Analysis of bioenergy potentials in rural landscapes using energy efficiency indices

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by

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Disclaimer

Abstract

The use of available land and its suitability for bioenergy plantation as a measure of bioenergy potential under an SEA framework is inadequate; the inclusion of non-energy cropping options like farm, domestic and industrial waste etc. gives a wider perspective and clearer representation of obtainable bioenergy potential over space and time. The use of monetary valuation can be misleading because it is based on prices which can always change and do not represent the true value of energy; it is not an indicator of how much energy was gained after energy was invested into the biomass/bioenergy production activity. The use of energy yield or output without considering the energy invested to get such energy will give a false representation of the actual bioenergy potential being added to the EU bioenergy policy targets; therefore integrating more holistic indices such as the Net Energy Gain (NEG) and energy efficiency or Energy Return on Energy Invested (EROEI) under an SEA framework will bridge this methodological gap and also measure the capacity of different biomass/bioenergy production activities to support continuous social and economic functions. Using the Overijssel province as case study, this study applied Life Cycle Inventory and GIS tools to estimate the stock of energy invested and energy obtainable from different conventional and unconventional biomass/bioenergy production activities. This study estimated the energy invested and energy obtainable from the wet anaerobic co-digestion of biomass proceeds from crop residues, farm manure, grasses from natural grasslands and grasses grown on surplus pasturelands. This study among other things determined the capacity of biomass/bioenergy production activities to support continuous socio-economic functions; assessed the feasibilities and vulnerabilities of these production activities to available policy constraints; and evaluated the potential contributions of such production activities to the local bioenergy policy drive. From this study, uncoventional biomass sources can produce enough to take care of the province’s projected renewable energy targets from bioenergy sources (66.01PJ) and also contribute to demands elsewhere.

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List of Abbreviations

AEBIOM: European Biomass Association

CBS: Central Bureau of Statistics

CLC: CORINE Land Cover

CO_2: Carbon Dioxide

CSTM: Centre for Studies in Technology and Sustainable Development

DEFRA: Department for Environment, Food and Rural Affairs

EBG: Energy from Biogas

EBPO: Energy for Biogas Plant Operation

EBS: Energy for Baling and Stacking

EDF (N): Energy Digestate: Fibre (Nitrogen)

EDF (P): Energy Digestate: Fibre (Phosphorus)

EDF (K): Energy Digestate: Fibre (Potassium)

EDL (N): Energy Digestate: Liquor (Nitrogen)

EDL (P): Energy Digestate: Liquor (Phosphorus)

EDL (K): Energy Digestate: Liquor (Potassium)

EFP (N): Energy for Fertilizer Production (Nitrogen)

EFP (P): Energy for Fertilizer Production (Phosphorus)

EFP (K): Energy for Fertilizer Production (Potassium)

ECPC (H): Energy for Crop Protection Chemical (Herbicides)

ECPC (I): Energy for Crop Protection Chemical (Insecticides)

ECPC (F): Energy for Crop Protection Chemical (Fungicides)

EEA: European Environment Agency

EHL: Energy for Human Labour

EHS: Early Harvest Scheme

EMC: Energy for Mowing and Chopping

EMCSH: Energy for Manure, Collection, Storage and Haulage

EPA: Environmental Protection Agency

EU: European Union

EUBIA: European Biomass Industry Association

EROEI: Energy Return on Energy Invested

ESS: Energy for Stalk Shredding

ET: Energy for Transportation

EWOP: Energy for Wet Oxidation Process

F: Fungicides

GIS: Geographical Information System

GJ: Giga Joule

H: Herbicides

ha: Hectare

I: Insecticides

IHS: Intermediate Harvest Scheme

ITC: Faculty of Geo-Information Science and Earth Observation of the University of Twente

K:Potassium

Km: Kilometer

KWh: Kilowatt hour

LCI: Life Cycle Inventory

LGN: Landelijk Grondgebruiksbestand Nederland (Dutch Land use database)

LHS: Late Harvest Scheme

LPG: Liquefied Petroleum Gas

MJ: Mega Joule

Mtoe: Mega tonne of oil equivalent

N: Nitrogen

N: type of (crop, animal)

NEG: Net Energy Gain

NSCA: National Society for Clean Air and Environmental Protection

ORNL: Oak Ridge National Laboratory

P: Phosphorus

PGG: Platform Groene Grondstoffen

PJ: Peta Joule

SEA: Strategic Environmental Assessment

TJ: Tera Joule

Ton: Tonnes

UNFCCC: United Nations Framework Convention on Climate Change

UNECE: United Nations Economic Commission for Europe

US: United States

Chapter 1

1.0 INTRODUCTION

1.1 Rising importance of biomass sources

The search for renewable sources of energy has become more intense, because global fossil fuel reserves are being depleted at faster rates than they are being renewed (Ng et al., 2010). The need for alternative sources of energy such as biomass has grown in importance, because global fossil fuel supplies are becoming more unstable due to arm conflicts, political unrest and sanctions affecting oil producing countries e.g. Iraq, Libya, Iran etc. (van der Hilst et al., 2010). The reduction of global fossil fuel consumption and the adoption of cleaner energies as a panacea to slowing down global warming rates are also receiving great attention amongst policy makers and stakeholders globally (UNFCCC, 2008).

Under the Kyoto Protocol obligation, the EU has pledged a minimum target of 20% share of total energy from renewable sources and 10% share of total transport fuel mix from bioenergy sources by the year 2020 (EEA, 2006). In line with these EU targets, the Netherlands has set an ambitious target of 44.4% of the total renewable energy from biomass sources (van Rooijen & van Wees, 2006); but the analysis of where and how this energy is going to be produced is quite scarce (Fischer et al., 2010).

1.2 The importance of land for biomass production

Conventional biomass production for bioenergy production is often associated with the availability of land for cultivation of bioenergy crops (Prochnow et al., 2009). 19 million hectares of surplus pasturelands can be economically available and freed up for bioenergy production within Europe (Ukraine inclusive) by the year 2030 (Fischer et al., 2010).

Some EU countries like the Netherlands are highly urbanized with well-developed infrastructures and services that can support massive bioenergy production. However, the intensive use of its limited land resources because of its high population density, makes meeting local biomass demand for bioenergy production difficult (van der Hilst et al., 2010). Using available arable land for the production of bioenergy crops can affect the local food production chain (Cramer et al., 2007); consequently, the bioenergy potential of biomass sources other than that cultivated on excess land can be exploited to meet its bioenergy goals. Examples of these include animal wastes, domestic and industrial human wastes, rooftop crops, water algae etc.

1.3 Sustainable biomass production

Of great importance to the production of biomass for bioenergy production is its sustainability; this can be evaluated in terms of relevant policy constraints such as food security, nature conservation needs, socio-economic needs and the well-being of the local people involved (Cramer et al., 2007).

Any biomass production activity considered as sustainable must not compete with any food production, food distribution or food use chains e.g. the use of land devoted to food production for bioenergy production should be prohibited. Biomass production activity for bioenergy production must not be at cross purpose with any nature conservation needs e.g. soil preservation, water conservation, ecosystem and habitat preservation, plant and animal biodiversity etc. (Fischer et al., 2010). Sustainable biomass production activities do not compete with the socio-economic needs of the local people involved e.g. use of biomass for agricultural, domestic and industrial purposes (Scarlat et al., 2010). Biomass production activities must not tamper with the well-being of the local people involved; this is reflected in the respect for the rights of the local people e.g. basic human rights and privileges, land ownership rights, housing rights, rights to space for recreation, industrial rights etc. (Cramer et al., 2007).

1.4 Research problem

Previous bioenergy potential assessments often consider how much land is available, the potential biomass yield, the potential energy output and the money to be invested and gained as measures of bioenergy potentials (Beccali et al., 2009, Prochnow et al., 2009, van der Hilst et al., 2010, Fischer et al., 2010, Hellman & Verburg, 2011); but all of this measures are not adequate because they do not take account of how much energy is being invested into getting the final energy output. Available land as a measure of bioenergy potential is inadequate, because it only considers few land related factors; e.g. the size of land that can be sustainably used for biomass/bioenergy production, the most suitable bioenergy crop under prevailing local conditions e.g. climate, soil and socio-economic factors etc. (Fischer et al., 2010).

Assessing bioenergy potentials in terms of biomass yield per hectare is only applicable to biomass that grow on land and are therefore quantifiable by size (hectare) of land; some other biomass sources are quantified differently because they are not products of direct growth of biomass on land, but products of other human activities e.g. farm manure, refuse, garden wastes, industrial wastes etc. (Hellman & Verburg, 2011). The use of available land, the potential biomass yield per hectare and the potential energy output does not also account for energy invested to obtain the energy output. Money invested and gained is also not adequate and reliable as a measure of bioenergy potential because prices fluctuate and are susceptible to lots of forces that are not related to energy (production and market forces); this makes money a poor and unreliable store of value for bioenergy potential (Beccali et al., 2009, van der Hilst et al., 2010).

Assessing bioenergy potentials in terms of energy integrates land (if applicable), biomass yield per hectare (if applicable) and the energy involved. Although land, monetary valuation, biomass yield per hectare and energy output are known measures of bioenergy potential; but the bioenergy potential of biomass sources cannot be fully accounted for, unless the energy invested into getting the energy output and the total energy gained from the biomass/bioenergy production activities is factored in (Scurlock, 1998, Hill et al., 2006, Harvey, 2007, Beccali et al., 2009, Hall et al., 2009, van der Hilst et al., 2010, Fischer et al., 2010, Hellman & Verburg, 2011).

There are two bioenergy potential measures that include the potential energy outputs, energy to be invested into obtaining the energy output and the energy gained from the various biomass/bioenergy production activities; they are the Net Energy Gain (NEG) and the Energy Return on Energy Invested (EROEI) indices.

NEG is the gained difference in energy between energy invested into a biomass/bioenergy production activity and the energy output returned after production (Hill et al., 2006).

$$Net\ Energy\ Gain\ (NEG) = \text{Energy Output} - \text{Energy Input}$$

Net Energy Gain becomes a loss when it is less than 0.

EROEI (also known as the energy efficiency) is the ratio of the energy output (expected return) obtained from a particular biomass/bioenergy production activity to the energy input (investment required) required to get that energy (Hall et al., 2009).

$$\text{EROEI} = \frac{\text{Expected energy Output}}{Required\ energy\ investment}$$

NEG estimates the amount of energy that will be gained after the biomass/bioenergy production activities; but is not a measure of the ability of the biomass/bioenergy production activities to support continuous socio-economic functions; EROEI estimates the amount of energy gained after the biomass/bioenergy production activities (in multiples or fractions), and it is also a measure of the ability of the biomass/bioenergy production activities to support continuous socio-economic functions (Hill et al., 2006, Hall et al., 2009). Biomass/bioenergy production activity with an EROEI value greater than 3 is capable of supporting continuous socio-economic function while those below 3 are not (Hall et al., 2009).

1.5 Scope of study

The biomass/bioenergy production activities examined by this study are limited to sustainable options on the rural landscape, they include:

- **Growing alfalfa (*Medicago sativa*) on surplus pasturelands**

Planting of alfalfa (a conventional forage/bioenergy crop) on surplus pasturelands can help meet future needs for grass forage. Surplus pasturelands exists because of the advent of high-performance animal diets (with less grass content), and consequent reduction in importance of grass as animal feed (Coetto, 2008, Prochnow et al., 2009). Using surplus pasturelands as a biomass source is sustainable in terms of food security, because such lands are presently not in demand for food production (animal production) (Fischer et al., 2010). Planting alfalfa is not at cross purpose with nature conservation needs; because it conserves the soil structures, fixes nitrogenous nutrients from the atmosphere and enhances pastureland biodiversity (Biemans et al., 2008). Planting alfalfa does not threaten the socio-economic needs and well-being of the local people;

because it will be a new source of employment and income for farmers, and it will not trample on the land ownership rights of the local people.

- **Utilizing crop residues**

Use of crop residues does not compete with food production, distribution or use chain; however, some crop residues are often used as low-quality animal (cattle) feed e.g. maize stover, for soil conversation purposes such as compost making for nutrient replacement, for growing mushroom substrates (wheat), for animal beddings, as insulating materials for buildings and to a less extent in pulp and paper industries. This notwithstanding, there still exists excess crop residues available for bioenergy production within the EU (Scarlat et al., 2010). Crops whose residues are of interest to this study include maize, rapeseed, wheat, oat, triticale and barley; this is because they are high residue yielding crops, and also because they are grown locally in commercial quantities within the Overijssel province (Scarlat et al., 2010, CBS, 2012).

