resources]	Mass	3,278E-006	kg
		Cadmium [Non renewable elements]	Mass	9,1471E-005	kg
		Carbon dioxide [Renewable resources]	Mass	6,653	kg
		Carbon, in organic matter, in soil [Non r	Mass	0,00030287	kg
		Cerium [Non renewable elements]	Mass	-1,2096E-015	kg
		Chromium [Non renewable elements]	Mass	0,62505	kg
		Chrysotile [Non renewable resources]	Mass	1,718E-005	kg
		Cinnabar [Non renewable resources]	Mass	1,5895E-006	kg
		Clay [Non renewable resources]	Mass	137,33	kg
		Cobalt [Non renewable elements]	Mass	5,2693E-006	kg
		Colemanite ore [Non renewable resour	Mass	0,00084647	kg
		Copper [Non renewable elements]	Mass	3,8547	kg
		Crude oil [Crude oil (resource)]	Mass	222,35	kg
		Diatomite [Non renewable resources]	Mass	3,7772E-008	kg

Outputs Show all flows

	Alias	Flow	Quantity	Amount	Unit
■		Ash [Waste for recovery]	Mass	12881	kg
■		Synthetic gas (CO:H = 1:3) [Inorganic intermedi	Mass	2,2838E006	kg
		1,1,1-Trichloroethane [Halogenated organic emi	Mass	8,1343E-010	kg
		1-Butanol [Group NMVOC to air]	Mass	1,0546E-012	kg
		1-Butanol [Organic emissions to fresh water]	Mass	1,0522E-007	kg
		2,4-Dichlorophenoxyacetic acid (2,4-D) [Pesticid	Mass	6,8631E-008	kg
		Acenaphthene [Hydrocarbons to fresh water]	Mass	5,8402E-008	kg
		Acenaphthene [Hydrocarbons to sea water]	Mass	2,384E-008	kg
		Acenaphthylene [Hydrocarbons to sea water]	Mass	1,4909E-009	kg
		Acenaphthylene [Hydrocarbons to fresh water]	Mass	3,6525E-009	kg
		Acentaphthene [Group NMVOC to air]	Mass	3,2028E-010	kg
		Acetaldehyde (Ethanal) [Group NMVOC to air]	Mass	0,00071315	kg
		Acetaldehyde (Ethanal) [Organic emissions to fr	Mass	1,9194E-007	kg
		Acetic acid [Group NMVOC to air]	Mass	0,0005244	kg
		Acetic acid [Hydrocarbons to fresh water]	Mass	1,5612E-005	kg
		Acetone (dimethylcetone) [Organic emissions to	Mass	1,3171E-010	kg
		Acetone (dimethylcetone) [Group NMVOC to air]	Mass	5,8703E-005	kg
		Acetonitrile [Group NMVOC to air]	Mass	2,0452E-007	kg
		Acid (calculated as H+) [Inorganic emissions to f	Mass	5,7117E-006	kg
		Aclonifen [Pesticides to agricultural soil]	Mass	6,3129E-008	kg
		Acrolein [Group NMVOC to air]	Mass	1,6242E-007	kg
		Acrylic acid [Group NMVOC to air]	Mass	1,5937E-008	kg

Data quality

Technique: No statement

Location: No statement

Time: No statement

Grouping

Nation:

Type:

Enterprise:

User defined:

The process flow diagram of the combined cycle unit is given in Figure G.13.

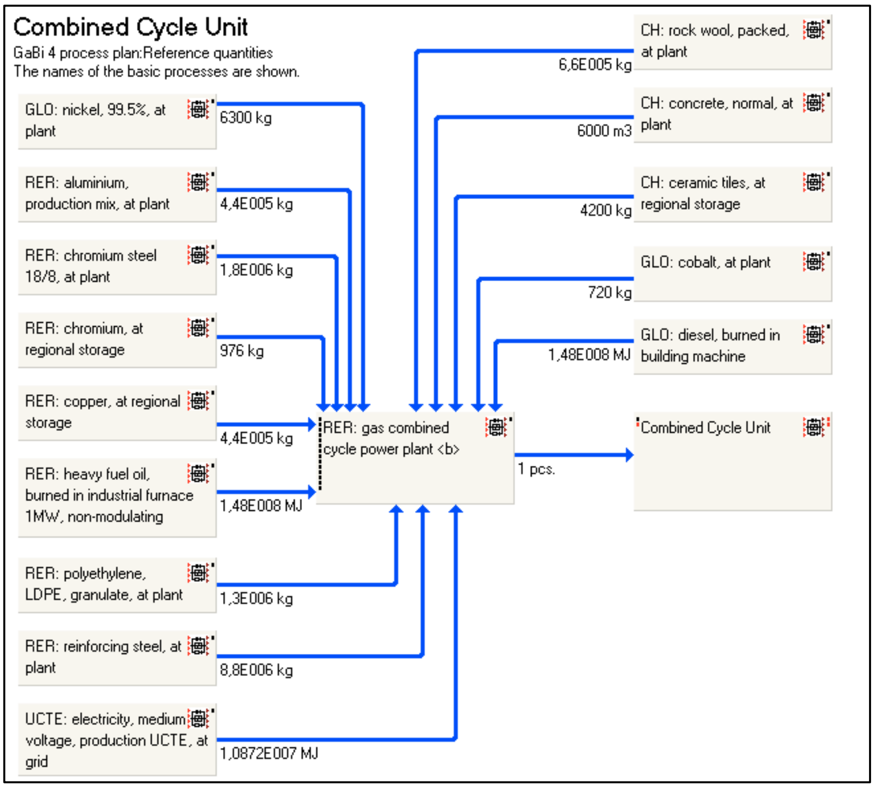
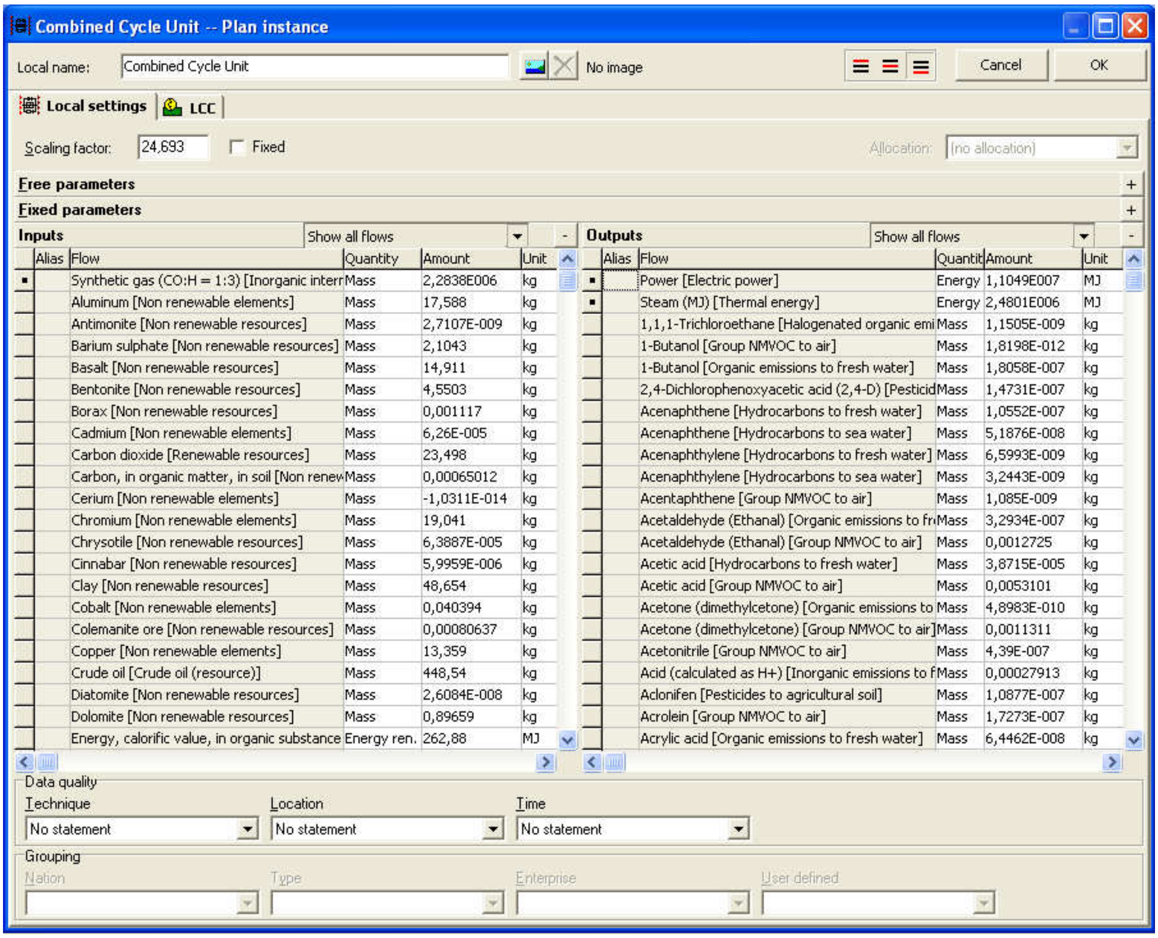


Figure G.13. Process flow diagram of the combined cycle unit.

Table G.20. Input and output data of the combined cycle unit.



Combined Cycle Unit -- Plan instance

Local name: Combined Cycle Unit

No image

Scaling factor: 24,693

☐ Fixed

Allocation: (no allocation)

Free parameters

Fixed parameters

Inputs (Show all flows)

	Alias	Flow	Quantity	Amount	Unit
■		Synthetic gas (CO:H = 1:3) [Inorganic interr	Mass	2,2838E006	kg
		Aluminum [Non renewable elements]	Mass	17,588	kg
		Antimonite [Non renewable resources]	Mass	2,7107E-009	kg
		Barium sulphate [Non renewable resources]	Mass	2,1043	kg
		Basalt [Non renewable resources]	Mass	14,911	kg
		Bentonite [Non renewable resources]	Mass	4,5503	kg
		Borax [Non renewable resources]	Mass	0,001117	kg
		Cadmium [Non renewable elements]	Mass	6,26E-005	kg
		Carbon dioxide [Renewable resources]	Mass	23,498	kg
		Carbon, in organic matter, in soil [Non renew	Mass	0,00065012	kg
		Cerium [Non renewable elements]	Mass	-1,0311E-014	kg
		Chromium [Non renewable elements]	Mass	19,041	kg
		Chrysotile [Non renewable resources]	Mass	6,3887E-005	kg
		Cinnabar [Non renewable resources]	Mass	5,9959E-006	kg
		Clay [Non renewable resources]	Mass	48,654	kg
		Cobalt [Non renewable elements]	Mass	0,040394	kg
		Colemanite ore [Non renewable resources]	Mass	0,00080637	kg
		Copper [Non renewable elements]	Mass	13,359	kg
		Crude oil [Crude oil (resource)]	Mass	448,54	kg
		Diatomite [Non renewable resources]	Mass	2,6084E-008	kg
		Dolomite [Non renewable resources]	Mass	0,89659	kg
		Energy, calorific value, in organic substance	Energy ren.	262,88	MJ

Outputs (Show all flows)

	Alias	Flow	Quantit	Amount	Unit
■		Power [Electric power]	Energy	1,1049E007	MJ
■		Steam (MJ) [Thermal energy]	Energy	2,4801E006	MJ
		1,1,1-Trichloroethane [Halogenated organic emi	Mass	1,1505E-009	kg
		1-Butanol [Group NMVOC to air]	Mass	1,8198E-012	kg
		1-Butanol [Organic emissions to fresh water]	Mass	1,8058E-007	kg
		2,4-Dichlorophenoxyacetic acid (2,4-D) [Pesticid	Mass	1,4731E-007	kg
		Acenaphthene [Hydrocarbons to fresh water]	Mass	1,0552E-007	kg
		Acenaphthene [Hydrocarbons to sea water]	Mass	5,1876E-008	kg
		Acenaphthylene [Hydrocarbons to fresh water]	Mass	6,5993E-009	kg
		Acenaphthylene [Hydrocarbons to sea water]	Mass	3,2443E-009	kg
		Acentaphthene [Group NMVOC to air]	Mass	1,085E-009	kg
		Acetaldehyde (Ethanal) [Organic emissions to fr	Mass	3,2934E-007	kg
		Acetaldehyde (Ethanal) [Group NMVOC to air]	Mass	0,0012725	kg
		Acetic acid [Hydrocarbons to fresh water]	Mass	3,8715E-005	kg
		Acetic acid [Group NMVOC to air]	Mass	0,0053101	kg
		Acetone (dimethylcetone) [Organic emissions to	Mass	4,8983E-010	kg
		Acetone (dimethylcetone) [Group NMVOC to air]	Mass	0,0011311	kg
		Acetonitrile [Group NMVOC to air]	Mass	4,39E-007	kg
		Acid (calculated as H+) [Inorganic emissions to f	Mass	0,00027913	kg
		Aclonifen [Pesticides to agricultural soil]	Mass	1,0877E-007	kg
		Acrolein [Group NMVOC to air]	Mass	1,7273E-007	kg
		Acrylic acid [Organic emissions to fresh water]	Mass	6,4462E-008	kg

Data quality

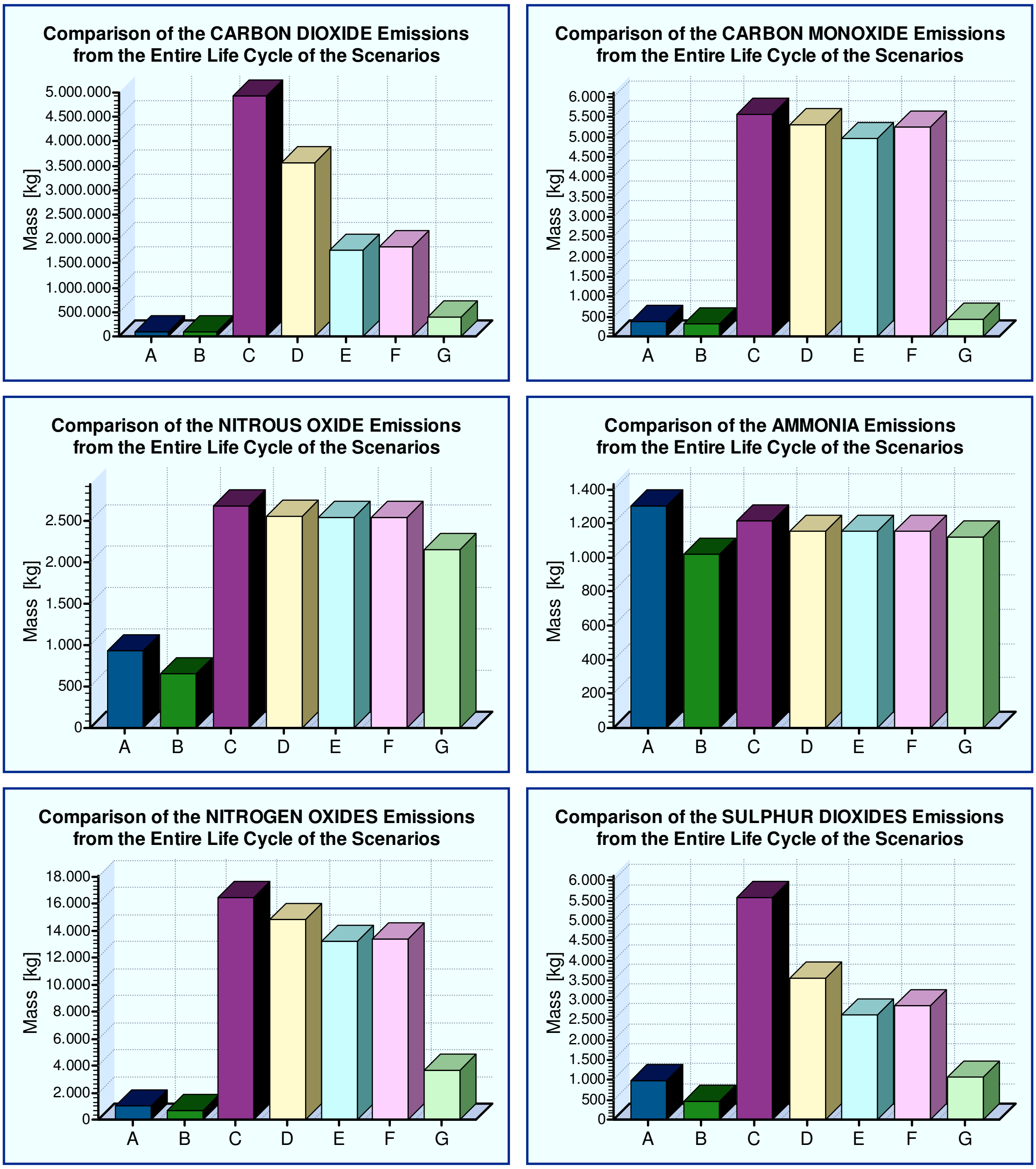
Technique: No statement

Location: No statement

Time: No statement

Grouping

APPENDIX H– CLASSIFICATION RESULTS of LCA ANALYSIS



A: Pilot Plant/Waste Recipe
B: Pilot Plant/Cattle Manure
C: Coal PP
D: Natural Gas PP
E: Hydro PP
F: Wind PP
G: IGCC

Figure H.1. Quantities of inorganic emissions to air released from the entire life cycle of the scenarios.

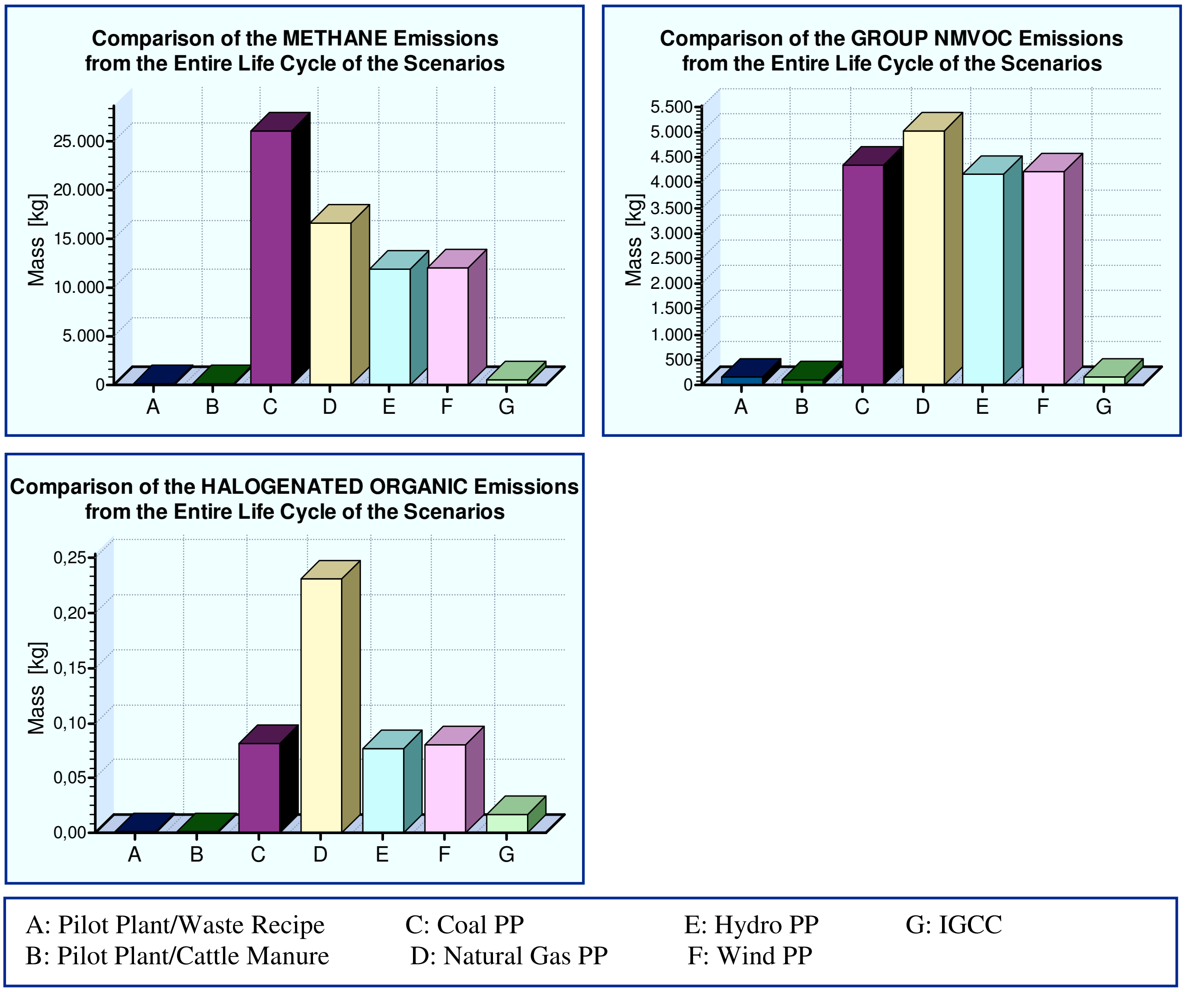


Figure H.2. Quantities of organic emissions to air released from the entire life cycle of the scenarios.

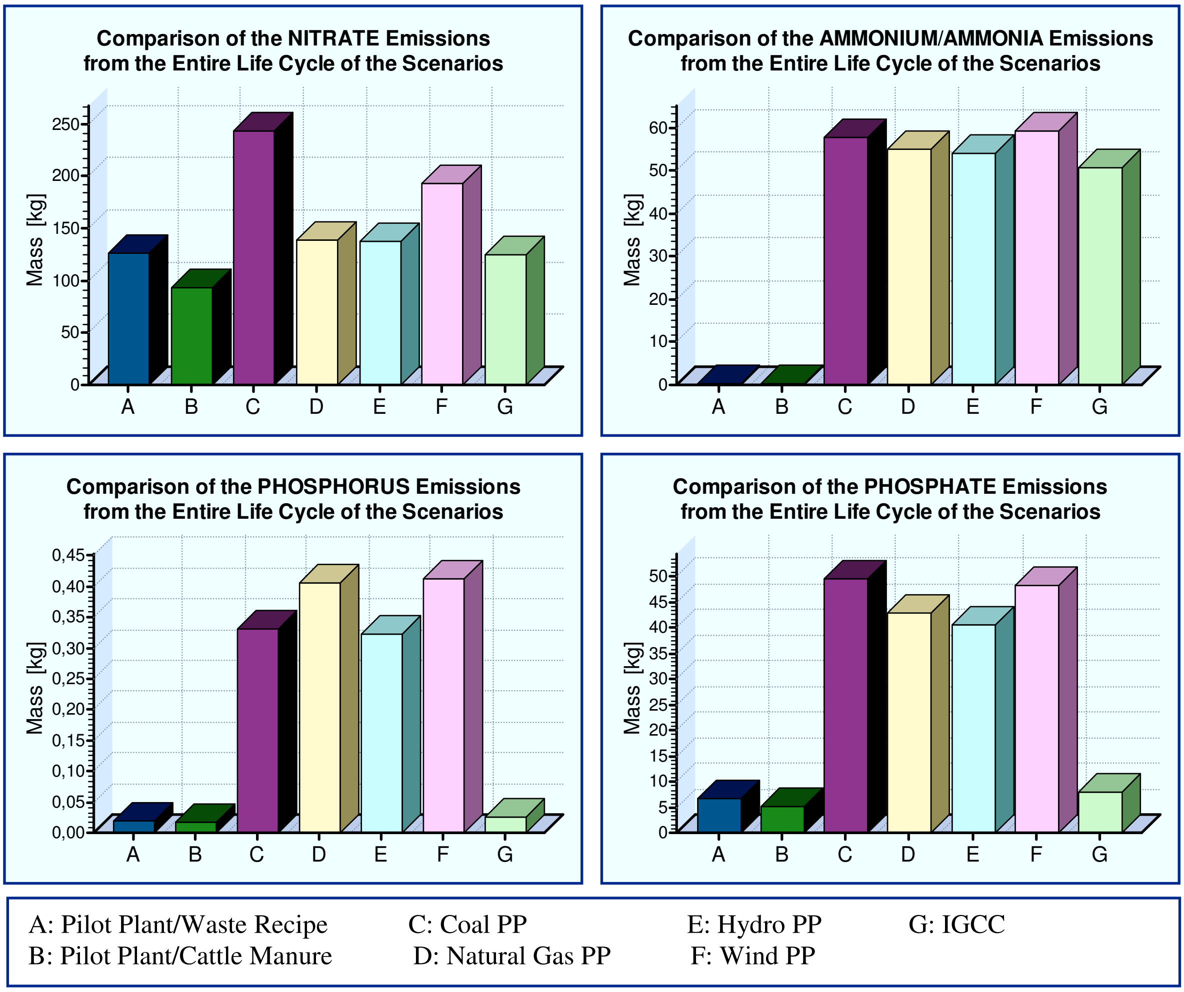


Figure H.3. Quantities of inorganic emissions to fresh water released from the entire life cycle of the scenarios.

APPENDIX I– CHARACTERISATION RESULTS of LCA ANALYSIS

The GWP of all scenarios are given and compared below.

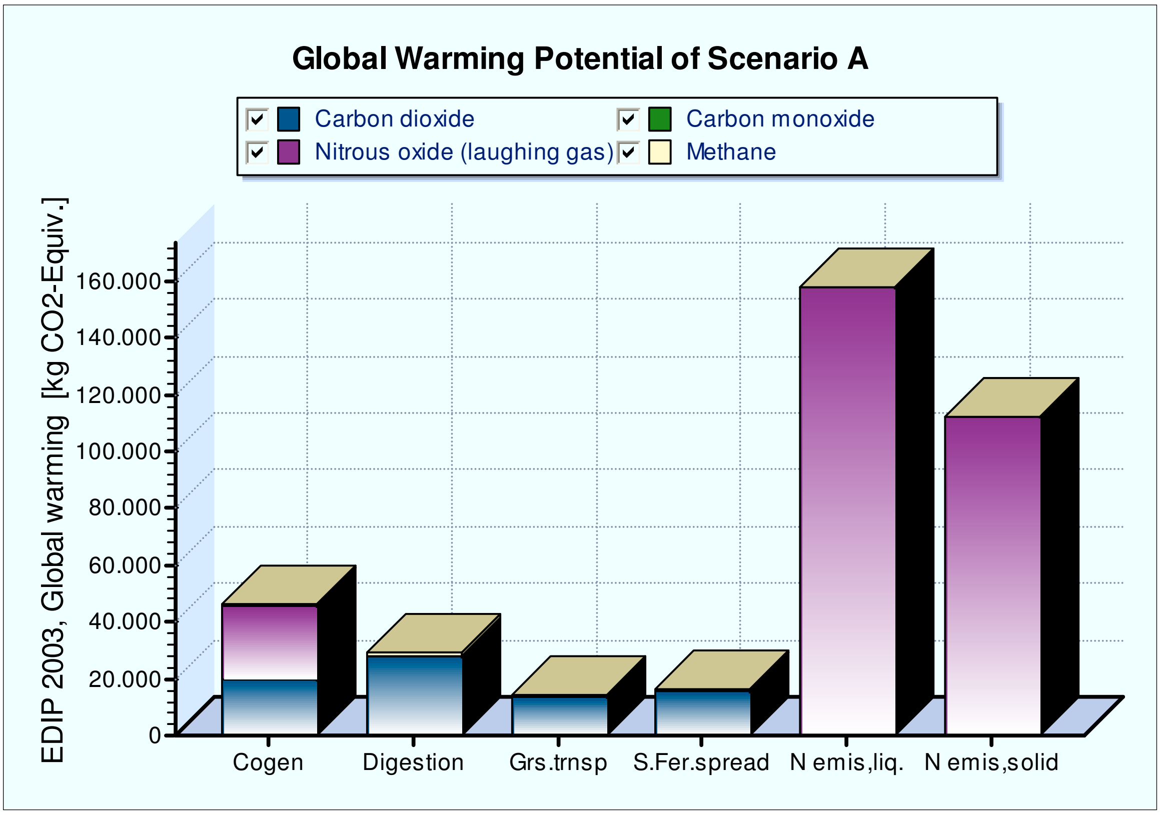


Figure I.1. Global warming potential of Scenario A.

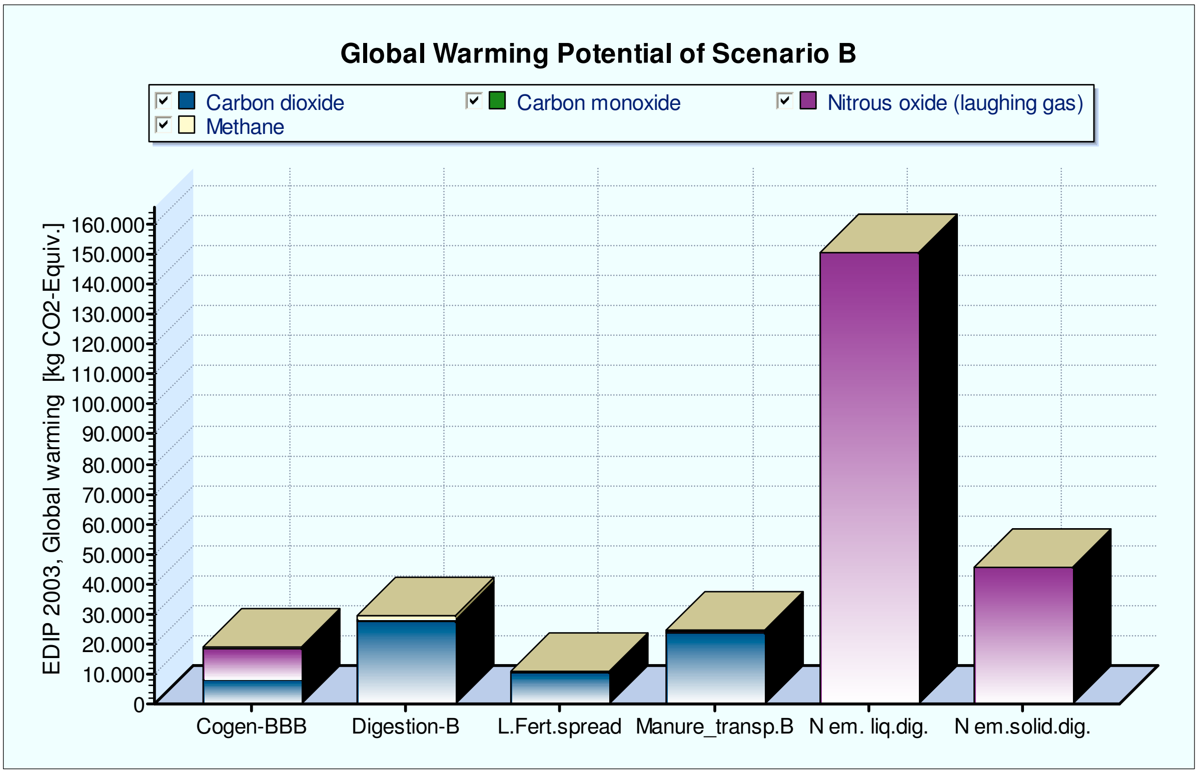


Figure I.2. Global warming potential of Scenario B.

