BIOMASS POTENTIALS FOR BIOENERGY PRODUCTION FROM BUILD-UP AREAS.

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MARCH, 2012

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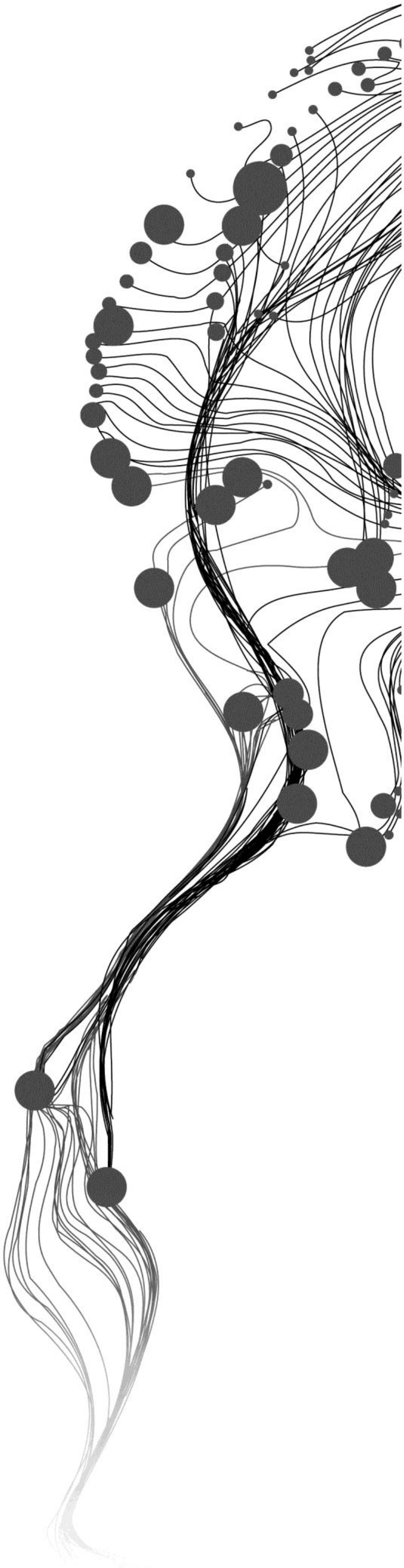

BIOMASS POTENTIALS FOR BIO-ENERGY PRODUCTION FROM BUILD-UP AREAS.

ESTHER SHUPEL IBRAHIM
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ABSTRACT

There is much interest in bioenergy because it is the only promising alternative renewable source of liquid fuels that can replace conventional fossil fuels for transportation needs with no major need of a new infrastructure. It can help mitigate carbon dioxide (CO_2) emissions, can decrease dependency on fossil fuels and ensure security of future energy supply. However, generating bioenergy is dependent on large biomass production which may cause land use conversions, impact agricultural production, food prices, water supply, forests and nature conservation. The question then is where to produce more biomass for sustainable bioenergy production?

The aim of this research was to consider unconventional sources of biomass with a focus on build-up areas. Geographic information and quantitative Life Cycle Assessment (LCA) tools were used to identify and estimate potential bioenergy that can be produced from build-up areas (urban and residential) areas in the Netherlands province of Overijssel. As such the potential sources include: abandoned construction sites, organic domestic waste, urban wood waste, bulky garden waste, areas under trees in recreational parks, and green roofs. The potential spaces were identified from detailed GIS layers and overlaid on orthophoto for visual analysis. The areas of all the potential layers were geometrically calculated and used to estimate the biomass/bioenergy potential with different species, different growing conditions and different yields per hectare. It is insufficient to calculate only energy output, because energy is also used in the production process. The energy efficiency was calculated by comparing the energy that was used in the energy production with the energy output. Inputs in the production were converted to energy (input energy) and estimated biomass yield was also converted to energy (output energy). A model was built to estimate the input and output energy in order to calculate net-energy and Energy Return On Energy Invested (EROEI) for the various potential sources.

The research findings indicate that, potential net-energy from build-up areas can hypothetically meet 0.5–2.7% of the overall energy demands and 2.3-13% of the 2020 renewable energy targets in the province of Overijssel, which are set under European Union (EU) regulations. This is in addition to CO_2 reduction and other environmental benefits for the urban environments. The EROEI results indicate a strong correlation between the input and output energy. Species with the same biomass yield/ output energy have different EROEI values when produced in different locations. Bioenergy from waste had a high EROEI of 5.5-15, which is attributed to low energy input. Generally, EROEI of bioenergy is dependent on the type of specie, production practice, species nutrient requirements, as well as the location of production. Green roofs had the most untapped potential in Overijssel in terms of biomass but also the lowest EROEI value if produced mainly for bioenergy (0.8-1.1). However, considering the environmental benefits of green roofs (insulation, scenery, climate mitigation etc.) and considering biomass as a by-product, the green roofs gave an impressive EROEI value of 51-54. This was comparable to energy production from solar photovoltaic panels (4-47 EROEI).

It should be noticed that Overijssel's land cover scales up well to the whole of the Netherlands, so the results have wider implications.

Keywords: bioenergy, carbon dioxide (CO_2), build-up areas, potential, energy efficiency, emission, environment and GIS.

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LIST OF ABBREVIATION AND ACRONYMS

EROEI	-	Energy Invested On Energy Return
EU	-	European Union
LCA	-	Life Cycle Assessment
NEG	-	Net Energy Gain
GIS	-	Geographic Information Systems
SEA	-	Strategic Environmental Assessment
CBS	-	Central Bureau of Statistics
CAGR	-	Compounded Annual Growth Rate
EEA	-	European Environmental Agency
UNFCCC	-	United Nations Framework Convention On Climate Change
KML	-	Keyhole Make-up Language
LIDAR	-	Light Dictation and Ranging
NPK	-	Nitrogen Phosphorous and Potassium
CO_2	-	Carbon dioxide
CH_3Cl	-	Chloromethane
MT	-	Metric Tons
T	-	Tons
HA	-	Hectare
M^2	-	Meter Square
KG	-	Kilograms
G	-	Grams
KWH	-	Kilowatts per Hour
GJ	-	Gigajoules
MJ	-	Megajoules
PJ	-	Pegejoules
DBF	-	dBase
PV	-	Photovoltaic

1. INTRODUCTION

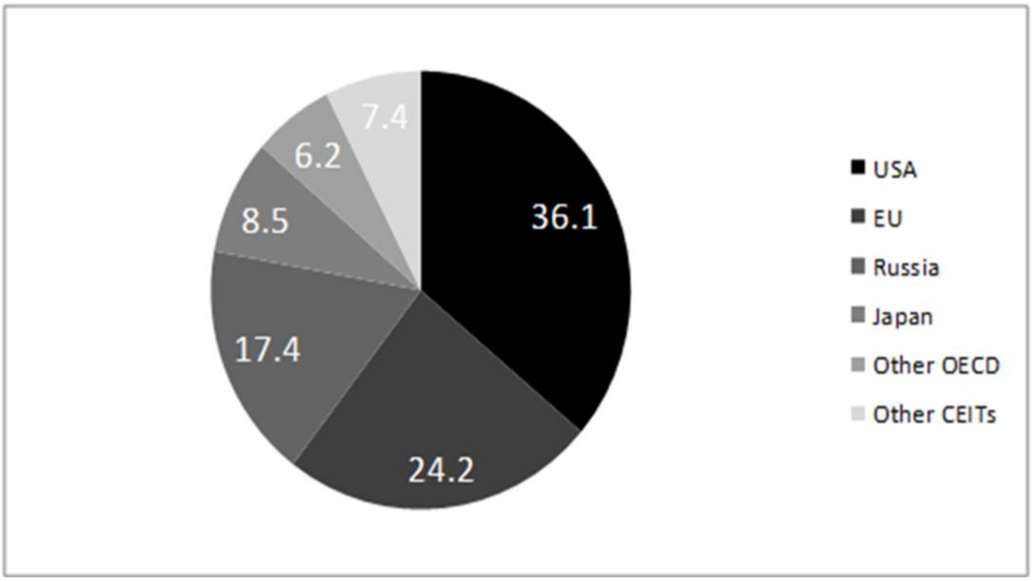
1.1. Background

Since their discovery, fossil fuels have been the major driver of modern economy. They are used to generate electricity and are the main source of energy in transportation. Nevertheless, fossil fuels are a finite resource and their reserves world over have started dwindling with no major new reserves being discovered (Withagen, 1994; Murray & King, 2012). There has been persistent increase in the prices of crude oil due to unrest in most producing countries and uneven distribution of the resource (UN- Energy, 2007; Murphy & Power, 2009). Besides, when burning fossil fuels we emit carbon dioxide (CO_2) and other greenhouse gasses, which are responsible for climate change (Houghton et al., 1992; Grubb, 2001). Consequently, the use of fossil fuels is emphasized by many scientists as the major cause of climate change (McKendry, 2002; Read & Lermit, 2005). These concerns have led to the search for other alternative energy sources (Sovacool & Watts, 2009). These alternatives unlike the fossil fuels are from renewable sources. The 21st century is seen as the era of renewable energy, with new sources discovered through the millennium. Some of these renewable energies include; geothermal energy, solar energy, wind energy, tidal energy, wave power, hydro-power, bioenergy etc. Bioenergy is by far the most widely used renewable energy source, supplying about 12% of the world's energy consumption it accounts for 80% of the yearly global renewable energy production (www.energymap.dk, 2011). Biomass is derived from plant matter of: trees, agricultural crops, grasses, animal waste, organic materials and waste. The biomass is then converted to energy, either as liquid fuel for transportation or electricity for power and heat. Bioenergy, in theory is a CO_2-neutral energy source: the amount of CO_2 absorbed during photosynthesis equals the quantity emitted when biomass is converted to energy (McKendry, 2002). Therefore, bioenergy has proven to be more useful in combating the global climate change issues (McKendry, 2002; Read & Lermit, 2005). However that is under the assumption that no extra energy, including fossil, carbon emitting energy is used in the production of bioenergy.

Bioenergy has been an active research theme with remarkable amount of scientific findings to estimate the global bioenergy potentials (Fischer & Schrattenholzer, 2001; Berndes et al., 2003; Moreira, 2006; Haberl et al., 2010). Most of these scientists estimated the global biomass potential by calculating global arable lands, excluding areas for food production, nature conservation etc. This led to estimates of potential biomass production under different scenarios. They concluded that there are global potentials in bioenergy, but whether these potentials are able to meet future energy demands depends on population growth, agricultural technologies, surplus lands, energy efficiency etc. However, most of the studies have highlighted the need for sustainability when producing bioenergy (Ericsson & Nilsson, 2006; Miskinis et al., 2006; Suntana et al., 2009; Qu et al., 2010; Duku et al., 2011).

The CO_2 emissions report compiled in 1990 by joint industrial nations indicates an alarming rise of global temperatures by 0.3° to 0.6° C since the 19th century. It was projected to keep rising to reach 1 to 3° C by the year 2100 (Oberthür & Ott, 1999). This is as a result of various human activities (combusting fossil fuels, deforestation, etc.), that release greenhouse gases like CO_2, methane, nitrogen (N_2O) etc. to the atmosphere. However, CO_2 released from fossil fuel combustion alone accounts for about 70-72% of the increased greenhouse effect (Oberthür & Ott, 1999). The increase in temperature is expected to have varying impacts on extreme weather events across the globe but largely endangering human, plant and animal well-beings, with worst effects in coastal and low laying areas (Peters, 1990; Bale et al., 2002; Botkin et al., 2007). The estimated global CO_2 in 1990 was about 21.400 MT and European Union (EU) had a share of 3,326 MT accounting for about 24.3% of the aggregate emissions (Figure 1) (Oberthür & Ott, 1999). The per capita CO_2 emissions in EU was about 8.7 tons and between 4.5 to 5 tons in the Netherlands (Municipality of Enschede, 2010). With that realization, at the conference held by United Nations Framework Convention On Climate Change (UNFCCC) in 1997, the Kyoto protocol treaty was signed to regulate global climate change (Oberthür & Ott, 1999; Municipality of Enschede, 2010). Thus, EU targets 30% reduction of its 1990 CO_2 emission by the year 2020 (European Commission, 2009).

The EU has also placed the transition towards renewable energy on its political agenda (Rosende et al., 2010). With mandatory renewable energy targets for all its member countries, the goal is to provide 20% of overall energy needs and 10% in the transport sector from renewable sources by the year 2020 (European Commission, 2009).



Source: Framework Convention on Climate Change, 1997.

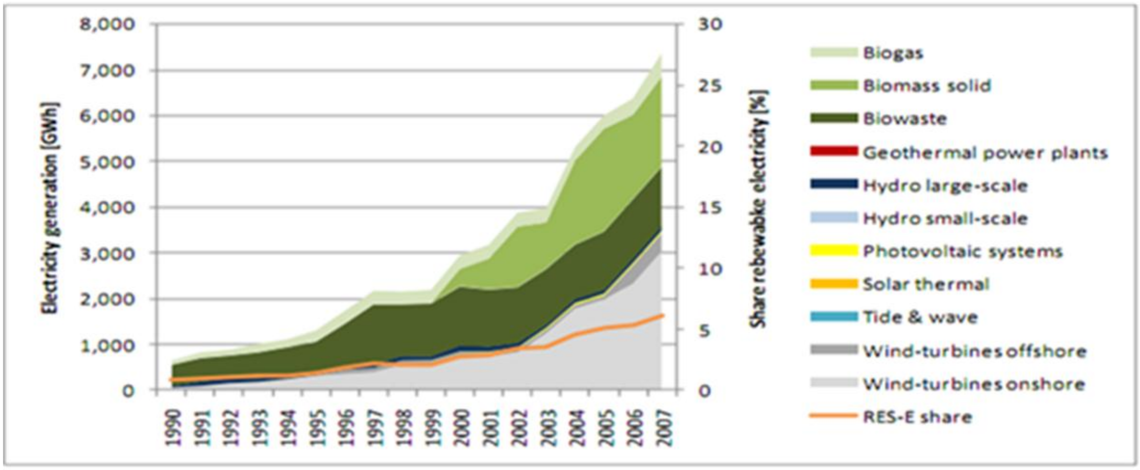
Figure 1: 1990 CO_2 emissions of the world's industrialized countries (with the exception of Lithuania and Ukraine

With that regard, the Netherlands in 2007 reviewed its renewable energy directive to an ambitious 20% target by the year 2020, exceeding the 14% target mandated for the country by the EU. The Netherlands targets a yearly increment of 2 to 2.3% after 2011 to reach 20% in 2020 (European Renewable Energy Council, 2007). Nevertheless, meeting the trajectory goal will be challenging considering the start at 2.40%

in 2005 (Table 1). Remarkably, the share of renewable energy in the generation of electricity in the Netherlands has increased from 1% to about 6% from 1990 to 2007 with a Compounded Annual Growth Rate (CAGR) of 15%. The dominant supplier in 2007 was biomass and wind energy (Figure 2). Likewise, biofuels consumption in the transport sector began in 2006 and accounts for only 0.3% of the total consumption but grew rapidly to about 2% by the year 2007 (Rosende et al., 2010).

Table 1: Renewable energy targets and trajectories in the Netherlands

START	AVERAGE				
2005	**2011-2012**	**2013-2014**	**2015-2016**	**2017-2018**	**2020**
2.40%	4.72%	5.88%	7.62%	9.94%	14.00%



Source: Eurostat, (2009)

Figure 2: Renewable energy supply-Electricity generation in the Netherlands 1990 – 2007

1.2. Problem analysis and research justification

Despite the potentials in bioenergy, there are global concerns regarding the consequences of increased biomass production on the environment, agricultural production, food prices, water supply, forests and nature conservation (McLaughlin & Walsh, 1998; de Fraiture et al., 2008; Muller et al., 2008). It is alarming that with the present bioenergy targets of about 40 countries, the net increase in greenhouse emissions is projected to remain in the atmosphere till the year 2043 due to land use conversions alone (Oxfam International, 2009). Similarly, there have been conflicts between biomass and food productions leading to global debates on the conversions of agricultural lands to biomass production, which can eventually lead to food crisis (McLaughlin & Walsh, 1998; de Fraiture et al., 2008; Muller et al., 2008). Likewise, exploitation of forests for biomass production can accelerate deforestation, climate change, loss of species habitats and bio-fragmentation. Hesselink, (2010) suggests the need to seek caution and restraints in establishing biomass policies to reduce forest area conversion for biomass production. Therefore the question remains: where to produce more biomass for sustainable bioenergy? Scientists have been investigating how to optimize biomass productions in agricultural lands and forest areas (Suntana et al., 2009). Nevertheless this may result in the release of more harmful gasses like nitrogen (N_2O), CO_2 etc. to the environment (PBL Netherlands environmental assessment agency, 2010). The question whether to produce biofuels or not is no longer an issue but the debate now remains, where and how to produce bioenergy (Lavigne & Powers, 2007).

There is a recent focus on global pollutions and climate change issues. This is as a result of various human activities that emits greenhouse gasses and results to impacts like; urban heat, health and environmental hazards etc.(Bornstein, 1968; Cohen et al., 2004). Therefore, scientists and policy makers have been seeking ways to; reduce atmospheric CO_2 content, reduce energy demands, supply sustainable renewable energy etc. (Howard et al., 2006; Municipality of Enschede, 2010; Hoppe et al., 2011). The core problem this research is addressing is identifying non-conventional urban spaces where biomass can be produced. This biomass will be used to generate sustainable bioenergy. Correspondingly, the biomass will absorb CO_2 during photosynthesis (Wahlund et al., 2004) and substitute fossil fuels (Harro & Curran, 2007). The research findings can be used as an important tool for Strategic Environmental Assessment (SEA) and planning.

1.3. Bioenergy potentials within build-up areas

Recently, scientists are focusing on evaluating biomass production from unconventional and sustainable sources that does not jeopardize agricultural production and forest areas.(Kapdan & Kargi, 2006; Shilton et al., 2008; Murphy & Power, 2009; University of York, 2011). These sources include: crop residues, algae, animal waste, domestic and commercial organic waste (food, fruits and vegetables), etc. This research is aimed at identifying more potential sources of biomass within build up areas for sustainable bioenergy production and quantifying the amount of producible bioenergy from these spaces/sources. Geographic information and quantitative tools were used to estimate bioenergy that can be produced from build-up areas in Overijssel. The sources considered included: roof tops, construction sites, recreational parks, garden waste and domestic organic waste (foods, vegetables, fruits etc.). Biomass estimations were based on the assumptions made, calculated available areas, plants to be grown and different options of production (Figure 3 and Figure 4). Recently grasses are extensively explored by scientists to evaluate their energy efficiency for bioenergy production and they have proven that the production of most perennial grasses for bioenergy is energy efficient (Murphy & Power, 2009; Smyth et al., 2009). The criteria for selecting perennial grasses to be grown within the identified spaces in this study includes; energy efficiency of production, nativity/climatic adaptions of plants, reseeding plants and aesthetic value in some cases (Figure 3).

