CARBON BALANCE FOR SUSTAINABLE LAND USE SCENARIOS AND A "GREEN" CAMPUS AT THE UNIVERSITY OF TWENTE

ASTUTI TRI PADMANINGSIH
March, 2015

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dr. I.C. Van Duren
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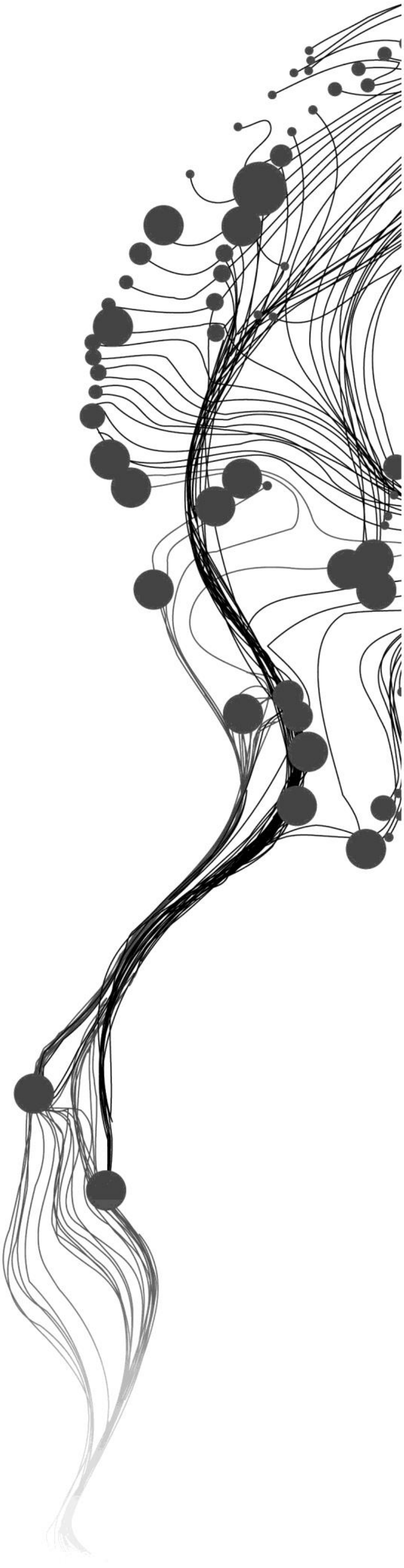

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Enschede, The Netherlands, March, 2015

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Natural Resources Management

SUPERVISORS:
dr. I.C. Van Duren
drs. J.M. Looijen

THESIS ASSESSMENT BOARD:
Prof. Dr. A.K. Skidmore (Chair)
Dr. M.J. Arentsen (External Examiner, University of Twente-CSTM)

ABSTRACT

This study aims to estimate carbon stock and carbon emission to develop different land cover scenarios to provide insight how different vegetation types and maintenance of the green areas influence the carbon balance of the University of Twente campus. The methods were consisted of: (1) calculating carbon stock of green areas, (2) calculating carbon emission and carbon sequestration of green areas, (3) calculating carbon balance of the green areas and (4) developing and comparing scenarios in terms of carbon balance. The total carbon stock of the green areas was estimated based on the sum of carbon stock of trees, grass and soil organic matter. The estimation of tree carbon stock has been carried out based on field measurements and allometric equations. The estimation of grass carbon stock and soil carbon stock was estimated based on laboratory analysis. The carbon emission and carbon sequestration rate were estimated based on the literatures. The carbon balance of the green areas was calculated based on the differences between the carbon sequestration and the carbon emission. Furthermore, four scenarios including the carbon balance estimation of each scenario were delivered.

The results showed that the total carbon stock of the green areas in the University of Twente was 12,045.9 ton, consist of: broad-leaved forest (2,817.9 ton, 23.4%), coniferous forest (741.5 ton, 6.2%), mixed forest (1,373.9 ton, 11.4%), lawn grassland (2,420.9 ton, 20.1%) and agriculture grassland (857.4 ton, 7.1%) and soil in the forest area (3,834.3 ton, 31.8%). The total carbon emission of the green areas in University of Twente was found to be 24.9 ton/year, consist of: broadleaved (0.6 ton/year, 2.3%), coniferous (0.3 ton/year, 1.2%), mixed trees (0.3 ton/year, 1.2%), lawn grasslands (22.2 ton/year, 89.1%) and agriculture grasslands (1.5 ton/year, 6.1%). The total carbon sequestration of the green areas in University of Twente was 159.6 ton/year, consist of: broadleaved trees (40.5 ton/year, 25.4%), coniferous trees (20.0 ton/year, 12.5%), mixed trees (20.5 ton/year, 12.8%), lawn grasslands (66.3 ton/year, 41.5%) and agriculture grasslands (12.2 ton/year, 7.7%). The carbon balance of the green areas in the University of Twente was 134.7 ton/year.

Four scenarios were proposed to enhance carbon balance in the green areas of University of Twente. The locations to develop scenarios were based on the potential land use which was 47.1 ha of the green areas or 30% of the total campus areas. This area consists of 8.8 ha (18.7%) from existing grassland and 38.3 ha (81.3%) from existing forest area. The scenarios were: (A) current situation (B) optimizing carbon stock by admixing coniferous trees to mixed trees (C) optimizing carbon sequestration by selective harvesting and replacing coniferous trees with willow trees (D) reducing emission by abandoning grazing and replacing pastures with sunflower crop. The results showed that if the scenario A were applied the carbon balance will be 134.7 ton/year, if the scenario B were applied the carbon balance will be 135.0 ton/year, if the scenario C were applied the carbon balance will be 153.4 ton/year and if the scenario D were applied the carbon balance will be 191.2 ton/year. The scenarios will contribute about 5.8% - 8.2% to sequester the carbon emission from the University of Twente buildings.

Keywords: carbon balance, land use scenarios, university campus

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Astuti Tri Padmaningsih,
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1. INTRODUCTION

1.1. Background

Carbon dioxide (CO_2) is a major greenhouse gas which is responsible for atmosphere heat-and-gas-trapping, thus resulting in the increase of Earth's surface temperature (US EPA, 2014). Based on empirical measurement from IPCC (2007), the amount of global CO_2 has risen by 1.9 ppm in average per year from 1995 to 2005. It was simulated that CO_2 will contribute to an increase in temperature of the Earth's surface, ranging from 1.8°C to 4°C for more than a millennium. Numerous studies argued the increased global CO_2 will affect global water availability (Kerr, 2012), biodiversity (D'Amen and Bombi, 2009; Nogué et al., 2009), food security (Funk and Brown, 2009), human health (Saniotis and Bi, 2009) and many more. By these wide ranges of causal damage, declining carbon emissions has become the global goal of many countries to preserve future human life.

It was reported that in 1990, the European Union (EU) contributed to 24.3% of the global CO_2 emissions (Oberthur and Ott, 1999). The combustion of fossil fuels was over 100 million tonnes of CO_2-equivalent in the EU in the period of 2009-2010. The greenhouse emissions originating from energy industries such as heating plants, refineries and power plants including fossil fuels contributed to 40% from all detected emitters in the EU (EEA, 2011). The United Nations Framework Convention on Climate Change (UNFCCC) resulted in the EU goal to reduce 30% of its 1990 CO_2 emission in 2020 and to provide 20% of the total energy needs from renewable sources and 10% for the transportation sector (UNFCCC, 2014). The agreement bonds EU country members to involve reduction of carbon emission as their nation policy.

The Netherlands has the target to reduce the CO_2 emission and increase its renewable energy 20% in 2020 (UNFCCC, 2014). Based on the EEA (2012) report, the greenhouse gases emissions have decreased about 7.6% for the period 1990-2011 in the Netherlands. In line with the national government, the province of Overijssel also has a new energy programme which policy is to minimise CO_2 emissions and develop 20% of new energy supply from renewable sources and 10% in the transport sector in 2020 (Overijssel Province, 2013). The province of Overijssel works together with the municipalities, business sectors and other organisations in Overijssel, in order to reach the energy programme target.

The University of Twente (UT) is a university campus located in the province of Overijssel and the only one university in the Netherlands which became one of 516 members (October 2013) of the Global Universities Partnership on Environment for Sustainability (GUPES). GUPES is one of the main programmes from The United Nations of Environment Programme (UNEP) to encourage the concerns of environment and sustainability development into educational world, including greening the university both in the campus area, teaching and researches (UNEP, 2014). The World Commission on Environment and Development (WCED) defined the sustainable development as "the ability to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nation, 1987).

In 2013, GUPES-UNEP introduced a Greening Universities Toolkit (Osmond et al., 2013) as a guidance for universities to achieve a sustainable campus. According to the toolkit, there are four categories to be concerned in order to become a sustainable university included as follows:

- Energy, carbon and climate change. This category covers the greenhouse gas emissions, energy consumption of electricity, natural gas and transportation.
- Use of water, such as water consumption and waste water production.
- Use of land – campus ecology, planning, design and development for green buildings proportion, pervious and impervious surfaces, and vegetation cover.
- Material flows – the use of materials, procurement, toxicity and pollution, solid waste disposal and recovery.

There are seven universities of the GUPES members which are used as case studies of sustainable campus based on the Greening Universities Toolkit (Osmond et al., 2013). They are the Tongji University (China), Princeton University (USA), Middle East Technical University (Turkey), University of Nairobi (Kenya), University of Copenhagen (Denmark), University of British Columbia (Canada) and University of South Wales (Australia). Several issues addressed by different universities in an attempt to operate in a more sustainable manner namely forest areas, "green" buildings, energy (energy efficiency and renewable energy), water conservation, waste management, carbon emission and purchasing more sustainability product. Most of the universities were mainly focus on the energy, "green" buildings, water conservation, also on recycling of materials and more environmental-friendly products. Two universities considered the management of green areas, namely the Middle East Technical University (METU) which had the re-forestation project of 75% of the whole campus area which is 4500 hectares and Princeton University which restored five acres of the forest area. Table 1 shows different approaches and methods of carbon studies on university campuses.

Table 1. Different objectives and methods of carbon studies on university campus

Case studies	Objectives	Methods	Remarks
Tongji University, Shanghai, China (Li et al., 2015)	Carbon footprint analysis	Estimation of average carbon footprint of students' activities	The average students' yearly carbon footprint was 3.84 tons CO2-e, 65% from daily life, 20% transport and 15% academic activities
University of Aurangabad, India (Chavan and Rasal, 2011)	Carbon sequestration from the above-ground and below-ground biomass of young trees	Biomass estimation, destructive (ash method) and non-destructive (measure the tree properties) method	AGB carbon for Emblica officinalis 33.07 kg C/ha, Mangifera indica 30.6 kg C/ha and Tamarindus indica 36.96 kg C/ha and Achras sapota 12.86 kg C/ha, Annona retiaculata 83.1 kg C/ha and Annona squamosa 73.5 kg C/ha
Pondicherry University, Puducherry, India (Sundarapandian et al., 2014)	Biomass and carbon stock assessments of woody vegetation	Biomass estimation using allometric equation	Overall inclusive carbon stock was 2590.48 Mg, above ground biomass was 4438 Mg and below ground biomass 753 Mg with species *Acacia auriculiformis* as the highest carbon stock storage.

University of Cape Town, Africa (Letete and Marquard, 2011)	Carbon footprint	Campus energy emission sources from direct and indirect emissions	The carbon footprint of the year 2007 was 83400 tons CO_2-eq, 81% energy consumption, 18% transport and 1% Goods and Services. Carbon emission was 4.0 tons CO_2-eq, carbon footprint was 3.2 tons CO_2-eq per student.
Gujarat University, Ahmedabad, India (Rathore and Jasrai, 2013)	Carbon sink of urban green patches	Carbon stock estimation of above and below ground biomass	The total carbon stock calculated was 3162.9 t/ha, consists of 2501.60 t/ha and 661.30 t/ha from soil and trees, respectively.
Erasmus University, Rotterdam, the Netherlands (Sprangers, 2011)	Universities carbon footprint	CO_2 emission of direct and indirect sources	The total CO2 emission was 12601.349 kg CO2, consist of 61% from student commuting activities, 20% from purchased energy, 13% from employee commuting, 6% from waste and product use.
Pune University, India (Haghparast et al., 2013)	Carbon sequestration in university campus	Carbon estimation from above and below ground biomass, combined with geographical information system (GIS)	In terms of carbon sequestration, it was found in Pune University that the most dominant species were Dalbergiamelanoxylon and Gliricidia sepium with sequestration of 49% and 30% respectively.
University of Strathclyde, Glasgow, UK (Bezyrtzi et al., 2006)	Carbon footprint analysis	Carbon footprint estimation of the student residence	Carbon footprint was found 199 tonnes for transportation (58%) and 144 from building (42%).
Bharathiar University, India (Pragasan and Karthick, 2013)	Carbon stock estimation of the tree plantations	Non-destructive method to estimate carbon sequestration of the tree species	The total carbon stock sequestered for Eucalyptus plantation (EP) and mixed species plantation (MP) were 27.72 and 22.25 ton/ha respectively.
The Ohio State University, Mansfield (The Ohio State University At Mansfield, 2012)	Greenhouse Gas Emissions Inventory Report 2009-2012	CO_2 emission of direct and indirect sources, namely scope 1, scope 2 and scope 3	The total GHG emission was 6867, 7158, 7271 and 6896 for the year 2009, 2010, 2011 and 2012 respectively. Emission contribution was 20-23% for scope 1, 69-72% for scope 2 and 7-9% for scope 3.
Rice University, America (Rice University, 2008)	Carbon balance	CO_2 emission of direct and indirect sources and CO_2 offset from forest	CO_2 emission was 108,443 metric tons, CO_2 offset from institution-owned forest was 57,640 metric tons; thus the CO_2 balance was 50,803 metric tons.

University Campus, Jalgaon (MS) India (Suryawanshi et al., 2014)	Carbon sequestration potential of tree species	Carbon stock estimation of above and below ground biomass	The carbon sequestration of different tree species *Moringa olifera* was 15.775 tons, *zadirachta indica* 12.272 tons, *Eucalyptus citriodora* was 1.814 tons.
University of Delaware (University of Delaware, 2008)	Carbon Footprint: Greenhouse Gas Emissions Inventory	CO_2 emission of direct and indirect sources and trend analysis	Total emissions of the year 2007-2008 was 152,542 MTCO2e, gave the total emissions per student was 8.7 MTCO2e and per capita was 7.1 MTCO2e.
The University of Warwick, England (The University of Warwick, 2014)	Carbon Management Implementation Plan	CO_2 emission of direct and indirect sources and emission projection	In the year 2012-2013, total carbon emissions (based on scope 1 and 2) was 47,428 tonnes CO_2-e.

In fact, the carbon studies are ranging from carbon footprint, carbon stock, carbon sequestration, biomass estimation and carbon balance, but most of the studies at university level were conducted on one emphasis, on the carbon footprint or carbon sequestration part. There was the Rice University America which the only university conducted study on the carbon balance. They estimated their carbon balance between the carbon emission and the carbon offset from the forest area at university level.

Estimating a carbon balance requires quantitative calculation of carbon emission and carbon sequestration (Peckham et al., 2012). The methods to address carbon emission vary and depend on different concepts and methodologies, for example by grouping CO_2 emission into territorial, production and consumption emission (EEA, 2013). Similarly, methods for calculating carbon sequestration also vary from destructive (Liaudanskienė et al., 2013) to non-destructive methods (Dobbs et al., 2011; Paul et al., 2013). A carbon balance study at individual organisations, businesses or institutions (e.g. university campus) is important to have insight the national or regional carbon balance.

Smith (2004) argued that land management is the most effective approach to decrease the flux of carbon to the atmosphere for European countries. Sufficient lands and land use optimization of green areas are needed to sequester carbon in order to mitigate and balance the significant amounts of CO_2 emissions (Peckham et al., 2012; Rokityanskiy et al., 2007). Karjaleinen et al. (2003) argued that interventions on forest management might significantly increase the amount of carbon sequestered in Europe. In addition, Abberton et al. (2010) found that different type and intensity of green area management (e.g. grassland management) will affect to the different amount of carbon stored in the soil due to the different amount of nitrogen (N) inputs and the frequent cutting. As a result, green area management in term of enhance carbon sequestered may become a measure to obtain sustainability according to the GUPES criteria.

The University of Twente has different land cover/land use on the campus terrain, for example grasslands used as multi-functional use (such as recreational, aesthetic), sports fields and also agriculture land. In addition, there are also built-up areas used for educational and research purposes and residential buildings, water bodies and forests. Regarding to their functionality, UT has activities which leads to carbon emission such as the energy consumption (electricity, heat and steam), operational and maintenance machines, transportation, generation of waste from product use and many more.

Based on information about sustainability mission of the University of Twente campus (University of Twente, 2014), there are several possibilities in research and innovations on environment aspects for campus area and its surroundings. The University of Twente has also offer the campus area as a "green campus for a living laboratory" for researches about sustainable campus. The existing researches are mainly focus about sustainable energy and water. In addition, based on the interviews with the energy coordinator and maintenance manager of the University of Twente, the approach to achieve sustainability campus are in green energy initiatives in order to cut back the carbon emissions as the goal. While the green areas have potential to store and sequester carbon, the management of green area may contribute to reduce carbon emission and reach carbon balance. For that reason, this current study aims to estimate carbon emission and carbon stock to develop and compare land use scenarios on the University of Twente campus.

1.2. Problem Statement

The University of Twente (UT) represents a unit management with policy, visions and future target for a sustainable campus management. The University of Twente campus area have different land covers which are buildings, roads and parking facilities, water and also the green areas, consist of tree-covered areas and grasslands. The green areas play an important role in the carbon balance. The management of green areas such as grasslands has an influence to emissions, in terms of use of machines for mowing, inefficient vehicles for transportation of waste, applying fertilizer and grazing activities from the cattle which emit methane. Despite the fact the green area has potential in sequester and store carbon from biomass on trees and grass. Therefore, several scenarios can be developed to reduce the emission and/or enhance sequestration from the green areas to reach the carbon balance. However, it is not yet known where carbon stock can be increased and by what land use management options to reduce carbon emission in an attempt to manage the green space as sustainable as possible.

This study aims to estimate carbon emission and carbon stock to develop different land cover scenarios to provide insight how different vegetation types and maintenance of the green areas influence the carbon balance of the University of Twente campus. An important aspect of this study is to evaluate carbon balance at a unit management scale and to propose solution based on land use scenarios. Outcome of this study will be useful for supporting the UT management to address their commitment on sustainable campus. Even though the current study area is located in University of Twente, The Netherland, the study applicability is in worldwide since many university campuses throughout the world have similar conditions.