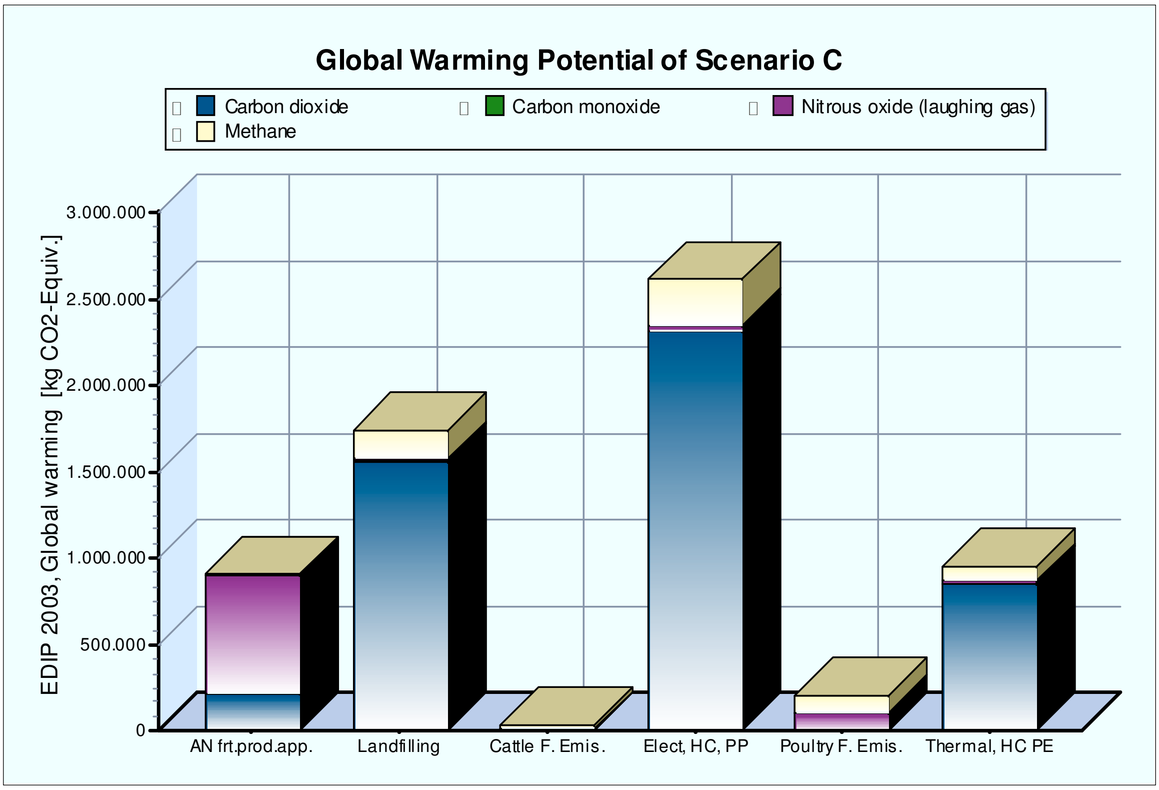


Figure I.3. Global warming potential of Scenario C.

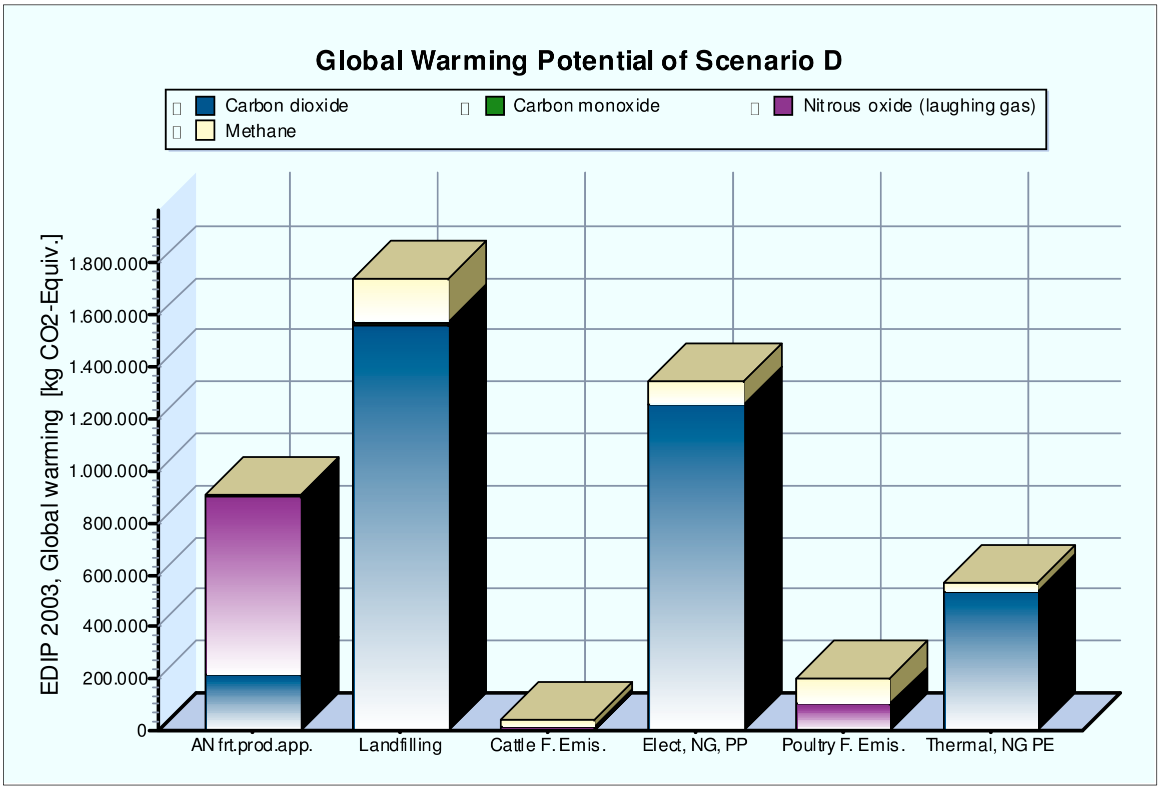


Figure I.4. Global warming potential of Scenario D.

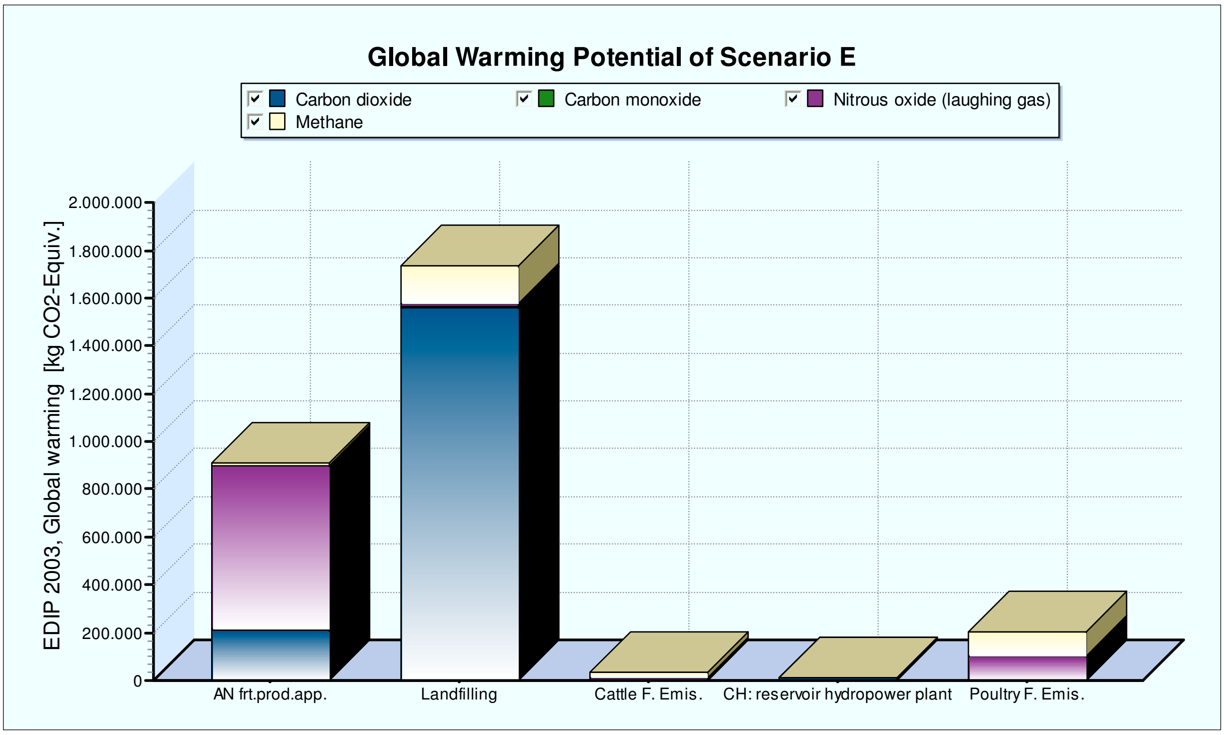


Figure I.5. Global warming potential of Scenario E.

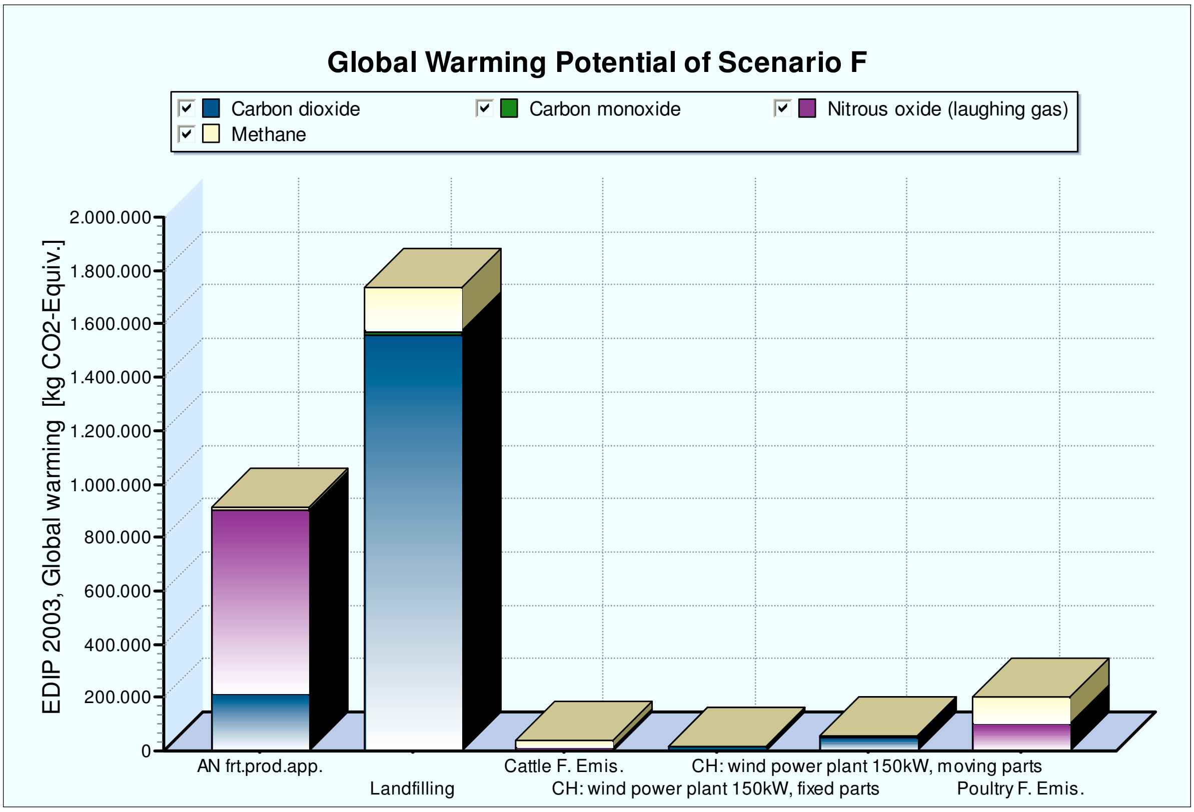


Figure I.6. Global warming potential of Scenario F.

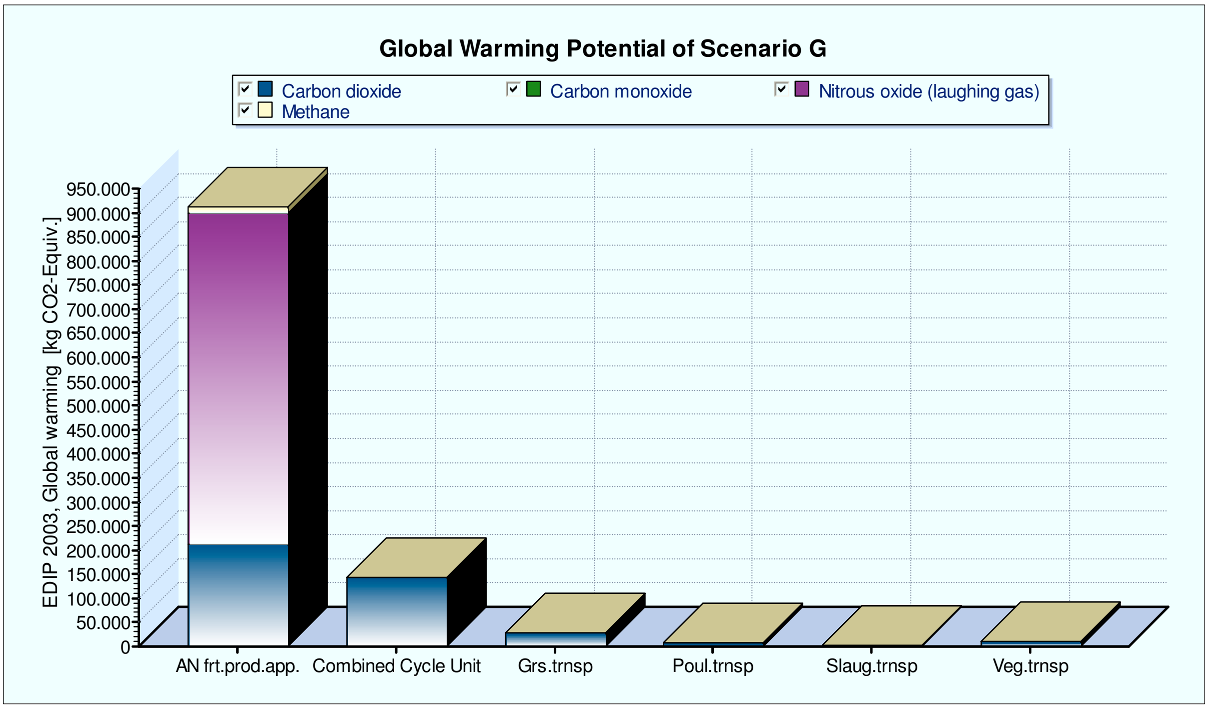


Figure I.7. Global warming potential of Scenario G.

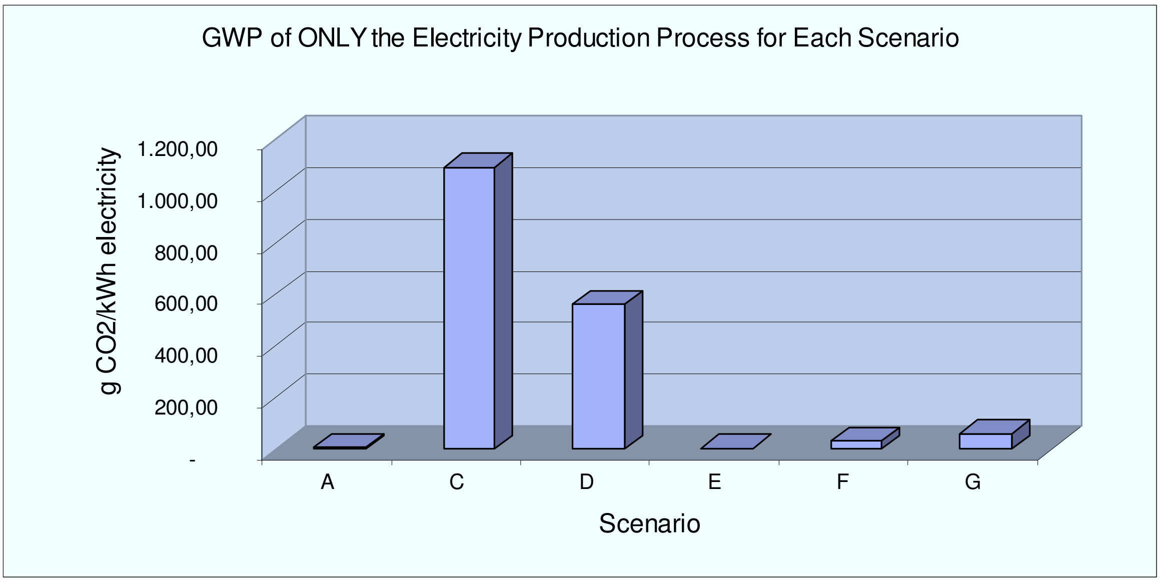


Figure I.8. Comparison of global warming potential of only electricity production processes for each scenario.

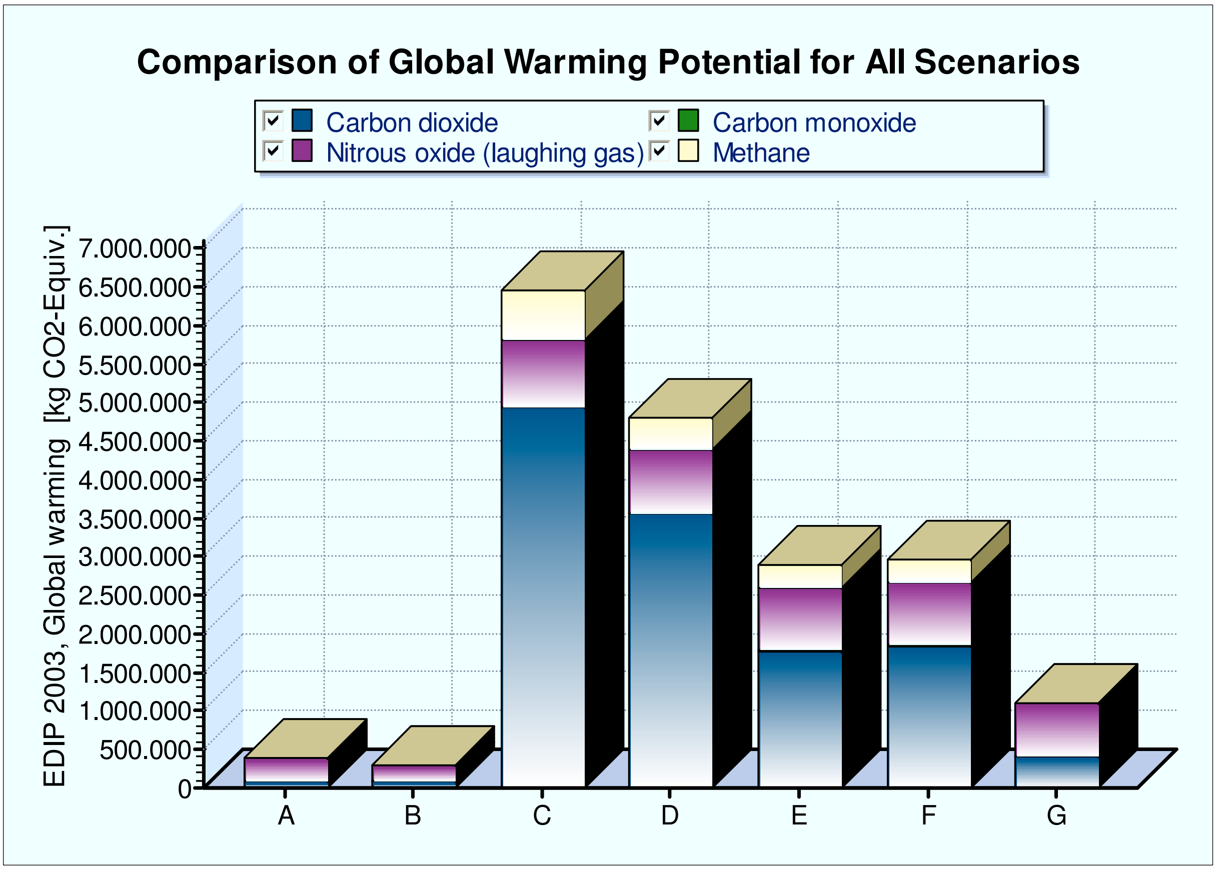


Figure I.9. Comparison of global warming potential of all Scenarios.

Table I.1. GWP Savings of Scenario A with respect to other scenarios in terms of some different activities and goods.

Goal Definitions for GWP Saving	**Minimum Goal**	**Achieved Savings of Scenario A with respect to**				
		Scenario C	**Scenario D**	**Scenario E**	**Scenario F**	**Scenario G**
Saving urban trees (pcs.)	≥500,000	5,165,079	3,757,856	2,130,244	2,188,375	603,424
GWP saving equal to yearly emissions of a considerable amount of average World Citizens*	≥150 citizens	1,483	1,079	612	628	173
GWP Saving equal to a considerable amount of TVs running for a year*	≥30,000 pcs.	263,088	191,410	108,506	111,467	30,736
GWP Saving equal to the extraction and refinery of crude oil to make a considerable amount of petrol*	≥1,000 tonne	10,616	7,724	4,378	4,498	1,240
GWP Saving equal to manufacturing of a considerable amount cell phone*	≥10,000 pcs.	100,850	73,374	41,594	42,729	11,782
GWP Saving equal to flying a considerable distance in economy class (long distance flight, emissions per passenger*	≥3,000,000 kilometres	27,504,625	20,011,006	11,343,790	11,653,340	3,213,298
GWP Saving equal to manufacturing a considerable amount of computers and monitors*	≥2,500 pcs.	22,004	16,009	9,075	9,323	2,571
GWP Saving equal to producing a considerable amount of steel*	≥300 tonne	2,631	1,914	1,085	1,115	307
GWP Saving equal to driving a considerable distance with an average European car*	≥ 4,500,000 kilometre	42,020,955	30,572,370	17,330,790	17,803,714	4,909,206
GWP Saving equal to producing a considerable amount of sugar*	≥900 tonne	8,289	6,031	3,419	3,512	968

* GWP Savings are calculated according to GHG emission amounts generated by different activities or goods given in Ref. [Kirby, 2008].

The acidification potential of all scenarios are given and compared below.

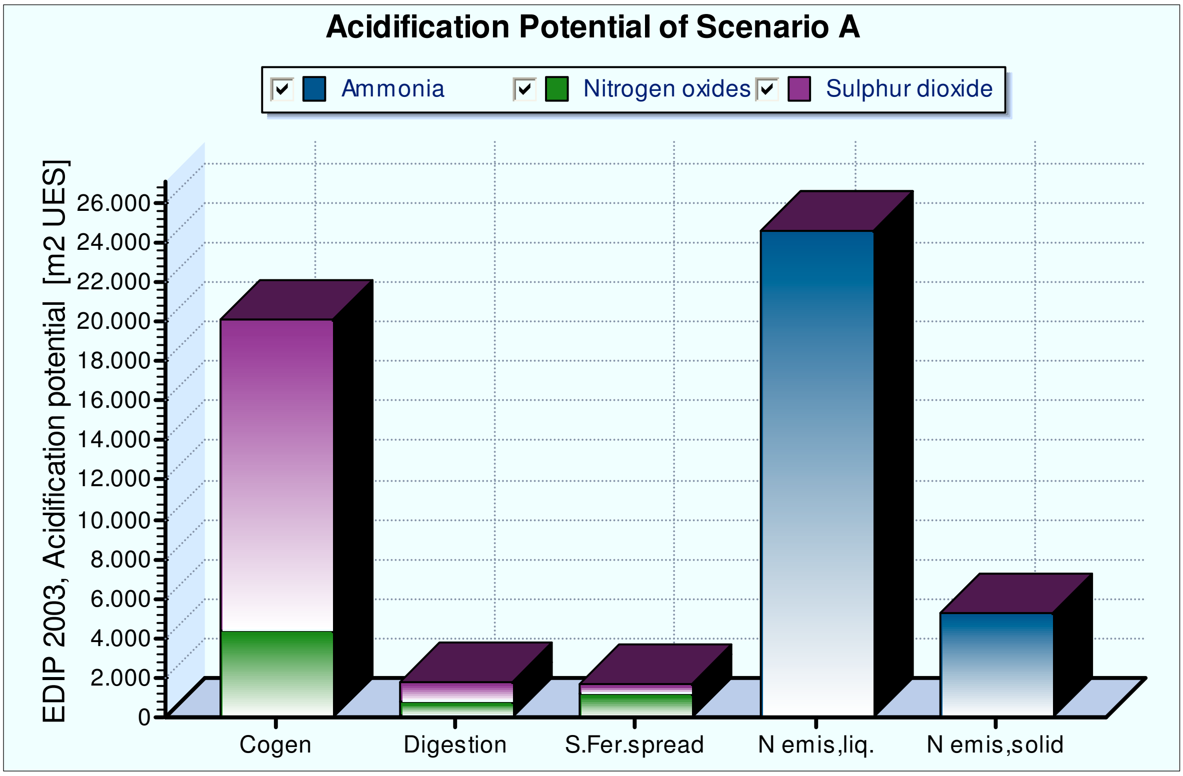


Figure I.10. Acidification potential of Scenario A.

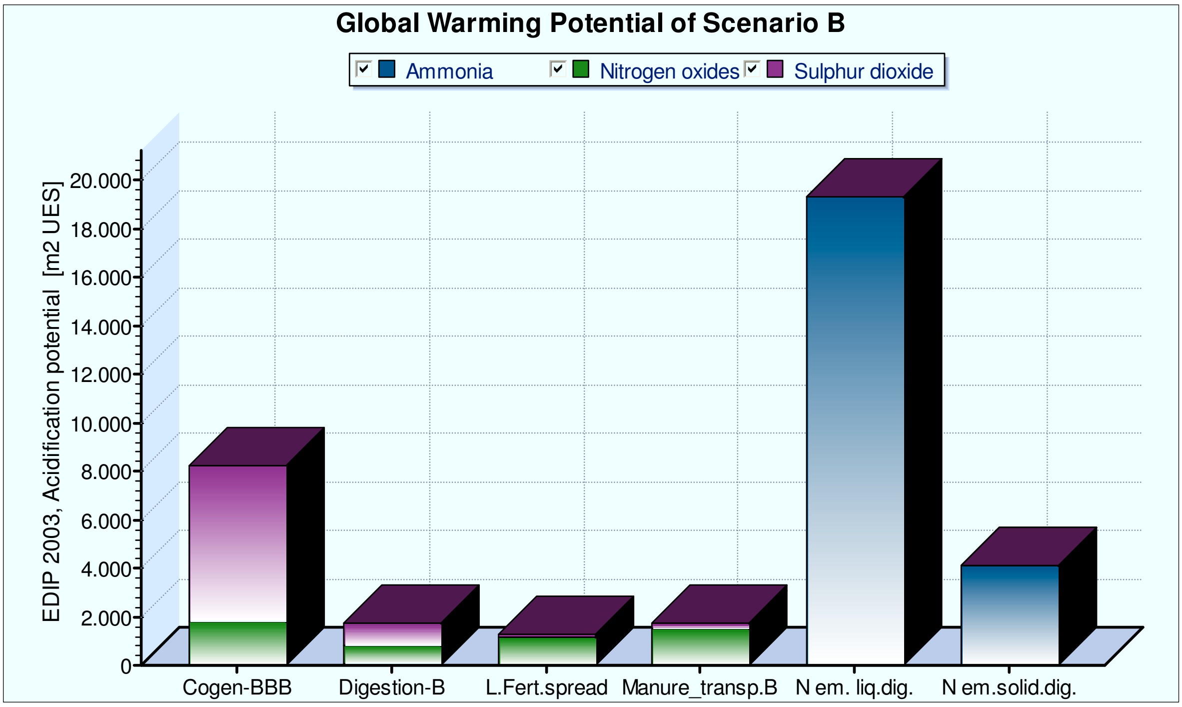


Figure I.11. Acidification potential of Scenario B.

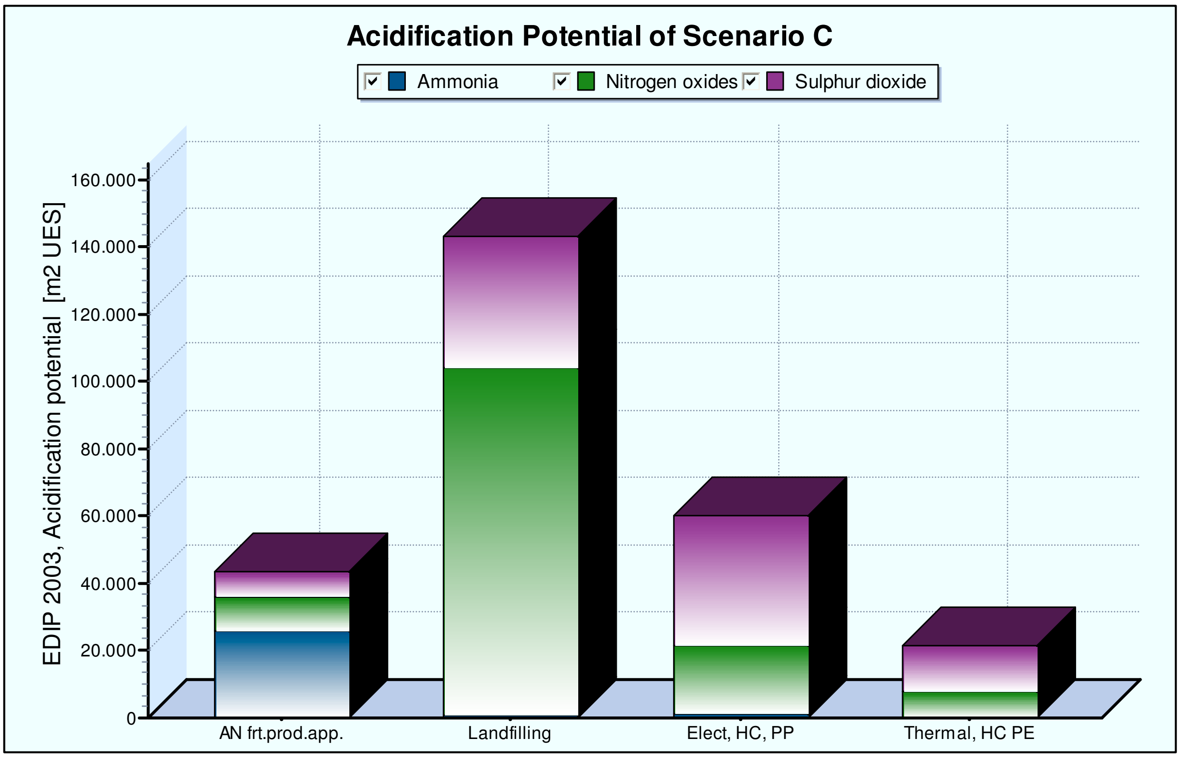


Figure I.12. Acidification potential of Scenario C.