- **Collecting farm manure**

According to the EU Nitrates Policy and the EU Water Framework Directive, the direct use of farm manure for soil conservation and food production is prohibited; this is to prevent the over-enrichment of soils and nearby surface and groundwater (Mulleneers, 2010). Manure nutrients are expected to be refined, recovered and applied to the farmlands in required quantities; this is after mineral accounting has been done and the nutrient deficiency of the soil has been identified. These policies favour the use of farm manure for bioenergy production; this is because the digestate left after the bioenergy production can be used as fertilizers, this reduces or eliminates the energy and money costs of fertilizer production, and reduces the smell and air pollution associated with manure wastes (DEFRA, 2008). Of special interest to this study, is the bioenergy potential of manure from dairy and beef cattle, pigs and chicken, this is because of the population advantage (large number) of these animal types within the Overijssel province, high manure yield (dairy and beef cattle) and high manure-energy yield (pig and chicken) (DEFRA, 2008, CBS, 2012).

- **Using grasses from natural grassland**

The Natural grassland management policy of the Netherlands requires that grasses on natural grasslands be mown two to three times annually for nature conservation reasons; this practice prevents over-enrichment of the soils and nearby surface and ground water, prevents mono-culture grasslands and promotes plant, animal, habitat and ecosystem biodiversity on grasslands (Oenema et al., 2006). Grass cuttings from natural grasslands are usually used to supplement the grass from pasturelands; they can be used alongside crop residues as animal feed for feeding livestock, as insulating materials in buildings, as animal beddings, as raw materials for pulp and paper making and as biomass for bioenergy production (Scarlat et al., 2010, van Vuuren et al., 2010).

There are three possible harvest schemes on both natural grasslands or pasturelands in the Netherlands; the first harvest scheme is the early harvest scheme (EHS), usually done when grasses are less than 12 cm, usually results in lower yield per harvests (2 tonnes/hectare), but allows for more regrowth and harvest opportunities (3 harvests annually). The second scheme is the late harvest scheme (LHS); usually done when grasses are more than 25cm, usually results in higher yield (5 tonnes/ha), but less opportunity for fast re-growth and therefore less number of harvests (just 1 harvest annually). The third harvest system is harvest at an intermediate period called the Intermediate Harvest scheme (IHS), when grasses are between 15 – 20 cm, this also gives relatively high yield (up to 4 tonnes/hectare) and allows for one more re-growth and harvest opportunity (2 harvests annually) (Veepro Holland, 2011).

The use of grass from natural grassland for bioenergy production does not affect food production because natural grasslands are not primarily under grass cultivation like pasturelands but only supplements crop residue and grass use in other sectors when necessary. Natural grasslands are not owned for commercial purposes and therefore do not affect the rights, employment and sources of income of the local people. Mowing natural grasslands at least twice a year helps prevent over-enrichment of ground water and nearby surface waters; and also enhances biodiversity by preventing the growth of mono-culture grasslands.

Unconventional biomass sources such as crop residues, farm manure and left over grass will not remain as wastes, but constitute nuisance to the environment, decompose, release innate CO_2 back to the atmosphere and contribute to already high global warming rates (NSCA, 2006). However, if they are used as biomass for bioenergy production, the carbon constituents of the waste will be captured and converted into usable energy, hereby preventing the waste of usable biomass, and saving the funds and energy that would have been used in disposing them (Prochnow et al., 2009, Scarlat et al., 2010). By-products from bioenergy production can be further used as fertilizer replacements or processed for nutrient recovery (British Biogen, 1997). Also, this unconventional biomass sources can be exploited by farmers and grassland mangers involved as sources of extra income and employment (Cramer et al., 2007).

1.5.1 Bioenergy production technology (wet anaerobic co-digestion)

The energy conversion technology used for the evaluation of bioenergy potential by this study is the wet anaerobic co-digestion technology; this is because of the proximity and contiguity of the different biomass sources and the convenience of being able to process them together e.g. grass, manure, straw etc. (Steffen et al., 1998). This technology spends no energy on drying of biomass, produces higher biogas yield and better mixed digestate (with more balanced NPK ratio) than those mono-digested (British Biogen, 1997).

The products of wet anaerobic co-digestion of grass, manure and crop residue (straw) are biogas and digestate (Monnet, 2003). Digestate constitutes about 96% of co-digested biomass, while the remaining 4% is released in form of biogas; also 25% of digestate is usually in the form of fibre, while the remaining 75% are in liquor form (British Biogen, 1997). Biogas can be used for producing transport fuels and fuel cells, generating heat in boilers, producing heat and electricity together via Combined Heat and Power (CHP) technology; while digestates can be used as replacements for fertilizers or for mineral recovery e.g. phosphate from pig manure (British Biogen, 1997, Monnet, 2003).

1.5.2 Case study: Overijssel province

For the purpose of this study, the Overijssel province of the Netherlands (Figure 1) is the case study area. Overijssel provinces has a mix of land cover distribution similar to that obtainable for the whole of the Netherlands(Overijssel province- build-up-10%, agriculture-79.8%, and forest-10.2%; the Netherlands- build-up-14%, agriculture-74.3%, forest-12.1%) (CORINE, 2006); this therefore makes Overijssel province a good case study for the analysis of bioenergy potential of rural landscapes in the Netherlands. Overijssel province's relatively low population density (6.82% of the Netherlands' population) and relative large land area (9.85% of the Netherlands' land area) also put it at a vantage point to be able to produce enough biomass/bioenergy to meet the demand of its low population, and also to contribute to the Dutch-EU bioenergy transition targets.

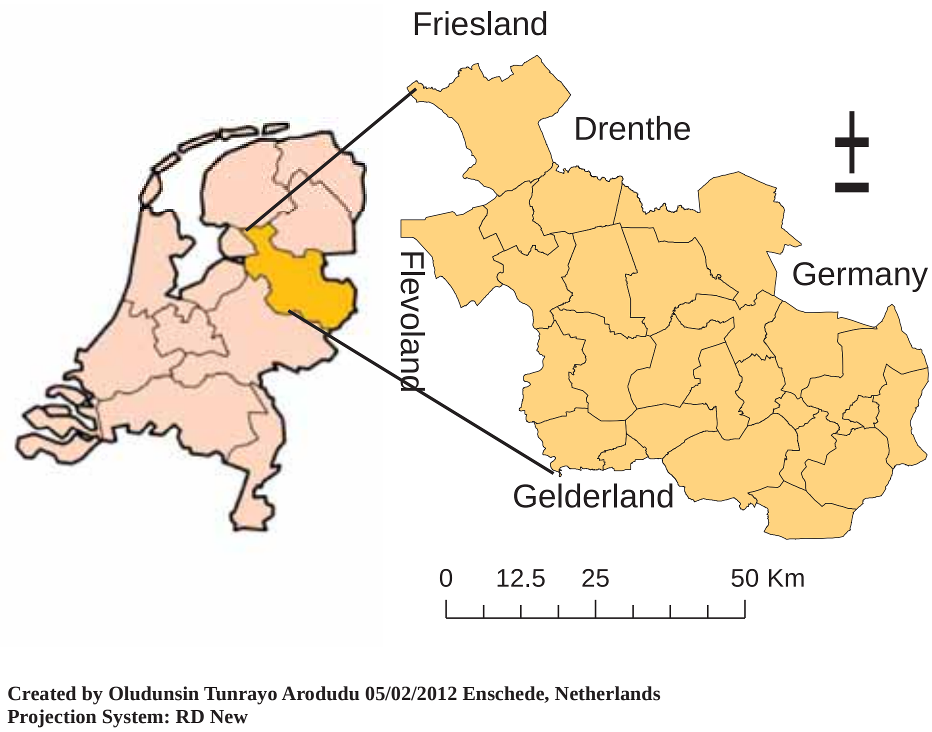

Figure 1:Location of the case study area- Overijssel province

(Sources: http://nl.wikipedia.org/wiki/Overijssel, Provincie Overijssel)

1.5.3 Energy target

Based on Overijssel's population, its projected renewable energy target from bioenergy sources by 2030 as extrapolated from the PGG (Platform Groene Grondstoffen) forecast is as follows: about 23 PJ/yr of transport fuels, 13 PJ/yr of heat, 14 PJ/yr of electricity and 10 PJ/yr of industrial raw materials (totaling about 60 PJ/yr) (Rabou et al., 2006).

1.6 Strategic Environmental Assessment (SEA)

Strategic Environmental Assessment is an environmental assessment method that examines the impacts, feasibility and sustainability of policy objectives (European Commission, 2010). SEA also offers alternatives for avoiding the negative impacts and constraints associated with a policy; the alternatives may be in form of plans, programmes, projects or policies (UNECE, 2003, European Commission, 2010). Based on article 4 of EU directives on SEA (UNECE, 2003), an SEA process will be required to assess the sustainability of energy production (bioenergy production inclusive) within its member state (e.g. the Netherlands). Under an SEA framework for bioenergy production, the following preliminary questions may be asked:

- How much land is available for biomass production and how much biomass and bioenergy can be produced from them sustainably?
- What are the facilities required for the production of biomass and bioenergy?
- Where are the biomass/bioenergy production facilities located or where are the best sites for citing them if not available?
- What are the alternative sources of biomass available?
- Where are these alternative biomass sources situated and how much biomass and bioenergy can be produced from them?
- Which existing policy constraints do not favour the exploitation of such biomass sources?
- What can be done to minimize the policy constraints and maximize biomass/bioenergy production?
- What are the immediate and future environmental and socio-economic impacts of biomass/bioenergy production in the area of interest?
- Is the bioenergy target realizable?

However, an SEA for bioenergy production like other SEAs should be holistic in nature i.e. should fully account for all the interactions in the biomass/bioenergy production chain (UNECE, 2003); this can be achieved if the energy invested into obtaining the biomass/bioenergy yield and the total energy gained from the production activity is considered (Hill et al., 2006, Hall et al., 2009).

This study is not a full-fledged SEA, this study will only seek to demonstrate the impact of using more holistic measures of bioenergy potential such as the NEG and EROEI under an SEA framework. This will help evaluate the actual energy being added to the provincial bioenergy policy drive, after the energy invested must have been considered. This will help to determine and chose the most energy efficient and profitable bioenergy production options at provincial scales. This will also offer clues on alternatives to minimizing energy waste and maximizing energy gains of different biomass/bioenergy production activities.

1.7 Objectives

The general objective of this study is to assess the bioenergy potential of conventional and unconventional biomass sources on rural landscapes in terms of NEG and EROEI, under an SEA framework, using the Overijssel province as a case study.

Within the context of this study, the following specific objectives have been formulated:

- To estimate the potential biomass yield, potential energy output and the energy to be invested into getting energy from the different biomass sources.
- To obtain the Net Energy Gain (NEG) and the Energy Returned on Energy Invested (EROEI) for the different biomass sources under consideration.
- To assess the bioenergy potential of unconventional biomass sources on rural landscapes and compare them to conventional planting of bioenergy crops.
- To evaluate the significance of the bioenergy potential on rural landscapes.

1.8 Research questions

To achieve the objective of the study, the following questions have been designed to help address the specific concerns of the study:

- How much land (if applicable) and tonnes of biomass is available for bioenergy production under the different biomass sources?
- How much of energy input is required to obtain energy from the different biomass sources?
- How much of energy output is obtainable from the different biomass sources?
- Which of the different biomass sources has more net energy gain or is more energy efficient than the other? Conventional sources or unconventional sources?
- How significant is the bioenergy potential obtainable from the rural landscapes?

Chapter 2

2.0 MATERIALS AND METHOD

2.1 Data description

The data available and used for this study and their descriptions are as follows:

- LGN 6 land cover data of the Netherlands (2007/2008); it is in raster format; 25 X 25m grid in resolution and has 39 land cover classes. It was made from visual interpretation of satellite images and Top 10 Vector; it has an accuracy of between 80-90% depending on the land cover. It was obtained from Landelijk Grondgebruiksbestand Nederland (Dutch Land use database), Wageningen University and Research Centre, Netherlands. The LGN 6 land cover was used for the extraction of statistics on the area covered by natural grasslands within the Overijssel province; it was also used for the estimation of the maximum possible travel distance from biomass sources to the available digesters within the Overijssel province. The maximum possible travel distance to the available digesters was used in calculating the energy for transportation of the different biomass types.

- Polygon layer containing the boundaries of the Overijssel province (2009); it is in vector format. It was obtained from the Government of the Overijssel province, Netherlands. It was used to clip the LGN 6 land cover of the whole of Netherlands to the boundaries of the Overijssel province.

- Point layer containing the present locations of digesters within the province of Overijssel (2009); it is in vector format. It was obtained from the CSTM (Centre for Studies in Technology and Sustainable Development), University of Twente, Netherlands. It was used for the estimation of the maximum possible travel distance from the different biomass sources to the available digesters and by extension, the calculation of the energy for transportation of the different biomass types.

