DEVELOPMENT AND APPLICATION OF A DECISION SUPPORT TOOL FOR TECHNOLOGY, ENVIRONMENTAL, SOCIO-ECONOMIC ANALYSIS FOR BIOFUELS PRODUCTION AND USE IN ZAMBIA

By

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ABSTRACT

One of the key issues of sustainable industrial development is the migration from fossil to renewable feedstocks in various sectors such as energy production, fuel production, chemical and related industries. Zambia and the rest of Africa is in the process of embracing utilisation of biofuels for the transport and industrial sectors. The drive to utilisation of biofuels is mainly prompted by energy security and high world oil prices affecting economic growth and increased poverty levels.

Development and assessment of various technological options and scenarios of biomass conversion to bio-fuels is quite complex. This is due to challenges of handling and interpretation of the amount and complexity of information on economic, environment and social issues related to biofuel production and use. In view of these challenges, a decision support tool for biofuels was conceptualised to attempt to address the problem. Consequently, the concept of decision support tool (DST) for biofuels formed the basis for this research. The principle behind DST is to provide the interested party, with relative ease, all the necessary information needed to assist in the decision making process among various feedstock types, technological options, and other scenarios regarding biofuels development.

Decision support tool (DST) has been designed as a software package built on visual basic language environment and is based on the principle of Well-to-Tank (biomass production through to biofuels uses). The tool consists of a number of modules namely; biomass production, biofuels production, socio-economic, environmental and multi criteria analysis. The scope of the tool so far is limited to biodiesel from soy bean and jatropha.

Application of DST revealed that jatropha feedstock for production of 2 million litres of biodiesel per annum requires 1,575 hectares of land. Investment and operations, and maintenance cost for a 2 million jatropha biodiesel production plant is U$3 million and US$ 0.17million, respectively. Financial analysis revealed, return on investment of 9.8% and unit production cost of US$0.9/litre at the biodiesel selling price of US$ 1.2/litre.

Mid-point environmental impacts analysis revealed human toxicity of 3054 kg 1,4-dichlorobenzene equivalent, climate change 880 million tonnes CO_2 equivalent including initial carbon loss from land use change), photoxidant of 320 kg of ethylene equivalent, acidification of 0.04 kg SO_2 emitted in Switzerland equivalent, eutrophication of 0.01 kg PO_4^{3-} equivalent, land competition of 315 million m^3yr. The total normalized value was calculated at 0.06. For the same plant size, results of environmental analysis show negligible impact on human toxicity, photoxidant formation, acidification, and eutrophication since their respective contribution to overall normalized value is negligible. It therefore implies that the environmental burden of biodiesel production is more on climate change than other category indicators.

On the other hand, a 2 million soy been based biodiesel require 11,815 hectares of land. Financial analysis revealed a unit production cost of US$1.2/litre with return on investment of 8.3%. Mid-point environmental impacts analysis revealed human toxicity of 2,315 kg 1,4-dichlorobenzene equivalent, climate change 6,600 million tonnes CO_2 equivalent(including initial carbon loss from land use change), photoxidant of 402 kg of ethylene equivalent, acidification of 0.02 kg SO_2 emitted in Switzerland equivalent, and land competition of 2,360 million m^3yr. The total normalized value was calculated at 0.456.

Multi Criteria Analysis of 2 million biodiesel plant from jatropha and soy bean provided an overall score of 53% and 49%, respectively. The higher the score, the better the overall perfomance of particular scenario taking care of economic, social, and envirnomental considerations. These results indicate jatropha based biodiesel has better performance on an overall balance of economic, environment and social aspects as opposed to soy bean based biodiesel.

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

AI	Active Ingredient
BOD	Biological oxygen demand
BtL	Biomass-to-Liquid
C	Carbon
CDSS	Coppice Decision Support System
CH4	Methane
CHDSS	Coppice Harvesting Decision Support System
CO	Carbon monoxide
CO_2	Carbon dioxide
COD	Chemical Oxygen Demand
DBFZ	German Biomass Research Centre
DDGS	Distillers Dried Grains Soluble
DME	Di methyl ether
DOM	Dead organic matter
DSS	Decision Support Systems
DST	Decision Support Tool
EN	European Standard
FAEE	Fatty acid ethyl esters
FAME	Fatty acid methyl esters
FT	Fischer-Tropsch
GHG	Green house gas
GIS	Geographic information system
GWP	Global Warming Potential
HC	Hydro Carbon
IRR	Internal Rate of Return
ISO	International Standard Organisation
K	Potassium
kWh	Kilo Watt hours
LCA	Life Cycle Analysis
LCI	Life Cycle Inventory
MCA	Multi Criteria Analysis

MS	Microsoft
MTBE	Methyl Tertiary Butyl Ether
N	Nitrogen
N2O	Nitrous Oxide
NGO	Non Governmental Organisation
NH3	Ammonia
NMVOC	Non Methane Volatile Organic Compound
NOx	Oxide of Nitrogen
NPV	Net Present Value
P	Phosphorous
PAN,	Peroxyacetylnitrate
POCP	Photochemical Ozone Creation Potential
PPO	Pure plant oil
SNG	Synthetic Natural Gas
SO_2	Sulphur Dioxide
SVOC	semi volatile organic compounds
US	United States of America
VOCs	Volatile Organic Compound
WTT	Well to Tank

CHAPTER 1.0 INTRODUCTION

1.1 Background

One of the key issues of sustainable industrial development is the migration from fossil feedstocks to renewable feedstocks in various sectors such as energy production, fuel production, chemical and related industries. Such a departure is driven by several factors which include; depleting fossil feedstock, need of diversification of feedstocks, abundance of renewable resources in many countries of the world, CO_2 “neutrality” of renewable feedstocks, concerted potential development of both industry and agriculture, new openings for green chemistry and related industries development, etc (Rutz and Janssen, 2008).

Zambia and like the rest of Africa is in the process of embracing utilisation of biofuels for the transport and industrial sectors. The drive to utilisation of biofuels is prompted by several reasons which include; (i) recent events related to global uncertainties in fossil fuels supplies, (ii) energy security, (iii) high world oil prices affecting economic growth and increased poverty levels, (iv) growing interest by small scale and large farmers to grow energy crops from different sources, (v) realisation that biofuels can be used for heating, power generation, transport purposes and related economic spin offs (CEEEZ, 2007).

There are several challenges that need to be addressed in the development of the biofuels sector. For example, there is a need for further development of suitable technologies including first and next generation of bio-fuels, availability of feedstocks, uncertainty of bio-feedstocks supply and their prices, risk of misconception in designing of bio-fuels strategies, etc. Therefore, further development and assessment of various technological options of various scenarios for bio-fuels exploitation is highly needed, considering the challenges of handling and interpretation of the amount and complexity of information related to biofuel production and use (Arumugam et.al 2007).

Development and assessment of various technological options and scenarios of biomass conversion to bio-fuels is quite complex (Arumugam et.al 2007). This is owing to the challenges of handling and interpretation of the amount and complexity of information on economic, environment and social issues related to biofuel production and use. In view of these challenges, a decision support tool for biofuels was conceptualised to attempt to address the problem. Consequently, the concept of decision support tool (DST) for biofuels formed the basis for this research.

The principle behind a DST is to provide the interested party with all the necessary information with relative ease in order to assist with decision making process among various feedstock type, technological options, and other scenarios regarding biofuels development. The target beneficiary group include decision-makers like the government, NGOs, research institutions, project developers and other stake-holders in developing countries, who are considering adopting new policies or projects in bioenergy sector.

Decision support tool (DST) is designed as a software package built on programming language environments such as visual basic, and it is based on the principle of Well-to-Tank (biomass production through to biofuels uses). The tool consist of a number of modules namely, biomass production, biofuels production, socio-economic, environmental and multi criteria analysis. The scope of the tool so far is limited to biodiesel from soy bean and jatropha.

Conceptually, the Decision Support Tools (DSTs) refer to analysis, comparison, and selection of possible options (technologies or products) according to their characteristics. Such characteristics should be presented as the quantified data that can describe a variety of aspects of decision maker's interest. These aspects often refer to the process performance, environmental, social economic, and risk aspects (Arumugam et.al 2007). Decision support tool is based on data collection, modelling and analysis of information according to defined criteria.

1.2 Problem Statement

The biofuels development process currently, lacks an integrated approach in planning scenarios of biofuels production which takes account of technical, socio-economic, and environment factors. For this reason, determination of an appropriate biofuels production pathway which is cost effective, suitable production technology, contributes to social well being and environmentally benign in a given situation is still a challenge in the biofuels industry. This research therefore presents a potential solution in the biofuels industry on how best to achieve optimal and sustainable production conditions.

1.3 Objectives

The main objective of this research is to develop an integrated well-to-wheel biofuels decision support tool that provides an opportunity to compare among various biofuel production pathways/options to enable selection of optimal scenario.

The specific objectives of a DST include are

(i) To develop of a software package aimed at helping decision-makers in assessment and adoption of the most environmentally friendly, efficient and economic technological approaches,

(ii) To create awareness towards environmental and sustainability issues,

(iii) To understand implications of choice of feedstock on standards on social economic and environmental issues,

(iv) To undertake financial analysis through evaluation of net present value, annual production costs, annual expected profit, , profitability, static payback period and specific production cost,

(v) To suggest the appropriate treatment/processing options in order to obtain higher yields and quality of products, lower costs and environmental impacts

(vi) To make easy handling and interpretation of the amount and complexity of information related to biofuel production and use

1.3 Scope

The principle adopted for developing the DST is based on Well-to-Tank of biofuels production. Here, all upstream and downstream processes that are somehow involved or affect the strictly defined biofuel pathway are taken into consideration. It implies therefore that, if a certain auxiliary material (e.g. chemical fertilizer) is used during the cultivation of a feedstock material, then all the expenditures (energy and material) and subsequent emissions for the production of this chemical are included in the calculations of the final expenditures and impacts of the biofuel pathway. This procedure is followed for all expenditures stepwise and backwards until the original primary resource is reached.

Otherwise mentioned as “Cradle-to-Grave” approach, it follows the path of every material throughout its lifespan, from the primary resource consumed for its production until its final use. It is therefore, an inflow (resource)-outflow (emission) approach that also reflects the environmental impacts of a certain process or scenario. The proper evaluation of related production processes should be based on their sustainability analysis, which implies the assessment of associated economic and environmental indicators.

The DST is focused on biodiesel from first generation point of view and the bioenergy feedstock considered included jatropha and soy bean for biodiesel. The tool is a modular software based tool built on visual basic environment, and it consists of several modules which include;

(i) Biomass production(energy crop production), agriculture input assessment,

(ii) Biofuels production(crude oil production and refining)-assessment of production technologies and recipes of biofuels),

(iii) Environmental (Life Cycle Analysis)-using ISO 14040 and 14043,

(iv) Financial analysis); -financial analysis of energy crop production, crude oil production and biofuels production,

(v) Socio-economic issues (e.g direct job creation etc),

(vi) Multi Criteria Analysis

CHAPTER 2.0 METHODOLOGY

The methodology employed in this research involved literature review, analysis, software development and application of decision support tool. Detailed methodology for this research is provided in the following sections.

2.1 Approach for Literature Review

Literature review focused on energy crop cultivation techniques, biofuels production technologies, life cycle analysis, transport logistics, financial analysis, and multi criteria analysis. Additionally, a review of a wide array of existing decision support tools for various applications was undertaken so as to draw lessons on their development. The decision support tools considered include; (i) decision support tool to evaluate alternative policies in regulating wind integration into autonomous energy systems, (ii) decision support system for exploiting local renewable energy sources: A case study of the Chigu area of south-western Taiwan, and (iii) development of decision support systems for bioenergy applications.

2.2 Approach for Analysis

Analysis in this research was carried out through determination of main modules of DST, formulation of flow chart and algorithms, software development and application of DST by considering three plant size scenarios of biodiesel production. Detailed methodology for analysis is provided as follows:

2.2.1 Approach for Determination of Main Modules of DST.

This process involves determination of main components of DST and grouping them into modules (i.e. biomass production, biofuels production, environment, economic, and multi-criteria analysis modules).

2.2.2 Approach for Formulation of Flow Chart

Flow chart is a key element in DST design as it depicts graphical presentation of module interrelationships, characteristics, and information flow from Well-to-Tank. The flow chart also presents several steps required in order to reach the final result in a DST. Formulation of flow chart involved connection of different modules according to their respective inter-relationships to form one unit. The flow chart provides a basis for development of algorithms.

2.2.3 Approach for Development of Algorithms

Algorithms presents mathematical presentation of components and their relationships within and across modules which serves as basis for writing computer codes in a computer programming language. These modules include, biomass production module, biofuels production module, biofuels transport, and life cycle analysis. The algorithms (mathematical equations) were developed based on the flow chart. Numerous, unique mathematical equations were developed for each module representing biomass production processes, biofuels production processes, financial analysis, job creation, environmental flows(life cycle analysis). A particular module may receive a set of data computed from either, database or another module or may receive direct inputs from the user. A module may also make use of results computed by its components, inputs. Similary a module can also provide outputs to other modules or to the user.

2.2.4 Approach for Software Development

Software development involved writing software codes (computer programming) based on the algorithms and making provision for graphical user interface. Essentially this process is a translation of flow chart and algorithms into software package through programming. This DST for biofuels was designed in Visual Basic 2008 Programming language environment and the tool is deployed as desk top application.

Software development consists of two main stages namely database development and programming. Database development was built on the premise of the requirements of the algorithms and functions governing the modules. The choice of biofuel type and production technology employed is associated wide array of data characteristics which is stored in a database. The additional data to complete analysis is provided by the user. The tool is equipped with provisions for ‘User Defined’ parameters (related to consumables, waste and by products) so as to accommodate user’s preferences.

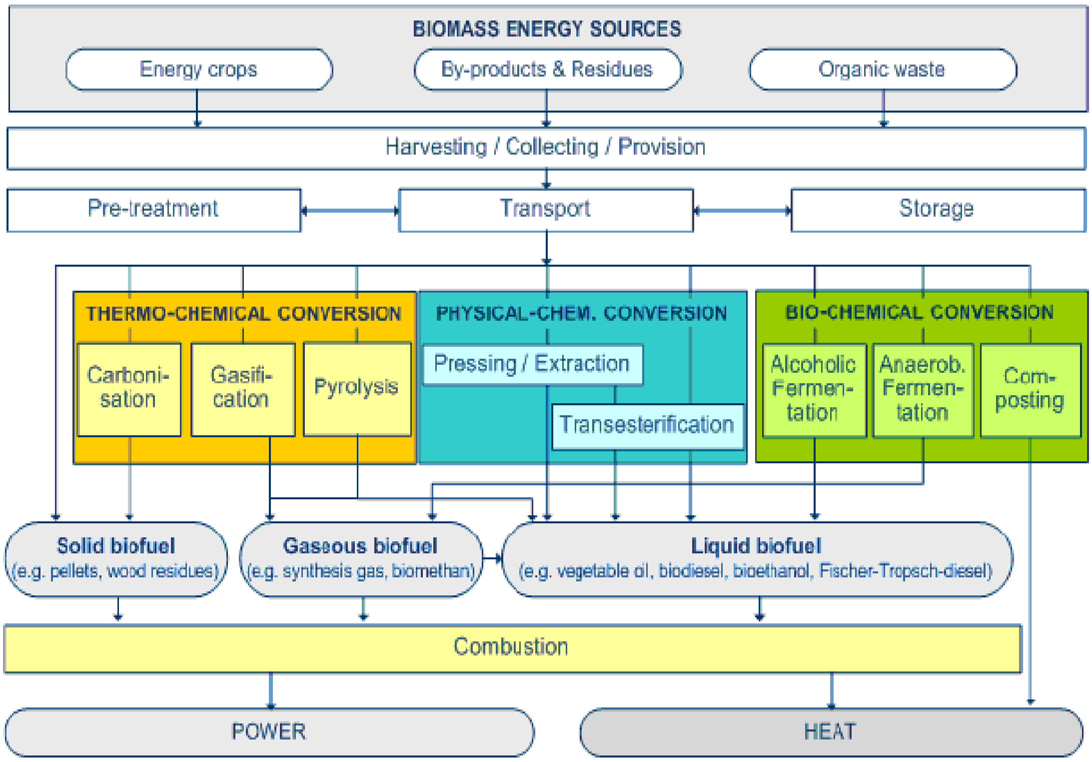
2.2.5 Approach for Application of DST.

This process involves application of decision support tool using three scenarios. These scenarios are plant sizes of 2, 20 and 50 million litre biodiesel production per annum for both jatropha and soy bean based feedstocks.

CHAPTER 3 LITERATURE REVIEW

3.1 Biofuels

Depending on the conversion of biomass, in principle three main pathways come into consideration in bioenergy production and these include; (i) the thermo-chemical pathway, (ii) the physical-chemical conversion pathway, (iii) the bio-chemical conversion pathway (Arumugam et.al 2007). These processes provide biofuels in the form of solids (mainly charcoal), liquids (mainly biodiesel and alcohols), or gases (mainly mixtures with methane or carbon monoxide), which can be used for a wide range of applications, including transport and high-temperature industrial processes (VDI, 1996). These pathways are provided in figure 3.1.



Source: DBFZ, 2008

Figure 3.1 Basic pathways for the provision of final energy derived from biomass

Biofuel is any fuel that is derived from biomass, recently living organisms or their metabolic by products, such as manure from cows. It is a renewable energy source, unlike other natural resources such as petroleum, coal and nuclear fuels. Biofuels can be grouped in 'generations', according to the type of technology they rely on and the biomass feedstocks they convert into fuel (Arumugam et.al 2007). First (1st)-generation biofuels are biofuels which are produced from food crops (sugar or oil crops) and other food based feedstock (e.g. food waste).

These biofuels are on the market in considerable amounts today and their production technologies are well established. The most important biofuels of the 1st-generation are bioethanol, biodiesel, and biogas. Bioethanol is produced by fermenting sugars from starch and sugar biomass (e.g. cereal crops such as corn or maize and sugarcane). It can be used in pure form in specially adapted vehicles or blended with gasoline in any proportion up to 10% as is the case in the USA, provided that fuel specifications are met (Arumugam et.al 2007). Biodiesel blends became mandatory in early 2008 in Brazil, followed by a raise in blend levels from 2 to 3 percent in the same year and from 3 to 4 percent in 2009. The increase to 5 percent was effected in 2010.

Second (2nd) or 'next' generation of future biofuels can be produced from wider range of feedstocks, which are represented mainly by non-food crops. For example, the whole plant biomass can be used or waste streams that are rich in lignin and cellulose, such as wheat straw, grass, or wood. In order to breakdown this biomass, two main conversion pathways come into consideration: 1) hydrolysis (can be done via chemical and biochemical pathways) of ligno-cellulose into sugars, which can then be fermented into alcohol -this technology is best known as 'cellulosic bioethanol' and is still in development; 2) thermochemical processes (use of high temperatures to pyrolyse or gasify biomass) of lignocelluloses to a raw gas or oil (Arumugam et.al 2007).

The resulting gas is then treated and conditioned into synthesis gas (syngas), consisting mainly of carbon monoxide and hydrogen. This gas can further be processed into different types of liquid and gaseous fuels via different fuel syntheses. Fuels from this route are then called 'synthetic biofuels'. Most promising liquid synthetic biofuels, also called BtL biomass-to-liquids, are biomethanol and Fischer-Tropsch fuels. Gaseous synthetic biofuels are e.g. dimethylether (DME) and Bio-SNG**,** which is also a form of biomethane and can be similarly used as natural gas substitute like biogas. Alternatively, the cleaned and conditioned product gas can be converted into hydrogen. Bio-oil obtained from biomass via pyrolysis or hydrothermal treatment can also be converted into high quality liquid fuels by deoxygenation (Arumugam et.al 2007).

Biofuels can have positive or negative impacts on various issues. In order to assess benefits from the utilization of biofuels compared to fossil fuels, life cycles have to be determined. Life cycles largely depend on type of feedstock, choice of location, production of by-products, process technology and on how the fuel is used. Within this variety, the basic components of life cycles in biofuel processing are always the same (Rutz and Janssen, 2008).

In each process step of biofuel production, different actors are involved. Biomass is produced and transported by farmers. It is sometimes also transported by logistic services or by the biomass conversion industry itself. The conversion of biomass to biofuels can be either made by farmers or by industry, which is more common. Finally, biofuels are distributed by logistic services or fuel stations and consumed by private or industrial consumers. The life cycle is also influenced by horizontal attributes which have to be carefully assessed in order to allow comparisons among different biofuels: energy balance, emissions, greenhouse gas emissions, other environmental impacts, biofuel costs, and socio-economic impacts (Rutz and Janssen, 2008).

For example, total costs of biofuels at the filling station include costs for biomass production, biomass transportation, biomass conversion and distribution. Also taxes and profit margins of distributors have to be considered. External costs, like costs for environmental damages, are also important, but they are often neglected. Finally, biofuels have the potential to create socio-economic benefits. During the life cycle of biofuels, new jobs can be created and agricultural income can be increased. On the other side, labour standards have to be respected and e.g. child labour and slavery has to be avoided (Rutz and Janssen, 2008).

3.1.1 Biodiesel

Depending on the biomass feedstock and the type of technology employed in the production, biodiesel can be named either first generation or second generation biodiesel. Biodiesel produced from food crops (oil crops) and other food based feedstock (e.g. waste oil, animal waste) is often referred to as first generation biodiesel. First generation biodiesel today has a considerable market share and its production technologies are well established. Second generation biodiesel is produced form lingo-cellulosic biomass. In relation to the conversion technology, the *bio-chemical conversion* pathway is referred to first generation and the *thermo-chemical* pathway to the second generation production process.

Chemically, first generation biodiesel is equivalent to fatty acid methyl esters or ethyl esters, produced from triacylglycerols via trans-esterification or fatty acids via esterification. Fatty acid methyl esters (FAME) today are the most commonly used biodiesel type, whereas fatty acid ethyl esters (FAEE) so far have been only produced at laboratory or pilot scale (Bacovsky et al. 2007). There are many options to use different biomass feedstock types for pure plant oil (PPO) and biodiesel production. Besides dedicated oilseed crops such as rapeseed and soybean, microalgae, animal fats and waste oil provide viable feedstock opportunities for fuel production. However, these last three feedstock types are not yet used on a large-scale (Rutz and Janssen, 2008).

The most common bioenergy crop for biodiesel production in Sub-Saharan Africa is jatropha, mainly because it is non edible, drought tolerant and suitable for cultivation in almost all countries. Other potential feedstocks include coconut, oil palm, sunflower, soybean, animal fat, and castor oil. Second generation biodiesel can be produced from a wider range of feedstocks, which are represented mainly by non-food crops such as lignocellulosic materials. Mainly thermo-chemical processes are employed in converting such biomass feedstock into biodiesel (Arumugam et al. 2007).