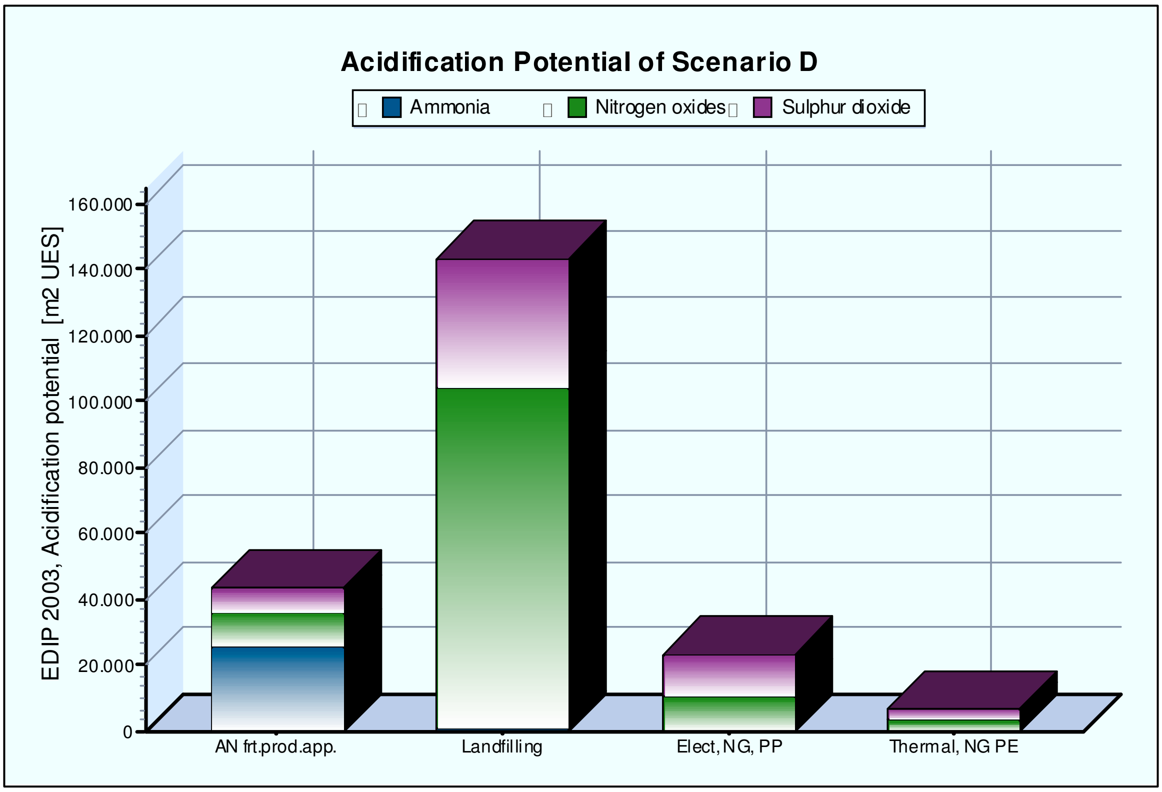


Figure I.13. Acidification potential of Scenario D.

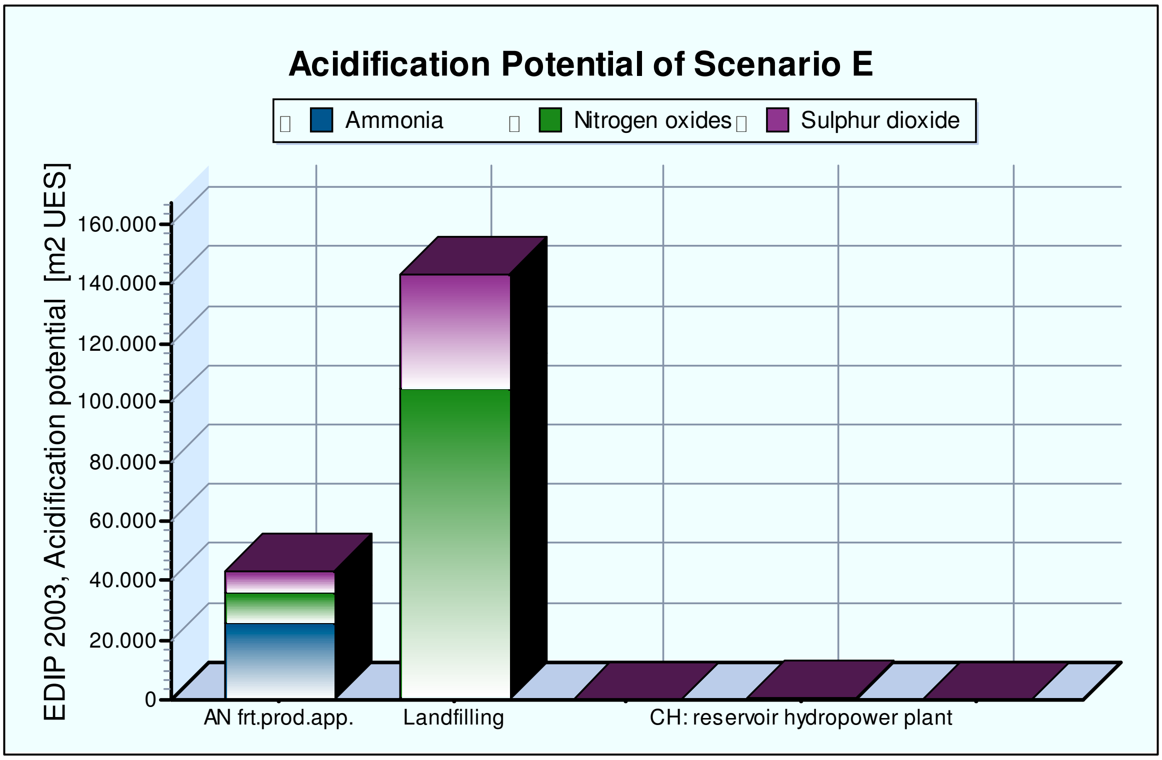


Figure I.14. Acidification potential of Scenario E.

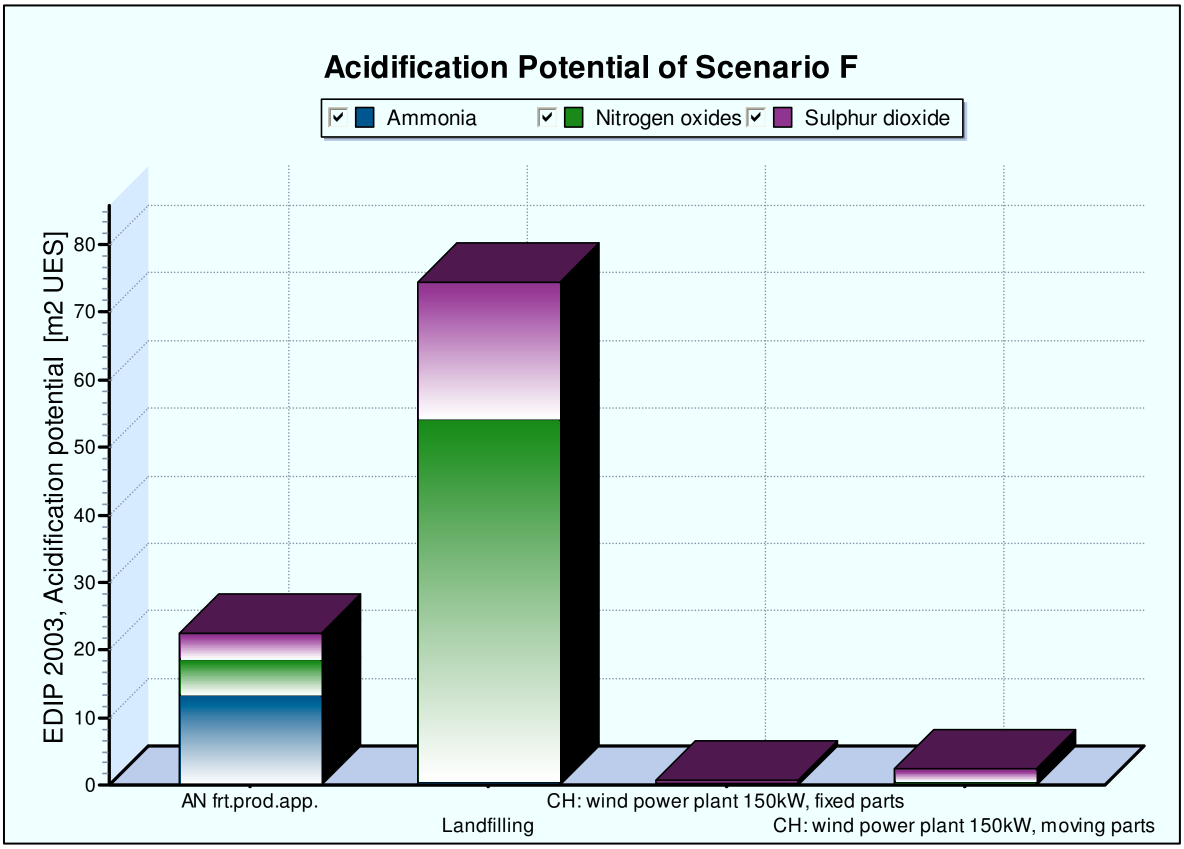


Figure I.15. Acidification potential of Scenario F.

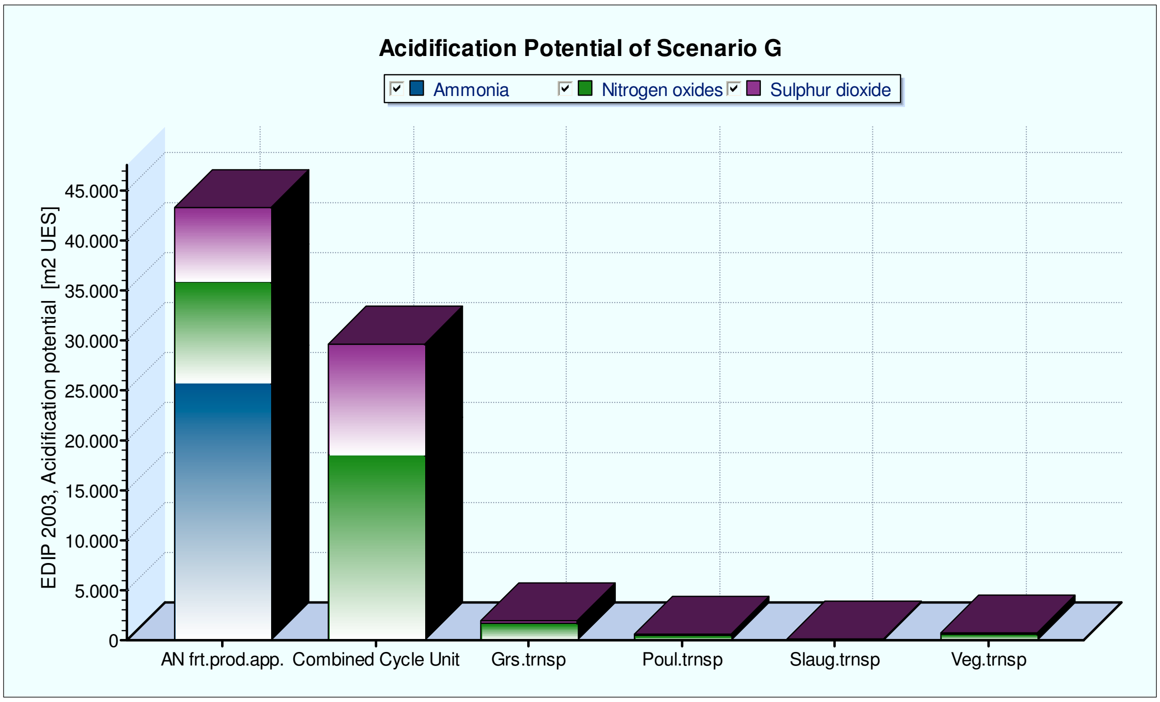


Figure I.16. Acidification potential of Scenario G.

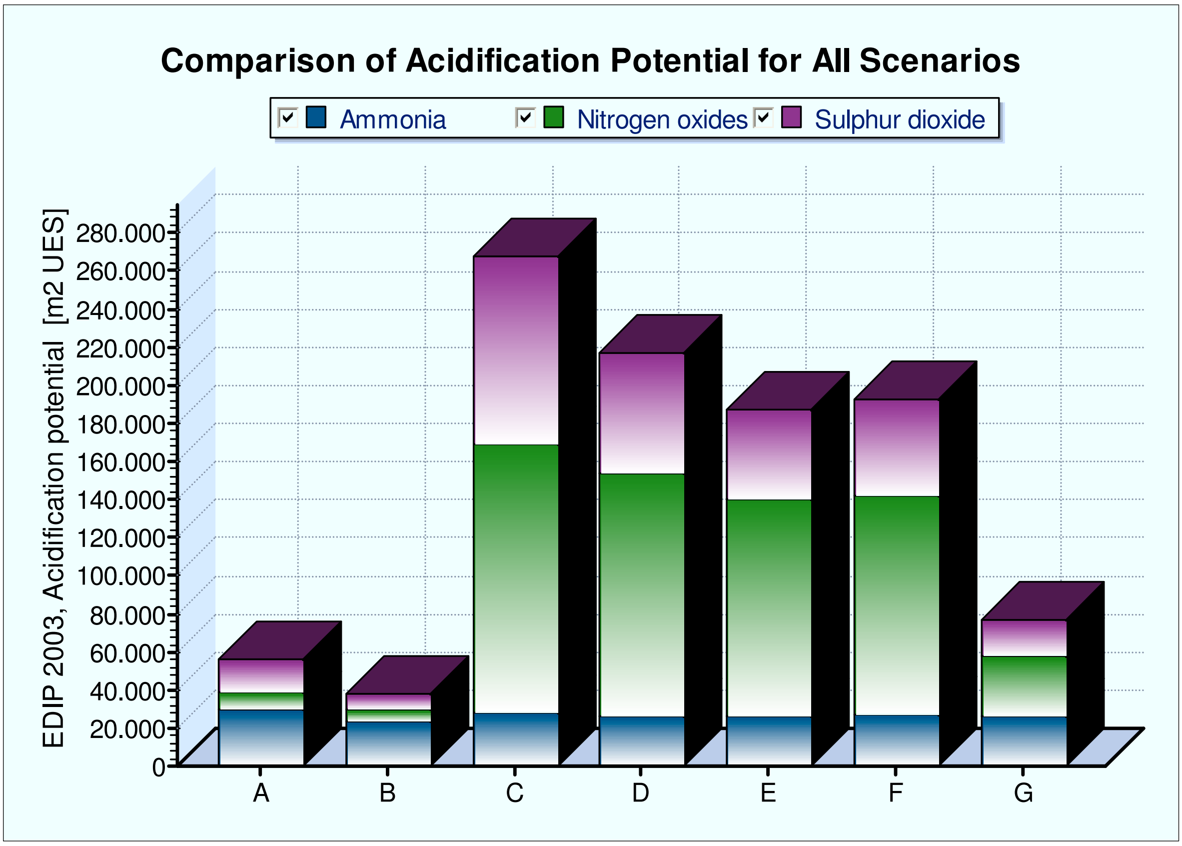


Figure I.17. Comparison of acidification potential of all Scenarios.

The aquatic eutrophication potential of all scenarios are given and compared below.

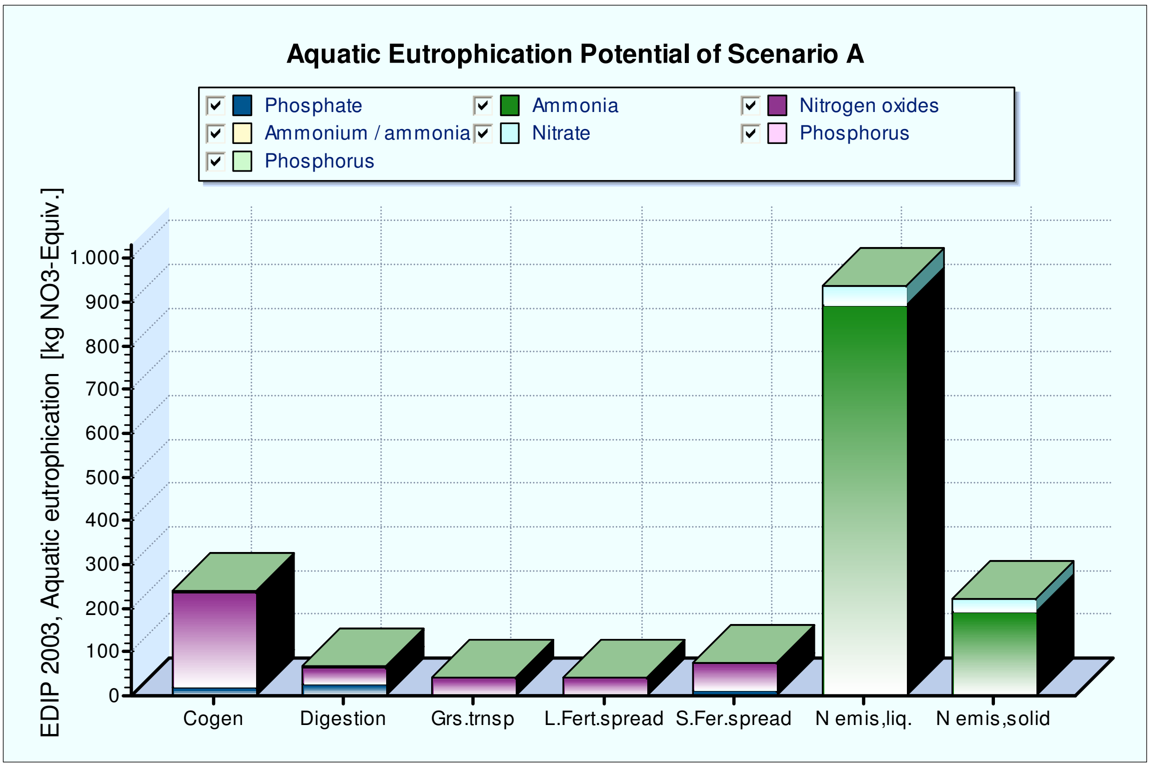


Figure I.18. Aquatic eutrophication potential of Scenario A.

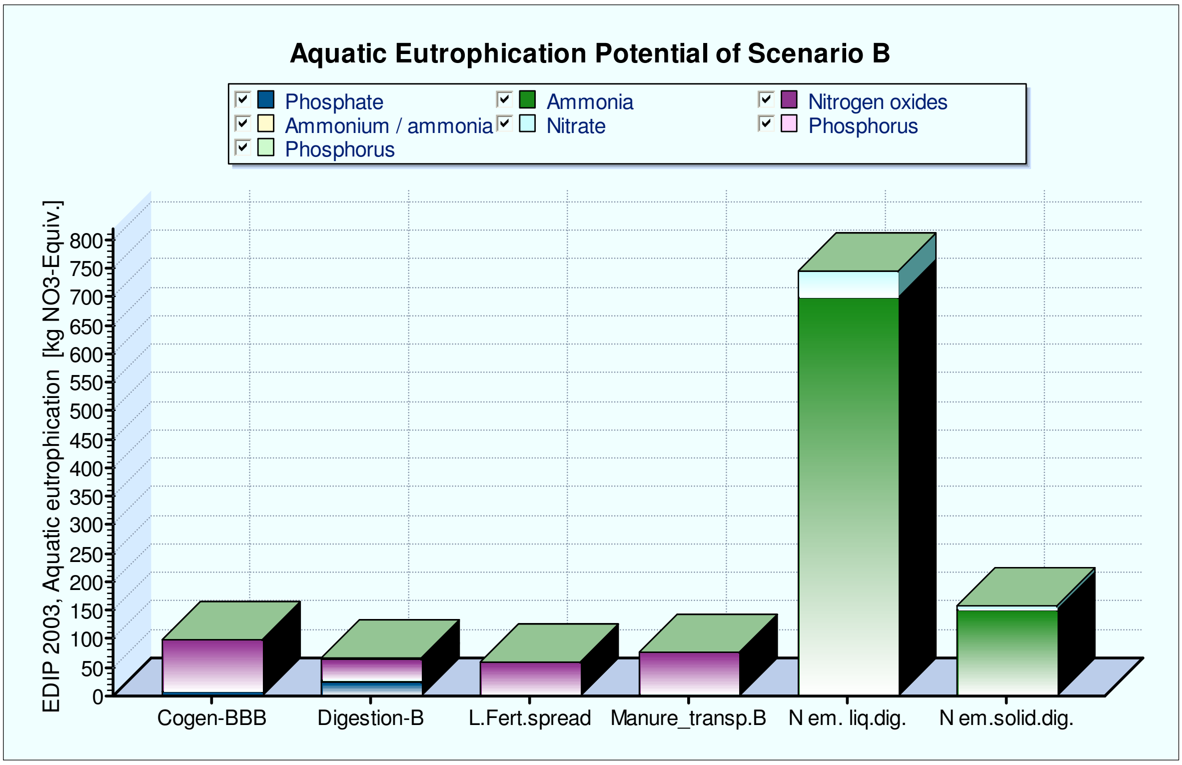


Figure I.19. Aquatic eutrophication potential of Scenario B.

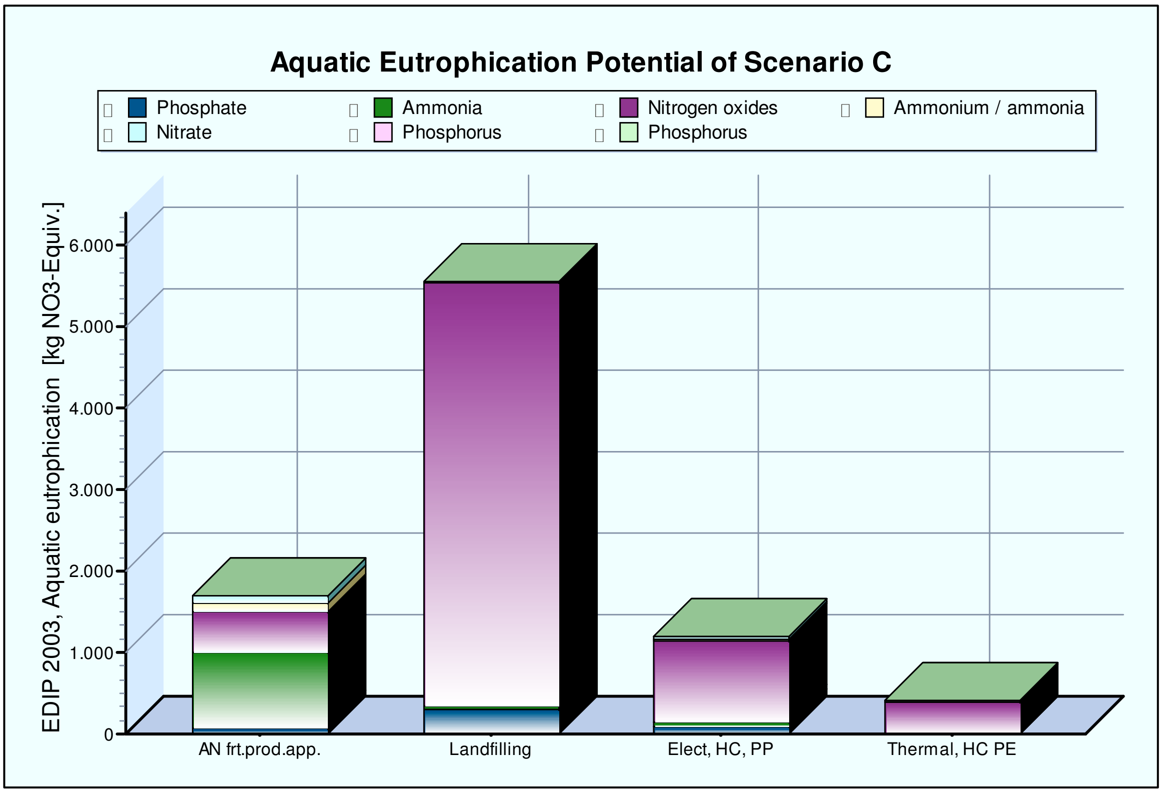


Figure I.20. Aquatic eutrophication potential of Scenario C.

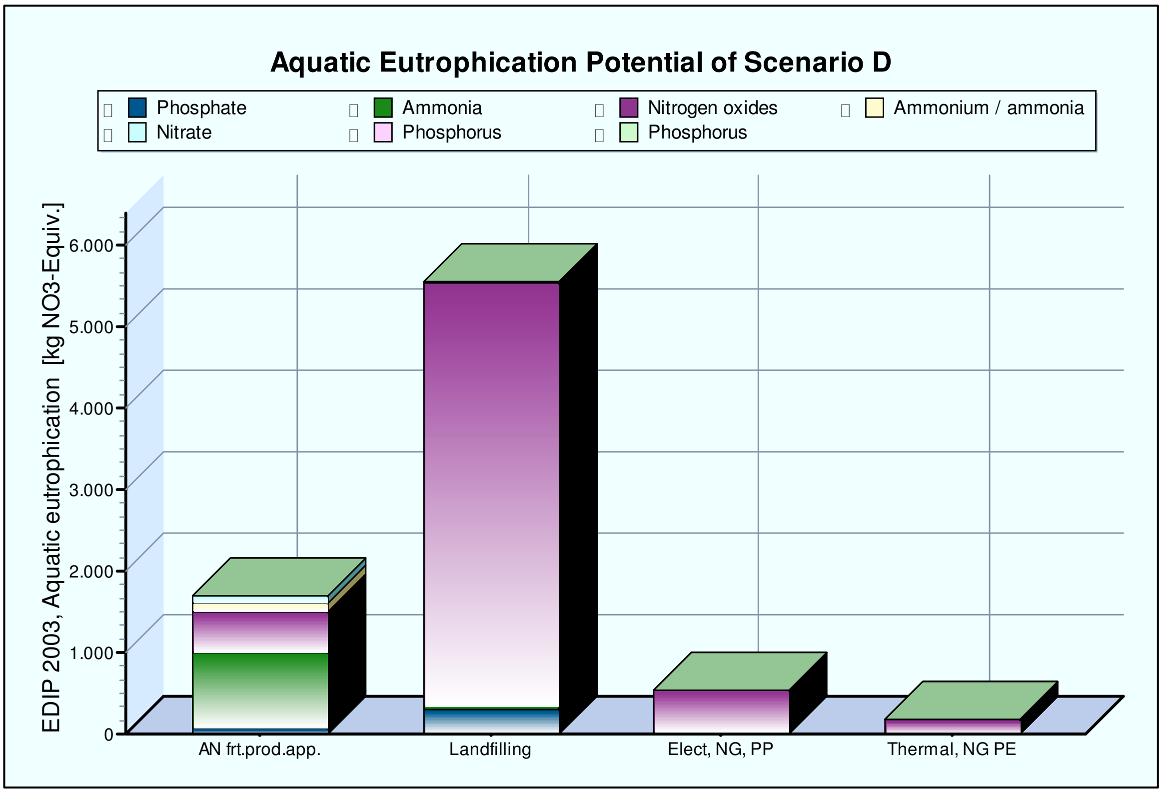


Figure I.21. Aquatic eutrophication potential of Scenario D.

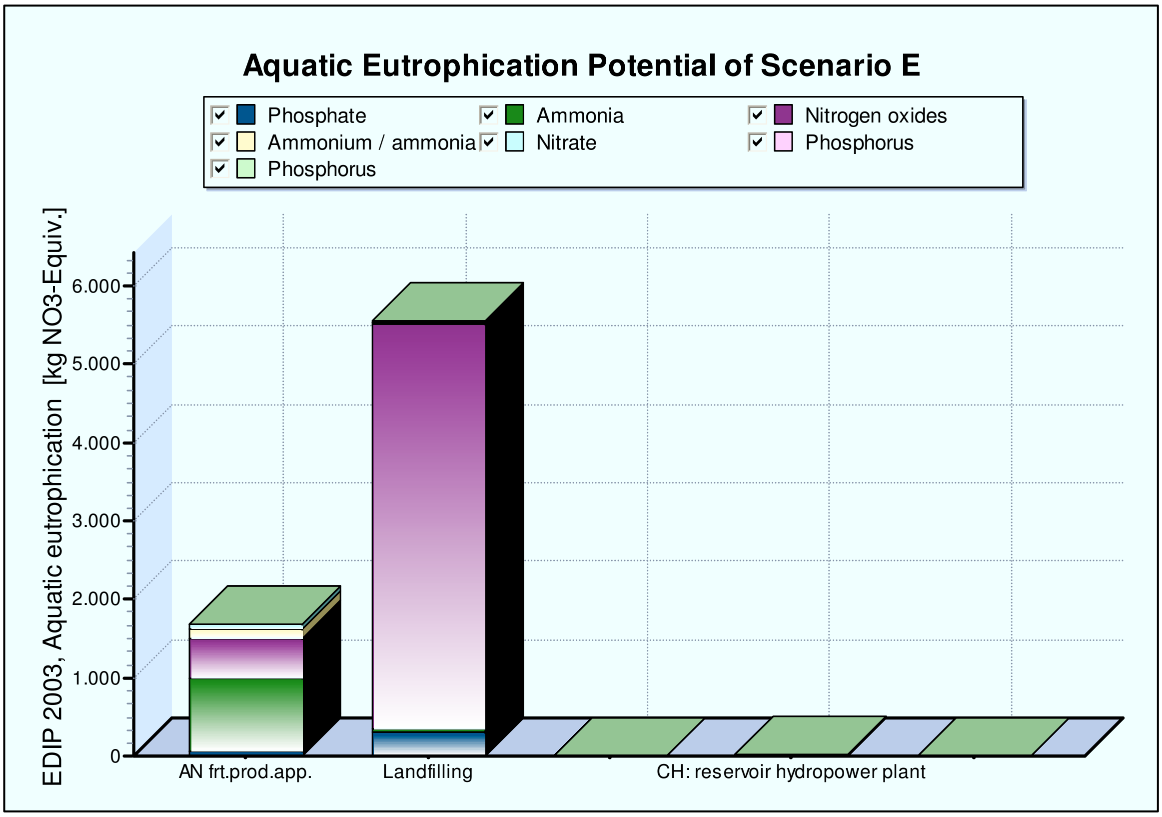


Figure I.22. Aquatic eutrophication potential of Scenario E.