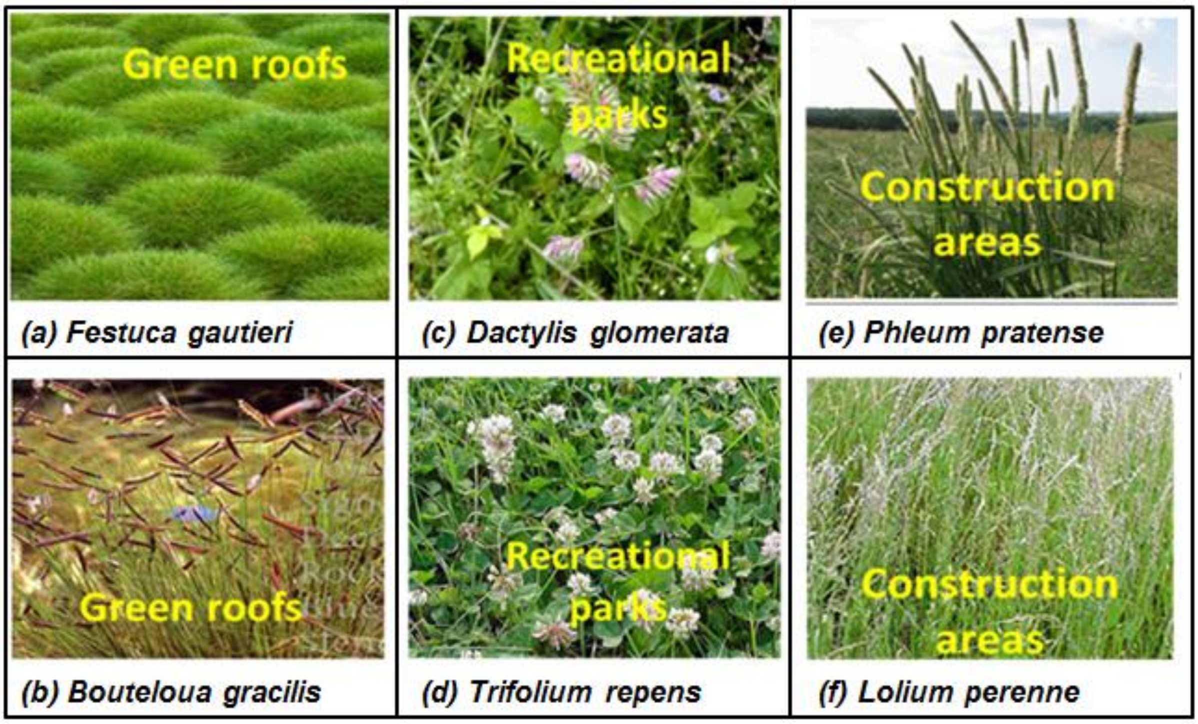


Figure 3: Some of the species identified for biomass production within build-up areas

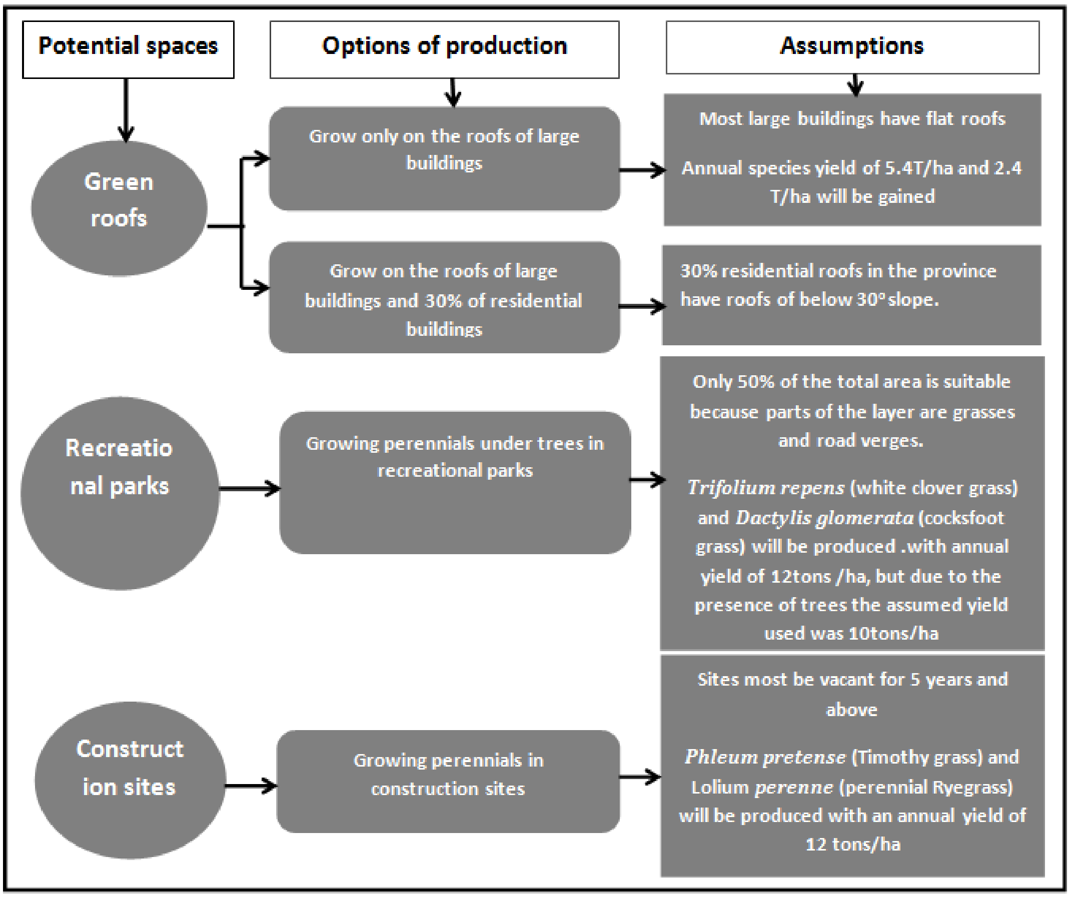


Figure 4: Options and some assumptions considered in the study for estimating potential biomass production within build spaces in Overijssel.

The challenge is to produce bioenergy that is energy efficient and environmentally friendly. Therefore, assessing Life Cycle Analysis (LCA) of producing bioenergy from each of the identified space became important. This is to pursue the possibility of producing energy efficient biomass within build-up areas. Producing bioenergy is energy demanding and requires large amounts of biomass, which may require fossil fuels. Energy is required to grow, collect, dry, ferment, and burn in order to produce energy, which is the input energy in production. Therefore it is insufficient to look at only energy produced. The input energy also has to be accounted for. There are two indices that are widely used in energy analysis. Net-energy or Net Energy Gain (NEG), it is the energy output from the production minus the required input energy. The Energy Return On Energy Invested (EROEI) is the ratio of gained energy (Berglund & Borjesson, 2006; Correia et al., 2010). If:

Input energy = the energy required to produce biomass and convert biomass to energy

And

Output energy = the energy produced.

Then

Net-energy Gain (NEG) = output energy- input energy (energy gain)

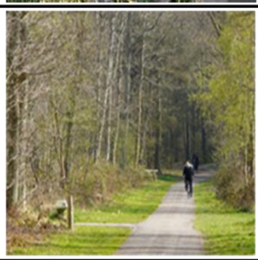
EROEI= output energy /input energy (ratio)

To calculate these indices, inputs in the system were converted to energy (input energy) and estimated biomass yield were also converted to energy (output energy). A model was built to estimate the input and output energy in order to calculate net-energy and EROEI of the various potential sources.

1.4. Benefits of biomass production within urban environments

Aside bioenergy production, growing biomass on roofs, recreational parks, construction sites etc. has other environmental and economic benefits. Growing more vegetation within build-up areas generally will reduce the levels of CO_2 that are constantly emitted in most urban environments. Likewise roof tops are mostly bare or paved, rainfall is immediately lost from rooftops to surface runoffs which are directed to rivers/canals and when intense, results in erosion and flooding (Murray-Hudson et al., 2006). Vegetation on roofs can; reduce the impact of surface run-off, reduce energy demands, improve air-quality in the urban areas by filtering pollutants in the atmosphere, improve human health etc. (Getter & Rowe, 2006). Some of the socio-economic and environmental benefits of growing and collecting biomass from some build-up areas for bioenergy are outlined in Table 2.

Table 2: Existing and potential sources of biomass in urban environments and some their benefits and constraints.

URBAN SPACES	EXISTING PRACTICE	PICTURES	BENEFITS	CONSTRAINTS
SEASIONAL LEAF-FALL	Collected for bioenergy		1.No cost of biomass production 2. collection reduces the release of methane to the atmosphere	
DOMESTIC /COMMERCIAL ORGANIC WASTE	Collected for bioenergy		1.No cost of biomass production 2.Motivates frequent collection of domestic waste	
GARDEN	Mowed garden grasses and flower clippings are collected and used for bio-energy.		No cost of biomass production	
RECREATIONAL PARKS	Mowed grasses and seasonal leaf-fall are collected for bio-energy		Growing beautiful perennial grasses will give the parks a more gorgeous scenery	The type of biomass to be grown has to be pleasing to the public
CONTRUCTION SITES	Construction sites are left vacant		Reduce surface run-off/erosion.	Areas are not permanently vacant.
ROOF TOP	Not collected for bio-energy .Green roofs is optional, with a monetary incentive ranging between 25-50 Euros per square meter.		1.Reducing the impacts of urban heat and climate change 2.Improving water retention and air-quality in the urban areas 3.Protecting roofs from ultraviolent rays, wind and rain 4.Providing beautiful sceneries in the urban areas	1.High cost initial installation 2. vegetation weight 3.Length & direction of roof

1.5. Research objectives and questions

The main research objective of this project was to identify and evaluate potential spaces within built-up areas for biomass production and to estimate the quantity of net-energy that can be produced from this biomass in a sustainable and least environmentally damaging way.

1.5.1. Specific objectives

- Identify potential empty spaces within build-up areas where biomass can be produced and evaluate the environmental and economic benefits of producing biomass from these build-up areas.
  - *i. Where are the vacant spaces within urban areas that can be utilised for biomass production?*
  - *ii. What environmental and economic values can biomass production within build-up areas add to the environment?*
- Identify the types of biomass to be grown within the identified spaces.
  - *iii. What are the criteria for selecting biomass to be produced within each identified area?*
- Assess other types of biomass produced within build-up areas that are already utilised for bioenergy and quantify the productions.
  - *iv. How much biomass can be generated/collected within build up areas and what is the quantity presently harnessed for bioenergy production (e.g. organic domestic and waste (foods, fruits and vegetables, bulky garden waste, wood waste etc.)*
- Estimate the amount of biomass/energy that can be produced from each of the identified sources under different options of production.
  - *v. What is quantity of potential biomass/net-energy that can be produced from each of the source identified?*
- Evaluate the energy efficiency of producing biomass from the identified spaces.
  - *vi. What is the energy required to produce energy from each of the identified urban space?*
  - *vii. Is the output energy more than the input energy?*
  - *viii. What amount of Overijssel's overall targeted 20% renewable energy demands and 10% transport energy needs can the potential producible energy meet?*
- Compare efficiency of bioenergy production on green roofs with other types of renewable energy that can be produced there (e.g. solar photovoltaic panels on roofs).
  - *ix. Is the production of biomass from green roofs worth considering?*

2. STUDY AREA

2.1. An overview of the study area

The province of Overijssel is located at the eastern part of Netherland, on latitude 52.42 (52° 25' 0 N) and longitude of 6.5 (6° 30' 0 E). Overijssel is bordered by Germany to east, Gelderland to the south/west and former moors of Drenthe to the north (Figure 5). The province had a population of 1.058 million (6.5% of The Netherland) in 2006, with 26 municipalities that were amalgamated from the former 44 municipalities. The provincial capital city is Zwolle and other major cities are Enschede, Almelo, Hengelo and Deventer.

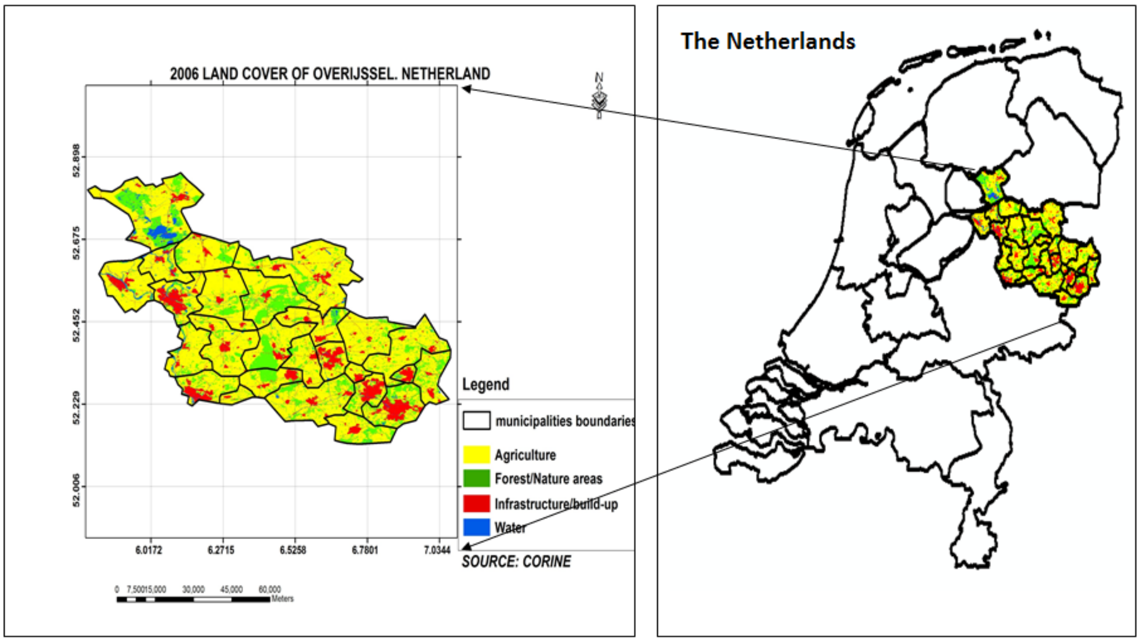


Figure 5: The map of the study area showing municipalities administrative boundaries and land cover.

2.2. Criteria for study area selection

Certain conditions were considered in selecting the study area for this research (Overijssel). The factors include:

Data availability

Research is data driven; the availability of data supports the motivation for research. One of the motivations for this research was data availability, with most layers available in ITC and from reputable sources.

The provincial interest and targets on renewable energy

The province has also set an ambitious target of 20% of its energy supply from renewable sources and 10% in the transport sector by the year 2020. To achieve that, the province has completed 200 renewable energy projects geared towards supplying energy and reducing CO_2 emissions, with 200 more projects planned (Gemeente Rijssen-Holten, 2011; Province of Overijssel: energy atlas, 2011). Presently, only 3.3% of the total provincial energy demand is met by renewable sources and the province is researching for means to increase these supplies (Hoppe et al., 2011).

The need for energy potential maps in Overijssel

The province has companies and institutions formed by the government to evaluate bioenergy production in east Netherlands (Bio-energiecluster Oost Nederland, 2008-2011). Bio-Energy-2-Overijssel (BE2O) is another project for the enhancement of bioenergy technologies in the province. "New Energy for Enschede" is formed towards intensifying climate friendly energy sources in the municipality of Enschede by reducing energy use, identifying sustainable energy sources and reducing CO_2 emissions. These efforts have shown interest in maps for their SEA process, which was one of the motivations for this study.

The provincial land cover and bioenergy potentials

The major land cover in Overijssel is agriculture and one of its main sources of revenue with 9,000 agricultural and horticultural farms and holdings (Bont et al., 2011). Agriculture occupies about 68.9% of the total provincial land cover, followed by forest/nature areas with 18.5%, then build-up areas and infrastructures with 9.8% and lastly, water having 2.9% (Ibrahim, 2012). Considering the provincial land cover, Overijssel has more potential in producing green energy, with a potential of producing up-to 10-15% of its energy supply from bioenergy by 2020 (Province of Overijssel: energy atlas, 2011). Therefore, the province is most interested in bioenergy due to other potential benefits of the green renewable energy (Haberl et al., 2010). Nevertheless, despite this potential in bioenergy there are concerns on the future consequences of biomass production on the environment, agricultural production and food prices

Similarities between provincial and national land cover

The mix of forest, agricultural and urbanized land uses in Overijssel is quite close to most provinces in the Netherlands and the average for the whole country. Therefore, the findings of this study can further be extrapolated for the entire country. In south (Zuid) Holland, north (Noord) Holland, IJsselmeer and Zeeuwse meren where some major cities are located (Hague, Rotterdam and Amsterdam) there are even more potentials for biomass production within build-up areas, but they are not a fair representation of the Netherlands (Table 3).

Table 3: Provincial land cover distribution in the Netherlands

PROVINCES	BUILD-UP (%)	AGRICULTURE (%)	FOREST (%)
Drenthe	7.3	78.4	14.3
Flevoland	9.4	75.4	15.2
Friesland	6.6	86.4	6.95
Gelderland	11	67.1	21.8
Groningen	8.6	88.3	3.08
IJsselmeer	22	72.1	6.21
Limburg	17	68	15
Noord-Brabant	15	69.4	15.3
Noord-Holland	23	67.3	10.1
Overijssel	**10**	**79.8**	**10.2**
Utrecht	21	65	14.3
Zeeland	9.1	87.4	3.51
Zeeuwse meren	37	21.2	41.9
Zuid-Holland	27	67.7	4.94
NETHERLAND	**14**	**74.3**	**12.1**

Source: Corine land cover map 2006

3. MATERIALS AND METHODS

3.1. Materials

3.1.1. Data

Both spatial (GIS layers) and non- spatial data were used for the research analysis. The data used for the research are described below:

- The boundary shape file of Overijssel was used to clip all layers to the size of the study area.
- The Top10 vector is a layer of highly detailed (1-10m) land cover classes of the Netherland with a closed surface structure, composing of coded and interconnected line elements (Data archiving and networked services (Data archiving and networked services (DANS), 2011). The Top10 data of the province was acquired from DANS/EASY. The data composed 75 map sheets covering of North and South (75*2=150sheets) of Overijssel.
- Corine is a land cover/ land use map of all European countries produced by the European Environmental Agency (EEA) for the periods of 1999, 2000 and 2006 at a pixel size of 100m*100m. The data is based on satellite image interpretation and contained 44 land cover classes. The 2006 Corine map of Overijssel was downloaded and used. The Corine map legend comprises three levels of classification in varying details for different purposes. The first level had five major land cover classes (water, forest, agriculture, artificial surfaces and wetland). The 2nd level had 12 classes which are a sub-division of the first 5 major classes. Lastly, the third level is a finer detail of the 2nd level into 44 classes (European environment agency (EEA), 2006). Thus the third level of the urban classes were extracted and used to extract the construction sites layer.
- The point shape file of digesters within Overijssel was used to estimate the distance from production sites to digesters.
- An Orthophoto/ orthoimage is an aerial photo of an area which is geometrically corrected/orthorectified. The orthophoto of some parts of Overijssel were explored to visualize suitable areas for biomass production.
- The Google earth is a free global high resolution imagery (e.g. 0.5m Geoeye, 0.6m Quickbird and 1m Ikonos). The resource was used to visually analyse representative areas identified for biomass production within build-up areas. Results were further extrapolated to the rest of the province.
- The "Energieatlas Overijssel" website provides spatial information on the province's renewable energy targets, requirements, progress etc. The website was explored to analyse the provincial bioenergy requirement, present sources and future potentials.