3.1.1.1 Biodiesel production technologies

There are different possibilities to classify different biodiesel production technologies, namely according to the type of catalyst (homogenously or heterogeneously catalyzed processes), according to reaction conditions (low and high temperature and pressure reactions), or between continuous or batch operation. On the other hand, it is also possible to classify according to the type of feedstock. The so-called single feedstock technologies use half or fully refined vegetable oils like rapeseed, soybean, sunflower, etc. With these technologies the content of free fatty acids should be very low, resulting in low formation of soaps. Normally alkaline catalysts like sodium methoxide or potassium hydroxide are used, and the soaps formed as by-products during the reaction are either removed by water washing or recycled by esterification with acid catalysts. With this technology also a small amount of other feedstock like recycled frying oil or higher acidic palm oil can be blended to the refined vegetable oils (Bacovsky et al. 2007). The so-called multi-feedstock technologies are capable of processing feedstock with higher amounts of free fatty acids. Here, pre-esterification of the free fatty acids is necessary. Alternatively, all fatty material is directly converted to FAME in one step during a high pressure and temperature process. These processes are capable to process any type of feedstock, including acid oils, animal fat, high acidic palm oil or even fatty acids, and they can easily be adapted to change of feedstock (Bacovsky et al. 2007).

Apart from single and multi feedstock technologies there are small-scale production units. These plants have a production capacity of up to 5,000 t/a, using different feedstock and different production technologies. Mostly these plants have not been built by large biodiesel technology companies, but the technology has been developed by individual groups and organizations based on own experience and developments. The glycerol by-product is mostly used directly without any purification (e.g. as substrate for biogas plants). The catalyst for trans-esterification is mainly potassium hydroxide, because it leads to the highest conversion rates. Several of these production plants are organized as co-operatives, using locally produced vegetable oils as feedstock and the biodiesel as fuel for agricultural vehicles. Most very small production units do not have own facilities for quality control. Thus, the quality of the product might vary and not meet the European fuel standard EN 14214, representing a serious risk for diesel engines (Bacovsky et al. 2007).

Through thermo-chemical processes (use of high temperatures to pyrolyse or gasify biomass) lignocellulosic biomass can be converted to a raw gas or oil. The resulting gas is then treated and conditioned into synthesis gas (syngas), consisting mainly of carbon monoxide and hydrogen. This gas can further be processed into different types of liquid and gaseous fuels via different fuel syntheses. Fuels from this route are called 'synthetic biofuels' (Arumugam et al. 2007). The most promising liquid synthetic biofuel currently is BtL fuel (Biomass-to-Liquid) produced with the Fischer-Tropsch (FT) process. Gaseous synthetic biofuels are e.g. dimethylether (DME) and Bio-SNG (Synthetic Natural Gas). Bio-oil obtained from biomass via pyrolysis or hydrothermal treatment can be converted into high quality liquid fuels by deoxygenation. On the other hand, bio-chemical conversion involves pressing and/or extraction of oil from oil crops followed by the transesterification process (Arumugam et al. 2007).

3.1.1.3 Catalysts for trans-esterification and esterification reactions

(i) Homogeneous catalysts

Alkaline or basic catalysis is by far the most commonly used reaction type for biodiesel production. The main advantage of this form of catalysis over acid catalyzed transesterification is high conversion under mild conditions in comparatively short reaction times (Bacovsky et al. 2007). Moreover, alkaline catalysts are less corrosive to industrial equipment, and thus enable the use of less expensive carbon-steel reactor material. The main drawback of the technology is the sensitivity of alkaline catalysts to free fatty acids contained in the feedstock material. Therefore, alkali-catalyzed transesterification optimally work with high-quality, low-acidic vegetable oils, which are however more expensive than waste oils. If low-cost materials, such as waste fats with a high amount of free fatty acids, are processed by alkaline catalysis, deacidification or pre-esterification steps are required. Acid catalysis offers the advantage of also esterifying free fatty acids contained in the fats and oils and is therefore especially suited for the transesterification of highly acidic fatty materials (Bacovsky et al. 2007).

However, acid-catalyzed transesterification is usually far slower than alkalicatalyzed reactions and requires higher temperatures and pressures as well as higher amounts of alcohol. The typical reaction conditions for homogeneous acid catalyzed methanolysis are temperatures of up to 100°C and pressures of up to 5 bars. A further disadvantage of acid catalysis, probably prompted by the higher reaction temperatures, is an increased formation of unwanted secondary products, such as dialkylethers or glycerol ethers (Bacovsky et al. 2007). The major disadvantage of homogeneous catalysts is that they cannot be reused. Moreover, catalyst residues have to be removed from the ester product, usually necessitating several washing steps which increase production costs.

(ii) Heterogeneous catalysis

Traditional heterogeneous catalysis offer a series of advantages, such as easy separation, re-usable pure glycerol and no side products (salts) (Mittelbach 2005). There have been various attempts aimed at simplifying product purification by applying heterogeneous catalysts, which can be recovered by decantation or filtration or are alternatively used in a fixed-bed catalyst arrangement. The most frequently cited heterogeneous alkaline catalysts are carbonates and oxides of alkali metals and alkaline earth metals (Bacovsky et al. 2007).

(iii) Enzymes as catalysts

In addition to the inorganic or metallo-organic catalysts presented so far, also the use of lipases from various microorganisms has become a topic in biodiesel production. Lipases are enzymes which catalyze both the hydrolytic cleavage and the synthesis of ester bonds in glycerol esters (Bacovsky et al. 2007). As compared to other catalyst types, biocatalysts have several advantages. They enable conversion under mild temperature, pressure, and pH-conditions. Neither the ester product nor the glycerol phase has to be purified from basic catalyst residues or soaps. Therefore, phase separation is easier, high-quality glycerol can be sold as a by-product, and environmental problems due to alkaline wastewater are eliminated. Moreover, both the transesterification of triglycerides and the esterification of free fatty acids occur in one process step (Bacovsky et al. 2007). However, lipase-catalyzed transesterifications also entail a series of drawbacks. As compared to conventional alkaline catalysis, reaction efficiency tends to be poor, so that bio-catalysis usually necessitates far longer reaction times and higher catalyst concentrations. The main hurdle to the application of lipases in industrial biodiesel production is their high price, especially if they are used in the form of highly-purified, extra cellular enzyme preparations, which cannot be recovered from the reaction products (Bacovsky et al. 2007).

3.2 Decision Support Tools

This section of the report provides brief descriptions of various decision support systems reviewed as part of this research with the view to drawing lessons on their development. The decision support tools considered include; (i) decision support tool to evaluate alternative policies regulating wind integration into autonomous energy systems, (ii) decision support system for exploiting local renewable energy sources- a case study of the Chigu area of south-western Taiwan, and (iii) Development of decision support systems for bioenergy applications

3.2.1 DST to evaluate alternative policies regulating wind integration

Integration of wind power into autonomous electricity systems strongly depends on the specific technical characteristics of these systems; the regulations applied should take into account physical system constraints. Introduction of market rules makes the issue even more complicated since the interests of the market participants often conflict each other. In this paper, an integrated tool for the comparative assessment of alternative regulatory policies was presented along with a methodology for decision-making, based on alternative scenarios analysis. The social welfare concept is followed instead of the traditional Least Cost Planning (Zouros N et.al, 2005).

The paper concluded that the policies for wind power exploitation in autonomous systems should take into account all relevant technical issues and the special characteristics of each system since they strongly affect economics of the market participants. In this paper, an integrated methodology and associated tools to assess the impact of large-scale wind penetration into autonomous electricity systems was presented. The social welfare concept is proposed vs. the traditional least cost optimization as an unbiased criterion in the new market-oriented environment. The paper reports on a number of emerging technical issues related to wind exploitation in autonomous systems, i.e. estimation of the secure wind power penetration, optimization of network interface, transmission expansion, production simulation, and economical analysis. The integration of the methodologies proposed in a tool and its utilization for decision-making and evaluation of alternative policies were also discussed (Zouros N et.al, 2005).

3.2.2 DST for exploiting local renewable energy sources

A case study of the Chigu area of south-western Taiwan

The topic of climate and energy policy has drawn new attention since the Kyoto Protocol has now come into force. It is hoped that strengthened use of renewable energy sources can meet new international environmental requirements and provide self-sufficient domestic energy supplies. The decision support system established in this study integrated potential evaluations, cost analyses, legal incentives, and analysis of returns on investments with the aid of a geographic information system (GIS). This system can provide insights for policymakers into where and the extent of the potentials, for lawmakers into whether the current legal incentives are sufficient to encourage private investment, and for investors into whether investments in exploiting local renewable energy sources are economically feasible.

Under the current incentive framework in Taiwan, the amortization periods of investment on renewable energy are generally longer than the period over which the investment is to be recovered. This presents an unfavourable condition for attracting investments to and for developing renewable energy. An increase in remuneration through legal revisions is needed before domestic investment in renewable energy will actively expand (Cheng-Dar Yue and Grant Gwo-Liang Yang; 2007).

This study which attempted to establish a decision support system for exploiting local renewable energy sources reached the following conclusion. The decision support system established in this study integrates evaluation of the potential, cost analysis, legal incentives, and analysis of the return on investments with the aid of a GIS. By increasing the feed-in tariff from US$0.063 to 0.10/kWh, the annual mean wind speed of areas attractive for investment would decrease from 5.3 to 4.5 m/s, and the share of wind resources attractive for exploitation of the total wind potential exploitable in the Chigu area with annual mean wind speeds exceeding 4 m/s would increase from 15.3% to 97.8% ((Cheng-Dar Yue and Grant Gwo-Liang Yang; 2007).).

With current capital grants from the government at 50% of capital costs, a remuneration price of US$0.50/kWh is needed for a household installation of a rooftop PV system of 2 kW in order to provide an amortization period of 20 years relative to 30 years over which the investment is to be recovered. Remuneration prices of US$0.55/litre and US$0.65/litre are needed for ethanol and biodiesel production, respectively, in order to provide an amortization period of 11 years relative to the 15 years over which the investment is to be recovered. These prices are already lower than the market price of gasoline and diesel at US$0.92 and US$0.66/litre, respectively, and present a profit potential for investors. The probable further increases in oil prices in the future would make the investment even more profitable. The current legal framework providing a single remuneration price for electricity generated by various renewable energy sources in Taiwan does not appear to be adequate, for different kinds of renewable energy sources require different levels of financial support according to individual energy and environmental benefits and energy costs((Cheng-Dar Yue and Grant Gwo-Liang Yang; 2007).).

In addition to legislatively stipulated remuneration prices as an economic tool, institutional regulation would be effective and complementary for introducing new alternatives to the energy market to overcome structural and non-cost factors of the barriers to introducing new technologies. A decision support system involving an analysis of current investment incentives and sensitivity analyses can help policymakers choose adequate and sufficient remuneration intensities in order to attract private investment in renewables. The decision support tool integrating potential evaluations, cost analyses, legal incentives, and analyses of returns on investments is applicable to other forms of renewable energy sources, and also transferable to localities in other countries where an energy supply system from renewables is to be established ((Cheng-Dar Yue and Grant Gwo-Liang Yang; 2007).).

The decision support system established in this study with the aid of a GIS can facilitate the evaluation of investing in local renewable energy sources. The information produced may provide insights for investors, policymakers, and lawmakers to exploit more sustainable energy systems based on locally available natural resources. This appears particularly significant for countries such as Taiwan who are tackling the thorny problems of surging domestic energy demand and greenhouse gas emissions in a time when international climate policy has begun to seriously mitigate greenhouse gas emissions in the post-Kyoto era ((Cheng-Dar Yue and Grant Gwo-Liang Yang; 2007).).

3.2.3 Development of decision support systems for bioenergy applications

As the amount and complexity of information relating to the development of bioenergy systems increases so does the problem of how to handle the information in a manner which is helpful for decision making. Hypertext-based information systems and decision support systems are being developed to aid deployment of bioenergy systems. These approaches are discussed with reference to a short rotation forestry production information system and decision support systems for harvesting wood for energy from conventional forestry and short rotation forestry. The development of a model which integrates biomass production, conversion and electricity generation is discussed. Problems encountered when combining different models into an integrated model are addressed (Mitchell, 2000).

A suite of applications has been developed covering short rotation coppice using information and data collected from actual field trials. The first of these is the Coppice Decision Support System (CDSS) which is a spreadsheet model that can be used to model the costs of growing short rotation coppice under UK conditions. The user can chose whether to grow willows or poplars, select a cutting cycle, the operations to be undertaken by farm labour or contractors, and estimate yield. Land rent is considered and there is an option to include subsidies. CDSS calculates the cost of production in terms of \$/wet tonne; \$/dry tonne; \$/GJ and net present value once a discount rate has been selected. The second system is the Coppice Harvesting Decision Support System (CHDSS) which was written in Visual Basic 3. CHDSS was developed using data and functions collected and derived during a series of trials of harvesting, storage, drying and delivery systems conducted in Europe. It models the supply chain from the standing coppice crop through harvesting, storage and transport and contains extensive in formation about each of the harvesters evaluated in the field trials (Mitchell , 2000).

The program works in the Microsoft Windows environment. The user selects from a number of options which define the system being analysed. The user progresses through the following screens to define the system. Defining the machine and crop (machine used, species, plantation design and method of working). Defining the system in terms of basic density of the products and moisture content. Defining the point at which comminution is carried out. Selecting from a range of primary and secondary transport options. Selecting the form of stored product and the method and length of time in storage. CHDSS allows the examination of supply scenarios for the delivery of wood fuel of different specifications (e.g. form and moisture content) and generates results in terms of costs (euros) to deliver one oven dry tonne of woody biomass to the power or district heating plant. Costs are generated separately for each of the elements in the supply chain (crop, harvest, chipping of whole shoots, storage and transport). A potential problem with such a development is one of size and run times (although these are becoming less of an issue with increased computer memories and speeds) (Mitchell , 2000).

When developing applications of this nature the question of who the product is aimed at needs to be addressed. Many models are only used in-house, often because of the difficulties of updating the information, protecting the software or providing help and maintenance. There are not many examples of models being sold commercially. Where the model is used in-house the use of the package is closely controlled and the results can be readily interpreted and reported. For something like short rotation coppice, there is a perception that colleges, extension agents and even practitioners need the model to help them through the planning and decision stages of project development.

These different constituencies probably operate with similar information but will be asking different questions and will probably require different reporting formats. A recent study in Canada on the use of DSS provided by companies to aid forest operations planning found that most forest managers relied more on their own knowledge rather than that held in a computer. The situation may be radically different in a new practice, such as short rotation coppice, where managers do not have any or much previous knowledge of the system. A significant problem with all such systems is that experience and new knowledge soon overrides the specifications of the systems, hence the need to build in flexibility for continued development (Mitchell , 2000).

3.2.4 Decision Support Tool for Biofuels

The International Centre for Science and High Technology (ICS UNIDO) in collaboration with German Biomass Research Centre (DBFZ) attempted to develop an Excel based prototype DST for biofuels. The tool focused on rapeseed and life cycle analysis was restricted to climate change impact category only. In addition, financial analysis considered unit production cost only as an output and indicator.

The DST being developed as part of this research considers two feedstock options namely, jatropha and soy beans as opposed to one provided in the ICS UNIDO tool. Further, financial analysis considers several indicators to include; annual expected profit, net present value, return on investment, simple payback period, and unit production cost. As regards life cycle analysis, the tool takes account of mid-point environmental impacts categories which include; human toxicity, climate change, photoxidant, acidification, eutrophication and land competition.

Whereas the ICS UNIDO tool considered only unit production cost and climate change and primary energy demand, in multi criteria analysis, the indicators used in this tool include; total normalised environment score, land competition, primary energy demand, return on investment, simple payback period, net present value, unit production cost, and jobs created. It should be noted that total normalised environment score takes account of all the six mid-point environmental impact categories mention above.

3.3 Life Cycle Analysis

The increased awareness of the importance of environmental protection, and the possible environmental impacts associated with products, both manufactured and consumed, has increased interest in the development of methods to better understand and address these impacts. One of the techniques developed for this purpose is life cycle assessment (LCA)(ISO 14040, 2006). LCA addresses the environmental aspects and potential environmental impacts and it considers use of resources and the environmental consequences of releases) throughout a product's life cycle, that is, from raw material acquisition through production, use, end of- life treatment, recycling and final disposal (i.e. cradle-to-grave). LCA can assist in identifying opportunities to improve environmental performance of products at various points in their life cycle, Strategic planning, priority setting, product or process design or redesign, Selection of relevant indicators of environmental performance and Marketing (e.g. eco-labelling scheme, making an environmental claim, or producing an environmental product declaration).

The framework (Figure 3.2) for Life Cycle Analysis involves Goal and scope definition, Life cycle inventory analysis (LCI), Life cycle impact assessment (LCIA), Life cycle interpretation and Reporting. The international standards contained in the 14040 series (ISO 14040; 2006) provide a basic framework in which the LCA is undertaken.

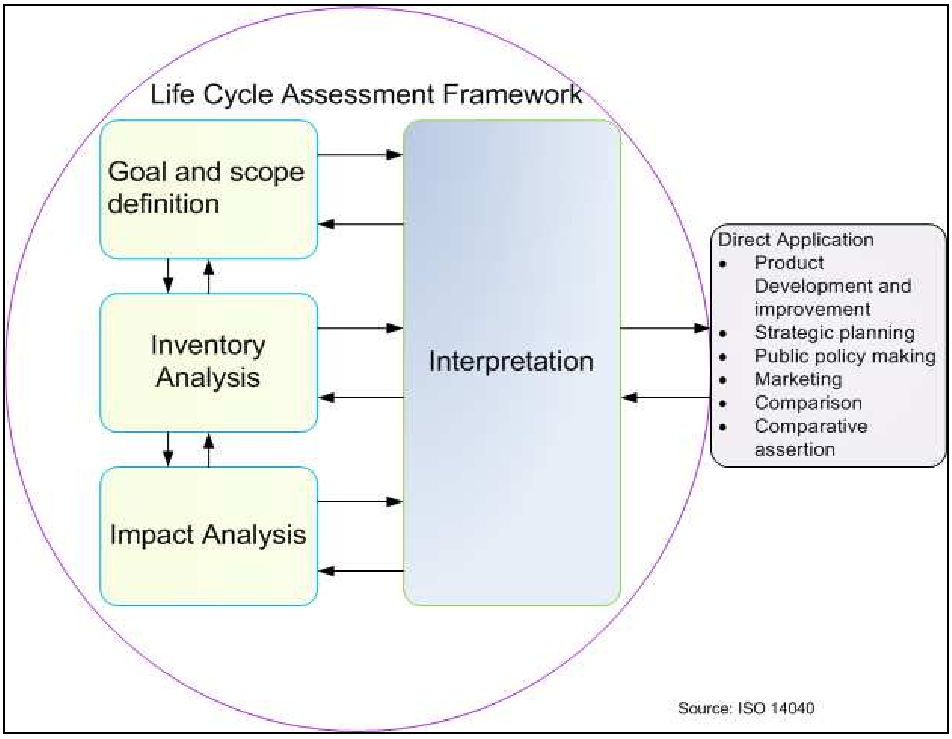


Figure 3.2 Life cycle assessment framework

(a) Goal and scope definition

The goal and scope definition considers the following: (i) intended application, (e.g. product development and improvement, strategic planning, public decision making, prioritisation, Marketing, Parties involved etc, (ii) scope definition entails entails deciding on type of LCA to apply. Type of LCAs include; attributional or consequential LCA, structural decision(s), detailed LCA, geographical coverage, technology consideration, coverage of processes, coverage of interventions and impacts, (iii) system qualities identification entails determination of system function, functional unit, selection of alternatives, and determination of reference flow for each alternative (ISO 14044, 2006).

(b) Life Cycle Inventory (LCI)

LCI analysis is the LCA phase involving the compilation and quantification of inputs and outputs, for a given product system throughout its life cycle)(ISO 14040). Key aspects in LCI are; (i) economic system boundaries which boundary separates what is included in the product system from what is excluded, (ii) flow diagrammes which is a presentation of a graphical representation of structure of product system showing the interdependence of economic processes , (iii) format and data categories, (iv) cutt of and data estimation(trade off), (v) multifunctionality and allocation (system expansion, substitution, or partitioning/allocation), (vi) calculation, and (vii) results of Inventory analysis.

(c) Impact Analysis

LCA impact assessment is aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system. Key issues considered under this aspect are selection of impact categories, and selection of characterisation methods, category indicators, characterisation models and factors (Table 3.1). For example, CO_2 and CH_4 both contribute to climate change. Global Warming Potential (GWP) is a measure for climate change in terms of infrared radiative forcing of a mass-unit of greenhouse gas (UNEP, 2008).

Table 3.1 Impact categories and respective indicators

Impact Category	Indicator	Characterisation Model	Characterisation Factor	Equivalency unit
Abiotic depletion	Ultimate reserve/annual use	Guineee & Heijungs 95	Abiotic depletion potential	Kg Sb eq.
Climate Change	Infrared radiative forcing	Intergovernmental Panel on Climate Change	Global warning potential	Kg CO_2 eq.
Stratospehric ozone depletion	Stratospheric ozone breakdown	World Meteorological Organisation model	Stratospheric ozone layer depletion potential	Kg CFC-11 eq.
Human toxicity	Predicted daily intake, accepted daily intake	EUSES, California Toxicology Model	Human toxicity potential	Kg 1,4-DCB eq.
Ecological toxicity	PEC, PNEC	EUSES, California Toxicology Model	AETP, TETP, etc	Kg 1,4-DCB eq
Photo-oxidant smog	Tropospheric ozone production	UN-ECE trajectory model	Photo-oxidant chemical potential	Kg C_2H_6 eq
Acidification	Deposition/critical load	Regional acidification information & Simulation	Acidification potential	Kg SO_2 eq.

Source: UNEP, 2008 LCA Training Kit

(d) Optional Steps

Optional steps in LCA include; classification, characterisation (mid-point and endpoint-oriented), normalisation, grouping and weighting.

(e) Intepretation

LCA intepretation involves consistence check, completness check, sensitivity and uncertainty, conclusion and recommendation (UNEP, 2008).

3.4 Multi-Criteria Analysis

MCA is a tool developed for complex multi-criteria problems that include qualitative and quantitative aspects. There are several types of MCA methods available. The following MCA methods are summarised and discussed below (Yamba, 2005)

(i) Preferential Ranking

This is the simplest approach to ranking, and does not require scoring as such but indicates differences between indicators with '+' and '-' signs (Yamba, 2005).

(ii) Normal Ranking

Normal Ranking and preferential ranking are very closely related, except that in normal ranking the range is indicated with numbers rather than + and- symbols. Ranks are assigned according to a scale shown in table 3.2

Table 3.2 Scale of ranking

1	3	5	7	9
Weakly important	Less Important	Moderately Important	More Important	Extremely Important

(iii) Ordinal Ranking

Ordinal Ranking is a technique where each expert is asked to put the list of decision elements in order of importance. Unlike regular ranking where different decision elements can be given the same ranking, ordinal ranking forces the experts to put the elements in a hierarchy of importance; each element is deemed more or less important relative to the other elements involved (Yamba, 2005)

(iv) Rating

Rating requires that a decision maker to allocate an indicator a score between 1 and 100. Ideally the total will add up to 100 but this is rarely the case in practice and usually totals will have to be corrected once indicators scored, in order to ensure the total is 100.

(v) Pair-wise ranking

Pair wise ranking is simply a round tournament technique by which every item in a list is compared to every other item according to a single criterion. Each sustainable development criteria is compared with each other species, and one of the two is selected as better for that particular use. At the end the indicators are ranked according to the number of times they were chosen as the better of the pair. Pair wise ranking therefore indicates the degree to which one indicator is considered more important than another (Yamba, 2005).