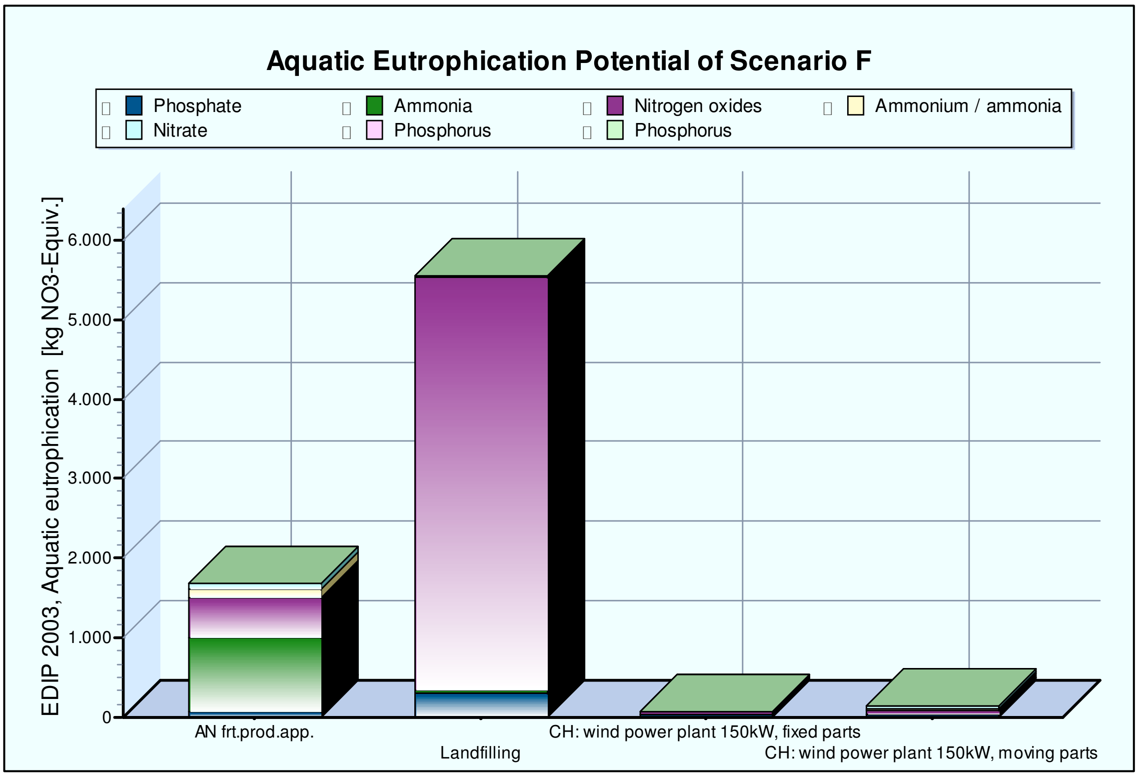


Figure I.23. Aquatic eutrophication potential of Scenario F.

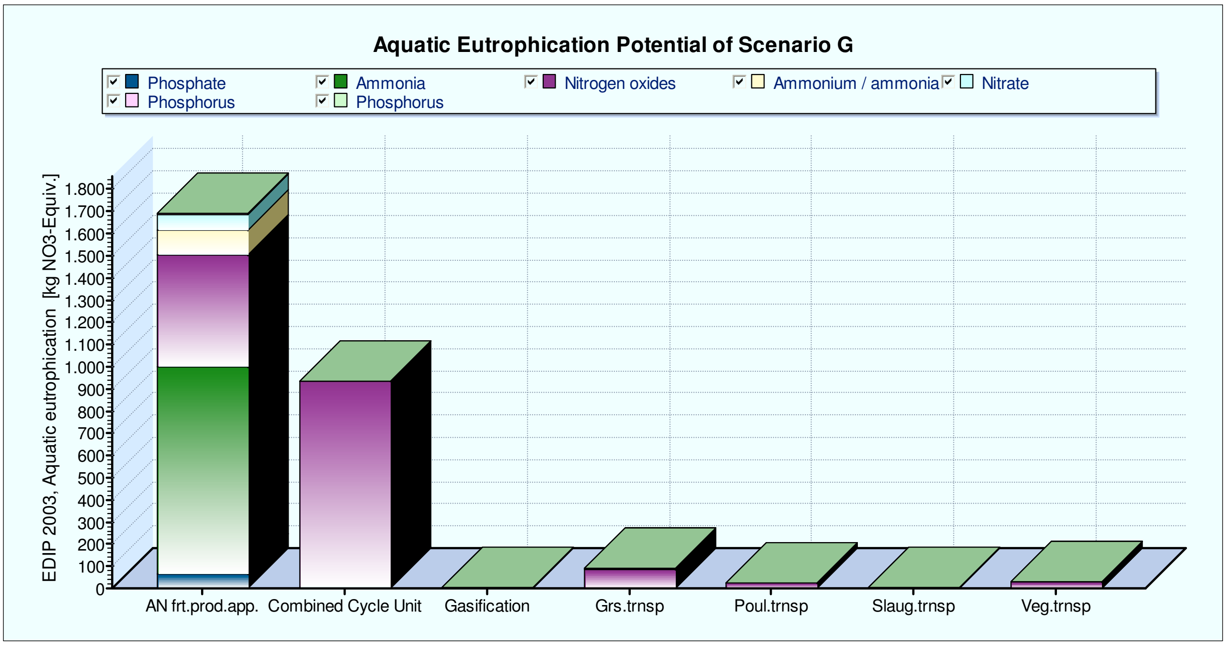


Figure I.24. Aquatic eutrophication potential of Scenario G.

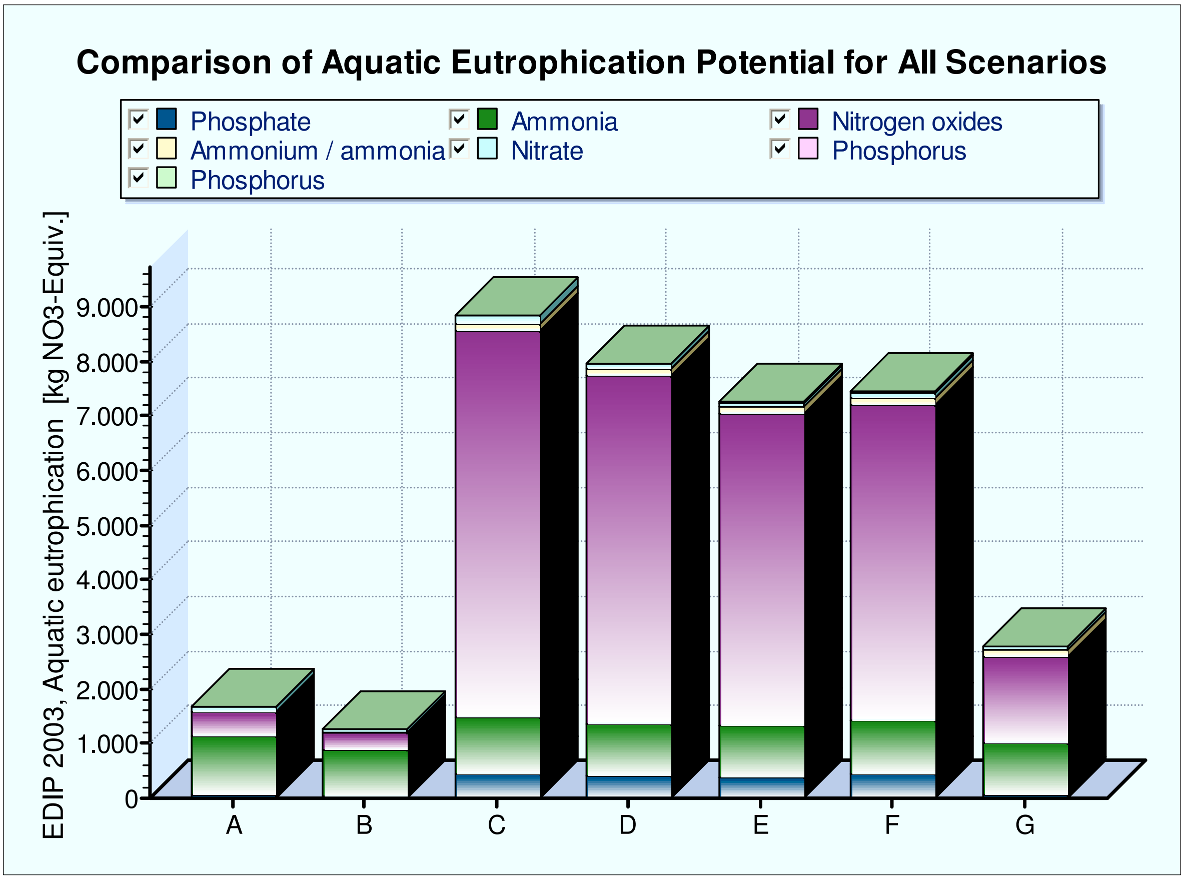


Figure I.25. Comparison of aquatic eutrophication potential of all scenarios.

The terrestrial eutrophication potential of all scenarios are given and compared below.

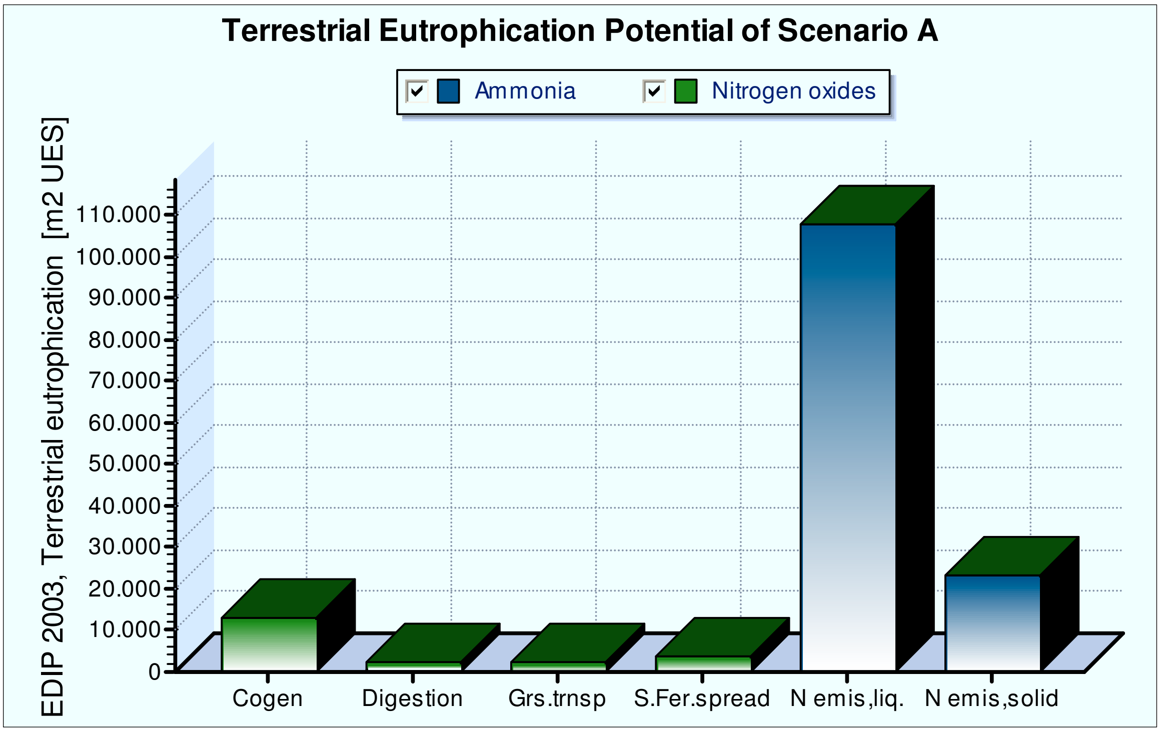


Figure I.26. Terrestrial eutrophication potential of Scenario A.

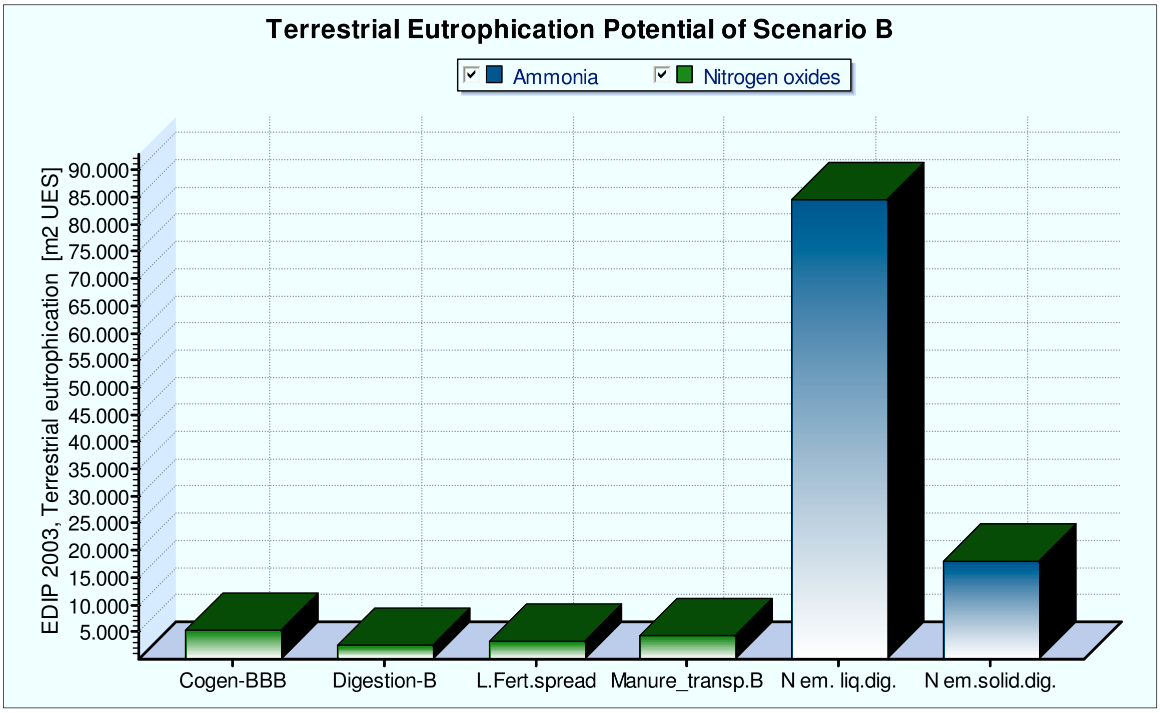


Figure I.27. Terrestrial eutrophication potential of Scenario B.

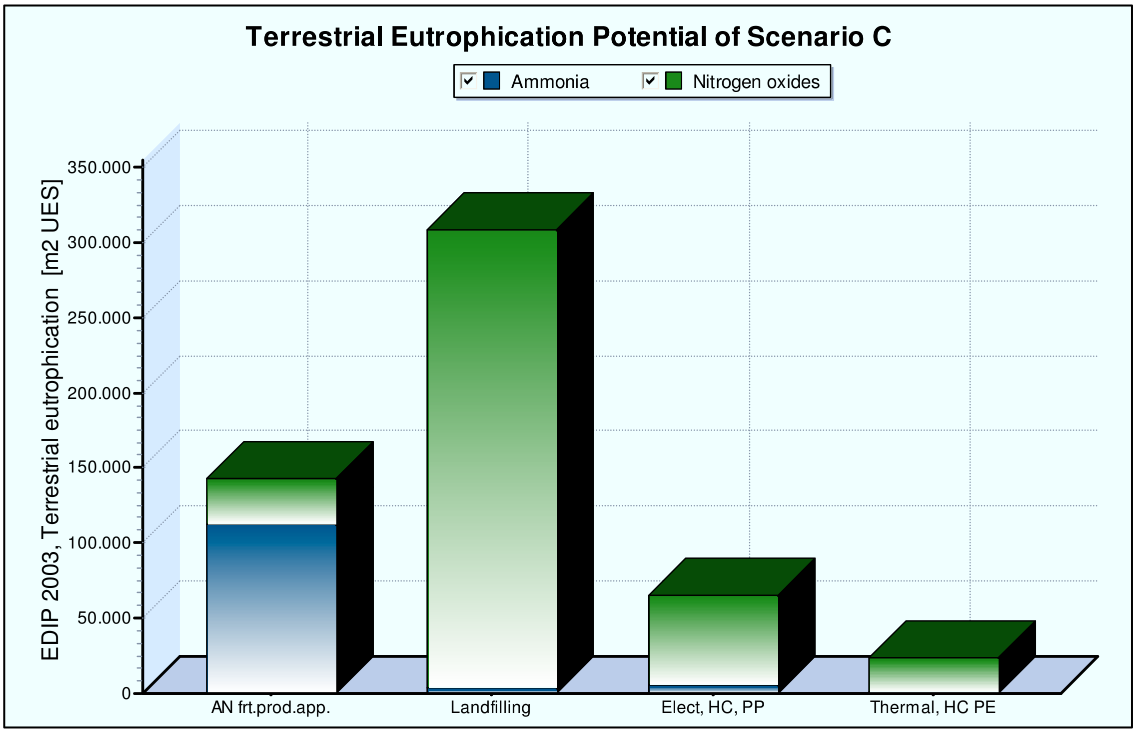


Figure I.28. Terrestrial eutrophication potential of Scenario C.

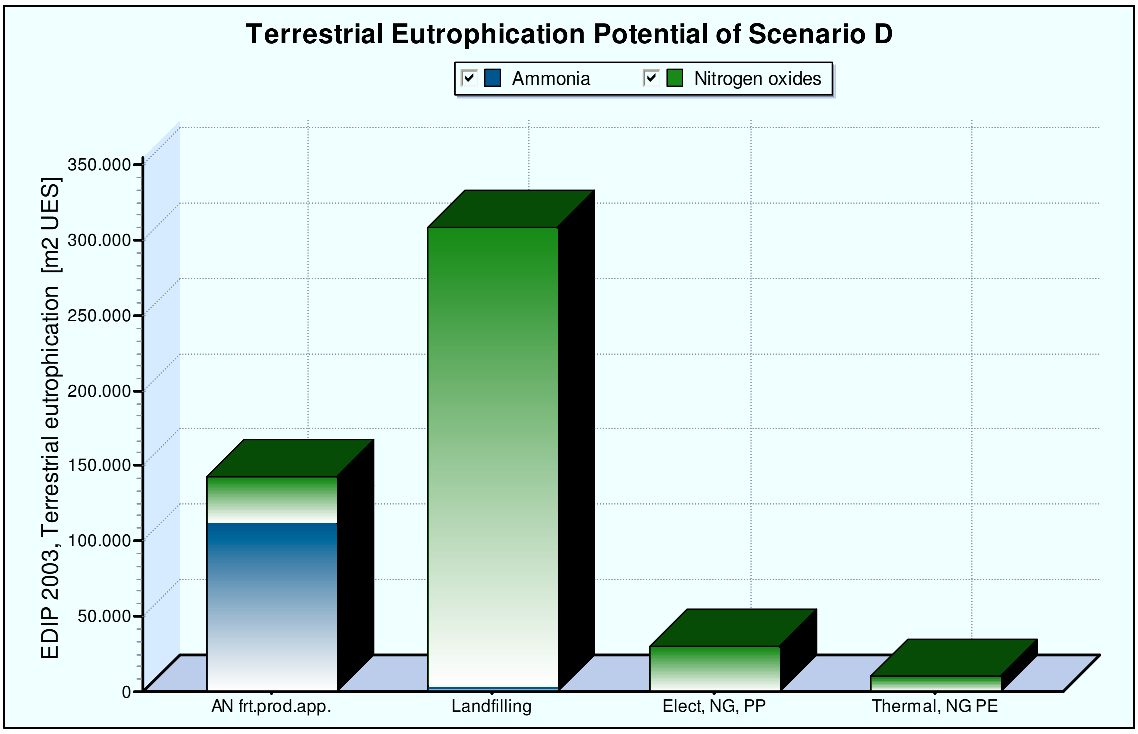


Figure I.29. Terrestrial eutrophication potential of Scenario D.

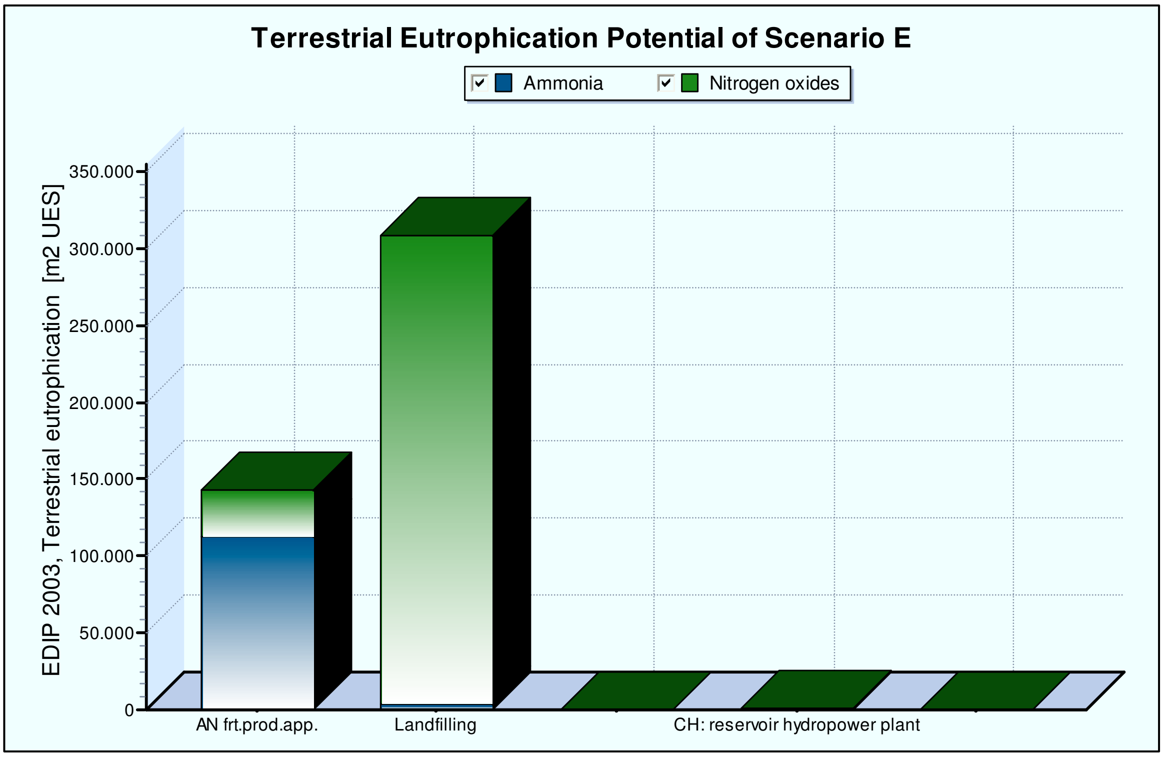


Figure I.30. Terrestrial eutrophication potential of Scenario E.

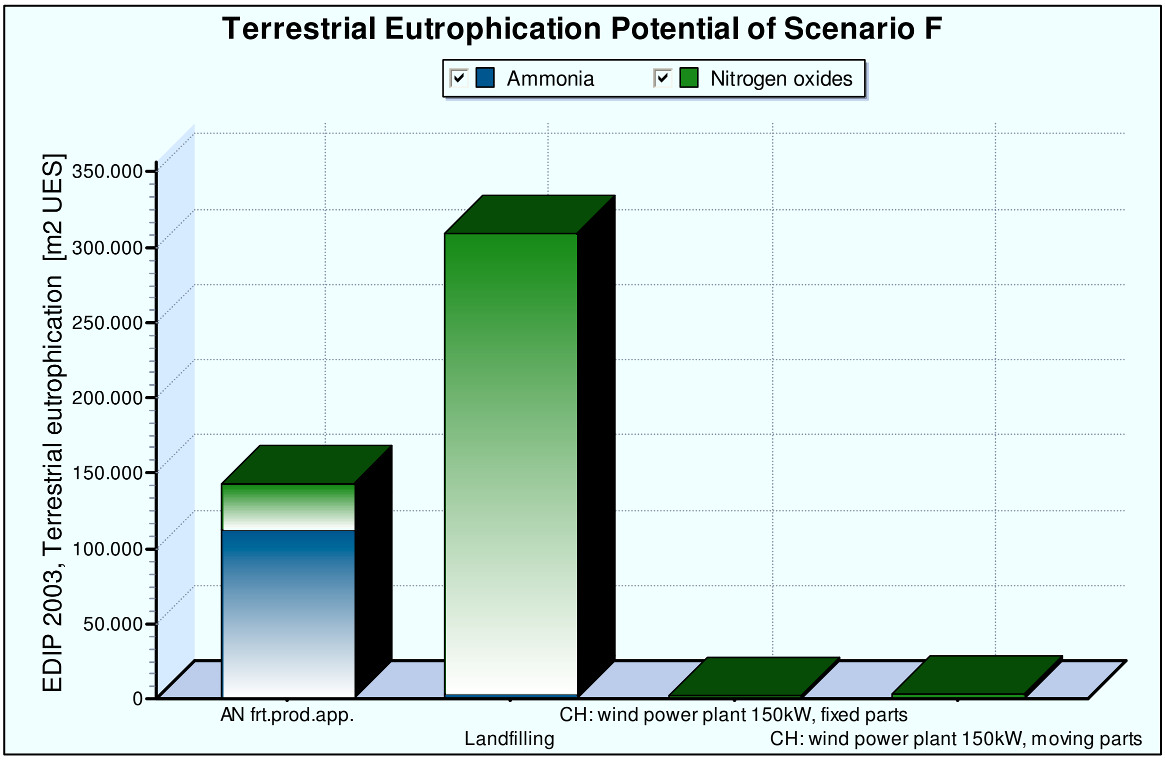


Figure I.31. Terrestrial eutrophication potential of Scenario F.

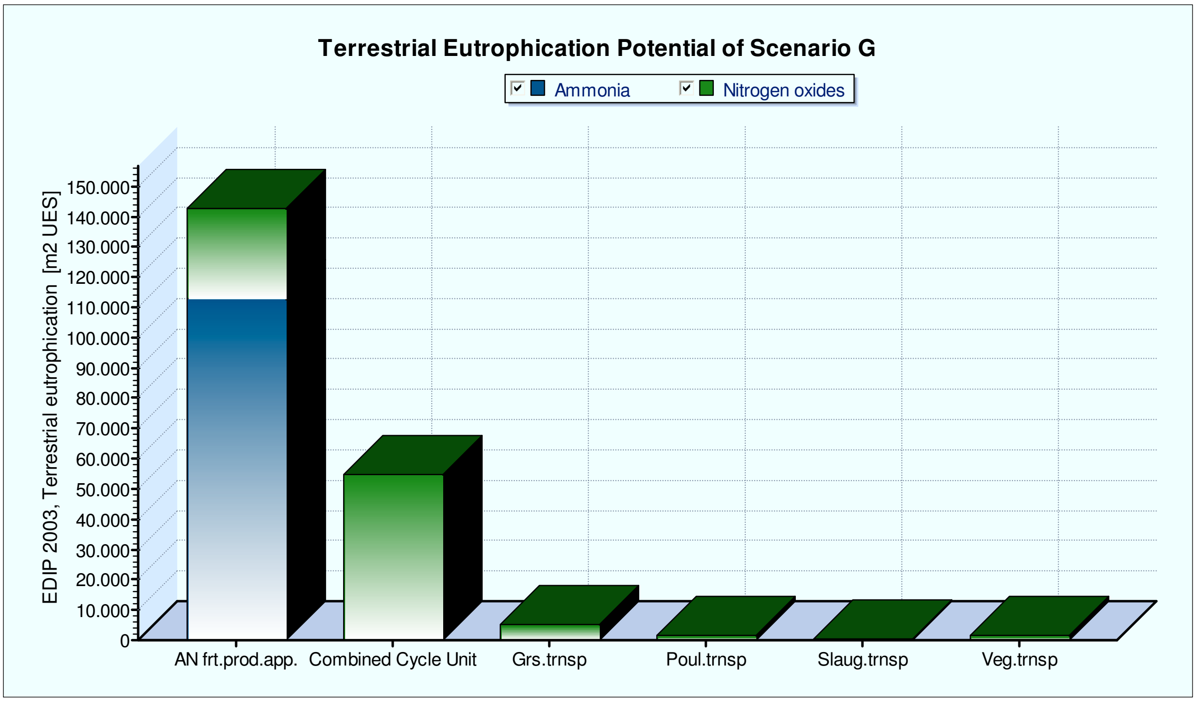


Figure I.32. Terrestrial eutrophication potential of Scenario G.

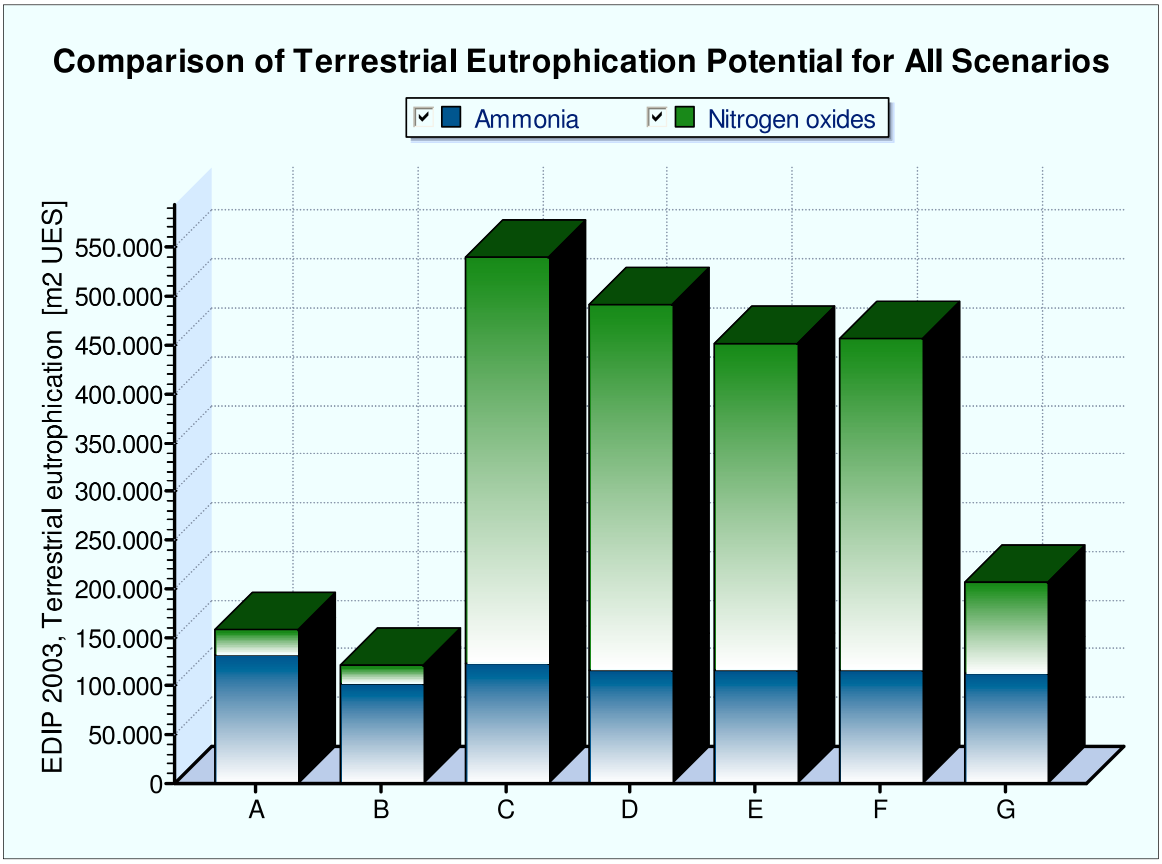


Figure I.33. Comparison of Terrestrial eutrophication potential of all Scenarios.

The photochemical ozone formation - impact on vegetation potential of all scenarios are given and compared below.