1.3. Research Objectives

The overall objective of this research is to estimate carbon emission and carbon stock to develop the most sustainable scenario on the University of Twente campus. This aim will be achieved through these objectives as follows:

1. To quantify existing carbon stock and carbon emission of the vegetation areas on the UT campus
2. To identify analyse potential zones for optimizing green areas
3. To develop different planting design and management scenarios aiming at a more positive carbon balance at the UT campus and compare different scenarios for UT campus development.

1.4. Research Questions

To address the research objectives, several research questions were made as follows:

1. To quantify existing carbon emission and carbon stock on the UT campus
   a. How much is the carbon stock of the vegetation areas on the UT campus?
   b. How much is the carbon emission related to vegetation growth and maintenance of the vegetation on the UT campus?
2. To analyse potential zones for optimizing green areas
   Which areas on the campus have a fixed land cover type and where can land cover changes contribute to land use?
3. To develop different planting design and management scenarios aiming at a more positive carbon balance at the UT campus and compare different scenarios for UT campus development
   a. What are the possible planting design and management scenarios for UT campus?
   b. What are the criteria and indicators for sustainable UT campus?
   c. How much is the carbon balance of each scenario for the UT campus?

1.5. Conceptual Framework of the study

The outcome of the study was to obtain a sustainable University of Twente campus. A sustainable campus is defined as a well-managed campus which considers environmental protection, ecological conservation, also deliberate efficiency in energy and economy, as described in Greening Universities Toolkit (Osmond et al., 2013). This study used a carbon balance of green area as a measure of sustainability.

Figure 1 shows how the University of Twente system under works. The boundary of the system is the University of Twente campus area managed under the management office. The elements consist of the University of Twente management, buildings, and the green areas i.e. forest resources and grasslands. On the one hand, forest resources and grasslands captured and stored carbon through the trees, plantation and soil. On the other hand, these green areas managed and maintained by the University of Twente Management also produce biomass waste regularly, thus resulting to carbon emission not only from the waste but also from the use of machines. The University of Twente buildings generate energy use from electricity, heat and gas consumption which leads to carbon emission as well. The UT goal to reduce its carbon emission from the energy use of the buildings has been implemented in green energy initiative programme and the energy consumption has been monitored every year. The unknown part or knowledge gap is the carbon emission and potential carbon sequestration from the green areas. Therefore, this study excludes the component of the University of Twente buildings and focus on the vegetated areas. It concentrates on the carbon balance of the land cover which is determined by the type of use.

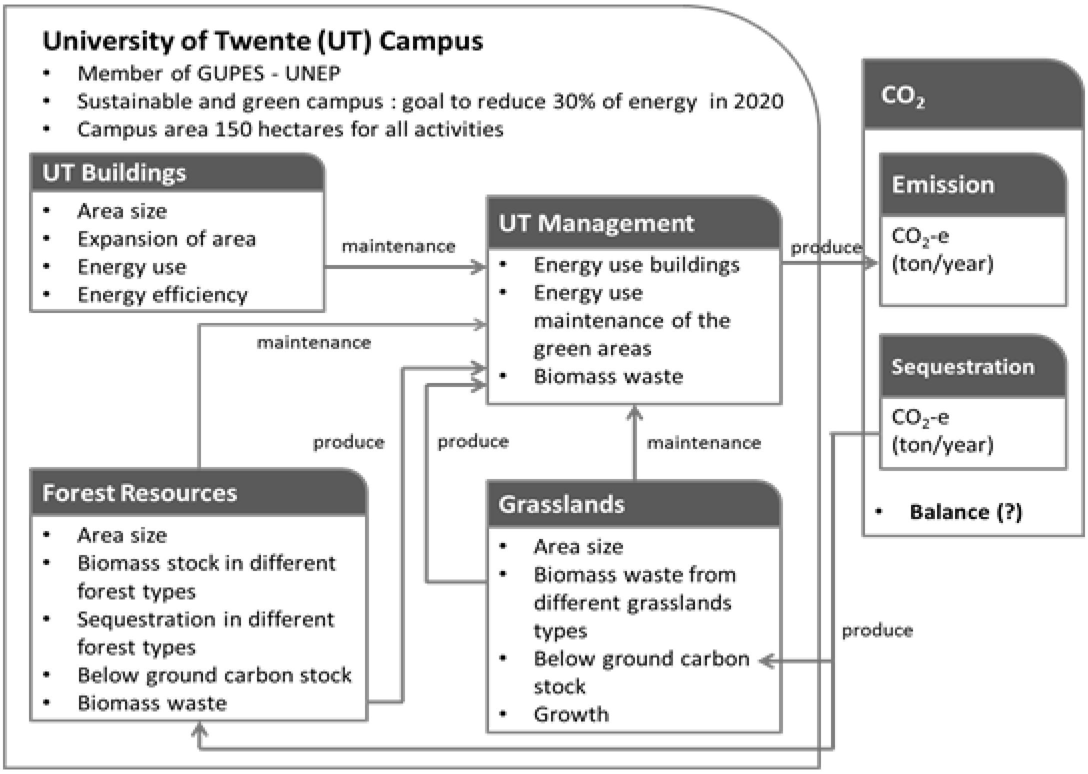

Figure 1. The UT system in the carbon balance measure

1.6. Definitions used in the study

Several terms important and the definitions in the study are presented as follows to ease understanding on the present study.

Biomass is defined as "organic material both aboveground and belowground, and both living and dead, e.g., trees, crops, grasses, tree litter, roots etc. Biomass includes the pool definition for living biomass (i.e. above ground and below ground biomass), dead organic matter (i.e. dead wood and litter) and soil organic matter" (IPCC, 2012). This study mainly focussed on living biomass and soil organic matter.

Above ground biomass is defined as "all living biomass above the soil including stem, stump, branches, bark, seeds, and foliage" (IPCC, 2012). In this study, estimation on above ground biomass was limited to the trees biomass based on allometric equation.

Below ground biomass is defined as "all living biomass of live roots. Fine roots of less than (suggested) 2mm diameter are sometimes excluded because these often cannot be distinguished empirically from soil organic matter or litter" (IPCC, 2012).

Soil organic matter is defined as "an organic carbon in mineral soils to a specified depth" (IPCC, 2012). In this study, the depth is specified up to 30 cm below the soil surface.

Allometric is defined as "a linear or non-linear correlation between increases in trees dimensions and tree parameters" (e.g. tree diameter, tree height, etc.) (Picard, 2012)

Carbon stock is defined as "the quantity of carbon stored in a pool (i.e. above ground, below ground, dead wood, litter and soil organic matter" (IPCC, 2012). In this study, the carbon stock estimation is limited to the above ground pool and soil organic matter. A conversion factor of 0.47 was used to define the amount of carbon content in the tree biomass.

Carbon emission is defined as "an emission rate of a given greenhouse gases for a given source" (IPCC, 2012)

Carbon sequestration is defined as "the process of increasing the carbon stock of a carbon pool" (IPCC, 2012)

Carbon balance is defined as "The balance of the exchanges of carbon between carbon pools which the examination of the budget of a pool will provide information whether it is acting as a source or a sink" (IPCC, 2012). In this study, carbon balance is estimated based on the differences between the amount of carbon sequestration and carbon emission in time.

CO_2 equivalent is defined as "a measure used to compare emissions and sequestration of different greenhouse gases based on their global warming potential" (IPCC, 2005)

Land cover is defined as "an observed physical and biological cover of the earth's land, as vegetation or man-made features" (Choudhury and Jansen, 1998)

Land use is defined as "an arrangements, activities, and inputs that people undertake in a certain land cover type" (Choudhury and Jansen, 1998)

Forest is defined as "a land cover category which includes all land with woody vegetation" (Choudhury and Jansen, 1998). In this study, the forest is categorized into three classes based on the tree domination such as: broadleaves forest, coniferous forest and mixed forest

Broadleaves forest is defined as "a forest area which most of trees and shrubs are classified botanically as Angiospermae and (sometimes) referred to as non-coniferous or hardwoods" (Choudhury and Jansen, 1998)

Coniferous forest is defined as "a forest area which most of trees are classified botanically as Gymnospermae and (sometimes) referred to as softwoods" (Choudhury and Jansen, 1998)

Mixed forest is defined as a forest area where no dominant tree. In this study, mixed forest area defined as a forest area which neither broad-leaves species nor coniferous species dominated (50%-50% or 40%-60%).

Grassland is defined as "a land cover category which includes rangelands and pasture land that is not considered as cropland" (Choudhury and Jansen, 1998)

2. STUDY AREA

2.1. Overview of the study area

The study will take place in the University of Twente (UT), Enschede, The Netherlands with focus area at the campus area managed under the UT. UT is located between 52°14'0" – 52°15'30" latitude and 6°50'30"– 6°52'0" longitude. The campus area has total about 150 hectares geographical areas, defined as an organizational boundary. The criterion for study area selection is defined as the area which has responsibility to be under the university management. The boundary of the study area is not based on the land ownership, since in some part of the university are being leased or owned by private land owners.

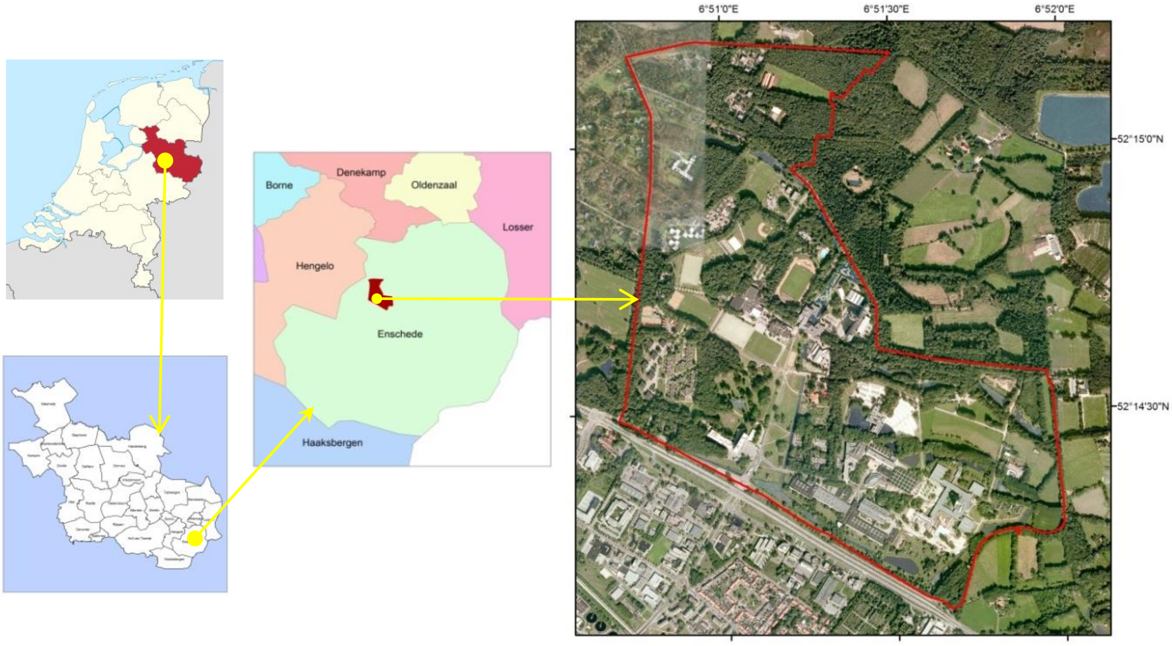

Figure 2. Location of the UT campus

Based on the information in De Nieuwe Campus/The New Campus about historical background of the University of Twente campus (University of Twente, 2011) it was stated that the origin of the University of Twente campus was the Drienerlo country estate. The land was donated by the municipality of Enschede in 1961, and was chosen to locate a new university to be the third university of technology of the country after University of Delft and Eindhoven. The campus design was inspired by Oxford and Cambridge University. It was designed to accomplish a place for students and staff of the University for working, learning, living and socializing in one campus area. In general, the campus area was divided into three big parts: open spaces in the centre for social and recreational activities, the left (west) side for residential and student housing and the right (east) side for offices, educational and research activities.

In 1990 it was decided that the campus needed modernization, thus the agreement was made to renovate the campus from the year 1998 to 2008. However, in the year 2002 there was a major fire at Cubicus building. As a result, the construction project covers the whole area was designed in order to renovate the old buildings to more modern-sustainable-green buildings, with additional access such as elevators and covers safety issue in the building i.e. fire escape routes. The new buildings were constructed in the period 2008-2010, namely Carré, Nanolab and The Chalet. Several sustainable ways have been implemented into the new buildings, for example an addition of tropical roof to gain nature ventilation and prevent overheating, triple-glazed windows to make climate control system, tiles which filter CO_2, heat of fusion material to release large amount of thermal energy, and also the cold circle pond (ten metres deep, thirty metres across) as water reservoir and cooling system.

The land cover types of the campus area consist of green areas (with vegetation covers are trees, shrubs and grass), artificial surfaces i.e. roads and built-up areas and also water bodies. The campus has a range of features from a garden landscape and outdoor architectural museum for a living-laboratory and unique ideas (University of Twente, 2014).

2.2. Management of the University of Twente Campus

Based on the vision of energy on University of Twente (University of Twente, 2014), the University of Twente campus has a long-time agreement to reduce 30% of the 2005 energy consumption by the year 2020. The 30% energy savings is divided into 20% of the university (from 62364 MWh to 49891 MWh) and 10% in the energy chain. This energy savings will mainly come from efficient use of sustainable and renewable energy sources and less fossil fuels usage (University of Twente, 2008). The University of Twente claimed that "In this context our green campus acts as a living laboratory whereas many findings as possible from our own research are applied in practice" (University of Twente, 2014). The focus is to manage energy and explore the possibility of renewable energy sources use, such as wind, solar energy and biomass. Figure 3 shows the energy use consist of electricity, heat and gas consumption from 2005-2013 and the goal of 20% energy saving. Based on the information from the energy coordinator of the University of Twente, increased peak of energy use in 2010 was occurred as a consequence of the building construction and the need of heating both in old and new building during transition period.

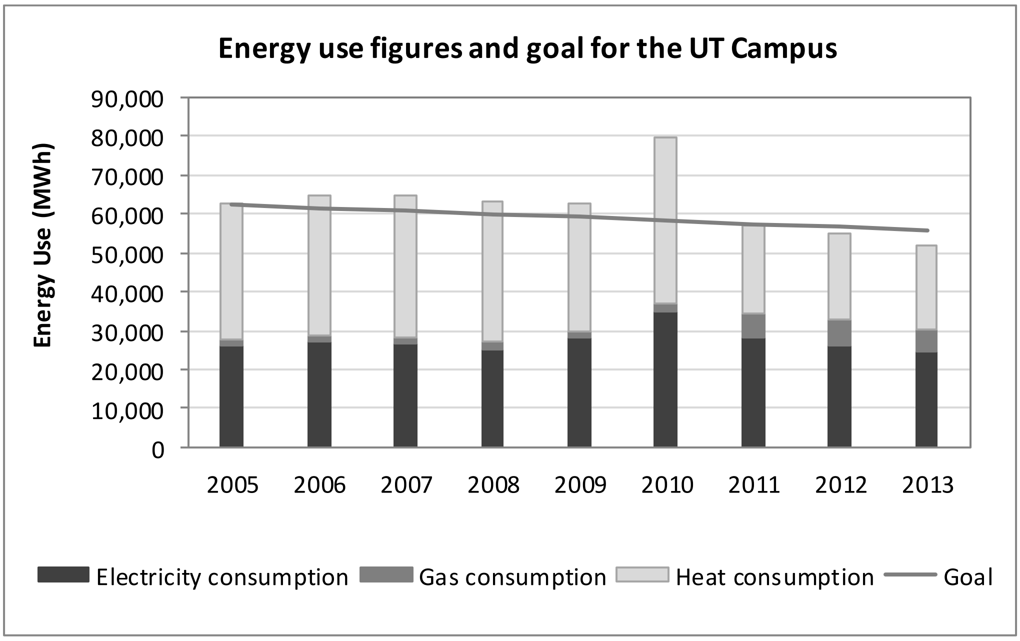

Figure 3. UT campus energy use figures (Source: Energy coordinator, University of Twente, 2014)

From the information about sustainable campus (University of Twente, 2014), the University of Twente sustainable programmes and actions at the University of Twente not only covers issue of energy and material, but also management of water, buildings, transportation, waste (garbage), catering and purchasing. The strategy in conserving water is to save, manage, purify water, and increase the awareness about water consumption and the water footprint of the University of Twente students and staffs. Different types of waste are collected separately to be recycled and processed in an environmental-friendly process. This also include waste which is generated from the management of the green areas, mainly used for natural composting and the rest of the waste are collected to be processed into organic fertilizer and it will be used again for the green areas. However, the University of Twente development to construct new buildings on 2008-2010 has implication on an increase of the use of the energy, thus leads to increase of carbon emission. The land cover/use conversion from green areas to buildings has also an impact on less forest area on the campus which means reduction on carbon stored on these certain land. Therefore, sustainable development to balance the environment and socio-economic needs is necessary, since the University of Twente campus has the potential green areas to maximise carbon sequestration.

There is an existing land use design that includes buildings and vegetation. The type of buildings in the vicinity and/or the specified land use determines the vegetation. In some areas the land use does not allow changes in vegetation. For other land use allows flexibility in the type of vegetation to be planted, for example the forest (tree-covered areas) and grasslands. Based on the interview with the maintenance manager of the University of Twente, development of the campus area has several restrictions to follow, which are:

- The land cover of the University of Twente campus for the forest area should be kept as it is.
- Grasslands lawn areas which designed for socio-cultural activities, for aesthetic and also multi-purpose use, such as the front of University of Twente campus area should be kept as open spaces.
- Grassland areas around the sports fields and student residential surroundings should also only covered with low-height vegetation grasslands to keep a clean view, healthy environment and aesthetical purpose. These constraints should be considered although it will be limited the design and develop scenarios for sustainable University of Twente campus management.

3. MATERIALS AND METHODS

3.1. Dataset and Materials

Datasets

This research used various dataset to obtain the research objective. The datasets were comprised of spatial data and non-spatial data. Details datasets and its sources are described in the Table 2.

Table 2. Datasets used for research

No		Data	Sources
1. Spatial data			
	a.	Google Earth images with the acquisition date on 31 Dec 2005; 23 April 2006; 27 Feb 2007; 9 Feb 2008; 2 April 2009; 24 March 2011 and April 06, 2012 Compass	http://www.earth.google.com
	b.	Topographic map of UT with the scale of 1:10,000	http://www.kadaster.nl
	c.	Management map of University of Twente with the scale of 1:2,500	University of Twente
2. Non-spatial data			
	a.	Energy consumption of University of Twente year 2005 – 2013	University of Twente
	b.	Documentary and reports of University of Twente	University of Twente

Field Instruments

Various field instruments were used to collect data during field work which mainly related to carbon stock estimation in the University of Twente. Details of the field instruments and its purposes are shown in the table 3.