The non-spatial data used here were the population and waste data from the Central Bureau of Statistics (CBS) website. CBS provides statistical information like population, population density, birth rate, waste, migration, divorce, deaths etc. for the entire Netherlands. Overijssel's population and waste data were downloaded from this website. More information on organic residential/commercial waste collection was obtained from the municipalities' waste websites (Twentemilieu, 2011).

	TYPE OF DATA		**RESOLUTION/ SCALE**	**SOURCE(S)**
1	Spatial data	High resolution	0.5m	Google earth
		Boundary of the study area (shapefile)		
		Shape files of buildings , trees and recreational parks	1:10000 – 1:25000	Top 10 vector layer (Kadaster)
		Shape file of roads		
		Land use/ land cover map	100m*100m	Corine 2006
		Shapefile of digesters		University of Twente
	Non-spatial data	Waste and population data		Central Bureau of Statistics, the Netherlands(CBS)

Table 4: Data types and sources

3.1.2. Software and purpose

Tools and software used in this thesis for analysis and reporting are listed in table 5.

Table 5: Software used in the study and their purpose (s)

SOFTWARE	**PURPOSE**
ArcGIS 10	Geometric corrections
	Layers clipping
	Layers extraction
	Calculation geometry
	Map preparations and composition
Microsoft excel	Area calculations
	Biomass estimations modelling
	Energy efficiency modelling
Microsoft word	Report writing
Microsoft power point	Mid-term exams and final research presentation

3.2. Research approach

The research was categorized into five main stages to achieve the research objectives (Figure 6). Stage "I" was linked to the identification and extraction of spaces (roof tops, construction sites and recreational areas) for biomass production which was in response to objective one. The stage also included the evaluation of environmental and economic benefits attached to biomass production within these urban environments. Stage "II" was about estimating the areas available for biomass production. This stage also involved the selection of suitable types of biomass to be grown in response to research objective two. Stage "III" was dedicated to biomass estimation in respect to objective four. The stage also includes the estimation of biomass generated in build-up areas already in use (domestic organic waste, garden and wood waste) to address objective three. Stage "IV" focuses on evaluating the energy efficiency and LCA of bioenergy production of each of the identified space/source, which was in response to objective five. Finally stage "V", was a comparison of two types of renewable energy production on roof-tops: bioenergy on green roofs vs. photovoltaic installed there.

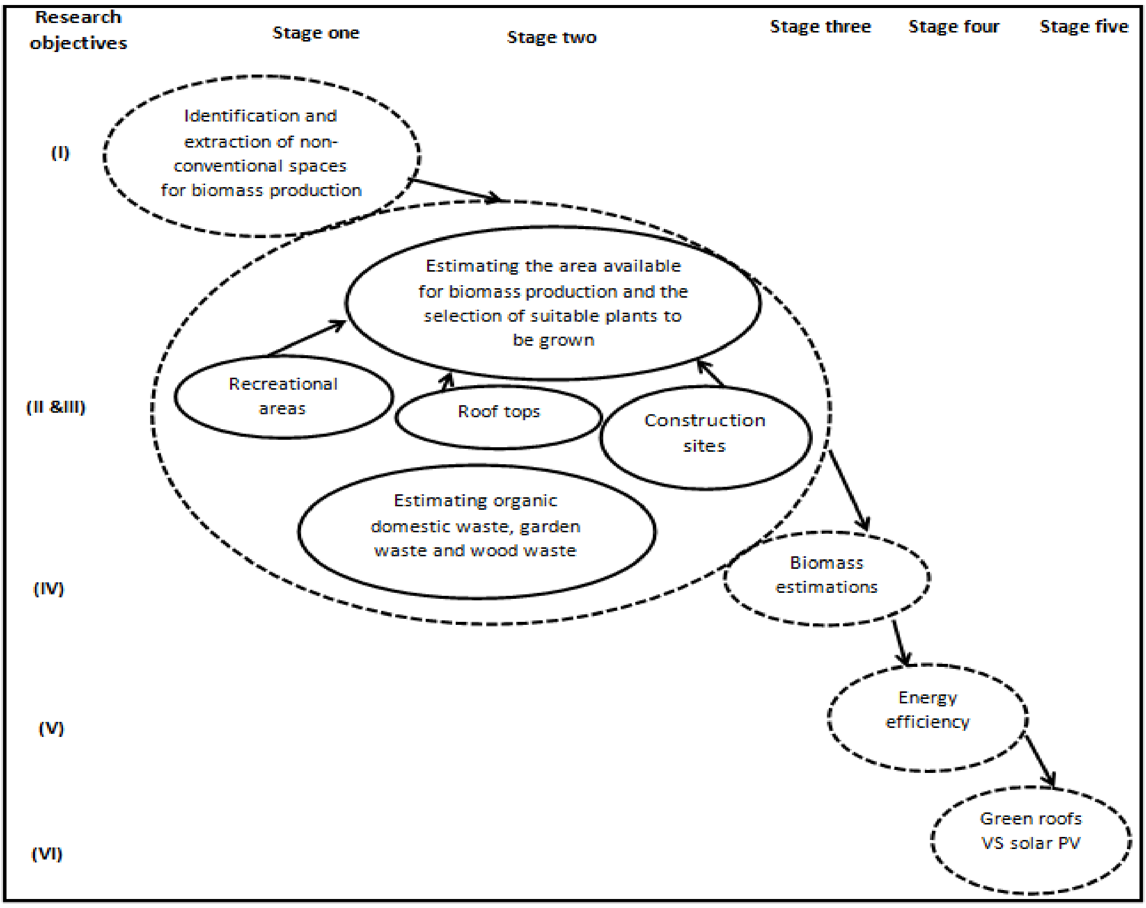


Figure 6: The overview of individual stages of this thesis

3.2.1. GIS analysis

All spatial data were projected to "the national European grids/RD New.prj" and under "Amersfoort_To_ERTF_1989" geographic transformation, which is the projection of the study area and this enabled the calculation of geometry in hectares.

Four Top10 layers were identified for the extraction of appropriate classes for the respective research analysis. The first layer was "huizen" (homes), it comprised of residential buildings. 150 sheets of the "homes" layer were joined and then clipped with the shape file of the study area. The attributes of the layer "vlakken"(surfaces) included "Groot Gebouw" (Large Buildings), "Loofbos" (deciduous) and "Weiland" (meadow). The attribute "large building" was a layer of large public/commercial buildings in the province. This layer was extracted from the 150 sheets, joined and clipped to the size of the study. The attribute "deciduous" was a layer of areas covered by deciduous trees in Overijssel. This layer was also extracted from the 150 sheets, joined and clipped to the size of the study. Lastly, the attribute "meadow" was the layer that showed the distribution of all green areas within the province. Most importantly, meadows within build-up were flowers/grasses and trees planted at the fringes of roads and in recreational parks. Based on that observation, the layer was also extracted from the 150 sheets, joined and clipped to the size of the study area. Another layer was the "sympoint" which was a point shape file encompassing sign post, individual trees, wind mills, cemeteries, individual trees etc. The "Losse Boom" (individual trees) attribute was extracted from all 150 sheets, union and clipped to the size of the study. The construction site layer was not available in the Top10 vector layers. Consequently, the urban land cover classes were extracted from Corine land cover map of 2006. The construction sites was then extracted from the urban classes and clipped to the size of Overijssel. The municipalities' layer was crossed with all individual layers to calculate the coverage of each layer within the municipalities in Overijssel.

3.2.2. Visual analysis of the extracted layers

The respective extracted layers were converted to Keyhole Makeup Language (KML) data format and over-laid on the Google earth for visual analysis. This was to examine the corresponding layers and verify if the layers are indeed what they are said to be. Most layers were appropriately classified in different locations within the province and the results were extrapolated for the entire province (Figure 7). This was with the exception of the layer for "individual trees" which was highly underestimated as shown in (Figure 8). It was also observed that the layer for recreational areas "meadow" included vegetation planted at the verges of roads (Figure 8). However, it was perceived that most of the small residential buildings have steep roofs while the large buildings have flat roofs (Figure 9).

3.2.3. Biomass estimations

A new field "area" was added to the attribute table of all the extracted layers (construction sites, large buildings, residential buildings, recreational areas and deciduous areas). The geometry of these layers was calculated in hectares (ha) to get the area coverage of each polygon and the table was exported as dBASE file format (dbf).

The biomass estimations were based on the assumptions described in (Table 6) area available, plants to be grown (Figure 3) and different options of production (Figure 4).

Green roofs are vegetated with species usually from dry, semi dry and rocky areas. They include a wide variety of grasses, grass-herbs-shrubs, lawn/perennials, shrubs, trees etc. (Peck & Kuhn, 2003). Some of these green roof species are; *Festuca gautieri, Bouteloua gracilis, Carex nigra, Rudbeckia fulgida, Schizachyrium scopari*us etc. (Green garage mordern+green roof design, 2007). Tewari, Mittra, & Phartiyal, (2008) estimated the annual yield of these types of rocky desert plants to be in the range of 2.6–5.4 tons /ha. The projected yields were used to generate the biomass estimations for the green roofs. However, different options were computed for comparison (annex 2). Five options of production were considered in estimating biomass production. Option one was based on the assumption that all large buildings (public/ commercial) will be used for biomass production. This area was multiplied by 2.6 tons/ha and 5.6 tons/ha to generate an estimate (option 1 and 2). The next option was based on the assumption that 30% of residential buildings (residential buildings with flat roofs or roof slope below 30^{o}) will be utilized for biomass production. Therefore, the area of these buildings was added to option one and multiplied by 2.6 and 5.4 (options 3 and 4). The fifth option was based on the assumption that both yields will be equally achieved on large buildings and 30 % of houses. Similarly, the potential area was divided by two (50 % for 2.6 tons/ha and 50 % for 5.4 tons/ha).

The biomass estimation for the recreational parks was calculated based on the assumption that perennial grasses will be grown under trees in recreational parks. This was based on the assumption that species like *Trifolium repens* (white clover grass) and *Dactylis glomerata* (cocksfoot grass) will be grown with an annual yield of 12 tons/ha (Smyth et al., 2009). The presence of trees within the parks will obstruct these estimated yields due to tree shadow effects (Davis et al., 1999). Therefore 10 tons/ha was assumed to be the obtainable yearly yield. This estimated yield was multiplied by the area available for biomass production. Also, based on the knowledge that some parts of that layer are grasses and road verges, only 50% of the total area was used for the estimate.

Only one option was considered for biomass production within plots allocated for constructions. The assumption was that species like *Phleum pretense* (Timothy grass) and *Lolium perenne* (perennial

Figure 7: The potential areas (Top10 vector) over laid on an orthophoto of parts of the study area

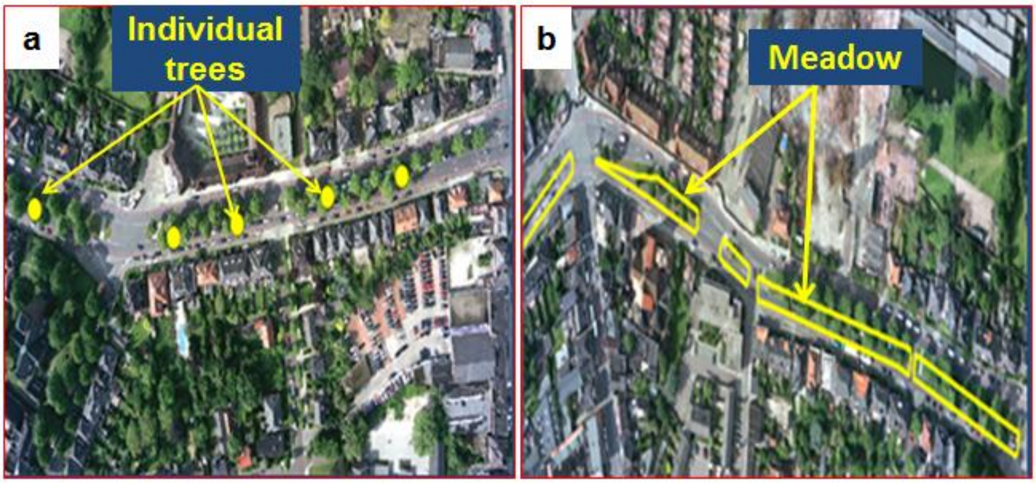


Figure 8: (a) **I**ndividual trees and (b) Meadow overlaid on an orthophoto of parts of the study area

Figure 9: An orthophoto showing the roof tops of large (a) and small buildings (b) in parts of the study area

Ryegrass) will be grown with an estimated yield of 12 tons/ha, (Smyth et al., 2009). Therefore, the estimated yield of these species was multiplied by the total area of construction sites in Overijssel.

The 2004 waste data downloaded from the Central Bureau of Statistics (CBS) website was calculated in kilograms (kg) per capita for all municipalities. The 2004 population data of municipalities in the province was then downloaded and multiplied by the per capita waste to generate the total kilograms of waste collected by each municipality in the province. This was then converted to tons since the biomass estimations for other sources were performed in tons. The suitable bioenergy wastes identified from the data were; bulky garden waste, wood waste and GFT-wastes which contain fruits and vegetable waste (annex 4). Waste data for 2004 were not available for some municipalities, hence the amount collected in other years were used.

Table 6: An overview of the criteria and assumptions used for the biomass estimations

Source	Species	Yield	Reference (s)	Assumptions
Green roof	*Festuca gautieri* *Bouteloua gracilis* *Carex nigra* *Rudbeckia fulgida* *Schizachyrium scoparius*	2.6 - 5.4 tons/ha	(Tewari et al., 2008)	All large buildings (public/ commercial) will be used for biomass production The estimated yield of 2.6 tons/ha and 5.4 tons/ha was used for biomass estimation. 30 % of residential roofs assumed to have flat roofs or roof slope below 30° was used along with the large buildings
Recreational areas	*Trifolium repens* (white clover grass) *Dactylis glomerata* (cocksfoot grass)	10 tons/ha	(Smyth et al., 2009) (Ibrahim, 2012)	Perennials grasses will be grown under trees in recreational parks Due to presence of tree within the parks which will obstruct 12 tons/ha estimated yields, 10 tons/ha was used Based on the knowledge that some parts of that layer are grasses and road verges, only 50% of the total area was used for the estimates
Construction sites	*Phleum pretense* (Timothy grass) *Lolium perenne* (perennial Ryegrass)	12 tons/ha	(Smyth et al., 2009)	All construction site vacant for 5 years and above can be utilized for biomass production
Domestic waste	Food waste (GFT)	97.7kg per capita (0.1 tons per capita)	(Central Bureau of Statistics, 2011).	All organic domestic waste collected within the province are used for bioenergy The average kg per capita of all the municipalities and maximum was also extrapolated for the province.
	Bulky garden waste	24.9kg per capita (0.03 tons per capita)		
	Wood waste	16kg per capita (0.02 tons per capita)		

3.2.4. Life Cycle Assessment (LCA)

Energy is required to: plant, grow, harvest/collect and convert biomass in order to produce bioenergy. Therefore, the total energy of primary and secondary inputs used to produce bioenergy was estimated. The primary energy refers to the energy directly used in production (e.g. fossil fuels etc.), while the secondary energy is the indirect energy used in producing some of the materials used in the system e.g. machinery, fertilizers etc. (Smyth et al., 2009). The energy spent was compared to the estimated producible energy to evaluate the energy efficiency of producing bioenergy from the potential urban space/sources (Net-energy and EROEI).

The essential input energy required for green roofs biomass is dependent on several variables. For the sake of this research it was estimated as follows:

Construction and installation of green roof layer: The life cycle costing data of roofs indicates that green roofs cost the same or less than conventional roofs (Peck & Kuhn, 2003). Based on that assumption the least energy required to install a normal roof (ferroconcrete) was used to estimate the energy required for per square meter of green roof membrane (Reddy & Jagadish, 2003).

Plants/seeds: Here it was assumed that mountainous or desert grass species grown on roofs will be produced for bioenergy production and the energy required to produce grass seedlings was used for the estimate (Smyth et al., 2009).

Fertilization: The extensive green roofs require little fertilization every 6-12 months after installation with little necessity for watering. While the intensive green roofs require regular maintenance (Great lakes water institute, 2011). However, some fertilization is required for green roofs and this done with only controlled-release fertilizers in order to avoid polluting storm water (Emilsson et al., 2007). The approximated nutrient requirement of vegetated roofs is 5 g/m^2 and with substrate that does not contain too much nutrients (Landschaftsbau.e.v, 2009). Nevertheless, the energy required to produce normal fertilizers was used to generate an estimate for the green roof (Kyle, 2011).

Harvest: Here the assumed method of harvesting could be mowing for flat roofs and manual harvesting using high lifts for steep roofs. However, energy required for mowing on land was used for the estimation (George & Mark, 2001).

Transportation of other materials: This was the energy required to transport fertilizers, seeds and other materials to the production sites (Correia et al., 2010).

Transportation of biomass: The harvested biomass has to be transported to the digesters in order to be converted to energy. There were 21 digesters scattered around the province and a buffer was performed to generate the suitable maximal, minimal and average distances to digesters. The minimal distance was 0 km, average was 9 km and maximum was 19 km from potential production sites to digesters (Figure 10). An estimated energy of 0.000224 MJ/m^2 by Smyth, et al. (2009) was used with the average distance (9 km) to calculate required energy in transporting biomass from all potential production areas to digesters.

Biomass conversion: Biomass is converted through chemical and biological conversion methods into power for electricity or bio-fuels for transportation. The chemical conversion is by gasification, pyrolysis, anaerobic digestion, and modular processes. The energy required for the conversion process depends on the method of conversion (Haq, 2001; State energy conservation office, 2011). Here the Anaerobic Digestion was used to generate the energy required to convert biomass to biogas (Uellendahl et al., 2008).