(vi) Decision hierarchy

Decision Hierarchy is an approach that combines normal ranking and pair-wise ranking with simple vector mathematics. It was developed to assist decision makers select the best criteria when such a choice involved the comparison of dissimilar criteria (e.g. could be a quantifiable criteria such as cost and an qualitative criteria such as social benefit). The framework can be extended to many levels of criteria, each a function of the previous level. If we want to rank the sustainable development principles of Social, Environment and Economic factors, pair-wise ranking method described above can be used. However, rather than simply stating which indicator of the pair is better than the other, each indicator is ranked in terms of a normal ranking scale to identify the extent to which it is better than the other. In this first prototype Decision Support Tool Normal Ranking approach was employed

MCA uses criteria, scores and weightings, which are necessarily subjective concepts, requiring human judgement for their determination. It therefore acknowledges the fact that there is no such thing as objective decision and subjective judgements are explicitly elicited, encoded and tested for coherence against uncertainties.

The decision process in general has the following elements:

1. Selection of appropriate Multi Criteria Analysis ranking method

2. Identification of sustainable development criteria under mitigation and adaptation
3. Identification of indicators under each criteria
4. Scoring which is essentially an assessment of expected performance of each option against the criteria
5. Weighting which entails assigning weights for each of the criteria to reflect their relative importance to the decision
6. Combination of weights and scores in a linear additive manner for each option to derive an overall expected value
7. Obtaining and examining of results
8. Sensitivity analysis on uncertainties in scores and weights, perspectives and "what if" scenarios
9. Iteration of above steps to achieve better results

For the purpose of this study, a combination of Rating and Normal Ranking approaches have been used. The rating approach gives appropriate weighting to the three broadly agreed upon principles of sustainable development goals, namely economic, technical, environmental and social. Indicators related to each of these principles are then identified in relation to the indicators agreed upon. The normal approach then weighs each indicator in each given category after which the total marks accrued are proportionally related to a percentage of a given category. Under this process the following weightings for the main principles are used but they can be adjusted accordingly. In this research the weighting used were economic 38%, environmental 33%, and social 29%. The rationale behind this weighting is development should be carried out in an environmentally friendly manner and thus improve the social life.

CHAPTER 4 ANALYSIS OF DST DEVELOPMENT

4.1 Biofuels Decision Support Tool Composition

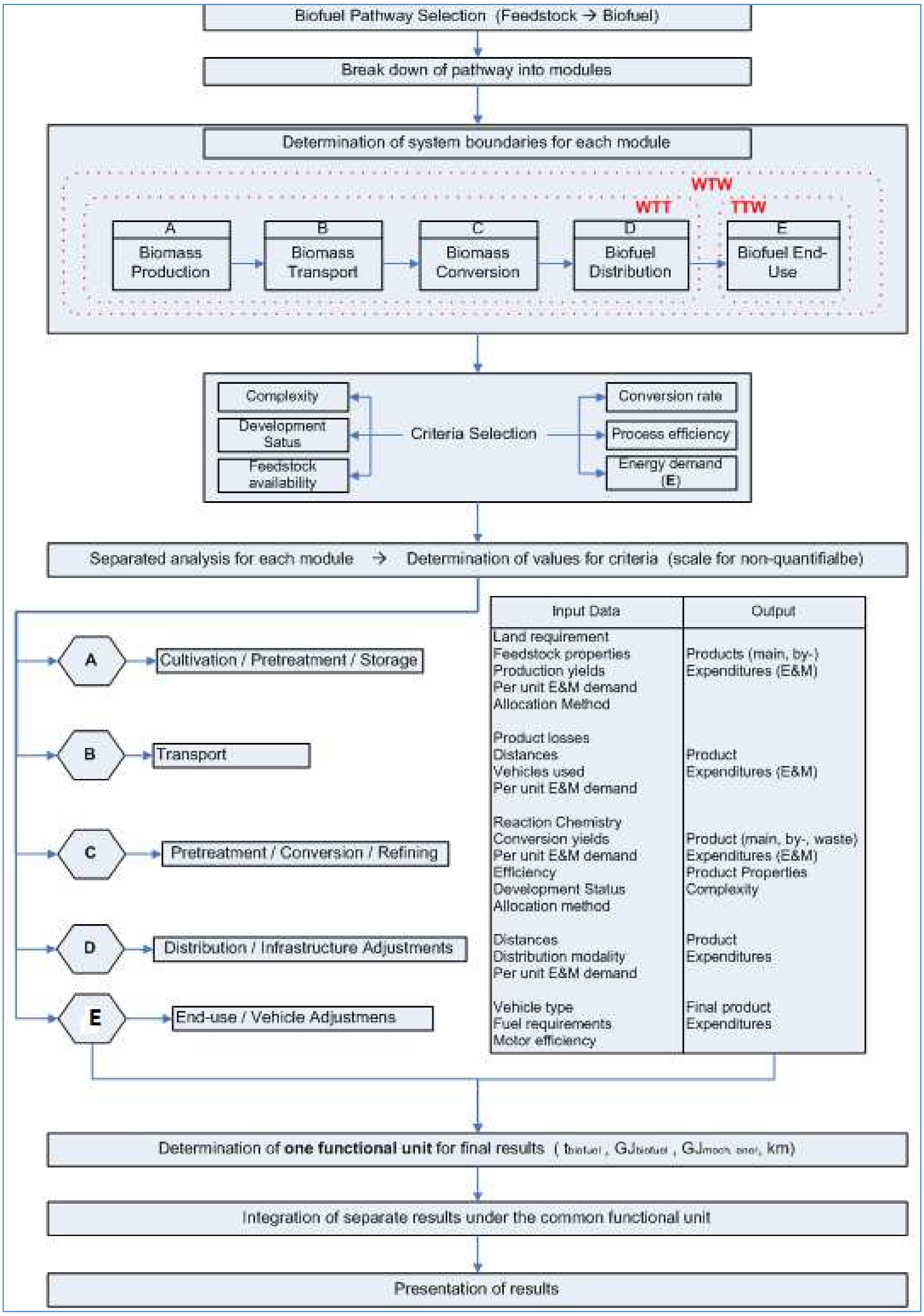
DSTs are based on data collection, modelling and analysis of information according to defined criteria. A decision support tool can offer substantial assistance to the assessment of different biofuel production pathways, and different bio-feedstock exploitation scenarios. The proper evaluation of related production processes is based on their sustainability analysis, which implies the assessment of associated economic and environmental indicators. The analysis of DST follows a Well-to-Tank approach involving biomass production, transportation, crude oil extraction, biodiesel production and end use.

In this research, the framework of a decision support tool has been developed, in an effort to efficiently handle the huge information associated with biofuels assessment and provide the decision maker with an effective and easier means to investigate various biofuel options from well-to-tank. This will enable users to make informed desions to come up with the most cost effective and environmentally sound pathway. The intended benefeciaries of the tool include; decision makers, policy makers, business entrepreneurs and academic stakeholders involved in technology transfer activities.

4.1.1 Overview of DST Development

The DST constitutes of five modules namely, biomass production assessment, biofuels production assessment, economic assessment, social assessments and environment (life cycle analysis) modules. Each module contains a number of components that interrelate to produce modular output for use in the subsequent modules or provide output to the user. The interrelationships among modules is governed by numerous algorithms.

Provided on figure 4.1 is a flow chart for the determination of all the relevant algorithms and respective parameters of the technical aspect of a biofuel option. It presents the different steps required in order to reach the final result, that is, from the biofuel pathway selection to the criteria selection and the presentation of the results.



DBFZ, 2008

Figure 4.1 DST flow chart

The first step involved in the decision process is the selection of a biofuel pathway. Biodiesel or bio-ethanol can be produced, from a single or several resources via a variety of pathways. A complete pathway is the combination of successive stages necessary to turn the resource into a fuel. The processes involved in these stages may be common to several pathways (EUCAR 2007). To depict this succession of processes and for a better analysis, the pathway was broken down into stages. In this work, each pathway is separated into five primary stages that define the whole course of production.

Each of the aforementioned stages consists of several processes. The pathway that incorporates the first four stages, namely from the production of the resource up to the provision of the fuel in the vehicle tank is referred to as the Well-to-Tank (WTT) pathway. The fifth stage, namely the use of the biofuel in the vehicle motor, is referred to as the Tank-to-Wheel (TTW) pathway. The integration of the two pathways together, is referred to as the Well-to-Wheel (WTW) pathway and follows the course of the whole pathway. The analysis in this work is based on the WTT concept.

After breaking down the pathway into stages, the criteria for each module are identified and this provides the basis for the analysis. As stated earlier, each module produces output (parameters) that define its performance. These parameters are termed as indicators since they define the performance of a module. Overall performance of a module is termed as criteria and these were selected under the following principles: (i) whole range representation without being numerous, (ii) straightforward and not ambiguous in terms of definition, (iii) less complex calculations that would divert the point of attention from the essence of the analysis and, (iv) general but clear idea of the technical performance of an option.

The criteria are grouped according the modules. The financial analysis criteria are based on financial indicators and include; profitability, pay-back period, net present value (NPV), unit production cost and annual expected profit. Environmental criteria has two indicators based on results of Life Cycle Analysis and these are; total normalised environment score and land competition. Total normalized environmental score encompasses several environmental impact categories to include; abiotic depletion, climate change, stratospehric ozone depletion, human toxicity photo-oxidant smog formation and acidification. The social criterion considered in this research as part of DST development, was direct jobs created which is a common quantifiable social indicator.

(a) Biomass Production Assessment Module

The biomass production module is the stage where the feedstock of the process is made available before transportation to the conversion facilities. The biomass production involve production (cultivation, harvesting), pre-treatment (separation, drying, shredding, etc.) and storage. As part of module development, the most essential step for this module is the selection of the appropriate feedstock. Selection of feedstock for implementation is dependent on several factors such as the availability of the feedstock, the chemical and physical properties of the feedstock, the type and availability of land, the desired final product (e.g. energy, fuels or chemicals), the conversion rate of the feedstock, the regional weather and climate conditions, the amount and availability of resources (e.g. energy, material, water) required for their production and others.

Analysis was carried out with the aim of determining the product output of the module. Depending on the feedstock, the sequence of processes is different. For example, residues need no cultivation or harvesting. For the determination of the criteria value for this module information such as land requirement (if cultivation is needed), material input per product unit (fertilizers, pesticides, other chemicals), energy input per product unit (electricity, heat, fuel), product and by-product yield (if not residues), water demand, economic, environmental and social aspects are needed.

(b) Biofuels Production Assessment Module

Once biomass is delivered to the plant, it is ready to be processed in order to generate the desired biofuel. Biofuels production module involves more than one step to realise the final product. First the biomass delivered is stored in order to be ready for treatment. Then it is subjected to a pre-treatment stage where it is transformed in a form more suitable for conversion. This may include processes such as drying, shredding, mashing, conditioning with chemicals and others. The conversion step follows and may consist of more than one stage until the final product is reached. In this work, each conversion process is treated separately, meaning that each has its own products and by-products, separate auxiliaries and generates separate emissions. The last step is the refining stage, where the separation of by-products and impurities and the upgrading of the final product take place. The sequence and type of processes applied depend on the technology selected for the conversion.

(c) Economics Assessment Module

Economic sustainability assumes that economic development needs to occur without jeopardising the social and environmental dimensions of development. The bottom line is to ensure attainment of economic efficiency and improved rational use of natural resources as a key component of economic development, taking into account the equitable distribution of wealth in the society and the preservation of the ecosystem's functions (Stavroulia, 2003).

Economic viability of a pathway is normally assessed against NPV, capital efficiency, return on average capital employed, IRR, payback period, risk management, sensitivity analysis and production cost. However, for the purpose of this study, only net present value, annual production costs, return on investment, payback period and unit production cost have been considered.

(d) Social Assessment Module

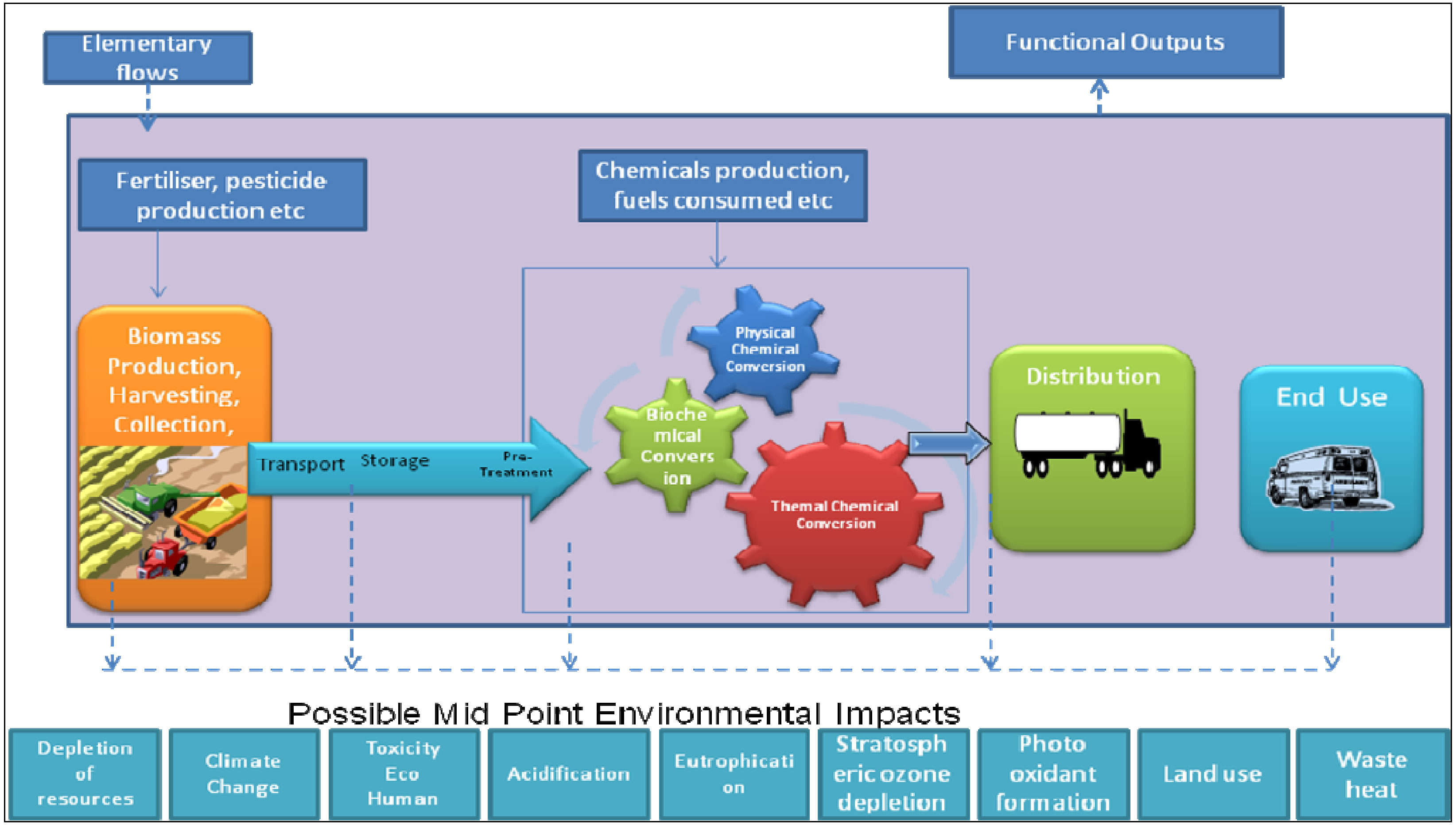
Renewable energy sources offer a diverse array of jobs and they also tend to offer more jobs than conventional energy sources. Biomass is particularly employment intensive (Domac et al 2005). Socio-economic benefits of bioenergy use can clearly be identified as a significant driving force in increasing the share of bioenergy in the total energy supply. Avoiding carbon emissions, environment protection, security of energy supply on a national level or other issues are for local communities an added bonus, but the primary driving force are much more likely to be employment or job creation, contribution to regional economy and income improvement.

Direct employment results from operation, construction and production. In the case of bioenergy systems, this refers to total labour necessary for crop production, construction, operation and maintenance of conversion plant and for transporting biomass. On the other hand, indirect employment comes from jobs generated within the economy as a result of expenditures related to the said fuel cycles. Indirect employment results from all activities connected, but not directly related, like supporting industries, services and similar activities. The higher purchasing power, due to increased earnings from direct and indirect jobs may also create opportunities for new secondary jobs, which may attract people to stay or even to move in. These latter effects are referred to as induced employment (Domac et al 2005). For the purpose of this DTS, only direct employment creation has been considered.

(e) Life Cycle Analysis Module

Objectives in LCA for biofuels are to; (i) provide quantified life cycle analyses (LCAs) of the environmental outcomes, (ii) identify environmental advantages and disadvantages of biofuels in comparison to conventional fuels, (iii) estimate reduction potential for GHG emissions due to the use of bio-fuels, (iv) understand better production pathways for different biofuels, (v) learn and compare different production routes and biomass sources for biofuels as far as the environment is concerned, (vi) to improve production routes for biofuels.

System boundary for biofuels is based on Well-to-Tank (WTT) which involves resource extraction or biomass production, transportation, storage, fuel processing and distribution. The extent to which biofuels provide environmental and health benefits depends not only on the type of fuel, but also on its production and use. Life cycle analysis (LCA) of locally produced biofuels gives credibility to their greenhouse potential, particularly for export markets or where carbon trading is involved. Provided in figure 4.2 is LCA system boundary for biofuels.



Source: Adapted from UNEP, 2008 LCA Training Kit

Figure 4.2 LCA System boundary for biofuels

LCA results are always calculated relative to the delivery of utility or function, usually a product or service. Most product systems are focused around a primary function while, along the way, contributing to other product systems or providing other utilities that can be seen as secondary functions.

In case of a biodiesel plant, the primary function of the biodiesel plant is the production of fuel-grade biodiesel for use in transport fuels. Because of price volatility in the marketplaces for tallow, biodiesel and glycerol, conditions might arise when the main co-product, namely glycerol, could be regarded as the plant's primary function. The secondary function of the biodiesel plant is assumed to be glycerol production (CSIRO, 2008).

The functional unit in LCA quantifies the system functions and defines the basis for comparison of systems alternatives. The functional unit incorporates all the services provided by all the scenarios.

(f) Multi Criteria Analysis

Provided in table 4.1 are ranges of figures that were provided to govern the scoring for each indicator of the three criteria (economic, environmental and social). Scoring for each indicator is picked automatically from computed values of the indicators from the modules.

Table 4.1 Ranking of biofuels production pathway and overall DST indicators,

Points received	Ranking (Normal)					
Range of performance	1	3	5	7	9	Total
Criterion	Weakly important	Less Important	Moderately Important	More Important	Extremely Important	
ECONOMIC						
Unit Production Cost (UP) US$	1<UP<10	0.8>UP<1.0	0.4>UP<0.8	0.1>UP<0.4	0>UP<0.1	
Payback period (PP) Years	PP>50	50>PP<20	20>PP<15	15>PP<5	5<PP<0	
Return on Investment (PFB) (%)	0>PFB<2	2>PFB<5	5>PFB<10	10>PFB<20	20<PFB<100	
Annual expected profit (EP) million US$	0 >EP < 1	1 >EP < 10	10> AP < 30	30> EP < 60	EP < 60	
Sub Total						
ENVIRONMENT						
Total Normalised[1]	TN> 2	0.8>TN<1	0.1>TN<0.8	0.02>TN<0.08	0>TN<0.02	
Sub Total						
SOCIAL						
Direct jobs created per tonne of biodiesel (J)	0>J<0.06	0.06>J<0.08	0.08>J<0.10	0.10>J<0.16	J> 0.16	
Total						

Source: Own analysis

Overall score assessment of the final score of a pathway was computed as provided in table 4.2.

[1] Total normalised include; climate change, human toxicity, acidification, photo oxidant smog formation, and Stratospheric ozone depletion

Table 4.2 Overall assessments for criteria for DST based on the rating

Indicator	Marks Obtained	Representative Weighting (%)	Total (%)
Economic	Total score economic	38	=Total score economic X 38/100
Environmental	Total score environmental	33	=Total score environment X 33/100
Social	Total score Jobs	29	=Total score Social X 29/100
Total		100	**Overall score(sum of scores)**

Source: Own analysis

4.2 Algorithms for Biofuels Decision Support Tool

4.2.1 Algorithms for Biomass Production Module

The biomass production module consists of several linked components that make up the structure of the module. These components include; land requirements, seed consumption, fertilisers, pesticides, herbicides, agriculture lime, water, electricity for water pumping, and diesel for field transport. In each of these components, algorithms were provided for computations and analysis on financial, environmental, and social modules.

On using the DST, the user begins with selection of biofuel type biodiesel or bioethanol (Figure 4.3). This is followed by selection of energy crop of interest which give rise to acquisition of "energy crop yield" from the database in the DST. Subsequent selections and data input are then made until final result is obtained.

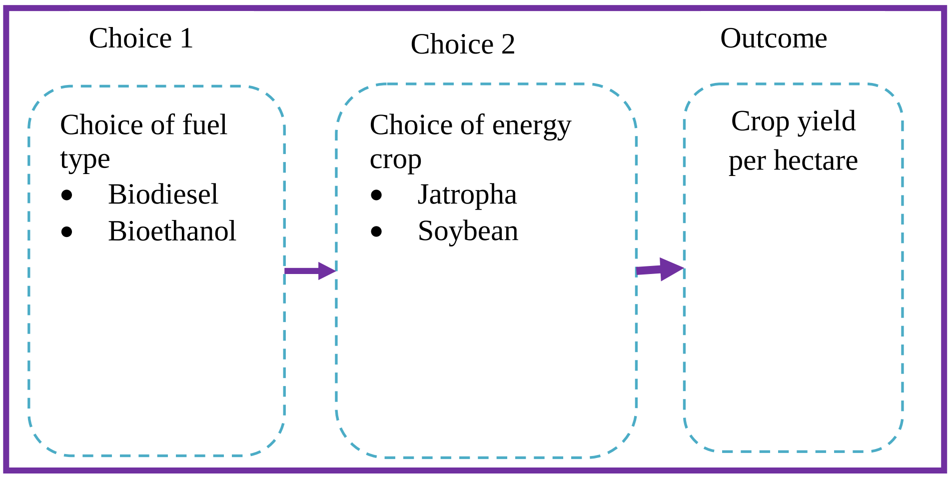


Figure 4.3 User´s choices and choices´ outcome

Biomass module algorithms have been developed for its components which include land requirements, seed consumption, fertilisers, pesticides, herbicides, agriculture lime, water, electricity for water pumping, and diesel for field transport, and are provided as follows:

(a) Land Requirements

BM - total biomass(energy crop) required (tonnes); will vary depending on the oil crop chosen. In case of sugar cane, BM will vary also according to the production scenario of a factory**.** Calculations of land requirements for oil crops to include jatropha, soybean, and rapeseed are provided in equations 4.1 and 4.2 (Rossilo-Calle, 2010).

$$LAND = \frac{BM}{BMy * HTY} \qquad 4.1$$

$LAND$ - total annual land requirement (hectares); BM - total biomass (energy crop) required (tonnes); BMy - Biomass (Oil crop) yield per hectare (tonnes/hectare); HTY - Number of harvest times in a year *(Source: Own analysis).*

$$BM = \frac{BF * \rho_{fuel}}{OC * PG * \left[(1 - PG) * HE_{efficiency}\right] * OFE * 1000} \qquad 4.\ 2$$

BM - total biomass (energy crop) required (tonnes); BF - total annual desired biofuels production (litres); OC - percentage oil content in seed(%); PG - percentage pressing grade of oil press (%), $HE_{efficiency}$ - hexane extraction efficiency (%), OFE - Crude oil to biofuel conversion efficiency (%), ρ_{fuel} - density of biofuel (kg/litre) (*Source: Own analysis*).