- Information required for the calculation of the energy inputs and outputs of the different biomass source examined. These includes:

(a.) The types of energy inputs and outputs involved in exploiting each biomass sources.

(b.) The potential biomass yield of the different biomass types.

(c.) The relative availability of different biomass types for bioenergy production.

(c.) The potential energy output or yield of the various types of biomass.

(d.) Relevant energy conversion models and coefficients. These information were obtained from several literature sources.

- GIS and other data processing softwares available on the ITC network such as ArcGIS, Microsoft Excel etc. Various ArcGIS features were used for the extraction of statistics on the area covered by the natural grasslands; they include raster to polygon, clip, select, calculate geometry, select by attribute and summary statistics features. Some ArcGIS features were also used in the estimation of the average maximum travel distances from the different biomass sources to the available digesters; they include select and buffer features. Excel Spreadsheet was used for the calculation of the potential biomass yield, quantity of biomass potentially available for bioenergy production, energy inputs, energy outputs, net energy gain (NEG) and energy returned on energy invested (EROEI).

2.2 Methodology

The NEG and EROEI of all biomass sources (Conventional and Unconventional) are a function of the potential energy invested into obtaining energy from such sources, and the potential energy output (yield) obtainable from them. As illustrated in Figure 2 below, this study used a combination of Life Cycle Inventory (LCI) and GIS capabilities for the compilation of all the energy inputs and outputs involved in the production of energy from biomass sources on the rural landscapes of the Overijssel province. Data (in form of models, parameters, land cover, coefficients and statistics) used for the calculation of the energy inputs and outputs was obtained from GIS databases and literature sources; the energy input and output stocks obtained was used to compute the NEG and the EROEI.

The entire methodological framework of this study is as illustrated below (Figure 2)

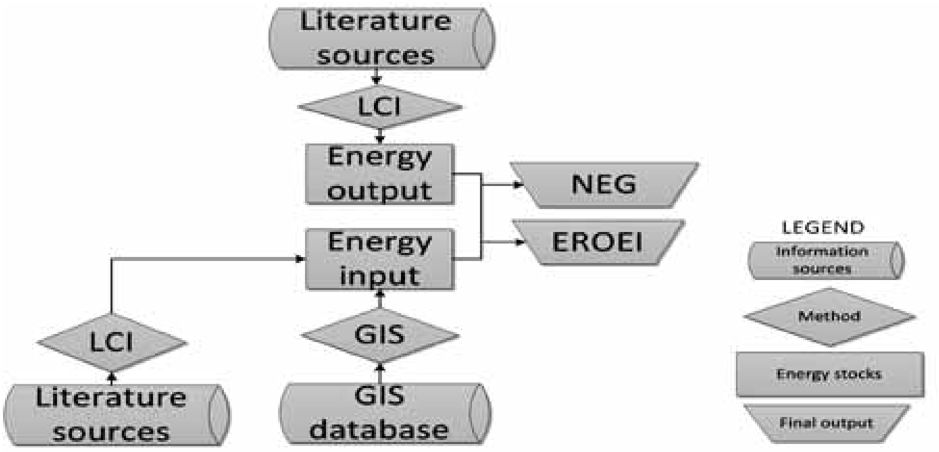

Figure 2: Methodological framework

- Life Cycle Inventory (LCI)

An LCI for a biomass source involves a listing of all the energy input that will be involved in obtaining energy from a biomass source and the potential energy output obtainable from such a source (EPA, 2006). While estimating the energy inputs and outputs of the various biomass sources, an LCI for a biomass source also takes into consideration the various biomass/bioenergy conversion models and coefficients involved in the estimation. The LCI was done by drawing instances from literature sources; however, some biomass/bioenergy conversion models and coefficients were not explicitly found. In such a case we made assumptions based on similar processes or production chains. The total energy input and output obtained for each biomass source was used for the computation of the NEG and EROEI.

- GIS Tools

A variety of GIS operations were also used for the estimation of the energy inputs; these include:

I. Statistics: This involves the extraction of the statistics of the total area covered by the natural grassland within the Overijssel province. The following procedures were followed:

(a.) Conversion of the raster based LGN 6 land cover data to a polygon.

(b.) Clipping the Overijssel province's land cover out of the LGN 6 Land cover data of the whole of Netherlands.

(c.) Re-calculation of the areal geometry of the clipped Overijssel land cover map to eliminate errors arising from clipping operation.

(d.) Selecting the natural grassland land cover from the clipped Overijssel land cover map.

(e.) Checking the areal statistics of the selected natural grassland land cover using the STATISTICS feature.

The description of the procedures involved in the extraction of statistics on the area covered by the natural grassland from the LGN 6 land cover map is as illustrated below (Figure 3).

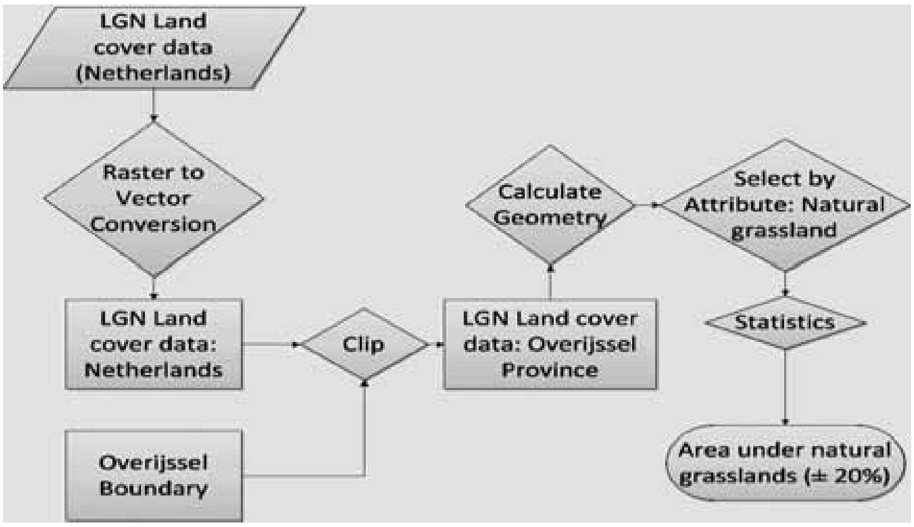

Figure 3: Estimation of area under the natural grassland cover

However, because the LGN 6 land cover classification is 80-90% accurate, an error margin of ± 20% (worst case scenario) was included in subsequent calculations of potential biomass yield and availability for bioenergy production, energy inputs, outputs, NEG and EROEI of grasses from natural grasslands.

II. Buffering: This involve a rough estimation of the maximum possible travel distance from the biomass sources (croplands, natural grasslands, pasturelands and farm holdings) to the present locations of digesters within the Overijssel province using trial and error buffering operations. The following procedures were followed:

(a.) Selection of the land cover types representing the rural landscapes from the clipped land cover map of the Overijssel province. The selected land cover types are the locations from which biomass will be transported to the available digesters e.g. crop residues from maize farms, cereal farms and rapeseed farms; grasses from natural grasslands and pasturelands; and farm manure from pasturelands and farm holdings).

(b.) Creating buffers around the locations of all the available digesters to see the average maximum travel distances from the different biomass sources to the available digesters. Different buffer distances where tried (5Km, 10Km, 15Km etc.); the buffer distance that covers all of the biomass production areas without leaving out any part was taken to be the maximum possible travel distance between the biomass sources and the digesters.

The description of the procedures involved in the estimation of the maximum possible travel distance using trial and error buffering is as illustrated below (Figure 4).

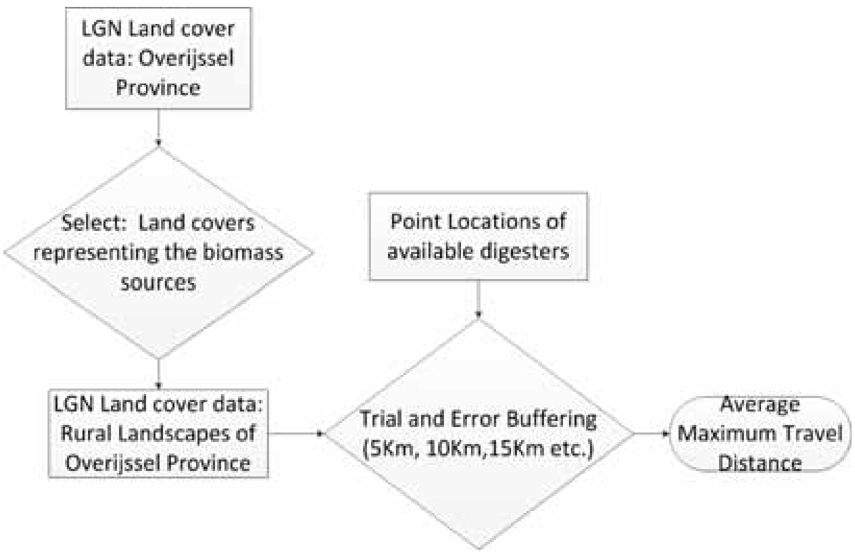

Figure 4: Estimation of the maximum possible travel distance

2.3 Energy inputs and outputs

The following energies are expected to be involved in the different biomass/bioenergy production streams considered by this study:

- **Crop residues or straws**

The energy inputs and outputs that constitute the LCI boundary for the estimation of the NEG and EROEI of crop residues are illustrated in the diagram below (Figure 5).

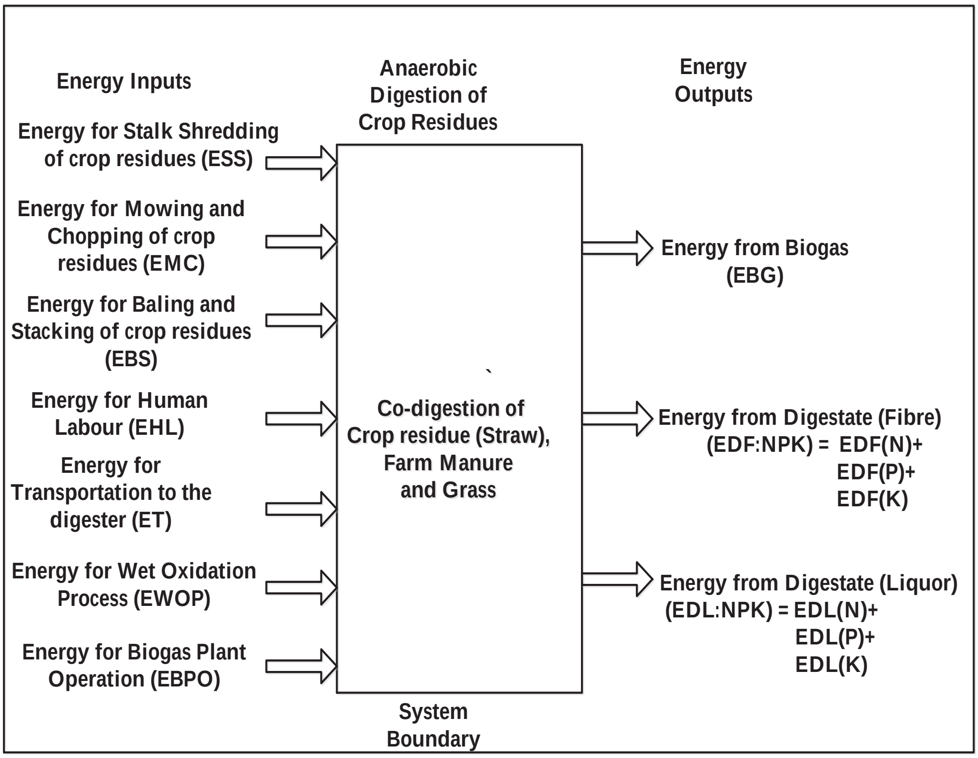

Figure 5: LCI boundary for wet anaerobic co-digestion of crop residues

Energy inputs involved in the wet anaerobic co-digestion of straw include:

I. Energy for stalk shredding (ESS) of crop residues to prevent clogging during digestion.
II. Energy for mowing and chopping (EMC) of crop residues.
III. Energy for baling and stacking (EBS) of crop residues.
IV. Energy for human labour (EHL).
V. Energy for transportation of crop residue to the digester (ET).
VI. Energy for wet oxidation process (EWOP).