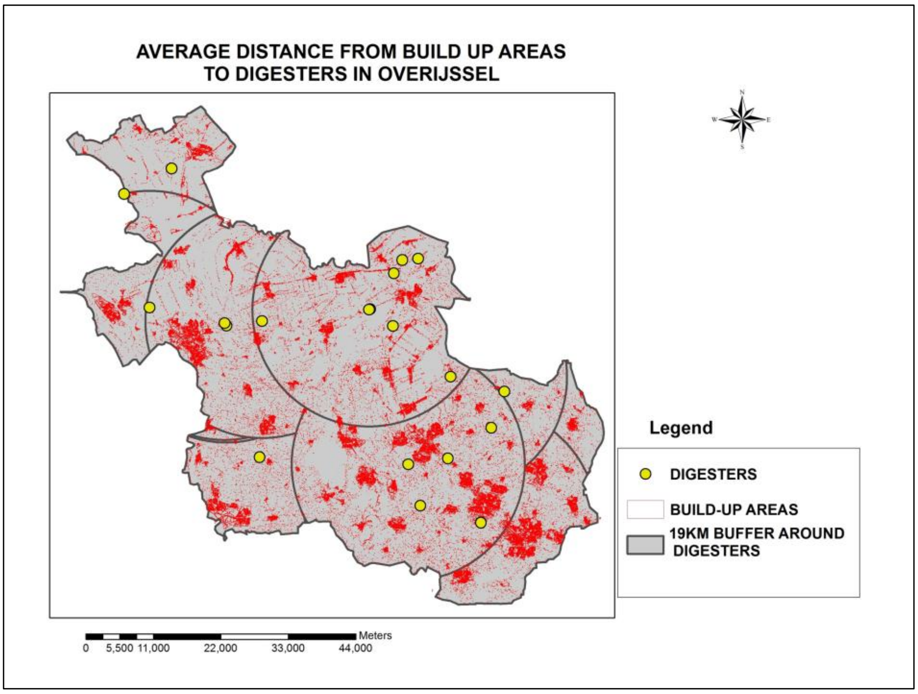


Figure 10: Distances of digesters to build-up areas

Output energy: The yearly estimated yields used was 2.6 and 5.4 tons/ha (Table 6). Based on the total output energy estimations by Smyth, et al., (2009). The output energy for 2.6 tons/ha yield was then estimated as 3.1MJ/m^2 and 5.4 tons/ha yield as 6.2MJ/m^2.

Digestate: An estimated 90 to 96 % of a ton of biomass contains digestate which comprises Nitrogen, Phosphorous and Potassium (NPK) used as fertilizers (Berglund & Borjesson, 2006; Murphy & Power, 2009; McEniry et al., 2011). The nutrient content of digestate is 2.1, 0.087 and 3.08 for N, P and k respectively (McEniry et al., 2011). This was converted to energy values and energy embodied in these nutrients are 48.4, 32 and 10 for N, P and k respectively (Kyle, 2011). This energy gain was added to the output energy.

Therefore **input energy** for green roofs = production of biomass (Installation (membrane)+ Fertilization+ Harvest+ Transportation of biomass + Transportation of other input) + conversion energy

Output energy = original output energy + digestate energy

To avoid duplication of science, the net-energy estimates of Smyth et al., (2009) were used for production within construction sites with the assumption that similar grasses (Timothy grass and Ryegrass) will be grown and all digestate produced from biomass will be utilized for fertilization in production. All necessary inputs energy were considered in their estimations; they included field preparations, sowing, harrowing, rolling, fertilization, herbicide and lime, forage harvesting, silage transport, ensiling, digestate processing and biomass conversion. The energy as calculated by Smyth et al., (2009) considering the use of digestate produced in the system gives a yearly input energy of 44.74 GJ/ha, the yearly grossed output energy was 122.4 GJ/ha, the yearly net-energy was 77.66 GJ/ha.

The net-energy estimates of Smyth et al., (2009) were also used for production under trees in recreational areas with an assumption that cocksfoot grass and white clover grass will be grown and all digestate produced from biomass will also be utilized for fertilization in the production (Smyth et al., 2009). However due to the presence of trees in the parks, this will obstruct a full production. Therefore it was assumed that the annual usable input energy was 38 GJ/ha (85 % of the total input energy). Similarly, the gross annual output energy of 77.66 GJ/ha was also assumed to be unobtainable. The output energy was also re-estimated to 104 GJ/ha yearly (85 % of the total output energy).

The output energy per ton of waste biomass as calculated by energy technology support unit Harwell laboratory, (1997) was 46 m^3. They also estimated the MJ per m^3 to range between 22-25 MJ. Therefore the output energy as calculated in this study was 46*23 (average MJ/m^3), which was 1,058 MJ/ton and converted to GJ/ton was 1.058. Although it was assumed that no energy was required to produce the waste, but energy was required to transport waste from collection points to digesters and also convert the waste to bioenergy. The energy requirement for transporting per ton of biomass was calculated (Smyth et al., 2009). This was multiplied by 9 which was the average distance from build-up areas to digesters (figure 10). Here the energy requirement for anaerobic digestion was also used to generate the estimated energy required to convert biomass to biogas (Uellendahl et al., 2008). However, different input and output energy estimates were reported by EUBIA, (2011) this was also used to generate a second potential energy gain from domestic organic waste.

The energy production potential of solar PV on roofs in the Netherlands as calculated by Alsema & Nieuwlaar, (2000) was 1700kwh/m^2 (6,120 MJ/ha). The author estimated that energy can be produced from solar PV on roofs with a 2 years payback time and a life span of 30 years. Based on that estimation, the EROEI was calculated for comparison with bioenergy production from green roofs.

4. RESULTS

4.1. Biomas potentials

Approximately, 104,054 hectares were covered by buildings in Overijssel. Hardenberg has 12.6% of the total buildings, followed by Enschede 8.4%, then Ommen with 5.7% and Hengelo with 5.6%. Only 1.4% of the total buildings are public/commercial large buildings. The remaining 98.6 % are covered by small individual residential buildings (annex 1). However, this was with the exception of some towns where there are higher percentages of large buildings, such as Zwolle 7%, Almelo 6% and Zwartewaterland 5% (Figure 11 and annex 1). As expected municipalities covered by large area of buildings gave a higher potential for biomass production from green roofs (annex 1 and 2). Biomass estimates considering the use of only large commercial/public buildings gave a rather low annual potential of 8,063 tons for 5.4 tons/ha yield and 3,882 tons for 2.6 tons/ha yield, compared to the estimates that included 30% of residential buildings which gave 174,212 tons for 5.4 tons/ha yield and 79,998 tons for 2.6 tons/ha yield for the entire province (annex 2).

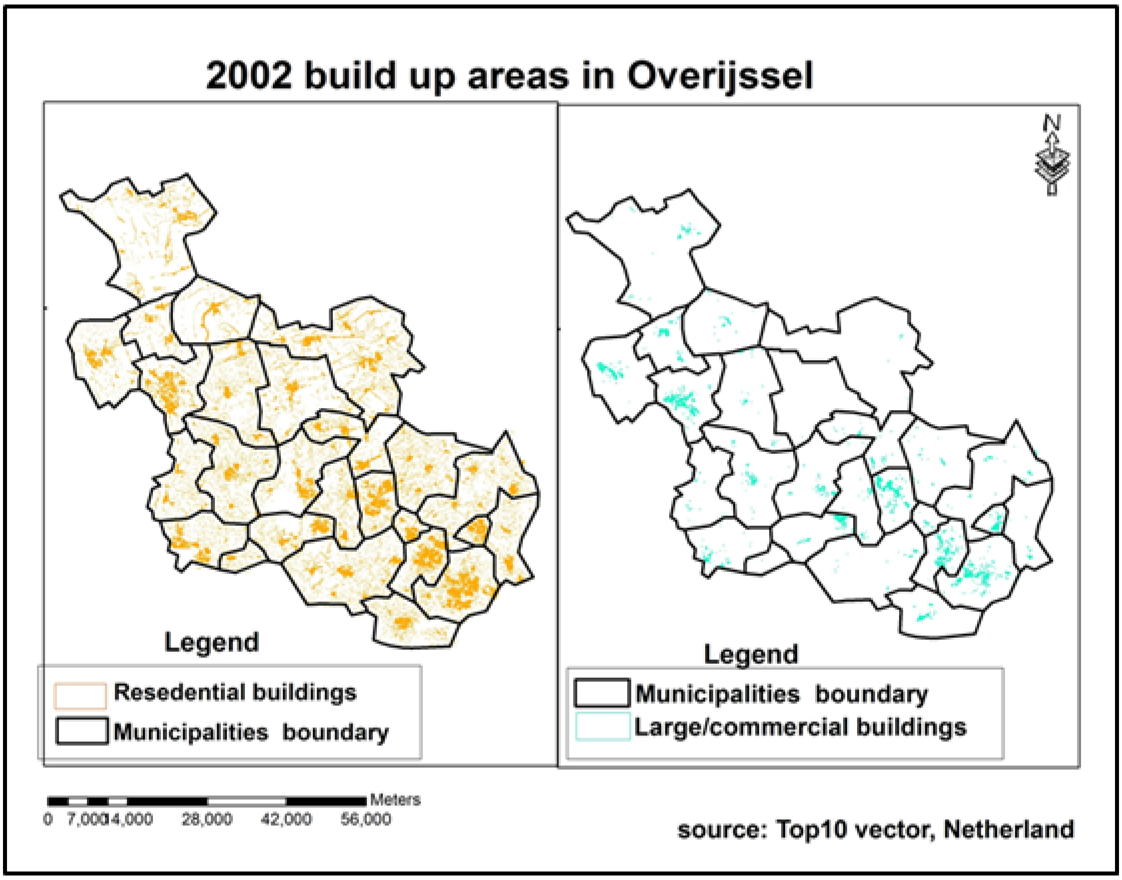


Figure 11: Potential sites for green roof biomass production in Overijssel

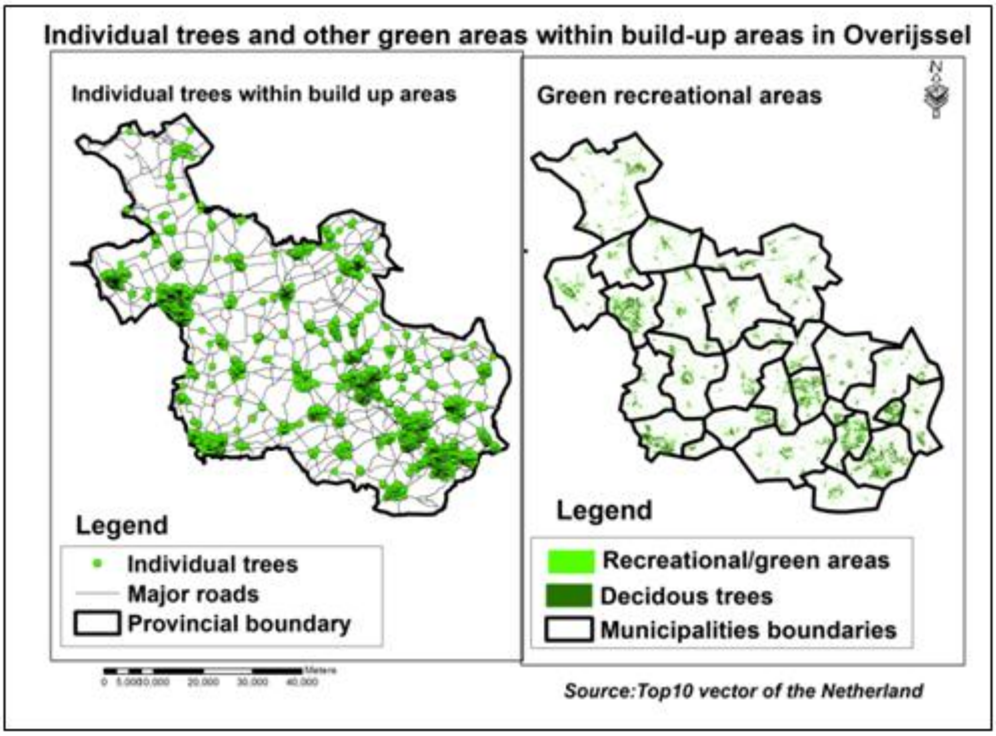


Figure 12: Green areas/recreational parks and individual trees within build-up areas Overijssel, a potential for production

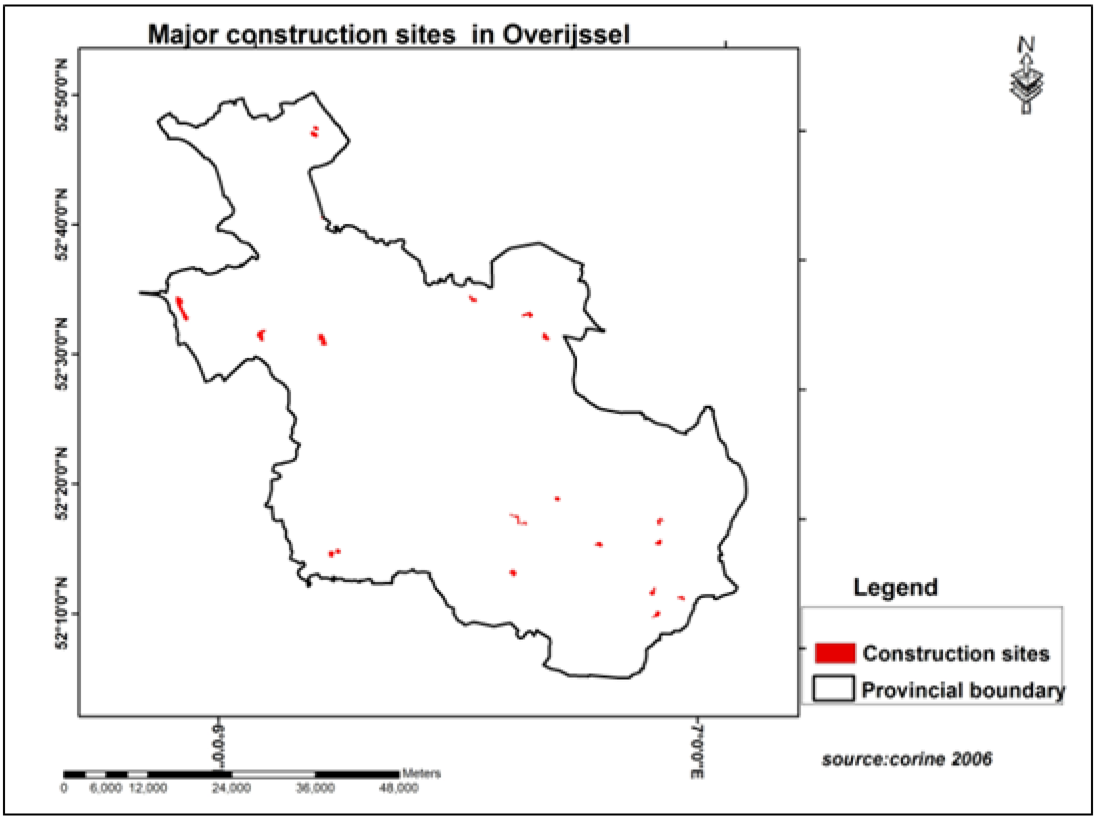


Figure 13: Plots allocated for construction in Overijssel, a potential for biomass production

An area of 955 hectares was calculated available from construction sites and the estimated biomass production was 11,456 tons yearly (Figure 13). The total area covered by recreational sites was 4,792 hectares, with Zwolle having the largest coverage of 12%, followed by Enschede with 9 % and Hengelo with 8%. An estimated 23,960 tons of biomass can be produced if perennials are grown under trees in recreational parks using 50 % of the total area (annex 3).

The 2004 domestic waste collected from wood, gardens and domestic organic waste in Overijssel was 1,584,086 tons of which 73.5% was collected from fruits, vegetables and food waste (annex 4). The average per capita waste collection was 133 kg. The maximum was 245 kg per capita and collected in Tubbergen and minimum was 39 kg per capita and collected in Kampen (Figure 14). The total waste collected in Overijssel was 158,409 tons base on the 2004 waste collections. However, due to per capita variations in the waste data, average and maximum per capita waste generated were extrapolated for the entire province. The yearly potential calculated using the 2004 average collected waste (133 per capita) was 157,912 tons which was almost the same with the original collection. The calculated potential with the maximum waste (245 kg per capita) extrapolation was a potential of 290,891 tons, this is about twice the amount of the original collection.

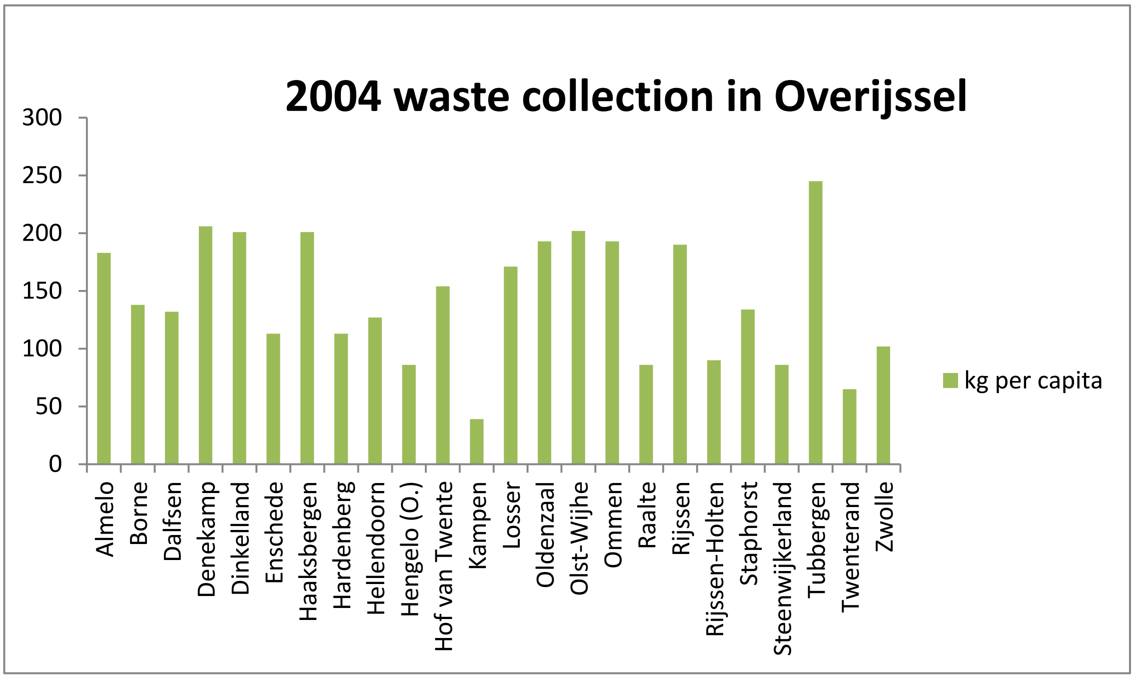


Figure 14: Per capita domestic collection waste across municipalities in Overijssel

Table 7: A summary of data used and total areas of the identified spaces in Overijssel

Source	Total areas (ha)	Data used	Resolution/Scale
Roofs of large/commercial buildings	1493.1	Top 10 vector (2002)	1:10000
Roofs of residential/small buildings	102561	Top 10 vector (2002	1:10000
Recreational areas	4792	Top 10 vector (2002)	1:10000
Construction areas	954.7	Corine (2006)	100m*100m

Putting together all the annual biomass production (from available and prospective sources), it resulted in a potential of 372,828 tons of biomass that can be produced from build-up areas in Overijssel. The "prospective" sources are those proposed in this research (green roofs, recreational and construction sites) and the "available" are those already harnessed for bioenergy production (i.e. organic waste) (Figure 15). Enschede had the most potential with 10% of the total biomass potential, Denekamp was next to Enschede with 8% and then Hardenberg 7.6%. Production from green roofs had the most potential, accounting for 47% of the overall potentials, followed by waste with 42% recreational sites with 7.7% and construction sites accounting for only 3. 1%.