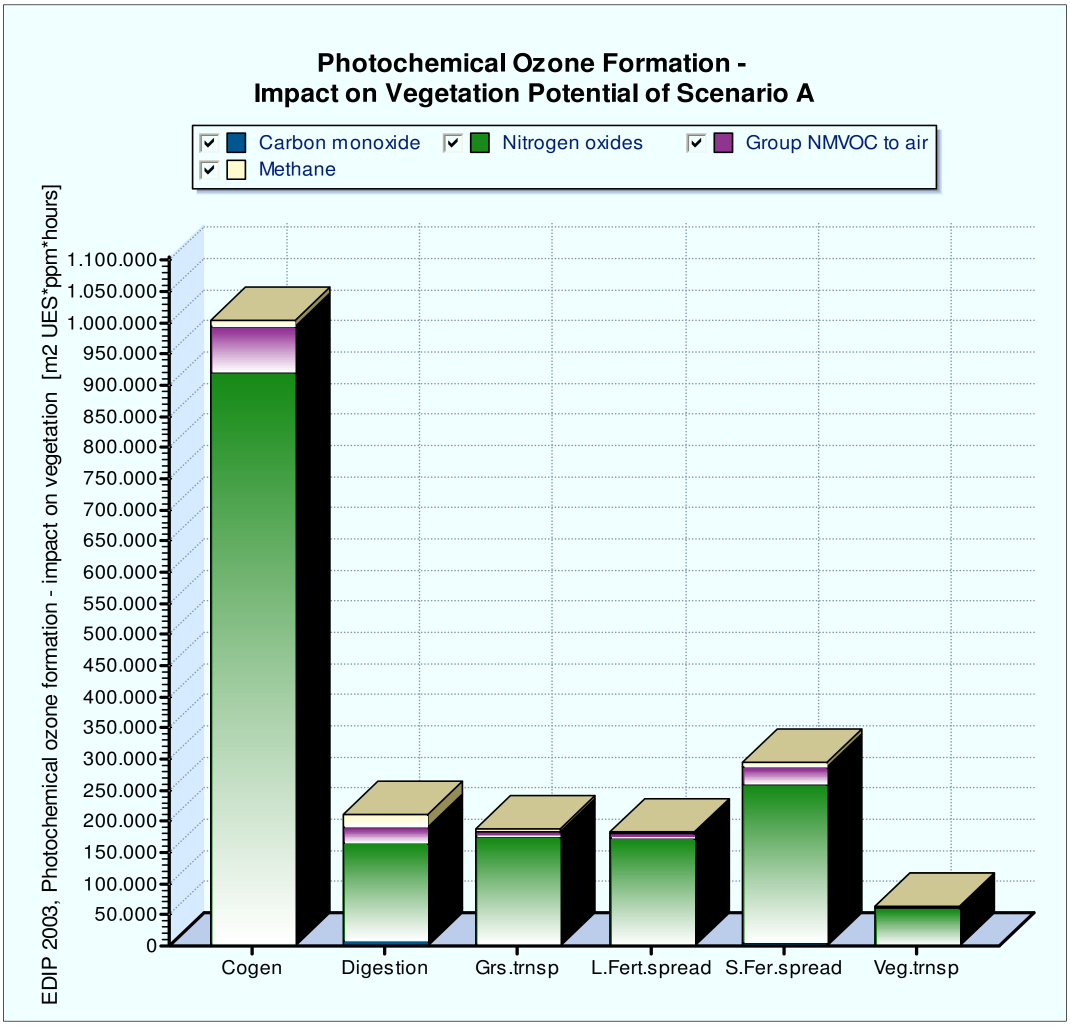


Figure I.34. Photochemical ozone formation - impact on vegetation potential of Scenario A.

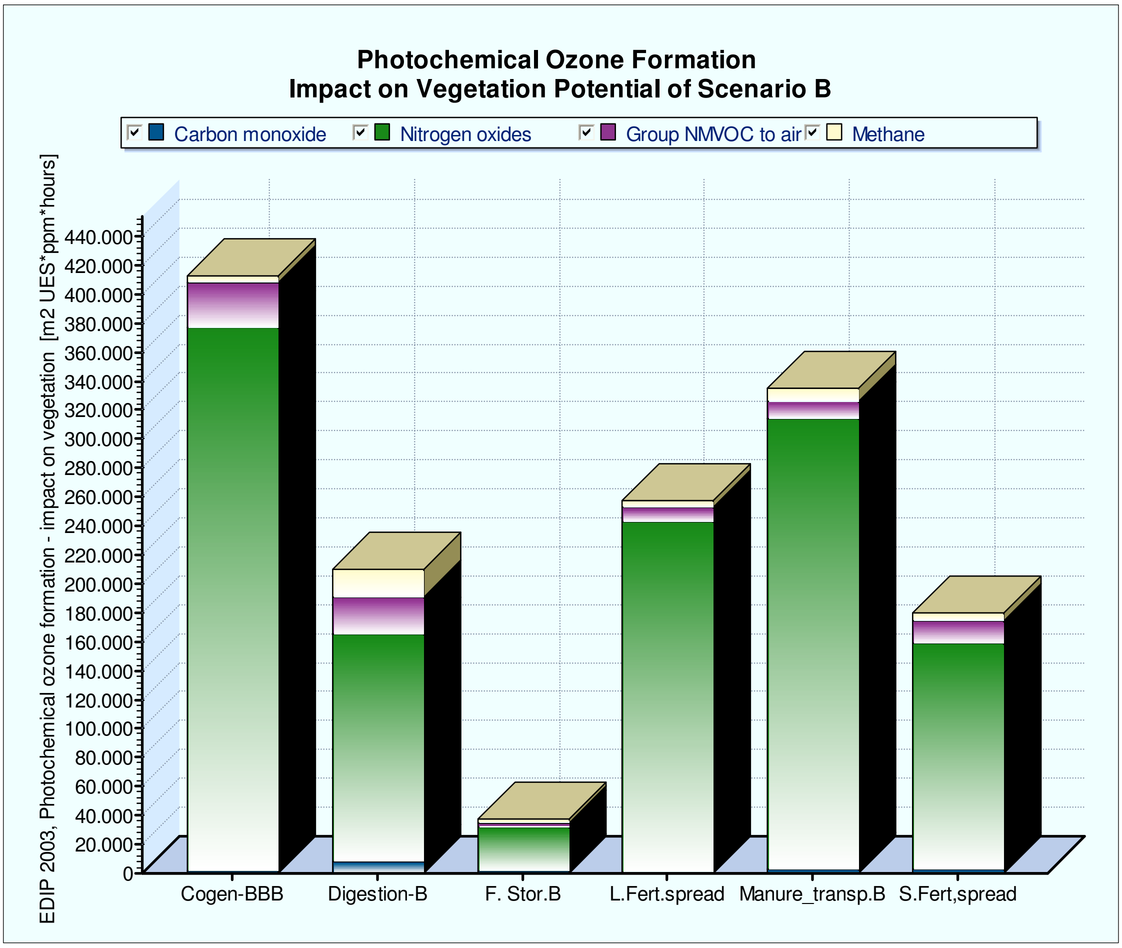


Figure I.35. Photochemical ozone formation - impact on vegetation potential of Scenario B.

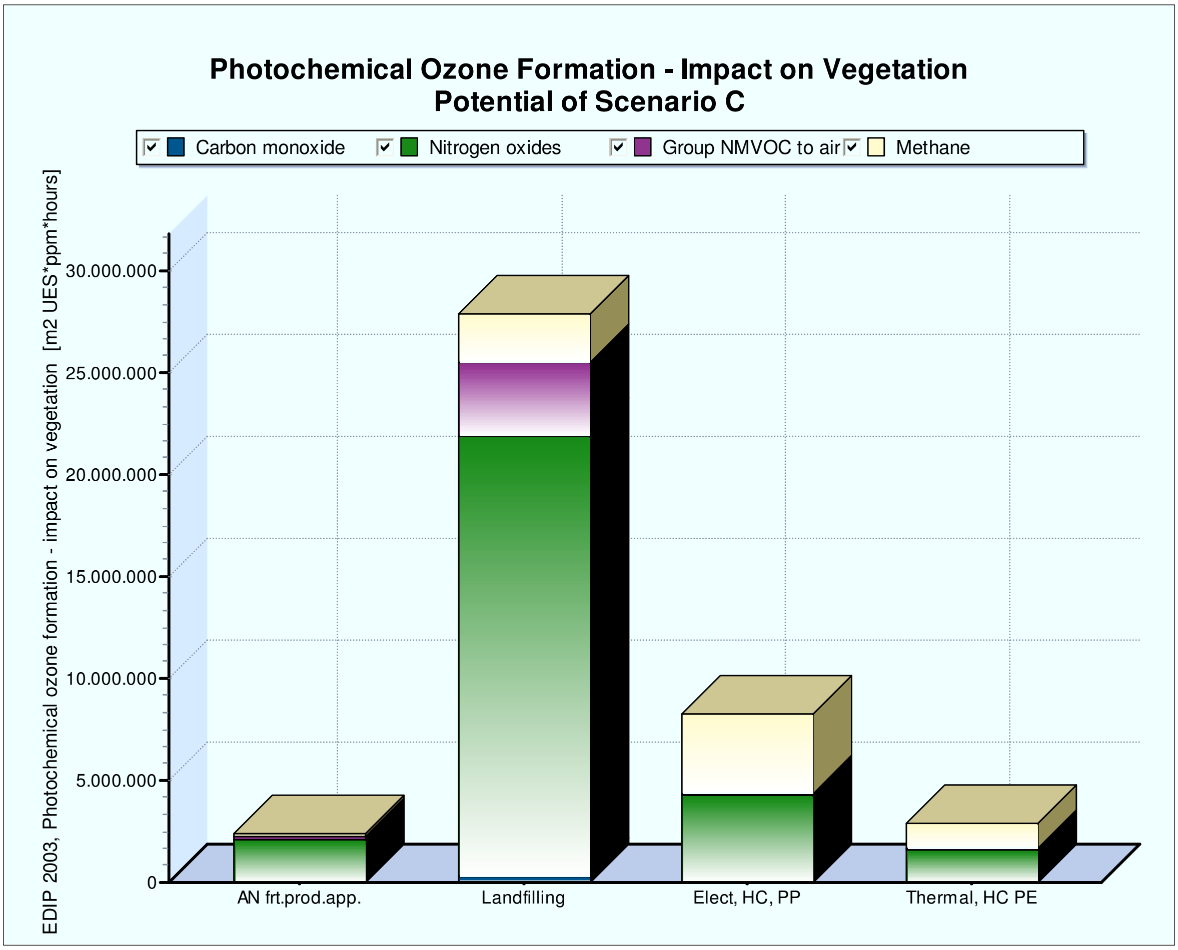
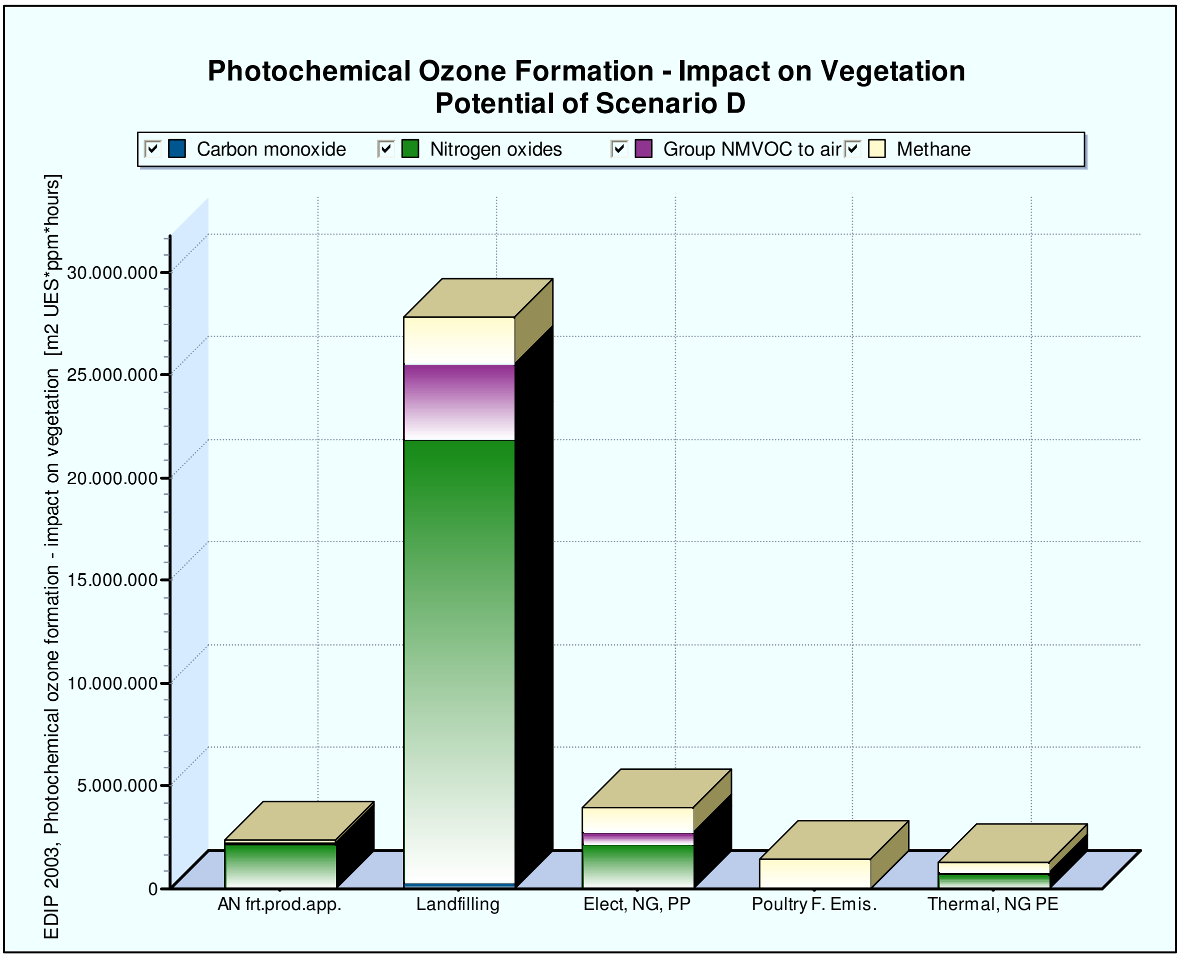


Figure I.36. Photochemical ozone formation - impact on vegetation potential of Scenario C.



.

Figure I.37. Photochemical ozone formation - impact on vegetation potential of Scenario D.

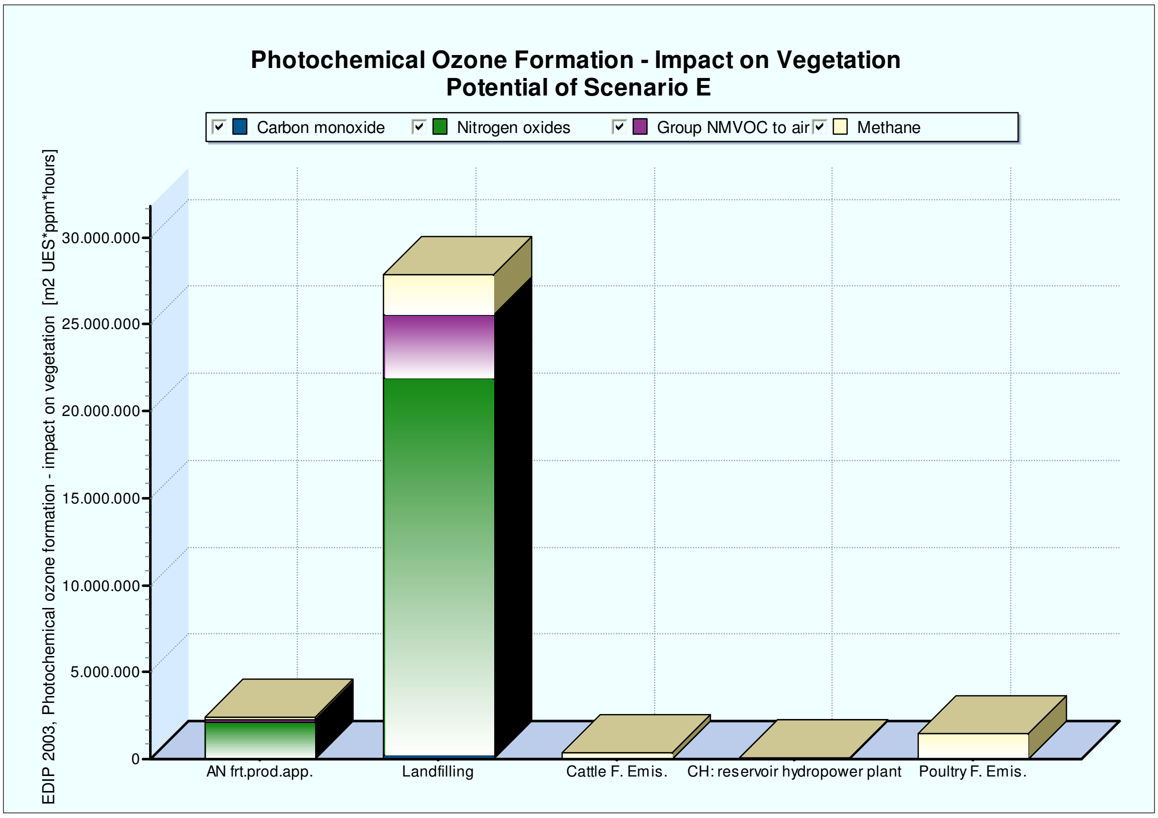


Figure I.38. Photochemical ozone formation - impact on vegetation potential of Scenario E.

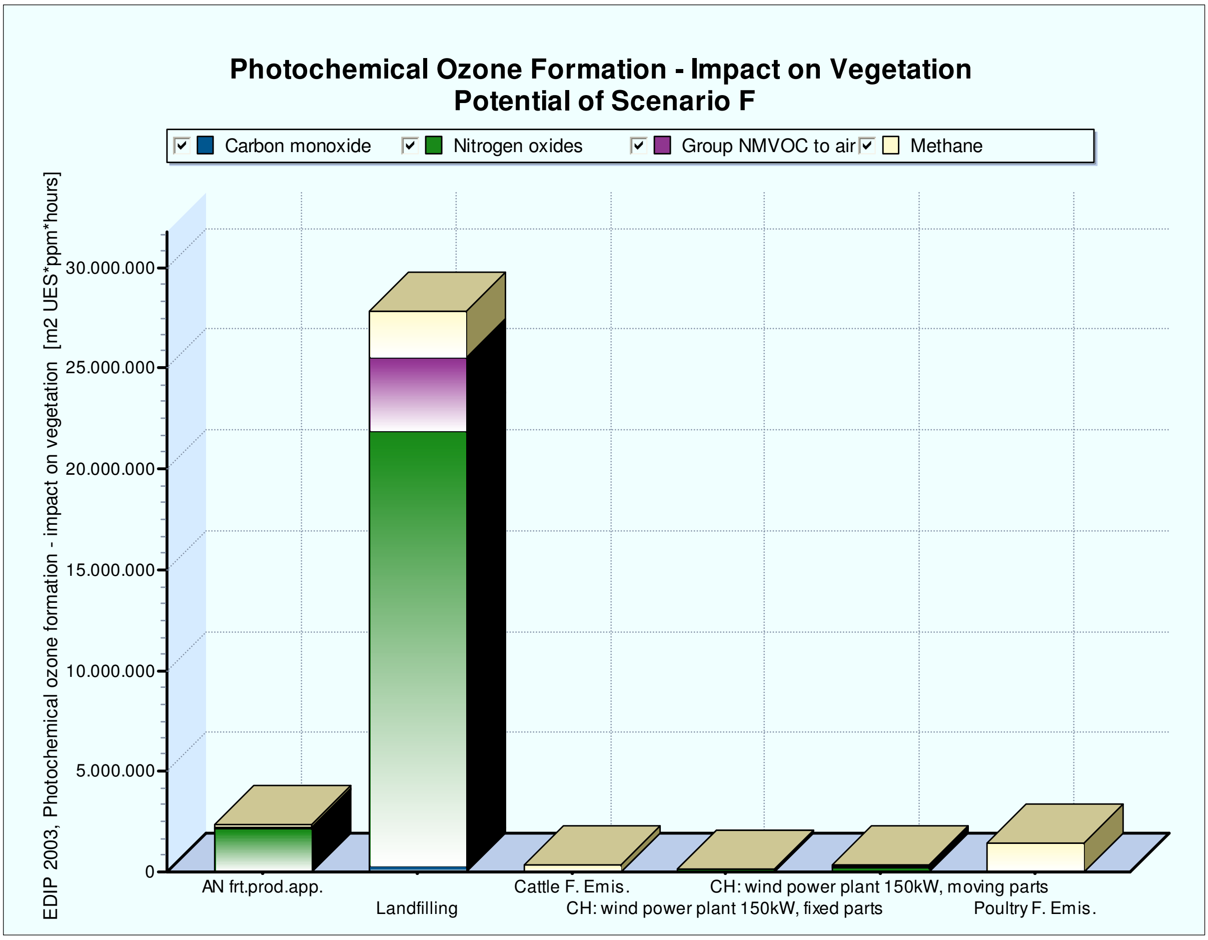


Figure I.39. Photochemical ozone formation - impact on vegetation potential of Scenario F.

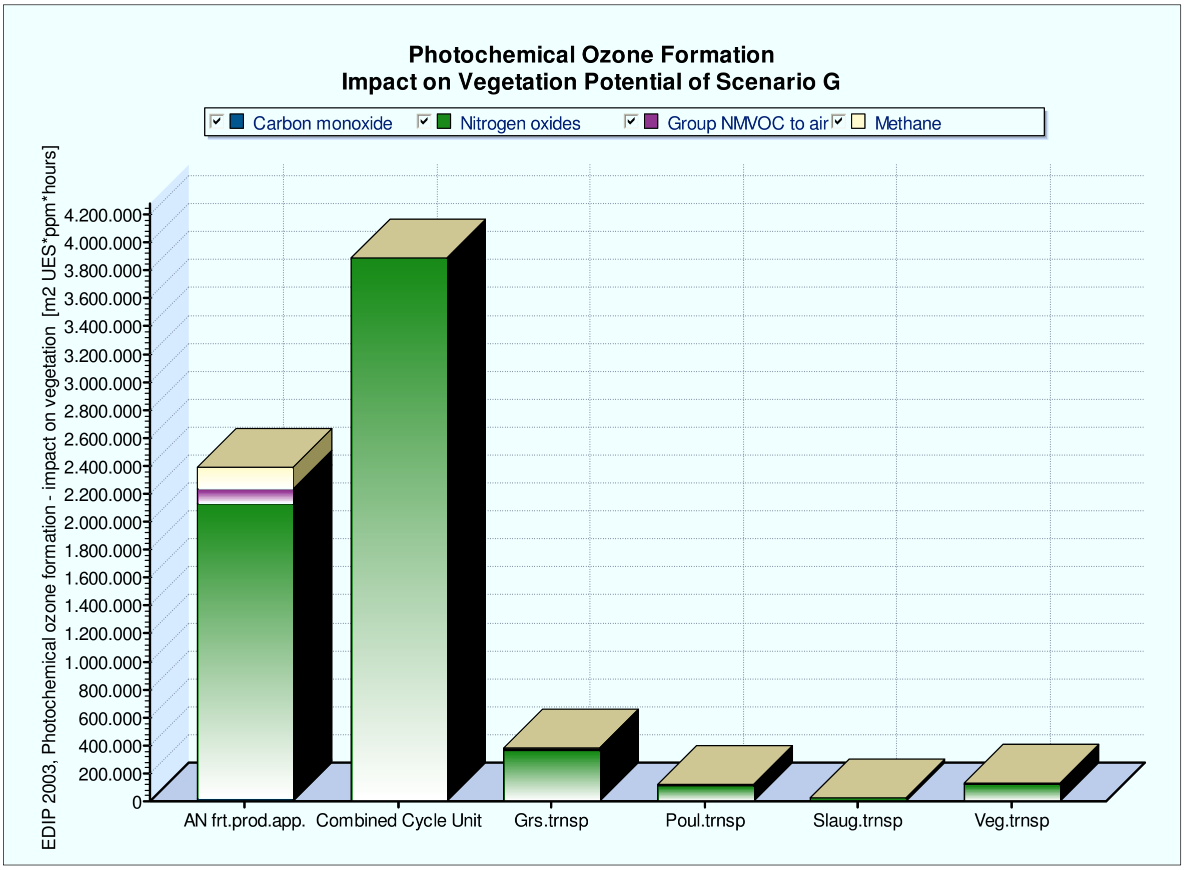


Figure I.40. Photochemical ozone formation - impact on vegetation potential of Scenario G.

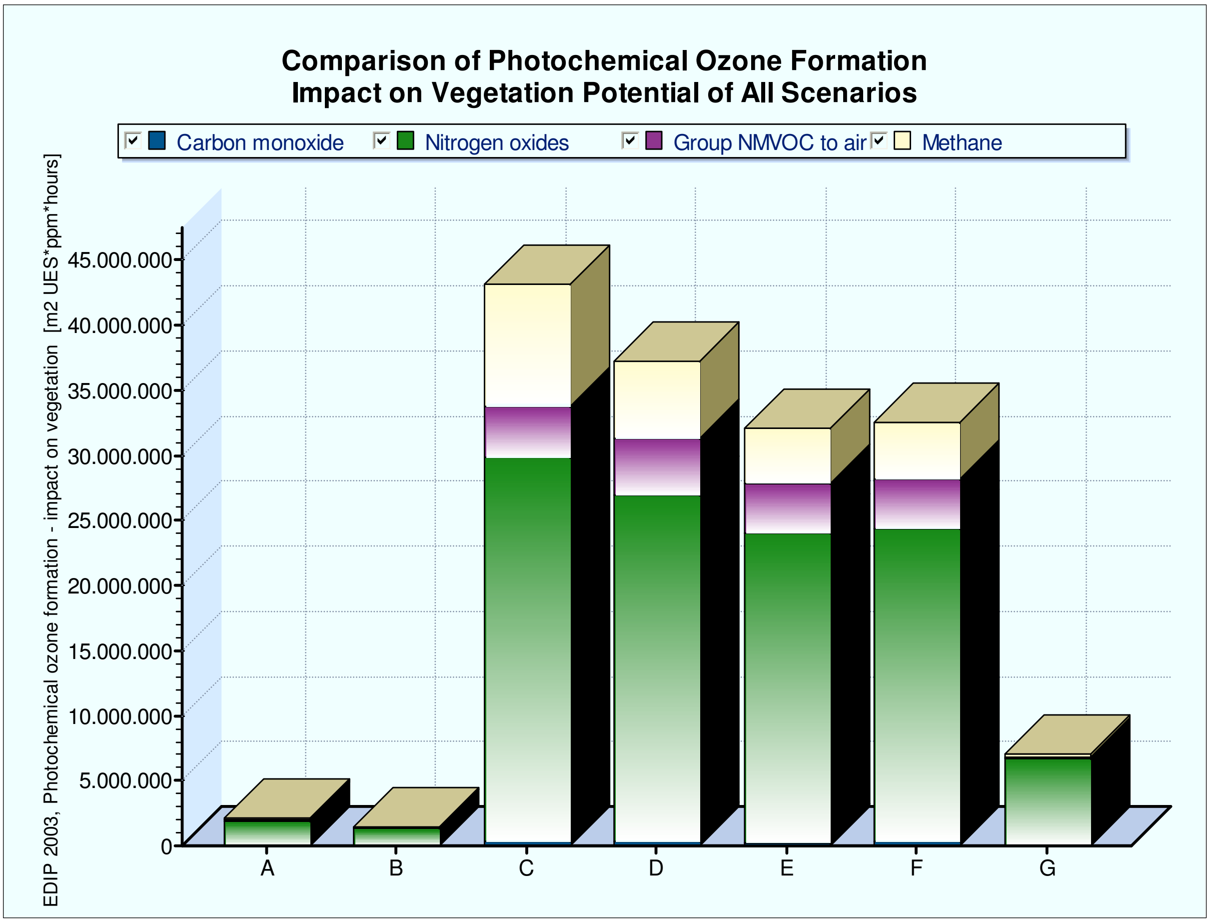


Figure I.41. Comparison of Photochemical ozone formation - impact on vegetation potential of all Scenarios.

The stratospheric ozone depletion potential of all scenarios are given and compared below.

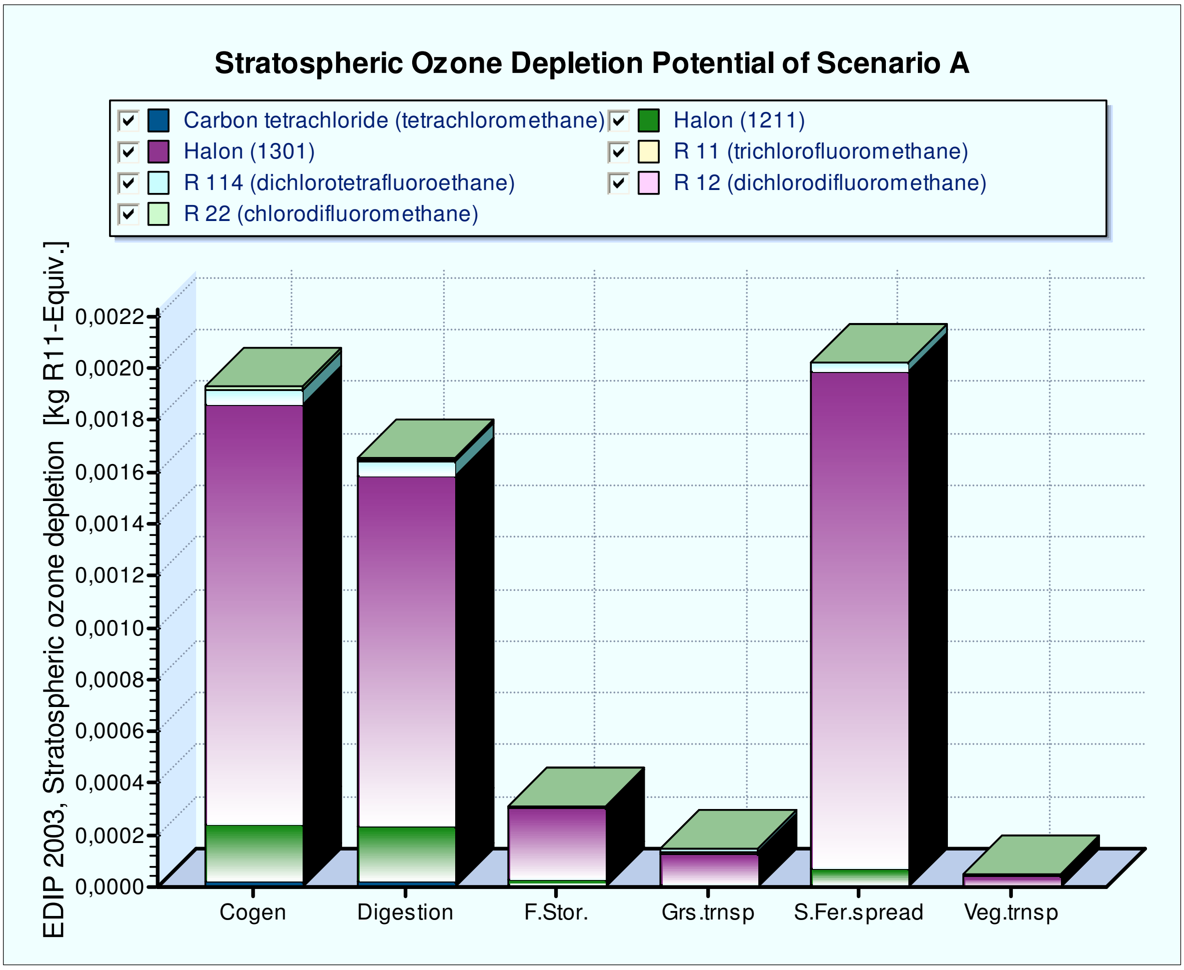


Figure I.42. Stratospheric ozone depletion potential of Scenario A.