Table 3. Field instruments used for research

No	Instruments	Purpose
1.	GPS and IPAQ	navigation
2.	Compass	navigation and tree positioning
3.	Measuring tape, 30m	Measuring radius of plot and trees distance
4.	Diameter tape	Measuring diameter of tree at breast height
5.	Altimeter	Measuring tree height
6.	Soil sampling kit (i.e. hammer, spade, soil sample rings, soil sampler, field knife)	Collecting soil sample
7.	Data sheets and stationary	Collecting field data

Software and Tools

Different software was used to analyse data which mainly related to spatial data analysis and numeric calculation for carbon balance estimation. Details of software and its specific use are described in the Table 4.

Table 4. Software used for research

No	Software	Purpose
1.	ArcGIS 10.2	For vector analysis and map layout
2.	eCognition Developer 8.8	For raster analysis in particularly to obtain land cover map of University of Twente
3.	Google Earth Plus	For download Google Earth imageries
4.	sexiFS	For making cross section of plot measurements
5.	Microsoft Office 2010	For numeric analysis and reporting

3.2. Methods

The method of this research were consisted of: (1) calculating carbon stock of green areas, (2) calculating carbon emission and carbon sequestration of green areas, (3) calculating carbon balance of the green areas and (4) developing and comparing scenarios in terms of carbon balance. The carbon stock in University of Twente was calculated based on the above ground carbon stock and the soil organic matter. The estimation of above ground carbon stock has been carried out based on biomass estimation of trees at the University of Twente; whereas for soil organic matter in grasslands area was estimated based on laboratory analysis. Another carbon pool namely dead organic matter (i.e. dead wood and litter) was not included in the measurements since their amount was considered relatively small in University of Twente and the data about dead organic matter was limited. The details of each step are explained as follows.

3.2.1. Reconnaissance Visit

A reconnaissance visit was conducted to get an overview about the land use and land cover in University of Twente campus. Before the reconnaissance visit, an interview with the University of Twente energy coordinator and the maintenance manager, namely John Susebeek and André de Brouwer has been done to get information about land management of the University of Twente campus. From the interview, a management map showing the information about the area managed by the University of Twente was defined to be the study area boundary. The University of Twente boundary map then was used to overlay a land cover map from the TOP10NL to provide a preliminary land cover map in University of Twente (see Figure 4). The results from the preliminary land cover map and reconnaissance visit then were used for preparation of sampling design for carbon stock estimation of the University of Twente.

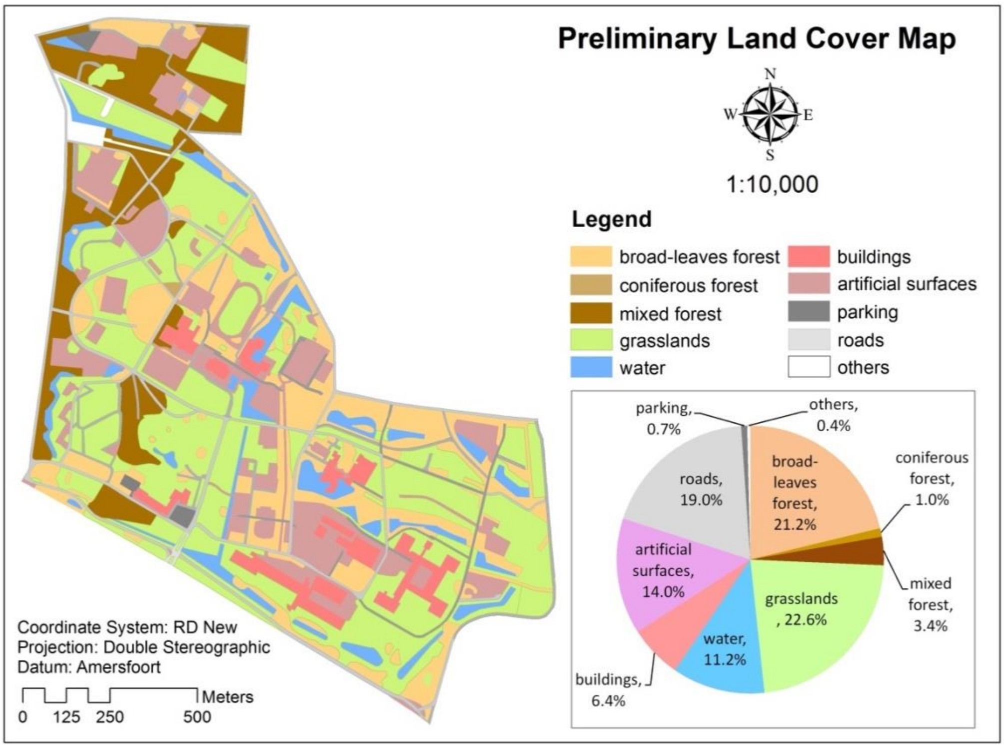

Figure 4. Preliminary land cover map of the University of Twente from TOP10NL map

3.2.2. Sampling Design

The sampling design of plot measurements was determined on preliminary land cover map derived from the TOP10NL map. Two sampling designs were used in this study which are stratified random sampling for trees carbon stock estimation and purposive sampling for grass and soil organic matter estimation. Stratified random sampling was selected to ensure tree biomass representation within all different tree types (i.e. broad-leaved, coniferous and mixed trees) in the study area. In each tree type, a number of plots with a circular shape were established. The circular plot was selected for the tree biomass calculation because it was simple to implement in the field, less problematic than other plot shapes (e.g. square, hexagon, etc.) in deploying the exact shape and size of a plot and requires fewer personnel to establish a plot (DOF, 2004). The number of sampling plots for trees biomass calculation is determined using the equations provided by DOF (2004), as follows:

$$Area\ of\ sampling\ (a) = \frac{sampling\ intensity\ (I) x\ total\ area\ (A)}{100} \quad \text{(eq.1)}$$

$$Number\ of\ plots\ (n) = \frac{area\ of\ sampling\ (a)}{area\ of\ single\ sample\ plot\ (p)} \quad \text{(eq.2)}$$

where sampling intensity was determined 4% of the total forest areas. The 4% value was considered sufficient to represent the actual condition since the stratification approach increases the homogeneity (Ravindranath and Ostwald, 2007).

The circular plot was made with 12.62 meters radius, 500m² sizes of sampling plot. Within the plot, trees with the diameter at breast height (DBH) ≥ 1 cm were measured. A limit of diameter at breast height above 1 cm was selected to ensure all potential carbon stock from trees at any life stages were included in the carbon estimation.

A purposive sampling method, basically a sampling selection based on the judgement of the researcher (Ravindranath and Ostwald, 2007), was selected for estimating grass carbon stock. The plot locations and size for grass carbon stock estimation was determined based on a relative measure of the researcher which considering the distribution of grassland in the UT. In each plot, grass species were identified and a number of soil samples were taken for laboratory analysis. Empirical soil carbon stock estimation in different grassland management is important since carbon accumulation in grassland ecosystems occurs mostly below ground beneath the soil (Soussana et al., 2007). In addition, a number of soil samples were also taken in each tree type to represent total carbon stock in the green areas of the University of Twente.

3.2.3. Data Collection

The objective of data collection was mainly to obtain data for carbon stock estimation of University of Twente. Several plot measurements as mentioned in the prior section were established to collect field data for carbon stock estimation. The data collection for tree carbon stock estimation was comprised of the parameters as follows: (1) name of species, (2) tree diameter at breast height (dbh), (3) tree height; (4) tree position from the centre of the plot and (5) crown radius. The first two parameters were used to estimate the biomass using allometric equation whereas the other parameters were used to make the cross section of each plot. The aim to make plot profile was to provide information about the vegetation composition per plot measurement which later used for further analysis in the scenarios development.

Name of species

The first parameter to be recorded was the name of the species including determining the divisions (i.e. coniferous or broad-leaved). The species identification was done by visual identification on tree physical condition. For tree which researcher was doubtful about the species name, a sample of leaves was taken for further identification based on literature study.

Diameter at breast height (DBH)

The diameter at breast height (DBH) was one of the most important parameters and represents the volume or weight of a tree, which converted to biomass per unit area (tonnes/hectare or tonnes/hectare/ year) (Ravindranath & Ostwald, 2007). DBH was directly measured in the field using phi-band on tree stem at 130 cm above the ground. The techniques to measure DBH in the different tree and topographic characteristics are described in the Figure 5, while the Figure 6 shows the DBH measurement of the trees in the field.

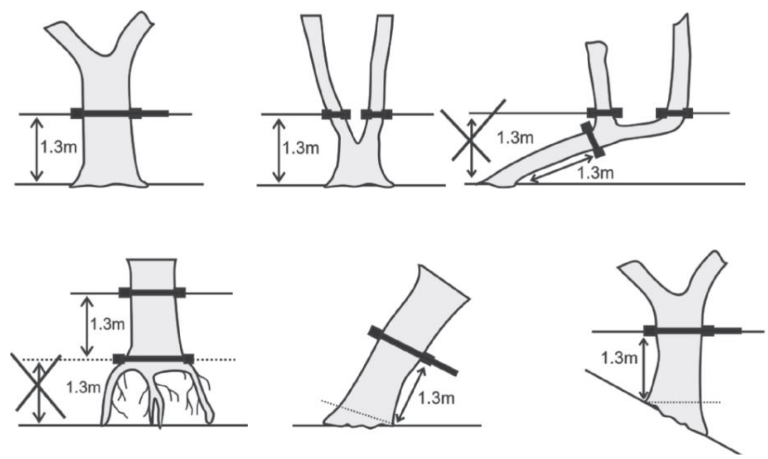

Figure 5. Measuring Diameter at Breast Height (DBH) for trees with different characteristics (Ravindranath and Ostwald, 2007)

Figure 6. Diameter at Breast Height (DBH) measurement conducted by surveyor in the field

Tree Height

Tree height is also an important parameter besides DBH to measure biomass of a tree. An altimeter with the producer of Haga was used to measure height directly in the field. Each tree was measured three times to minimize human error. The final tree height was acquired based on the average value.

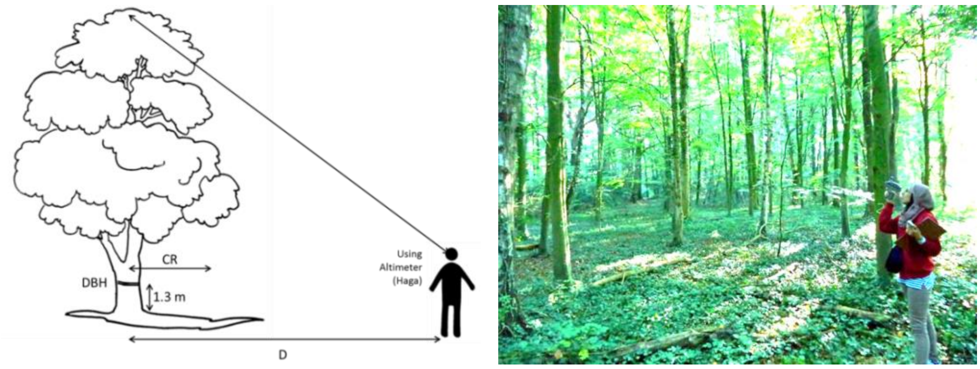

Figure 7. The illustration of tree parameters measurement in each plot, where CR is Crown Radius, DBH is Diameter at Breast Height, D is distance between surveyor and the observed tree when measuring tree height using altimeter (Haga). The D value is depending on the scale used in the altimeter which mostly is 15 metres (left).The researcher measure tree parameters on the field (right).

Tree position from the centre of the plot

The tree position was determined based on the angle and the distance of the estimated tree from the centre of the plot. A compass and a measuring tape were used to estimate the slope and the distance, respectively.

Crown radius

Crown radius is the length of foliage and branches growing outward from the trunk of the tree. Since tree foliage and branches commonly grows in irregular shape which is mostly influenced by tree competition (Pretzsch, 2009), a simplification was made using a circle shape for each tree. The radius of crown was estimated based on an average of visual estimation from two surveyors on the same tree.

For grasslands, the data collection in each plot was the dominant species and the type of land use management. Since the grassland in UT are frequently mown which make difficult to measure the carbon stock based on its standing grass stock, the carbon stock was estimated based on the soil carbon content measurements. The data collection process for measuring soil carbon content comprised of several steps such as: (1) following Hairiah et al. (2011) a soil sample in three different depth i.e. 0-10 cm, 10-20 cm and 20-30 cm was taken in each plot, (2) the undisturbed soil sample was collected using soil ring with an internal diameter of 57 mm and 40.5 mm high, giving the volume of 100 cm^3, (3) the collected soil sample then immediately analysed for organic matter content in the ITC laboratory within 24 hours after taken from the field. A similar procedure was executed for measuring soil carbon stock in different tree types. The details of soil carbon calculation were described in Section 3.2.5.

3.2.4. Image Segmentation for Land Cover Classification

To estimate the total carbon stock in the UT, the carbon estimation at a plot area was extrapolated at the campus area, under assumption that 4% of sampling intensity could represented the whole area. For that reason, information about the current land cover types and areas must be obtained. The available land cover map from TOP10NL map was considered not up-to-dated since several buildings (constructed in 2008-2010) were not detected indicating bias in the land cover areas. As a result, a current land cover map of UT was acquired from a high resolution remote sensing data. A high resolution data (i.e. spatial resolution is less than 1 metre) was needed to provide a detailed land cover map so as to every land cover patches in UT could be detected. The high resolution remote sensing data was made available by Google Earth. The most recent Google Earth image available for UT was acquired on April 6, 2012. The Google Earth image was downloaded using 'save-images' tools in the Google Earth Plus software with a premium quality (4,800 x 3,225 pixel size) to maintain the high resolution image. The procedures to download the Google Earth images followed several steps as follow: (1) zoom-in the Google Earth image into optimum resolution where the object on images appeared a clear view, (2) save the image in a premium quality, (3) move to another location on map and repeat the prior steps until area of University of Twente was covered. Figure 8 shows the Google Earth image downloading process using Google Earth Plus software.

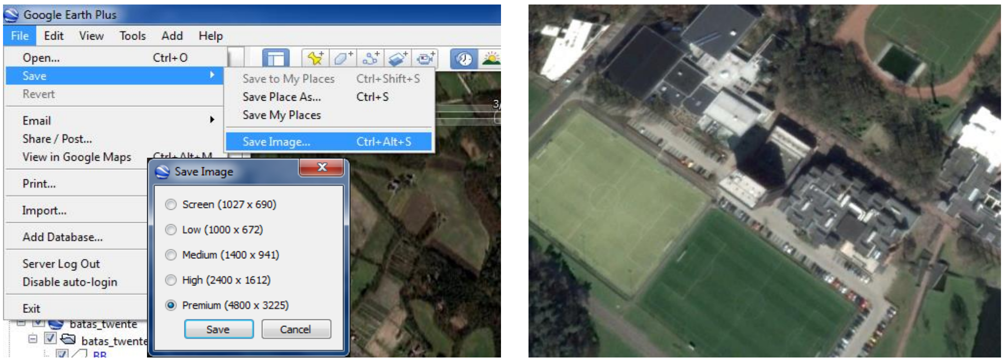

Figure 8. The procedure to download Google Earth image (left). A part of area in the University of Twente which was downloaded in a premium quality by Google Earth Plus software (right)

A land cover map was extracted based on the Google Earth image, using image segmentation procedure by eCognition software. Before image processing, two steps of pre-processing analysis have been applied for the selected images such as: (1) a geometric correction, performed to correct errors in object positioning of the earth surface. The image was geo-referenced using image-to-map registration based on the nationwide TOP10vector map of the Netherlands scale 1:10.000 from the Land Registry Kadaster (Land Registry, 2014); (2) a masking analysis, performed to obscure the area beyond our study area. The study area boundary map defined from University of Twente was used for delineating our study area. After the pre-processing analysis completed, a segmentation process was applied to distinguish each object which had similar characteristics found on the image. Image segmentation is a process of completely partitioning an image into non-overlapping regions (segments) in scene space (Schiewe, 2002). Using Multiresolution Segmentation Algorithm tool in eCognition software, adjustment in object parameter was determined based on trial and error process to visually determine the optimum parameter values. Table 5 shows the adjustment results after trial and error in the segmentation process for this current study.

Table 5. Parameter values after trial and error process in image segmentation adjustment

Parameter	Value
Scale	50
Color	0.99
Shape	0.01
Smoothness	0.5
Compactness	0.5

The accuracy of the resulted segmentation was assessed using 'goodness of fit' (D) proposed by Clinton et al. (2008). The quality of segmentation outputs were determined by the goodness of fit (D) value for under segmentation and over segmentation. Under segmentation is defined as a condition where two or more objects are located within single segment (e.g. a building and a tree are in one segment). Over segmentation is defined as a condition where one object is located within two or more segment (e.g. a tree is located in two or more segment). The goodness of fit (D) was calculated using following equation.

$$Over\ segmentation = 1 - \left[\frac{area\ (Xi \cap Yj)}{area\ (Xi)}\right] \quad \text{(eq.3)}$$

$$Under\ segmentation = 1 - \left[\frac{area\ (Xi \cap Yj)}{area\ (Yj)}\right] \quad \text{(eq.4)}$$

$$Goodness\ of\ fit = \sqrt{\frac{(Over\ segmentation^2) + (Under\ segmentation^2)}{2}} \quad \text{(eq.5)}$$

where Xi = training objects and Yj = set of all segments (in the segmentation). The goodness of fit (D) value increase following the higher of over segmentation and under segmentation of the objects, showing mismatch level between objects segmented (Workie, 2011).

The accuracy assessment was executed iteratively until the segmentation results show a good result according to Clinton et al. (2008). Next, the segmentation results were reclassified into land cover classes based on land cover map from Top10Vector at scale 1:10,000. For land cover classification system, this study used a land cover classification from the Eurostat Land Use/Land Cover Area Frame Statistical Survey (LUCAS) classification (European Union, 2015). Using LUCAS classification system, eight land cover classes were identified in UT such as: broad-leaves trees, coniferous trees, mixed trees, grass, water, buildings, artificial surface and bare soil. Broad-leaves trees is tree-covered areas which are dominated by broad-leaves species (>60% cover). Coniferous trees is tree-covered areas which are dominated by conifer trees species (>60% cover). Mixed forest is forest areas which neither broad-leaves species nor coniferous species dominated (50%-50% or 40%-60%). Grassland is described as areas dominated by grass. Water is surface water within the study area which refers to rivers, lakes and ponds. Buildings are described as a result of human activities for built-up areas. Artificial surface is associated with artificial cover as a result of human activities for transportation, such as roads and parking areas. Bare soil is described as areas that do not have an artificial cover with less than 4% vegetative cover. We deliberately distinguished artificial surface areas and built-up areas since those two classes represent different human-related activities which later are used for further analysis.