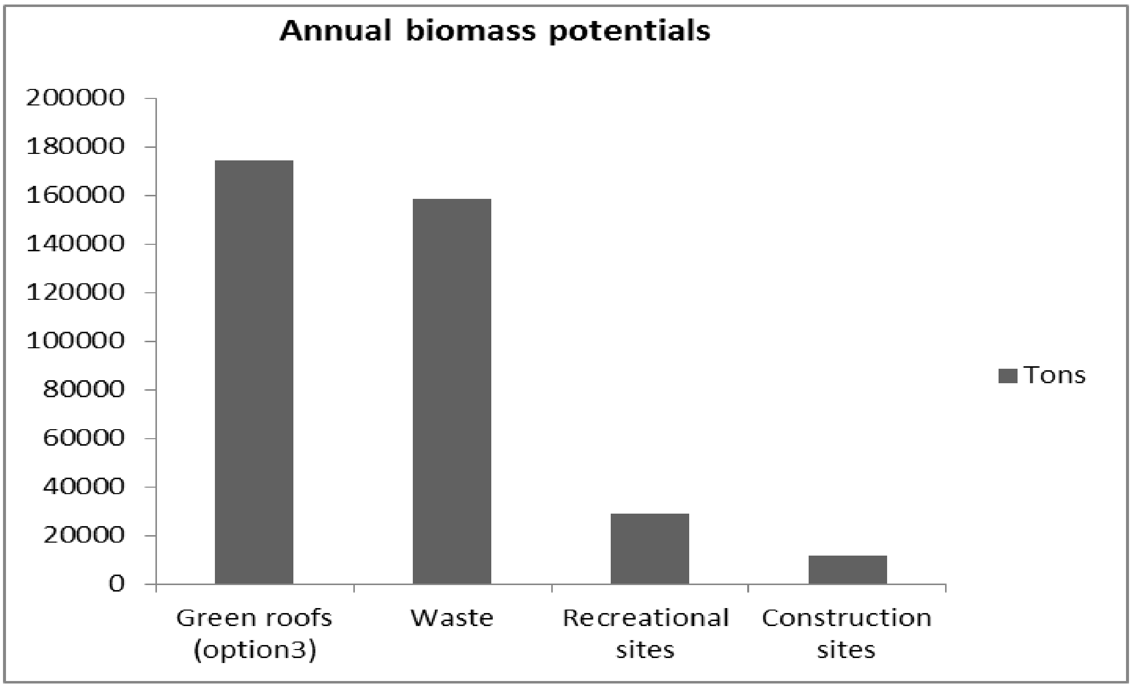


Figure 15: Estimated biomass from prospective and available sources within build-up areas

4.2. Estimated energy efficiency (LCA)

The input energy/m² for green roofs stretching from installation to biomass conversion was intensive (Table 8). The net-energy as calculated for 2.6 tons/ha annual yield was -0.4 MJ/m² and 5.4 tons/ha annual yield was 0.7 MJ/m². This was with an EROEI of 0.8 and 1.1 for 2.6 and 5.4 tons/ ha yields respectively if mainly produced for bioenergy. A negative net-energy indicates that the input energy is more than the output energy, this means no energy is gained with 2.6 tons/ha yield. Based on the calculated net-energy gain, 9,917 GJ/ year was the overall provincial potential if 5.4 tons/ha yield is achieved using only large building and 214,282 GJ/year using large buildings and 30% of the small residential buildings (annex 7).

Putting a higher emphasis on the environmental and social benefits of the green roofs and assuming biomass production as a by-product made the net-energy and EROEI quite impressive (Table 9). The net-energy rose to 3 MJ/m² for 2.6 tons/ha yield and 6.1 MJ/m² for 5.4 tons/ha yield. The EROEI came at a surprising value of 51 and 54 for 2.6 and 5.4 tons/ha yields respectively. Similarly, the overall provincial annual net-energy gain was 967,842 GJ/year with 2.6 tons/ha yield and 1,958,641 GJ/year with 5.4 tons/ha yield both using large buildings and 30 % of the small residential buildings (annex 7 and Table 14).

No calculations were performed to estimate the inputs energy and net-energy for biomass production within construction sites, since the work of Smyth, et al., (2009) was used. Only the EROEI value was calculated. Considering the author's calculated input and output energy, the net-energy gain was 77.6 and the EROEI value became 2.74. However, the estimated provincial net-energy gain as calculated was 74,138 GJ/year (Table 14).

The same input estimations with the construction sites were used for the production within recreational parks. However, the gross annual input energy of 44.7 GJ/ha was re-calculated to 38 GJ/ha and the output energy was also re-estimated to 104 GJ/ha yearly. As a result, the net-energy gain became 66 GJ/ha but the EROEI remained the same (2.74) with the production from construction sites (Table 10). Consequently, the estimated provincial net-energy gain from this source was 134,416 GJ/year (Table 14).

Table 8: Energy balance of producing bioenergy from green roofs

Items	Energy per operation (5.4 tons/ha yield)	Energy per operation (2.6 tons/ha yield)	References
Membrane [a]	5.3 MJ/m² (30years)		(Reddy & Jagadish, 2003)
Seeds [b]	0.0003 MJ/m² (10years)		(Smyth et al., 2009)
Fertilization	0.24 MJ/m²		(Kyle, 2011).
Harvest	0.01 (MJ/m²)		(George & Mark, 2001)
Transportation of other inputs	0.000013 (MJ/m²)		(Correia, et al., 2010)
Transportation of biomass [c]	0.0002 (MJ/ m²)		(Smyth et al., 2009)
Conversion [d]	0.1 (MJ/ m²)	0.05	(Uellendahl et al., 2008)
Digestate [e]	0.03 (MJ/ m²)	0.02(MJ/ m²)	(McEniry, et al., 2011)
Output energy	6.2 (MJ/ m²)	3.1(MJ/ m²)	(Smyth et al., 2009)
Net-energy	0.7 (MJ/ m²)	- 0.4 (MJ/ m²)	(Ibrahim, 2012)
EROEI	1.1	0.8	(Ibrahim, 2012)

a. *The energy required to install a normal roof (Reddy & Jagadish, 2003) was used to estimate the energy entailed in installing a square meter of roof membrane (Peck & Kuhn, 2003). Nevertheless green roofs are designed to last for 30 years (Green roofs.com, 2011). The energy for installation of membrane was then divided by 30 to calculate the yearly membrane energy requirement.*

b. *Reseeding grass species will be grown with a regenerating period of 10 years (McEniry et al., 2011). Therefore the energy required for seeds and planting was divided by 10 to calculate the yearly seeding and planting energy requirement.*

c. *The energy requirement for transporting biomass per km is 0.0016, multiplied by the average distance (Figure 10) to a digester in Overijssel (Smyth et al., 2009).*

d. *To convert a ton of biomass, 192 MJ is required (Uellendahl et al., 2008) and biomass yield of 2.6 and 5.4 were used (Tewari et al., 2008).Therefore, the total area in m² to produce one ton of biomass was divided by 192 to get the required energy for converting MJ/m² (Uellendahl et al., 2008).*

e. *90 to 96% of a ton of grass biomass is digestate; it contains NPK which was converted to energy value. The digestate nutrient content is 2.1, 0.087 and 3.08 for N,P and k respectively (McEniry et al., 2011) and the energy embodied in these nutrients is 48.4, 32 and 10 for N, P and k respectively (Kyle, 2011). This energy was summed and multiplied by 0.9 (90) to calculate the energy value of digestate/ton which was added to the output energy (McEniry et al., 2011).*

f. *The total output yield used was 6.2 MJ/m² based on 5.4tons/ha and 3.1 MJ/m² based on 2.6 tons/ha yield (Smyth et al., 2009), but the energy gained from digestate was also added.*

Table 9: Energy balance of bioenergy production as by-product on green roofs

Items	**Energy per operation** (5.4 tons/ha yield)	**Energy per operation** (2.6 tons/ha yield)	**References**
Harvest	0.0098 (MJ/ m²)		(George & Mark, 2001)
Transportation of biomass	0.0002237 (MJ/m²)		(Smyth et al., 2009)
Conversion	0.10368 (MJ/ m²)	0.04992	(Uellendahl et al., 2008)
Total input energy [a]	0.12		(Ibrahim, 2012)
Output energy	6.2 (MJ/ m²)	3.1 (MJ/ m²)	(Smyth et al., 2009)
Net-energy	6.1 (MJ/ m²)	3 (MJ/ m²)	(Ibrahim, 2012)
EROEI	53.5	51	(Ibrahim, 2012)

a. *The energy required from green roof's installation to the energy required for biomass fertilization was excluded from the calculation. Only the energy for biomass harvest, biomass transportation and conversion was calculated as input energy.*

Table 10: Energy balance of producing bioenergy from recreational parks

Items	**Energy per operation/year**	**References**
Total input energy with the use digestate [a]	44.7 GJ/ha	(Smyth et al., 2009)
85% of the total input energy [b]	38 GJ/ha	(Ibrahim, 2012)
Total output energy	122.4 GJ/ha	(Smyth et al., 2009)
85% of the total output energy [b]	104 GJ/ha	(Ibrahim, 2012)
Net energy	66 GJ/ha	(Ibrahim, 2012)
EIOER	2.74	(Ibrahim, 2012)

a. Refer to description "e" in Table 8

b. Due to the presence of trees in the park, it will obstruct a full production. It is assumed that only 85% of the total input and output energy is practicable.

The energy produced from domestic waste was calculated in GJ/ton, which was contrary to the other three, with quantities produced by area. The first calculated yearly net-energy from waste was 0.9 GJ/ton. Here no energy was required to produce the biomass and this resulted in a higher EROEI value of 5.5 (Table 11). The total net-energy from waste in Overijssel with that net-energy gain was 142,568 GJ based on the 2004 waste collections (Table 14). However, the yearly potential energy calculated for the average collection waste was 142,121 GJ and 261,802 GJ with the maximum waste extrapolation.

The second calculated option for waste was an estimated net-energy gain of 13.1 GJ/ton and an EROEI of 15 (Table 12). This resulted to a higher total net-energy potential of 2,075,151 GJ/year from waste in Overijssel based on the 2004 waste collections (Table 14). Similarly, the yearly potential energy calculated for the average extrapolated collection was 2,068,653 GJ and 3,810,677 GJ with the maximum waste extrapolation.

Table 11: Energy balance of producing bioenergy from organic domestic waste (minimum potential)

Items	Energy per operation (Total GJ/Ton)	Average (GJ/Ton)	References
Total output energy [a]	1.058 (GJ/T)		(Harwell laboratory, 1997)
Transportation energy [b]	0.000185 (GJ/T/KM)	0.00168 (9km)	(Smyth et al., 2009)
Conversion energy	0.192 (GJ/T)		(Uellendahl et al., 2008)
Input energy	0.194 (GJ/T)		(Ibrahim, 2012)
Net energy	0.86 (GJ/T)		(Ibrahim, 2012)
EROEI	5.5		(Ibrahim, 2012)

*a. The output energy/ton was 46 m³ and MJ/m³ is 21-25. Therefore the output was 46*23(average MJ/m³), which is 1058 MJ/T and converted to GJ/ton is 1.058 (Energy technology support unit Harwell laboratory, 1997).*

b. The energy requirement per ton was 0.187 (Smyth et al., 2009) for transporting biomass. This was multiplied by 9 which was the average distance from build-up areas to digesters (Figure 10).

Table 12: Energy balance of producing bioenergy from organic domestic waste (maximum potential)

Items	Energy per operation (Total GJ/Ton)	Average (GJ/Ton)	References
Energy for handling raw materials	0.6 (GJ/T)		(EUBIA, 2011)
Transportation energy [a]	0.015 (GJ/T/KM)	0.14 (9km)	(Smyth et al., 2009)
Conversion energy	0.2 (GJ/T)		(Uellendahl et al., 2008)
Input energy	0.9 (GJ/T)		(Ibrahim, 2012)
Total output energy	14 (GJ/T)		(EUBIA, 2011)
Net energy	13.1 (GJ/T)		(Ibrahim, 2012)
EROEI	15		(Ibrahim, 2012)

a. The energy required for transporting a ton of waste from residential areas to digesters is 15 MJ/ton (EUBIA, 2011). This was multiplied by 9 which is average distance from build-up areas to digesters (Figure 10).

Different authors reported different inputs and outputs energy in the LCA of bioenergy. For further analysis and providing a range in production, different inputs, outputs, yields were also assessed (Table 13). This was to model different (maximum and minimum) prospective of energy potentials, since real life situations are not static.

Combining all the potential net-energy from the prospective and available sources, the annual potential amounted to 565,403 GJ, 2,250,710 GJ and 3,370,613 GJ for minimum, average and maximum prospect respectively (Table 14). These were based on the net-energy gain calculated in Table 13. For the average potential Enschede had 10% of the total followed by Denekamp 8.1% and then Hardenberg 7.3%. The provincial average was 94,442 GJ/year, with most municipalities having a yearly potential ranging from 40,000 – 80,000 GJ/year (annex 9). However, waste had 45% of the overall potential then green roofs 44%, followed by recreational areas with 6% and production from construction sites accounting for only 5%. The map in Figure 16 illustrates areas with more bioenergy potentials within build-up and combined with other information it shows where more digesters can be installed /clustered and verse versa.

The total provincial energy demand in 2005 was 125 PJ (125,000,000 GJ) (Hoppe et al., 2011). The target in Overijssel is that 20% of the overall energy demand in addition to 10% for the transport sector is to be supplied from renewable sources by 2020. Therefore, the estimated targets that can be met from the potential build-up sources were calculated in Table 15. This was computed by using the combinations of minimal, average and optimal prospect described in Table 14.

Table 13: Different variations in input energy, output energy, net-energy and EROEI

(a). **GREEN ROOFS (Mainly for bioenergy)**				(b). **Green roofs (as By-product)**				(c). **Construction sites**				(d). **Recreational areas**				(e). **Waste**			
Minimum (2.6 tons/ha)		**Maximum (5.4 tons/ha)**		**Minimum (2.6 tons/ha)**		**Maximum (5.4 tons/ha)**		**Minimum**		**Maximum**		**Minimum**		**maximum**		**Minimum**		**maximum**	
Input	output	Input	output	Input	output	Input	output	Input	output	Input	output	Input	output	Input	output	Input	output	Input	output
26 GJ/ha	*31 GJ/ha*	*55.2 GJ/ha*	*61.8 GJ/ha*	*0.5 GJ/ha*	*31 GJ/ha*	*1.2 GJ/ha*	*61.8 GJ/ha*	*44.7 GJ/ha*	*122.4 GJ/ha*	*44.7 GJ/ha*	*225 GJ/ha*	*38 GJ/ha*	*104 GJ/ha*	*38 GJ/ha*	*118 GJ/ha*	*0.2 GJ/T*	*1.1 GJ/T*	*0.9 GJ/T*	*14 GJ/T*
Minimum		**Maximum**		**Minimum**		**maximum**		**Minimum**		**Maximum**		**Minimum**		**maximum**		**Minimum**		**maximum**	
Net-energy	*-4 GJ/ha*	Net-energy	*7 GJ/ha*	Net-energy	*30 GJ/ha*	Net-energy	*60.7 GJ/ha*	Net-energy	77.7 *GJ/ha*	Net-energy	180 *GJ/ha*	Net-energy	66 *GJ/ha*	Net-energy	80 *GJ/ha*	Net-energy	0.9	Net-energy	13.1
EROEI	*0.8*	EROEI	*1.1*	EROEI	*51*	EROEI	*54*	EROEI	*2.7*	EROEI	*5*	EROEI	*2.7*	EROEI	*3.1*	EROEI	*5.5*	EROEI	*15*

(a). If production is mainly for bioenergy, the yearly estimated input energy from green installation to biomass conversion was 26 GJ/ha yield for 2.6 tons/ha yield and 55.2 GJ/ha for 5.4 tons/ha yields (Tewari et al., 2008; Ibrahim, 2012) .The yearly estimated output energy for 2.6 tons/ha yield was (31 GJ/ha) and for 5.4 tons/ha yield was 62.8 GJ/ha (Smyth et al., 2009). This values were used to compute the net-energy gain and EROEI for both minimum (2.6 tons/ha) and maximum (5.4 tons/ha) specie yields.

(b). The input energy for production as by-product for green roofs was from harvest to conversion, which was 0.5 GJ/ha for 2.6 tons/ha yield and 1.2 GJ/ha for 5.4 tons/ha yield (Ibrahim, 2012). Using the same specie yields and output energy described in "a", the minimum and maximum net-energy gain and EROEI was computed.

(c). The annual input for perennials with the use of digestate as calculated by Smyth et al., (2009) was 44.7 GJ/ha, while the output was 122.4. However, McKendry, (2002) gave higher output energy estimates of between 225-555 GJ/ ha for perennials (miscanthus). Both output energy gains were used to estimate the minimum and maximum net-energy gain and EROEI of production within construction sites.

(d). The input energy as estimated for recreational parks in table 10 was 38 GJ/ha (Ibrahim, 2012). The annual output energy gain described in table 10 (104 GJ/ha) was used to compute the minimum net-energy gain and EROEI of production in recreational parks. However, , McKendry, (2002) gave an output energy estimates of 139 GJ/ ha for perennials (switch grass), this value was used to compute maximum net-energy gain and EROEI of production within recreational areas.

(e). The minimum input as calculated in this research was 0.2 GJ (Ibrahim, 2011). While the output energy GJ/ton as regards to Energy technology support unit Harwell laboratory,(Energy technology support unit Harwell laboratory, 1997) estimations was 1.1 GJ (table 11). The maximum inputs estimates was 0.9 GJ and the maximum output was 14 GJ/T (EUBIA, 2011). These values were used to compute both minimum and maximum net-energy gain and EROEI of bioenergy production from domestic organic waste (refer to Table 12).