(b) Seed Consumption

Each bioenergy crop in the database is attached with crop yields per hectare, seed requirement per hectare and other parameters. The crop yield per hectare and the pre-defined biofuel quantity determines the area required for energy crop cultivation to satisfy the demand. The seed requirement per hectare can either be user defined or default from the database depending on the user's desire (Equation 4.3).

$$C_{Seed\ annual} = C_{specific\ seed} * BM \qquad 4.3$$

$C_{Seed\ annual}$ - total annual seed requirement (kg) ; $C_{Specific\ seed}$ - specific seed requirement (kg/tonne of biomass (energy crop); BM - total biomass (energy crop) required (tonnes). Source: Own analysis.

(c) Fertilisers, Pesticides; Herbicides and Lime

Fertiliser entity of this component which is contained in the database allows the user to first select desired types of fertiliser to apply so as to suit the soil characteristics and cultivated crop among other conditions. The choice is made through a "drop down list" containing various types of fertilisers to include; anhydrous ammonia, urea, ammonium nitrate, ammonium sulphate, and ammonium chloride (Table 4.3). The Others include (P_2O_5), potash (K), Nitrogen (N), manure (press cake), manure (cow dung), sulphur (s), Zinc, lime and other manure.

Table 4.3 Equivalent nitrogen content of common chemical fertilizers

Type of fertiliser	Chemical Formula	Nitrogen Content (Weight Percent)	Equivalent Nitrogen Content, lb fertiliser per kg N
Anhydrous ammonia	NH_3	82.3	0.55
Urea	$CO(NH_2)_2$	46.7	0.95
Ammonium nitrate	NH_4NO_3	35.0	1.32
Ammonium sulfate	$(NH4)_2SO_4$	21.2	2.14
Ammonium Chloride	NH4Cl	26.2	1.73

Source: www.epa.gov/ttnchie1/ap42/ch09/draft/d09s0201.pdf

The user is at liberty to select one or more fertiliser types from the database to suit the prevailing conditions. Besides, the user can also input other forms of fertiliser not listed in the drop down list if need arise. In such cases, application rates of that particular fertiliser has to be provided. The algorithm and function governing fertiliser type, lime, herbicides and insecticides is provided in equation 4.4

4.4

$$C_{f(i)} = C_{sp(i)} * BM$$

$C_{f(i)}$ - total annual quantities requirement (tonnes) for any fertiliser, pesticide, insecticide and lime; $C_{sp(i)}$ - specific requirement of any fertiliser, pesticide, insecticide and lime (tonne/tonne of biomass (energy crop); BM - total biomass (energy crop) required (tonnes) (Source: Own analysis).

(d) Water requirements and electricity for water pumping

Irrigation component of the biomass production module provides water requirements for irrigation. The algorithms for water requirements and electricity requirements for water pumping is provided in equations 4.5 and equation 4.6) (Rossilo-Calle, 2010).

4.5

$$C_{water} = \frac{C_{specific\ water}}{1000} * LAND * 10000$$

4.6

$$C_{electricity} = C_{specitic\ \ electricity} * LAND$$

$C_{electiricity}$ - total annual electricity requirements (kWh) ; $C_{Specific\ electricity}$ - specific electricity requirements (kWh/hectare); $LAND$ -total annual land requirement (hectares)-calculated from equation 1, $C_{Specific\ water}$ - specific water requirements (litres/hectare) *(Source: Own analysis).*

(e) Diesel for Field Transport

Field transport in this context implies usage of machinery such as tractors, combine harvesters, sprayers and other forms of motorised transport used for bioenergy crop production. The purpose of this component is to estimate the annual fuel requirements (equation 4.7) for energy crop production.

4.7

$$C_{diesel} = C_{specitic\ \ diesel} * LAND$$

C_{diesel} - total annual diesel requirements (litres, $C_{Specific\ diesel}$ -

specific electricity requirements (kWh/hectare); $LAND$ -total annual land requirement (hectares) *(Source: Own analysis).*

4.2.2 Algorithms for Biofuels Production Module

The biofuels production module consists of biodiesel module containing several components (i.e. feedstock, chemical recipe and other consumables, residue and waste material, and by products).

(a) Biodiesel Production

Biodiesel production is generally produced in two stages. Biomass conversion and biodiesel production. Biomass conversion involves oil extraction through expellers(oil press) and or solvent extraction and biodiesel production. Biodiesel production is the transformation of crude pure plant oil into biodiesel through a process called transesterification. This section of the report provides details of algorithms for biofuels production considering the two stages of biodiesel production.

(b) Biomass conversion step 1(Vegetable oil extraction)

Biomass conversion component contains algorithms for chemicals and other consumables such as electricity, heat and water. Algorithms for products, by-products and wastes have also been considered in this section.

(i) Chemicals and Other Consumables for Crude Oil Production

Data and information on electicity, heat, and other materials required for crude oil production are computed using algorithms presented in equation 4.8 to 4.12. Other consumables and materials required for crude oil extraction are bleaching earth, extraction solvent, water and other materials. The general algorithm for these requirements is provided in equation 4.12.

$$C_{electricity\ annual(1)} = C_{specific\ electricity} * BF \qquad 4.8$$

$C_{electricity\ annual}$ - annual electricity requirement oil extraction (kWh) ; $C_{Specific\ electricity}$ - specific electricity requirement (kWh/tonne of biodiesel; BF -

Desired biofuel production (tonnes). Source: Own analysis.

$$C_{heat\ annual(1)} = C_{specific\ heat(1)} * BF \quad 4.9$$

$C_{heat\ annual(1)}$ - total annual heat requirement (kWh) in oil extraction; $C_{specific\ heat\ (1)}$ - specific heat requirement in oil extraction(kWh/tonne of biodiesel; BF - Desired biofuel production (tonnes); Source: Own analysis

The primary source of heat energy required as process heat for crude oil extraction may be obtained from several resources namely, coal, biomass(i.e. wood/forest residue, maize husks, wheat straw), and heavy fuel oil, etc. An algorithm for heat requirements is provided in equation 4.10.

$$ERH(1)_i = \frac{3.6 * C_{heat\ annual}}{CV_{ERH\ (i)}} \quad 4.10$$

$ERH_i(1)$ - total annual energy resource for heating (tonnes) ; $C_{heat\ annual(1)}$ - total annual heat requirement (kWh); $CV_{ERH\ (i)}$ - Lower Heating Value of energy resource for heating(i) (MJ/tonne). Source: Own analysis.

(ii) Products, by products and wastes

The main product of extraction process is vegetable oil, however by product and wastes are also produced in form of press cake and wastewater and their algorithms are provided in equations 4.20 and 4.21, respectively.

$$C_{press\ cake\ annual} = BM\{1 + OC((1 - PG) * (1 - HE_{efficiency}) - 1)\} \quad 4.11$$

$C_{press\ cake\ annual}$ - total annual press cake produced (tonnes) ; BM - total biomass(energy crop) required (tonnes); OC - percentage oil content in seed(%); PG - percentage pressing grade of oil press(%), $HE_{efficiency}$ - hexane extraction efficiency(%). Source: Own analysis.

As regards waste material this process generates mainly used bleaching earth, and wastewater whose algorithm is provided in equation 4.12.

$$C_{Waste \quad annual\ (W)} = C_{specific\ waste\ (W)} * BF \qquad 4.12$$

$C_{Waste\ \ annual}$ - total annual waste (W) generated which may include used bleaching earth and wastewater (tonnes) ; $C_{specific\ waste\ \ (W)}$ - specific waste (W) generated (tonne/tonne of biodiesel). ; BF - Desired biofuel production (tonnes). Source: Own analysis.

(b) Biodiesel Production (Biomass conversion step 2)

This component of the biofuels module, deals with all aspects related to biodiesel production from crude oil. The algorithms cover aspects to do with chemicals and other consumables. Other elements contatined are algorithms for products, by-products and wastes.

(i) Chemicals and Other Consumables

This component determines the amounts of chemical, heat and electricity needed for the production of biofuels in the desired quantity. The component draws data on chemicals from a database equipped with the types, quantities of each chemical and consumables(heat and electricity) needed for production of a tonne of biofuel and this is linked with each technology/chemical recipe. Equation 4.13 provides algorithms and functions governing electricity demand.

$$C_{electricity\ annual\ 2} = C_{specific\ electricity\ 2} * BF \qquad 4.13$$

$C_{electricty\ annual\ 2}$ - total annual electricity requirement (kWh) for biodiesel production ; $C_{Specific\ electricity\ 2}$ - specific electricity requirement for biodiesel production (kWh/tonne of biodiesel); BF - Desired biofuel production (tonnes). Source: Own analysis

The heating requirements for biodiesel production could be obtained from several sources such as coal, biomass (i.e. forest residue, maize husks, wheat straw), and heavy fuel oil, etc(equation 4.14 and 4.15) (Rossilo-Calle, 2010).

$$C_{heat\ annual\ 2} = C_{specific\ heat\ 2} * BF \quad 4.14$$

$C_{heat\ annual\ 2}$ - total annual heat requirement for biodiesel production (kWh) ;

$C_{heat\ electricity\ 2}$ - specific heat requirement for biodiesel production (kWh/tonne of biodiesel); BF - Desired biofuel production (tonnes). Source: Own analysis.

$$ERH(2)_i = \frac{3.6 * C_{heat\ annual}}{CV_{ERH(i)}} \quad 4.15$$

$ERH(2)_i$ - total annual energy resource for heating (tonnes) ; $C_{heat\ annual(2)}$ - total annual heat requirement (kWh); $CV_{ERH(i)}$ - Lower Heating Value of energy resource for heating(i) (MJ/tonne). Source: Own analysis.

A wide range of chemicals are utilised in the process of biodiesel production (transesterification). A combination of chemicals(recipe) used in this process may be obtained from chemicals which include methanol, potassium hydroxide (KOH), Phosphoric acid (H_3PO_4), methanol, bleaching earth(bentonite), phosphoric acid (H_3PO_4), water, nitrogen, sodium methylate, hydrochloric acid (HCl), calcium hydroxide ($Ca(OH)_2$), sodium carbonate (Na_2CO_3), sulphuric acid (H_2SO_4), hexane and potassium hydroxide (KOH). Possible chemicals for transesterification based on recipe/material balance is provided in Appendix I. Equation 4.16 provides an algorith for chemical requirements.

$$C_{chem(i)} = C_{specific\ Chem(i)} * BF \quad 4.16$$

$C_{chem\ (i)}$ - total annual chemical (i) requirement for biodiesel production only (litres), i-water(litres), calcium hydroxide (tonnes), methanol (tonnes), sodium methylate (tonnes), etc ; $C_{specific\ chem(i)}$ - specific chemical (i) requirement for biodiesel production only (litres/tonne of biodiesel); BF - Desired biofuel production (tonnes); Source: Own analysis

Products, by products and wastes

The main product of this process is biodiesel and by-products include glycerine and other by-products. Equation 4.17 provides a general algorithm for by-product.

$$C_{BP\ annual} = C_{BP\ specific} * BF \quad 4.17$$

$C_{BP\ annual}$ - total annual by product (BP) which may include glycerine and other by products (tonnes) ; $C_{BP\ specific}$ - specific by product (BP) produced (tonnes/tonne of biodiesel); BF - desired biofuel production (tonnes). Source: Own analysis

As regards waste, prudent residue and waste material management is an important aspect in the process of biofuels production so as to minimise environmental impacts which can results in costs of disposal. This biofuels DST has taken into consideration the cost attributed to waste disposal. The database of the DST contains a list of commonly known waste/residues materials in biofuels production with their respective characteristics for bio-ethanol and biodiesel production. The list include wastewater, slag, used bentonite, chemicals etc. General algorithms for waste is provided in equation 4.18.

$$C_{W\ annual\ 2} = C_{specific\ W\ 2} * BF \quad 4.18$$

$C_{W\ annual\ 2}$ - total annual waste (W) generated in biodiesel production(tonnes). This may include wastewater, and other wastes ; $C_{specific\ W\ 2}$ - specific waste (W) generated in biodiesel production (tonne/tonne) of biodiesel; BF - Desired biofuel production (tonnes).Source: Own analysis.

4.2.3 Economic /Financial Analysis Algorithms

Financial assessment for both biofuels and biomass production was undertaken on the principle of annuity method. This section of the report provides financial assessment for biomass and biofuels production.

(a) Financial Analysis Algorithms for Biomass Production

In order to carry out financial assessment which include determination of unit production cost, IRR, NPV as well as other financial assessments the user need to provide input data on capital costs, cost of consumables, other costs such as incidentals, miscellaneous, rentals/lease crop insurance, administrative , labour and other necessary cost. The user may also need to input other miscellaneous revenues where possible. The following (equations 4.19 to 4.27) are the formulae utilised in building software functions for financial assessments for biomass production.

(i) Capital related Costs

Capital related costs is associated with equipment and machinery such as tractor cultivators, combine harvesters, sprayers, storage, land and buildings, utilities (irrigation equipment) and other machinery. The equations governing capital costs components are provided in equations 4.19 to 4.21 (VDI, 1996).

$$E_{capital\ \cos t\ \ annuity} = NCVIM * a \qquad 4.19$$

$E_{capital\ \cos t\ annuity}$ - Capital cost annuity (US$); $NCVIM$ - Net capital value of investment and maintenance cost (US$),; a - price dynamic annuity factor (VDI, 1996).

$$a = \frac{\left[(1+i)-1\right]*(1+i)^{t}}{\left[(1+i)^{t}-1\right]} \qquad 4.20$$

a - price dynamic annuity factor; i - imputed interest (%); t - project life. (VDI, 1996).

$$i = (iek * EKA) \quad + (ifk * FKA) \qquad 4.21$$

i - imputed interest rate (%), iek - interest on equity (%), EKA - share of equity (%), ifk - interest rate on leverage(borrowed capital)(%), FKA - leverage borrowed capital (%), t -project life (years) (VDI, 1996).

$FKA = 1 - EKA$

(ii) Consumption related Costs

Consumption related costs relate to cost of seed, fertiliser, pesticides, insecticides, etc and the equations governing this component is provided in equation 4.22 (VDI, 1996).

$$E_{Annuity\ of\ consumption\ \cos t} = \sum_{n=1}^{n} (C_i * UC_i) * a \qquad 4.22$$

$E_{Annuity\ of\ consumption\ \cos t}$ - annuity of total consumption costs (seed, fertilisers, pesticides, herbicides etc. (US$), C_i-annual quantity of material agricultural inputs (tonnes), UC_i - unit cost of input materials(US$/tonne), a - price dynamic annuity factor for consumption related costs (VDI, 1996).

(iii) Operations related costs

Equations for operations related costs associated with personnel, service and operations of machinery, insurance, administration, contingency, rentals, and other costs were formulated as follows:(equation 4.23) (VDI, 1996).

$$E_{Annuity\ of\ operations\ \cos t} = \sum_{n=1}^{n} (Y_i * E_i) * a \qquad 4.23$$

$E_{Annuity\ of\ operations\ \cos t}$ - annuity of total operations related cost (personnel costs, service and operations, (US$), Y_i-operations and other related cost to include; personnel, service and operations, insurance, administration, contingency, rentals and other additional costs (US$), E_i - percentage of total investment, service and operations, insurance, administration, contingency, rentals and other additional costs, In case of personnel cost Y_i denotes number of employees and E_i denotes annual labour cost per employee, a - price dynamic annuity factor for consumption related costs (VDI, 1996).

(iv) Revenues

Revenues from sale of main product, subsidies and other revenues are computed using equation 4.24 (VDI, 1996).

$$D_{total\ revenue\ \ ANNUITY} = \sum_{i}^{n} MP_{main} * BF\ ) * a \qquad 4.24$$

$D_{total\ revenue\ ANNUITY}$ -Annuity of total revenue(US$), MP_{main} - market price of main product (biomass) (US$/tonne), BM - total biomass produce(tonnes) , a price dynamic annuity (VDI, 1996).

The main expected outcomes is the total annual production cost, and unit production cost which is taken as input into biofuels production module.

(b) Financial Analysis Algorithms for Biodiesel Production

(i) Capital related

For biodiesel production, capital related costs is associated with equipment and machinery such as, oil press and solvent extraction equipment, pure plant oil pre-treatment(degumming, bleaching, physical refining), biodiesel production, glycerine distillation, utilities(steam boiler section, water cooling and pumping, weighbridge and oil receipt section, raw oil ,intermediate & product storage), engineering and installation, land and buildings, etc.

The equations governing capital costs are similar to those provided under biomass production module. The capital cost annuity calculation is similar as in biomass financial alculation. The only difference is investment cost which takes account of biodiesel equipment and machinery.

(ii) Consumption related

$$E_{ANNUITY TOTAL CONSUMPTION COST} = \left(E_{Biomass\ Cost\ \ annual} + \sum_{n=1}^{n} E_{annual input(i)} * C_{unit cost(i)} \right) * a \qquad 4.25$$

$E_{ANNUITY\ TOTAL\ CONSUMPTION\ COST}$ - annuity of total consumption related cost (US$),

$a_{consumption}$ - price dynamic annuity factor for consumption related costs, $E_{Annual \quad input(i)}$ -annual quantity requirement of input(i)(units/year); $C_{unit \quad cost(i)} =$ unit cost of all inputs (i) (VDI, 1996).

The above formulae(equatio 4.25) applies to all scenarios of biodiesel production.

(iii) Operations related costs

Costs related to operations which include personnel, service and operations, insurance, administration, contingency, rentals and other additional costs are provided in equation 4.26

$$E_{Annuityu \quad of \quad operations \quad cost} = \sum_{n=1}^{n} (Y_i * E_i) * a \qquad 4.26$$

$E_{Annuity\ of\ operations\ cost}$ - annuity of total operations related cost (personnel costs, Service and operations, (US$), Y_i -operations and other related cost to include; (US$), E_i - percentage of total investment, service and operations, insurance, administration, contingency, rentals and other additional costs, In case of personnel cost Y_i denotes number of employees and E_i denotes annual labour cost per employee, a - price dynamic annuity factor for consumption related costs (VDI, 1996).

The above formulae applies to all the scenarios of biodiesel production.

(iv) Revenues

Annuity of revenues from sale of main product, by-product, co-product, and subsidies of co-product, by-product and other revenues is provided in equation 4.27 (VDI, 1996)

$$D_{total\ revenue \quad ANNUITY} = \Big(\sum_{i}^{n} \left(MP_{co=product(i)} * C_{co=product \quad annual(i)} \right) + \qquad 4.27$$

$$\sum_{i}^{n} \left(MP_{by=product(i)} * C_{by=product \quad annual(i)} \right) + MP_{main} * BF + \sum_{i}^{n} SB_i * BF_i \Big) * a$$

$D_{total\ revenue\ ANNUITY}$ -Annuity of total revenue(US$), MP_{main} - market price of main product (biodiesel) (US$/tonne), BF - total biodiesel produce (tonnes) , $MP_{co-product}$ - market price of co-product, (US$/tonne), $C_{co-product \quad annual}$ - total annual co-product produced (tonnes), $MP_{by\ product}$ - market price of by product (i) such as glycerine and press cake for biodiesel (US$/tonne), $BP(i)$ - total by product(i) produced in (tonnes) SB_i -subsidy on unit by-product (i) (US$/tonne), a price dynamic annuity (VDI, 1996).

Output from biodiesel financial analysis include; total annual production cost, unit production costs, and taking account of by products and other revenues, annual expected profit, net present value, payback period and return on investment. Detailed algorithms for financial analysis is provided in Appendix II.

4.2.4 Social Assessment Module

As part of this research only direct jobs of total labour necessary for crop production, construction, operation and maintenance of conversion plant and for transporting biomass was considered. Labour requirements for crop production was deduced based on specific labour requirements per hectare associated with cultivation of a particular energy crop. For biofuels production, specific labour requirements related to plant size was used. The following algorithms were used to calculate labour requirements for biomass transportation.

Distance = averages speed * Working Hours

Number of Trucks = Distance / Round Trip

Trips = Total Biomass Quantity / (Truck Capacity)

Number of vehicles = Trips / Number of Trucks

Fuel Diesel = Distance * Annual Working Days * 0.5 * (Fuel consumption when empty + Fuel consumption when full)

Fuel Diesel = (Distance * 250 * 0.5 * (Fuel consumption when empty + Fuel consumption when full)) * Number of vehicles

Jobs Biomass Transport = Number of vehicles * 2 (persons per vehicle)

4.2.5 Life Cycle Analysis (Environment) Module

Procedural organization in LCA involves a common treatment of all general and specific subjects in impact assessment phase. Attention is given to the choice of impact categories to be taken into consideration (whether or not quantified), the choice (and/ or development) and use of the characterization methods (s). The choice of process groups/substance groups to be taken apart from calculation and presentation and calculation of effect scores per impact category are also considered. Eventually, quantitative results of the impact assessment per impact category are presented.

4.2.5.1 Inventory Analysis

(a) Environmental Interventions from Biomass Production

This section considers as much as possible, emissions from biomass production (i.e. emissions from land use change, diesel powered irrigation pumps, fertiliser application, pesticide application, field transport and biomass transport), and process emissions from biofuels production. Each of the above mentioned emissions source segments are dealt with individually and their respective detailed algorithms are provided in Appendix III.

(b) Emissions from Land use change

According to the IPCC 2006 Guidelines, land is classified into several categories which include, forest land, crop land, grass land, wetlands, settlements and other lands. Plant biomass constitutes a significant carbon stock in many ecosystems. Biomass is present in both aboveground and below-ground parts of annual and perennial plants. Biomass associated with annual and perennial herbaceous (i.e., non-woody) plants is relatively ephemeral, i.e., it decays and regenerates annually or every few years. Emissions from decay are balanced by removals due to re-growth making overall net carbon stocks in biomass rather stable in the long term. Thus, the methods focus on stock changes in biomass associated with woody plants and trees, which can accumulate large amounts of carbon (up to hundreds of tonnes per ha) over their lifespan (IPCC, 2006). Algorithms for emission calculations from land use change are provided in equations 4.28 to 4.32.

(i) Change in carbon stocks in biomass

$$\Delta C_B = \Delta G_G + \left[\left(0 - B_{Before} \right) * A \right] * CF - \Delta Cl \qquad 4.28$$

ΔC_B Annual change in carbon stocks in biomass(tonnes C yr^{-1}) -, A-Annual area Land Converted to Cropland (hectares), ΔG_G-Annual biomass (Table A8.3) carbon growth (tonnes C per hectare per year) , B_{Before}-Biomass stocks before (Table A8.2) the conversion (tonnes dm/ha), CF -Carbon fraction of dry matter[tonnes C (tonne dm)$^{-1}$, ΔCl -Annual loss (table A8.1) of biomass carbon (tonnes C ha^{-1} yr^{-1}),

Note: CF=0.5 (IPCC 2006 Guidelines).

(ii) Loss of carbon stocks in dead organic matter due to land conversion

$$\Delta C_{DOM} = A * \left(C_n - C_o \right) / T_{on} \qquad 4.29$$

ΔC_{DOM} -Annual change in carbon stocks in dead wood/litter (tonnes C yr^{-1}), A - Annual area Land Converted to Cropland for biofuels (hectares), C_o - Dead wood/litter stock (Table A8.4) under the old land-use category (tonnes C ha^{-1}), C_n -Dead wood/litter stock under the new land-use category (default value is zero) (tonnes C ha^{-1}), T_{on} -Time period of the transition from old to new land-use category (default value is 1) (year) (IPCC 2006 Guidelines).