An error matrix (Congalton, 1991) was made to calculate the accuracy of land cover classification using four measures: the producer's accuracy, the user's accuracy, the overall accuracy and the Kappa coefficient. The producer's accuracy was to measure how well the accuracy of certain area can be classified, the user's accuracy was to measure how well the reliability of classes in the classified image, the overall accuracy was to measure the total number of correct samples divided by total number of samples and the Kappa coefficient was the coefficient of agreement between the classification map and the reference data. The accuracy of land cover classification was calculated using following equations (Foody, 2002).

Actual Class

Predicted Class	A	B	C	D	Σ
A	n_{AA}	n_{AB}	n_{AC}	n_{AD}	n_{A+}
B	n_{BA}	n_{BB}	n_{BC}	n_{BD}	n_{B+}
C	n_{CA}	n_{CB}	n_{CC}	n_{CD}	n_{C+}
D	n_{DA}	n_{DB}	n_{DC}	n_{DD}	n_{D+}
Σ	n_{+A}	n_{+B}	n_{+C}	n_{+D}	n

$$User's\ accuracy = \frac{n_{ii}}{n_{i+}} \qquad \text{(eq.6)}$$

$$Producer's\ accuracy = \frac{n_{ii}}{n_{+i}} \qquad \text{(eq.7)}$$

$$Overall\ accuracy\ (\%) = \frac{\sum_{k=1}^{q} n_{kk}}{n}\ x\ 100 \qquad \text{(eq.8)}$$

$$Kappa\ coefficient = \frac{n\sum_{k=1}^{q} n_{kk} - \sum_{k=1}^{q} n_{k+}n_{+k}}{n^2 - \sum_{k=1}^{q} n_{k+}n_{+k}} \qquad \text{(eq.9).}$$

3.2.5. Carbon Stock and Carbon Sequestration Estimation

In this present study, the biomass for trees and grass was calculated using non-destructive method which was performed by using the allometric equations from Lambert et al. (2005). The similar allometric has also been used by Workie (2011) to estimate biomass in Haagse Bos and Snippert Forest, The Netherlands. The allometric equations were available for softwood and hardwood trees which in this present study were defined as coniferous trees and deciduous trees. By using the parameters measured from the plot measurement (Section 3.2.3), the biomass estimation for each plot were estimated.

Table 6. Allometric equation for softwood and hardwood trees (Lambert et al., 2005)

	Dry biomass (kg)	
	Softwood	**Hardwood**
Stem wood	= 0.0648 * (DBH^2.3923) + 0.0107	= 0.0871 * (DBH^2.3702) + 0.0493
Branch dry	= 0.0156 * (DBH^2.916) + 0.0005	= 0.0167 * (DBH^2.4803) + 0.0002
Foliage dry	= 0.0861 * (DBH^1.6261) + 0.0006	= 0.0340 * (DBH^1.622) + 0.0056
Bark dry	= 0.0162 * (DBH^2.1959) + 0.0001	= 0.0241 * (DBH^2.1969) + 0.0030
AGB = [Stem wood biomass + Branch biomass + Foliage biomass + Bark biomass]		

To determine the soil carbon, destructive techniques was obtained to quantify organic matters and carbon in the soils (Schumacher, 2002). There are three methods of destructive techniques; however in this research the dry combustion followed by ashing method was chosen. This method was simple, using no hazardous chemical which result to no waste, thus more environment-friendly, compared to the other methods of destructive techniques such as the Walkley-Black method. The laboratory analysis of soil organic carbon was using the method for ash and organic matter content ASTM D2974 1988. For sample preparation, the 36 soil samples were dried in the oven (105°C, 24 hours) and the mass of wet and dried is weighted. A 2-grams sample of each oven-dried-soil-sample was weighed into a crucible and put in the 550°C furnace for 16 hours (Andrejko et al., 1983). After 16 hours, the crucible and the ash were removed from the furnace, placed and covered in a desiccator to cool and finally weighed by analytical balance with 0.1-mg accuracy. Figure 9 shows the tools and process in the ITC laboratory for soil analysis. Next, within the ash content, % organic matter and % carbon were calculated using the following equations.

$$Ash\left(\frac{g}{100g}\right) = \left[\frac{(a-c)}{(b-c)}\right]x100 \qquad \text{(eq.10)}$$

$$\%\,Organic\ matter = 100 - \%\,ash\ (mineral\ content) \qquad \text{(eq.11)}$$

$$\%\,Carbon = \frac{\%\,Organic\ matter}{2} \qquad \text{(eq.12)}$$

Where a = final weight of crucible and ash, b = weight of crucible and sample and c = weight of empty crucible. According to Nelson & Sommers (1982), the conversion factor of organic matter to carbon with a factor of 2 found to be more appropriate then the former factor of 1.72.

Figure 9. The soil carbon laboratory analysis (soil samples preparation, soil samples were weighed before and after drying, the ashing method and the weighing of soil samples using analytical balance).

Biomass estimation for UT campus was obtained by upscaling the biomass estimation at plot level into campus area. The upscaling process was executed by multiplying the biomass estimation at plot level and the total area of the plot representation. The equation of biomass estimation at university level is expressed in the eq.13, and the carbon stock estimation is expressed in the eq.14.

$$TB = \sum TB_i * A_i \quad \text{(eq.13)}$$

$$TCS = \mu TB \quad \text{(eq.14)}$$

Where: *TB* is Total Biomass (kg), *A* is area per land cover type *I* at university, *TCS* is Total Carbon Stock, μ is conversion factor which is determined 0.47 according to IPCC (2006).

Carbon sequestration in this study is defined as the amount of carbon stored in the green space carbon reservoir in time. Estimating carbon sequestration requires estimation on the overall balance between photosynthetic gain of CO_2 and losses in ecosystem respiration as well as lateral flows of carbon (Chapin et al., 2006) which is a complex calculation and needs a long term empirical carbon measurements. Due to the data limitation, this study estimated carbon sequestration based on the change of carbon stock in time. The carbon stock change estimations were performed based on land cover change extracted from Google Earth images from prior dates i.e. year 2005, 2006, 2007, 2008, 2009 and 2011. The procedures to obtain land cover map for each year were similar to the Section 3.2.4. In addition, the amount of carbon sequestered was also estimated based on the vegetation growth which was obtained from Bascietto et al. (2004) for broadleaves tree, Churkina et al. (2003) for coniferous tree and grasslands (Ammann et al., 2007; Jones et al., 2006). An average carbon sequestration rate from broadleaves and coniferous was used to determine the carbon sequestration for mixed trees. Table 7 shows the assumption based on literature used in this study to measure carbon sequestration.

Table 7. Carbon sequestration rate for different land cover types

Land cover	Carbon sequestration (ton/ha/year)	Remarks
Broadleaves	2.18±0.562	Based on empirical measurements using tree rings. The value is an average value for 70 years old tree
Coniferous	2.00±1.00	Based on biogeochemistry model. The value is the mean value of their estimation range
Mixed	2.09	
Grassland (lawn)	1.47±1.30	Based on measurement of intensive managed grasslands
Grassland (pastures)	1.39±0.58	Based on the empirical measurements of cattle manure on grasslands

3.2.6. Carbon Emission Estimation

3.2.7. Carbon emission Estimation

The carbon emission from the University of Twente campus consists of the energy consumption from the buildings or human activities and emission from maintenance of the green areas. From the data about energy use 2005-2013, following Kuipers (2012) a conversion factor of 0.165 (kg CO_2e/kWh) was multiplied to the energy use to get the total carbon emission. This emission was used as the total emission and to see how much the green area can contribute to the carbon emission from the buildings.

For carbon emission rate of the green areas was based on literature as shown in Table 8. Carbon emission for trees were based on trees management such as applying herbicide and weeds monitoring (Jones et al., 2006). Thinning activities were added as carbon emission which based on the energy use for trees thinning, giving the emission rate of 0.387 ton/ha according to Mangoyana (2011). For the emission rate of different grasslands management were following Jones et al (2006) and Clair et al. (2008).

Table 8. Carbon emission rate for different land cover types

Land cover	Carbon emission (ton/ha/year)	Remarks
Broadleaves	0.031	Based on the post sowing management, such as applying and spraying herbicide
Coniferous	0.031	Based on the post sowing management, such as applying and spraying herbicide
Mixed	0.031	Based on the post sowing management, such as applying and spraying herbicide
Grassland (lawn)	0.492	Based on intensive management which used high nitrogen input and frequent of mowing
Grassland (pastures)	0.174	Based on the empirical measurements of cattle manure on grasslands

3.2.8. Calculating Carbon Balance

Carbon balance is defined as the differences between carbon emission and carbon sequestration within the green vegetated areas. Carbon sources is defined as forest emits carbon more than absorbs carbon, while carbon sink when forest absorbs more carbon than releases carbon. In other words, the green areas acts as carbon source if the carbon emission is higher than the sequestration, while the green areas acts as carbon sink if the carbon sequestration is higher than the emission (see eq. 16). Using the carbon stock and carbon emission data from year 2005, a change trend on carbon balance can be estimated.

$$CB = TCE - TCS \qquad \text{(eq.16)}$$

Where: CB is Carbon Balance, TCE is Total Carbon Emission, TCS is Total Carbon Sequestration.

3.2.9. Scenarios Development

The scenarios development was intended to provide alternatives for future University of Twente land management to achieve sustainability. Some land use types restrict changes in land cover. The scenarios only considered the areas where vegetation or management of vegetation can be changed. Therefore, the first step was to identify the areas where adaptations in vegetation were possible. The potential land use was established based on criteria from University of Twente management i.e. (1) the tree-covered areas should remain forest, (2) grasslands which are used for multi-purposes (such as festivals, camping, recreational), near the sports fields and residential surroundings should be kept as open spaces with low-vegetation species, means the lawn area was not possible to change the vegetation.

Before defining the potential land use map, a current land use map of University of Twente was acquired using the resulted land cover map (see Section 3.2.4) and then reclassified into land use map based on the management map, the relation between land cover and land use in campus area and information from management officers of the University of Twente. The management map of University of Twente was made available from the maintenance manager of University of Twente. To reclassify the land cover map into a land use map, a look-up table was made based on discussion between researcher and the energy coordinator and the maintenance manager of University of Twente. The look-up table was shown in Table 9. Next, the potential land use map was determined based on land cover and information from the energy coordinator and the maintenance manager of the University of Twente.

Table 9. Relation between land cover and land use in University of Twente campus

		Land use						
		Nature conservation	Recreational and multi-purpose use	Sports fields	Agricultural (pastures)	Offices, education, residential	Transport (roads, parking)	Ponds, canals
Land cover	Broad-leaved trees	√						
	Coniferous trees	√						
	Mixed trees	√						
	Grasslands		√	√	√			
	Built-up areas					√		
	Artificial surfaces			√			√	
	Water							√

Based on table 9, it shows that a land cover class can have a different land use, for example grasslands which is used for recreational use, sport fields or agriculture land (grazing area) and artificial surface for transportation or sports fields.

3.2.10. Land Cover Optimization Scenarios

Based on the Greening Universities Toolkit (Osmond et al., 2013), a sustainable campus development should consider several aspects such as environment, ecology and economy. The proposed scenarios for sustainable University of Twente management were developed based on the existing carbon balance and the potential land use. The scenarios were related to the objectives for a "green" and sustainable UT campus, includes reducing carbon emission and enhancing carbon stock/sequestration to achieve carbon balance, also for supporting biodiversity as described in the Greening Universities Toolkit (Osmond et al., 2013).

To achieve the objectives for carbon balance in a "green" and sustainable campus, there are several strategies and scenarios which can be applied, consider adaptation in the green areas and to exclude the buildings which are:

1) Increasing carbon stock.
   The strategy of optimizing carbon stock can be reached by allowing tree growth in forested area, without any harvesting and/or replacing pastures with flower-rich vegetation or carbon crop vegetation. Forest acts as carbon storage, as trees grow over time and absorb carbon from the atmosphere through photosynthesis and deposit the carbon into the living biomass and soil. By simply keep the forest to be undisturbed as nature conservation area or adding/admixing more trees which stored relatively high above-ground biomass and allow the trees to grow will increase the carbon stock of the green areas. Grasslands also contribute as dynamic carbon storage, mainly on below-ground biomass from roots and also soil organic matter. However, grasslands management determines the carbon fluxes for example intensive management with frequent mowing and fertilizer leads to emits carbon, or cattle grazing on agricultural land also emits methane. Therefore good management practices and vegetation types on grasslands were important decision to achieve carbon balance.
2) Increasing carbon sequestration.
   The strategy to increase carbon sequestration can be accomplished by selective harvesting or logging of a portion of the trees in forested areas and/or sequester carbon in grasslands, comparing pastures to lawn grasslands. In this study, carbon stock estimation the plot measurement was used to evaluate the tree types which have relatively low above ground biomass. To achieve this strategy in the tree-covered areas the proposed scenario was to thinning or selective harvesting of the low-carbon tree areas and replacing the species which can increase sequestration with short rotation woody crops such as Willow or Poplar trees. According to Volk et al (2004), Willow (*Salix spp*) was found to be fast growing trees and compared to agriculture or fossil fuel energy, willow was found to be more sustainable and has high energy efficiency ratio. The total carbon emissions of growing Willow trees was found to be 114 kg CE/ha/year or 0.114 ton CE/ha/year (Clair et al., 2008), while Willow trees was found to increase carbon of 5.9 ton/ha/year (Dewar & Cannell, 1992).
3) Reducing emissions by abandoning grazing.
   This strategy focuses on reducing emissions to reach carbon balance. In grasslands used for pastures, cattle grazing emit methane to the atmosphere which leads to greenhouse gases emissions, thus the proposed scenario was to abandoning grazing and reducing the use of inefficient machinery and transport vehicles. This strategy can be achieved by selecting carbon-crop vegetation such as sunflower or rapeseed. Numerous researches have studied about potential crop from sunflower or rapeseed, however the option of growing rapeseed for biodiesel in Europe has relatively low energy efficiency, lower than 2.2 of EROEI according to Van Duren et al. (2015). Sunflower (*Helianthus annuss*) was mainly cultivated as food crops in temperate regions. Based on Buratti et al. (2012) carbon emission of sunflower was found to be 0.484 ton/ha/year and organic dry matter of sunflower yield was found to be 8.13 ton/ha/year (Balodis et al., 2011).

3.2.11. Flow-chart of study

Figure 10 shows flow-chart of the study. The flowchart illustrates the systematic steps to obtain the objective of study.

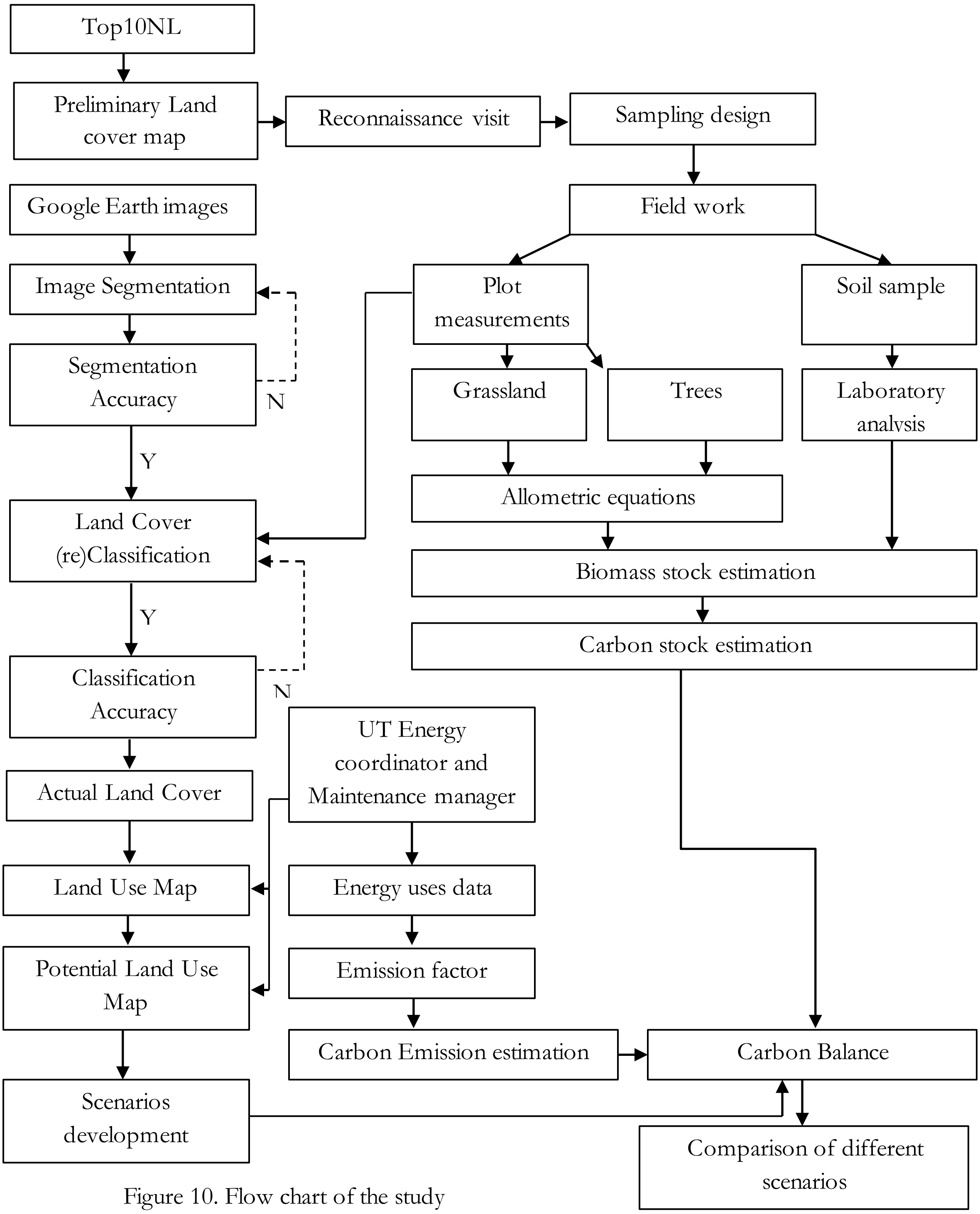

Figure 10. Flow chart of the study

Y = The result of accuracy assessment is classified in a good agreement
N = The result of accuracy assessment is not classified in a good agreement so that the process is looping back (i.e. iterative process).

4. RESULTS

4.1. Land Cover Map

Using adjusted parameter (see Table 5) for object segmentation, the image segmentation of University of Twente was obtained (Figure 11). The result of overall segmentation accuracy assessment was found to be 79.3% which included under segmentation (67.8%) and over segmentation (74.0%). Table 10 shows the segmentation accuracy assessment for each land cover class. It is shown in the Table 10 that the segmentation accuracy of the green areas for broadleaved trees (79.4%), coniferous trees (71.7%) and mixed trees (76/6%) was better than grasslands (59.8%). The image segmentation accuracy for built up areas (88%), bare soil (87.8%) and water (87.9%) was highest among others.