Table 14: A combination of various prospective annual net-energy in Overijssel

Sources	Minimum potential [a] (GJ/year)	Average [b] (GJ/year)	Maximum [c] (GJ/year)
Green roofs (mainly for bioenergy)	-	-	214,282
Green roofs (by-product)	960,697	1,459,669	1,958,641
Green roofs [d]	**214,282**	**587,489**	**960,697**
Organic waste	142,568	1,108,859	2,075,151
Recreational areas	134,416	148,671	162,928
Construction sites	74,138	122988	171,837
Total net-energy gain [e]	**565,403**	**1,968,008**	**3,370,613**

a. The minimum potential is the combination of the minimum energy gains described in Table 13.
b. The average option is a combination of 50 % both minimum and maximum options described in Table 13.
c. This is the combination of the maximum annual net-energy gain described in Table 13
d. Maximum "mainly for bioenergy" and minimum by-product production from green roofs were used (hence it is a by-product, production might not yield up 5.4 tons/ha)
e. The summation of all and "green roof [d]"

Table 15: Bioenergy production within build-up areas VS renewable energy demands in Overijssel

	GJ in 2005	Total net-gain	Percentage [b]	Percentage [c]
Overall energy demands	125,000,000	-	-	-
Renewable energy demand [a]	25,000,000	-	-	-
Minimum potential	-	565,403	0.5	2.3
Average potential	-	1,968,008	1.6	7.8
Maximum potential	-	3,370,613	2.7	13.5

a. The target is to supply 20% of the overall energy demands from renewable sources by the year 2020
b. The percentage of the potential energy gain to the overall energy demand
c. The percentage the potential energy gain can contribute to the renewable energy demand

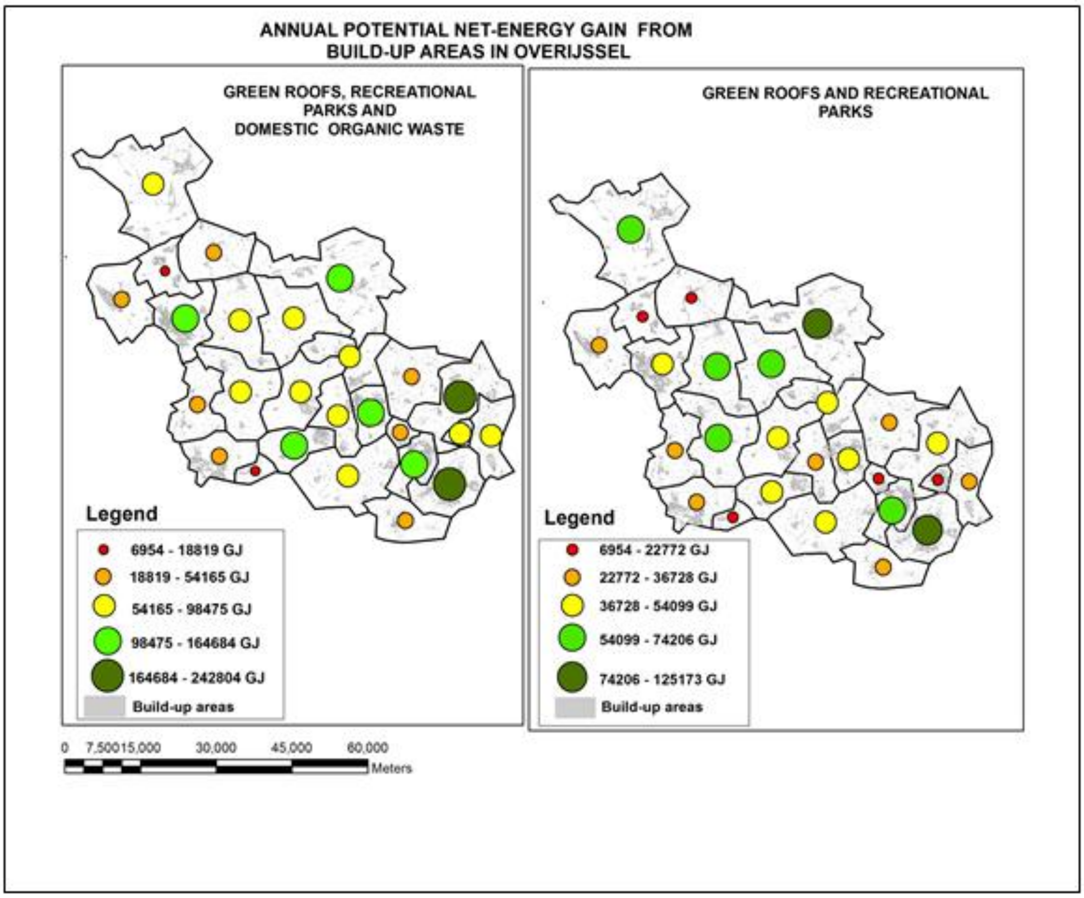


Figure 16: Potential net-energy from build-up areas based on estimated biomass yield and waste generated

4.3. Energy efficiency of green roofs bio-energy production and solar photovoltaic solar energy

The calculated output energy for solar PV was 6,120 MJ/year based on the annual energy estimated by Alsema & Nieuwlaar, (2000). The EROEI calculated was 15 for solar PV energy production on roofs in the Netherland (Table 16 and 17) Espinosa et al., (2011) gave a wide range base on the active area of the solar PV, the author's range was between 4 - 47 EROEI (Table 17).

Table 16: An estimation of the energy production from solar photovoltaic modules

Items	Energy	Reference
Energy/m^2 [a]	6120 MJ/m^2	(Alsema & Nieuwlaar, 2000)
Input energy [b]	408 MJ/m^2	(Alsema & Nieuwlaar, 2000)
Net-energy [c]	5,712 MJ/m^2	(Ibrahim, 2012)
EROEI	15	(Ibrahim, 2012)

a. *Assumed annual potential was 1700 kwh/m^2 (Alsema & Nieuwlaar, 2000) converted to MJ was 6,120/year*

b. *The payback time of solar PV on roofs is 2 years (Alsema & Nieuwlaar, 2000). Therefore the input energy is energy produced per year* 2*

c. *The life span is 30 years (Alsema & Nieuwlaar, 2000) ,then the output is annual energy produced per year* 30 and input is energy produced* 2*

Table 17: A comparison of energy efficiency of solar PV and green roof bioenergy

Type	Life span	Energy efficiency (EROEI)	Reference
Solar PV (67% active area)	15 years	4- 37	(Espinosa, et al., 2011)
Solar PV (85% active area)	15 years	5- 47	(Espinosa, et al., 2011)
Solar PV (The Netherlands)	30	15	(Alsema & Nieuwlaar, 2000)
Green roof (mainly for bio-energy)	30 years	1.1 (5.4tons/ha)	(Ibrahim, 2012)
Green roof (used as by-product)	-	54 (5.4tons/ha)	(Ibrahim, 2012)
Green roof (mainly for bio-energy)	30 years	0.8 (2.6tons/ha)	(Ibrahim, 2012)
Green roof (used as by-product)	-	51 (2.6tons/ha)	(Ibrahim, 2012)

5. DISCUSSION

5.1. Potentials, EROEI and benefits of bioenergy production from within build-up areas

Up to 98.6% of the building structures in Overijssel were small single residential buildings and only 1.4% were large buildings. However despite the spaces available from the residential buildings, visual analysis shows that most of these buildings have steep roofs (Figure 9). Green roofs require roofs with slopes below 30^{o} due to potential roof erosion (Mentens et al., 2003; Clark et al., 2008). Although in most cases, the residential buildings have annex buildings with flat roofs, usually garages, stores etc. but mainly occupying a small area. Though large buildings have flat roofs that are more suitable for green roofs, they occupy only 1.4% of the total build-up area in Overijssel.

The energy required to produce biomass on roofs depends on the type of green roof. Extensive green roofs are 15 cm or shallower, while the intensive roofs are deeper and can support the growth of lawns, large perennial plants, and trees (National institute of building science, 2010). The extensive roofs are cheaper and easier to maintain, they are lighter than the intensive roofs with a soil depth of 2.5 - 15 cm and weight load of 7-23 kg/m^2. Intensive roofs have a soil depth of 15-61 cm (or more) and can support a weight load of 36-68 kg/m^2 (Great lakes water institute, 2011). This means that the type of roof affects; the type of vegetation it can support, the required inputs, the expected yield, energy gain and the EROEI. In Europe, the cost of a professionally installed green roof is between 100 to 200 euros/m^2 depending on the type of roof, building structure, the type of plants used etc. Even so residential green roof installations are more expensive per square meter than large commercial/public roofs, because the cost of the installation cannot be spread over a larger area due to size and slope of roofs (Green-Buildings.com, 2008; Wikimedia foundation Inc, 2011). The method of harvesting biomass from the roof top has not yet been established, the author assumed it can be done by mowing for flat roofs or by the use of high construction lifts in the case of steep roofs. However, this might be difficult for small residential roofs usually with steeper roof slopes.

The findings of this research indicate that, the largest untapped potential of bioenergy production within build-up areas in Overijssel are roof tops. In terms of the area available, green roofs had the highest potential but they also have the worst EROEI of 0.8-1.1 if produced mainly for bioenergy. Although this low EROEI is mainly attributed to the major disadvantage of biomass productions on roofs, which is its initial energy/cost of installation. Nevertheless, the energy requirement of membranes was the highest input energy (Table 8). It is important to note that the actual energy embedded in membranes was not available during the research and the least energy requirement of installing a normal roof was used, based on a LCA findings that claims they cost the same (Peck & Kuhn, 2003; Reddy & Jagadish, 2003). The concrete energy embodied in membranes could be more or less than the estimates given in this study and this in-return can affect the net-energy and the EROEI. It is imperative to note that old roofs may incur extra cost of repairs before the installation of membranes, vegetation, etc. However, green roofs are a long time investment and some membranes (thermoplastic polyolefin (TPO), Vinyl, etc.) are designed to save energy thereby reducing the initial input energy, but this aspect could not be included in this research. Although green roofs are usually designed to last for 30 years but have been reported to last for sixty years without major repairs (Green roofs.com, 2011). Of most importance to note is that the environmental and socio-economic benefits in the long term may outweigh the cost of initial installation. Below are some direct and indirect socio-economic and environmental benefits of green roofs to the building owner and the community at large:

- Potential of greenhouse gas emissions trading credits (carbon trading)
- Minimizing the impacts of fire disasters due to the presence of membranes and vegetation on roofs.
- Cooling and heating needs of building during summer and winter respectively are reduced, thereby saving energy cost (an estimated of 25.9 MJ (£4,300) is saved per year in London using current electricity rates)
- Aesthetic value of green roofs makes roofs become landscapes themselves
- Increasing the property value of a building
- Increasing storm water retention, reducing the impact of rain water flows and eventual urban flooding.
- Lessening the need to expand or rebuild separate storm sewer system in a building.
- The reduction of pollutant loads by plants on the rooftops.
- Noise reduction in high noise areas like near airports or in major urban centres
- Green roofs improve air quality and human health and thereby reduce medication cost.
- Serve as habitat to animal species like birds, bees, reptile, insects etc.
- Potential of recycling some roofing membranes.

(Peck & Kuhn, 2003; ARDEX TPO Membranes, 2009; Safeguard Europe Limited, 2010; GreenBuildingssolutions.org, 2010-2011)

The calculated net-energy of the green roofs for 2.6 tons/ha annual yield was a negative, it implies that the threshold for producing bioenergy from green roofs should be a yield above 3 tons/ha annually. While the net-energy of 5.4 tons/ha was 7 GJ/ha (Table 8). It is important to note that the benefits listed above are the current reasons why people install green roofs. The plants presently used are mostly nice looking species and used only as gardens and not harnessed for bioenergy. Considering the environmental benefits of producing biomass from green roofs, it can complement energy efficiency issues and biomass production can be a bonus. The challenge remains if to assess production mainly for bioenergy and include the energy/cost of green roofs installation, fertilization, etc. or put a higher emphasis on the socio-economic and environmental benefits of the green roofs and assume biomass production as a by-product? It was for this reason that the net-energy and EROEI were estimated for both situations. When calculated as by-product the EROEI was impressive (Table 9), but there is need to produce bioenergy species if they are to be explored for bioenergy.

The installation of solar photovoltaic panels on roofs is the existing global practice and it is fast becoming more popular in Europe. Though minimal in the Netherlands due to its cost but it is highly considered in future energy production (Municipality of Enschede, 2010). The solar photovoltaic modules are a more energy efficient source of energy with efficiency ranging from 4-47 (Alsema & Nieuwlaar, 2000; Espinosa et al., 2011). However it is important to note that there are monthly variations of output energy due to monthly weather inconsistencies (Celik, 2002). This makes production less efficient in temperate regions where the sun is visible for only few months yearly. Though the case is different in tropical regions, where the sun is available almost throughout the year (Fadare, 2009). The advantage of the renewable energies is the collection from a range of sources depending on locations and seasons. Energy can be produced from various sources throughout the year and this can complement their inadequacies. For example, in windy days/season energy can be produced from wind energy, in sunny days/season, it can be tapped from the sun and collection can be done from biomass in summer etc. Therefore, the mix of options is highly recommendable to ensure optimized security in energy supply. The energy efficiency of producing energy from solar PV is expected to keep rising , hence it has repeatedly been reported by scientist that, the energy embedded in the input materials of solar modules has constantly been declining through the years and is expected to continue to decline (Celik, 2002; Branker et al., 2011). The output energy gain per meter of the solar PV was 5,712 MJ/year (Alsema & Nieuwlaar, 2000), while the gain from the green roofs was -0.4 and 0.7 MJ/year. In comparison to the net-energy gain and EROEI of solar PV (4-47) and energy production from green roofs (0.8-1.1), it will be far more reasonable to concentrate on the production of solar energy from roofs and not consider bioenergy production from green roofs. Although the most important aspect is how bioenergy production from green is perceived, either mainly for bioenergy or as a by-product. This is where there is a substantial gap in net-energy gain and EROEI. With regards to the socio-economic and environmental benefits of the green roofs listed above, it is highly recommendable to exclude the energy/cost of green roof installation and calculate production as a by-product. The net-energy gain and energy efficiency was better, with net energy gain as 30 MJ/m^2-60 MJ/m^2. Even though the net energy gain from the solar PV was still higher, the EROEI values of the green roofs was an astonishing 51-54, while solar PV produces with an EROEI of 15. This value was even more than the highest production EROEI from solar PV panels calculated by Espinosa, et al., (2011).

The potential annual net-energy gain for construction sites bioenergy production was 78 GJ/ha and 180 GJ/ha, while the EROEI was 2.7 and 5 respectively. However, if production is harnessed for only 5 years from construction sites, the remaining specie yield will go waste since these perennials produce biomass for 12 years and above (Murphy & Power, 2009; Smyth et al., 2009). Therefore, it is important for municipalities and provincial planners to establish the duration of the vacancy of sites, before they are harnessed for biomass production.

The EROEI of bioenergy production from recreational sites was 2.7 and 3 with an annual net-potential energy gain of 66 GJ/ha and 80 GJ/ha respectively. However, these areas are public relaxation spots and aesthetic values matters to citizens. Therefore, exotic species should be produced in theses parks, in order to produce energy as well as enhance the looks of these areas. Although Walter, (1990) has evaluated the impacts of social principles on endangered species and the author discussed the need to save endangered species in recreational areas despite aesthetic values. Likewise, grasses in most recreational parks are usually slow growing species in order to minimize the rates of mowing. Fast growing species should be considered in some of these areas and mowed regular in order to optimize its collection for bioenergy. Finally, the presence of trees in the parks has tree shadow effects on lower vegetation (Davis et al., 1999). Therefore, it is essential to determine areas with less shadow cast effects. The challenge remains for scientists to seek innovative means to plan production in such a way that; energy is produced, social values are respected, tree shadow effects are minimal and endangered species are conserved.

Dyson & Ni-Bin, (2005) modelled waste generation and concluded that tons/year solid waste generation was a factor of total income per service area, number of people per household, historical amount generated, income per household and population. The last three factors better explain the variation in tons by municipalities' waste collection in Overijssel, but do not explain the per capita waste collection. There are wide variations between per capita waste collection values among municipalities in Overijssel, despite the similarities in total income per service area, number of people per household, historical amount generated and income per household (Central Bureau of Statistics, 2011). The variations are puzzling since wastes are collected by similar companies across the province (Twentemilieu, 2011). Similarly, Brian & Ni-Bin, (2005) estimated per capita waste generation as 1.2 kg/day in developed countries but up-to 1.7–1.9 kg/day in the US. This is about 438 kg/year in developed countries, but of course this includes other types of waste not harnessed for bio-energy. This can explain the high waste collection of 245 kg per capita in Tubbergen but not the 39 kg per capita collected in Kampen. Likewise, the Australian government estimated annual organic food waste collection in Australia as 2,080 kg per capita (Australian government, 2010). The gap between collection in the Netherlands and Australia is large despite the fact that both are developed countries. Even though, author suspects that the reason accounting for low per capita collection in some rural municipalities in Overijssel could be as result of fact that, rural residents decompose some of the waste locally. However, this does not clearly explain the low collection in some urbanized municipalities like Enschede, Zwolle, Hengelo, etc. The breach could be as a result of the method of waste generation/collection data and in the Australian government report, they have pointed out the importance of waste data quality towards informed and timely decision making.

It was expected that the municipalities with high populations will have more potential. Conversely, due to the variations in per capita waste collection between municipalities, municipalities with high population and low per capita waste collections, had lower potentials compared to municipalities with lower population and high per-capita waste collection (annex 5). For example, Enschede had the highest population in Overijssel with 156,071 inhabitants but had a per capita waste collection of 113 kg. On the other hand, Denekamp with a lesser population of 97,892 people and 201 kg per capita waste collection, has more waste potential of 21,689 tons compared to Enschede with 19,440 tons in 2004 (annex 5 and 7). This evaluation makes the determinant of waste potential both population factor and per capita waste generation/collection. Apparently, waste potential is mainly as a factor of collection since income, sizes of households and other factors seem fairly same in most municipalities across the province (Central Bureau of Statistics, 2011). Waste collections in Overijssel like other parts of The Netherlands are paid for by the citizens, this could account for the low wastes collection in parts of the province. Domestic organic and green waste across most municipalities are collected only once in two weeks and paid for per kilogram, but payment varies across the province and depends on local policies and taxes (Twentemilieu, 2011). The Chartered institution of waste management, (Chartered institution of wastes management, 2003) have already evaluated some of the impacts of charging residents for waste collection in the United Kingdom (UK), they reported that most respondents agree with waste reduction when charged for waste collection . This seems to concur with some variations of waste collection in Overijssel. For example, Denekamp charges per year € 166,00 for "single person household" and € 226.00 for "More Person Household" for waste collection, while Enschede charges € 272.04 for "single person household " and € 306.00 for "More Person Household". However, Dijkgraaf & Gradus (2008) explained the variations of waste collections and prices across Holland, which they found dependent on competition amongst private and public owned companies which can reduce the prices of wastes collection. This also can affect the quantity of waste collected in Overijssel and explain some of the variations in waste collection. The estimated net-energy produced from wastes was between 0.9 GJ/ton and 13.1 GJ/tons for minimum and maximum prospect. The calculated EROEI of bioenergy production from waste was 5.5 for the minimal and 15 for the maximum prospective. The high EROEI was as a result of lower input energy demand in the production.