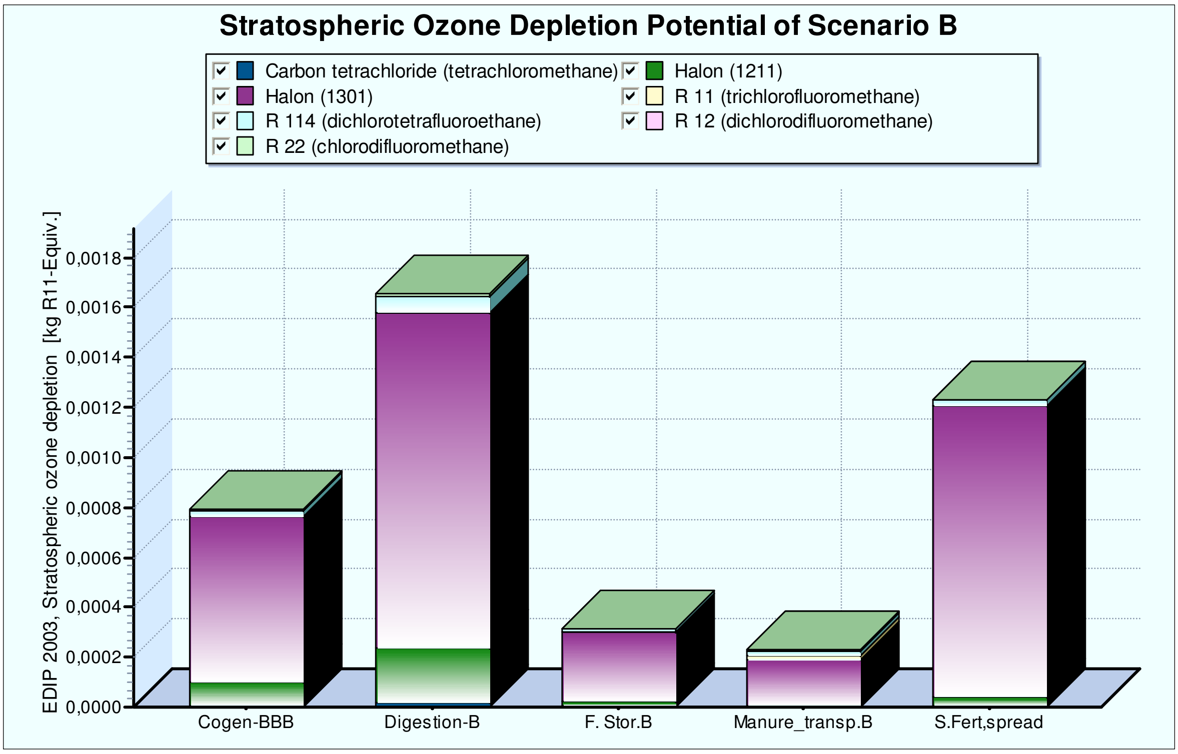


Figure I.43. Stratospheric ozone depletion potential of Scenario B.

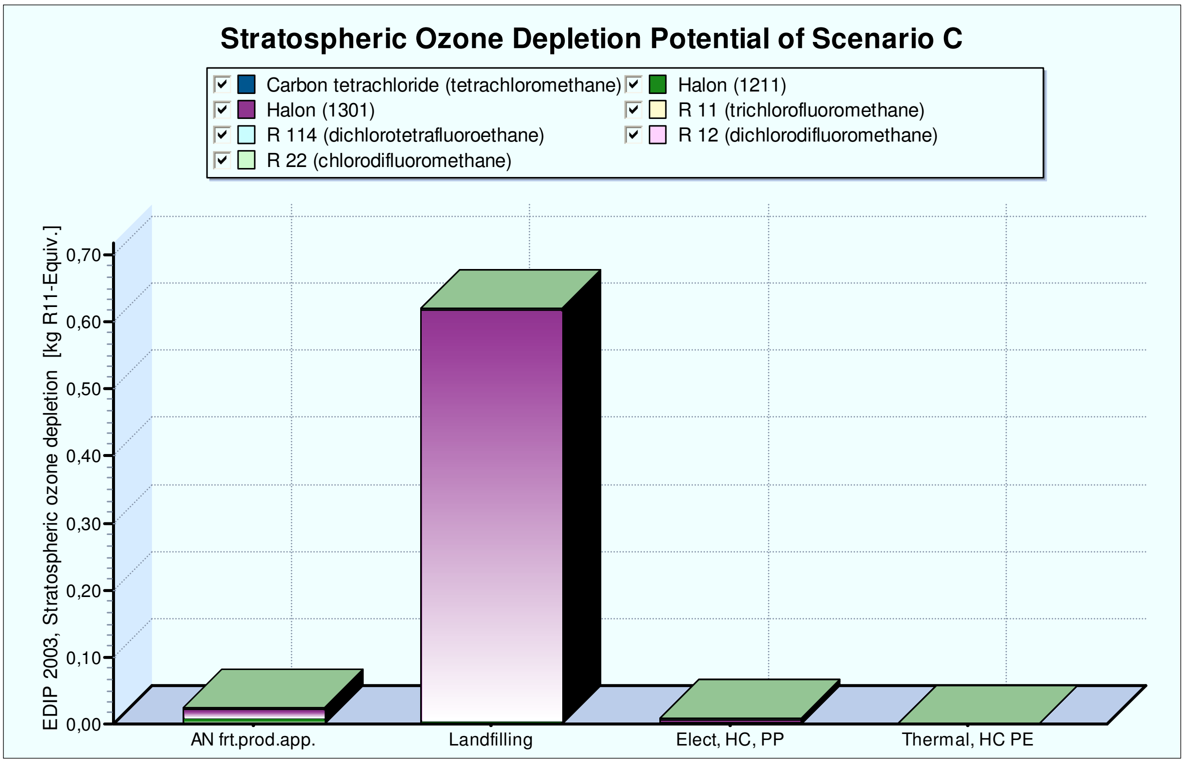


Figure I.44. Stratospheric ozone depletion potential of Scenario C.

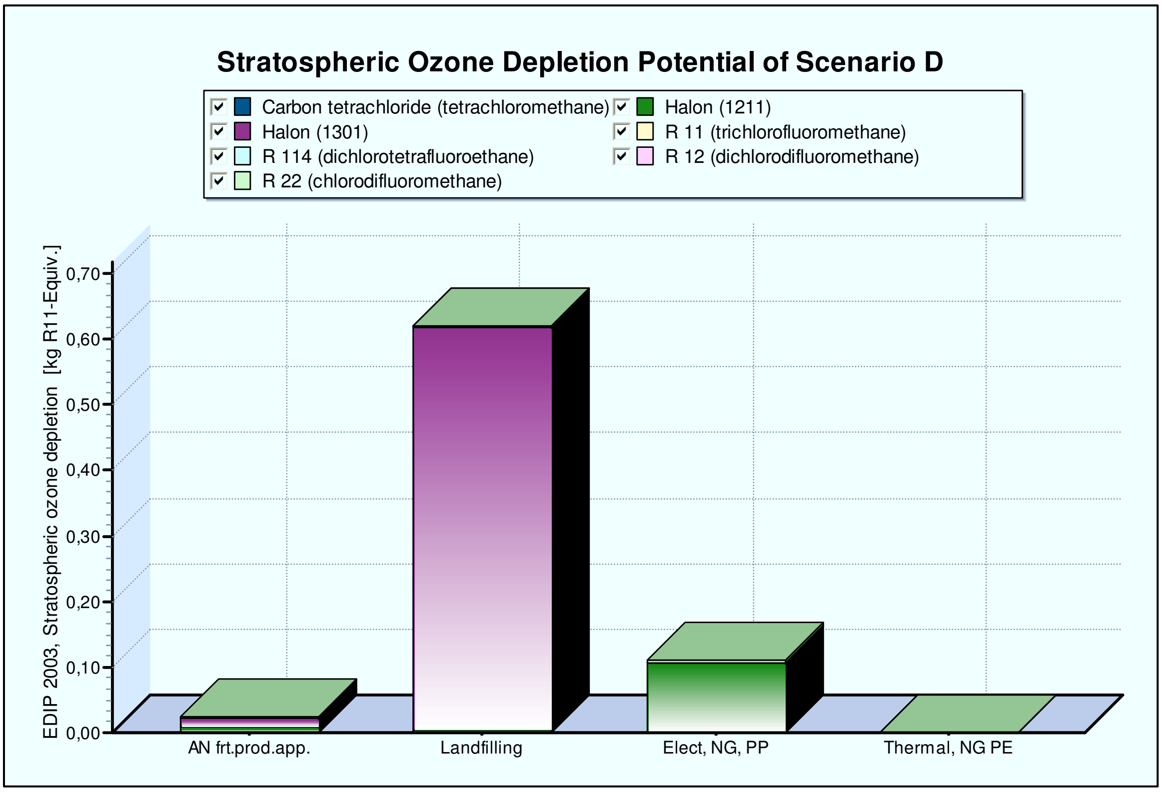


Figure I.45. Stratospheric ozone depletion potential of Scenario D.

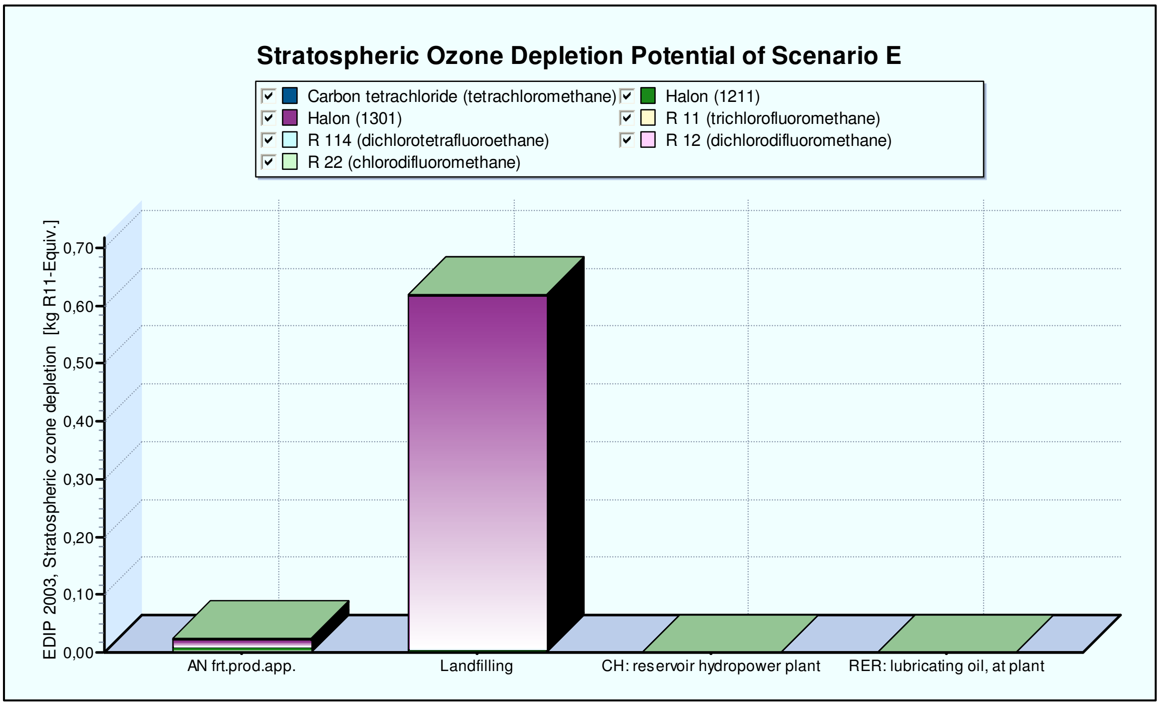


Figure I.46. Stratospheric ozone depletion potential of Scenario E.

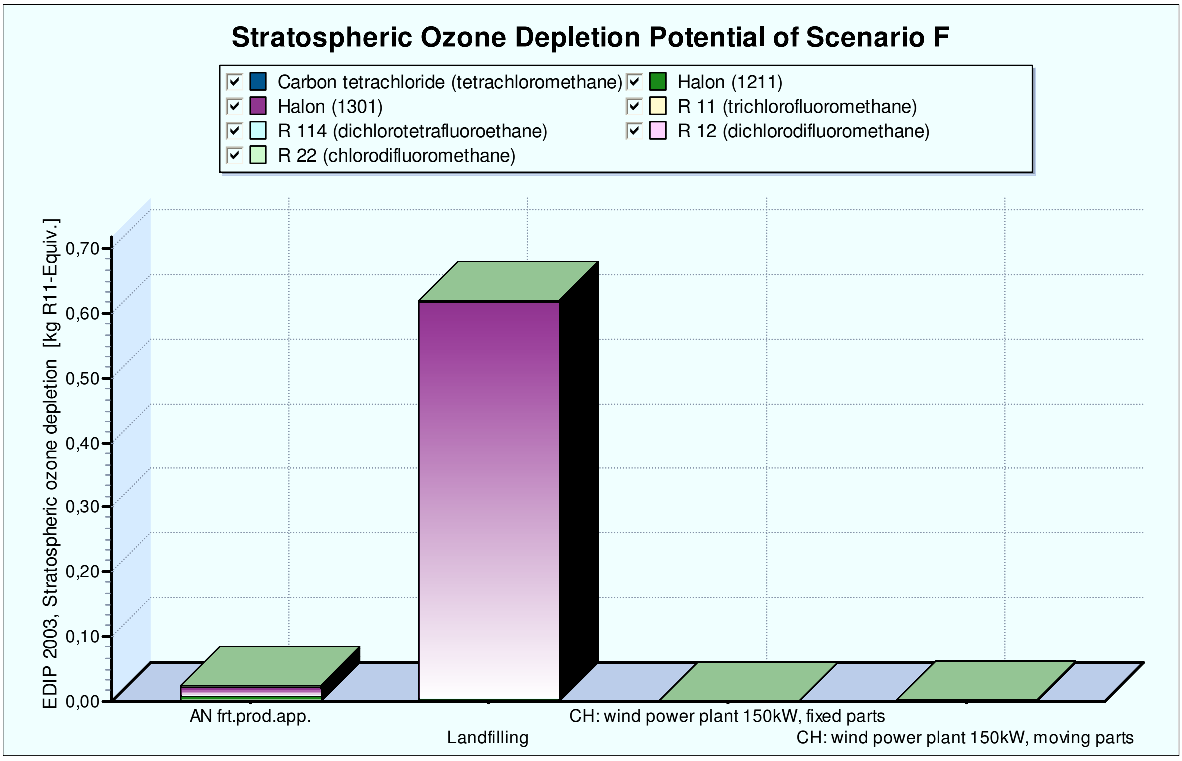


Figure I.47. Stratospheric ozone depletion potential of Scenario F.

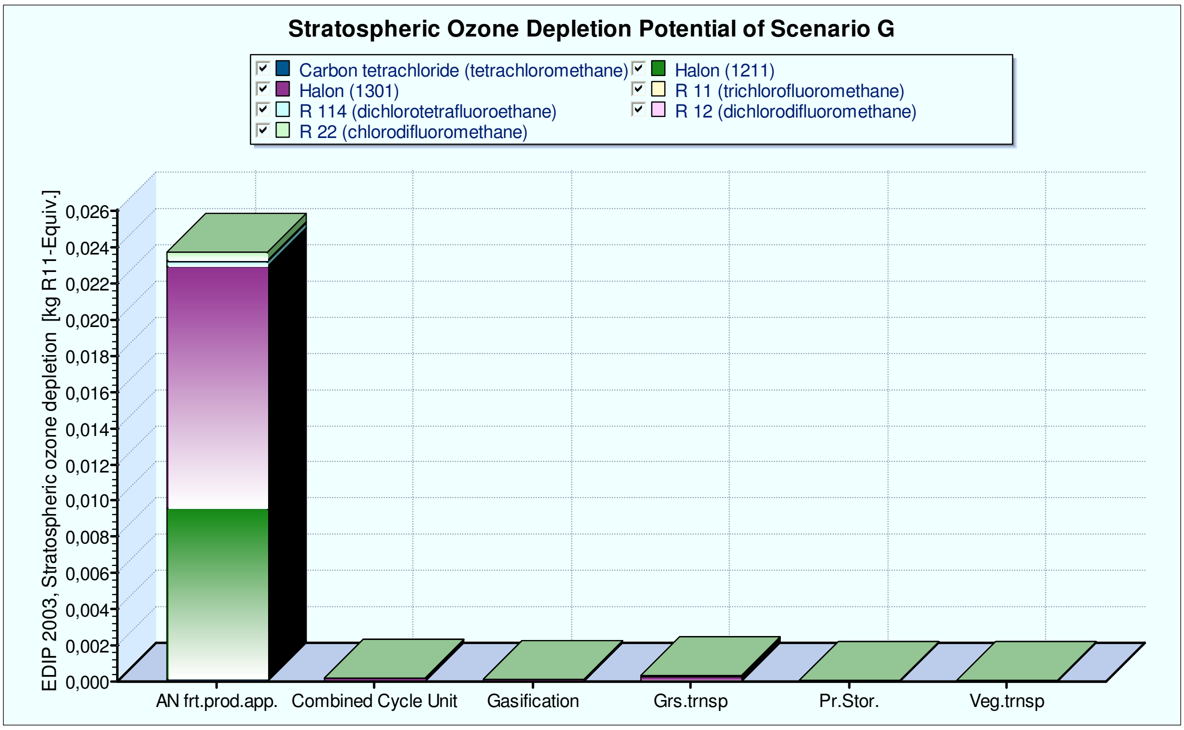


Figure I.48. Stratospheric ozone depletion potential of Scenario G.

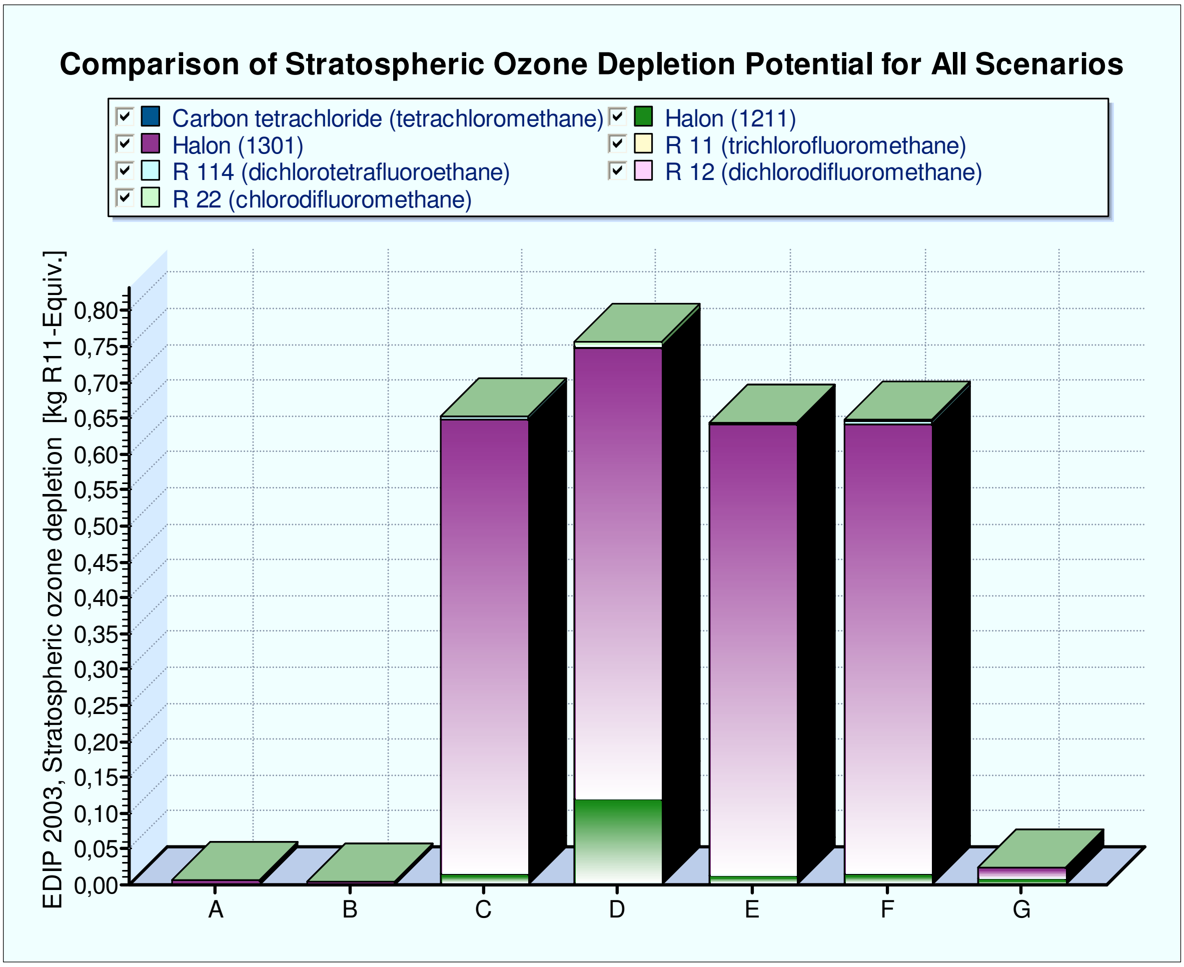
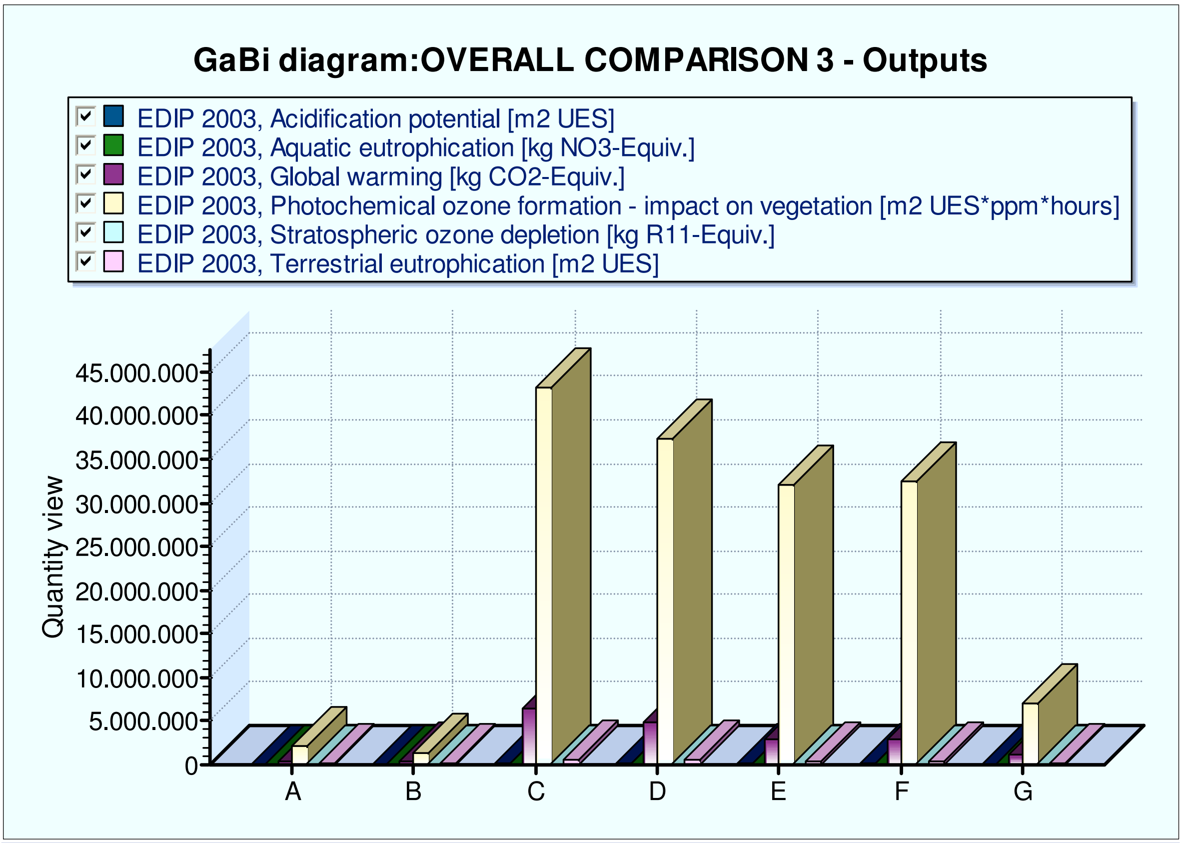


Figure I.49. Comparison of stratospheric ozone depletion potential of all scenarios.

The characterisation results of all scenarios are given and compared below.

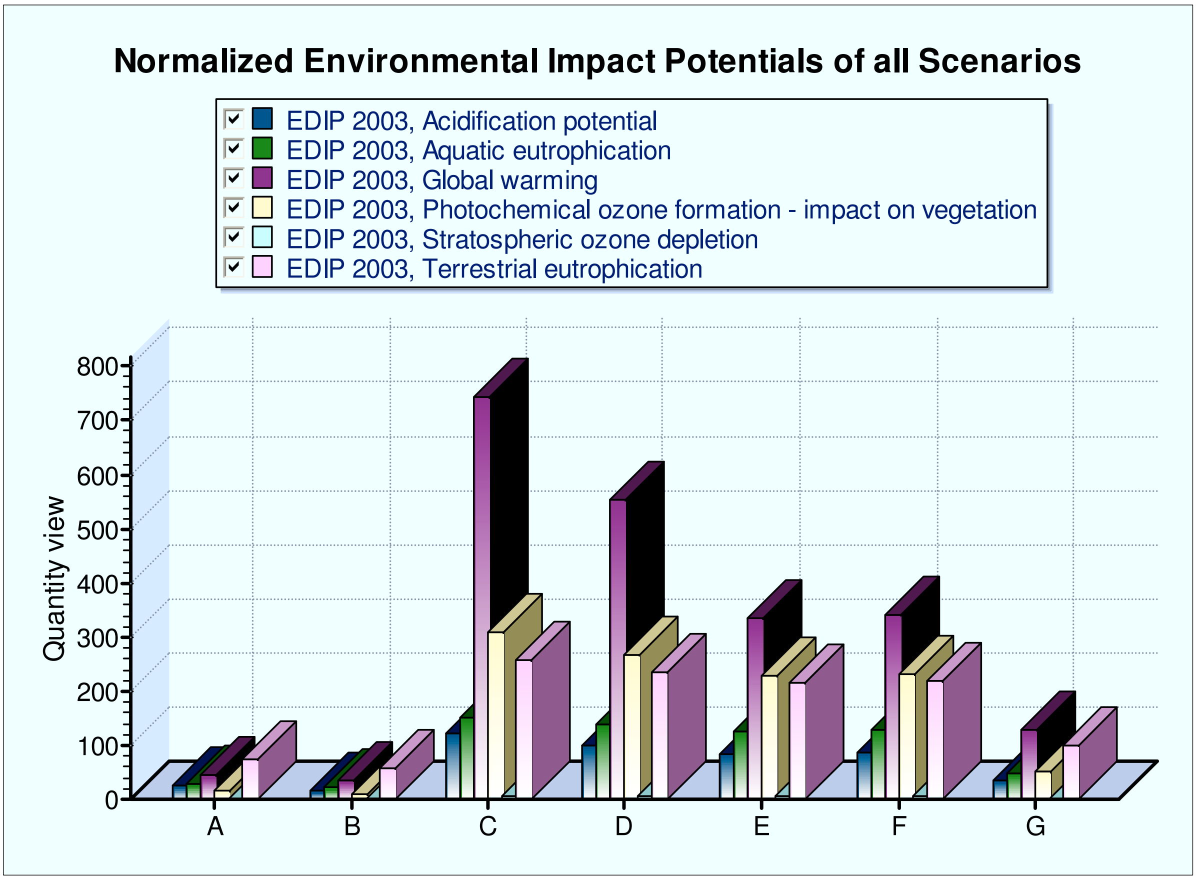


A: Pilot Plant/Waste Recipe
B: Pilot Plant/Cattle Manure
C: Coal PP
D: Natural Gas PP
E: Hydro PP
F: Wind PP
G: IGCC

Figure I.50. Characterisation results of all scenarios.

APPENDIX J– NORMALISATION RESULTS OF LCA ANALYSIS

The normalisation results of all scenarios are given and compared below.



A: Pilot Plant/Waste Recipe
B: Pilot Plant/Cattle Manure
C: Coal PP
D: Natural Gas PP
E: Hydro PP
F: Wind PP
G: IGCC

Figure J.1. Normalized environmental impact potentials of all scenarios.

APPENDIX K– WEIGHTING RESULTS OF LCA ANALYSIS

The weighted environmental impact potential of all scenarios are given and compared below.

The weighted environmental impact potential diagram of Scenario A is given in Figure K.1.