VII. Energy for biogas plant operation (EBPO).

The expected energy outputs include:

I. Energy from biogas (EBG).

II. Energy from digestate- fibre (EDF (N), EDF (P), EDF (K) N-nitrogen, P-phosphorus, K-potassium).

III. Energy from digestate- liquor (EDL (N), EDL (P), EDL (K) N-nitrogen, P-phosphorus, K-potassium).

- **Manure from farm animals**

The energy inputs and outputs that constitute the LCI boundary for the estimation of the NEG and EROEI of farm manure are illustrated in the diagram below (Figure 6).

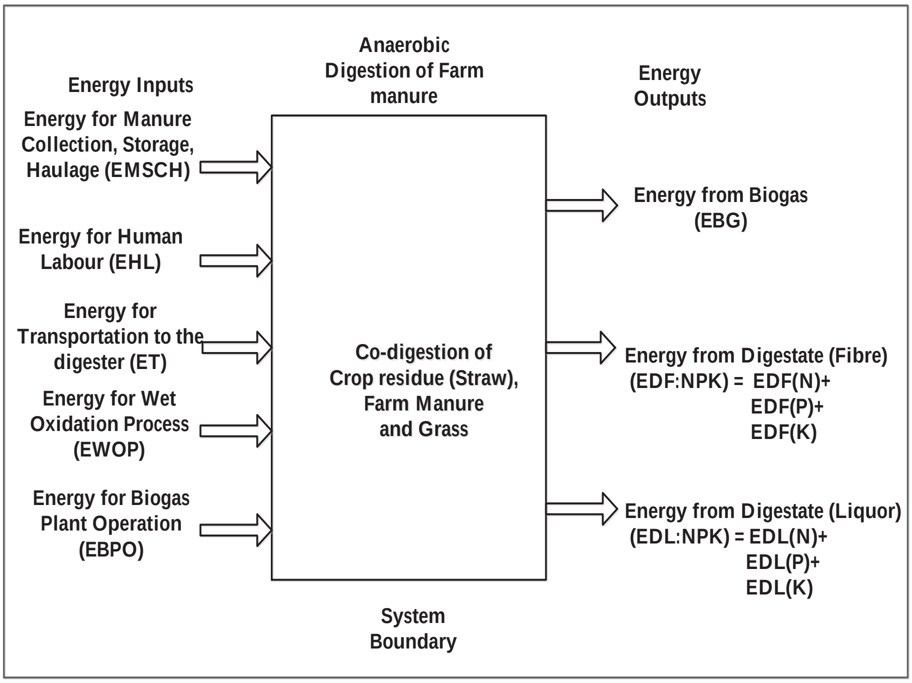

Figure 6: LCI boundary for wet anaerobic co-digestion of farm manure

Energy inputs into wet anaerobic co-digestion of farm manure for bioenergy production include:

I. Energy used for manure collection, storage and haulage (EMSCH).

II. Energy for human labour (EHL).

III. Energy for transportation of farm manure to the digester (ET).

IV. Energy for wet oxidation process (EWOP) and

V. Energy for biogas plant operation (EBPO).

The energy outputs are:

I. Energy from biogas (EBG).

II. Energy from digestate- fibre (EDF(N), EDF(P),EDF(K) N-nitrogen, P-phosphorus, K-potassium).

III. Energy from digestate- liquor (EDL(N), EDL(P),EDL(K) N-nitrogen, P-phosphorus, K-potassium).

- **Grass cuttings from natural grassland**

The energy inputs and outputs that constitute the LCI boundary for the estimation of the NEG and EROEI of grasses from natural grasslands are illustrated in the diagram below (Figure 7).

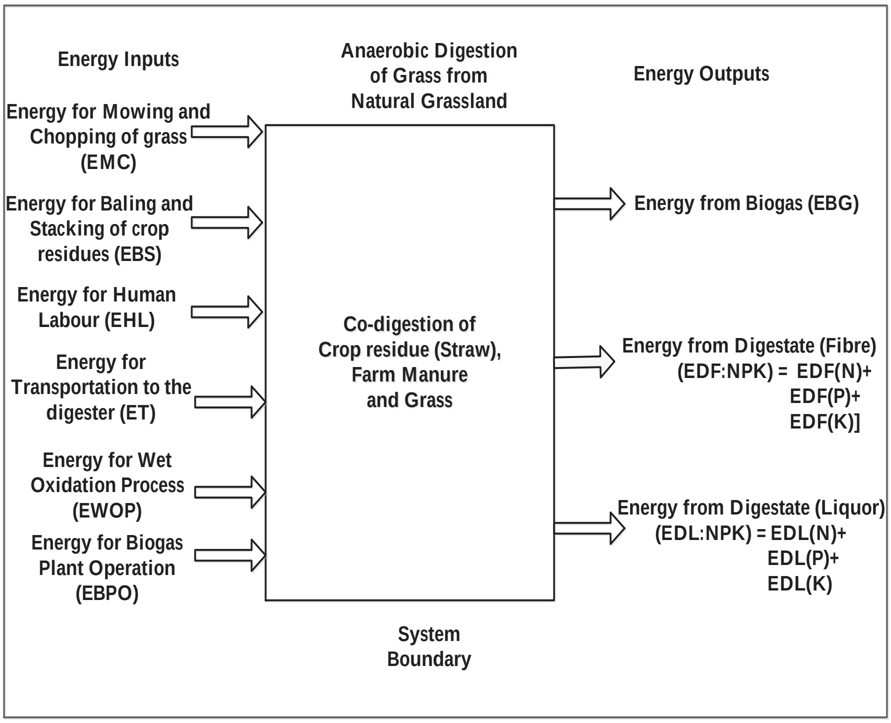

Figure 7: LCI boundary for wet anaerobic co-digestion of grass cuttings from natural grassland

Energy inputs into the wet anaerobic co-digestion of grasses from natural grasslands include:

I. Energy for mowing and chopping (EMC) of grasses.
II. Energy for baling and stacking (EBS) of grasses.
III. Energy for human labour (EHL).
IV. Energy for transportation of grasses to the digester (ET).
V. Energy for wet oxidation process (EWOP)
VI. Energy for biogas plant operation (EBPO)

The energy outputs are:

I. Energy from biogas (EBG).
II. Energy from digestate- fibre (EDF(N), EDF(P),EDF(K) N-nitrogen, P-phosphorus, K-potassium).
III. Energy from digestate- liquor (EDL(N), EDL(P),EDL(K) N-nitrogen, P-phosphorus, K-potassium).

- **Grasses cultivated on surplus pasturelands**

Energy inputs involved in the wet anaerobic co-digestion of grasses cultivated on surplus pasturelands include:

I. Energy for cultivation (EC) of the alfalfa.
II. Energy for production of fertilizer applied (EFP (N), EFP (P), EFP (K), N-nitrogen, P-phosphorus, and K-potassium).
III. Energy for production of crop protection chemicals applied (ECPC (H), ECPC (I), ECPC (F); H-herbicides, I-insecticides, F-fungicides).
IV. Energy for mowing and chopping (EMC) of grasses.
V. Energy for baling and stacking (EBS) of grasses.
VI. Energy for human labour (EHL).
VII. Energy for transportation of grasses to the digester (ET).
VIII. Energy for wet oxidation process (EWOP)
IX. Energy for biogas plant operation (EBPO)

The energy outputs expected include:

I. Energy from biogas (EBG)

II. Energy from digestate- fibre (EDF(N), EDF(P),EDF(K) N-nitrogen, P-phosphorus, K-potassium)

III. Energy from digestate- liquor (EDL(N), EDL(P),EDL(K) N-nitrogen, P-phosphorus, K-potassium).

These energy inputs and outputs that constitute the LCI boundary for the estimation of the NEG and EROEI of cultivated grasses on surplus pasturelands are illustrated in the diagram below (Figure 8).

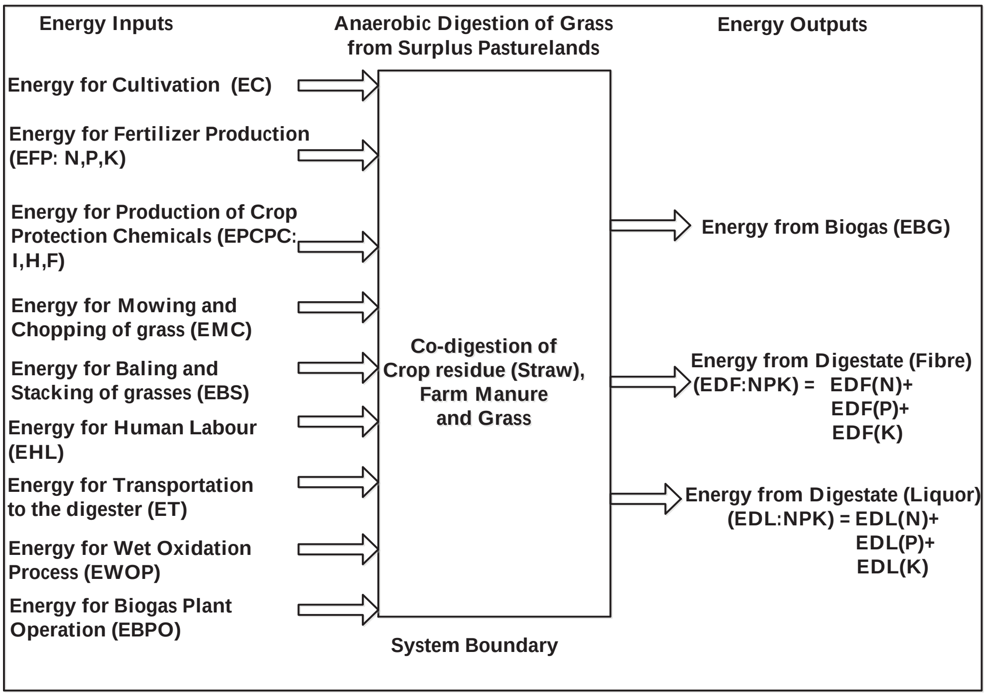

Figure 8: LCI boundary for wet anaerobic co-digestion of alfalfa from su1rplus pasturelands

2.4 Potential biomass yield and availability for bioenergy production

A description of the relevant models and coefficients for the computation of the potential biomass yield from the different biomass sources and their relative availability for bioenergy production are as follows:

I. Crop residues: The potential biomass yield of crop residues is dependent on the annual crop yield and the average crop to residue yield (in ratio) of the crops, while their relative availability for bioenergy production depends on their relative use for soil conservation and socio-economic needs e.g. maize stover for cattle feed, wheat residues as mushroom substrates etc. (Scarlat et al, 2010). The coefficients for calculating the potential biomass yield from triticale (*x. Triticosecale* Wittmack), and the amount of triticale residue potentially available for bioenergy production (based on the degree of use for soil conservation and other uses) was assumed to be the same as that of wheat due to the similarities in their plant morphology. Where n=crop type e.g. maize, wheat etc.

Potential biomass yield of (n) crop residues = Annual yield of (n) crop * Average crop to residue yield of the (n) crop.

Biomass (crop residue) potentially available for bioenergy production = Potential biomass yield of (n) crop residues * % available for bioenergy production. The coefficients for the calculation of the potential biomass yield from crop residue and the biomass (tonnes of crop residue) potentially available for bioenergy production are listed below (Table 1).

Table 1: Coefficients for the computation of biomass yield and their relative availability for bioenergy production (crop residues)

Crop Type	Average crop to residue yield	% Availability for bioenergy production	References
Maize	1	50%	Scarlat et al., 2010
Wheat	1.2	40%	Scarlat et al., 2010
Rye	1.7	40%	Scarlat et al., 2010
Triticale	1.2	40%	Scarlat et al., 2010
Oat	1.4	40%	Scarlat et al., 2010
Barley	1.3	40%	Scarlat et al., 2010
Rapeseed	1.5	50%	Scarlat et al., 2010

II. Farm manure: The potential biomass yield of farm manure is dependent on the animal population and the average manure yield per animal per year (in tonness) (DEFRA, 2008), while their relative availability for bioenergy production depends on the percentage of farm manure collectable, the percentage of farm manure collectable depends on the amount of time that animals spent on barns and hard surfaces (Fehrs, 2000). Where n=animal type e.g. dairy cattle, beef cattle, pig, chicken etc.

Potential biomass yield of (n) manure = Average Manure yield per animal per year * Annual animal population.

Biomass (manure) potentially available for bioenergy production = Potential biomass yield of (n) crop residues * Amount of time spent on barns and hard surfaces (in %).

The coefficients for the calculation of the potential biomass yield from farm manure and the biomass (tonnes of farm manure) potentially available for bioenergy production are listed below (Table 2).