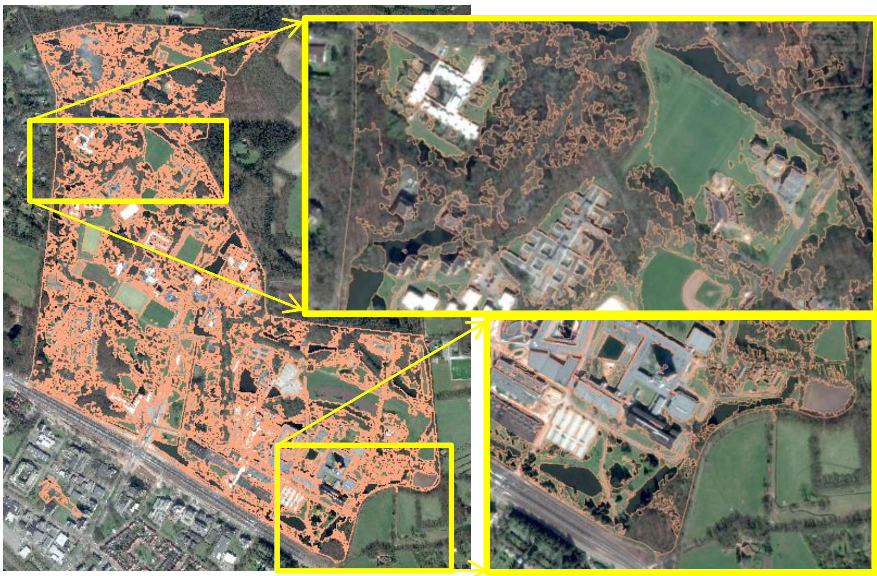

Figure 11. The image segmentation of Google Earth Image for the University of Twente campus area

Table 10. Segmentation accuracy for each land covers class

Class	Over Segmentation	Under Segmentation	D	D (%)
Artificial Surfaces	0.3889	0.4095	0.3993	60.0670
Bare Soil	0.1033	0.1384	0.1221	87.7859
Broad-leaved tree	0.1252	0.2629	0.2059	79.4077
Built-up Areas	0.0306	0.1663	0.1196	88.0423
Coniferous tree	0.1192	0.3819	0.2829	71.7104
Grass	0.3917	0.4120	0.4020	59.8018
Mixed tree	0.1886	0.2725	0.2343	76.5656
Water	0.0176	0.1708	0.1214	87.8566

The under segmentation was found mostly in the built-up area and vegetation area. As shown in Figure 12 (left), the segmentation process between grassland and less vegetated area were difficult to be distinguished. The closeness of colour brightness, smoothness and compactness between the two objects were likely the cause of under segmentation. Figure 12 (right) shows the similar condition which the roof building was not well delineated and interfered by the bare land in the surrounding building area. Similar to the under segmentation, the over segmentation was also found mostly in the built up area and the vegetation area. The segmentation process has not well delineated the shape of the sport yard and the roof buildings. Figure 13 (left) shows the segmentation process cannot well delineated the tree area and resulted in over segmentation. A similar condition occurred for built areas where the segmentation process was difficult to delineate the boundary of the built up areas. The image segmentation was found to be well delineated object especially for a solitaire object. Figure 14 shows examples of good segmentation result where object were well delineated.

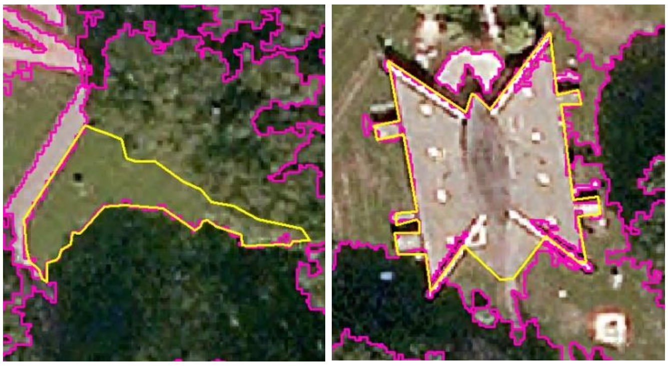

Figure 12. Two examples of under segmentation, the purple colour shows the segmentation line and the yellow colour represents the object delineation based on visual interpretation. It is shown that the purple colour is not well delineated the object.

Figure 13. Two example of over segmentation, the purple colour shows the segmentation line and the yellow colour represents the object delineation based on visual interpretation. It is shown that the purple colour is not well delineated the object.

Figure 14. Two examples of good results of the image segmentation, the purple colour shows the segmentation line and the yellow colour represents the object delineation based on visual interpretation. It is shown that the purple colour is well delineated the object.

The resulted image segmentation then was reclassified based on land cover class from TOP10NL land cover map and field check. Using 210 (unit) of ground truth samples from field check, an error matrix (Congalton, 1991) was performed and resulted to the producer's accuracy with the value of 80.5%, the user's accuracy with the value of 78.6%, the overall accuracy with the value of 86.7% and the Kappa coefficient with the value of 84.0%. The land cover map is shown in Figure 15 and the accuracy assessment is shown in Table 11.

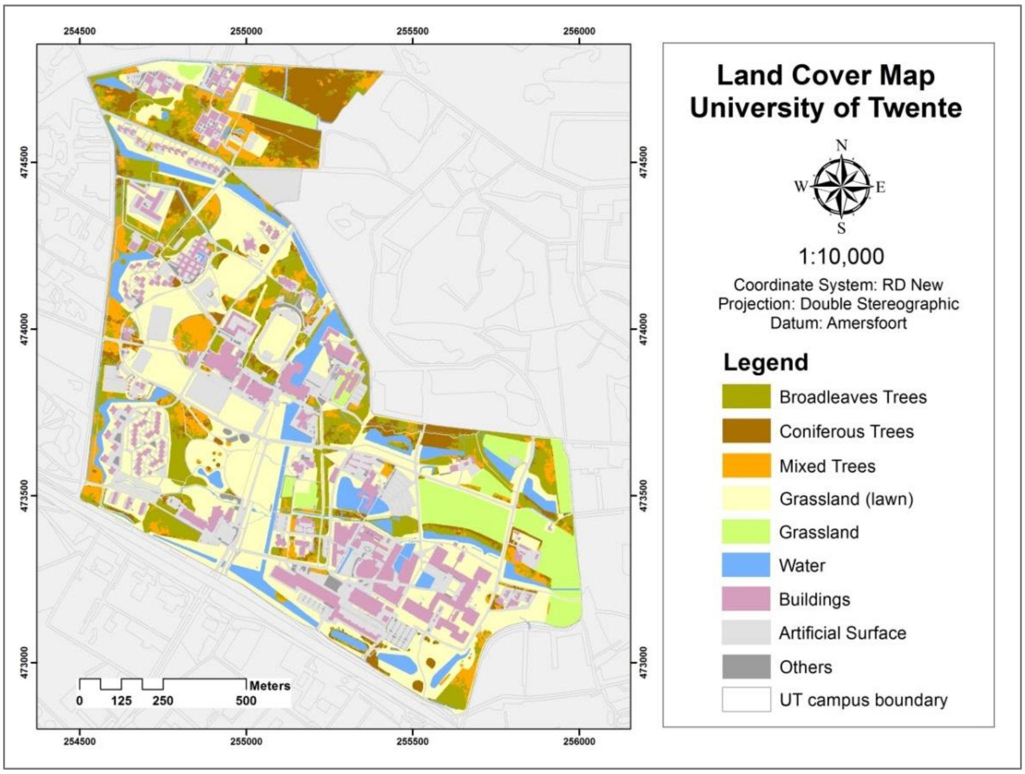

Figure 15. Land cover map of the University of Twente

Table 11. Land cover map accuracy

		Reference									Total	UA (%)
		BF	CF	MF	GL	G	W	B	AS	BS		
Classification	BF	10	1	4							15	66.7
	CF		5	3							8	62.5
	MF	1	2	10				1			14	71.4
	GL				23	3		1			27	85.2
	G				2	14					16	87.5
	W						40				40	100.0
	B				1			52	5	1	59	88.1
	AS							1	26		27	96.3
	BS							2		2	4	50.0
Total		11	8	17	26	17	40	57	31	3	210	
PA (%)		90.9	62.5	58.8	88.5	82.4	100.0	91.2	83.9	66.7		
Total Accuracy (%)			86.7									
Kappa			0.840									

BT = Broad-leaves Trees, CT = Coniferous Trees, MT = Mixed Trees, G = Grass, W = Water, B = Buildings, AS = Artificial Surface, BS = Bare Soil, UA = User's Accuracy, PA = Producer's Accuracy

From the land cover map in figure 15, the area of each land cover class were derived in table 12, which shows the distribution of land cover classes of the study area. The green areas consist of grasslands (lawn and not lawn) and the forest area with three different tree-covered types, namely broadleaves, coniferous and mixed trees. The grasslands and tree-covered area are the most two dominant areas with the total area of 53.9 Ha and 38.4 Ha, respectively. Artificial surface and buildings followed with the area of 28.2 Ha and 15.1 Ha, respectively. The others are together occupied the area of 21.0 Ha.

Table 12. Land cover distribution at the University of Twente

Land Cover	Area (hectares)	%
Broadleaves trees	18.6	11.9
Coniferous trees	10.0	6.4
Mixed trees	9.8	6.2
Grasslands (lawn)	40.8	26.1
Grasslands	13.1	8.4
Water	12.8	8.2
Buildings	15.1	9.6
Artificial Surface	28.2	18.0
Others	8.2	5.2
Total	156.4	

The results of land cover changes analysis presented in figure 16, showing the map of land cover change and table 13 shows the area of land covers which have changed during the period 2005 – 2013. The built up area has increased during the last nine years especially in the period 2005 – 2006 and 2009 – 2012. Grassland area has also increased after the year 2009. The forest areas, particularly broad-leaved trees area has decreased especially in the period 2005 – 2006 and 2009 – 2011. Coniferous and mixed trees areas have been relatively stagnant during the period 2005 – 2013. In general, there was an increasing trend for the area of buildings and decreasing of the trees area (i.e. broad-leaved trees).

Table 13. Change of land cover area in University of Twente for the year 2005, 2006, 2007, 2008, 2009, 2011 and 2013

Land Cover	**Area (hectares)**						
	2005	**2006**	**2007**	**2008**	**2009**	**2011**	**2012**
Broad-leaved trees	21.05	19.99	19.99	19.99	19.99	18.58	18.58
Coniferous trees	9.95	9.95	9.95	9.95	9.95	9.95	9.95
Mixed trees	9.77	9.77	9.77	9.77	9.77	9.77	9.77
Grasslands (lawn)	40.45	40.27	40.27	40.27	40.27	40.89	40.84
Grasslands	13.15	13.15	13.15	13.15	13.15	13.15	13.15
Water	12.71	12.53	12.53	12.53	12.53	12.79	12.79
Buildings	14.22	14.26	14.26	14.26	14.26	15.05	15.10
Artificial surfaces	27.24	28.55	28.62	28.56	28.55	28.20	28.20
Others	8.20	8.20	8.20	8.20	8.20	8.20	8.20

Figure 16. Land cover change map of the University of Twente.

4.2. Carbon Stock Estimation

Empirical carbon stock calculation for trees has been done based on field measurements in thirty sample plots giving an area of sampling 4% which represent different three types of trees in the University of Twente. Based on the plot measurements (see Appendix 2), the majority of the trees were found to be broadleaves trees (73%). The others (27%) were coniferous trees. The dominant species of the broadleaves trees consisted of European Beech (*Fagus sylvatica*), Oak (English Oak/*Quercus robur* and Red Oak/*Quercus rubra*), European White Birch (*Betula pendula*). The coniferous trees consisted of species: Scots Pine (*Pinus sylvestris*), Douglas fir (*Pseudotsuga menzoiesii*), Norway spruce (*Picea abies*) and European Larch (*Larix decidua*). Figure 17 shows examples of tree species found in University of Twente.

Figure 17. The European Beech (*Fagus sylvatica*) and leaves in broad-leaved trees (left). The Scots pine (*Pinus sylvestris*) and Douglas fir (*Pseudotsuga menzoiesii*) coniferous trees in the sample plots (right)

By measuring the canopy cover of the trees within each plot, a plot was defined based on the canopy cover of the trees. The plots which covered by broadleaves trees were found in 20 plots, the plots which covered by coniferous trees found in 3 plots and the plots which considered covered by mixed trees found in 7 plots. The plot profiles (i.e. vertical and horizontal) were made for plot representing broadleaved trees, coniferous trees and mixed trees (see Appendix 3).

The tree parameter used for calculating carbon stock was diameter at breast height (DBH). Trees on the plot measurements were classified based on the DBH values into four different tree size classes (The Good Forestry in the Granite State Steering Committee, 2010), which are seedling with DBH less than 2.5 cm, sapling with DBH 2.5-12 cm, pole with DBH 12-28 cm and trees with DBH more than 28 cm. For broadleaved trees, sapling is dominant (38.9%), followed by seedlings (22.7%), pole (19.7%) and trees (18.7%). While for coniferous trees, trees is dominant (57.1%), followed by pole (29.7%), sapling (10.7%) and seedling (2.5%). Figure 18 shows the trees composition of the forest structure in the plot measurement.

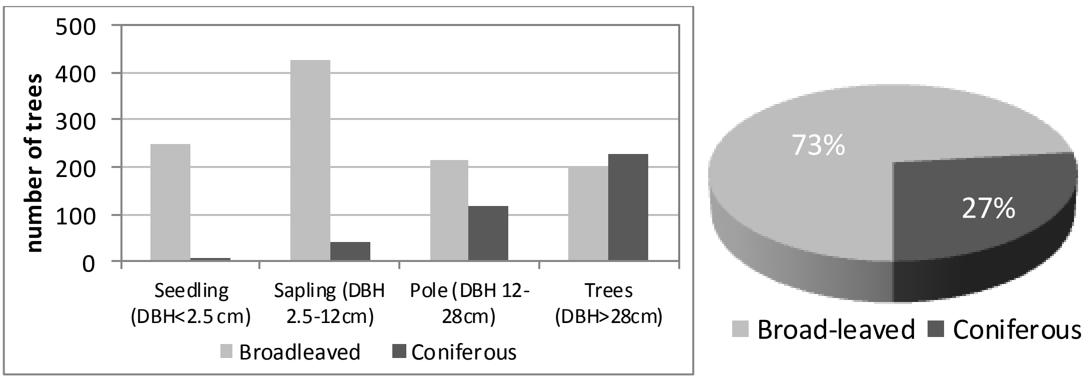

Figure 18. Trees composition in the plot measurements

Based on the plot measurements, the distribution and area of tree types in University of Twente was determined. Broadleaves trees area was found to be dominant with the value of 18.6 Ha (48.5%) and followed by coniferous trees with the value of 10 Ha (26%) and mixed trees with the value of 9.8 Ha (25.5%). The distribution and areas of broadleaves, mixed and coniferous trees were spread over the UT campus area. Figure 19 shows tree types of the University of Twente campus.

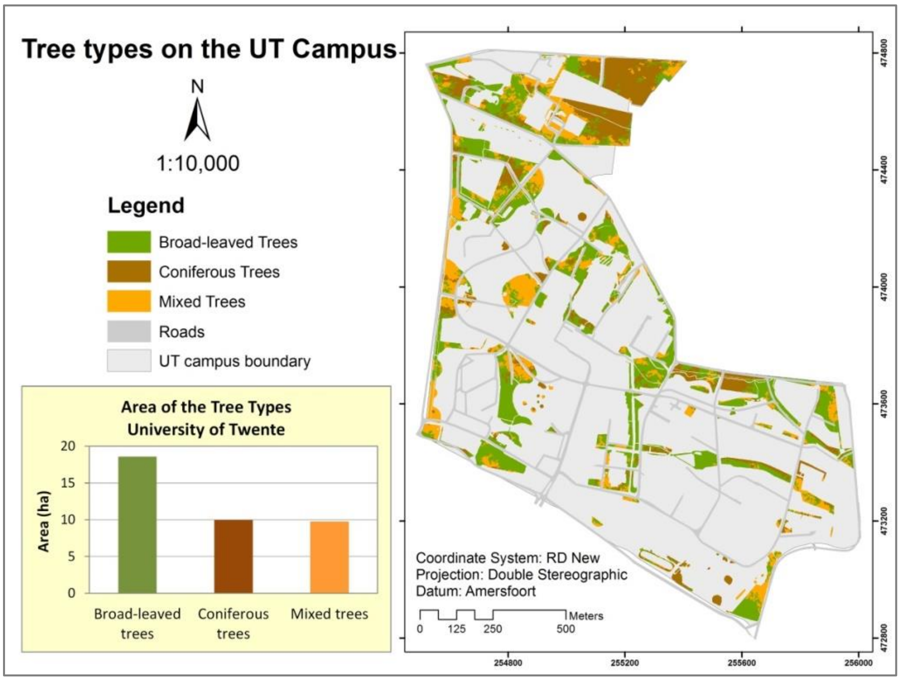

Figure 19. Distribution of tree types and area on the UT campus

The carbon stock for trees was calculated using allometric equation (see section 3.2.5). Using the measured tree parameter of DBH, carbon estimation for each plot was determined and then extrapolated at university level. Figure 20 shows the descriptive statistics of above-ground biomass (AGB) estimation on different tree types (broadleaved, coniferous and mixed trees) based on plot measurements. From the figure 20, the variability of the AGB value in broadleaved trees was higher compared to coniferous and mixed. The highest AGB value was shown in broadleaved trees. Compare to the others, the AGB in coniferous trees was relatively low in terms of value and average. For the mixed trees mean and median have the same value, showing normal distribution of the AGB with low variability.

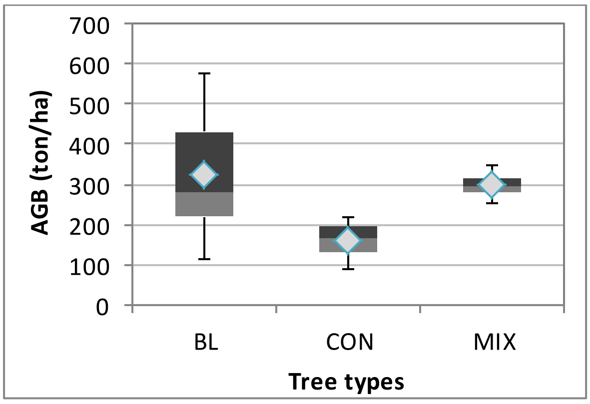

Figure 20. The descriptive statistics of carbon estimation, different tree types based on plot measurements. BL= Broad-leaved trees, Con = Coniferous trees, Mix = Mixed trees.