Generally, the calculated EROEI for bioenergy production within build-up areas is between 0.8-15. The calculated EROEI were comparable to the EROEI computed for some bioenergy crops. For example, bioenergy production from green roofs was comparable to ethanol production from wheat (Murphy & Power, 2008), while production from recreational parks and construction sites was comparable to the production of biomethane from palm oil, with both having similar net-energy, gross output energy and EROEI (Smyth et al., 2009). The net-energy potential is mainly a result of area available for production and the species yield in the case of green roofs, recreational parks and construction sites and for the organic domestic waste, a factor of per capita waste collection and population. The energy efficiency of bioenergy are generally low, this is attributed to the intensive input energy demands in the system (McKendry, 2002; Smyth et al., 2009). Different input and output energy combinations were collected from literature and used to generate different net-energy gain and EROEI. It shows varying results due to the model's sensitivity to input and output energy (Table 13). This shows that the estimated potential is not static and varying literature and production practices may result to different potentials. This observation is similar to discussions made by Thamsiriroj & Murphy, (2009) about the important parameters that determine energy efficiency being; the biomass/bioenergy yield of species, the energy required producing and converting the biomass as well as the area available. For further analysis, the same biomass yield/ output energy was experimented for different locations. With a yield of 12 tons/ha, production from recreational parks and construction sites has a net-energy gain of 78 GJ/ha and 66 GJ/ha respectively with both having an EROEI value of 2.7. However, green roofs can yield only 49 GJ/ha with an EROEI of only 1.5 if produce mainly for bioenergy. This observation concurs with some of the conclusions that, the site of production is also an important factor in input and output energy and in-return energy efficiency, since some locations require more inputs than others (McLaughlin & Walsh, 1998; Moreira, 2006; Haberl et al., 2010). Haberl et al.,(2010) also discussed that, the lower the inputs in cultivation the lower the emissions and also the lower the yields.

5.2. The implication and applicability of findings

Potentials for bioenergy production within build-up areas in Overijssel could be lower compared to other urbanized provinces the Netherlands. This is due to the fact that Overijssel is not the most industrial part of the country and most municipalities within the province consist of a more rural settings (Hoppe et al., 2011). This could explain the large variations in the potentials across rural and urban municipalities in Overijssel (annex 8). It complies with Berndes, et al., (2003) discussions, where authors reviewed some studies that evaluated global biomass potentials and came to a conclusion that the most important parameters in estimating bioenergy potentials is the land availability and yield levels in energy crop production. Nevertheless, for provinces like south (Zuid) Holland, north (Noord) Holland, IJsselmeer and Zeeuwse meren, where some major cities are located (Hague/Rotterdam and Amsterdam) could have more potential for biomass production within build-up areas. However, the land cover in Overijssel represents the Netherlands better (Table 3). This implies that findings from this research can be inferred for the entire country.

The total energy consumption in Overijssel in 2005 was 125 PJ (125,000,000 GJ), with 29% used by household, 20% by the service sector and 43% by the industrial sector (Hoppe et al., 2011). Hypothetically, the potentials from these unconventional build-up areas can meet 0.5-2.3% of the overall energy demands, depending on the potential achieved. The target in Overijssel is that 20% of the overall energy demand in addition to 10% for the transport sector is to be supplied from renewable sources by 2020. The minimum estimated annual potential net-energy from build-up areas was 565,403 GJ. This means that 2.3% of the 25,000,000 GJ provincial renewable energy targets can be supplied from the identified build-up areas if that potential is produced. The average estimated potential was 1,968,008 and that is 9% of the renewable target. Lastly is the maximum potential, which was 3,370,612 and 13.5% of the targeted renewables.

Although the bioenergy that can be produced from these build-up areas is minimal compared to the demands, the renewable energy demand and target is high and no potential source should be neglected. Of most importance to note is that, the production of more biomass within the build-up spaces comes with additional socio-economic and environmental benefits. These socio-economic and environmental benefits include amongst other things; improving air quality, reducing atmospheric CO_2 contents, reducing heating and cooling energy demands, reducing surface run-offs, etc.

The traditional sources of bioenergy have been rural landscapes e.g. agricultural crops, crops residue, forest areas, animal waste etc. (McLaughlin & Walsh, 1998; Fischer & Schrattenholzer, 2001; Berndes et al., 2003; Moreira, 2006; Haberl et al., 2010). Recently some amounts are collected from the build-up areas e.g. garden waste, food and fruit waste, seasonal leaf-fall etc. (Kapdan & Kargi, 2006; Shilton et al., 2008; Murphy & Power, 2009; University of York, 2011). However, the first generation of bioenergy has potential effects on food security, water supply etc., hence the government of Overijssel has discouraged the use of first generation of bioenergy crops (Hoppe et al., 2011). It is also important to note that the spaces highlighted in this study are mostly vacant (roof tops, construction sites) or used for singular purposes (recreational areas). This study has proven that biomass can come from unconventional areas as well as the conventional sources. Therefore the assessment of additional unconventional sources in this study can be used as beneficial tools for policy makers towards achieving sustainable bioenergy production, reducing energy demands and the reduction of CO_2 both locally, nationally and globally (Howard et al., 2006; Municipality of Enschede, 2010). Hence this work is an empirical contribution to natural resources management research community by developing a multi-disciplinary Geo-Information science and bioenergy potential estimations. The research findings can be used to fill in data needs on; socio-economic and environmental benefits of biomass production from within unconventional build-up sources, the estimates of how much energy needs to be spent in the production, estimates of energy that can be produced, areas where more or less can be produced (location), factors leading to more or less production, mitigated steps to be taken before establishing production, etc.

5.3. Research strengths and limitations

The net-energy gain was estimated, using a collection of literature which resulted to a range of potentials. However, most scientist estimate biomass/bioenergy potential by computing only the output energy and not the net-energy gain (Fischer & Schrattenholzer, 2001; Moreira, 2006; Haberl et al., 2010), only a few included input energy and calculated the net energy gain (Murphy & Power, 2009; Smyth et al., 2009; EUBIA, 2011). Including the inputs in estimating potentials, provides a wider and appropriate understanding of the actual gained energy.

Errors can be expected from the energy efficiency model of the green roofs. Hence estimates were collected from different literature, some data were missing, different assumptions were made (Figure 4, methods and LCA tables) and most important is the energy benefits of green roofs described above (section 5.1) that were not included in the model. Therefore the energy model can be improved, for further analysis scientist can quantify the energy/cost of some of the benefits of the green roofs on; urban air quality, CO_2 reduction, human health, insulation, etc. this is for policy makers to use such information in deciding how to view production (mainly for bioenergy or as a by-product) towards achieving a better urban environment. Similarly, an under estimation of the input energy could be suspected, since some secondary input energy of the green roofs were not estimated due to the difficulty in converting energy requirements of secondary materials (Shapouri et al., 2002) and the lack of technical know-how to do so. For further analysis scientists can include these input energies. Some of the excluded inputs are:

Irrigation system: A sprinkler and drainage is permanently installed within the intensive roofs to water the plants. This is not necessary with extensive green roofs because the vegetation survives long periods of no rainfall. (Peck & Kuhn, 2003).

Human labour: The human labour required for physical analysis of roofs, designing, landscaping, contracting ,physical manual labour etc. (Great lakes water institute, 2011).

Repairs: For safety reasons, some repairs may be required before installation on certain potential old existing roofs, but this is not required with new roofs (Great lakes water institute, 2011).

Transportation of green roof materials: Some materials (e.g. membrane kit) for the green roofs installation are not produced in Overijssel and energy will be required to transport these materials to the province. These materials are manufactured from concrete manufacturing companies with a closest approximate distance of 595 km (Green roofs.com, 2011).

GIS and remote sensing tools have proven quite useful and most appropriate tools in identifying, locating, extracting and quantifying suitable areas for biomass production for estimating the bioenergy potential. Generally, identifying, extracting and quantifying the potential areas using remote sensing and GIS tools were quite expedient and data used were detailed and appropriate for the analysis. The data however had a few under-estimations of objects, especially large buildings and trees. Similarly, the layer used for extracting construction sites was coarser than the others. For the construction sites, a finer layer than the Corine (100*100m) should be used to improve the identification, extraction and quantification of smaller construction sites. Likewise, more areas were identified within build-up areas as potential sites for biomass production (large car parks, seasonal leaf-fall, etc.), the required data essential to generate the area coverage were also not available during the period of the research. The estimations of the seasonal leaf-fall could have been done by quantifying the amount leafs a trees sheds in a year (tons/year) (Nowak, 1996). Nevertheless, the layer for the individual trees provided was highly under-estimated and will result to a lot of errors (Figure 8). For future analysis, both layers required can be acquired from cadastral maps or extracted from detailed remote sensing imagery of the area. The information extraction can be done through the conventional on-screen digitization (Ali & Algarni, 2004) or through new robust GIS methods of automatic information extraction, Object Oriented Analysis (OOA) (Blaschke, 2010).

The recent Top10 data of the entire province was also not available during the research. Estimations were carried out using 2002 buildings and recreational park data, 2006 construction sites data and 2004 waste data. This implies in general, that the potential from the various build-up sources might be more considering the infrastructural growth over the years in Overijssel.

5.4. The way forward towards climate change regulation and bioenergy production from build-up areas

It is most significant to note that, biomass production from within build-up areas can reduce CO_2 considerably. This CO_2 reduction can be estimated to determine the ratio of the 30% targeted CO_2 drop that can be gained from producing biomass from build-up areas. It can be achieved either by estimating the potential CO_2 that the plants can absorb during photosynthesis (Bertil et al., 2004), or by subtracting the CO_2 reduced by replacing fossil fuels (Harro & Curran, 2007; Thamsiriroj & Murphy, 2009). The estimated CO_2 emitted during the production of bioenergy is less than 0.02 kg/ kWh, while solar PV on roofs is between 0.05-0.06 kg/kWh and fossil fuels is as high as 0.4–1 kg/kWh (Harro & Curran, 2007; Thamsiriroj & Murphy, 2009). CO_2 reduction gained from replacing fossil fuels can be estimated using these values to calculate the reduced CO_2. Therefore, author expects that the CO_2 reduction with bioenergy production within build-up areas will be more effective and immediate towards combating climate change. This aligns with Ibrahim, (1999) conclusions that, the CO_2 reduction prospect with the solar PV on roofs is slower, the author argued that CO_2 reductions with solar PV takes a longer period to be effective. This also agrees with programs implemented by the government of Overijssel, where they choose bioenergy as the core renewable option towards CO_2 reduction (Hoppe et al., 2011). However, Alsema & Nieuwlaar (2000), suggested that the CO_2 value of solar PV will decline to 0.02-0.03 kg/kWh within the next 10 years if less materials are used and etc. Bertil, et al., (2004) also discussed that, the most important factor in CO_2 reduction by replacing fossil fuel, is the amount of fossil fuel used in producing the renewable energy.

There are substantial numbers of trees planted within build up areas in most municipalities in Overijssel. These trees are planted mainly along road sides/fringes and within recreational parks, covering up to 4,792 hectares (annex 3 and Figure 12). About 1,042 hectares of the total area was covered by deciduous trees (annex 3 and Figure 12). They shed their entire leafs between autumn and winter to survive the season (Colin et al., 1992). The annual leaf- fall is almost a nuisance to the public due to the litters they generate, making the surroundings unclean during these periods (Figure 17). The seasonal leaf-fall are collected by the wastes company (Twence etc.) and utilized for bioenergy. These leaf-fall collection can be improved, hence leafs decay are still deliberated to be one of the sources of chloromethane (CH_3Cl) release to the atmosphere which are also responsible for degrading the ozone layer and thereby raising global concerns (Hamilton et al., 2003; Keppler et al., 2006). Therefore, it is important to evaluate how much biomass is collected, how much energy is required to collect the biomass and how much energy is produced from seasonal leaf-fall yearly. This is in order to optimize collection in Overijssel and reduce the release of methane to the environment and probably gain more bioenergy.

Figure 17: Seasonal leaf-fall in Overijssel, (a.)A deciduous tree at the start of autumn, (b) the same tree after 6 weeks, (c) Leafs-fall along walking slaps before collection, (d) Leaf-fall biomass along road sides before collection.

Figure 18: A recreational pond within build-up areas

Recently, the potentials of bioenergy from algae are explored. They have been reported to produce a potential of up to 40 tons/ha in aquatic environments (Clarens et al., 2010; Hoppe et al., 2011). Although there are considerable numbers of ponds within build-up areas in Overijssel, they are used as recreational fishing ponds during summer and for skating during winter. Some of these ponds can be utilised to produce algae for a sustainable bioenergy production, as well as provide recreation to citizens.

The exact number of residential buildings with slope $>30^{o}$ could not be calculated due to time constraints. It is important to map out; buildings that are in good condition, the slope angle/ aspect of roof, height of the building, etc. This suitability mapping is most important before establishing green roofs and solar PV on roofs. Recently, Light Dictation and Ranging (LIDAR) remote sensing data are explored to map out such information, using advanced GIS methods of information extraction (Bluesky international limited, 2011).

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

The estimated annual potential net-energy from unconventional build-up areas can hypothetically meet 0.4–2.7% of the provincial overall energy demands and up to 2.3-13.5% of the renewable energy demands. The potential compared to annual energy demand is small, but the present renewable energy demands /target are high and no potential source should be neglected. However, the important socio-economic and environmental benefits (improving air quality, reducing atmospheric CO_2 contents, reducing heating and cooling energy demands, surface run-off, etc.) associated with this innovative production cannot be over emphasized due to the increase in energy demands and global climate change issues. Similarly, this potential bioenergy sources can reduce some of the pressure on traditional sources of bioenergy.

Overijssel's land cover well represents the Netherlands in general. This implies that findings from this research can be inferred for the entire country. Nevertheless, some provinces like south (Zuid) Holland, north (Noord) Holland, IJsselmeer and Zeeuwse meren where some major cities are located (Hague/Rotterdam and Amsterdam) could have more potential for biomass production within build-up areas.

The calculated EROEI is comparable to the EROEI of some bioenergy crops. Production within recreational areas had an EROEI of 2.7-3, construction areas had 2.7-5, while green roofs can produce with an EROEI of only 0.8-1.1 if produced mainly for bioenergy. However, the case of organic domestic waste was different with an EROEI value of 5.5-15, which is due to the low input energy demand in the production. Nevertheless, waste collection can be made optimal. Present charges on organic/green waste collection should be deliberated hence these wastes are utilized for bioenergy. Of all the potential bioenergy production sources proposed in the study, green roofs had the most potential but also the lowest EROEI value. Nevertheless, there is need to improve the energy model by including important energy aspects of the green roofs like energy savings from buildings cooling and heating, carbon credit trade etc. which can increase the EROEI value. This makes it highly recommendable to exclude the energy/cost of green roof installation and ruminate production as a by-product considering the other environmental benefits of the green roofs, which when calculated gave an impressive net-energy and EROEI value (51-54) and comparable to the EROEI of solar energy.

Studying the overall provincial bioenergy potential from build-up areas (annex 2, 3 and 8), the variations in potential across municipalities can be attributed mainly to the area available from green roofs, construction sites and recreation sites. Nevertheless, the potentials from wastes are in contrast to the biomass potentials from green roofs, recreation areas and construction sites, whereby the more the area and specie yield, the more the bioenergy potential. The variation in the potential from wastes is more complicated. It was attributed to both per capita waste collections and populations. Perhaps this can be studied in detail per municipality (urban vs. rural municipalities).

Generally, identifying, extracting and quantifying the potential areas using remote sensing and GIS tools were quite expedient and data used were detailed and appropriate for the analysis. Therefore findings of this study can be used as useful tools for policy makers towards achieving sustainable bioenergy production, reducing energy demands and the reduction of CO_2 both locally, nationally and globally.

6.2. Recommendations

The most important aspect of bioenergy production from roof tops is how energy production from green roofs is perceived, either mainly for bioenergy or as a by-product. This is where there was a substantial gap in net-energy gain and EROEI. With regards to the socio-economic and environmental benefits of the green roofs listed in the report, it is highly recommendable to exclude the energy/cost of green roof installation and assess production as a by-product.

Up to 98.6% of the present buildings in Overijssel were small residential buildings mostly with steep roof slopes. This is not very suitable for green roofs but usable for solar PV. Therefore it is recommendable to combine energy production on roofs from both solar and green roofs. Using the solar PV and the by-product green roofs biomass will generate a sustainable energy production. Perhaps more bioenergy production from green roofs can then be incorporated in future building codes considering the CO_2 reduction (carbon trading prospect) and energy gain as a bonus. Hence the existing old roofs may have a need for repairs for both green roofs and solar PV, due to vegetation and PV weights.

The suitability mapping of buildings before installation of green roofs and solar PV on roofs is most imperative. This is in order to map out; buildings that are in good condition, the slope angle/ aspect of roof, height of the building, etc. LIDAR can be explored to map out such information, using robust GIS methods of information extraction.

It is also recommendable to explore other build-up biomass sources like large car parks, ponds for algae production, public seasonal leaf-fall collection etc. The seasonal leaf-fall are not optimally collected, with leafs lithered within build-up areas between autumn and winter and left to decay. This can lead to the release of methane to the atmosphere. It is therefore important to estimate annual leaf-fall and their collections and in order to evaluate the energy required to collect and the energy produced from it.

Most importantly, the need to estimate the potential CO_2 that can be reduced by biomass production from these build-up spaces cannot be over-emphasized. This is to calculate the amount of the targeted 30% of CO_2 reduction that can be achieved by growing biomass within build-up areas for bio-energy. This can help policy makers incorporate innovations in future plans.

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ANNEXES

Annex 1: Buildings in Overijssel.