Table 2: Coefficients for the computation of biomass yield and their relative availability for bioenergy production (farm manure)

Type of animal	Average manure yield per animal per year	% Availability for bioenergy production	References
Dairy cattle	20.31	88%	Fehrs, 2000; DEFRA, 2008
Beef cattle	12.26	10%	Fehrs, 2000; DEFRA, 2008
Pig	3.29	50%	Fehrs, 2000; DEFRA, 2008
Poultry (chicken)	0.04	80%	Fehrs, 2000; DEFRA, 2008

III. Grass: The potential biomass yield of grasses from natural grasslands and surplus pasturelands is a function of the size of the land and the type of harvest scheme that can be implemented based on current grassland management policies. For instance, natural grasslands are expected to be mowed at least twice a year to promote grassland biodiversity; therefore the late harvest scheme is not feasible on natural grassland (Veepro Holland, 2011). While the relative availability of grass for bioenergy production for surplus pasturelands is 100%, that of natural grasslands based on uses grass as forage, animal beddings etc. is 50% (Fischer et al. 2010, van Vuuren et al, 2010).

Where n=natural grassland or surplus pasturelands

Potential biomass yield of (n) grass = Size of the land*Average Grass yield per Hectare per year

Biomass (grass) potentially available for bioenergy production = Potential biomass yield of (n) grass * % available for bioenergy production.

The coefficients for the calculation of the potential biomass yield from grasses and the biomass (tonnes of grasses) potentially available for bioenergy production are listed below (Table 3).

Table 3: Coefficients for the computation of biomass yield and their relative availability for bioenergy production (grass)

Grass Harvest Scheme: Natural Grassland	Possible number of Harvests (times)	Average Grass yield per Hectare (tonnes/ha)	Average Grass yield per Hectare per year (tonnes/ha/yr)	% Availability for bioenergy production	References
Early	3	2	6	50%	van Vuuren et al, 2010, Veepro Holland, 2011
Intermediate	2	4	8	50%	van Vuuren et al, 2010, Veepro Holland, 2011
Late	1	5	5	50%	van Vuuren et al, 2010, Veepro Holland, 2011
Grass Harvest Scheme: Surplus Pasturelands	Possible number of Harvests	Average Grass yield per Hectare	Average Grass yield per Hectare per year	% Availability for bioenergy production	References
Early	3	2	6	100%	Fischer et al. 2010, Veepro Holland, 2011
Intermediate	2	4	8	100%	Fischer et al. 2010, Veepro Holland, 2011
Late	1	5	5	100%	Fischer et al. 2010, Veepro Holland, 2011

2.5 Energy conversion factors

The description of the relevant energy conversion factors for the calculation of the individual and total energy inputs and outputs of the different biomass sources are as follows (Table 4):

Table 4: Energy input table

Energy Input	Biomass type	Unit	Coefficient	References
Energy for Cultivation	Grass	GJ/ha	3.09	Meisterling, 2011
Energy for Fertilizer Production: N (0kg/ton DM)	Grass	GJ/Kg	0.0484	Meisterling, 2011
Energy for Fertilizer Production: P (2.6kg/ton DM)	Grass	GJ/Kg	0.032	Meisterling, 2011
Energy for Fertilizer Production: K (20kg/ton DM)	Grass	GJ/Kg	0.0106	Meisterling, 2011
Energy for Crop Protection Chemicals: Insecticides(0.31kg/ton DM)	Grass	GJ/Kg	0.278	Meisterling, 2011
Energy for Crop Protection Chemicals: Herbicides(0.31kg/ton DM)	Grass	GJ/Kg	0.278	Meisterling, 2011
Energy for Crop Protection Chemicals: Fungicides(0.31kg/ton DM)	Grass	GJ/Kg	0.278	Meisterling, 2011
Energy for stalk shredding	Crop residues	GJ/ha	0.25	Downs & Hansen, 1998
Energy for mowing and chopping	Crop residue and grass	GJ/ha	0.67	Downs & Hansen, 1998
Energy for baling and stacking	Crop residue and grass	GJ/ha	0.33	Downs & Hansen, 1998
Energy for wet oxidation process	All biomass types	GJ/ton	0.005	Uellendahl et al, 2008
Energy for biogas plant operation	All biomass types	GJ/ton	0.288	Uellendahl et al, 2008
Energy for manure collection, storage and haulage	Dairy cattle manure	GJ/ animal	0.91	Ozkan, 2001
Energy for manure collection, storage and haulage	Beef cattle manure	GJ/ animal	0.2	Ozkan, 2001
Energy for manure collection, storage and haulage	Pig manure	GJ/ animal	0.26	Ozkan, 2001
Energy for manure collection, storage and haulage	Chicken manure	GJ/ animal	0.036	Ozkan, 2001 Porter, 2009
Energy for human labour	All biomass types	GJ/year	4.2	Grzywiński, 2004
Energy for the transportation of the biomass to the digester	Crop residue and grasses	GJ/ton/ Km	0.0048	EUBIA, 2007

Energy inputs in form of the litres of fossil fuel (diesel and/or gasoline) used by tractors, tankers, trucks and farm machineries for field operations, or in form of the quantity of natural gas (LPG) or electricity consumed for post-field operations, pre-treatment and processing were all converted into the SI unit for energy (Joules) for data harmonization. 1 litre of gasoline fuel is equivalent to 32 MJ; 1 litre of diesel fuel is equivalent to 36.4 MJ; 1 litre of LPG natural gas is equivalent to 34.6 MJ while 1 KWh of electricity is equivalent to 3.6MJ (ORNL, 2003).

The energy for the collection, storage and haulage of chicken manure was based on the assumption that a chicken uses 1/25th of the space a dairy cattle uses (Ozkan, 2001, Porter, 2009). The energy for human labour was based on the assumption that human labour for bioenergy production per day does not exceed the upper limit of human energy consumption for timber harvesting for a day (Grzywiński, 2004).

Biogas yield is a function of the quantity of biomass, the percentage of volatile solids and the average biogas yield per unit tonne of biomass (AEBIOM, 2009), this can be expressed as:

Biogas yield = Tonnes of (n) Biomass * Volatile Solids (n)* Average Biogas yield (n)

The conversion coefficients for the estimation of biogas yields from different types of biomass are listed below (Table 5).

Table 5: Coefficients for the estimation of biogas yield

Biomass Type	Volatile Solids	Average Biogas Yield per tonne	References
Straw (crop residues)	90%	350	Steffen et al., 1998, AEBIOM, 2009
Cattle manure	85%	266.67	Steffen et al., 1998, AEBIOM, 2009
Pig manure	80%	516.67	Steffen et al., 1998, AEBIOM, 2009
Chicken manure	80%	483.33	Steffen et al., 1998, AEBIOM, 2009
Grasses	90%	500	Steffen et al., 1998, AEBIOM, 2009

The conversion factors for the conversion of biogas yield to its fossil fuel and natural gas equivalent, and the estimation of the potential CO_2 amount that can be saved by producing biogas are listed below (Table 6):

Table 6: Conversion factors for the conversion of biogas yield to fossil fuel and natural gas equivalent, equivalent and estimation of CO_2 saved.

Output yield	Conversion models and coefficients	References
Fossil fuel Equivalent	0.0024 toe/GJ of energy from biogas (toe-ton of oil equivalent)	AEBIOM, 2009
Natural gas equivalent	0.6 * Energy from Biogas	AEBIOM, 2009
Kg CO_2 saved from combined heat and electricity generation	454.1 per tonne of biomass digested	NSCA, 2006
Kg CO_2 saved from production of transport fuel	413 per tonne of biomass digested	NSCA, 2006

The conversion coefficients for the conversion of biogas and digestate yield to energy is as listed below (Table 7).

Table 7: Energy output table: Energy conversion factors for biogas and digestate

Energy Output	Units	Coefficients	References
Energy from Biogas	GJ/Nm^3	0.0216	AEBIOM, 2009
Energy from fibre co-digestate-N (9.3 Kg per tonne)	GJ/Kg	0.0484	Gebrezgabher et al., 2009, Meisterling, 2011
Energy from fibre co-digestate-P (19.2 Kg per tonne)	GJ/Kg	0.032	Gebrezgabher et al., 2009, Meisterling, 2011
Energy from fibre co-digestate-K (5.9 Kg per tonne)	GJ/Kg	0.0106	Gebrezgabher et al., 2009, Meisterling, 2011
Energy from liquor co-digestate-N (6.8 Kg per tonne)	GJ/Kg	0.0484	Gebrezgabher et al., 2009, Meisterling, 2011
Energy from liquor co-digestate-P (0.6 Kg per tonne)	GJ/Kg	0.032	Gebrezgabher et al., 2009, Meisterling, 2011
Energy from liquor co-digestate-K (11.5 Kg per tonne)	GJ/Kg	0.0106	Gebrezgabher et al., 2009, Meisterling, 2011

The Energy for digestate is assumed to be equivalent to the energy for the production of the fertilizer that it replaces (Gebrezgabher et al., 2009, Meisterling, 2011).

Chapter 3

3.0 RESULTS

3.1 Area under natural grassland cover

The area under natural grassland cover as obtained from the LGN land cover was **7634.9** hectares with an error margin of 20% **(±1908.7)**; this is because the LGN land cover has a classification accuracy of 80-90%. Under the worst case scenario, the classification accuracy of the natural grassland cover of the LGN land cover data will be 80% and the error margin will be 20%. The error margin was duly considered in computing the potential biomass yield, the biomass available for bioenergy production, the energy inputs and outputs involved in the calculation of the NEG, NEG per hectare, NEG per tonne of biomass and EROEI of the natural grassland option.

3.2 Maximum possible travel distance

Based on the present locations of the biomass sources and the available digesters; a buffer distance of **20Km** around the digesters covers all of the biomass production areas (relevant land cover types: croplands, natural grasslands, pasturelands and farm holdings). Not all the biomass production areas where covered at 5Km, 10Km, 15Km buffer distances from the available digesters; this is as shown below (Figure 9, Figure 10, Figure 11).

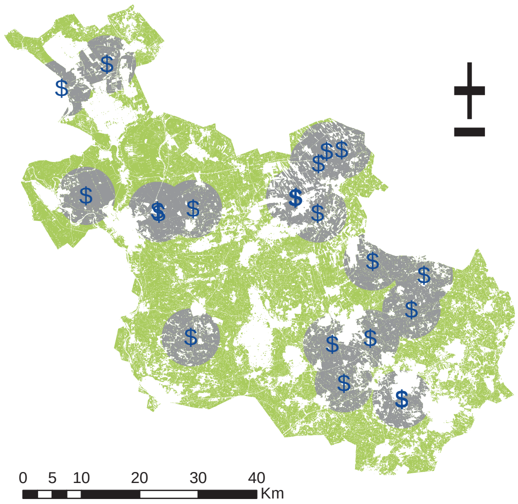

Figure 9: Coverage of biomass production areas at 5Km buffer distance

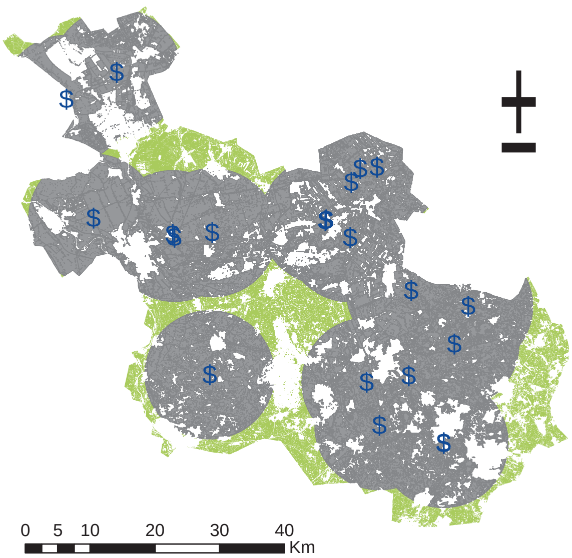

Figure 10: Coverage of biomass production areas at 10Km buffer distance

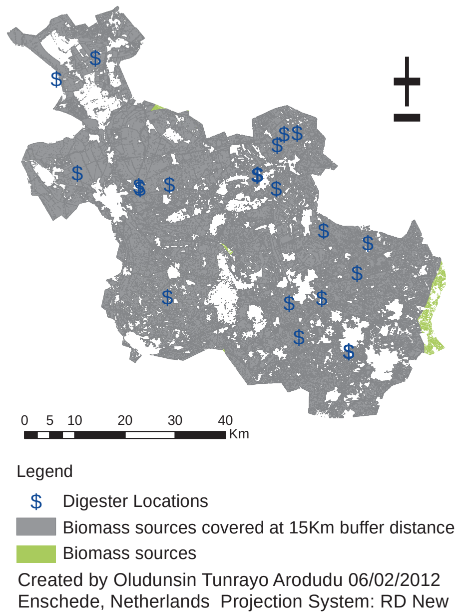

Figure 11: Coverage of biomass production areas at 15Km buffer distance

At 19Km buffer about 400m radius was left but at

20Km all biomass production areas where adequately covered; this is illustrated below (Figure 12).