The above ground biomass and carbon stock for the trees was estimated based on sample plots and presented in figure 21, also the location of soil and grass sample plots in University of Twente Campus.

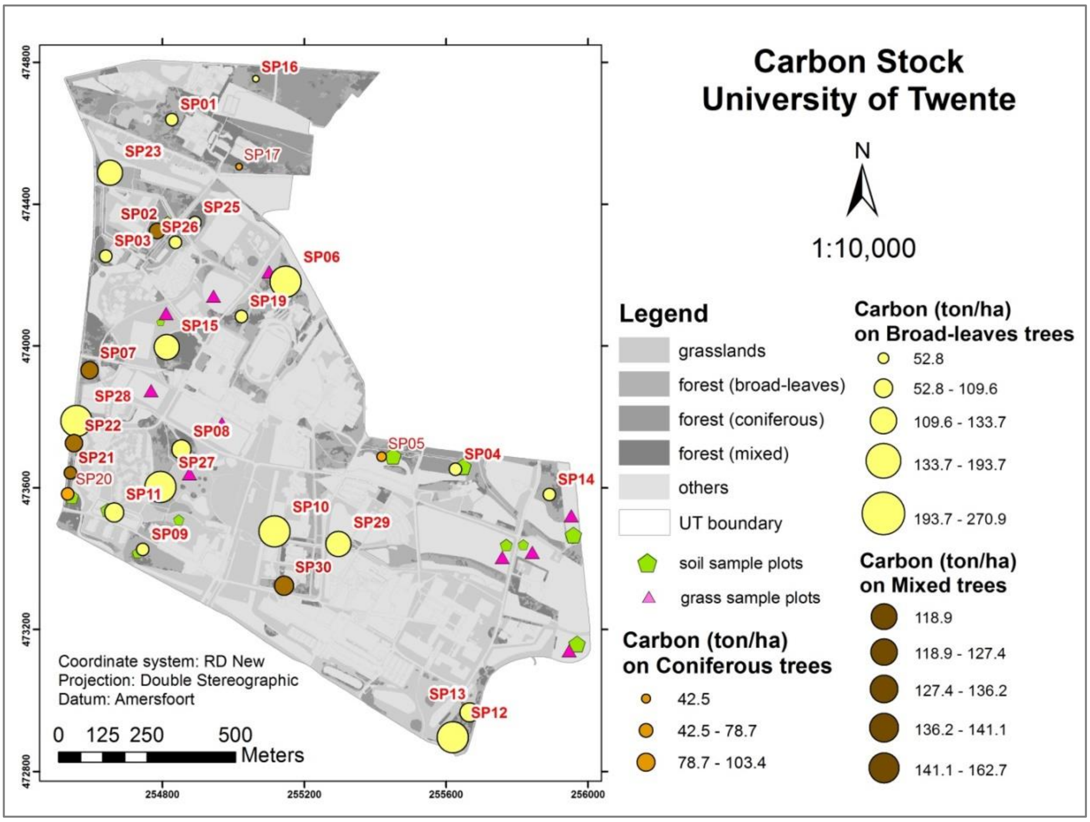

Figure 21. Carbon stock on sample plots

The total carbon stock of University of Twente was estimated based on the sum of carbon stock from above ground (trees) and soil (grasslands and trees) giving a total value of 12045.9 ton. The soil carbon stock (59%) was found to be higher compared to carbon stock of the trees (41%). The carbon stock in trees has the highest value for broadleaved trees of 2817.9 ton, followed by mixed trees of 1373.9 ton and coniferous trees of 741.5 ton. Table 13 shows the total carbon stock for University of Twente for each carbon pool and Figure 22 shows the map of carbon stock in green areas at the University of Twente.

Table 13. Total carbon stock of the UT campus

Carbon pool	Total carbon (ton)	%
Trees	4,933.3	41.0%
- Broadleaves	2,817.9	23.4%
- Coniferous	741.5	6.2%
- Mixed	1,373.9	11.4%
Grasslands		
- lawn	2,420.9	20.1%
- agriculture	857.4	7.1%
Soil in trees area	3,834.3	31.8%
Total	12,045.9	

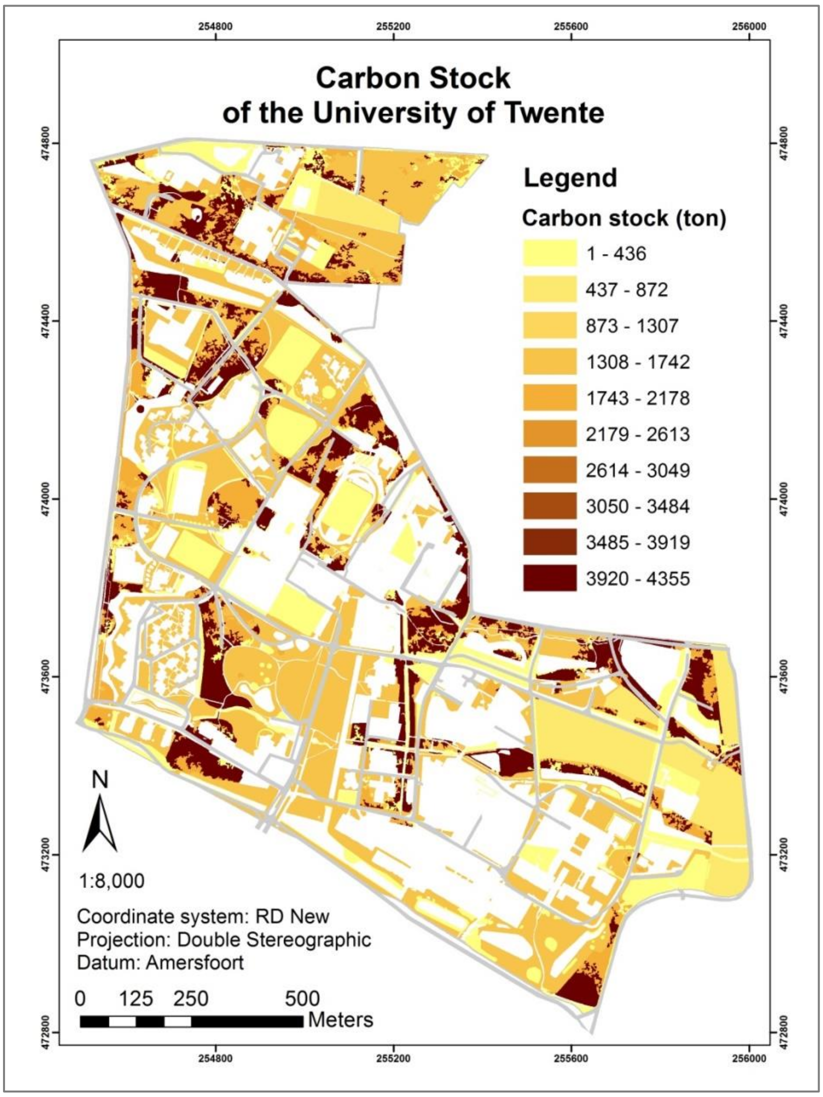

Figure 22. Map of Carbon Stock at the University of Twente

The carbon stock for trees was calculated and the result of total carbon stock for the trees was found to be 4,933 ton with the composition of broad-leaved forest was 2,817 ton (57.1%), coniferous forest was 741 ton (15%) and mixed forest was 1373 ton (27.9%). Based on the AGB for tree per hectare area, broadleaved forest has the largest AGB than mixed forest and coniferous forest with the value of 298.3 ton, 295.9 ton and 159.4 ton, respectively. Total carbon per tree types was estimated by multiplying average AGB with the conversion factor of 0.47 to get the average carbon value, then multiplying average carbon with the total area of each tree types, the total carbon stock for each tree type were calculated as shown in the Table 14.

Table 14. Carbon stock estimation of trees in University of Twente

Tree types	Area (ha)	Average Carbon (ton/ha)	Total Carbon from AGB of trees (ton)	Percentage of Carbon (%)
Broad-leaved trees	18.6	151.5	2817.9	57.1%
Coniferous trees	10.0	74.9	741.51	15.0%
Mixed trees	9.8	140.2	1373.96	27.9%
Total			4933.37	

Based on the results of plot measurements for estimating grass carbon stock, it was found that the species of grassland area was *Holcus lanatus*, *Taraxacum sp*, *Solanum sp*, *Ranunculaceae acris*, *Elymus sp*, *Urtica Dioica*, *Rumex acetosa*, *Plantago*, *Poa annua*, *Trifolum sp*, *Bellis perrenis*, and also presence of herbs and mushroom species. In the grasslands used for agriculture (pastures and meadows), the dominant species was *Holcus lanatus*. Whilst in the grasslands used for recreational and sports fields, the dominant species was *Poa annua* (75-90%) and small presence of *Trifolum sp*. (15-20%). Figure 23 shows several grass species found in the study area.

Figure 23. Grass and herbs species in grasslands area

The carbon content (%) in soil and total soil carbon for depth 0-30 cm for each sample plot is shown in Table 15 as follows. From table 15, the carbon content of the soil in trees areas was relatively higher than in grasslands area. The soil carbon in broad-leaves trees was higher than coniferous trees, while in mixed trees the carbon content value showed a high variation. Soil carbon content in grasslands used for agriculture (pastures or meadows) was higher than showed in recreational/sports field area. In the same agriculture areas, the soil carbon of the meadows was relatively higher compared to the pastures area.

Table 15. Carbon content calculation for each soil sample plot

Land Cover	**Average carbon content (%)**	**Average soil carbon (ton/ha) depth 0-30 cm**
Trees (Broad-leaves)	9.6	96.4
Trees (Broad-leaves)	10.6	133.9
Trees (Coniferous)	8.9	100.2
Trees (Coniferous)	7.5	72.3
Trees (Mixed)	5.9	78.5
Trees (Mixed)	13.4	92.6
Grasslands (recreational)	4.5	69.0
Grasslands (recreational)	2.2	38.1
Grasslands (agriculture-pastures)	6.3	91.5
Grasslands (agriculture-pastures)	4.0	63.2
Grasslands (agriculture-meadows)	8.2	116.5
Grasslands (agriculture-meadows)	9.5	117.8

The table 16 below shows total soil organic carbon estimation in different land cover types for the green vegetated areas, the trees and grasslands. The total soil carbon was calculated from the average carbon for each land cover types multiplied to the area of each land cover types.

Table 16. Soil organic carbon estimation in different land cover types at the UT campus

Land Cover	Average C (ton/ha)	Area (ha)	Total soil carbon (ton)
Trees (Broad-leaves)	115.2	18.6	2139.8
Trees (Coniferous)	86.3	10.0	858.7
Trees (Mixed)	85.6	9.8	835.7
Grasslands (recreational)	53.6	45.2	2420.9
Grasslands (agriculture)	97.3	8.8	857.4
Total			7112.6

The changes of total carbon stock for period 2005-2012 were estimated based on changes in land cover area in University of Twente campus and growth of tree species. Figure 24, 25 and 26 show the change of the forest area, carbon stock and carbon sequestration in the forest area of the University of Twente campus. Changes in total carbon stock for grassland and soil were merely based on the changes of area. The Google Earth image for year 2010 was not available resulting no land cover map of 2010, thus the area in 2010 was compared to the forest area in 2011. This assumption was based on the construction of three new buildings from 2008-2010, and the data of the energy use showing a peak increase in 2010 which was explained by the energy coordinator because of the heating of the old and new building during transition time. Therefore it was concluded that in 2010, it was assumed that new buildings has already present. As shown in Figure 24, the change in broadleaved trees area has an impact on the reduction of the carbon stock. However, trees are growing over time and sequester carbon as shown in coniferous trees and mixed trees. In both plots where forest area remains the same and trees grow, the carbon stock has increased over time. Having the year 2005 as the baseline, in broadleaved trees the area has reduced from 21.1 ha to 18.6 ha period 2005-2012 (-2.5 ha) and the total carbon in 2005 was found to be 3190.4 ton and in 2012 was 3147.2 ton. While in coniferous and mixed trees, the area from 2005-2012 remains the same. For coniferous trees, the total carbon in 2005 was found to be 745.8 ton and in 2012 the total carbon was 885.1 ton. For mixed trees, the total carbon in 2005 was 1370.7 ton and the total carbon in 2013 was found to be 1520.1 ton.

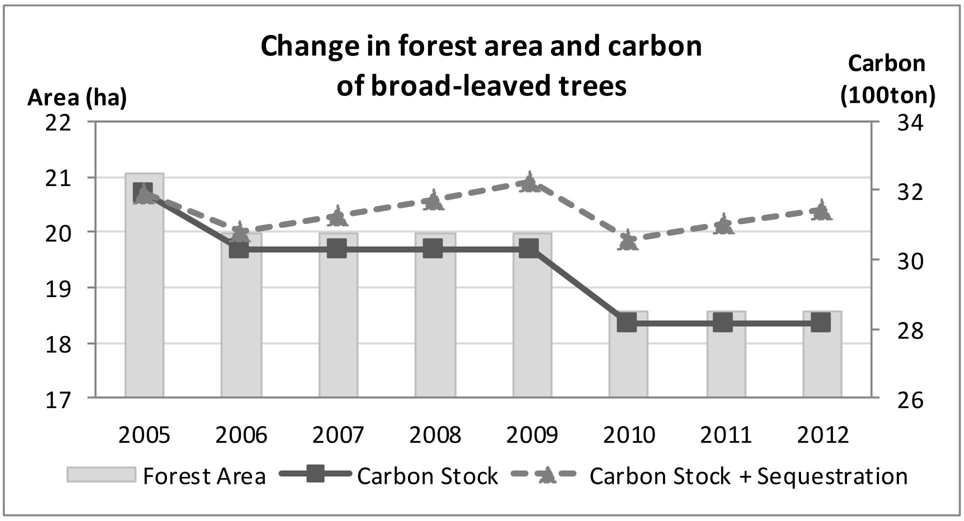

Figure 24. Change in forest area and in carbon of the broad-leaved trees

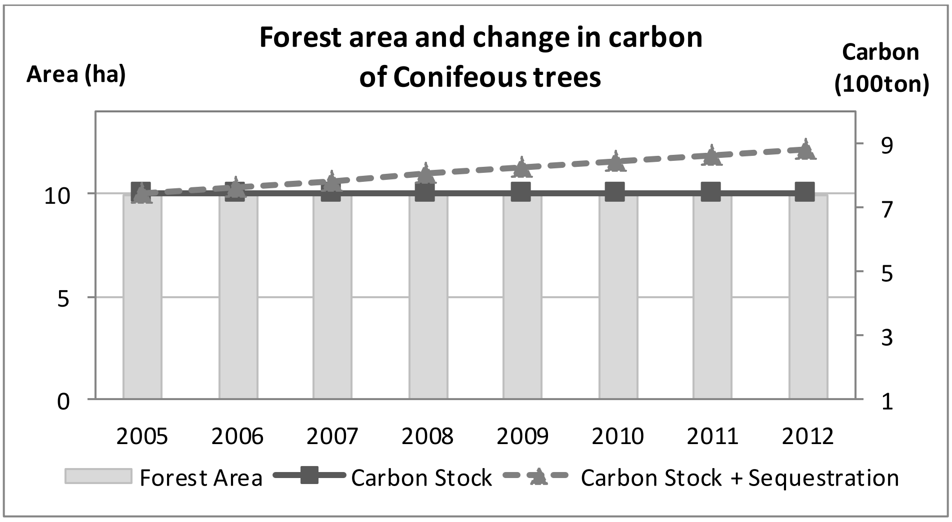

Figure 25. Forest area and change in carbon of the Coniferous trees

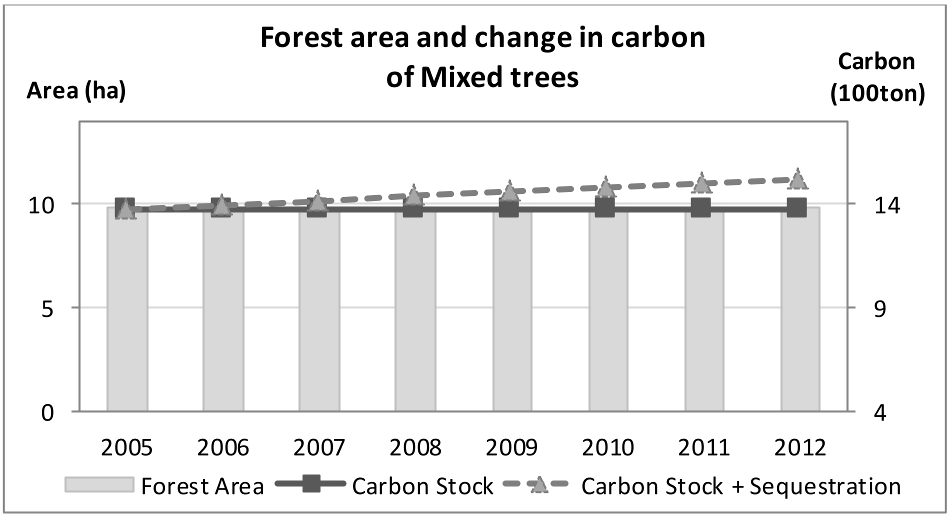

Figure 26. Forest area and change in carbon of the Mixed trees

4.3. Carbon Emission

From the data about energy use 2005-2013, it was found that the carbon emission from the University of Twente buildings in 2013 was 8578.52 ton CO_2-e. This 8578.52 ton CO_2-equivalent value was equal to 2318.52 ton C. This emission was used to see how much the green areas can contribute to the carbon emission from the buildings. While for the green areas, the total carbon emission was found to be 24.9 ton/year, where the highest emission was from lawn grasslands 22.2 ton/year (89.1%), followed by grasslands (agriculture) 1.5 ton/year (6.1%), and from the broadleaved, coniferous and mixed trees which are 0.6 ton/year (2.3%), 0.3 ton/year (1.2%) and 0.3 ton/year (1.2%).

4.4. Carbon Balance

The carbon sequestration was calculated and resulted to be 159.6 ton/year, consist of sequestration from lawn grasslands 66.3 ton/year (41.6%), followed by broadleaved trees 40.5 ton/year (25.4%), mixed trees of 20.5 ton/year (12.8%), coniferous trees of 20.0 ton/year (12.5%) and from grasslands (agriculture) 12.2 on/year (7.7%). The total carbon emission from the green areas is 24.91 ton/year, while total carbon sequestration from the green areas is 159.56, which result on the total carbon balance of 134.7 ton/year.