Note: C_n **= 0;** T_{on} **= 1**

(iii) Soils

a. Loss in carbon stocks in mineral soils

$$\Delta C_{mineral} = \frac{\left(SOC_0 - SOC_{(0-T)} \right)}{D} \qquad 4.30$$

$\Delta C_{mineral}$ -annual change in carbon stocks in mineral soils, tonnes C year, SOC_0 - soil organic carbon stock in the last year of an inventory time period, tonnes C, $SOC_{(0-T)}$ -soil organic carbon stock at the beginning of the inventory time period, tonnes C , SOC_0 and $SOC_{(0-T)}$ are calculated using the SOC equation in the box where the reference carbon stocks and stock change factors are assigned according to the land-use and management activities and corresponding areas at each of the points in time (time = 0 and time = 0-T) T = number of years over a single inventory time period, yr , D = Time dependence of stock change factors which is the default time period for transition between equilibrium SOC values, (yr). Commonly 20 years, but depends on assumptions made in computing the factors FLU, FMG and FI. If T exceeds D, use the value for T to obtain an annual rate of change over the inventory time period (0-T years) (IPCC 2006 Guidelines).

NOTE: D= 20 Years

$$SOC = \sum_{C.S.I} \left(SOC_{REF_{C.S.I}} * F_{LU_{C.S.I}} * F_{MG_{C.S.I}} * F_{I_{C.S.I}} * A_{C.S.I} \right) \quad \textit{4.31}$$

c = represents the climate zones, **s-**the soil types, and i- the set of management systems that are present in a country. SOC_{REF-} the reference (TableA8.5) carbon stock, tonnes (C ha^{-1}), FLU- stock change factor for land-use systems (Table A8.6) or sub-system for a particular land-use, dimensionless , [Note: FND is substituted for FLU in forest soil C calculation to estimate the influence of natural disturbance regimes. FMG - stock change factor for management regime (Table 8.6 dimensionless, FI - stock change factor for input of organic matter (Table A8.6) dimensionless, A = land area of the stratum being estimated (IPCC 2006 Guidelines).

b. Loss of carbon stocks in organic soils

$$L_{Organic} = A * EF \quad 4.32$$

$L_{Organic}$ -Annual carbon loss from cultivated organic soils (tonnes C yr^{-1}), EF - Emission factor (Table A8.7) for climate type (tonnes C ha^{-1} yr^{-1}), A -Annual area Land Converted to Cropland for biofuels (hectares) (IPCC 2006 Guidelines).

(c) Fertilizer, pesticides, fungicides and pesticides application

(i) Fertiliser

This section deals with estimating total anthropogenic emissions of N_2O and CO_2 from bioenergy crop cultivation arising from production and application of lime and fertilisers. Both particulate matter (PM) and gaseous air emissions are generated from the application of nutrients as fertilizers or manures. Emissions from the storage and application of animal wastes and green manures are not considered in this section. For emissions from the production of commercial dry manure fertilizers, manure processing. Emissions may be immediate (occurring during or shortly after application), and latent (occurring days or weeks following application). Four possible sources of uncontrolled emissions have been observed with the process of fertilizer and lime application. These sources are (i) liming-annual CO_2-C emissions from liming, (ii) urea fertilization-annual CO_2 emissions from urea fertilization, (iv) direct N_2O emissions from soils, (v) NO_2 emissions from N fertilizer application, (vi) NH_3 emission, (vii) in-direct N_2O emissions from Soils: N_2O from atmospheric deposition of N volatilised from soils, (viii) indirect N_2O emissions from managed soils: N2O from N leaching/runoff from managed soils(IPCC, 2006).

(ii) Pesticides, fungicides and pesticides application

Pesticides are substances or mixtures used to control plant and animal life for the purposes of increasing and improving agricultural production, protecting public health from pest-borne disease and discomfort, reducing property damage caused by pests, and improving the aesthetic quality of outdoor or indoor surroundings. Pesticides are used widely in agriculture. The largest usage of chemicals with pesticidal activity, by weight of "active ingredient" (AI), is in agriculture. Agricultural pesticides are used for cost-effective control of weeds, insects, mites, fungi, nematodes, and other threats to the yield, quality, or safety of food. Air emissions from pesticide use arise because of the volatile nature of many AIs, solvents, and other additives used in formulations, and of the dusty nature of some formulations. Most modern pesticides are organic compounds. Emissions can result directly during application or as the AI or solvent volatilizes over time from soil and vegetation. There are insufficient data available on particulate emissions to permit emission factor development (IPCC, 2006).

(d) Fuel use in field transport (e.g. cultivation, harvesting etc.)

This section of the report considers emissions arising from transport (fuel combustion) in the cultivated field during bioenergy crop production. The field transport under consideration include combine harvester, tractor cultivator, sprayer etc which are used during cultivation, crop management, and harvesting. The emissions from field transport include CO_2, CH_4, N_2O, NOx, CO, NMVOC and SO_2(IPCC, 2006).

(e) Biomass transportation

It is worthy also to consider emissions from fuel combustion activities during transportation of biomass feedstock to biofuels production factory. These emissions largely depend on transport distance and to some extent the quantity of biomass to be transported. It should be noted that total annual diesel requirements for transportation of biomass to factory is calculated from biomass transport module.

(f) Emissions from Biofuels production

(i) Emissions to air

For fossil fuels, emissions are calculated from biofuels production module such as diesel, coal, heavy fuel oil and LPG used as fuel for process heat, the formulae for emissions estimations of CO_2, CH_4, N_2O, NOx, CO, NMVOC and SO_2.

(ii) Waste water

The database of the DST contains list of commonly known waste/residues materials with their respective characteristics associated with bio-ethanol and biodiesel production. The list include waste water, slag, used bentonite, chemicals etc.

(iii) Biofuels transportation

It should be noted that fuel combustion activities during transportation of biofuels from factory to storage depot results in emissions into the atmosphere. These emissions largely depend on transport distance and to some extent the quantity of biofuels to be transported and emissions from such sources include CO_2, CH_4, N_2O, NOx, CO, NMVOC and SO_2 .

4.2.5.2 Impact Analysis

This section of the report provides LCA impact assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of various biofuels production scenarios(Leiden, 2001). The impact categories considered in the DST are provided as follows:

(a) Land Competition

This sub category of land use impacts is concerned with the loss of land as a resource in the sense of being temporarily unavailable. The areas of protection are natural resources and the man-made environment. Aggregation of inventory data by multiplying the surface area used by the occupation time (equation 4.33); characterization factor equals 1 for all land-use types (Leiden, 2001).

$$Increase \quad of \quad land\ competition = a * t * 1 \qquad 4.33$$

a -is the area used and , t -the occupation time. The indicator result is expressed in m^3yr (Leiden, 2001).

(b) Climate change

Climate change is defined here as the impact of human emissions on the radiative forcing (i.e. heat radiation absorption) of the atmosphere. This may in turn have adverse impacts on ecosystem health, human health and material welfare. Most of these emissions enhance radiative forcing, causing the temperature at the earth's surface to rise. This is popularly referred to as the green house effect. The areas of protection are human health, the natural environmental and the man-environment. The equation for calculating impact assessment under climate change is provided in equation 4.34(Leiden, 2001).

$$Cimate \quad change = \sum_i GWP_{a,i} * m_i \qquad 4.34$$

The indicator result is expressed in kg of the reference substance, CO_2.$GWP_{a,i}$ is the Global Warming Potential for substance i integrated over a years, while m_i (kg) is the quantity of substance i emitted (Leiden, 2001).

(c) Photo Oxidant Smog Formation

Photo-oxidant formation is the formation of reactive chemical compounds such as ozone by the action of sunlight on certain primary air pollutants. These reactive compounds may be injurious to human health and ecosystems and may also damage crops. The relevant areas of protection are human health, the man-made environment, the natural environmental and natural resources (Leiden, 2001).

Photo-oxidants may be formed in the troposphere under the influence of ultraviolent light through photochemical oxidation of Volatile Organic Compounds (VOCs) and carbon monoxide (CO) in the presence of nitrogen oxides (NOx), Ozone is considered the most important of these oxidizing compound along with peroxyacetyl nitrate (PAN), photo-oxidant formation also known as summer smog (Leiden, 2001). Estimation of photo-oxidant formation is provided in equation 4.35.

$$Oxidant \quad formation = \sum_i POCP_i * m_i \qquad 4.35$$

The indicator result is expressed in kg of the reference substance, ethylene, $POCP_i$ is the Photochemical Ozone Creation Potential for substance i, while m_i (kg) is the quantity of substance i emitted. Note that in this case it is of specific importance to specify NOx emissions in terms of its constituent NO and NO2 emissions since the POCP values for these two chemical species are extremely different. Source (Leiden, 2001).

(d) Acidification

Acidifying pollutants have a wide variety of impacts on soil, groundwater, surface waters, biological organisms, ecosystems and materials (buildings). The major acidifying pollutants are SO_2, NO_x, and NH_x. Areas of protection are the natural environmental, the man-made environment human health and natural resources. Estimation of acidification is calculated using equation 4.36 (Leiden, 2001).

$$Acidification = \sum_i AP_i * m_i \qquad 4.36$$

The indicator result is expressed in kg SO2 emitted in Switzerland equivalent., AP_i is the Acidification Potential for substance i emitted to the air, while m_i is the emission of substance i to the air (Leiden, 2001).

(e) Eutrophication

Eutrophication covers all potential impacts of excessively high environmental levels of macronutrients, the most important of which are nitrogen (N) and phosphorus (P). Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems. In addition, high nutrient concentrations may also render surface waters unacceptable as a source of drinking water. In aquatic ecosystems increased biomass production may lead to depressed oxygen levels, because of the additional consumption of oxygen in biomass decomposition (measured as BOD, biological oxygen demand). As emissions of degradable organic matter have a similar impact as emissions they are also treated under the impact category 'eutrophication'. The areas of protection are the natural environment, natural resources and the man-made environment. Eutrophication is computed using to equation 4.37(Leiden, 2001).

$$Eutrophication = \sum_i EP_i * m_i \qquad 4.37$$

The indicator result is expressed in kg PO_4^{3-} equivalent. EP_i is the Eutrophication Potential for substance i emitted to air, water or soil, while m_i is the emission of substance i to air, water or soil. Note: If the Biological Oxygen Demand (BOD)[2] is specified it can generally be converted to a COD. The conversion factor will depend on the situation (Leiden, 2001).

(f) Human toxicity

This impact category covers the impacts on human health of toxic substances present in the environment. The health risks of exposure in the workplace are also sometimes included in LCA. These latter risks are often included in a wider impact category encompassing more than exposure to toxic substances (e.g. accidents at work). The area of protection for this impact category is human health. Notice that the discussion on characterization of toxicity-related impact categories is far from settled (Leiden, 2001). Computation for human toxicity is provided in equation 4.38

$$Human \quad Toxicity = \sum_{i} \sum_{econ} HTP_{ecom\ j} * m_{ecom\ j} \qquad 4.38$$

The indicator result is expressed in kg 1,4-dichlorobenzene equivalent. $HTP_{ecom\ j}$ is the Human Toxicity Potential (the characterisation factor) for substance, i emitted to emission compartment, ecom (=air, fresh water, seawater , agricultural soil or industrial soil), while $m_{ecom\ j}$ is the emission of substance (i) to medium ecom (Source: Leiden, 2001).

(g) Eco-toxicity

The impact categories covers the impacts of toxic substances on aquatic, terrestrial and sediment ecosystems. The area of protection is the natural environment (and natural resources) (Leiden, 2001).

(h) Abiotic depletion

Abiotic resources are natural resources (including energy resources) such as iron ore, crude oil and wind , which are regarded as non-living. Abiotic resources depletion is one of the most frequently discussed impact categories and there is consequently a wide variety of methods available for charactering contributions to this category. To a large extent, these different methodologies reflect differences in problem definition. Depending on the definition, this impact category includes only natural resources, , human health and the natural environment, among its areas of protection. Equation 4.39 provides the formula for estimation of abiotic depletion (Leiden, 2001).

$$Abiotic \quad Depletion = \sum_{i} ADP_i * m_i \qquad 4.39$$

The indicator result is expressed in kg of the reference resource antimony. ADP_i is the Abiotic Depletion Potential of resource i , while m_i (kg, except for natural gas and fossil energy) is the quantity of resource i used (Source: Leiden, 2001).

4.2.5 Multi Criteria Analysis Module

This section of the report provides algorithms for multi criteria analysis for the three criteria namely, economic, technical, and social. Scores and weightings were used in ranking using a combination of Rating and Normal Ranking approaches (Yamba, 2005). Total score economic, social and environmental aspects were calculated (equations 4.40-4.42) as follows:

(i) Total economic score

$$Total\ Score\ Economic = \frac{(NPV + UP + PP + EP + PFB)}{45} * 100 \qquad 4.40$$

NPV-Net present Value of Money, UP-Unit Production Cost , PP-Pay back period, EP-Annual expected profit (EP) and , PFB-Profitability (PFB). Source: Own analysis

(ii) Total environmental score

$$Total\ Score\ Environment = \frac{(Total\quad normalised)}{9} * 100 \qquad 4.41$$

(iii) Total social score

$$Total\ Score\ Jobs = \frac{(Direct\quad Jobs\quad Created)}{9} * 100 \qquad 4.42$$

Overall pathway score is the summation of scores from environment, economic and social

CHAPTER 5 SOFTWARE DEVELOPMENT

After formulation of flow chart and algorithms, the next stage in DST development is software development. Software development involved writing software codes (computer programming) based on the algorithms and making provision for graphical user interface. The development of DST for biofuels was undertaken in Visual Basic 2008 Programming language.

As described earlier under methodology section, software development consists of two main stages namely, database development and programming. Database development was built on the premise of the requirements of the algorithms and functions governing the modules. The choice of biofuel type and production technology employed is associated with wide array of data characteristics which is stored in a database. The additional data to complete analysis is provided by the user. The tool is equipped with provisions for 'User Defined' parameters (related to consumables, waste and by products) so as to accommodate user's preferences

5.1 Database development

Database development involves compilation of all sets of common data required in execution of software application of DST. In instances where the user opts to use 'User Defined' parameters (related to consumables, waste and by products), the DST is flexible and has provision to accommodate such preferences. The database therefore, as much as possible consist of various datasets which are necessary for the execution of the algorithms/functions in the DST software structure with the view to generating reasonable expected results. The database in the DST was developed using xml files. Table 5.1 provides DST database and data flow framework.

Table 5.1 Database and data flow framework for the DST

User Interface data areas	Input			Output
	User Input	User selection/ Options	Built-In (Database)	
Bioenergy crop production (agriculture)	Seed cost, fertiliser application rates (for user defined otherwise provided in database),fertiliser costs, Pesticide application rates(for user defined otherwise provided in database); pesticide costs, Capital costs(farm machinery and storage), Labour, insurance and other cost, Irrigation cost, Field transport cost	Bioenergy crop type (jatropha, soybean, sugarcane, sweet sorghum, corn etc), fertiliser type, diesel or grid electricity powered irrigation pumps	Country specific crop yield per hectare for fertiliser and pesticides application rates	Biomass production cost , fertiliser, pesticides and diesel annual quantities as input for LCA analysis(GHG calculations)
Biofuels production (Conversion)	Desired annual biofuel production, chemical application rates(for user defined otherwise provided in database), heat electricity demand(for user defined otherwise provided in database), residual generation rates(for user defined otherwise provided in database), by-product production rates(for user defined otherwise provided in database), capital cost(refinery, mill/press etc), cost of labour, operation and other costs, cost of chemicals, electricity, heat	Biofuel type, chemical types (for user defined technology selection), by products(for user defined recipe), source of feedstock(own farm or out-growers)	Heating values, oil and moisture content, Specific chemical application rates, specific electricity and heat requirements, specific residue and by product quantities, consumables , Emission factors	Production cost of biofuel(as input into), Fuel energy produced, Conversion rate, Energy efficiency, annual chemical and by products for GHG emissions calculations
Biomass and biofuels transport	Fossil or biofuel fuel consumption, total transport distance, Average truck capacities and Fuel cost		Emission factors, times, typical parameters for field equipment(i.e speed, times	Feedstock transport cost , biofuel transport cost, GHG emissions ,

User Interface data areas	Input			Output
	User Input	**User selection/ Options**	**Built-In (Database)**	
			over, width),	
Life Cycle Analysis	N/A	N/A	Emission factors, Global Warming Potential, Human Toxicity potential, Eutrophication potential, acidification potential,	Total pathway emissions, normalised environmental score
Multi Criteria Analysis	Weights for main criteria(technological, environmental, economical and social)	N/A	Threshold(cut of point)	Pathway score and Verdict (whether pathway is cost effective and environmentally benign)

5.2 Computer Programming of DST

Programming involved writing computer language codes in Visual Basic Programming language. Essentially this process is a translation of flow chart and algorithms into software package through programming. The DST application package was developed in Visual Basic 2008 environment as a desktop application package.

A Visual Basic program is built up from standard building blocks. A solution comprises one or more projects. A project in turn can contain one or more assemblies. Each assembly is compiled from one or more source files. A source file provides the definition and implementation of classes, structures, modules, and interfaces, which ultimately contain all the code. http://msdn.microsoft.com/en-us/library/022td33t%28v=vs.80%29.aspx (visited 25th January 2011).

The DST for biofuels comprises programming tools, windows, and menu commands, controls, forms, properties, and program code which make up the application package. The user's point of interaction with tool is a graphical interface (figure 5.1 and figure 5.2) designed on visual basic forms. Each module of the DST has a uniquely designed form and associated code.

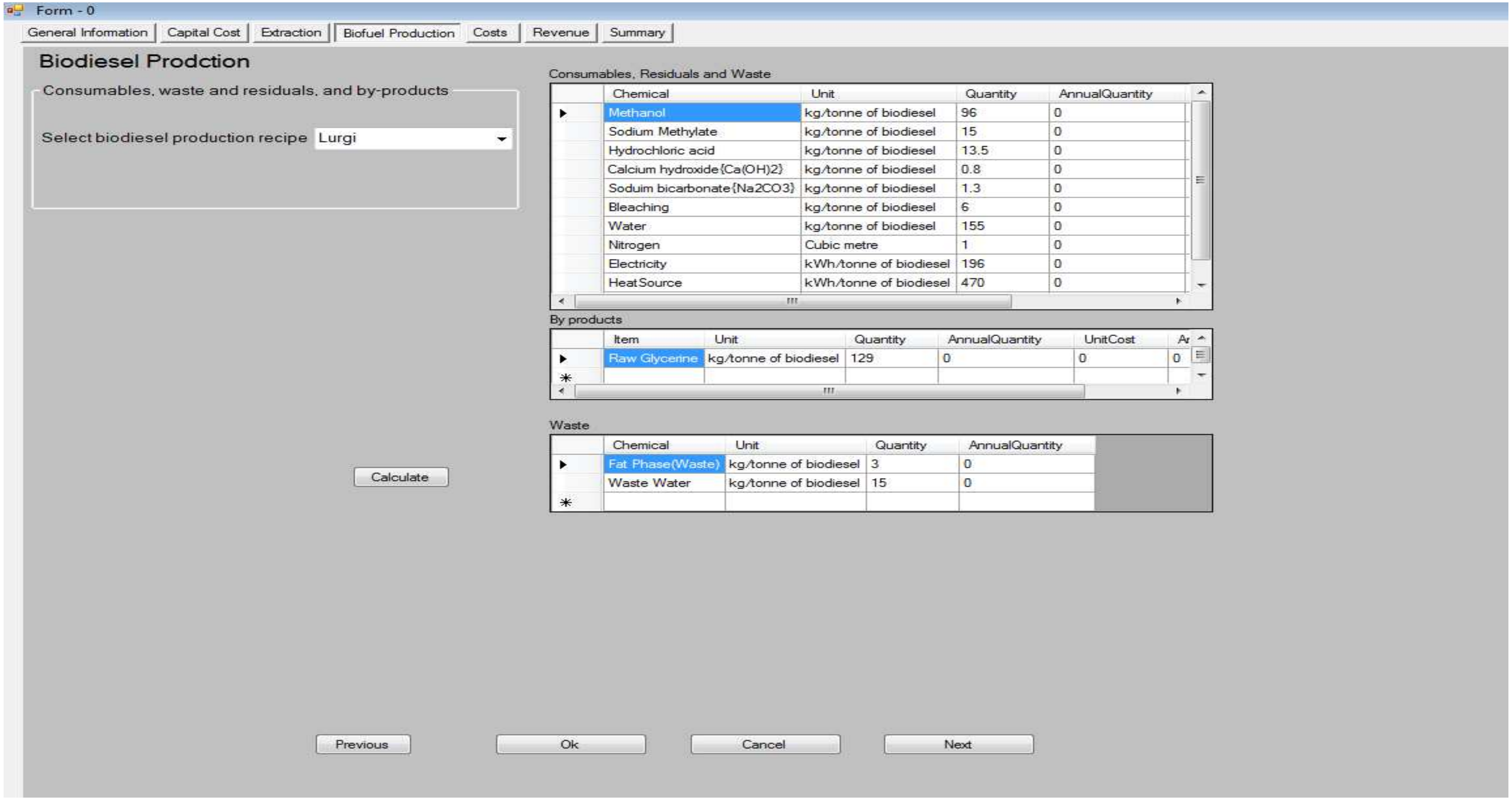


Figure 5.1 Graphical user interface for biofuels production module

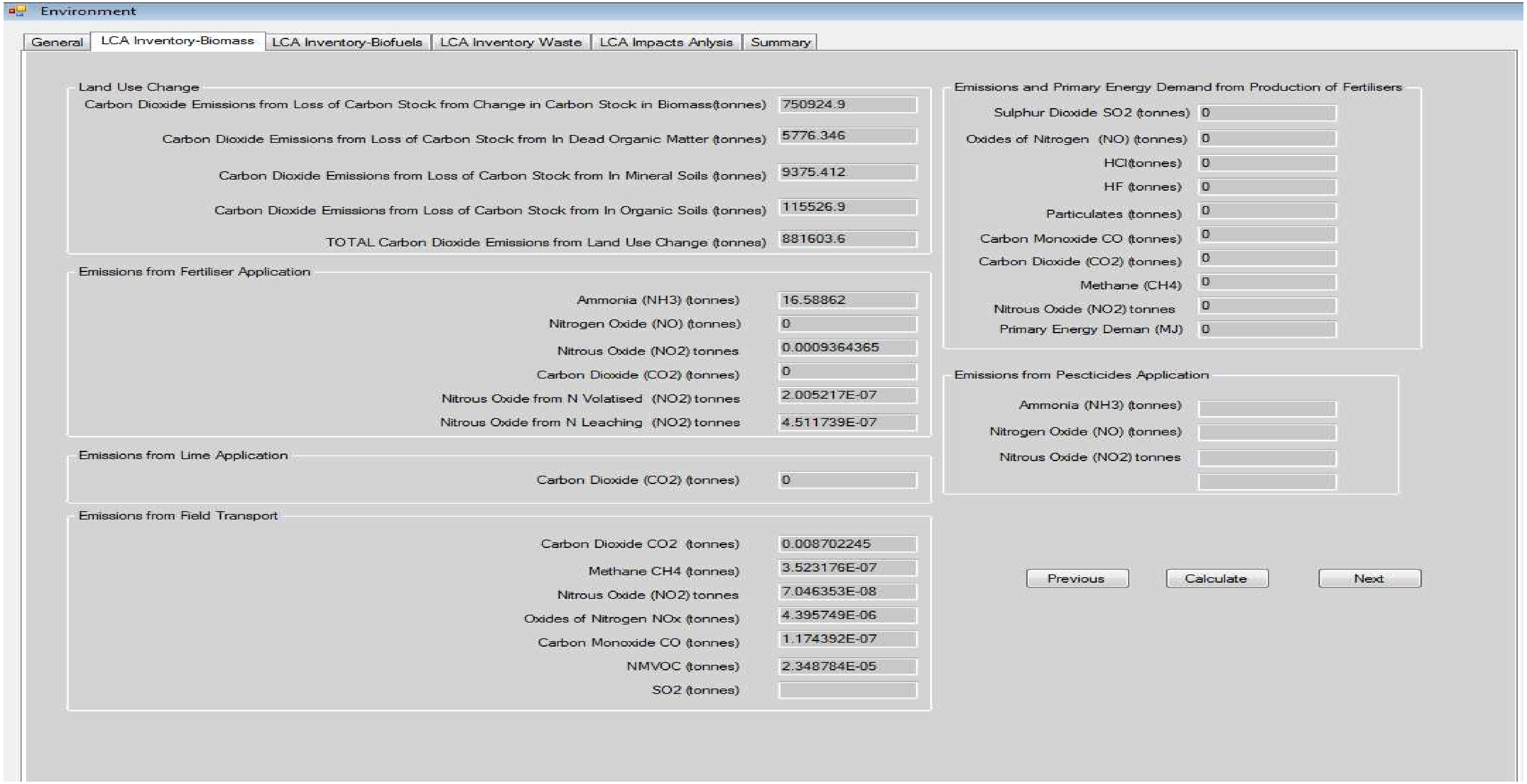


Figure 5.2 Graphical user interface for environment module

CHAPTER 6.0 APPLICATION AND RESULTS OF DST

As part application of the DST, case studies of 2, 20 and 50 million litre biodiesel production plants using jatropha and soy beans were investigated. In this case the energy crop considered was cultivated at own farm. It was assummed that the land earmarked for jatropha cultivation has existed as grass land and there has not been any land transformation for over 30 years. It was also assumed that biodielse is produced based on the Lurgi recipe (Appendix I). The DST is being applied to assess the economic viability, technological concerns, social aspects, transport logistics and envrionmental issues.