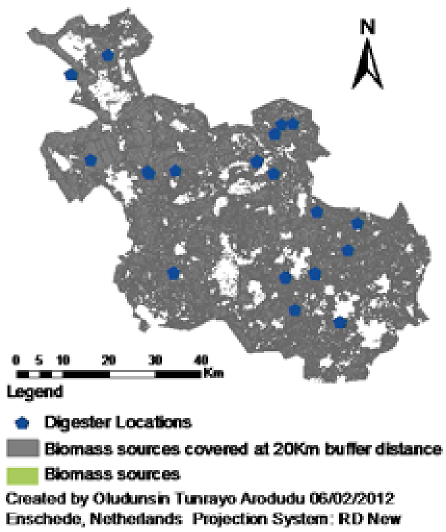

Figure 12: Coverage of biomass production areas at 20Km buffer distance

The maximum possible travel distance from the biomass production areas to available digester (20Km) was used to calculate the energy for transportation of biomass to digesters for the different biomass types.

3.2 LCI analysis

The LCI component of this study produced series of results needed for the computation of the NEG and EROEI, these include the potential biomass yield, biomass available for bioenergy production, energy inputs and outputs.

3.3.1 Potential biomass yield and biomass available for bioenergy production

- **Conventional biomass sources**

As shown below (Table 8), the intermediate grass harvest scheme produces more biomass and provides more room for maximizing potential grass yield from the same size of land.

Table 8: Potential biomass yield and biomass available for bioenergy production in tonnes (Grasses from surplus pasturelands): With an area of 75.54 ha and a percentage availability of 100% .

Grass Harvest Scheme	Potential Biomass Yield and Biomass available for bioenergy production
Early	453.24
Intermediate	604.32
Late	377.7

- **Unconventional biomass sources**

As shown below (Table 9), the maize farms produce far more residues than other crops within the Overijssel province despite its low average crop to residue yield (in ratio) because it is produced in relatively higher quantity than other high residue bearing crops.

Table 9: Potential biomass yield and biomass available for bioenergy production in tonnes (Crop residue)

Crop Type	Annual Crop yield (CBS 2011)	Average Crop to Residue Yield Ratio	Potential Biomass Yield	% Availability for bioenergy production	Biomass available for bioenergy production
Maize	1918502	1	1918502	50%	959251
Rye	1542	1.7	2621.4	40%	1048.56
Triticale	2467	1.2	2960.4	40%	1184.16
Wheat	14057	1.2	16868.4	40%	6747.36
Oat	392	1.4	548.8	40%	219.52
Barley	9916	1.3	12890.8	40%	5156.32
Rapeseed	516	1.5	774	50%	387

As shown below (Table 10), the dairy cattle makes more biomass available for bioenergy production because of the continual optimization of indoor management systems to get more milk from them, this makes them stay more indoor on hard surfaces and makes their manure more collectable. However, better management options and housing designs that ensures that beef cattle and pigs stay longer on barns or hard surfaces can help maximize their potential biomass yield for bioenergy production.

Table 10: Potential biomass yield and biomass available for bioenergy production in tonnes (Farm manure)

Animal Type	Animal population (CBS, 2011)	Average Manure Yield per animal per year	Potential Biomass Yield	% Availability for bioenergy production	Biomass available for bioenergy production
Beef Cattle	179349	12.26	2198818.74	10%	219881.87
Dairy Cattle	435296	20.31	8840861.76	88%	7779958.35
Pig	1660141	3.29	5461863.89	50%	2730931.95
Chicken	10631637	0.04	425265.48	80%	340212.38

Based on the estimate and range of accuracy of the area under natural grassland as obtained from the LGN land cover data (as shown in Table 11 below), the intermediate harvest scheme still produced the highest biomass yield like that of the scenario of the grasses cultivated on surplus pasturelands.

Table 11: Potential biomass yield and biomass available for bioenergy production in tonnes (Grasses from natural grasslands): With an area of 7634.87 ±1908.72 ha, a percentage availability of 50% .

Grass Harvest Scheme	Potential Biomass Yield	Biomass available for bioenergy production
Lower Limit (-): Early	34356.92	17178.46
Intermediate	45809.22	22904.61
Late	28630.76	14315.38
Mid-point (0): Early	45809.22	22904.61
Intermediate	61078.96	30539.48
Late	38174.35	19087.18
Upper Limit: (+): Early	57261.53	28630.76
Intermediate	76348.7	38174.35
Late	47717.93	23858.97

3.3.2 Energy input, energy output, NEG and EROEI

- **Conventional biomass sources:**

  As shown below (Table 12, 13, 14 and 15), conventional planting of bioenergy crops are less energy efficient than the use of unconventional biomass sources for bioenergy production.

Table 12: Bioenergy production from grasses on surplus pasturelands: Input energies, output energies, NEG in GJ and EROEI

Input Energies	Early	Intermediate	Late
Cultivation	1051.52	466.84	117.09
Fertilizer production: N	0	0	0
Fertilizer production: P	113.13	100.56	31.42
Fertilizer Production: K	288.26	256.23	80.07
Total Energy for Fertilizer Production	401.39	356.79	111.50
Crop Protection Chemicals: Insecticides	117.18	104.16	32.55
Crop Protection Chemicals: Herbicides	117.18	104.16	32.55
Crop Protection Chemicals: Fungicides	117.18	104.16	32.55
Total Energy for Crop Protection Chemicals	351.54	312.48	97.65
Mowing and chopping	151.84	101.22	50.61
Baling and stacking	74.78	49.86	24.93
Transportation	43.51	58.01	36.26
Human labour	4.2	4.2	4.2
Wet oxidation process	2.27	3.02	1.89
Biogas plant operation	130.53	174.04	108.78
Total Input Energy	2211.58	1526.47	552.90
Output Energies	Early	Intermediate	Late
Biogas	4405.49	5873.99	3671.24
Fibre co-digestate-N	48.96	65.28	40.80
Fibre co-digestate-P	66.83	89.11	55.69
Fibre co-digestate-K	6.80	9.07	5.67
Total Energy from Fibre	122.60	163.47	102.17
Liquor co-digestate-N	107.40	143.20	89.50
Liquor co-digestate-P	6.27	8.35	5.22
Liquor co-digestate-K	39.78	53.04	33.15
Total Energy from Liquor	153.45	204.60	127.87
Total Energy from Digestate	276.05	368.06	230.04
Total Output energy	4681.54	6242.05	3901.28
Net Energy Gain (NEG)	2469.96	4715.58	3348.38
NEG per Hectare	32.7	62.42	44.33
NEG per tonne of biomass	5.45	7.80	8.87
Energy Return on Energy Invested (EROEI)	2.12	4.09	7.06

The late harvest scheme is the most energy efficient and feasible harvest scheme for the conventional planting of bioenergy crop (alfalfa) on surplus pasturelands; therefore the late harvest scheme was chosen for subsequent collation of net energy gains done under this study. The energy efficiency trends toward inefficiency (below 3) as more energy is invested more times into cultivation, fertilizers and crop protection chemicals. Although a higher net energy gain is obtainable under the intermediate production and harvest scheme, far less energy is needed to reap considerably high net energy gain under the late scheme.

- **Unconventional Biomass Sources:**

As shown below (Table 13), crop residues from maize is the most energy efficient, energy feasible and energy profitable crop residue type for bioenergy production within the Overijssel province, with an EROEI of 16.68 and a net energy gain of about 6.68PJ.

Table 13: Bioenergy production from crop residues: Input energies, output energies, NEG in GJ and EROEI

Input Energies	Maize	Rye	Triticale	Wheat	Oat	Barley	Rapeseed
Stalk shredding	10608.25	86.00	113.00	517.25	23.3	451.00	32.50
Mowing and chopping	28430.11	230.48	302.84	1386.23	62.3	1208.7	87.10
Baling and stacking	14002.89	113.52	149.16	682.77	30.7	595.32	42.90
Transportation	92088.10	100.66	113.68	647.75	21.0	495.01	37.15
Human labour	4.20	4.20	4.20	4.20	4.20	4.20	4.20
Wet oxidation process	4796.26	5.24	5.92	33.74	1.10	25.78	1.94
Biogas plant operation	276264.29	301.99	341.04	1943.24	63.2	1485.02	111.46
Total Input Energy	426194.09	842.09	1029.84	5215.17	205.8	4265.0	317.24
Output Energies	Maize	Rye	Triticale	Wheat	Oat	Barley	Rapeseed
Biogas	6526743.8	7134.4	8057.02	45909.04	1493.6	35083.6	2633.1
Fibre co-digestate-N	103626.73	113.27	127.92	728.91	23.71	557.03	41.81
Fibre co-digestate-P	141447.32	154.62	174.61	994.94	32.37	760.33	57.07
Fibre co-digestate-K	14397.97	15.74	17.77	101.28	3.29	77.39	5.81
Total Energy from Fibre	259472.02	283.63	320.31	1825.12	59.38	1394.8	104.68
Liquor co-digestate-N	227310.26	248.47	280.61	1598.90	52.02	1221.9	91.71
Liquor co-digestate-P	13260.69	14.50	16.37	93.28	3.03	71.28	5.35
Liquor co-digestate-K	84191.54	92.03	103.93	592.20	19.27	452.56	33.97
Total Energy from Liquor	324762.48	355.00	400.91	2284.38	74.32	1745.7	131.02
Total Energy from Digestate	584234.51	638.63	721.22	4109.50	133.70	3140.47	235.70
Total Output energy	7110978.3	7773.0	8778.2	50018.54	1627.3	38224.1	2868.9
Net Energy Gain (NEG)	6684784.2	6930.9 4	7748.40	44803.36	1421.5	33959.1	2551.61
NEG per Hectare	157.54	20.15	17.14	21.65	15.28	18.82	19.63
NEG per tonne of biomass	6.97	6.61	6.54	6.64	6.48	6.59	6.59
Energy Return on Energy Invested (EROEI)	16.68	9.23	8.52	9.59	7.91	8.96	9.04

All unconventional biomass sources considered under this study were energy efficient, the least energy effiecient source was farm manure from dairy cattle (as shown in Table 14); this was because of the comparatively high energy input to output ratio.

Table 14: Bioenergy production from farm manure: Input energies, output energies, NEG in GJ and EROEI

Input Energies	Beef Cattle	Dairy Cattle	Pig	Chicken
Manure collection, storage and haulage	43976.37	7079762.10	710042.31	12247.65
Transportation	61566.92	2178388.34	764660.94	95259.47
Human labour	4.20	4.20	4.20	4.20
Wet oxidation process	1099.41	38899.79	13654.66	1701.06
Biogas plant operation	63325.98	2240628.00	786508.40	97981.17
Total Input Energy	169972.89	11537682.43	2274870.51	207193.54
Output Energies	Beef Cattle	Dairy Cattle	Pig	Chicken
Biogas	1076555.11	38091152.21	24381917.71	2841434.2
Fibre co-digestate-N	23753.57	840459.56	295019.30	36752.74
Fibre co-digestate-P	32422.90	1147201.54	402692.30	50166.36
Fibre co-digestate-K	3300.34	116774.06	40990.20	5106.45
Total Energy from Fibre	59476.82	2104435.17	738701.80	92025.54
Liquor co-digestate-N	52104.62	1843588.72	647139.11	80618.90
Liquor co-digestate-P	3039.65	107550.14	37752.40	4703.10
Liquor co-digestate-K	19298.59	682831.38	239688.43	29859.76
Total Energy from Liquor	74442.86	2633970.25	924579.95	115181.76
Total Energy from Digestate	133919.67	4738405.42	1663281.75	207207.31
Total Output Energy	1210474.78	42829557.63	26045199.45	3048641.5
Net Energy Gain (NEG)	1040501.89	31291875.19	23770328.90	2841448.0
NEG per Animal	5.80	71.89	14.32	0.27
NEG per tonne of biomass	4.73	4.02	8.70	8.35
Energy Return on Energy Invested (EROEI)	7.12	3.71	11.44	14.7

The representation of the energy input to output ratio of the farm manure examined are as shown below (Figure 13).