4.5. Land Use and Potential Land Use Map

The land cover map was used as a basis to acquire the land use map for University of Twente. The land cover map was reclassified into land use map and validated based on the information from the management office of the university. Grassland areas were divided into two classes based on different usages and managements i.e. agriculture (pastures) and recreational (multi-functional use). The grasslands for recreational, transport facilities, broad-leaves forest and buildings and residential are the dominant land uses with the area of 40.8 Ha, 25.0 Ha, 18.6 Ha and 15.1 Ha, respectively, as presented in table 17. The other land uses were occupied by coniferous forest, mixed forest, grass land for others purpose besides recreational uses, park/garden, water and others (i.e. construction zone, private area, etc.). Figure 27 shows the land use spatial distribution of the University of Twente.

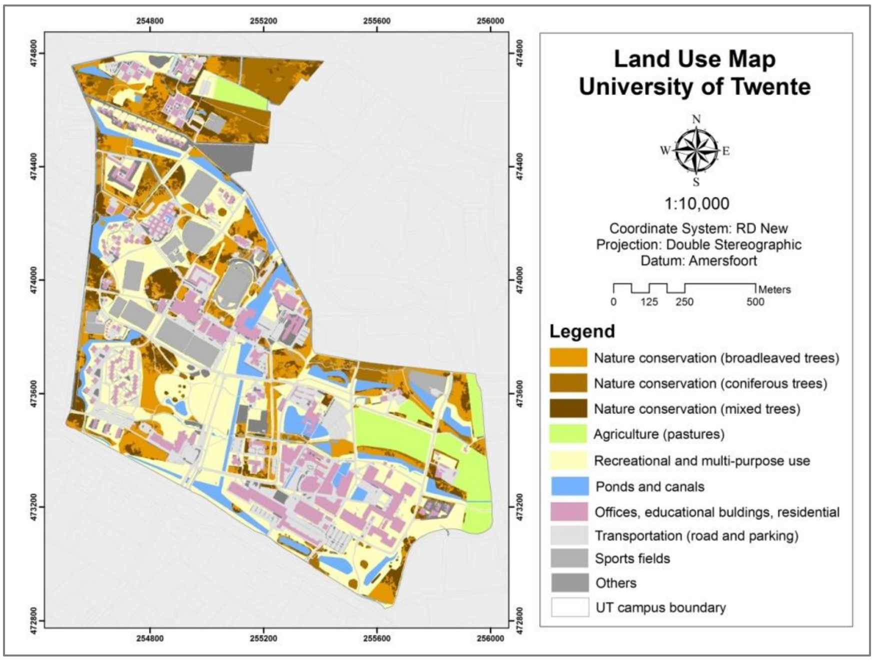

Figure 27. Land use map of the University of Twente campus

Table 17. Land use distribution at the UT campus

Land Use	Area (hectares)	%
Nature conservation (Broad-leaves)	18.6	11.9
Nature conservation (Coniferous)	10.0	6.4
Nature conservation (Mixed)	9.8	6.2
Agriculture (pastures)	8.8	5.6
Recreational and multi-functional use	40.8	26.0
Ponds and canals	12.8	8.2
Offices, Educational, residential	15.1	9.6
Transportation (road and parking)	25.0	16.0
Sport fields	8.2	5.3
Others	7.5	4.8
Total	156.4	100.0

Based on the space availability for potential land use, fixed areas with the area of 109.3 Ha (70%) and potential areas with the area of 47.1 Ha (30%) were determined. The developed scenarios were focused in this 30% green areas of University of Twente to adapt the vegetation and aiming at a more positive carbon balance. Figure 28 shows the potential land use map showing the areas that can potentially be converted to another land cover which is used for developing scenarios.

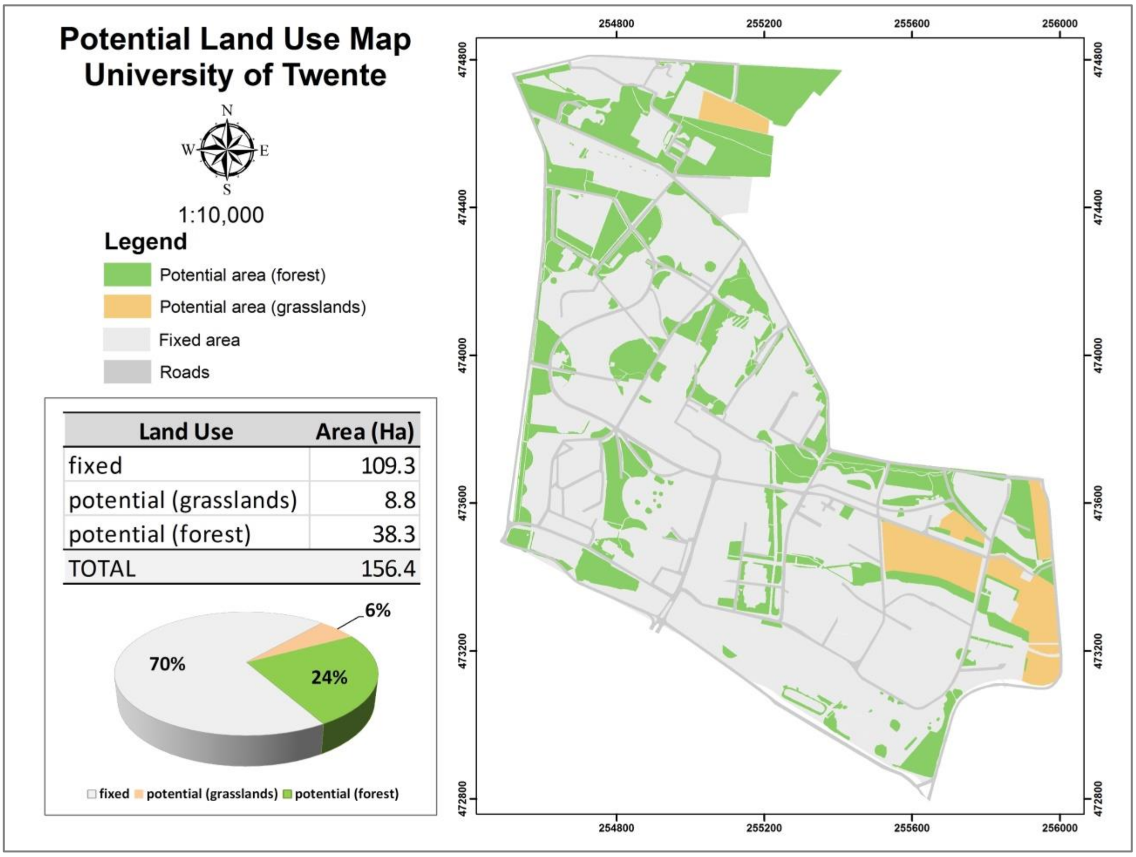

Figure 28. Potential land use map for developing scenarios.

4.6. Scenarios Comparison

Based on the land cover changes of the year 2005-2012 presented in table 13, the forest area (broadleaved trees) has decreased 2.47 ha and the built-up areas (buildings and artificial surfaces) has increased 1.84 ha. From the estimation of carbon stock and sequestration of broadleaved trees in figure 24, the total carbon in broadleaved trees has decreased from 3190.4 ton in 2005 to 3147.2 ton in 2012, although trees are growing and sequester more carbon. Similarly to forest, grasslands area has also changed but it was found to be increase 0.39 ha from 2005 to 2012. The change in grasslands area and types also has consequences in terms of carbon stock, sequestration and emissions. Therefore, several sustainable scenarios are needed to achieve carbon balance of the University campus. The scenarios developed are as follows:

1) Scenario A. Current Situation
   This scenario was the baseline scenario using the existing management plan on the current land cover/use, with no land cover changes to influence the carbon stock, carbon sequestration or carbon emissions. The green vegetated areas which consist of trees and grasslands areas were kept as it is. The estimation of the current carbon emission and sequestration linked to the different vegetation (forest, pastures) types were analysed.
2) Scenario B. Optimizing Carbon Stock in tree-covered area
   This scenario has emphasis on increasing the carbon stock in the green areas (the tree-covered area) by maintaining the trees to grow without any harvesting, 10% of the total tree covered area by admixing coniferous trees into mixed trees and keep the grasslands area as it is. The estimation of carbon emissions and sequestration for the vegetation with trees of particular types were calculated.
3) Scenario C. Optimizing Carbon Sequestration in tree-covered area
   This scenario has focus on increasing carbon sequestration by selective logging of a portion 10% of the trees in the forested areas, therefore carbon emissions due to harvesting and the sequestration for the vegetation will be estimated, while the grasslands areas were kept as they are. The proposed tree species were Willow (*Salix spp.*).
4) Scenario D. Reducing Carbon Emission by replacing current (grazed) pastures with sunflower crop
   This scenario has an aim to keep the tree cover as it is, while reducing emissions by abandoning grazing since cattle emits methane which leads to CO_2-equivalents emissions and reducing the use of inefficient machinery and transport vehicles by replacing pastures with carbon crop vegetation such as sunflower.

Estimation of Carbon Emissions and Carbon Sequestration of Each Scenario

1) Scenario A

Table 18. Carbon balance estimation for Scenario A

	Area (ha)	Emission (ton/ha/year)	Sequestration (ton/ha/year)	Carbon Emission (ton/year)	Carbon Sequestration (ton/year)
Broad-leaved trees	18.6	0.031	2.18	0.58	40.55
Coniferous trees	10.0	0.031	2.00	0.31	20.00
Mixed trees	9.8	0.031	2.09	0.30	20.48
Grasslands (recreational & sports fields)	45.1	0.492	1.47	22.19	66.30
Grasslands (pastures)	8.8	0.174	1.39	1.53	12.23
Total				24.91	159.56

The carbon emission and carbon sequestration for the green areas were 24.91 and 159.56 ton/year, as a result the carbon balance was 134.65 ton/year.

2) Scenario B

Table 19. Carbon balance estimation for Scenario B

	Area (ha)	Emission (ton/ha/year)	Sequestration (ton/ha/year)	Carbon Emission (ton/year)	Carbon Sequestration (ton/year)
Broad-leaved trees	18.6	0.031	2.18	0.58	40.55
Coniferous trees	6.16	0.031	2.00	0.19	12.32
Mixed trees	13.64	0.031	2.09	0.42	28.51
Grasslands (recreational & sports fields)	45.1	0.492	1.47	22.19	66.30
Grasslands (pastures)	8.8	0.174	1.39	1.53	12.23
Total				24.91	159.90

The carbon emission and carbon sequestration for the green areas were 24.91 and 159.9 ton/year, as a result the carbon balance was 134.99 ton/year.

3) Scenario C

Table 20. Carbon balance estimation for Scenario C

	Area (ha)	Emission (ton/ha/year)	Sequestration (ton/ha/year)	Carbon Emission (ton/year)	Carbon Sequestration (ton/year)
Broad-leaved trees	18.6	0.031	2.18	0.58	40.55
Coniferous trees	9	0.031	2	0.28	18.00
Mixed trees	9.8	0.031	2.09	0.30	20.48
Grasslands (recreational & sports fields)	45.1	0.492	1.47	22.19	66.30
Grasslands (pastures)	8.8	0.174	1.39	1.53	12.23
Willow (10% of coniferous trees area)	3.84	0.115	5.9	0.44	22.66
Coniferous trees thinning	3.84	0.387	0	1.49	0.00
Total				26.81	180.22

The carbon emission and carbon sequestration for the green areas were 26.81 and 180.22 ton/year, as a result the carbon balance was 153.41 ton/year.

4) Scenario D

Table 21. Carbon balance estimation for Scenario D

	Area (ha)	Emission (ton/ha/year)	Sequestration (ton/ha/year)	Carbon Emission (ton/year)	Carbon Sequestration (ton/year)
Broad-leaved trees	18.6	0.031	2.18	0.58	40.55
Coniferous trees	10	0.031	2.00	0.31	20.00
Mixed trees	9.8	0.031	2.09	0.30	20.48
Grasslands (recreational & sports fields)	45.10	0.492	1.47	22.19	66.30
Grasslands (pastures)	0	0.174	1.39	0	0
Sunflower	8.8	0.484	8.13	4.26	71.54
Total				27.64	218.87

The carbon emission and carbon sequestration for the green areas were 27.64 and 218.87 ton/year, as a result the carbon balance was 191.23 ton/year.

Based on the scenario developed, thus the scenario comparison can be described as follows:

Table 22. Carbon balance comparison of different scenarios

Scenario	**Area of change (ha)**	**Carbon Emissions (ton/year)**	**Carbon Sequestration (ton/year)**	**Total carbon Balance (ton/year)**	**TCB per hectare (ton/year/ha)**	**Contribution to sequester the emission from building**
A	0	24.91	159.56	134.65	-	5.8%
B	3.84	24.91	159.90	134.99	35.1	5.8%
C	3.84	26.81	180.22	153.41	39.9	6.6 %
D	8.80	27.64	218.87	191.23	21.7	8.2 %

For scenario A, there was no change in the area. For scenario B and C, the changes of the area were 3.84 ha. Agricultural grassland area proposed for change in scenario D was 8.8 ha. The highest total carbon balance was scenario D, giving the amount of 191.23 ton/year, followed by scenario C of 153.41 ton/year, scenario B of 134.99 ton/year and scenario A of 134.65 ton/year. Based on the total carbon balance per unit area, scenario C gives the highest total carbon balance which is 39.9 ton/year/ha, followed by scenario B of 35.1 ton/year/ha and scenario C of 21.7 ton/ha/year.

The total carbon emission from the buildings is 2318.52 ton. The scenarios of A, B, C and D will contribute 5.8%, 5.8%, 6.9% and 8.2% respectively, to sequester the carbon emission from the University of Twente buildings.

5. DISCUSSIONS

5.1. Accuracy of land cover delineation and classification

The accuracy of image segmentation presented in the Table 10 showed that the segmentation of the green areas (i.e. average 70%) is lower than the built up areas (i.e. average 80%). The under segmentation has more contribution than the over segmentation to the low segmentation accuracy value. These conditions indicate that the adjusted parameter for object segmentation was apparently difficult to delineate the grassland boundary and to differentiate between the broadleaves forest to the other forest. The closeness of colour brightness, the smoothness and the compactness between the grassland and the surrounding object as for instances bare soil and less vegetated forest area are likely the cause of under segmentation. In addition, the problem to delineate broadleaves forest and other forest type is due to the overlapping crown as similar to the result of Workie (2011). This low accuracy in the segmentation process for the green areas may result to the bias of the extent of each green area class in this study. However, the manual delineation was performed based on visual image inspection to minimize erroneous in the object delineation.

The accuracy of land cover classification presented in the Table 11 shows that the user's accuracy of the broadleaves tree, coniferous tree and mixed tree was lower than other classes. This low user's accuracy has been caused by miss-labelled of each tree class especially to assign the mixed tree. The mixed tree area in UT was comprised of broadleaves tree and coniferous tree in the similar proportion which the crown of mixed tree relatively similar to the crown of broadleaves tree (see Appendix 3). This condition leads to the difficulties to assign the correct label of the tree areas. Quite similar to the results of user's accuracy, the results of producer's accuracy were low for the coniferous tree and the mixed tree but not for the broadleaves tree. The overlapping crown in the mixed tree which leads to the incorrect identification was the cause of the low producer's accuracy. However, the manual correction of land cover classification was performed based on re-visit to the field to minimize erroneous in the land cover classification. A visit to re-check the land cover classification was made possible since the location of study area is affordable for the researcher.

5.2. Carbon balance estimation

The method used in this study to estimate carbon stock was similar to the prior studies of Lu (2006), Samalca (2007) and Brown (1997) which was based on the combination of field measurement and remote sensing analysis. The carbon stock in UT was estimated only for above ground carbon stock from trees and soil organic matter for grasslands. This study used a general allometric for estimating above ground biomass based on diameter at breast height which may result a high uncertainty on carbon stock estimation. This is similar to Clark et al. (2001) which argued that the use of generalized equations can lead to a bias in estimating biomass for a particular species. Furthermore, the carbon stock calculation in this study may leads to an under estimation of carbon stock value since individual trees along side of the roads were not included in the estimation.

The allometric equations used in this study were adopted from (Lambert et al., 2005) which originally was developed for hardwood and softwood species in the Canadian forest. Difference of the site condition between the original site of allometric equations and the site of this study may increase the uncertainty on the biomass/carbon stock calculation. However, this study could not provide a quantitative analysis of this uncertainty because beyond of the study. In addition, the allometric equation used for measuring carbon stock of broadleaved trees was also included tree foliage which may have caused over estimation of the carbon stocks estimation on the UT campus, since the foliages of broadleaved trees are seasonally present, different from coniferous trees.

Different with the carbon stock estimation for tree which used allometric equation, the carbon stock for grassland was estimated based on soil organic matter. This study merely used soil organic matter of grassland area since it was difficult to estimate the standing stock of grassland which frequently lawn. In addition, according to Soussana et al. (2007) the carbon accumulation in grassland ecosystems was dominant in below ground. The results of carbon stock estimation in UT for broadleaves trees (151.5 ton/ha) was in the range of broadleaves carbon stock estimation from Bascietto et al. (2004), for coniferous trees (74.9 ton/ha) was in the range of coniferous carbon stock estimation from Churkina et al. (2003) and grassland (53.6 ton/ha for recreational grassland and 97.3 ton/ha) was in the range of carbon stock estimation from Ammann et al. (2007) and Jones et al. (2006). The carbon stock reference for mixed forest was difficult to find so that this study proposed an estimation value for carbon stock in a mixed forest which consist of broadleaves trees and coniferous trees.

The carbon sequestration estimation in this study was performed based on the assumption of linier rate using the values from other studies. This study used these assumptions since there was no data available on the tree and grass growth rate in UT. In addition, an empirical tree and grass growth measurement using for example tree ring was not possible due to the time limitation. This study selected the carbon sequestration values according to Bascietto et al. (2004) who measured European beech forest in central Germany. However, the reference was developed for 70-years-old even aged stand while the broadleaved trees at the UT campus are ranging from seedling, sapling, pole and trees. The mature trees with DBH > 28 cm was 18%. Although the site of reference was comparable to the study site in terms of the condition such as temperature, rainfall and relatively flat terrain, the difference on ages of reference trees to the tree in the study site may result in an over estimation.

For estimating carbon sequestration in lawn grasslands, this study used the values from Jones et al (2006) and Claire et al. (2008) which originally used for an intensively managed lawn with frequent mowing. However, the UT is making a good effort in buying the most energy efficient mowing machines, and reducing the energy spent on transporting biomass. It was possible that the UT has a lower carbon emission than what was estimated for lawn maintenance grasslands.