6.1 Biomass Production

6.1.1 Investment Cost

The cost of agriculture equipment for biomass(soy bean and jatropha) production is provided in Table 6.1.

Table 6.1 Cost of Agricultural Equipment

Components	Number of Units	Investment Cost (US$)
	1	
Tractor 82 Hp(200 -250hectare) per season	1	42,000
4 Disc Plough	1	4,500
Planter	1	10,600
Harrower 32 Disc	1	6,600
Boom Spray Mounted	1	6,000
Combined harvester	1	120,000
Centre Pivot	1	80,000
Ridger Five furrow	1	8000
Harrower-Mounted, 23 Disc	1	16000
9 Tines Chisel	1	8000
Sprine Tine	1	16000

Source: Massey Ferguson-Yamaha; Power Equipment Ltd(a division of Motor Mart Group), Lusaka, Zambia, 2012

6.1.2 Agriculture Inputs Annual Requirements and Output

Annual agriculture inputs required for jatropha and soy bean for 2, 20 and 50 million litre biofuels plant are provided in table 6.2. The analysis of DST revealed that almost double the land area is needed for soy bean cultivation as opposed to jatropha production for the same quantity of biodiesel produced. Similarly, on an annual basis more quantities of inputs such as fertilisers, herbicides, pesticides, seeds, diesel and lime are needed to grow soy bean compared to growing Jatropha to produce same quantity of biodiesel. For this reason, production cost for soy bean is higher compared with jatropha. The production of 2 million litres of biodiesel per annum from jatropha require 1575 hectares of land, N-fertiliser (127 tonnes), P-fertiliser (48.8 tonnes), K-fertiliser (140.2 tonnes), and Seed (11.8 tonnes) . Production cost of jatropha for same area is 83 US$/tonne.

Table 6.2 Annual requirements for biomass production at different scenarios

Feedstock Type		Jatropha			Soy Beans		
Plant Capacity	(Million litres/annum)	2	20	50	2	20	50
Crop Production	tonnes/annum	6,616	66,165	165,413	13,233	132,330	330,827
Land Area	(hectares)	1,575	15,754	39,384	11,815	118,153	295,381
N-Fertiliser	tonnes /annum	128	1,276	3,190	44	437	1,093
P-Fertiliser	tonnes / annum	49	488	1,220	447	4,466	11,165
K-Fertiliser	tonnes / annum	140	1,402	3,505	175	1,748	4,372
Lime	tonnes / annum	0	0	0	23,630	236,305	590,763
Herbicides	tonnes / annum	0	0	0	15	153	384
Pesticides	tonnes / annum	0	0	0	0	8,187	0
Seed	tonnes / annum	12	118	295	819	4,584,318	20,470
Production Cost	US$/tone	83	28	27	97	70	68

Source: Own analysis

6.2 Biofuels Production

This section of the report provides results of DST analysis on annual consumable requirements for biofuels production at three scenarions (2, 20 and 50 million) biodiesel per annum) based on jatropha and soy bean feedstock.

6.2.1 Investment Cost for Biofuels Production

The capital costs of biodiesel plants vary from plant to plant and are heavily dependent on the technology applied by the equipment manufacturer. The analysis in this report made use of investment cost for two plant sizes obtained from the equipment manufacturer Lurgi (German Company). According to Lurgi, a plant size of 200,000tonnes of biodiesel per annum would cost €80million and a 100,000 tonne per annum plant would cost €55millions in total investment. These sets of figures were then utilised to derive the investment cost of any plant size so as to establish a trend using a plant factor of 0.7. Equation 6.1 was used to derive investment costs for various biofuels plant sizes.

$$C_{NP} = C_{OP}\left(\frac{S_{NP}}{S_{OP}}\right)^{exp} \quad (6.1)$$

C_{NP} - Investment Cost for New plant; C_{OP} - Investment Cost of Original Plant; S_{NP} - Size of a New Plant; S_{OP} - Size of Original Plant; exp - plant factor, *(Source: Walimwipi, 2008)*

Investment cost for various biodiesel production plant sizes based on equation 6.1 is provided in table 6.3.

Table 6.3 Investment cost for biofuels production

Plant size (million litres per annum)	Investment Cost (Million US$)
2	3
4	5
6	6
8	8
10	9
17	13
20	15
30	20
40	24
50	28
227	81

Source: Own analysis

6.2.2 Consumables Annual Requirements and Output

For a plant size of 2, 20 and 50 million litres of biodiesel production, methanol consumption was computed at 169, 1690 and 4224 tonnes per annum, respectively. Consumption of the rest of the consumables is provided on table 6.4. For a jatropha based biodiesel plant size of size 2 million litres, annual material requirements would be as follows: methanol 169 tonnes, sodium methylate 26 tonnes, hydrochloric acid

24 tonnes, calcium hydroxide 1.0 tonnes, sodium bicarbonate 2 tonnes, bleaching earth 11 tonnes, water 273 m^3, nitrogen 2 m^3, electricity 1,065kWh, coal 827 tonnes, Hexane 13tonnes. As regards waste streams, fat phase and waste water would be releases amounting to 5 tonnes and 26 tonnes, respectively.

Table 6.4 Annual consumption of materials for biodiesel production

Feedstock Type	Units	Jatropha			Soy Beans		
Plant Capacity	(Million litres/annum	2	20	50	2	20	50
Methanol	t/annum	169	1,690	4,224	169	1,690	4,224
Sodium Methylate	t/annum	26	264	660	26	264	660
Hydrochloric acid	t/annum	24	238	594	24	238	594
Calcium hydroxide{Ca(OH)2}	t/annum	1	14	35	1	14	35
Sodium bicarbonate{Na2CO3}	t/annum	2	23	57	2	23	57
Bleaching	t/annum	11	106	264	11	106	264
Water	m^3/annum	273	2,728	6,820	273	2,728	6,820
Nitrogen	m^3/annum	2	18	44	2	18	44
Electricity-Refinery	kWh/annum	345	3,450	8,624	345	3,450	8,624
Coal	t/annum	827	8,272	20,680	827	8,272	20,680
Electricity-Press only(KWh)	kWh/annum	286	2,863	7,157	573	5,726	14,315
Electricity Solvent Extraction KWh	kWh/annum	434	4,338	10,846	868	8,677	21,692
Hexane(tonne)	t/annum	13	134	334	27	267	668
Fat Phase(Waste)	t/annum	5	53	132	5	53	132
Waste Water	t/annum	26	264	660	26	264	660

Source: Own analysis

6.3 Financial Analysis

Financial analysis of a 2 million jatropha biodiesel production plant revealed an annuity of capital related cost of US$936,738, annuity of consumption related costs of US$317,554, annuity of other costs of US$239,642, and annual production costs of US$2,069,076. Annual expected profit was US$0.7 million, Net Present Value wasUS$5.7 million, Return on Investment was 10.5%, simple payback period of 4 years and unit production cost was US$0.81/litre at the biodiesel selling price of US$ 1.2/litre. The rest of the results of financial analysis are provided in table 6.5.

Table 6.5 Results of financial analysis

	Jatropha			**Soy bean**		
Plant Capacity(Million litres/annum)	**2**	**20**	**50**	**2**	**20**	**50**
Annual expected profit (Million US$)	0.7	16.6	45	0.5	13.9	38.6
Net Present Value (NPV) (million US$)	5.7	123.8	338	3.7	103.5	287.9
Simple Pay Back Period (Years)	4	0.9	0.6	6	1	0.72
Return on Investment (%)	10.5	17.5	21.8	9.2	16	19.8
Unit Production Specific (US$/litre)	0.81	0.4	0.3	1.0	0.5	0.4

The financial analysis further revealed that production cost is lower for jatropha based biodiesel compared to that of soy bean. It was also observed that generally for both jatropha and soy bean based biodiesel, production cost reduces with increase in plant size

6.4 Environmental Analysis

This section provides results of analysis of environment module (life cycle analysis). The section considers emissions form land use change which include; carbon dioxide emissions from loss of carbon stocks from change in carbon stocks in biomass, carbon dioxide emissions from loss of carbon stocks in dead organic matter due to land conversion, carbon dioxide emissions from loss of carbon stocks in mineral soils and carbon dioxide emissions from loss carbon stocks in organic soils. Other emissions considered include; emissions from fertilizer and lime, field transport, biomass transport, and process emissions from biofuels production. Detailed emissions from the above mentioned sources are provided Appendix V.

Mid-point environmental impacts analysis for a biodiesel plant of 2 million litres per annum revealed human toxicity of 3054 kg 1,4-dichlorobenzene equivalent, climate change 880 million tonnes CO_2 equivalent(including initial carbon loss from land use change), photoxidant of 320 kg of ethylene, acidification of 0.04 kg SO_2 emitted in Switzerland equivalent, eutrophication of 0.01 kg PO_4^{3-} equivalent, land competition of 315 million m^3yr (Table 6.6).

Table 6.6 Mid point environmental impacts analysis at different scenarios

	Jatropha			Soy bean		
Plant Capacity(million litres/annum)	2	20	50	2	20	50
Land Competition (million m^3yr)	315	3,150	7,880	2,360	23,600	59,100
Climate Change (million tonnes CO_2 equivalent)	880	8,800	22,000	6,600	66,000	165,000
Human toxicity (kg 1,4-dichlorobenzene equivalent)	3,054	30,540	76,351	2,315	23,152	57,881
Photoxidant (kg of ethylene)	320	3,205	8,013	402	23,152	10,054
Acidification (kg SO_2 emitted in Switzerland equivalent)	0.04	0.41	1.01	0.02	0.22	0.54
Eutrophication (kg PO_4^{3-} equivalent)	0.01	0.06	0.16	0.00	0.03	0.06

Source: Own analysis

Results of normalised impact category analysis for a 2 million biodiesel plant indicated the following values for impact categories; climate change 0.061, human toxicity (5.35E-11), Photoxidant (3.0E-9), Acidification (1.3E-7), and eutrophication (4.79E-08)(Table 6.7). The total normalized value was calculated at 0.06072. The results show that a plant size of 2 million litres biodiesel would have negligible impact on human toxicity, photoxidant formation, acidification, and eutrophication since their contribution to overall normalized value is negligible. It therefore implies that the environmental burden of biodiesel production is more on climate change than other category indicators.

Table 6.7 Normalised impact category values for 2, 20 and 50 million litre biodiesel production scenarios

	Jatropha			Soy bean		
Plant sizes(million litres)	2	20	50	2	20	50
Climate Change(year)	0.060715	0.6071531	1.517882	0.4554508	4.554508	11.38627
Human toxicity(year)	5.35E-11	5.35E-10	1.34E-09	4.05E-11	4.05E-10	1.01E-09
Photoxidant (year)	3.00E-09	3.00E-08	7.49E-08	3.76E-09	3.76E-08	9.40E-08
Acidification(year)	1.30E-07	1.30E-06	3.24E-06	6.95E-08	6.95E-07	1.74E-06
Eutrophication (year)	4.79E-08	4.79E-07	1.20E-06	1.90E-08	1.90E-07	4.74E-07
Total normalization(year)	0.060715	0.6071548	1.517887	0.4554509	4.554509	11.38627

Source: Own analysis

6.5 Multi Criteria Analysis

This section provides multi criteria analysis of all key outputs from all the modules, namely technical, economic, social and environment in form of indicators. The indicators are grouped according to their respective modules and are provided in Table 6.8.

Table 6.8 Indicators for multi criteria analysis at different scenarios

Feedstock type	Jatropha			Soy bean		
Plant sizes(million litres)	2	20	50	2	20	50
Total Normalised Environment Score (year)	0.06	0.61	1.52	0.46	4.55	11.39
Land Competition (million m^2 Year)	315	3,150	7,880	2,360	23,600	59,100
Simple Pay Back Period (Years)	4	0.9	0.6	6	1	0.72
Return on Investment (%)	10.5	17.5	21.8	9.2	16	19.8
Unit Production Specific (US$/litre)	0.81	0.4	0.3	1.0	0.5	0.4
Number of Jobs Created	398	3980	9950	871	3980	9950

Source: Own analysis

Provided on Table 6.9 is analysis of ranking for a 2 million litre jatropha based biodiesel plant. The total score for economic, environmental and social aspects were 29, 7 and 5, respectively.

Table 6.9 Ranking of biofuels production pathway for 2 million litre biodiesel plant.

Points received	Ranking (Normal)					
Range of performance	1	3	5	7	9	Total
Criterion	Weakly important	Less Important	Moderately Important	More Important	Extremely Important	
ECONOMIC						
NPV(million US$)				5		5
Unit Production Cost (UP) US$			5			5
Payback period (PP) Years			5			5
Profitability (PFB) (%)				7		7
Annual expected profit (EP) million US$		3				3
Sub Total						**25**
ENVIRONMENT						
Total Normalised[2] (TN)				7		7
Sub Total						**7**
SOCIAL						
Direct jobs created (J)			3			3
Total						**3**

Source: Own analysis

Overall score assessment of the final score of a pathway was computed as 56.44 % as provided in Table 6.10.

[2] Total Normalised is sum of normalised impacts from climate change, photo oxidant smog formation, acidification, eutrophication, and human toxicity

Table 6.10 Overall assessments for criteria for 2 million biofuels plant

Indicator	Marks Obtained	Representative Weighting (%)	Total (%)
Economic	0.55	38	20.9
Environmental	0.77	33	25.41
Social	0.33	29	9.66
Total		100	**56.44**

Source: Own analysis

Provided in Table 6.11 are ranking for jatropha and soy based biodiesel at various plant size scenarios

Table 6.11 Ranking for jatropha and soy biodiesel at various plant size scenarios

Feedstock type	**Jatropha**			**Soy bean**		
Plant size (million litres/annum	**2**	**20**	**50**	**2**	**20**	**50**
Economic						
Unit Production Cost (UP) US$	5	7	7	5	7	7
Payback period (PP) Years	5	7	7	3	5	7
Return on Investment (PFB) (%)	7	5	7	7	7	7
Sub Total	**25**	**29**	**37**	**23**	**29**	**35**
Environment						
Total Normalised	7	5	1	5	1	1
Sub Total	**7**	**5**	**1**	**5**	**1**	**1**
Social						
Direct jobs created (J)	3	5	9	5	7	9
Total	**3**	**5**	**9**	**5**	**7**	**9**

Source: Own analysis

Overall score for 2, 20 and 50 million litre jatropha based biodiesel was analysed to be 56.44%, 58.93% and 63.91% respectively. For the same plant sizes soy bean based biodiesel overall score for 2, 20, 50 million litre biodiesel were 53.87%, 50.71%, and 62.22%, respectively. Generally, it was observed that jatropha based biodiesel had better overall score than soy based biodiesel at all plant size scenarios. This implies jatropha has better performance on an overall balance of economic, environment and social aspects as compared to soy bean based biodiesel.

CHAPTER 7.0 CONCLUSIONS

The "biomass to biofuels Decision Support Tool" is a software application package designed in visual basic programming language. It is built with the view to providing a versatility of choosing biodiesel type with a wide ranging source of feedstock and options for biodiesel conversion technologies. Specifically, the tool is provided with two feedstocks options for biodiesel production and these are soy bean and jatropha. The tool is further equipped with two technological options (biofuels production techniques) for biofuels conversion.

Apart from feedstock and biofuels recipe, other options for possible scenario generation provided include fertiliser type, biodiesel production plant size, fuel type for process heat, and type of wastewater disposal. These options enable comparison of performance indicators based on technical, social, economic/financial analysis and environmental analysis.

The output of financial analysis include; unit production cost of biofuels, production return on investment, payback period, net present value and annual expected profit. Financial analysis component of the DST enables comparison of financial viability among different scenarios of biodiesel production. Job creation from Well-to-Tank is the main output from social assessment which is calculated and aggregated as total number of jobs created based on labour requirements per hectare, jobs from biomass transport, and labour requirements according to biodiesel plant size.

The environmental impact assessment of biodiesel production was based Life Cycle Analysis (LCA) from "Well to Tank". The environmental assessments module yields human toxicity (kg 1,4-dichlorobenzene equivalent), climate change (tonnes CO_2 equivalent), photoxidant (kg of ethylene), acidification (kg SO_2 emitted in Switzerland equivalent), eutrophication (kg PO_4^{3-} equivalent), and land competition (m^3yr).

Emissions sources contributing to environmental burden for biofuels production were mainly from the following; (i) carbon dioxide emissions from loss of carbon stocks due to change in carbon stocks in biomass, (ii) carbon dioxide emissions from loss of carbon stocks in dead organic matter due to land conversion, (iii) carbon dioxide emissions from loss of carbon stocks in mineral soils, (iv) carbon dioxide emissions from loss carbon. Other minor sources of emissions come from nutrients application(fertilizers and lime), emissions from field transport, emissions from biomass transport, and emissions from wastewater.

Upon completion of the formulation, design and software development, the DST was then applied on three case studies. The case studies considered three scenarios of 2, 20 and 50 million litre biodiesel production plants based on jatropha or soy beans. Key assumptions of the tool is that energy crop considered was cultivated at own farm and that the land earmarked for energy crop cultivation had existed as grass land prior to energy crop cultivation and that there has not been any land transformation for over 30 years.

Application of DST revealed that jatropha feedstock for production of 2 million litres of biodiesel per annum requires 1575 hectares of land, N-fertiliser (127 tonnes), P-fertiliser (48.8 tonnes), K-fertiliser (140.2 tonnes), Seed (11.8 tonnes) and diesel(3150 litres). Production of cost of jatropha for same area is 83.6 US$/tonnes. Annual material requirements (consumables) for biodiesel production for the same plant size is provided as follows: methanol 169 tonnes, sodium methylate 26 tonnes, hydrochloric acid 24 tonnes, calcium hydroxide 1.0 tonnes, sodium bicarbonate 2 tonnes, bleaching earth 11 tonnes, water 273 m^3, nitrogen 2 m^3, electricity 1,065 kWh, coal 827 tonnes, Hexane 13tonnes. As regards waste streams, fat phase and waste water releases would amount to 5 tonnes and 26 tonnes, respectively.

Investment, and O&M cost for a 2 million jatropha biodiesel production plant is U$3 million and US$ 0.17million, respectively. Financial analysis revealed return on investment of 9.8% and unit production cost of US$0.9/litre at the biodiesel selling price of US$ 1.2/litre.

Mid-point environmental impact analysis revealed human toxicity of 3054 kg 1,4-dichlorobenzene equivalent, climate change of 880 million tonnes CO_2 equivalent(including initial carbon loss from land use change), photoxidant of 320 kg of ethylene equivalent, acidification of 0.04 kg SO_2 emitted in Switzerland equivalent, eutrophication of 0.01 kg PO_4^{3-} equivalent, and land competition of 315 million m^3yr.

Results of normalised environmental impact category analysis were as follows: climate change (0.061), human toxicity (5.35E-11), photoxidant (3.0E-9), acidification (1.3E-7), and eutrophication (4.79E-08). The total normalized value was calculated at 0.06072. The results show that a plant size of 2 million litres biodiesel would have negligible impact on human toxicity, photoxidant formation, acidification, and eutrophication since their contribution to overall normalized value is negligible. It therefore implies that the environmental burden of biodiesel production is more on climate change than other impact categories.

On the other hand, a 2 million soy been based biodiesel requires 11,815 hectares of land. Financial analysis revealed a unit production cost of US$1.2/litre with return on investment of 8.3%. Mid-point environmental impacts analysis revealed human toxicity of 2,315 kg 1,4-dichlorobenzene equivalent, climate change 6,600 million tonnes CO_2 equivalent(including initial carbon loss from land use change), photoxidant of 402 kg of ethylene equivalent, acidification of 0.02 kg SO_2 emitted in Switzerland equivalent, and land competition of 2,360 million m^3yr. The total normalized value was calculated at 0.456.

Multi Criteria Analysis of 2 million biodiesel plant from jatropha and soy bean provided an overall score of 53% and 49%, respectively. The higher the score, the better the overall perfomance of particular scenario taking care of economic, social, and envirnomental considerations. These results indicate jatropha based biodiesel has better performance on an overall balance of economic, environment and social aspects as opposed to soy bean based biodiesel.

CHAPTER 8.0 RECOMMENDATIONS

As part of future improvement of the DST, another masters student could take up the study further by considering recommendations raised in this section. The weakness with this DST for biodiesel is that it does not include bioethanol production. For this reason, it is being recommended that bioethanol analysis based on sugarcane and sweet sorghum feedstock be integrated in the DST. The following are the issues which could be considered in the integration of bioethanol in the DST:

(i) DST component design for bioethanol from sugar crops (i.e. sugar cane and sweet sorgum), may be considered on three different scenarios which include; (i) bioethanol production only, (ii) bioethnaol and sugar production with ethanol produced from molasses only and bioethnaol and sugar production with ethanol produced from a mixture of juice and molasses.

(ii) Consideration could also be given to co-products and by-products in the component designs. Bioethanol production from sugarcane or sweetsorghum can produce a number of co-products (sugar and electricity) and by-products (vinasse, filter cake, etc) depending on a particular mode of production. The bagasse is used for process heat and electricity generation. Surplus electricity generated therefore takes account of electricity consumed in sugar and bio-ethanol production processes. The co-products and by-products are significant in reducing the production cost.