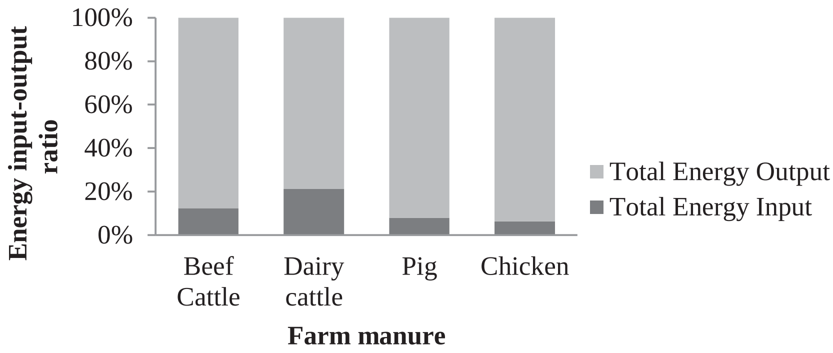

Figure 13: Input to output ratio of farm manure

As shown below (Figure 14), the energy input for manure collection, storage and haulage was responsible for the high energy input to output ratio of dairy manure, despite being the unconventional biomass source with the largest single net energy gain (31.29PJ); however, co-digestion of dairy manure with other kinds of manure and biomass can help increase its efficiency. Dairy cattle has the highest NEG per animal value (71.89 GJ/animal), this can be attributed to their high manure yield and the length of time they spend on hard surfaces and barns. EROEI is the real energy efficiency because it considers the energy output of each biomass/bioenergy production activity per unit input, this is not the case with the NEG. EROEI is the real energy efficiency. This is because it considers the energy output of each biomass/bioenergy production activity per unit input (Input to output ratio), this is not the case with the NEG. While NEG may be large as the case is with the dairy manure, the EROEI (energy efficiency) may be low; this implies that despite the fact that relatively large energy is being produced, the biomass/bioenergy production activity is less capable of supporting continuous socio economic activity because the energy cost is high.

Figure 14: Energy input into anaerobic co-digestion of dairy manure

As shown below (Table 15 below); all the harvest schemes under the natural grassland option were energy efficient. Although the late harvest scheme is the most energy efficient, it is not feasible because of the natural grassland management policy of the Netherlands, which mandates the mowing of natural grasslands two or three times annually (Oenema et al., 2006). Consequently, the next most energy efficient and most feasible harvest scheme which also gives the highest net energy gain on the natural grassland option is the intermediate harvest scheme; therefore, the average values obtained from the intermediate harvest scheme under the natural grassland option was chosen for subsequent collation of net energy gains under this study.

NEG per tonne of biomass, NEG per hectare and the EROEI of the different grass harvest scheme never changes, even under the influence of ±20% classification error. This implies that they are relatively more stable energy quantification index compared to NEG, which was liable to changes under the influence of the classification errors.

Table 15: Bioenergy production from grasses on natural grasslands: Input energies, output energies, NEG in GJ and EROEI

	Minimum limit			Average values			Maximum limit		
Input Energies	Early	Intermediate	Late	Early	Intermediate	Late	Early	Intermediate	Late
Mowing and chopping	13808.41	9205.61	4602.80	15346.09	10230.73	5115.36	16883.76	11255.84	5627.92
Baling and stacking	6801.16	4534.11	2267.05	7558.52	5039.01	2519.51	8315.88	5543.92	2771.96
Transportation	1978.52	2638.03	1648.77	2198.84	2931.79	1832.37	2419.17	3225.55	2015.97
Human labour	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20
Wet oxidation process	103.05	137.40	85.87	114.52	152.70	95.44	126.00	168.00	105.00
Biogas plant operation	5935.56	7914.08	4946.30	6596.53	8795.37	5497.11	7257.50	9676.66	6047.92
Total Input Energy	426194.09	24433.42	13554.99	31818.70	27153.80	15063.98	35006.51	29874.18	16572.97
Output Energies	Early	Intermediate	Late	Early	Intermediate	Late	Early	Intermediate	Late
Biogas	166974.61	222632.81	139145.51	222632.81	296843.75	185527.34	278291.01	371054.68	231909.18
Fibre co-digestate-N	1855.77	2474.36	1546.47	2474.36	3299.14	2061.96	3092.95	4123.93	2577.46
Fibre co-digestate-P	2533.07	3377.42	2110.89	3377.42	4503.23	2814.52	4221.78	5629.04	3518.15
Fibre co-digestate-K	257.84	343.79	214.87	343.79	458.39	286.49	429.74	572.72	329.83
Total Energy from Fibre	4646.68	6195.57	3872.23	6195.57	8260.76	5162.97	7744.46	10325.95	6453.72
Liquor co-digestate-N	4070.72	5427.62	3392.26	5427.62	7236.83	4523.02	6784.53	9046.04	5653.77
Liquor co-digestate-P	237.47	316.63	197.90	316.63	422.18	263.86	395.79	527.72	329.83
Liquor co-digestate-K	1507.72	2010.29	1256.43	2010.29	2680.39	1675.24	2512.86	3350.49	2094.05
Total Energy from Liquor	5815.91	7754.55	4846.59	7754.55	10339.40	6462.12	9693.19	12924.25	8077.65
Total Energy from Digestate	10462.59	13950.12	8718.82	13950.12	18600.16	11625.10	17437.65	23250.19	14531.37
Total Output Energy	177437.19	236582.93	147864.33	236582.93	315443.90	197152.44	295728.66	394304.88	246440.55
Net Energy Gain (NEG)	153572.12	216216.53	136565.29	204764.22	288290.10	182088.46	255956.33	360363.68	227611.62
NEG per Hectare	26.82	37.76	23.85	26.82	37.76	23.85	26.82	37.76	23.85
NEG per ton of biomass	8.94	9.44	9.54	8.94	9.44	9.54	8.94	9.44	9.54
Energy Return on Energy Invested (EROEI)	7.44	11.62	13.09	7.44	11.62	13.09	7.44	11.62	13.09

As seen in Table 15, the EROEI of the different grass harvest scheme remains the same, but the NEG changes with changing number of harvest times, and corresponding changing biomass/energy yields. Consequently, as shown below (Figure 15), the error level of the NEG estimates for the different grass harvest schemes increases with increase in the number of harvest times and corresponding increase in the biomass/energy yield. The late harvest scheme with just one harvest and the least biomass/energy yield has the least error level, while the intermediate harvest scheme with two harvests and the highest biomass/energy yield has the highest error level, because uncertainties where propagated continually with more harvests and higher biomass/energy yield.

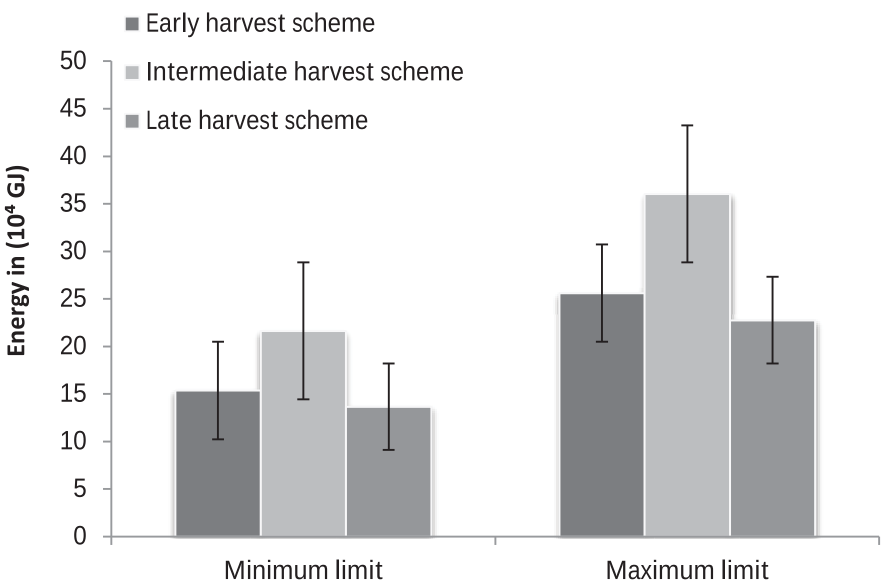

Figure 15: Error range of NEG estimation for grasses from natural grasslands

As shown below (Figure 16), aside dairy manure (with an EROEI of 3.71), the average lower limit of EROEI for unconventional biomass sources is about 7; conversely, the upper limit of EROEI for the conventional biomass sources is also about 7. Other implementations of the conventional biomass sources (the intermediate and early harvest schemes) trend down towards energy inefficiency (EROEI value of below 3). Grasses from natural grasslands can be considered the most energy profitable biomass in terms of unit energy output or yield, this is because they have the highest NEG per tonnes of biomass (an energy gain of above 9GJ/tonne of biomass), while crop residues from maize farms can be considered the most energy profitable biomass in terms of energy input spent to obtain the energy, this is because it has the highest NEG per hectare (an energy gain of 157.54 GJ/ha); the most energy profitable animal is the diary cattle, this is because they have the highest NEG per animal (71.89 NEG/animal).

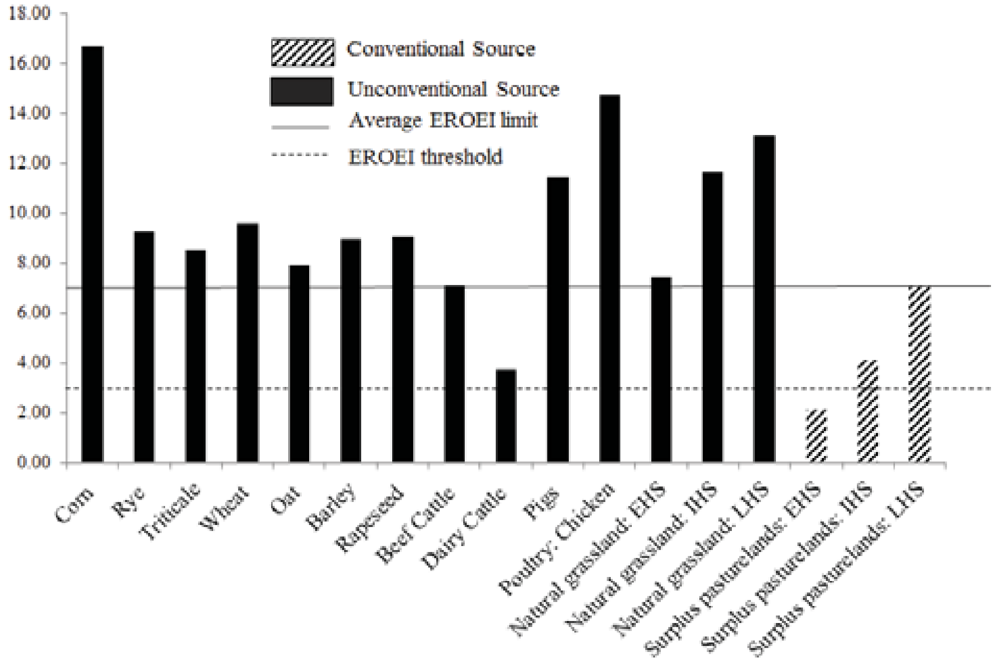

Figure 16: Comparison of EROEI levels

Chapter 4

4.0 DISCUSSION

4.1 Feasibility of bioenergy goals

As part of an SEA framework, this study analysed to what extent we can meet the bioenergy targets in the province of Overijssel; this was in terms of the net energy that can be added to the bioenergy targets, the amount of fossil fuel that can be replaced and the amount of CO_2 emissions that can be saved. From this study, 66.01PJ (more than 99% of net energy gain (NEG obtainable) was from unconventional biomass sources such as crop residues, farm manure and grsses from natural grassland; while only 3.34TJ (less than 1%) was from the conventional biomass sources. About 91% out of this was from biogas, while the remaining 9% was from Digestate (fertilizer replacement).

Under the best case scenario, where biogas conversion efficiencies are assumed to be 96% for transport fuels (AEBIOM, 2009), 70% and 35% for heat and electricity respectively (via combined heat and power generation- CHP) (Ecofys, 2010), the total NEG from biogas can produce enough electricity, heat and transport fuel to cover Overijssel's renewable energy targets from bioenergy sources. An extra 2.11PJ of energy from biogas can be further used for the production of either transport fuel or heat and electricity, and added to bioenergy targets elsewhere within the EU. Another 15PJ worth of heat can be added by the Overijssel province to bioenergy target elsewhere within the EU, if the combined heat and power generation (CHP) technology is used.

The digestates from wet anaerobic co-digestion of different types of biomass (farm manure, crop residue and grasses) can act as an industrial raw material for the production of chemical fertilizers or replace chemical fertilizers directly on farmlands (British Biogen, 1997, Gebrezgabher et al., 2009). Based on this study, the NEG obtainable from the digestates can replace about 59.4% of the industrial raw material stocks targeted from bioenergy sources. Although this is quite substantial; it should be noted that fertilizer is not the only chemical that will be needed; other forms of industrial raw materials are needed for the manufacture of other types of chemicals e.g. pesticides, herbicides, fungicides, plastics, rubber etc. (Rabou et al., 2006). Digestates that are surplus to requirements can help meet part of the bioenergy targets for industrial raw materials elsewhere. Other industrial raw materials can be produced from bioenergy outputs from other sources yet to be examined e.g. urban wastes, rooftops, forest residues, wetlands, peat bogs etc..