For carbon emission estimation, this study assumed that the carbon emission was zero for the forest area without intervention since the emission sources for instances tree thinning and fertilization was not occurred. Despite Krug et al. (2012) argued that unmanaged forest can be supposed to become a principle CO_2 sources, but its degeneration processes and related CO_2 fluxes in un-managed forest is remain a high uncertainty. This study assumed that the unmanaged forest become a carbon emission source when it was replaced to another land use or land cover which in this study were proposed under the scenario 3 and scenario 4. Different with forest area, the carbon emission in the grassland was determined based on the study from Jones et al. (2006) and Clair et al. (2008). The assumption of carbon emission in the grassland was made since the data was not available. The results showed that the amount of carbon emission in UT was lower than the amount of carbon sequestration. This indicates that the green areas of UT have become a carbon sink instead of carbon source.

The result of surplus carbon balance in the green areas management was likely because of the large portion of forest areas was available to store carbon. The carbon emission of the green areas was 15.6% of the total carbon stock of the green areas of UT indicating a 'green' measure has been done in UT. However, there was opportunity to enhance the carbon balance of UT through land management as discussed in the next section.

5.3. Interpretation of different scenarios for sustainable management of UT Campus

The management of the green areas plays an important role for contributing in carbon stock and carbon sequestration. The forested or tree-covered area itself stored carbon both in above-ground and below-ground biomass, and said to have "zero" emission since the forest is maintain as natural areas and not for production forest. However, thinning activities could take place to replace several patch of the trees area, especially for coniferous trees although the thinning process will contribute in carbon emission of 0.387 ton/ha (Mangoyana, 2011). Different from the management of the trees area, maintain grassland such as regular mown the recreational area or adding fertilizer may lead to emission of carbon of 0.492 ton/ha/year for lawn grasslands and 0.174 ton/ha/year for agriculture grasslands (Clair et al., 2008; Jones et al., 2006).

Having the University of Twente campus area as the system boundary, the major emission comes from the energy use or the whole activities of the building area. However, several efforts to reduce carbon emission such as applying green energy initiatives; also develop efficiency strategy in mowing, machines and one temporary garbage storage area, use of mown grass waste for organic fertilizer of the green areas has been implemented at the University of Twente campus and has reduced 16.63% from emission in 2005. On the one hand, management of the UT campus area as one place for all activities may leads to growing demand of space. As an example, in 2010 when new buildings were constructed and the built-up areas have increased 1.84 ha, the carbon emission increase significantly 27.6% from 2005 emission. On the other hand, land cover/use conversion of the natural "green" areas into built-up areas has impact decreased of the forest area of 2.47 hectares and leads to reduction of total carbon stock of 43.2 ton.

Based on the land cover changes 2005-2012 presented in table 12, the forest area (broadleaved trees) has decreased 2.47 hectares and the built-up areas (buildings and artificial surfaces) has increased 1.84 hectares. From the estimation of carbon stock and sequestration in figure 25, the total carbon in broadleaved trees has decreased from 3190.4 ton in 2005 and 3147.2 ton in 2012 although trees are growing and sequester carbon. Since the lowest average above-ground biomass was found in coniferous trees (159.4 ton/ha), therefore one scenario has emphasis on admixing the coniferous (Knoke et al., 2007) into mixed trees on 10% of the total forest area or 3.84 ha, which has an average of 298.4 ton/ha. It was found that the addition of coniferous and admixing of coniferous to mixed trees can increase the total carbon balance from 134.65 to 134.99 ton/year.

Another scenario is allowed harvesting in 10% of the whole forest area and replace with fast-growing Willow. Willow is a short-rotation woody crop and can be harvested in 3-4 years cycle of the total 20-25 years age of forest, therefore can enhance the carbon sequestration in the forest area (Clair et al., 2008).

By converting 10% of the coniferous forest which delivers the lowest average AGB (159.4 ton/ha), the total carbon balance can increase from 134.65 to 153.41 ton/year, including the estimation of carbon emission from thinning activities of coniferous trees.

Similarly to forest, grasslands area has also changed but it was found to be increase 0.39 ha from 2005 to 2012. The other scenario has focuses on reducing emissions for the agriculture area which covers 35% of the whole campus area. The assumption for the agriculture grasslands, pastures are used for cattle grazing, machinery and vehicles emits carbon, thus these scenario developed to replace pastures in agriculture area with carbon-crop vegetation species which is sunflower. Sunflower is found to have high carbon sequestration and low carbon emission, also support biodiversity and good for aesthetic purpose. However, based on the carbon balance estimation, the carbon emission of the sunflower scenario (27.64 ton/year) was found to be higher than the current situation (24.91 ton/year). However, growing sunflower on the 8.8 grasslands area shows a significant increase of carbon sequestration, thus result in an increase on carbon balance from 134.65 ton/year to 191 ton/year.

Both willow and sunflower have high carbon sequestration rate, 5.9 ton/ha/year and 8.13 ton/ha/year (Ammann et al., 2007; Jones et al., 2006), respectively. By comparing four different scenarios, the scenario of replacing pastures with sunflower give the highest carbon balance, followed by scenario of replacing 10% of the forested area with fast-growing Willow trees. However, the Willow scenario has higher carbon balance per hectare area, compared to Sunflower. Both of the Willow and Sunflower scenarios also result in low emissions compared to the baseline scenario. The baseline scenario current situation and admixing coniferous trees into mixed trees have no significant differences in carbon emission and sequestration.

Another possibility is comparing between scenarios, for example combining the scenario of Willow and Sunflower. Hence, the scenario will focus on 5% of the forest area (1.92 ha) use for thinning and replacing coniferous trees with Willow and 50% of the grasslands area (4.4 ha) for replacing pastures with sunflower. This scenario combination gives carbon emission of 27.1 ton/year and the carbon sequestration is 196.7 ton/year. The carbon balance of this willow-sunflower scenario is 169.5 ton/year. Having this scenario applied to the UT campus area will sequester 7.3% emissions from the buildings.

By comparing four different scenarios, the carbon emission and carbon balance of all scenarios show surplus in carbon balance, ranging from 134.65 to 191.23 ton/year which contribute to sequester the carbon emission from the UT buildings ranging from 5.8% - 8.2%. The scenarios to replace sunflower was found to give the highest carbon balance of all scenarios.

This study successfully set-up the calculation model and compare the scenarios. However, several parameters used for carbon balance measurements require further improvements. As a result, a further fine tuning and an updating of rates and input parameters for carbon balance estimation needs to be done to produce final and reliable numbers.

5.4. Reflection: Research Limitation and Future Recommendation

The remote sensing data used for land cover classification in this study is the open-source Google Earth images of 2005-2012. Although the classified land cover map gave a good result in accuracy assessment and goodness of fit, but up-to-date and high spatial resolution remote-sensing data is needed, more likely equipped with spectral resolution to gain more detailed land cover map, for example based on individual tree species or delineating small shrub species. The remote sensing data proposed was image from an

Unmanned Aerial Vehicle (UAV), however flying with drone was unable to be done because the issue of license, permission, safety, budget and limited time. Another issue is the temporal resolution of the data to add the accurate growth of the trees or forest area.

In terms of scoping the emission sources, another data can give significant contribution on carbon emission value, such as data about transportation, waste, and product use. Based on the literature it was found that emission from energy consumption plays a major role (40-80%) but still it was an under estimation of carbon emission estimation and another data available will give a more complete picture about total carbon emission of the UT campus area.

The method for above-ground biomass estimation for the trees is scaling up to land cover classes such as broad-leaved, coniferous and mixed trees, based on LUCAS classification and land cover classification of the TOP10NL map. However, there are also individual trees alongside the roads in the campus area which may leads to underestimation of the biomass calculation. Soil samples also need to represent all of the land cover classes. For the data collection of grasslands area, species identification of several grasslands for different land use was done to give an overview about the grass species in the area. Another approach which can be done is with destructive sampling, although it may cause difficulties since most of the grasslands areas are being mown regularly.

There are several possibilities for future research such as the use of UAVs or another high resolution images for better image classification, empirical measurements of trees growth in the UT campus area to give more accurate and precise value of sequestration rate, more emphasis on grasslands to see impact of different management of grasslands in terms of carbon stock, not only from soil carbon, but also from standing grass using destructive methods and also the root biomass.

6. CONCLUSIONS

1. The results of carbon stock, carbon emission and carbon balance estimation of UT can be described as follows.

a. The total carbon stock of the green areas in University of Twente was estimated based on the sum of carbon stock of trees, grass and soil organic matter giving a total value of 12045.9 ton. The broad-leaved forest contributed about 2,817.9 ton (23.4%), coniferous forest (741.5 ton, 6.2%), mixed forest (1,373.9 ton, 11.4%), lawn grassland (2,420.9 ton, 20.1%), agriculture grassland (857.4 ton, 7.1%) and soil in the forest area (3,834.3 ton, 31.8%).

b. The total carbon emission of the green areas in University of Twente was found to be 24.9 ton/year, where the highest emission is from lawn grasslands 22.2 ton/year (89.1%), followed by grasslands (agriculture) (1.5 ton/year, 6.1%), broadleaves tree (0.6 ton/year, 2.3%), coniferous (0.3 ton/year, 1.2%) and mixed trees (0.30 ton/year, 1.2%). The carbon emission of the green areas was 11.6% of the carbon emission from the building management of UT.

c. The carbon balance of the green areas in UT was estimated based on the rate of carbon sequestration and carbon emission giving the total carbon balance of 134.7 ton/year. The carbon sequestration was 159.6 ton/year; consist of sequestration from lawn grasslands 66.3 ton/year (41.5%), broadleaved trees 40.5 ton/year (25.4%), mixed trees of 20.5 ton/year (12.8%), coniferous trees 20 ton/year (12.5%) and grasslands (agriculture) 12.2 ton/year (7.7%).

2. The space availability for enhancing carbon balance in the green areas of University of Twente was found to be 47.1 ha or 30% of the campus areas. This area consists of 8.8 ha (18.7%) grassland and 38.3 ha (81.3%) forest area.

3. The results of developing and comparing sustainable scenarios can be described as follows.

a. The possible planting design and management scenarios for UT campus consist of the current situation, optimizing carbon stock by admixing coniferous trees into mixed trees, optimizing carbon sequestration by selective harvesting and replanting with fast-growing Willow species, and reducing emissions by abandoning grazing and replace pastures with Sunflower crop.

b. The criteria and indicators for sustainable UT campus are carbon emission and carbon sequestration for the green areas.

c. The carbon balance of current situation scenario is 134.7 ton/year, admixing coniferous trees is 135.0 ton/year, Willow scenario is 153.4 ton/year and for the Sunflower scenario is 191.2 ton/year. The scenarios will contribute about 5.8% - 8.2% to sequester the carbon emission from the UT buildings.

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APPENDIXES

APPENDIX 1. LUCAS – Classification of Land Cover and Land Use (European Union, 2015)

Land cover			
A00	ARTIFICIAL LAND	A10	Built-up areas
		A20	Artificial non built-up areas
B00	CROPLAND	B10	Cereals
		B20	Root crops
		B30	Non-permanent industrial crops
		B40	Dry pulses, vegetables and flowers
		B50	Fodder crops (mainly leguminous)
		B70	Permanent crops: fruit trees
		B80	Other permanent crops
C00	WOODLAND	C10	Broad-leaved woodland
		C20	Coniferous woodland
		C30	Mixed woodland
D00	SHRUBLAND	D10	Shrub land with sparse tree cover
		D20	Shrub land without tree cover
E00	GRASSLAND	E10	Grassland with sparse tree/shrub cover
		E20	Grassland without tree/shrub cover
		E30	Spontaneously re-vegetated surfaces
F00	BARE LAND AND LICHENS/MOSS	F10	Rocks and stones
		F20	Sand
		F30	Lichens and moss
		F40	Other bare soil
G00	WATER AREAS	G10	Inland water bodies
		G20	Inland running water
		G30	Coastal water bodies
		G50	Glaciers, permanent snow
H00	WETLANDS	H10	Inland wetlands
		H20	Coastal wetlands

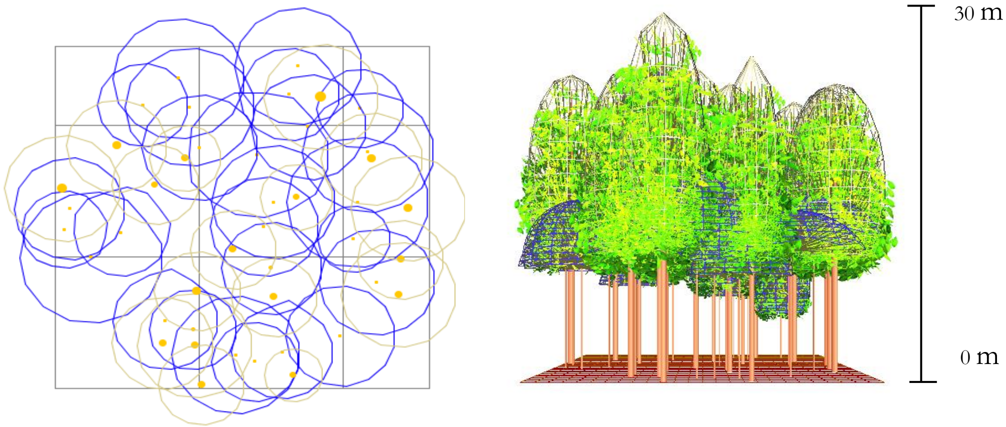
Land use			
U110	Agriculture	U320	Water and waste treatment
U120	Forestry	U330	Construction
U130	Aquaculture and fishing	U340	Commerce, finance, business
U140	Mining and quarrying	U350	Community services
U210	Energy production	U360	Recreation, leisure, sport
U220	Industry and manufacturing	U370	Residential
U310	Transport, communication networks, storage, protective works	U400	Unused

APPENDIX 2. Trees distribution in each plot measurements

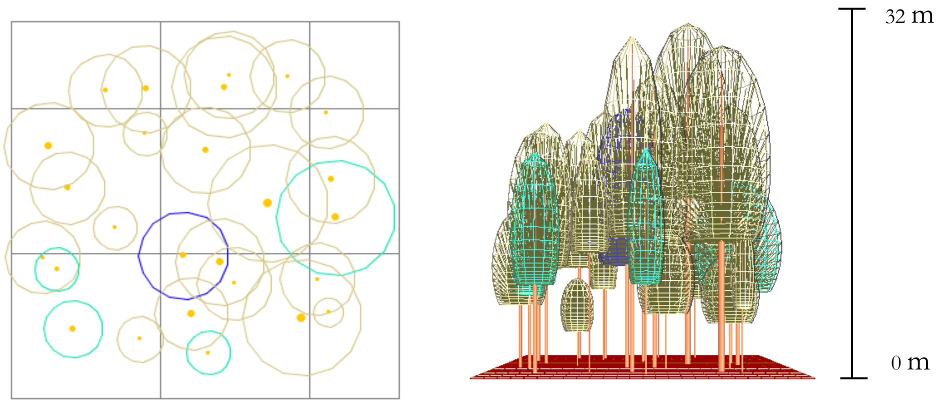
Nr Plot	Nr Trees	Nr Trees		Nr Trees based on range diameter at breast height (cm)					
		BL	C	0-10	11-20	21-30	31-40	41-50	>50
1	91	74	17	60	16	6	3	4	2
2	29	10	19	0	1	10	10	8	0
3	15	15	0	5	1	2	3	1	3
4	26	26	0	4	8	6	3	4	1
5	38	3	35	3	17	9	6	2	1
6	38	36	2	25	0	0	2	2	9
7	65	48	17	41	8	1	6	6	3
8	35	28	7	16	5	4	5	2	3
9	28	16	12	0	6	8	10	4	0
10	37	37	0	2	8	8	5	9	5
11	94	92	2	70	12	5	1	2	4
12	17	17	0	0	0	2	3	4	8
13	54	47	7	28	8	3	8	4	3
14	189	189	0	140	35	8	6	0	0
15	23	14	9	0	0	3	5	13	2
16	105	84	21	84	1	15	5	0	0
17	25	6	19	10	3	5	7	0	0
18	33	17	16	7	7	4	6	7	2
19	63	55	8	42	5	3	7	5	1
20	26	1	25	2	8	2	6	6	2
21	50	21	29	16	15	5	7	6	1
22	57	27	30	19	21	5	7	4	1
23	51	46	5	25	4	4	8	6	4
24	38	14	24	3	8	8	12	5	2
25	29	19	10	6	4	7	6	5	1
26	45	28	17	16	7	11	9	1	1
27	43	43	0	0	18	8	2	6	9
28	26	18	8	5	4	2	3	2	10
29	48	24	24	0	12	13	18	3	2
30	73	35	38	41	8	8	6	6	5
Total	1,491	1,090	401	670	250	175	185	127	85
in %		73.1	26.9	44.9	16.8	11.7	12.4	8.5	5.7

BL : Broad-leaved trees, C : Coniferous trees

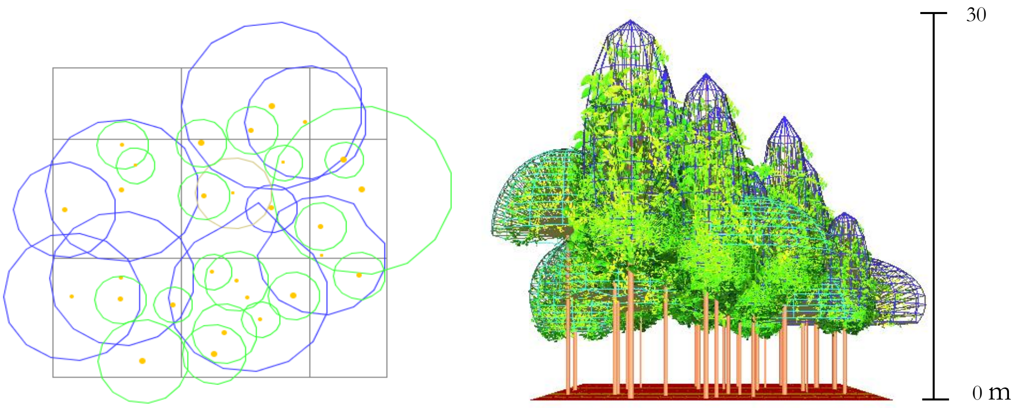
APPENDIX 3. Example of plot profiles for broadleaved, coniferous and mixed trees



An example of plot profile for broadleaves dominant trees (i.e. plot number 27). A vertical profile of the plot which the blue colour represents Beech species and the brown colour represents Oak species (left). The horizontal profile of the plot which illustrates a dominant height of Oak against Beech species (right).



An example of plot profile for coniferous dominant trees (i.e. plot number 20). A vertical profile of the plot which the blue colour represents Beech species, the light brown colour represents Douglas Fir species and the light green colour represents Pine species (left). The horizontal profile of the plot which illustrates a dominant height of Douglas Fii against other species (right).



An example of plot profile for mixed trees (i.e. plot number 2). A vertical profile of the plot which the blue colour represents Beech species, the brown colour represents Oak species and the light green colour represents Pine species (left). The horizontal profile of the plot which illustrates a dominant height of Beech species against other species (right).