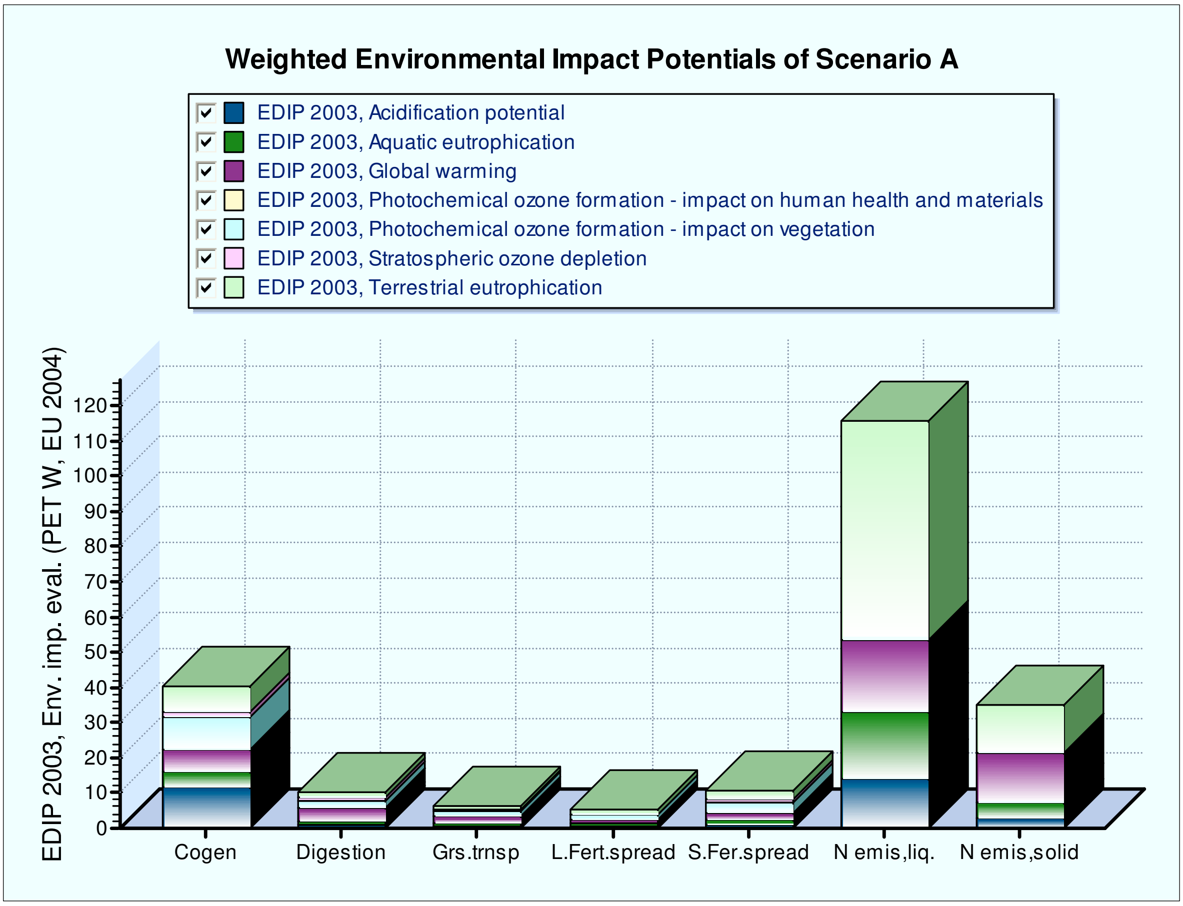


Figure K.1. Weighted environmental impact potential of Scenario A.

The weighted environmental impact potential diagram of Scenario B is given in Figure K.2.

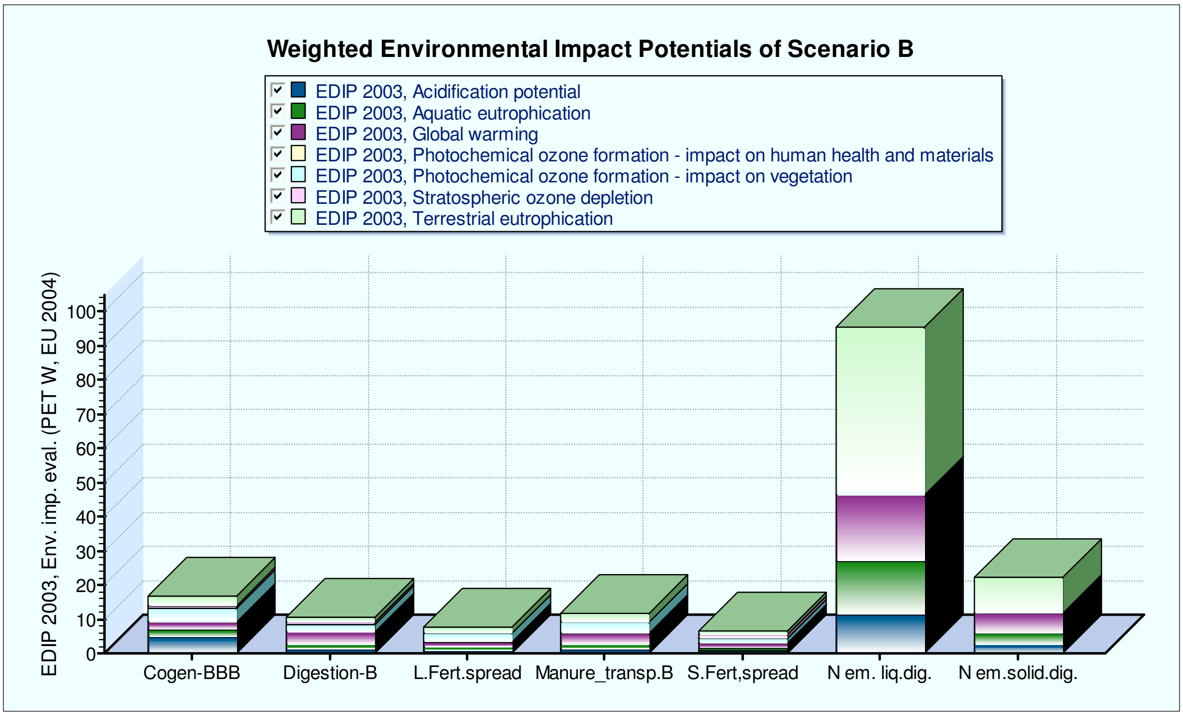


Figure K.2. Weighted environmental impact potential of Scenario B.

The weighted environmental impact potential diagram of Scenario C is given in Figure K.3.

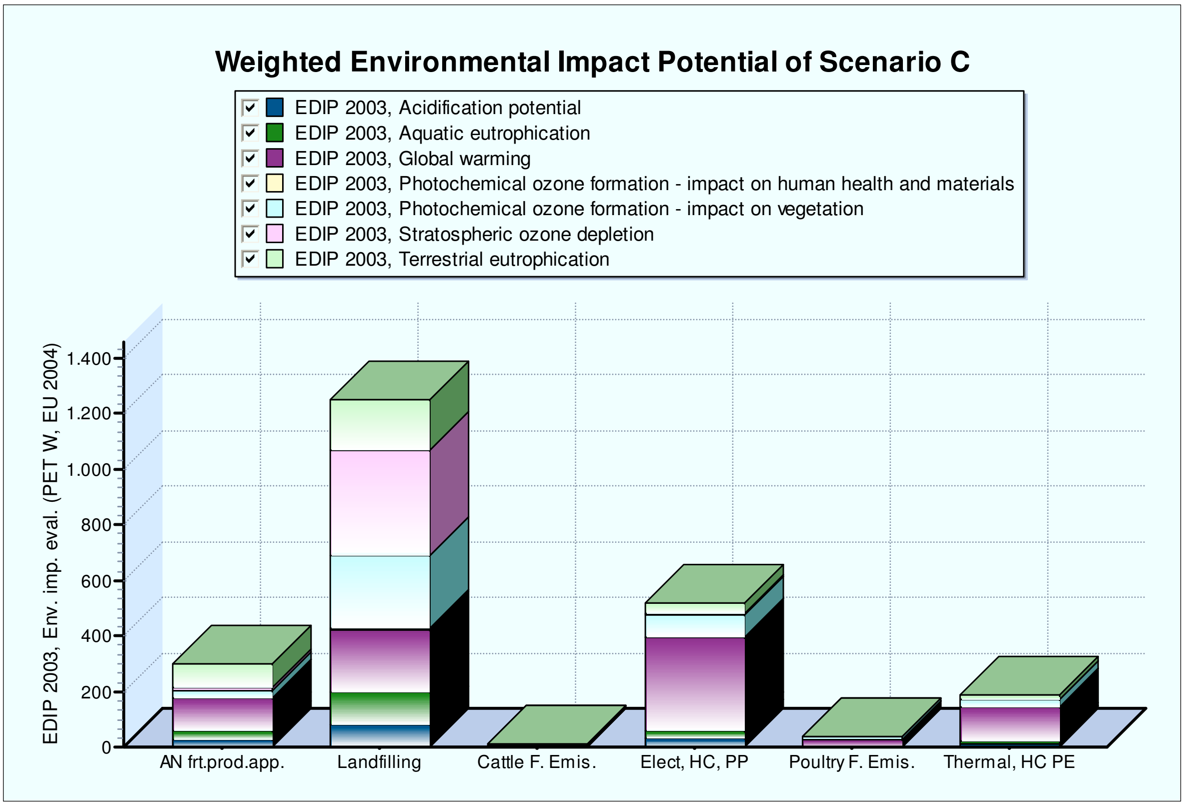


Figure K.3. Weighted environmental ımpact potential of Scenario C.

The weighted environmental impact potential diagram of Scenario D and Scenario E are given below.

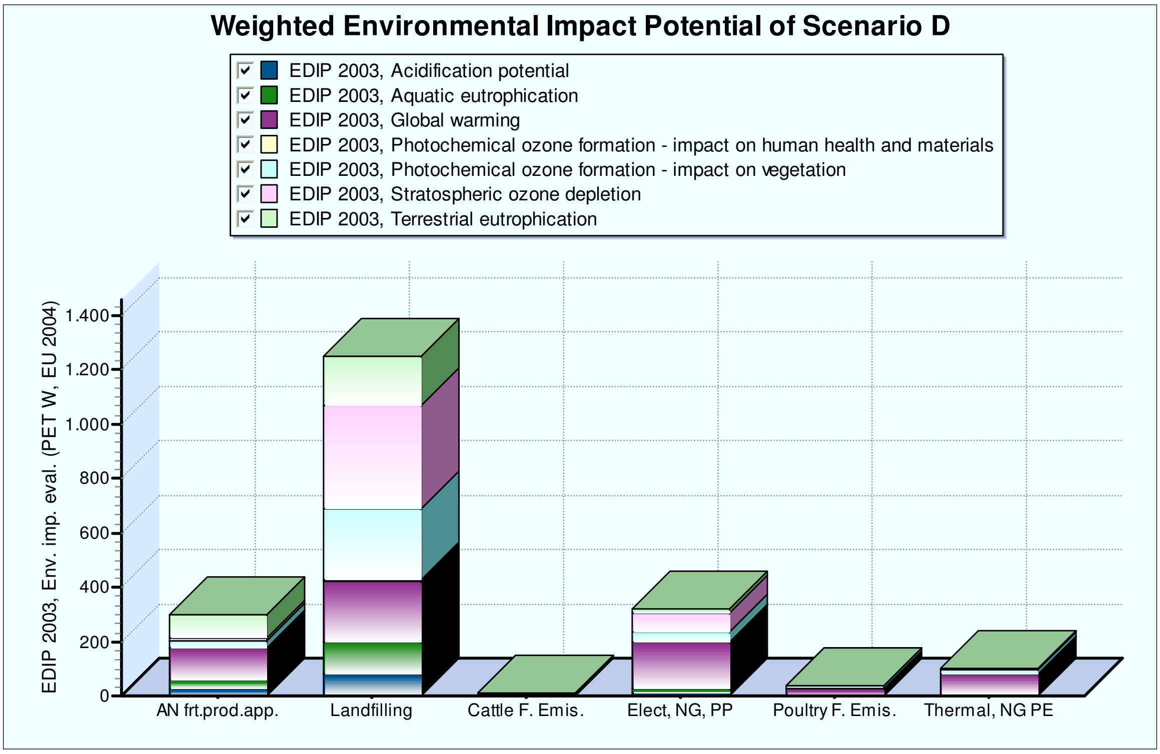


Figure K.4. Weighted environmental ımpact potential of Scenario D.

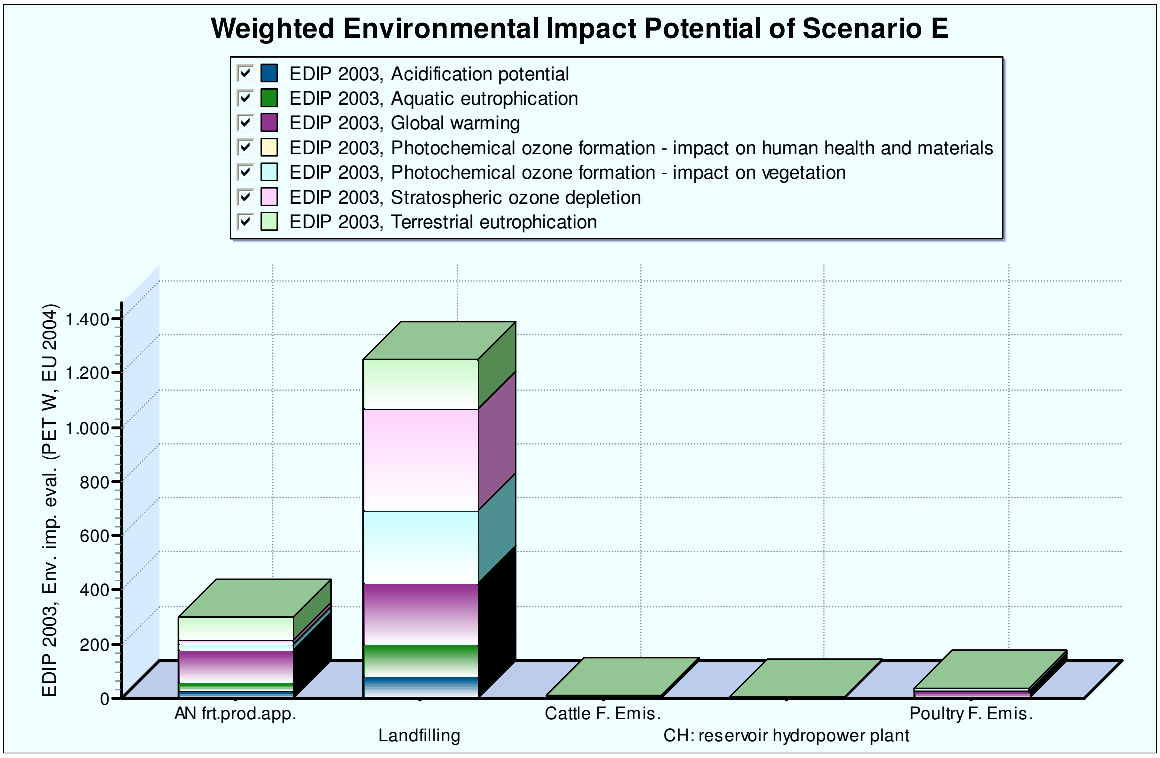


Figure K.5. Weighted environmental ımpact potential of Scenario E.

The weighted environmental impact potential diagram of Scenario F and Scenario G are given below

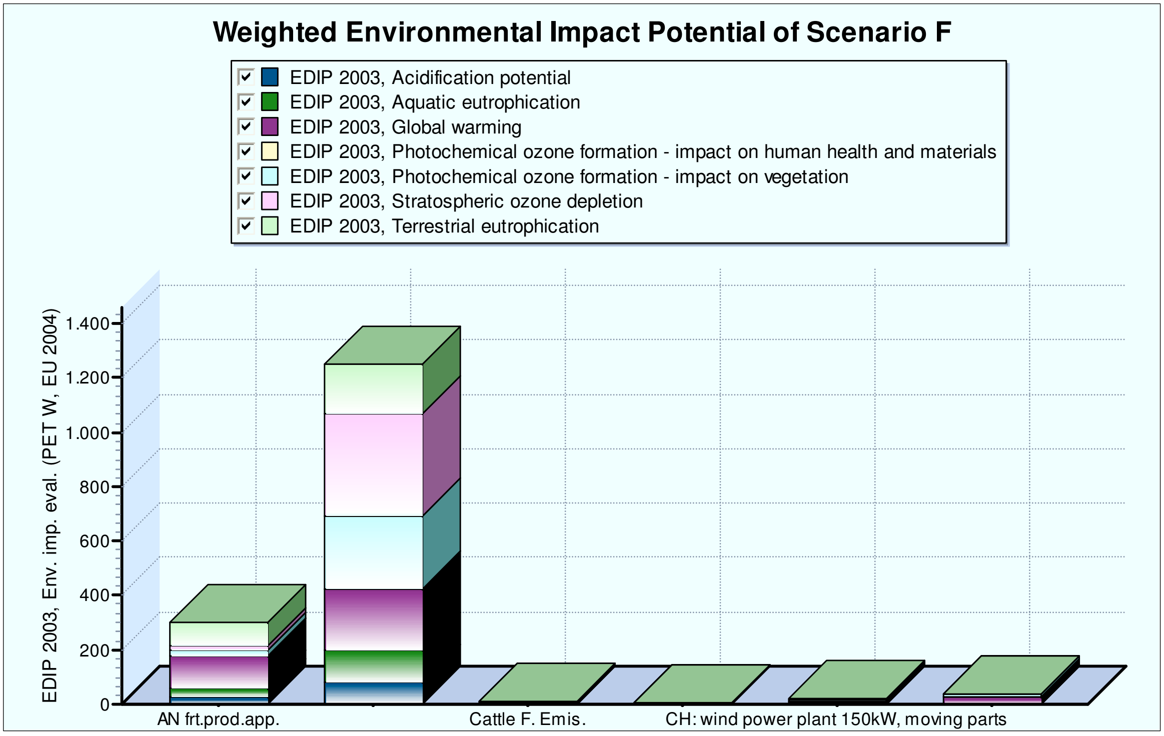


Figure K.6. Weighted environmental ımpact potential of Scenario F.

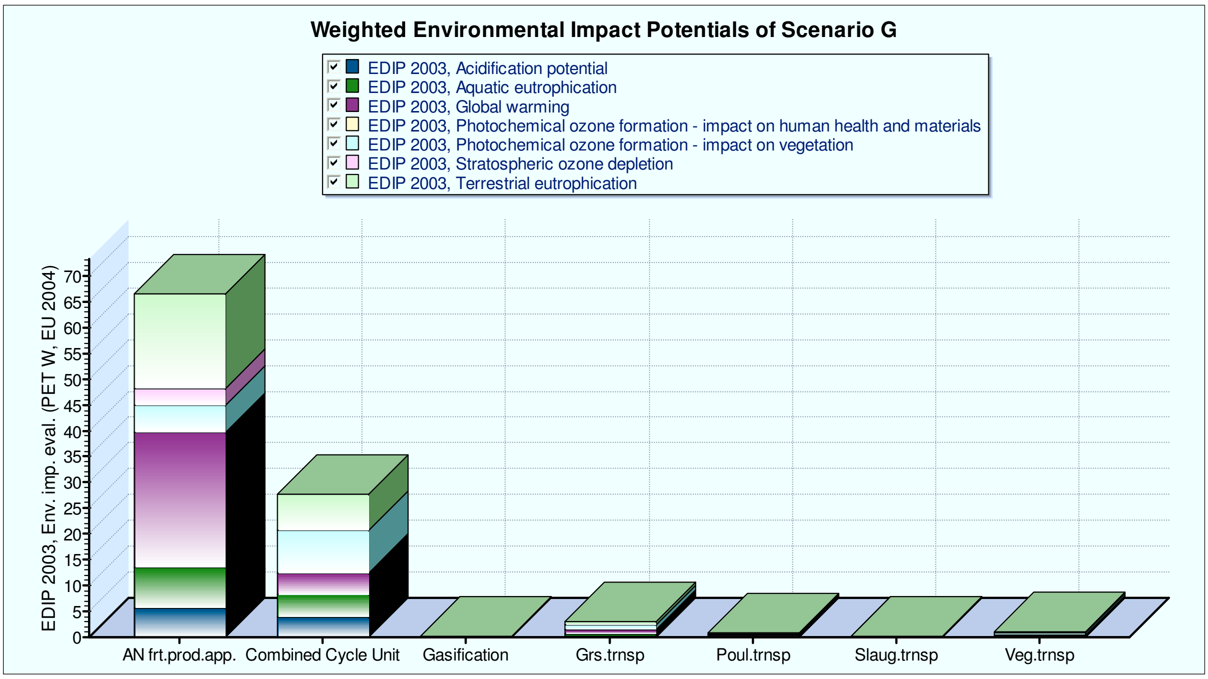
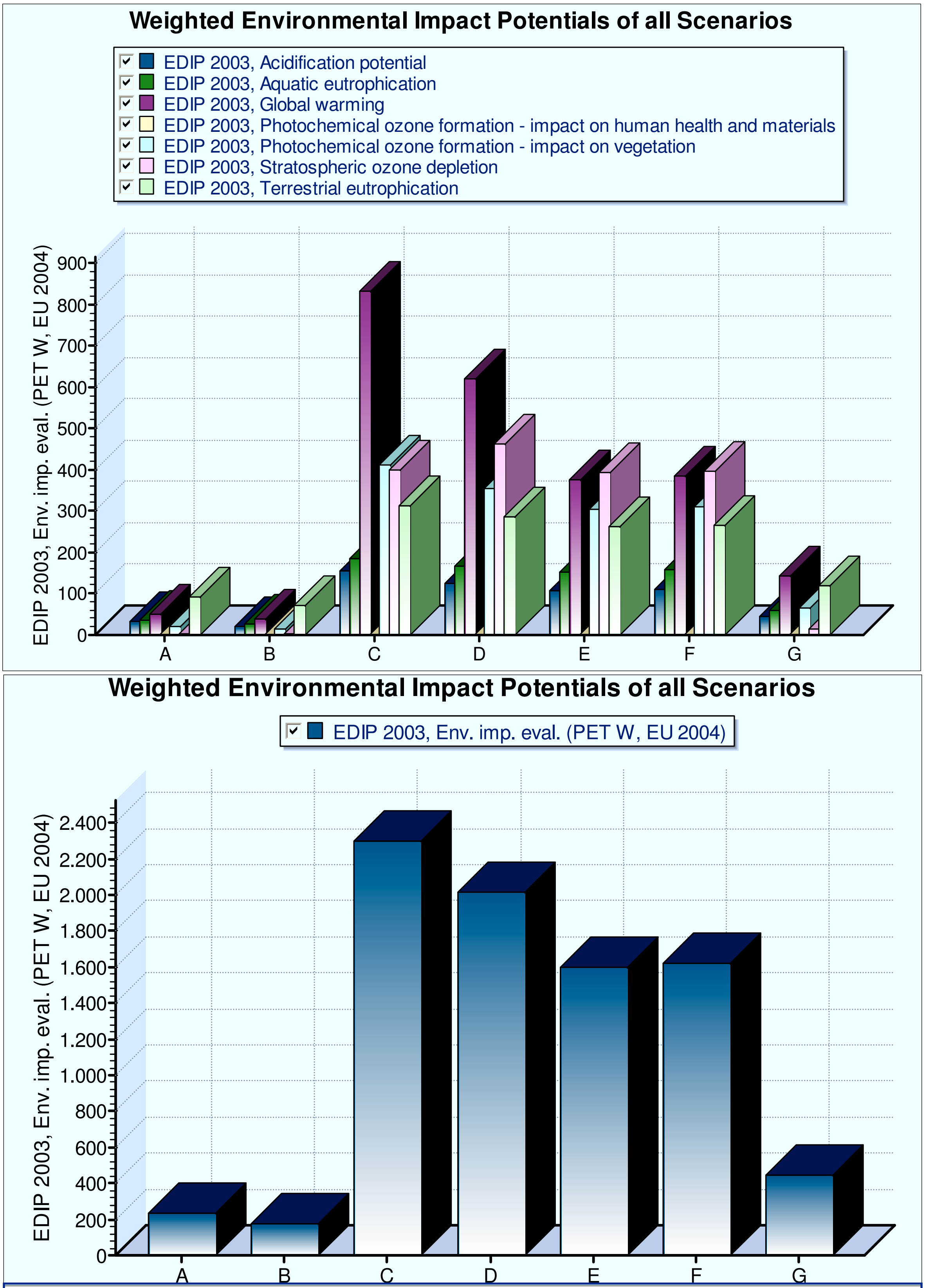


Figure K.7. Weighted environmental ımpact potential of Scenario G.



A: Pilot Plant/Waste Recipe	C: Coal PP	E: Hydro PP	G: IGCC
B: Pilot Plant/Cattle Manure	D: Natural Gas PP	F: Wind PP	

Figure K.8. Weighted environmental impact potentials of all scenarios.

APPENDIX L – PROFIT & LOSS ANALYSIS

Table L.1. Profit and Loss analysis summary for the pilot plant – Scenario A.

PROFIT & LOSS PARAMETERS		CALCULATION FORMULAS				UNIT PRICE		TOTAL PRICE
CONSTRUCTIONAL COST	=	**Electrical Capacity of the Pilot Plant**	x	**Unit Constructional Cost**				
Constructional Cost of the Digester	=	350 kWh	x	3,200 €/kWh (1)			=	1,120,000 €
Constructional Cost of the Cogeneration Unit	=	350 kWh	x	800 €/kWh (1)			=	280,000 €
Total Constructional Cost of the Pilot Plant	=	350 kWh	x	4,000 €/kWh (1)			=	**1,400,000 €**
LOSS = OPERATIONAL COSTS								
Annual O&M Cost of the Pilot Plant	=	Ratio of the Operation and Maintenance Cost to the Constructional Cost of the Pilot Plant	x	Constructional Cost of the Pilot Plant				
Annual O&M Cost of the Pilot Plant	=	3% (1)	x	1,400,000 €			=	42,000 €/yr
Annual O&M Cost of the Cogeneration Unit	=	Operational Duration/yr	x	(0.8 – 1.1 €/hr)				
Annual O&M Cost of the Cogeneration Unit	=	8,000 hr/year	x	0.95 €			=	7,600 €/year
Annual Insurance and taxes costs of the Pilot Plant	=	Insurance and taxes ratio to the constructional cost of the Pilot Plant	x	Total Constructional Cost of the Pilot Plant				
Annual Insurance and taxes costs of the Pilot Plant	=	7.50% (1)	x	1,400,000 €			=	105,000 €/yr
Annual Manpower Cost	=	Operational Employee #	x	Monthly Salary				
Annual Manpower Cost	=	three people	x	2,000 €/month (1)			=	72,000 €/yr
Annual Raw Material Cost	=	Unit Purchasing and Transportation Cost	x	Total Quantity of Raw Material				
Annual Raw Material Cost	=	three €/ton (1)	x	10,680 ton/yr			=	32,040 €/yr
Annual Water Cost	=	Unit Purchasing and Trasnportation Cost	x	Total Quantity of Raw Material Digested				
Annual Water Cost	=	2.9 €/ton (2)	x	3,577 ton/yr			=	10,409 €/yr
TOTAL ANNUAL LOSS								**269,049 €/yr**
PROFITS								
Profit from Electricity	=	Electrical Capacity of the Plant (kW)	x	(100%) x Working Hours	x	Electricity Unit Price		
Profit from Electricity	=	57 kWh	x	8,000 hr/yr	x	0.076 €/kWh (3)	=	34,892 €/yr
Profit from Electricity Trade	=	Electrical Capacity of the Plant (kW)	x	(100%) x Working Hours	x	Electricity Unit Price		

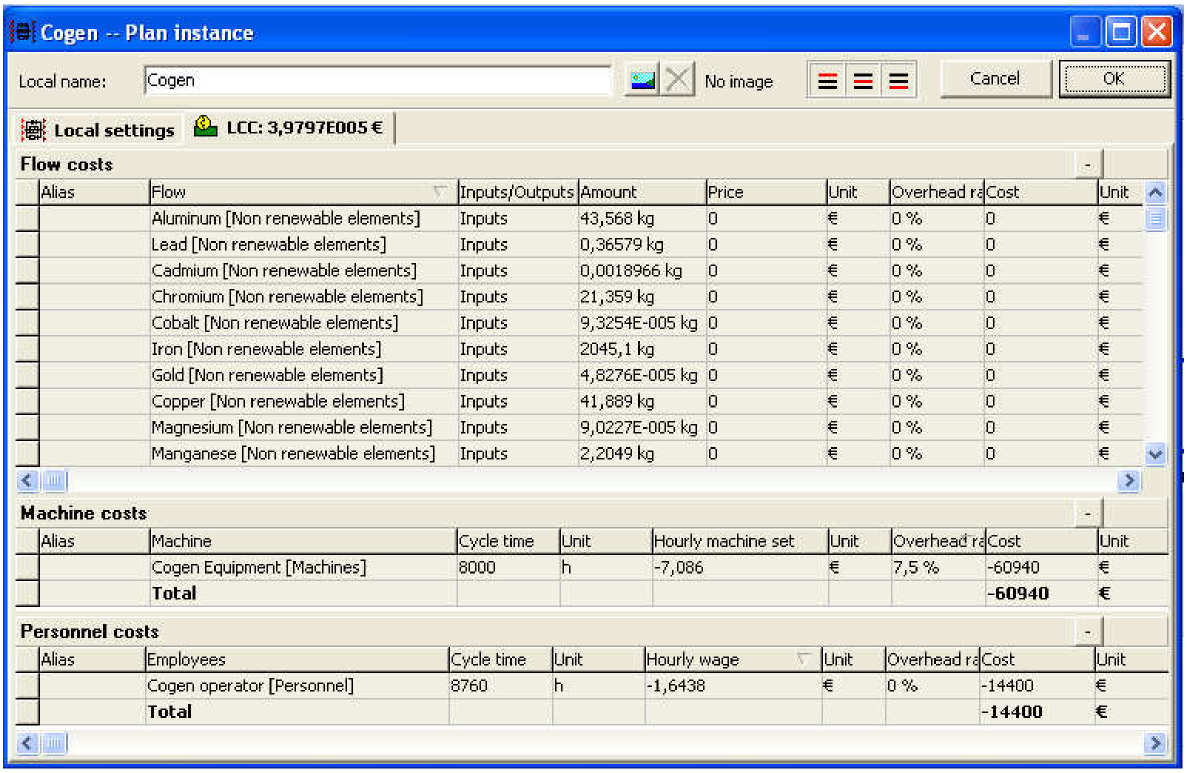
PROFIT & LOSS PARAMETERS		**CALCULATION FORMULAS**				**UNIT PRICE**		**TOTAL PRICE**
Profit from Electricity Trade	=	273 kWh	x	8,000 hr/year	x	0.094 €/kWh	=	205,216 €/year
Profit from Carbon Trade	=	Capacity of the Plant (kW)	x	(100%) x Working Hours	x	Electricity Unit Price		
Profit from Carbon Trade	=	273 kWh	X	8,000 hr/yr	x	0.020 €/kWh (1)	=	43,629 €/yr
Profit from Heat	=	Heat Capacity of the Plant (kW)	X	(100%) x Working Hours	x	Heat Unit Price		
Profit from Heat	=	395 kWh	X	8,000 hr/yr	x	0.03 €/kWh (1)	=	94,776 €/yr
Organic Fertilizer Trade	=	Quantity of Digested Matter	X	Unit Selling Price of Organic Fertilizer				
Organic Fertilizer Trade	=	5,187 ton/yr	X	30.00 €/ton (1)			=	155,610 €/yr
TOTAL ANNUAL PROFIT								**534.123 €/yr**
TOTAL ANNUAL NET PROFIT	=	LOSS	-	PROFIT				
TOTAL ANNUAL NET PROFIT	=	534,123 €/yr	-	269,049 €/yr			=	**265,074 €/yr**
PAYBACK PERIOD	=	TOTAL CONSTRUCTIONAL COST	/	TOTAL ANNUAL NET PROFIT				
PAYBACK PERIOD	=	1,400,000 €	/	265,074 €/yr			=	**5.3 yr**

(1) [Kaya et al., 2009]
(2) [ISKI Water Unit Price List, 2011]
(3) [Resmi Gazete, 2010]

APPENDIX M– LCC ANALYSIS RESULTS

The cogeneration unit process is shown below as an example to flow costs, machine costs and personnel cost information. Cost Information for the Unit Process of Cogeneration Unit is given in Table M.1.