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APPENDIX

Appendix I Lurgi recipe/material balance

Recipe	Lurgi	
Production Process	continuous	
Process parameter	60°C (to 75°C), Ambient Pressure	
Annual Production [t_{KS}/a]	100000	
Annual Operation Hours [h/a]	8000	
Specific Personnel (Person/ biofuels output, P/MWKS)	0.1630	
Transesterification agent	Methanol	96
Catalyst	Sodium Methylate	**15**
Support Chemical 1	Hydrochloric acid (HCl)	10 to 13,5
Support Chemical 2	Calcium hydroxide($Ca(OH)_2$)	0.8
Support Chemical 3	Sodium carbonate (Na_2CO_3)	1.3
Support Chemical 4	Bleicherde	6
Support Chemical 5	Water	155
Support Chemical 6	Nitrogen (N_2)	1
By product 1	Raw glycerine	129
By product 2	Press cake	0
Waste 1	Filter cake	10
Waste 2	Fat phase	3
Waste	Waste water	15
Heat/Electricity		
Input [kg/t_{KS}]		2488
Hu Input [MJ/kg]		24.1
Electricity Consumption [kWh_{el}/t_{KS}]		**196.00**
[MWhel/GJ_{KS}]		**5.28**
Heat Consumption [kWh_{th}/t_{KS}]		470
Heat Consumption [MWhth/GJ_{KS}]		12.67

Source: Lurgi

Appendix II Additional Algorithms for Financial Analysis

$$E_{TOTAL\ COST} = E_{capital\ \cos t\ annuity} + E_{annuity\ total\ consumption\ \cos t} + E_{operations\ service\ aEnnuity} + E_{other\ \cos t\ annuity}$$

Unit production costs

$$upc = \frac{E_{TOTAL\ COST}}{BM}$$

89

$$upc = \frac{E_{TOTAL\ COST}}{BM}$$

upc -specific (unit) production cost(US$/tonne) of biomass, $E_{TOTAL\ COST}$ - total annual production cost(US$), MB - total biomass produced(tonnes) from equation 2,

Unit production cost taking account of by products and other revenues

$$upc_{by\ products\ /\ reveneus} = \frac{(-E_{TOTAL\ COST}) + (D_{total\ reveneus} - D_{main\ product}) * a}{BM}$$

$upc_{by\ product\ /\ revenues}$ -specific (unit) production costs taking care of by products and other revenues(US$/tonne), $E_{TOTAL\ COST}$ - total annual production cost(US$), MB - total biomass produced(tonnes) from equation 2, $D_{total\ revenues}$ - Total annual revenue(US$), from equation 81, $D_{main\ product}$ -Total annual revenue from main product(US$) from equation 71, a - price dynamic annuity factor

Annual expected Profit

91

$$AEP = (-E_{TOTAL\ COST}) + D_{total\ revenue\ ANNUITY}$$

AEP -Expected annual profit(US$/annum), $E_{TOTAL\ COST}$ - total annual production cost(US$), $D_{total\ revenue\ ANNUITY}$ -Annuity of total revenue(US$) from equation 82

Net present value

$$NPV = AEP * \frac{q^t - 1}{q^t * i} \quad (92)$$

NPV - Net Present Value(US$) AEP -Expected annual profit(US$/annum), q -is calculated in equation 86, t -project life (years)

Static payback period

$$SPP = \frac{Investment}{Annual\ \mathrm{Pr}ofit} \quad (93)$$

SPP - simple payback period(years)

Profitability

$$ROI = \frac{AEP + \left(\frac{IP + CVNBC_{Total}}{2 * i}\right)}{\frac{IP + CVNBC_{Total}}{2}} \quad (94)$$

ROI - Return On Investment(%)

Appendix III Algorithms for emissions calculations

(iv) Change in carbon stocks in biomass

$$\Delta C_B = \Delta G_G + [(0 - B_{Before}) * A] * CF - \Delta Cl$$

204

ΔC_B Annual change in carbon stocks in biomass(tonnes C yr^{-1}) -, A -Annual area Land Converted to Cropland(hectares), ΔG_G -Annual biomass(Table A8.3) carbon growth(tonnes C per hectare per year) , B_{Before} -Biomass stocks before(Table A8.2) the conversion (tonnes dm/ha), CF -Carbon fraction of dry matter[tonnes C (tonne dm)$^{-1}$, ΔCl -Annual loss(table A8.1) of biomass carbon (tonnes C ha^{-1} yr^{-1}),

Note: CF=0.5

Table A8.1 Default coefficients for above-ground woody biomass and harvest cycles in cropping systems containing perennial species

Climate region	Above ground biomass carbon stock at harvest (tonnes C ha^{-1})	Harvest/Maturity cycle(year)	Biomass accumulation rate (G) (tonnes C $ha^{-1}yr^{-1}$)	Biomass carbon loss(ΔCl) (tonnes C $ha^{-1}yr^{-1}$)
Temperate(all moisture regimes)	63	30	2.1	63
Tropical, dry	9	5	1.8	9
Tropical, moist	21	8	2.6	21
Tropical, wet	50	5	10.0	50

Source: IPCC 2006 Guidelines

Table A8.2 Default coefficients for above-ground woody biomass and harvest cycles in cropping systems containing perennial species

Climate region	Ecological zone	Continent	Forest land	Grass land
			Above-ground biomass (tonnes d.m. ha^{-1})	Above-ground biomass (tonnes d.m. ha^{-1})
Tropical	Tropical rain forest	Africa	310	6.2
		North and South America	300	6.2
		Asia(continental)	280	6.2
		Asia(insular)	350	6.2
	Tropical moist deciduous	Africa	260	6.2
		North and South America	220	6.2
		Asia(continental)	180	6.2

	forest	Asia(insular)	290	6.2
	Tropical dry forest	Africa	120	2.3
		North and South America	210	2.3
		Asia(continental)	130	2.3
		Asia(insular)	160	2.3
	Tropical shrub land	Africa	70	2.3
		North and South America	80	2.3
		Asia(continental)	60	2.3
		Asia(insular)	70	2.3
	Tropical mountain system	Africa	40	2.3
		North and South America	60	2.3
		Asia(continental)	50	2.3
		Asia(insular)	50	2.3
Subtropical	Subtropical humid forest	220	50	2.3
		Asia(continental)	180	2.3
		Asia(insular)	290	2.3
	Sub tropical dry forest	Africa	140	2.3
		North and South America	210	2.3
		Asia(continental)	130	2.3
		Asia(insular)	160	2.3
	Subtropical steppe	Africa	70	2.3
		North and South America	80	2.3
		Asia(continental)	60	2.3
		Asia(insular)	70	2.3
	Subtropical mountain systems	Africa	50	2.3
		North and South America	60	2.3
		Asia(continental)	50	2.3
		Asia(insular)	50	2.3
Temperate	Temperate oceanic forest	Europe	120	1.6
		North America	660	1.6
		New Zealand	360	1.6
		South America	180	1.6
	Temperate continental forest	Asia, Europe	20	1.6
		North and South America	60	1.6
	Temperate mountain system	Asia, Europe	100	1.6
		North and South America	50	1.6

Boreal	Boreal coniferous forest	Asia, Europe, North America	10	1.7
	Boreal tundra woodland	Asia, Europe, North America	3	1.7
	Boreal mountain systems	Asia, Europe, North America	12	1.7

Source: IPCC 2006 Guidelines

Table A8.3 Default biomass carbon stocks present on land converted to cropland after conversion

Crop type by climate region	**Carbon stock in biomass after one year (ΔG_G)(tonnes C ha^{-1})**
Annual crop land	5.0
Perennial cropland	
Temperate (all moisture regimes)	2.1
Tropical dry	1.8
Tropical moist	2.6
Tropical wet	10.0

Source: IPCC 2006 Guidelines

(v) Loss of carbon stocks in dead organic matter due to land conversion1

$$\Delta C_{DOM} = A * (C_n - C_o) / T_{on}$$

205

ΔC_{DOM} -Annual change in carbon stocks in dead wood/litter (tonnes C yr^{-1}), A -Annual area Land Converted to Cropland for biofuels (hectares), C_o - Dead wood/litter stock(Table A8.4) under the old land-use category(tonnes C ha^{-1}), C_n -Dead wood/litter stock under the new land-use category (default value is zero) (tonnes C ha^{-1}), T_{on} -Time period of the transition from old to new land-use category(default value is 1) (year)

Note: C_n **= 0;** T_{on} **= 1**

Table A8.4 Default values for litter wood carbon stocks

Climate	**Broad leaf deciduous (tonnes C ha^{-1})**	**Needle leaf evergreen (tonnes C ha^{-1})**
Boreal, dry	10	6
Boreal, moist	11	7
Cold temperate, dry	23	17
Cold temperate, moist	5	10

Warm temperate dry	23.3	17.3
Warm temperate moist	2	6
Subtropical	2	4.1
Tropical	1	5.2

Source: IPCC 2006 Guidelines

(vi) Soils

c. Loss in carbon stocks in mineral soils

$$\Delta C_{\min eral} = \frac{\left(SOC_0 - SOC_{(0-T)}\right)}{D} \qquad 206$$

$\Delta C_{\min eral}$ -annual change in carbon stocks in mineral soils, tonnes C year, SOC_0 -soil organic carbon stock in the last year of an inventory time period, tonnes C, $SOC_{(0-T)}$ -soil organic carbon stock at the beginning of the inventory time period, tonnes C , SOC_0 and $SOC_{(0\text{-}T)}$ are calculated using the SOC equation in the box where the reference carbon stocks and stock change factors are assigned according to the land-use and management activities and corresponding areas at each of the points in time (time = 0 and time = 0-T) T = number of years over a single inventory time period, yr , D = Time dependence of stock change factors which is the default time period for transition between equilibrium SOC values, (yr). Commonly 20 years, but depends on assumptions made in computing the factors FLU, FMG and FI. If T exceeds D, use the value for T to obtain an annual rate of change over the inventory time period (0-T years).

NOTE: D= 20 Years

$$SOC = \sum_{C.S.I}\left(SOC_{REF_{C.S.I}} * F_{LU_{C.S.I}} * F_{MG_{C.S.I}} * F_{I_{C.S.I}} * A_{C.S.I}\right) \qquad 207$$

c = represents the climate zones, **s-**the soil types, and i- the set of management systems that are present in a country. SOC_{REF}- the reference(TableA8.5) carbon stock, tonnes (C ha^{-1}), FLU- stock change factor for land-use systems (Table A8.6)or sub-system for a particular land-use, dimensionless , [Note: FND is substituted for FLU in forest soil C calculation to estimate the influence of natural disturbance regimes. FMG - stock change factor for management regime(Table 8.6 dimensionless, FI - stock change factor for input of organic matter(Table A8.6) dimensionless, A = land area of the stratum being estimated, (ha).

Table A8.5 Default reference (under native vegetation) soil organic c stocks (SOC_{ref}) for mineral soils(tonnes c ha^{-1} in 0-30 cm depth)

Climate region	**HAC soils**[1]	**LAC soils**[2]	**Sandy soils**[3]	**Spodic soils**[4]	**Volcanic soils**[5]	**Wetland soils**[6]
Boreal	68	NA	10	117	20	146
Cold temperate, dry	50	33	34	NA	20	**87**
Cold temperate, moist	95	85	71	115	130	**87**
Warm temperate, dry	38	24	19	NA	70	**88**
Warm temperate, moist	88	63	34	NA	80	**88**
Tropical, dry	38	35	31	NA	50	**86**
Tropical, moist	65	47	39	NA	70	**86**
Tropical, wet	44	60	66	NA	130	**86**
Tropical montane	88	63	34	NA	80*	**86**

Source: IPCC 2006 Guidelines

1. Soils with high activity clay (HAC) minerals are lightly to moderately weathered soils, which are dominated by 2:1 silicate clay minerals (in the World Reference Base for Soil Resources (WRB) classification these include Leptosols, Vertisols, Kastanozems, Chernozems, Phaeozems, Luvisols, Alisols, Albeluvisols, Solonetz, Calcisols, Gypsisols, Umbrisols, Cambisols, Regosols; in USDA classification includes Mollisols, Vertisols, high-base status Alfisols, Aridisols, Inceptisols).

2 Soils with low activity clay (LAC) minerals are highly weathered soils, dominated by 1:1 clay minerals and amorphous iron and aluminium oxides (in WRB classification includes Acrisols, Lixisols, Nitisols, Ferralsols, Durisols; in USDA classification includes Ultisols, Oxisols, acidic Alfisols).

3 Includes all soils (regardless of taxonomic classification) having > 70% sand and < 8% clay, based on standard textural analyses (in WRB classification includes Arenosols; in USDA classification includes Psamments).

4 Soils exhibiting strong podzolization (in WRB classification includes Podzols; in USDA classification Spodosols)

5 Soils derived from volcanic ash with allophanic mineralogy (in WRB classification Andosols; in USDA classification Andisols)

6 Soils with restricted drainage leading to periodic flooding and anaerobic conditions (in WRB classification Gleysols; in USDA classification Aquic suborders).

Table A8.6 relative stock change factors (F_{LU}, F_{MG}, and F_I) (over 20 years) for different management activities on cropland

Factor value	**Level**	**Temperature regime**	**Moisture regime**	**IPCC defaults**
Land use(F_{LU})	Long-term cultivated	Temperate/boreal	dry	0.8
			Moist	0.69
		Topical	dry	0.58
			Moist/wet	0.48
		Tropical montane	NA	0.64
Land use(F_{LU})	Paddy rice	All	Dry and Moist/wet	1.10
Land use(F_{LU})	Perennial/Tree crop	All	Dry and Moist/wet	1.00
Land use(F_{LU})	Set aside (<20 years)	Temperate/Boreal and Tropical	Dry	0.93
			Moist/Wet	0.82
		Tropical montane	NA	0.88
Tillage (F_{MG})	Full	All	Dry and Moist/Wet	1.00
Tillage (F_{MG})	Reduced	Temperate/Boreal	Dry	1.02
			Moist	1.08
		Tropical	Dry	1.09
			Moist/wet	1.15
		Tropical montane	NA	1.09
Tillage (F_{MG})	No-till	Temperate/Boreal	Dry	1.10
			Moist	1.15
		Tropical	Dry	1.17
			Moist/wet	1.22
		Tropical montane	NA	1.16
Input (F_I)	Low	Temperate/Boreal	dry	0.95
			Moist	0.92
		Tropical	dry	0.95
			Moist/wet	0.92
		Tropical montane	NA	0.94
Input (F_I)	Medium	All	Dry and Moist/Wet	1.0

Input (F_I)	High without manure	Temperate/Boreal and Tropical	Dry	1.04
			Moist /Wet	1.11
		Tropical montane	NA	1.08
Input (F_I)	High with manure	Temperate/Boreal and Tropical	Dry	1.37
			Moist /Wet	1.44
		Tropical montane	NA	1.41

Source: IPCC 2006 Guidelines

d. Loss of carbon stocks in organic soils

$$L_{Organic} = A * EF$$ 208

$L_{Organic}$ -Annual carbon loss from cultivated organic soils (tonnes C yr^{-1}), EF -Emission factor(Table A8.7) for climate type(tonnes C ha^{-1} yr^{-1}), A -Annual area Land Converted to Cropland for biofuels (hectares),

Table A8.7 Annual emission factors (EF) for cultivated organic soils

Climatic temperature regime	IPCC default (tonnes C ha^{-1} yr^{-1})
Boreal/Cool Temperate	5.0
Warm Temperate	10.0
Tropical/Sub-Tropical	20.0

Source: IPCC 2006 Guidelines

Lime and fertilisers

(i) Liming: Annual CO2-C emissions from Liming

$$E_{CO2\ Lime} = EF_{Lime} * M_{Lime}$$ 209

$E_{CO2\ Lime}$ -Annual CO2-C emissions from C emissions from liming (tonnes C yr^{-1}) M_{Lime} -Annual amount of calcic limestone (CaCO3) (tonnes yr^{-1}), EF_{Lime} -Emission factor [tonnes of C (tonne of limestone)$^{-1}$]

Note : Default EF_{Lime} = 0.12

Table A8.8 Equivalent nitrogen content of common chemical fertilizers

	Type of N fertiliser	Chemical formula	Nitrogen content (weight percent)	Emission factors (kg/Mg)		
				NH3	NO	NO2
1	Anhydrous ammonia	NH_3	82.3			
2	Urea	$CO(NH_2)_2$	46.7	130		
3	Ammonium nitrate	NH_4NO_3	35.0		120	
4	Ammonium sulfate	$(NH_4)_2SO_4$	21.2		70	6
5	Ammonium chloride	NH4 Cl	26.2			

$$Nitrogen\quad content(weight\ percent) = \frac{atomic\ weight\ nitrogen}{molecular\ weight\ of\quad fertiliser} * 100\%$$

To determine the tonnes of nitrogen per tonne of fertiliser applied, multiply the nitrogen content(weight percent) times the tonnes of fertiliser applied

(ii) Urea Fertilization: Annual CO2 emissions from Urea Fertilization

$$E_{CO2\,Urea} = EF_{Urea} * M_{Urea} \quad 210$$

$E_{CO2\ \ Urea}$ -Annual CO2-C emissions from Urea Fertilization(tonnes C yr^{-1}), EF_{Lime} - Emission factor annual [tonnes of C (tonne of $urea)^{-1}$]), M_{Urea} -Annual amount of Urea Fertilization(tonnes urea yr^{-1}),

Note : Default EF_{Urea} = 0.20

(iii) Direct N_2O Emissions from Soils

a) synthetic fertilizers

$$E_{\text{N2O-SN}}(i) = EF_{SN} * M_{SN}(i) * N_{content}(i) \quad 211$$

$E_{N2O\ \ SN}$ -Annual direct N2O- emissions produced from N synthetic fertiliser (i) application (kg N2O-N yr $^{-1}$, EF_{SN} -Emission factor for N_2O emissions from N inputs[kg N_2O-N (kg N input)$^{-1}$], M_{SN} -Annual amount of N applied Synthetic fertiliser(i) (kg N yr^{-1}), $N_{content}$ -percentage nitrogen content (table 8.8) in fertiliser(i) (%)

b) Animal manure, compost, sewage sludge

$$E_{\text{N2O-AM}} = EF_{AM} * M_{AM} \qquad 212$$

$E_{N2O\ \ AM}$ -Annual direct N2O-N emissions produced from animal manure, compost, sewage sludge application (kg N2O-N yr $^{-1}$, EF_{AM} -Emission factor for N_2O emissions from N inputs[kg N_2O-N (kg N input)$^{-1}$], M_{SN} -Annual amount of N applied animal manure, compost, sewage sludge(kg N yr^{-1}),

c) Crop residues

$$E_{\text{N2O-CR}} = EF_{CR} * M_{CR} \qquad 213$$

$E_{N2O\ \ CR}$ -Annual direct N2O-N emissions produced from crop residues application (kg N2O-N yr $^{-1}$, EF_{CR} -Emission factor for N_2O emissions from N inputs[kg N_2O-N (kg N input)$^{-1}$], M_{CR} -Annual amount of N applied animal manure, compost, sewage sludge(kg N yr^{-1}),

(iv) NO emissions from N fertilizer application

$$E_{\text{NO-SN}}(i) = EF_{SN(NO)} * M_{SN}(i) * N_{content}(i) \qquad 213(a)$$

$E_{NO\ \ SN}$ -Annual direct NO- emissions produced from N synthetic fertiliser (i) application (kg N2O-N yr $^{-1}$, $EF_{SN(NO)}$ -Emission factor for NO emissions from N inputs[kg N_2O-N (kg N input)$^{-1}$], M_{SN} -Annual amount of N applied Synthetic fertiliser(i) (kg N yr^{-1}), $N_{content}$ -percentage nitrogen content (table A8.8) in fertiliser(i) (%)

(v) NH3 emission

$$E_{\text{NH3-SN}}(i) = EF_{SN(NH3)} * M_{SN}(i) * N_{content}(i)$$

214

$E_{NH3\ \ SN}$ -Annual direct NH_3- emissions produced from N synthetic fertiliser (i) application (kg N2O-N yr $^{-1}$, $EF_{SN(NH3)}$ -Emission factor for NH3 emissions from N inputs[kg N_2O-N (kg N input)$^{-1}$], M_{SN} -Annual amount of N applied Synthetic fertiliser(i) (kg N yr^{-1}), $N_{content}$ -percentage nitrogen content (table A8.8) in fertiliser(i) (%)

Table A8.8 Default emission factors to estimate direct N2O emissions

		Default emission factor
	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 N2O–N (kg N) -1]	0.01
	EF_4 [N volatilisation and re-deposition], kg N2O–N (kg NH3–N + NOX–N volatilised)	0.010
	EF_5 [leaching/runoff], kg N2O–N (kg N leaching/runoff)	0.0075
	$Frac_{GASF}$ [Volatilisation from synthetic fertiliser], (kg NH3–N + NOx–N) (kg N applied)	0.10
	$Frac_{GASM}$ [Volatilisation from all organic N fertilisers applied , and dung and urine deposited by grazing animals], (kg NH3–N + NOx–N) (kg N applied or deposited)	0.20
	$Frac_{LEACH}$-(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)	0.30

Source: IPCC 2006 Guidelines

(vi) Indirect N2O Emissions from Soils: N2O from Atmospheric Deposition of N Volatilised from soils

$$N_2O_{(ATD)} - N = [(F_{SN} * Frac_{GASF}) + (F_{ON/} * Frac_{GASM})] * EF_4$$

215

$N_2O_{(ATD)} - N$ -Annual amount of N2O-N produced from atmospheric deposition of N volatilised from managed soils (kg N2O-N yr $^{-1}$), F_{SN} -Annual amount of synthetic fertilizer N applied to soils (kg N yr $^{-1}$), $Frac_{GASF}$ - Fraction of synthetic fertilizer N that(Table A 8.8) volatilises (kg H3-N + NOx-N) (kg of N applied)$^{-1}$, F_{ON} -Annual amount of animal manure, compost, sewage sludge and other organic N additions intentionally applied to soils (kg N yr $^{-1}$), $F\ rac_{GASM}$ -Fraction of applied organic N fertilizer materials(Table A8.8) of animal manure, compost, sewage sludge and other organic deposited that volatilises (kg NH3-N + NOx-N) (kg of N applied or deposited) $^{-1}$, EF_4 - Emission factor for N2O emission from atmospheric deposition of N on soils (Table 8.8) and water surfaces (kg N2O-N) (kg NH3-N + NOx-N volatilized) $^{-1}$

(vii) Indirect N2O Emissions from Managed Soils: N2O from N leaching/runoff from Managed Soils

$$N_2O_{(L)} - N = [(F_{SN} + F_{ON\,/})^* Frac_{LEACH}]^* EF_5$$

216

$N_2O_{(L)} - N$ -Annual amount of N2O-N produced from managed soils in regions where leaching and runoff occurs (kg N2O-N yr $^{-1}$), F_{SN} -Annual amount of synthetic fertilizer N applied to soils (kg N yr $^{-1}$), $Frac_{LEACH}$ - Fraction of all N additions to managed soils that is lost Through leaching (Table 8.8)and runoff [kg N (kg of N additions)$^{-1}$], F_{ON} - Annual amount of animal manure, compost, sewage sludge and other organic N additions intentionally applied to soils (kg N yr $^{-1}$), EF_5 -Emission factor for N2O emission from N leaching(Table A8.8) and runoff [kg N2O-N (kg N leaching and runoff)$^{-1}$]