Based on the estimates of this study, about $5.48 * 10^9$ Kg of CO_2 can be saved if biogas is used for combined heat and electricity generation; about $4.99 * 10^9$ Kg of CO_2 can be saved if biogas is used for the production of transport fuels. The natural gas equivalent of the energy from the biogas is about 44PJ; the tonnes of oil equivalent (toe) of the energy from the biogas is about 0.18 Mtoe.

4.2 Research merits, limitations and opportunities

4.2.1 Research merits

The integration of energy indices such as Net Energy Gain (NEG) and Energy Return on Energy Invested (EROEI) into the assessment of unconventional and conventional biomass sources of proves a more holistic approach. This is because it opens up more opportunities for further analysis e.g. comparison of NEG and EROEI, NEG per hectare, NEG per tonnes of biomass, NEG per animal etc.. NEG gives a broader and clearer picture of the possibility of attainment of set bioenergy goals under an SEA framework (Hill et al., 2006). The use of land as a store of bioenergy potential does not hold for unconventional bioenergy sources; monetary value is unstable because prices are always changing (Beccali et al., 2009, van der Hilst et al., 2010, Fischer et al., 2010).

From Table 15, it was observed that EROEI, NEG per hectare and NEG per tonnes of biomass are relatively more stable and reliable indices than NEG; this is because both of them did not change, despite the fact that the errors from the LGN 6 land cover classification (from estimation of area under the natural grasslands) was propagated through the analysis. The use of EROEI, NEG and other NEG derivatives e.g. NEG per hectare, NEG per tonnes of biomass, NEG per animal etc. offers alternatives aimed at minimizing constraints to bioenergy production and maximizing its potential outputs.

From this study, the alternatives offered for bioenergy production within the Overijssel province include:

I. Increased exploitation of unconventional biomass sources e.g. farm manure, crop residue, grasses from grasslands etc.; as opposed to indefinite search for land for conventional planting of bioenergy crops (Scarlat et al., 2010, Fischer et al., 2010).
II. The use of farm scale wet anaerobic co-digestion as biomass production technology for all wet biomass types (manure,grasses, straws etc.), this is because of the ease of co-digestion of different biomass types, increase in efficiency as a result of proximity of biomass sources to digesters, and the opportunity it offers for mineral nutrient recovery (Monnet, 2003).
III. Better animal management options and farm structure technologies for increased energy efficiency e.g. piping of dairy manure to nearby farm scale digesters (British Biogen, 1997, Monnet, 2003).

The information generated from this analysis can form a basis for discussion, and help drive stakeholder interaction and participation under an SEA framework. The spreadsheet used for the calculation of the energies involved in the different biomass/bioenergy production activities can be modified for future analysis of same sort.

4.2.2 Research limitations

This study estimated the energy output of the different types of biomass (grasses, straws and manure) individually; however, much more energy than the potential energy of the individual biomass types can be obtained from the wet anaerobic co-digestion of manure, grass and straw biomass (Steffen et al., 1998, Monnet, 2003). An appropriate energy reference system for the wet anaerobic co-digestion of manure, grass and straw biomass will give more precise estimates of the potential energy output from this technology (Gebrezgabher et al., 2009). There was also lack of data as regards reference system for assesing the significance of the potential CO_2 saved.

The estimates from this study were based on the 2011 data of the Central Bureau of Statistics (CBS); this include variables such as annual crop yield, annual animal population, area under cultivation and area under surplus pasturelands etc. These statistics are subject to annual changes. They are however acceptable because they report the most recent state of those variables (CBS, 2011).

The maximum possible travel distance of biomass is the farthest distance (worst case scenario) that a biomass can travel from its source before it gets to a digester where it can be processed. However, many biomass sources are a lot close to the available digesters; but the shortest routes are not likely to be straight lines; so the choice of 20Km for maximum possible travel distance of biomass accounts for the farthest distance that biomass can travel within the Overijssel province under the worst case scenarios e.g. putting into consideration constraints from road network designs, barriers, discontinuities etc. (Xiaotang, 2009).

The available digesters within the Overijssel province are not all anaerobic wet co-digesters and their present capacities are unknown. Therefore, there might be need to modify existing digesters for wet anaerobic co-digestion. Also, there may be need to increase the capacity of some of the available digesters, so that they can process more biomass (Monnet, 2003).

Errors might have been propagated in the course of this study, and this could have been products of one or a combination of any of the following four sources namely:

- Classification error (10-20%) from the LGN land cover for area under natural grassland.
- Uncertainties arising from the use of conversion factors and coefficients from different reference systems from different EU countries and the US.
- Errors arising from assumptions as a result of non-availability of certain conversion factors and coefficients and
- Double counting errors arising from an overlap in certain energy investment (input) activities e.g. energy for stalk shredding of crop residues and energy for mowing and chopping of crop residues.

Errors from the LGN 6 classification (from estimation of area under the natural grasslands) were taken into account for the whole analysis. This was done by taking into consideration the worst case scenario i.e. taking ±20% as the error range or limits. The resulting values where however acceptable, because they were all under 500TJ (between 136 -361 TJ), none is significant enough to be approximated to 1PJ in the event of analysis, this therefore does not change the bigger picture of the total NEG obtained significantly.

Uncertainties arising from the use of energy conversion factors and coefficients from different energy reference systems within the EU and US are acceptable. This is due to the fact that the environmental conditions (temperate climate and landscapes), management practices and technologies, machine conditions and efficiencies, and the power of fossil fuel and electricity used for the various biomass/bioenergy production activities in the different countries are similar . The accuracy of some of the conversion factors and coefficients are also unknown, average values were most frequently used; although this gave fair estimates of the bioenergy potential of the various biomass/bioenergy production activities under study, but it is difficult to establish the range of uncertainties involved in those estimations. Errors arising from assumptions are not expected to produce outliers, because such assumptions were based on similar processes or production chains.

Errors arising from double counting of energy inputs can be ignored because some of the overlap actually exists in real life biomass/bioenergy production activities.

4.2.3 Research opportunities

An assessment of other biomass sources in terms of energy efficiency indices like NEG and EROEI should be subjects of future researches. This will help develop a full mental picture of the overall bioenergy potential obtainable within the Overijssel province. Examples of such biomass sources may include: domestic and industrial wastes, street refuse, landfills, forest residues, peat bogs, wetlands, urban rooftops, roadsides, railsides, river banks, algae ponds etc. Unconventional biomass sources use less energy to produce much more energy; but conventional planting of bioenergy crops uses large energy to produce little, zero or negative net energy; therefore exploring unconventional biomass sources that do not involve full scale ground tillage should be prioritized for increased efficiency and net energy gains (Scarlat et al., 2010, Fischer et al., 2010).

The factors that may be responsible for annual variations in biomass yield, NEG and EROEI of biomass sources differ from one location to the other (Scarlat et al., 2010). Such factors may include farmer's management practices and decisions, economic or market forces, climate variations, incidences of pest and diseases etc.; however, the impacts of such factors locally within the Overijssel province is not clearly known, these could be a subject of future research (Prochnow et al., 2009, Scarlat et al., 2010).
Better animal management operations, and housing designs can further enhance potential biomass yield of farm manure (beef cattle and pigs) (Ozkan, 2001, Porter, 2009). More efficient manure collection solutions such as piping manure from source to nearby digesters can help optimize the net energy gains from dairy manure and increase its energy efficiency (Monnet, 2003); this could be a subject of future building technology or agricultural engineering research.

The use of well distributed and strategically located farm scale wet co-digesters for bioenergy production can help harness the relatively large bioenergy potential available within the rural landscapes of the Overijssel province (British Biogen, 1997, Monnet, 2003). This can be done by putting the necessary locational factors into consideration e.g. proximity to raw materials (biomass sources), proximity to residential areas (air pollution concerns) etc. (Monnet, 2003).

Dairy manure is the unconventional biomass source with the highest single NEG (about 47.4% of total NEG and an NEG/animal of 71.89 GJ/animal) but the least EROEI (3.71); its efficiency (EROEI) can however be optimized by co-digestion with other types of manure and biomass since co-digested biomass are known to produce more energy than mono-digested ones (British Biogen, 1997).The co-digestion of pig manure with other types of biomass will not conflict with phosphate recovery from pig manure, this is because resulting digestate can be further processed for the recovery of phosphate and many other valuable minerals (Oenema et al., 2006).

There is a need to develop an appropriate reference system for the wet anaerobic co-digestion of crop residues, animal wastes and grasses (Gebrezgabher et al., 2009), this will help have better estimates of how much energy can be obtained. As part of an SEA, this study attempted to include stakeholders input into the formation of storylines for the different biomass/bioenergy production scenarios; but this was not possible due to logistic reasons, language barrier and the cost implications of doing so; this can also be a subject of future research. Other subjects of future research deduced from this study include the mapping of surplus pasturelands, mapping of NEG and EROEI using remote sensing and GIS platforms (Beccali et al., 2009, Fischer et al., 2010).

Chapter 5

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Incorporating energy efficiency indices into an SEA framework for bioenergy production makes it more robust and holistic in nature; because it gives room for further analysis and open up new possibilities aimed at minimizing constraints to bioenergy production and maximizing its potential output. The use of available land, monetary valuation, biomass yield and energy output alone as bioenergy potential is inadequate and may be misleading (Beccali et al., 2009, van der Hilst et al., 2010, Fischer et al., 2010). EROEI is the real energy efficiency, it is a more stable and reliable index for measuring bioenergy potential, because unlike NEG, it is not susceptible to known errors such as classification errors and it measures the capacity of the biomass source to support continuous socio-economic activity (Hall et al., 2009). NEG, however, also has the advantage of being able to evaluate the significance of total energy obtainable to set bioenergy targets. NEG per biomass type and NEG per hectare are also relatively stable and reliable indices that will not change in the event of error propagation as observed in Table 15 earlier.

From this study, it can be concluded that three unconventional bioenergy sources on the rural landscapes of the Overijssel province (crop residue, farm manure and grasses from natural grasslands) can produce enough bioenergy to meet the projected bioenergy targets for the province; and also contribute to bioenergy targets elsewhere within the EU. Unconventional bioenergy sources such as farm manure, crop residues and surplus grasses on natural grasslands produce far much more bioenergy than conventional cultivation of bioenergy crops. Consequently, it makes more sense practically to make use of unconventional bioenergy sources such as farm manure, crop residues and grasses from natural grasslands than investing energy into the cultivation of bioenergy crops.

5.2 Recommendations

Based on the findings of this study, the following are recommended:

- The integration of energy efficiency indices like NEG and EROEI into every SEA framework for bioenergy production.
- The use of well distributed and strategically located farm scale wet co-digesters for harnessing the large bioenergy potentials on the rural landscapes of the Overijssel province. This is because of the convinience of being able to use different types of biomass, the need to increase the efficiency of less efficient but large dairy manure resources and the ease of recovery of phosphate and other valuable mineral nutrients from the digestate produced (e.g from pig manure) (British biogen, 1997, Monnet, 2003). Alternatively, some of the available digesters can be modified for wet anaerobic co-digestion; the capacities of some of them can also be increased so that they can process more biomass (Monnet, 2003).
- Encouragement of research into better animal management and housing designs. This will further improve the present manure collection, storage and haulage facilities (pig and diary cattle especially), and help boost the energy efficiency of using farm manure as a biomass source. This can be done through efficient management of space devoted to breeding animal, and piping of farm manure to nearby digesters (British Biogen, 1997, Ozkan, 2001, Monnet, 2003, Porter, 2009).
- Adequate knowledge on the factors affecting the yield of the biomass sources under this study and their impacts should be sought; this will help optimize the energy efficiencies of the different biomass sources (Coetto, 2008, Prochnow et al., 2009, Scarlat et al., 2010, Veepro Holland, 2011).
- The development of a standard reference system for wet anaerobic co-digestion of different types of biomass will also be useful in providing better future estimates on the potential energy outputs from the technology (Gebrezgabher et al., 2009).
- The information generated by this analysis can form a basis for discussion, and drive stakeholder interaction and participation under an SEA framework. The spreadsheet made can also be modified and used for future calculations of this sort (DEFRA, 2008).
- Under an SEA framework for bioenergy production, stakeholders input into the formation of storylines for biomass/bioenergy production actvities should be

included; this will further enhance the practicability of the bioenergy goals (EEA, 2006, Hellman & Verburg, 2011).

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