Table M.1. Cost information for the unit process of cogeneration unit.



Local name: Cogen

LCC: 3,9797E005 €

Flow costs

Alias	Flow	Inputs/Outputs	Amount	Price	Unit	Overhead ra	Cost	Unit
	Aluminum [Non renewable elements]	Inputs	43,568 kg	0	€	0 %	0	€
	Lead [Non renewable elements]	Inputs	0,36579 kg	0	€	0 %	0	€
	Cadmium [Non renewable elements]	Inputs	0,0018966 kg	0	€	0 %	0	€
	Chromium [Non renewable elements]	Inputs	21,359 kg	0	€	0 %	0	€
	Cobalt [Non renewable elements]	Inputs	9,3254E-005 kg	0	€	0 %	0	€
	Iron [Non renewable elements]	Inputs	2045,1 kg	0	€	0 %	0	€
	Gold [Non renewable elements]	Inputs	4,8276E-005 kg	0	€	0 %	0	€
	Copper [Non renewable elements]	Inputs	41,889 kg	0	€	0 %	0	€
	Magnesium [Non renewable elements]	Inputs	9,0227E-005 kg	0	€	0 %	0	€
	Manganese [Non renewable elements]	Inputs	2,2049 kg	0	€	0 %	0	€

Machine costs

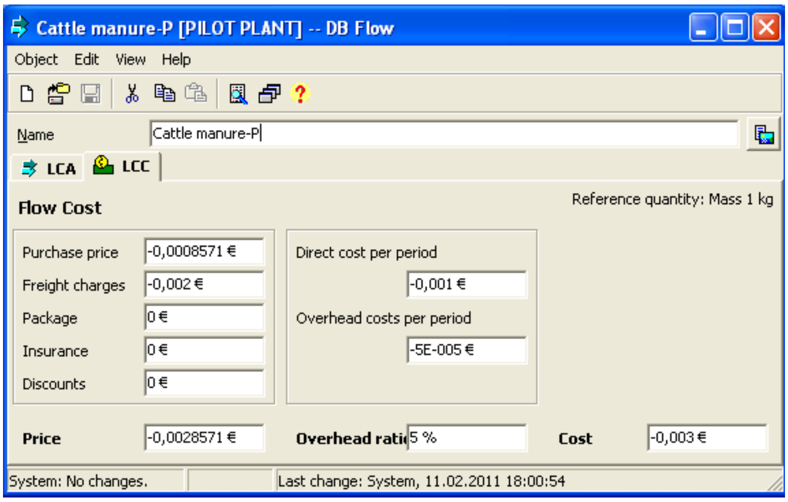
Alias	Machine	Cycle time	Unit	Hourly machine set	Unit	Overhead ra	Cost	Unit
	Cogen Equipment [Machines]	8000	h	-7,086	€	7,5 %	-60940	€
	Total						**-60940**	**€**

Personnel costs

Alias	Employees	Cycle time	Unit	Hourly wage	Unit	Overhead ra	Cost	Unit
	Cogen operator [Personnel]	8760	h	-1,6438	€	0 %	-14400	€
	Total						**-14400**	**€**

The unit flow cost of the raw material, “cattle manure”, is given in Table M.2 as an example.

Table M.2. Cost information for the unit flow of cattle manure.



Name: Cattle manure-P

Flow Cost

Reference quantity: Mass 1 kg

Purchase price: -0,0008571 €
Freight charges: -0,002 €
Package: 0 €
Insurance: 0 €
Discounts: 0 €

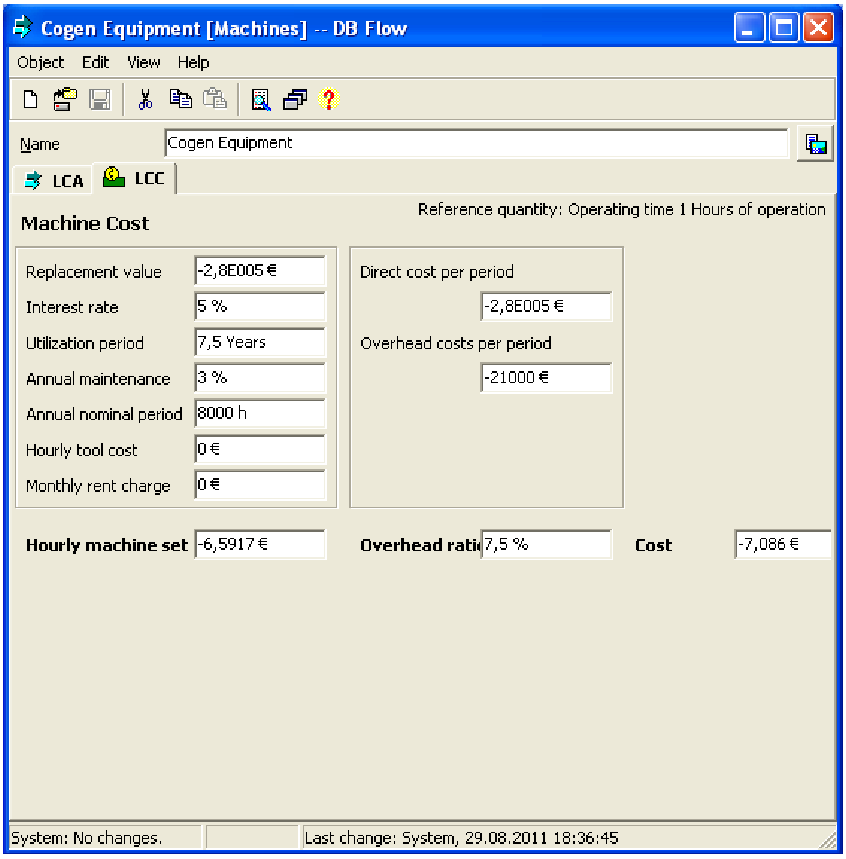
Direct cost per period: -0,001 €
Overhead costs per period: -5E-005 €

Price: -0,0028571 €
Overhead rati: 5 %
Cost: -0,003 €

System: No changes.
Last change: System, 11.02.2011 18:00:54

The machine cost of the cogeneration unit is given as an example in Table M.3.

Table M.3. Machine cost information of the cogeneration unit.



Name: Cogen Equipment

Machine Cost

Reference quantity: Operating time 1 Hours of operation

Replacement value: -2,8E005 €
Interest rate: 5 %
Utilization period: 7,5 Years
Annual maintenance: 3 %
Annual nominal period: 8000 h
Hourly tool cost: 0 €
Monthly rent charge: 0 €

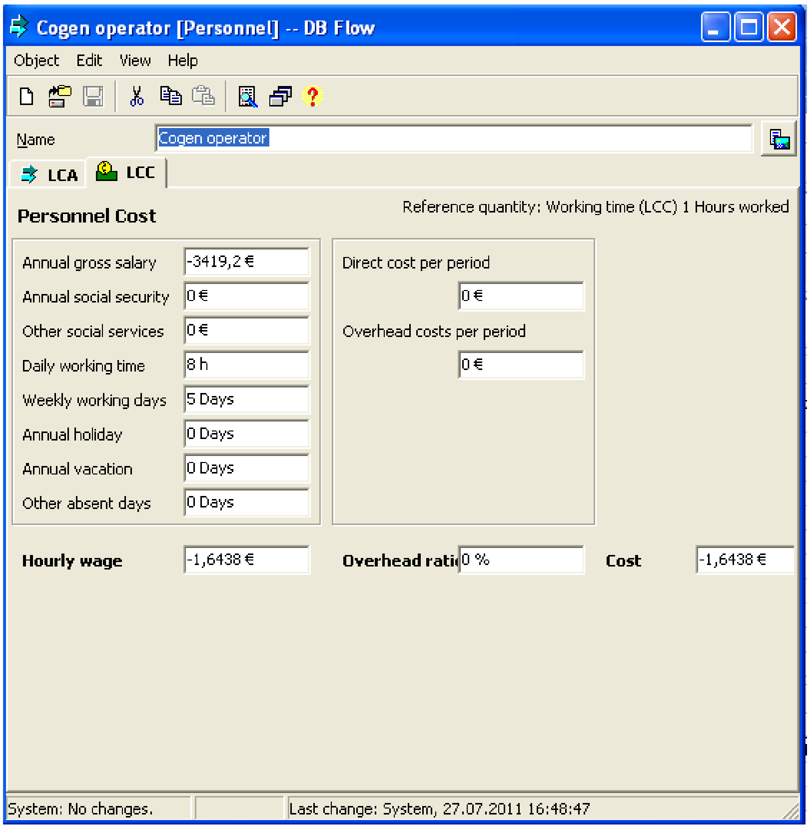
Direct cost per period: -2,8E005 €
Overhead costs per period: -21000 €

Hourly machine set: -6,5917 €
Overhead rati: 7,5 %
Cost: -7,086 €

System: No changes.
Last change: System, 29.08.2011 18:36:45

The personnel cost of the cogeneration unit is given as an example in Table M.4.

Table M.4. Personnel cost information of the cogeneration unit.



Name: Cogen operator

Personnel Cost

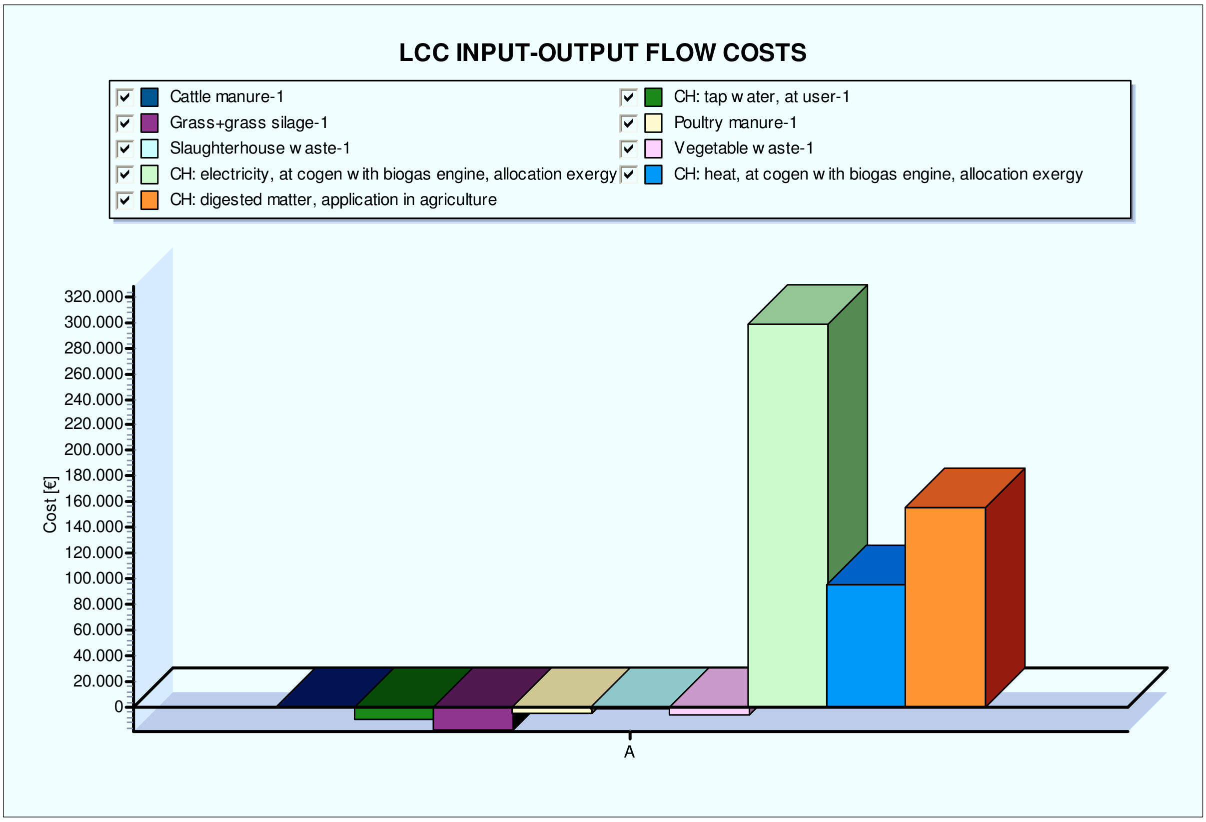
Reference quantity: Working time (LCC) 1 Hours worked

Annual gross salary	-3419,2 €
Annual social security	0 €
Other social services	0 €
Daily working time	8 h
Weekly working days	5 Days
Annual holiday	0 Days
Annual vacation	0 Days
Other absent days	0 Days
Direct cost per period	0 €
Overhead costs per period	0 €
Hourly wage	-1,6438 €
Overhead rati	0 %
Cost	-1,6438 €

System: No changes.

Last change: System, 27.07.2011 16:48:47

When all cost information for the flows are assigned to GaBi4, the following figures in Figure M.1 are obtained showing the total of all input and output flows of the pilot plant in Scenario A and Scenario B.



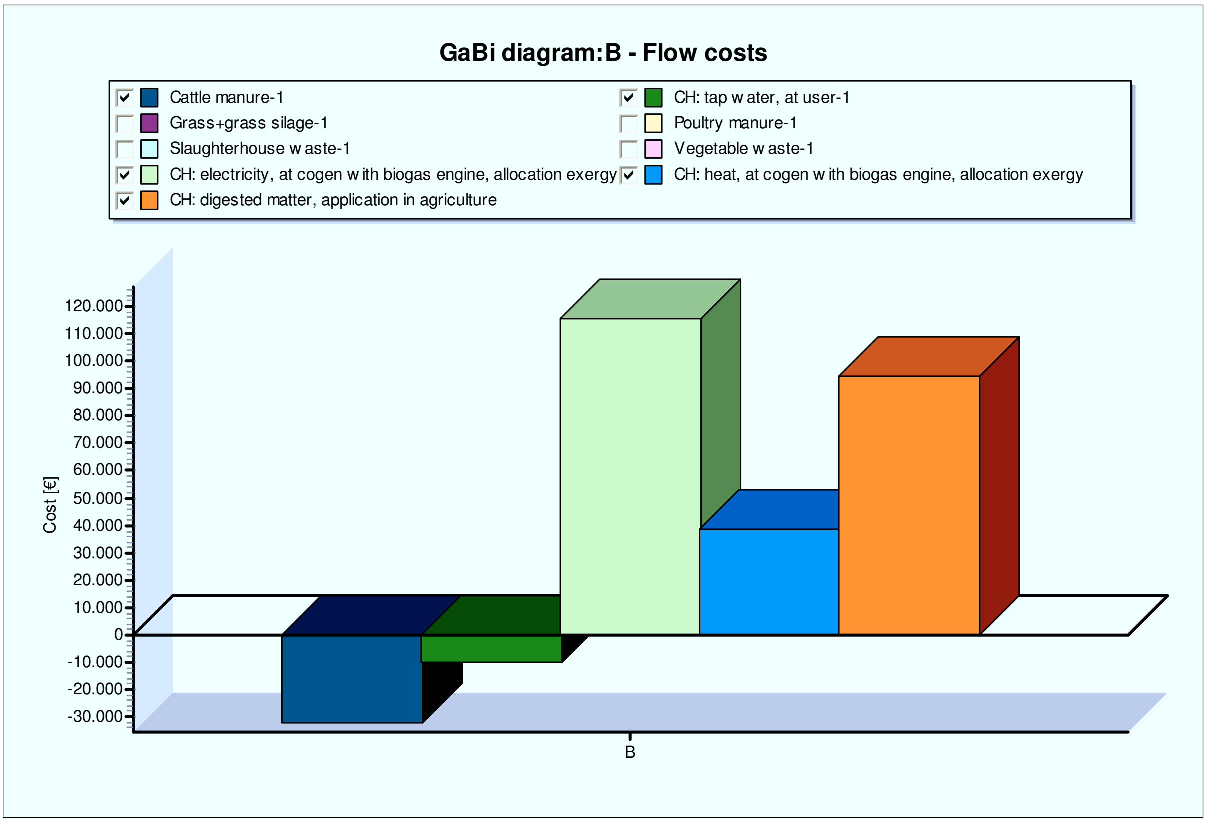
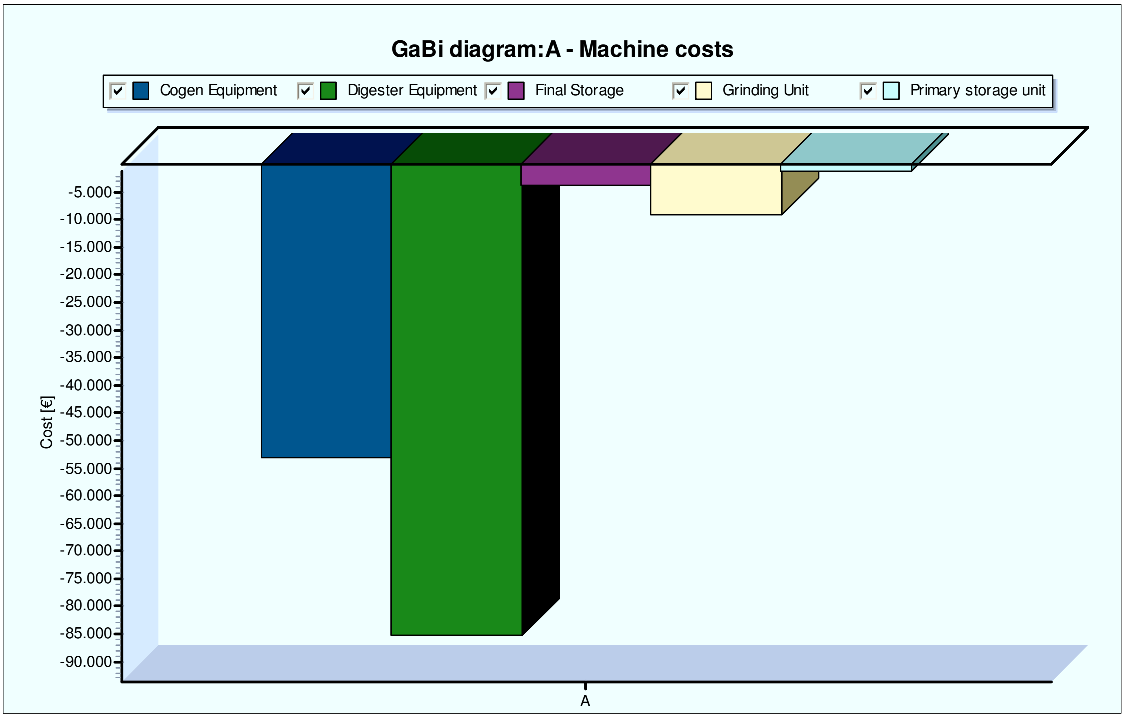


Figure M.1. Flow costs of Scenario A and Scenario B.

When all machine cost information is assigned to GaBi4, the following figures in Figure M.2 are obtained for the pilot plant units in Scenario A and Scenario B.



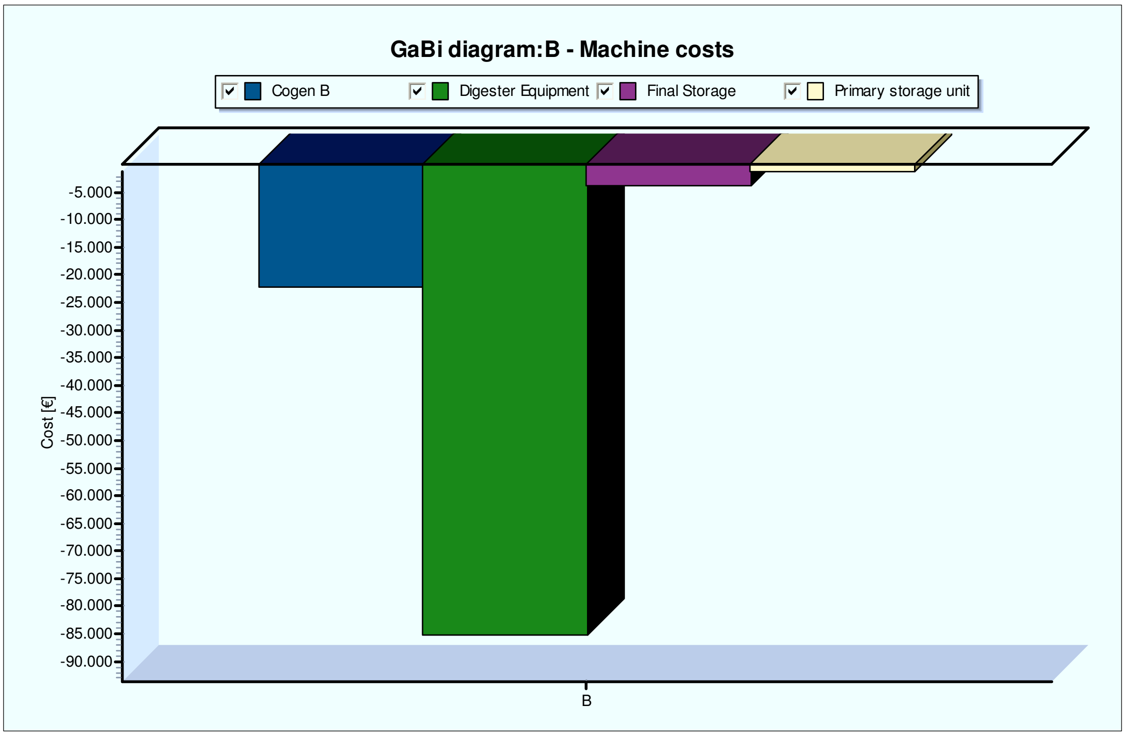


Figure M.2. Machine costs of Scenario A and Scenario B.

When all personnel cost information is assigned to GaBi4, the following figures in Figure M.3 are obtained for the pilot plant units in Scenario A and Scenario B. The personnel costs are same for both scenarios.

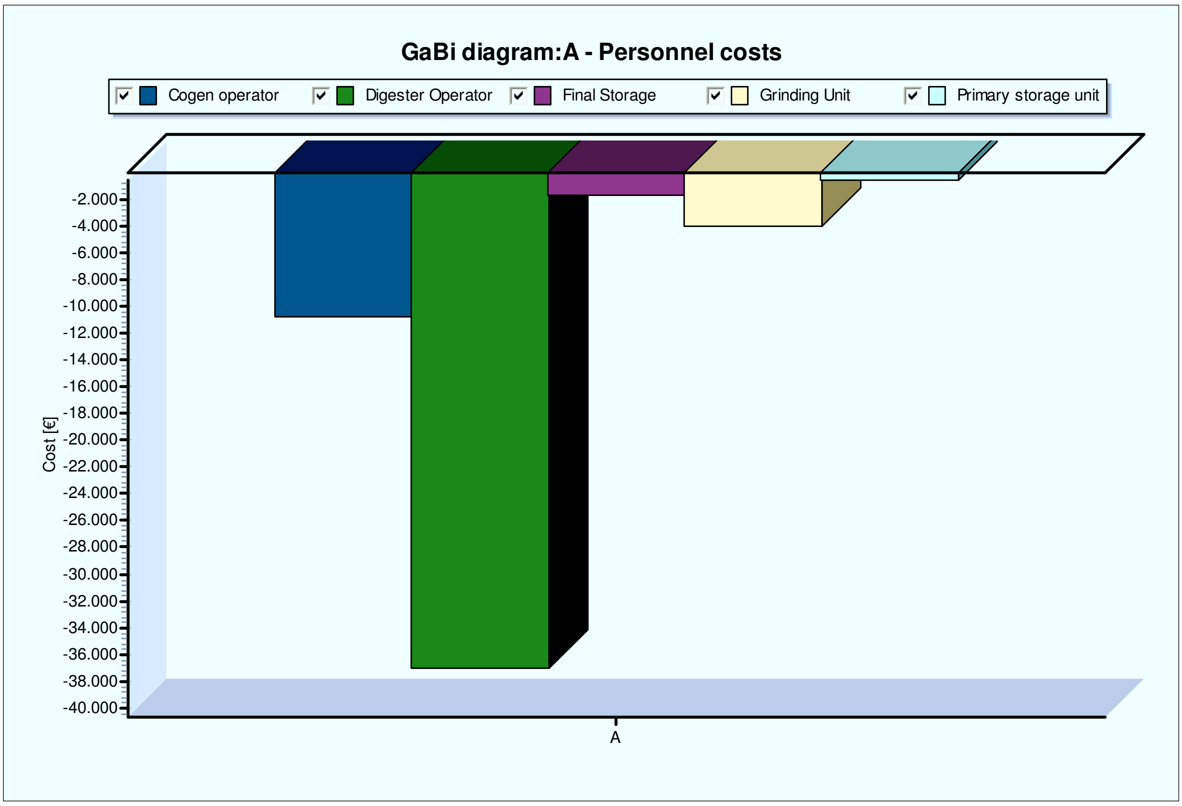


Figure M.3. Personnel costs of Scenario A and Scenario B.

When all flow, machine and personnel cost information are assigned to GaBi4, the Figure M.4 is obtained for the pilot plant units in Scenario A and Scenario B.

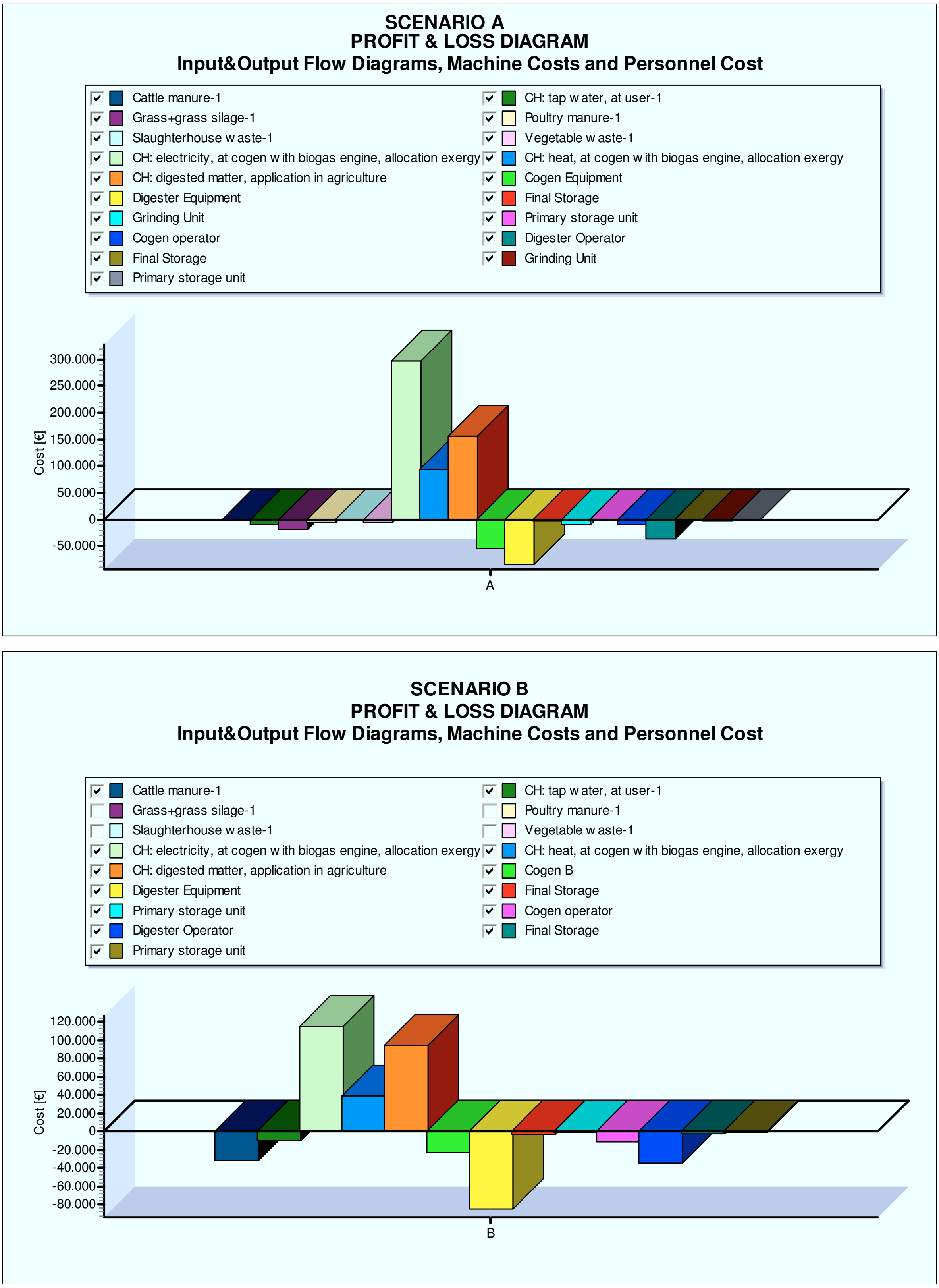


Figure M.4. LCC comparison of Scenario A and Scenario B.

APPENDIX N – LCA STUDIES BASED ON GaBi4 SOFTWARE

Alkaner, S., Zhou, P. 2006. “A comparative study on life cycle analysis of molten carbon fuel cells and diesel engines for marine application”. Journal of Power Sources, 158, 188–199.

Iakovou, E., Moussiopoulos, N., Xanthopoulos, A., Achillas, Ch., Michailidis, N., Chatzipanagioti, M., Koroneos, C., Bouzakis, K.-D., Kikis, V. 2009. “A methodological framework for end-of-life management of electronic products”. Resources, Conservation and Recycling, 53, 329–339.

Kennedy, C., Steinberger, J., Gasson, B., Hansen, Y., Hillman, T., Havranek, M., Pataki, D., Phdungsilp, A., Ramaswami, A., Mendez, G., V. 2010. “Methodology for inventorying greenhouse gas emissions from global cities”. Energy Policy, 38, 4828–4837.

Räsänen, T., Soukka, R., Kokki, S., Hiltunen, Y. 2008. “Neural networks in process life cycle profit modelling”. Expert Systems with Applications, 35, 604–610.

Rousset, P., Caldeira-Pires, A., Sablowski, A., Rodrigues, T. 2011. “LCA of eucalyptus wood charcoal briquettes”. Journal of Cleaner Production, 19, 1647-1653.

Russell, S.N., Allwood, J. M. 2008. “Environmental evaluation of localising production as a strategy for sustainable development: a case study of two consumer goods in Jamaica”. Journal of Cleaner Production, 16, 1327-1338.

Scharnhorst, W., Althaus, H., Classen, M., Jolliet, O., Hilty, L. M. 2005. “The end of life treatment of second generation mobile phone networks: Strategies to reduce the environmental impact”. Environmental Impact Assessment Review, 25, 540–566.

Scharnhorst, W., Hilty, L. M., Jolliet, O., 2006. “Life cycle assessment of second generation (2G) and third generation (3G) mobile phone networks”. Environment International, 32, 656–675.

Suebsiri, J., Wilson, M. 2011. "A model of carbon capture and storage with domenstration of global warming potential and fossil fuel resource use efficiency". Energy Procedia, 4, 2465-2469.

Tangsubkul, N., Parameshwaran, K., Lundie, S. Fane, A.G., Waite, T.D. 2006. "Environmental life cycle assessment of the microfiltration process". Journal of Membrane Science, 284, 214–226.