Pesticides, fungicides and pesticides application

(i) Emission of active ingredient

$$E_{Active\ \ ingredient}(i) = M_{Pesticides}(i)^*(\ 1 - C_{Inert\ \ ingredient\ \ content}(i)\ \ )^* EF_{Vapour\ pressure}(i)$$

21
7

$E_{Active\ \ ingredient}(i)$ -Annual active ingredient emissions from pesticide(i), (tonnes kg yr^{-1}), $M_{Pesticides}$ -annual quantity of pesticide(i) applied(Mg), $C_{inert\ ingredient\ \ content}$ -percentage content of inert ingredient in pesticide, $EF_{vapour\ pressure}$ -Emission factor for active ingredient in pesticide(i)(kg/Mg),

(ii) Emission of inert ingredient

$$E_{inert\ \ ingredient}(i) = M_{Pesticides}(i) * \left(C_{Inert\ \ ingredient\ \ content}(i) \right) * P_{VOC}(i)$$ 218

$E_{inert\ \ ingredient}(i)$ -Total quantity of emissions from inert ingredients of pesticide(VOC)(i), (tonnes kg yr^{-1}), $M_{Pesticides}$ -annual quantity of pesticide(i) applied(kg), $C_{inert\ ingredient\ \ content}$ - percentage content of inert ingredient in pesticide, P_{VOC} - average percentage of the VOC content of the inert portion of emulsifiable concentrates in pesticide(i)

Emissions from field transport

$$E_{CO2}(1) = \frac{C_{Diesel} * CV * \rho_{diesel} * EF_{CO_2}}{10^3}$$ 219

$E_{CO_2}(1)$ -Annual carbon dioxide emissions from diesel used in during energy crop production/cultivated (kg yr^{-1}), C_{diesel} - total annual diesel requirements (l) (from equation 15), EF -Emission factor for carbon dioxide(tonne/TJ)(74.10t/TJ); ρ_{diesel} -density of diesel(kg/litre)(0.832kg/l), CV -diesel Heating value(MJ/kg)(44.8MJ/kg),

$$E_{CH4}(1) = \frac{C_{Diesel} * CV * \rho_{diesel} * EF_{CH4}}{10^6}$$ 220

$E_{CH4}(1)$ -Annual methane emissions from diesel used in during energy crop production/cultivated (kg yr^{-1}), C_{diesel} - total annual diesel requirements (l) (from equation 15), EF -Emission factor for methane(kg/TJ)(3.0kg/TJ); ρ_{diesel} -density of diesel(kg/litre)(0.832kg/l), CV -diesel Heating value(MJ/kg),)(44.8MJ/kg),

$$E_{N2O}(1) = \frac{C_{Diesel} * CV * \rho_{diesel} * EF_{N2O}}{10^6}$$ 221

$E_{N2O}(1)$ -Annual nitrogen dioxide emissions from diesel used in during energy crop production/cultivated (kg yr^{-1}), C_{diesel} - total annual diesel requirements (l) (from equation 15), EF -Emission factor for nitrogen dioxide(kg/TJ)(0.6kg/TJ); ρ_{diesel} -density of diesel(kg/litre)(0.832kg/l), CV -diesel Heating value(MJ/kg),)(44.8MJ/kg),

$$E_{NOx}(1) = \frac{C_{Diesel} * CV * \rho_{diesel} * EF_{NOx}}{10^6}$$ 222

$E_{NOx}(1)$ -Annual oxides of nitrogen emissions from diesel used in during energy crop production/cultivated (kg yr^{-1}), C_{diesel} - total annual diesel requirements (l) (from equation 15), EF -Emission factor for oxides of nitrogen(kg/TJ)(800kg/TJ); ρ_{diesel} -density of diesel(kg/litre)(0.832kg/l), CV -diesel Heating value(MJ/kg))(44.8MJ/kg),,

$$E_{CO}(1) = \frac{C_{Diesel} * CV * \rho_{diesel} * EF_{CO}}{10^6} \qquad 223$$

$E_{CO}(1)$ -Annual carbon monoxide emissions from diesel used in during energy crop production/cultivated (kg yr^{-1}), C_{diesel} - total annual diesel requirements (l) (from equation 15), EF -Emission factor for carbon monoxide(kg/TJ)(1000kg/TJ); ρ_{diesel} -density of diesel(kg/litre)(0.832kg/l), CV -diesel Heating value(MJ/kg))(44.8MJ/kg),,

$$E_{NMVOC}(1) = \frac{C_{Diesel} * CV * \rho_{diesel} * EF_{NMVOC}}{10^6} \qquad 224$$

$E_{NMVOC}(1)$ -Annual NMVOC emissions from diesel used in during energy crop production/cultivated (kg yr^{-1}), C_{diesel} - total annual diesel requirements (l) (from equation 15), EF -Emission factor for NMVOC(kg/TJ)(200kg/TJ); ρ_{diesel} -density of diesel(kg/litre)(0.832kg/l), CV -diesel Heating value(MJ/kg))(44.8MJ/kg),,

$$E_{SO2}(1) = \frac{C_{Diesel} * CV * \rho_{diesel} * EF_{SO2}}{10^6} \qquad 225$$

$E_{SO2}(1)$ -Annual sulphur dioxide emissions from diesel used in during energy crop production/cultivated (kg yr^{-1}), C_{diesel} - total annual diesel requirements (l) (from equation 15), EF -Emission factor for sulphur dioxide(kg/TJ)(37.43kg/TJ); ρ_{diesel} -density of diesel(kg/litre)(0.832kg/l), CV -diesel Heating value(MJ/kg))(44.8MJ/kg),,

Default IPCC Emission factors for gases under energy combustion

	CO_2	**CH_4**	**N_2O**	**NOx**	**CO**	**NMVO**	**SO2**
	(t/TJ)	**(kg/TJ)**	**(kg/TJ)**	**(kg/TJ)**	**(kg/TJ)**	**(kg/TJ)**	**(kg/TJ)**
Gasoline	69.30	33.00	3.20	600	800	1500	4.66
Diesel	74.10	3.0	0.6	800.00	1,000.00	200.00	37.43
Coal	112.00	30.00	4.00	300	150	20	558.62
Heavy fuel oil	77.40	3.00	0.60	200	10	5	2.31
LPG	56 .10						

Source: IPCC 2006 Guidelines

Emissions from biomass transport

From farm to biofuels factory

Note: T_{diesel} - total annual diesel requirements for transportation of biomass to factory is calculated from biomass transport module.

$$E_{CO2}(2) = \frac{T_{Diesel} * CV * \rho_{diesel} * EF_{CO_2}}{10^3} \quad 226$$

$E_{CO_2}(2)$ -Annual carbon dioxide emissions from diesel used in biomass transportation to factory (kg yr^{-1}), T_{diesel} - total annual diesel requirements for transportation of biomass to factory , EF -Emission factor for carbon dioxide(tonne/TJ)(74.10t/TJ); ρ_{diesel} -density of diesel(kg/litre)(0.832kg/l), CV -diesel Heating value(MJ/kg)(44.8MJ/kg),

$$E_{CH4}(2) = \frac{T_{Diesel} * CV * \rho_{diesel} * EF_{CH4}}{10^6} \quad 227$$

$E_{CH4}(2)$ -Annual methane emissions from diesel used in biomass transportation to factory (kg yr^{-1}), T_{diesel} - total annual diesel requirements for transportation of biomass to factory, EF -Emission factor for methane(kg/TJ)(3.0kg/TJ); ρ_{diesel} -density of diesel(kg/litre)(0.832kg/l), CV -diesel Heating value(MJ/kg),)(44.8MJ/kg),

$$E_{N2O}(2) = \frac{T_{Diesel} * CV * \rho_{diesel} * EF_{N2O}}{10^6} \quad 228$$

$E_{N2O}(2)$ -Annual nitrogen dioxide emissions from diesel used in biomass transportation to factory (kg yr^{-1}), T_{diesel} - total annual diesel requirements for transportation of biomass to factory, EF -Emission factor for nitrogen dioxide(kg/TJ)(0.6kg/TJ); ρ_{diesel} -density of diesel(kg/litre)(0.832kg/l), CV -diesel Heating value(MJ/kg),)(44.8MJ/kg),

$$E_{NOx}(2) = \frac{T_{Diesel} * CV * \rho_{diesel} * EF_{NOx}}{10^6} \quad 229$$

$E_{NOx}(2)$ -Annual oxides of nitrogen emissions from diesel used in biomass transportation to factory (kg yr^{-1}), T_{diesel} - total annual diesel requirements for transportation of biomass to factory , EF -Emission factor for oxides of nitrogen(kg/TJ)(800kg/TJ); ρ_{diesel} -density of diesel(kg/litre)(0.832kg/l), CV -diesel Heating value(MJ/kg))(44.8MJ/kg),,

$$E_{CO}(2) = \frac{T_{Diesel} * CV * \rho_{diesel} * EF_{CO}}{10^6} \qquad 230$$

$E_{CO}(2)$ -Annual carbon monoxide emissions from diesel used in biomass transportation to factory (kg yr^{-1}), T_{diesel} - total annual diesel requirements for transportation of biomass to factory, EF -Emission factor for carbon monoxide(kg/TJ)(1000kg/TJ); ρ_{diesel} -density of diesel(kg/litre)(0.832kg/l), CV -diesel Heating value(MJ/kg))(44.8MJ/kg),,

$$E_{NMVOC}(2) = \frac{T_{Diesel} * CV * \rho_{diesel} * EF_{NMVOC}}{10^6} \qquad 231$$

$E_{NMVOC}(2)$ -Annual NMVOC emissions from diesel used in biomass transportation to factory (kg yr^{-1}), T_{diesel} - total annual diesel requirements for transportation of biomass to factory, EF -Emission factor for NMVOC(kg/TJ)(200kg/TJ); ρ_{diesel} -density of diesel(kg/litre)(0.832kg/l), CV -diesel Heating value(MJ/kg))(44.8MJ/kg),,

$E_{SO2} = \frac{T_{Diesel} * CV * \rho_{diesel} * EF_{SO2}}{10^6}$	232
E_{SO2} -Annual sulphur dioxide emissions from diesel used in during energy crop production/cultivated (kg yr^{-1}), T_{diesel} - total annual diesel requirements for transportation of biomass to factory , EF -Emission factor for sulphur dioxide(kg/TJ)(37.43kg/TJ); ρ_{diesel} -density of diesel(kg/litre)(0.832kg/l), CV -diesel Heating value(MJ/kg))(44.8MJ/kg),,	

Default IPCC Emission factors for gases under energy combustion

	CO_2	CH_4	N_2O	NOx	CO	NMVO	SO2
	(t/TJ)	(kg/TJ)	(kg/TJ)	(kg/TJ)	(kg/TJ)	(kg/TJ)	(kg/TJ)
Gasoline	69.30	33.00	3.20	600	800	1500	4.66
Diesel	74.10	3.0	0.6	800.00	1,000.00	200.00	37.43
Coal	112.00	30.00	4.00	300	150	20	558.62
Heavy fuel oil	77.40	3.00	0.60	200	10	5	2.31
LPG	56 .10						

Source: IPCC 2006 Guidelines

For fossil fuels used as fuel for process heat, the following emissions are considered

1	Diesel
2	Coal
3	Heavy fuel oil
4	LPG

Source: IPCC 2006 Guidelines

Default IPCC Emission factors for gases under energy combustion

	CO_2	CH_4	N_2O	NOx	CO	NMVO	SO2
	(t/TJ)	(kg/TJ)	(kg/TJ)	(kg/TJ)	(kg/TJ)	(kg/TJ)	(kg/TJ)
Gasoline	69.30	33.00	3.20	600	800	1500	4.66
Diesel	74.10	3.0	0.6	800.00	1,000.00	200.00	37.43
Coal	112.00	30.00	4.00	300	150	20	558.62
Heavy fuel oil	77.40	3.00	0.60	200	10	5	2.31
LPG	56 .10						

Source: IPCC 2006 Guidelines

$$E_{CO2}(3)(i) = \frac{ERH_i * CV * \rho_{diesel} * EF_{CO_2}}{10^3} \qquad 233$$

$E_{CO_2}(3)(i)$ -Annual carbon dioxide emissions from fuel for process heat in biofuels production from energy resource (i)(kg), ERH_i - total annual energy resource (Table 8.4) for heating from resource (i) (tonnes) (calculated from chapter 4), EF -Emission factor for carbon dioxide for energy resource (i) according to table 8.5 (tonne/TJ); ρ_{diesel} -density of diesel(kg/litre)(0.832kg/l), CV -diesel Heating value(MJ/kg)(44.8MJ/kg),

$$E_{CH4}(3)(i) = \frac{ERH_i * CV * \rho_{diesel} * EF_{CH4}}{10^6} \qquad 234$$

$E_{CH4}(3)(i)$ -Annual methane emissions from fuel for process heat in biofuels production from energy resource (i)(kg), ERH_i - total annual energy resource (Table 8.4) for heating from resource (i) (tonnes) (calculated from chapter 4), EF -Emission factor for methane for energy resource (i) according to table 8.5 (kg/TJ); ρ_{diesel} -density of diesel(kg/litre)(0.832kg/l), CV -diesel Heating value(MJ/kg),)(44.8MJ/kg),

$$E_{N2O}(3)(i) = \frac{ERH_i * CV * \rho_{diesel} * EF_{N2O}}{10^6} \qquad 235$$

$E_{N2O}(3)(i)$ -Annual nitrogen dioxide emissions from fuel for process heat in biofuels production from energy resource (i)(kg), ERH_i - total annual energy resource (Table 8.4) for heating from resource (i) (tonnes) (calculated from chapter 4), EF -Emission factor for nitrogen dioxide for energy resource (i) according to table 8.5) (kg/TJ); ρ_{diesel} -density of diesel(kg/litre)(0.832kg/l), CV -diesel Heating value(MJ/kg),)(44.8MJ/kg),

$$E_{CO}(3)(i) = \frac{ERH_i * CV * \rho_{diesel} * EF_{CO}}{10^6} \qquad 236$$

$E_{CO}(3)(i)$ -Annual carbon monoxide emissions from fuel for process heat in biofuels production from energy resource (i)(kg), ERH_i - total annual energy resource (Table 8.4) for heating from resource (i) (tonnes) (calculated from chapter 4), EF -Emission factor for carbon monoxide for energy resource (i) according to table 8.5 (kg/TJ); ρ_{diesel} -density of diesel(kg/litre)(0.832kg/l), CV -diesel Heating value(MJ/kg))(44.8MJ/kg),,

$$E_{NOx}(3)(i) = \frac{ERH_i * CV * \rho_{diesel} * EF_{CO}}{10^6} \qquad 237$$

$E_{NOx}(3)(i)$ -Annual oxides of nitrogen emissions from fuel for process heat in biofuels production from energy resource (i)(kg), ERH_i - total annual energy resource (Table 8.4) for heating from resource (i) (tonnes) (calculated from chapter 4), EF -Emission factor for oxides of nitrogen for energy resource (i) according to table 8.5 (kg/TJ); ρ_{diesel} -density of diesel(kg/litre)(0.832kg/l), CV -diesel Heating value(MJ/kg))(44.8MJ/kg),,

$$E_{NMVOC}(3) = \frac{ERH_i * CV * \rho_{diesel} * EF_{NMVOC}}{10^6}$$ 238

$E_{NMVOC}(3)$ -Annual NMVOC emissions from fuel for process heat in biofuels production from energy resource (i)(kg), ERH_i - total annual energy resource (Table 8.4) for heating from resource (i) (tonnes) (calculated from chapter 4), EF -Emission factor for NMVOC for energy resource (i) according to table 8.5 (kg/TJ); ρ_{diesel} -density of diesel(kg/litre)(0.832kg/l), CV -diesel Heating value(MJ/kg))(44.8MJ/kg),,

$$E_{SO2}(3) = \frac{ERH_i * CV * \rho_{diesel} * EF_{SO2}}{10^6}$$ 239

$E_{SO2}(3)$ -Annual sulphur dioxide emissions from fuel for process heat in biofuels production from energy resource (i)(kg), ERH_i - total annual energy resource (Table 8.4) for heating from resource (i) (tonnes) (calculated from chapter 4), EF -Emission factor for sulphur dioxide for energy resource (i) according to table 8.5 (kg/TJ); ρ_{diesel} -density of diesel(kg/litre)(0.832kg/l), CV -diesel Heating value(MJ/kg))(44.8MJ/kg),,

Emissions from waste

$$E_{CH4}(4) = [\ (TOW - S\ ) * EF\ ] - R$$ 240

$E_{CH4}(4)$ -Annual Methane (CH_4) emissions , kg CH_4/yr, TOW - total organically degradable material in wastewater from industry kg COD/yr , EF - emission factor for industry, kg CH_4/kg COD for treatment/discharge pathway or system(s) used; S -organic component removed as sludge in inventory year, kg COD/yr, R -amount of CH_4 recovered in inventory year, kg CH_4/yr

Assumption: No sludge removal, S= 0; No methane recovery R=0

$$EF = B_o * MCF$$ 198

EF - emission factor for industry, kg CH4/kg COD for treatment/discharge pathway or system(s) used -Annual Methane (CH4) emissions , B_o - maximum CH4 producing capacity, kg CH4/kg COD, MCF -methane correction factor (fraction) (See Table A10.)

NOTE: IPCC COD-default factor for B_o =0.25 kg CH_4/kg COD.

Table A10 DEFAULT MCF VALUES FOR INDUSTRIAL WASTEWATER

Type of treatment and discharge pathway or system	MCF
UNTREATED	
Sea, river and lake discharge	0.1
TREATED	
Aerobic treatment plant(well managed)	0
Aerobic treatment plant(Not well managed. Overloaded)	0.3
Anaerobic digester for sludge)	0.8
Anaerobic reactor (e.g., UASB, Fixed Film Reactor)	0.8
Anaerobic shallow lagoon(Depth less than 2 metres, use expert judgment)	0.2
Anaerobic deep lagoon (Depth more than 2 metres)	**0.8**

Source: IPCC 2006 Guidelines

$$TOW = C_{wastewater \quad annual} * COD \qquad 241$$

TOW - total organically degradable material in wastewater from industry kg COD/yr , $C_{wastewater\ annual}$ - total annual wastewater generated in biofuel production(m^3) calculated from chapter 4, COD - emission chemical oxygen demand (industrial degradable organic component in wastewater),kg COD/m^3;

NOTE: Default values:

Table A11 Default COD values

	Fuel type feedstock source	COD (kg COD/m^3)
1	**Biodiesel**	**0.5**
2	Bioethanol production from sugar crops	**5**
3	Bioethanol from starch crops	**1.5**

Source: IPCC 2006 Guidelines

Appendix IV Annual costs of biofuels production

Description	unit	Cost per unit (US$/unit)	Annual Cost (US$)					
Feedstock Type			Jatropha			Soy Beans		
Plant Capacity (Million litres/annum)		2	20	50	2	20	50	
Methanol (t)	t	84480		2112000	84480	844800	2112000	84480
Sodium Methylate (t)	t	5280		132000	5280	52800	132000	5280
Hydrochloric acid (t)	t	3564		89100	3564	35640	89100	3564
Calcium hydroxide{Ca(OH) 2} (t)	t	282		7040	282	2816	7040	282
Soduim bicarbonate{Na2C O3} (t)	t	275		6864	275	2746	6864	275
Bleaching (t)	t	1584		39600	1584	15840	39600	1584
Water (t)	t	2728		68200	2728	27280	68200	2728
Nitrogen (t)	t	35		880	35	352	880	35
Electricity (t)	t	17		431	17	172	431	17
Coal (t)	t	57904		1447600	57904	579040	1447600	57904
Electricity-Press only(KWh)	kWh	14		358	29	286	716	14
Electricity (Solvent Extraction)KWh	kWh	22		542	43	434	1085	22
Hexane(kg)	t	4010		100241	8019	80192	200481	4010
Fat Phase(t)	t	26		660	26	264	660	26
Waste Water (t)	t	158		3960	158	1584	3960	158

Source: Own calculations

Appendix V Emission from biomass production

Plant Capacity(Million litres/annum)	**2**	**20**	**50**	**2**	**20**	**50**
Emissions from Land Use Change		8790074	2.20E+07	6592555		1.65E+08
Carbon dioxide emissions from loss of carbon stocks from change in carbon stocks in biomass kg	750924.9	7509250	1.88E+07	5631937	5.63E+07	1.41E+08
carbon dioxide emissions from loss of carbon stocks in dead organic matter due to land conversion1 (kg)	5776.346	57763.46	144408.6	43322.59	433225.9	1083065
carbon dioxide emissions from loss of carbon stocks in mineral soils (kg)	6779.143	67791.45	169478.6	50843.57	508435.8	1271089
carbon dioxide emissions from loss carbon stocks in organic soils (kg)	115526.9	1155269	2888173	866451.9	8664518	2.17E+07
Emissions from fertiliser application						
Ammonia (kg)	16.58862	165.8862	414.7153	5.683137	56.83136	142.0784
Nitrogen oxide (kg)	0	0	0	0	0	0
Nitrous oxide (kg)	0.000936	0.009364365	0.02341091	0.000320816	0.003208162	0.008020405
Carbon dioxide	0	0	0	0	0	0
Nitrous oxide N volatised (kg)	2.01E-07	2.01E-06	5.01E-06	6.87E-08	6.87E-07	0.008020405
NO from N leached (tonnes)	4.51E-07	4.51E-06	1.13E-05	1.55E-07	1.55E-06	3.86E-06
Emissions from Lime application (kg)	0	0	0	10397.42	103974.2	259935.5
Emissions from field transport						
Carbon dioxide (kg)	0.008702	0.08702245	0.2175561	1.266177	12.66177	31.65442
Methane (kg)	3.52E-07	3.52E-06	8.81E-06	5.13E-05	0.000512622	0.001281555
Nitrous oxide(kg)	7.05E-08	7.05E-07	1.76E-06	1.03E-05	0.000102524	0.000256311
Oxides of nitrogen(kg)	4.40E-06	4.40E-05	0.000109894	0.000639582	0.006395815	0.01598954
carbon monoxide(kg)	1.17E-07	1.17E-06	2.94E-06	1.71E-05	0.00017087	0.000427185

Plant Capacity(Million litres/annum)	**2**	**20**	**50**	**2**	**20**	**50**
					4	
Non methane volatile organic compounds(kg)	2.35E-05	0.00023	0.000587	0.0034	0.03417481	0.08543702
Sulphur dioxide	0					
Emissions from biomass transport						
Carbon dioxide(kg)	9.183044	0.000234	229.5761	18.36609	183.6609	0.08543702
Methane(kg)	0.000372	0.00371	0.009294	0.000743	0.007435	0.01858916
Nitrous oxide(kg)	7.44E-05	0.000743	0.001858	0.000148	0.0014871	0.003717832
Oxides of nitrogen(kg)	0.099142	0.9914	2.478554	0.1982844	1.982844	4.957109
carbon monoxide(kg)	0.000124	0.001239	0.00309	0.00024	0.00247	0.006196386
Non methane volatile organic compounds(kg)	0.024786	0.2478	0.003098	0.04957	0.4957109	1.239277
Sulphur dioxide	0.004639	0.0463	0.1159	0.00927	0.09277	0.2319
Emissions from waste						
Untreated (discharge to river or lake) (kg)	3.3	33	82.5	33	33	82.5