Municipalities	Commercial buildings	Small houses	%	Percentages of large buildings	Percentages of small buildings
ALMELO	177.4	2838	2.9	6	94.1
BATHMEN	0.7	645	0.62	0.1	99.9
BORNE	10.8	1312	1.27	0.8	99.2
DALFSEN	21	5279	5.09	0.4	99.6
DENEKAMP	23	4296	4.15	0.5	99.5
DEVENTER	55.3	2764	2.71	2	98
ENSCHEDE	229.5	8526	8.41	2.6	97.4
HAAKSBERGEN	47	2686	2.63	2	98.3
HARDENBERG	4.4	13126	12.6	0.03	99.9
HELLENDOORN	50.3	4896	4.75	1	99
HENGELO	139.1	5734	5.64	2.4	97.6
HOF VAN TWENTE	18	4675	4.51	0.4	99.6
KAMPEN	97.3	2115	2.13	4.4	95.6
LOSSER	13.3	2552	2.47	0.5	99.5
OLDENZAAL	58.5	1682	1.67	3.4	96.6
OLST	10.7	2348	2.27	0.5	99.6
OMMEN	0.2	5928	5.7	0.003	99.9
RAALTE	44.6	5055	4.9	0.9	99.1
RIJSSEN	74.7	3770	3.69	1.9	98.1
STAPHORST	22.7	1871	1.82	1.2	98.8
STEENWIJK	39.4	5421	5.25	0.7	99.3
TUBBERGEN	18.4	3198	3.09	0.6	99.4
VRIEZENVEEN	42.3	4752	4.61	0.9	99.1
WIERDEN	22.2	3211	3.11	0.7	99.3
ZWARTEWATERLAND	68.4	1210	1.23	5.3	94.7
ZWOLLE	203.5	2671	2.76	7.1	92.9
Grand Total	1493.1	102561	100	1.4	98.6

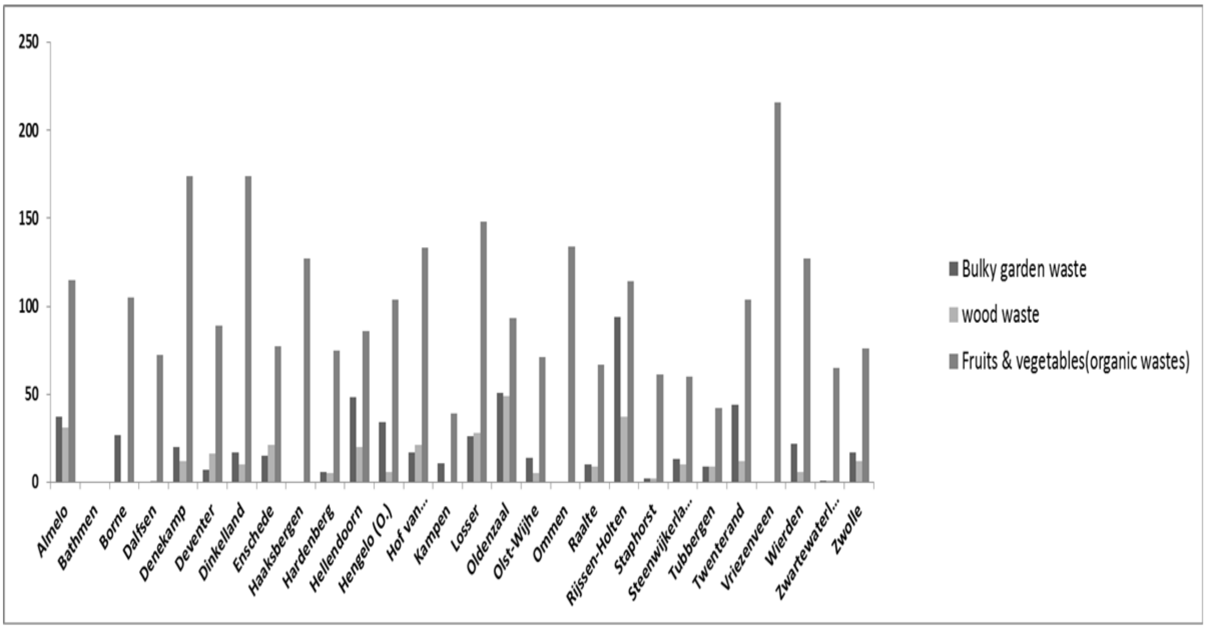
Annex 2: Green roofs biomass estimations under different options of production.

MUNICIPALITIES	Commercial buildings	Residential buildings	(option one) Estimated biomass on large buildings with 5.4T/HA yield	(option two) Estimated biomass on large buildings with 2.6T/HA Yield	(option three) Estimated biomass on large buildings and 30% houses with annual 5.4T/HA yeild	(option four) Estimated biomass on large buildings and 30% houses with 2.6T/HA yields	(option five) Estimated biomass on large buildings and 30% houses with both 5.4 and 2.6 (T/HA)
ALMELO	177.4	2838	957.83	461.2	5555.4	2674.82	4115.1
BATHMEN	0.68	645	3.6864	1.775	1048.6	504.875	776.73
BORNE	11	1312	58.243	28.04	2183.7	1051.4	1617.5
DALFSEN	21.1	5279	114.1	54.94	8666.1	4172.56	6419.3
DENEKAMP	23.4	4296	126.5	60.91	7086	3411.79	5248.9
DEVENTER	55.3	2764	298.49	143.7	4776.2	2299.64	3537.9
ENSCHEDE	229.5	8526	1239.1	596.6	15051	7246.89	11149
HAAKSBERGEN	47	2686	253.8	122.2	4605.1	2217.28	3411.2
HARDENBERG	4.4	13126	23.624	11.37	21288	10249.7	15769
HELLENDOORN	50.3	4896	271.69	130.8	8203.2	3949.69	6076.5
HENGELO	139.1	5734	751.23	361.7	10040	4834.22	7437.3
HOF VAN TWENTE	18	4675	97.203	46.8	7670.7	3693.3	5682
KAMPEN	97	2115	525.19	252.9	3951.5	1902.57	2927
LOSSER	13	2552	72.026	34.68	4206.3	2025.24	3115.8
OLDENZAAL	58.5	1682	315.86	152.1	3040.7	1464.04	2252.4
OLST	10.7	2348	57.693	27.78	3861.5	1859.22	2860.3
OMMEN	0.2	5928	0.8373	0.403	9604.2	4624.24	7114.2
RAALTE	44.6	5055	241.01	116	8430.1	4058.94	6244.5
RIJSSEN	74.7	3770	403.59	194.3	6511	3134.92	4823
STAPHORST	22.8	1871	122.95	59.2	3154	1518.58	2336.3
STEENWIJK	39.4	5421	212.88	102.5	8994.9	4330.88	6662.9
TUBBERGEN	18.4	3198	99.367	47.84	5280.1	2542.28	3911.2
VRIEZENVEEN	42.3	4752	228.25	109.9	7926.5	3816.46	5871.5
WIERDEN	22.2	3211	119.79	57.68	5321.6	2562.26	3941.9
ZWARTEWATERLAND	68.4	1210	369.12	177.7	2329.3	1121.52	1725.4
ZWOLLE	203.5	2671	1098.8	529.1	5425.9	2612.45	4019.1
Grand Total	1493.1	102561	8062.9	3882	174212	83879.7	129046

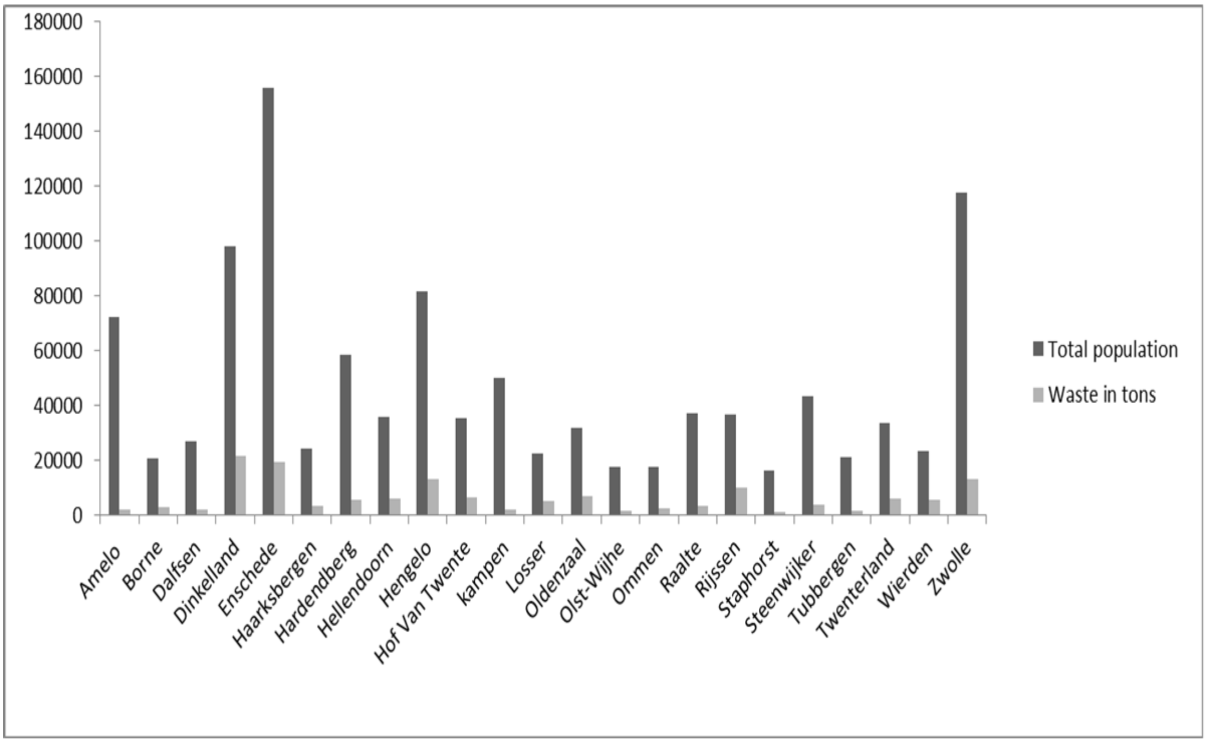
Annex 3: Biomass estimations within recreational parks and other green spaces within build-up areas in Overijssel.

MUNICIPALITY	Recreational parks and green areas within build-up areas (HA)	Area considered for biomass production (50% of the recreational areas)	Biomass estimation with cocksfoot grass or clover grass (10 tons/ ha yield)	Percentages
ALMELO	307.9	153.95	1539.5	6.4
BATHMEN	15.58	7.79	77.9	0.3
BORNE	46.08	23.04	230.4	1
DALFSEN	146.2	73.1	731	3.1
DENEKAMP	93.75	46.875	468.75	2
DEVENTER	233.9	116.95	1169.5	4.9
ENSCHEDE	446.3	223.15	2231.5	9.3
HAAKSBERGEN	67.8	33.9	339	1.4
HARDENBERG	277.4	138.7	1387	5.8
HELLENDOORN	112.2	56.1	561	2.3
HENGELO	394.9	197.45	1974.5	8.2
HOF VAN TWENTE	153.5	76.75	767.5	3.2
KAMPEN	351.6	175.8	1758	7.3
LOSSER	77.54	38.77	387.7	1.6
OLDENZAAL	123.2	61.6	616	2.6
OLST	72.03	36.015	360.15	1.5
OMMEN	99.37	49.685	496.85	2.1
RAALTE	177	88.5	885	3.7
RIJSSEN	144	72	720	3
STAPHORST	106.7	53.35	533.5	2.2
STEENWIJK	314.9	157.45	1574.5	6.6
TUBBERGEN	78.49	39.245	392.45	1.6
VRIEZENVEEN	146.3	73.15	731.5	3.1
WIERDEN	71.66	35.83	358.3	1.5
ZWARTEWATERLAND	143.3	71.65	716.5	3
ZWOLLE	590.2	295.1	2951	12
Grand Total	4792	2396	23960	100

Annex 4: Per capita domestic bioenergy waste generation in Overijssel.



Annex 5: Domestic organic waste and 2004 population distribution in Overijssel.



Annex 6: Annual biomass potential (tons/year) within build-up areas in Overijssel.

Municipalities	Green roofs (option 5)	Waste	Recreational sites	Construction sites	Total	%
ALMELO	5555.4	14610	1847.4		22013	5.9
BATHMEN	1048.6		93.48		1142.1	0.3
BORNE	2183.7	3005	276.48		5465	1.5
DALFSEN	8666.1	2176	877.2		11719	3.1
DENEKAMP	7086	21689	562.5		29338	7.9
DEVENTER	4776.2		1403.4		6179.6	1.7
ENSCHEDE	15051	19440	2677.8		37169	10
HAAKSBERGEN	4605.1	3378	406.8		8389.8	2.3
HARDENBERG	21288	5560	1664.4		28512	7.6
HELLENDOORN	8203.2	6086	673.2		14962	4
HENGELO	10040	12925	2369.4		25335	6.8
HOF VAN TWENTE	7670.7	6626	921		15217	4.1
KAMPEN	3951.5	2143	2109.6		8204.6	2.2
LOSSER	4206.3	5030	465.24		9701.3	2.6
OLDENZAAL	3040.7	6758	739.2		10538	2.8
OLST	3861.5	1734	432.18		6028	1.6
OMMEN	9604.2	2577	596.22		12777	3.4
RAALTE	8430.1	3497	1062		12989	3.5
RIJSSEN	6511	9935	864		17310	4.6
STAPHORST	3154	1148	640.2		4941.7	1.3
STEENWIJK	8994.9	3954	1889.4		14838	4
TUBBERGEN	5280.1	1388	470.94		7139.4	1.9
VRIEZENVEEN	7926.5	5927	877.8		14731	4
WIERDEN	5321.6	5587	429.96		11339	3
ZWARTEWATERLAND	2329.3		859.8		3189.1	0.9
ZWOLLE	5425.9	13234	3541.2		22201	6
Grand Total	174212	2E+05	28752	11455.8	372828	100

Annex 7: Estimated annual potential net-energy production from green roofs in Overijssel.

Municipalities	Large buildings	Residential buildings	30% of residential buildings	Large buildings and 30% residential buildings	Production bioenergy base on5.4tons/ha annual yield (GJ/year)	Production as by-product with 5.4 tons/ha annual yield(GJ/year)	Production as by-product with 2.6 tons/ha annual yield (GJ/year)
ALMELO	177.38	2838	851.4	1028.8	6833.2	62458.6	30635.4
BATHMEN	0.6827	645	193.5	194.	1289.8	11789.1	5782.47
BORNE	10.786	1312	393.6	404.4	2685.9	24550.9	12042
DALFSEN	21.131	5279	1583.7	1604.8	10659	97431.8	47789.5
DENEKAMP	23.427	4296	1288.8	1312.2	8715.9	79667.4	39076.2
DEVENTER	55.276	2764	829.2	884.5	5874.7	53697.9	26338.4
ENSCHEDE	229.46	8526	2557.8	2787.3	18513	169219	83000.6
HAAKSBERGEN	47	2686	805.8	852.8	5664.3	51774.8	25395.1
HARDENBERG	4.3748	13126	3937.8	3942.2	26184	239336	117392
HELLENDOORN	50.313	4896	1468.8	1519.1	10090	92227.8	45236.9
HENGELO	139.12	5734	1720.2	1859.3	12350	112882	55367.7
HOF VAN TWENTE	18.001	4675	1402.5	1420.5	9435	86240.9	42300.4
KAMPEN	97.257	2115	634.5	731.8	4860.4	44426.2	21790.6
LOSSER	13.338	2552	765.6	779	5173.7	47290.6	23195.6
OLDENZAAL	58.493	1682	504.6	563	3740.1	34186.3	16768.1
OLST	10.684	2348	704.4	715	4749.6	43413.9	21294.1
OMMEN	0.1551	5928	1778.4	1778.6	11813	107979	52962.7
RAALTE	44.632	5055	1516.5	1561	10369	94778.8	46488.2
RIJSSEN	74.739	3770	1131	1205.7	8008.6	73202.3	35905.1
STAPHORST	22.769	1871	561.3	584	3879.4	35459.7	17392.7
STEENWIJK	39.422	5421	1626.3	1665.7	11064	101129	49602.7
TUBBERGEN	18.401	3198	959.4	977.8	6494.6	59363.9	29117.5
VRIEZENVEEN	42.268	4752	1425.6	1467.9	9749.6	89116.6	43710.9
WIERDEN	22.183	3211	963.3	985.5	6545.6	59830.3	29346.2
ZWARTEWATERLAND	68.355	1210	363	431.4	2865.1	26188.2	12845.1
ZWOLLE	203.49	2671	801.3	1004.8	6673.8	61002.2	29921.1
Grand Total	1493.1	102561	30768.3	32261.4	214282	1958643	960697

Annex 8: Estimated annual potential net-energy production from organic waste in Overijssel.

		Actual collection (39-245 kg/capita)		Average (133 kg/capita)		Maximum (245 kg /capita)	
Municipalities	**Waste (total tons)**	**Potential 1 (0.9 GJ/T)**	**Potential 2 (13.1 GJ/T)**	**Potential 1 (0.9 GJ/T)**	**Potential 2 (13.1 GJ/T)**	**Potential 1 (0.9 GJ/T)**	**Potential 2 (13.1 GJ/T)**
Amelo	14610	13149	191396.1	9556.6	139102	17604.3	256241
Borne	3005	2704	39363.22	2724.8	39661.4	5019.42	73060.5
Dalfsen	2176	1959	28508.17	3568.4	51939.5	6573.31	95678.1
Dinkelland	21689	19520	284131.1	12917	188007	23793.6	346329
Enschede	19440	17496	254669.1	20593	299743	37934.6	552159
Haarksbergen	3378	3040	44250.54	3183.7	46341.1	5864.79	85365.2
Hardendberg	5560	5004	72835.32	7738.7	112641	14255.4	207496
Hellendoorn	6086	5477	79721.11	4730.2	68850	8713.45	126829
Hengelo	12925	11633	169323.5	10744	156389	19792.1	288085
Hof Van Twente	6626	5963	86797.93	4638.1	67509.5	8543.79	124360
kampen	2143	1929	28079.7	6578.9	95759	12119	176398
Losser	5030	4527	65890.67	2980.5	43383.5	5490.47	79916.9
Oldenzaal	6758	6082	88525.43	4191.2	61004.6	7720.55	112377
Olst-Wijhe	1734	1561	22720.04	2306.7	33575.2	4249.17	61849
Ommen	2577	2319	33757.96	2301.9	33506	4240.42	61721.6
Raalte	3497	3147	45813.6	4867.6	70851.3	8966.71	130515
Rijssen	9935	8941	130147.6	4853.9	70651.5	8941.44	130148
Staphorst	1148	1033	15032.91	2113.3	30759.6	3892.84	56662.5
Steenwijker	3954	3558	51795.04	5702.1	82996.9	10503.8	152889
Tubbergen	1388	1250	18187.82	2769.8	40316.3	5102.31	74266.9
Twenterland	5927	5334	77642.49	4434.1	64540.3	8168.02	118890
Wierden	5587	5029	73195.92	3096.4	45069.7	5703.88	83023.2
Zwolle	13234	11911	173365.7	15531	226055	28608.8	416418
Total	158408	142567.6	2075151	142121	2068653	261802	3810677

Annex 9: Estimated average net-energy potentials from build-up areas sources in Overijssel.

Municipalities	Recreational parks. GJ/year (Average)	Waste GJ/year (Average)	Green roofs. GJ/year (Average)	construction sites GJ/year (Average)	Total GJ/year	%
ALMELO	9553	102273	34280		146105	6
BATHMEN	483.4		6470		6953.7	0.3
BORNE	1430	21034	13475		35938	1.5
DALFSEN	4536	15233	53475		73244	3
DENEKAMP	2909	151826	43725		198459	8.1
DEVENTER	7257		29472		36728	1.5
ENSCHEDE	13846	136083	92874		242804	9.9
HAAKSBERGEN	2103	23645	28416		54165	2.2
HARDENBERG	8606	38920	1E+05		178883	7.3
HELLENDOORN	3481	42599	50618		96698	3.9
HENGELO	12252	90478	61954		164684	6.7
HOF VAN TWENTE	4762	46381	47333		98475	4
KAMPEN	10908	15004	24383		50296	2
LOSSER	2406	35209	25955		63569	2.6
OLDENZAAL	3822	47304	18763		69889	2.8
OLST	2235	12140	23827		38203	1.6
OMMEN	3083	18039	59263		80385	3.3
RAALTE	5491	24481	52019		81990	3.3
RIJSSEN	4468	69544	40176		114189	4.7
STAPHORST	3310	8032.9	19462		30805	1.3
STEENWIJK	9770	27677	55504		92950	3.8
TUBBERGEN	2435	9718.7	32581		44735	1.8
VRIEZENVEEN	4539	41488	48911		94938	3.9
WIERDEN	2223	39112	32837		74173	3
ZWARTEWATERLAND	4446		14373		18819	0.8
ZWOLLE	18311	92638	33481		144430	5.9
TOTAL	148672	1108859	1074983	122987.9	2455501.8	100