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Energy use and carbon footprint from lawn management

A case study in the Uppsala region of Sweden

Therese Wesström

ABSTRACT

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Atmospheric concentrations of greenhouse gas emissions are now higher than ever before, with severe implications for both humans and ecosystems around the world. To mitigate climate change, large and sustained reductions of greenhouse gas emissions are required. The management of lawns entail frequent maintenance activities, such as mowing, irrigation and fertilisation, which require energy and cause greenhouse gas emissions. Lawns cover a significant part of urban areas worldwide, with functions such as air quality improvement, flood mitigation and the potential to sequester carbon and consequently reduce carbon dioxide (CO_2) from the atmosphere. The existing knowledge about the environmental impact from lawn management is limited and more research is needed to determine related climate effects.

The objective of the study was to evaluate energy use and carbon footprint from urban lawn systems with different intensities through a life cycle perspective. The lawns included in the study consisted of utility lawns and meadow lawns, with management under responsibility of Uppsala municipality, and the two golf courses Upsala GK and Sigtuna GK, divided into the lawn types greens, tees, fairways and roughs. The energy use and carbon footprint was determined by an inventory of the existing lawn management practices through interviews with greenkeepers at the golf courses, stakeholder at Uppsala municipality and lawn caretakers. Additional information for the inventory was received from literature and databases. Based on the inventory, calculations of the energy use and carbon footprint throughout the life cycle was made.

The results showed that greens had the largest carbon footprint and energy use per hectare followed by tees, fairways, roughs, utility lawns and meadow lawns. The energy use was the highest for the golf courses, with 16.5 GJ ha^{-1} $year^{-1}$ for Upsala GK and 13.0 GJ ha^{-1} $year^{-1}$ for Sigtuna GK. Lower energy use was determined for the utility lawns and meadow lawns, where 3.0 and 0.5 GJ ha^{-1} $year^{-1}$ were required for the lawn management, respectively. The carbon footprint of the golf courses was 1.33 Mg CO_2-equivalents (CO_2e) $ha^{-1}$$year^{-1}$ for Upsala GK and 0.94 Mg CO_2e ha^{-1} $year^{-1}$ for Sigtuna GK, which was larger compared to the utility lawns of 0.2 Mg CO_2e ha^{-1} $year^{-1}$ and meadow lawns of 0.03 Mg CO_2e ha^{-1} $year^{-1}$. Mowing, irrigation and manufacturing of fertiliser were the management activities consuming most energy. The activities with largest carbon footprint were mowing, manufacturing of fertiliser and soil emissions from application of fertilisers.

This study was a part of a multidisciplinary research programme, where the results will be used to determine the net emission balance when the carbon sequestration potential of the lawns has been concluded. Suggested improvements at the golf courses were to reduce the applied amounts of nitrogen fertiliser and improve the documentation of used resources. Increasing the usage of hybrid and electrical mowers is recommended for both the municipality as well as the golf courses to reduce energy use and the carbon footprint.

Keywords: carbon footprint, life cycle assessment, energy, lawn management

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REFERAT

Energianvändning och klimatavtryck från skötsel av gräsytor – en fallstudie utförd i Uppsalaregionen

Therese Wesström

Halterna av växthusgaser i atmosfären är högre än någonsin, vilket medför stora konsekvenser för både människor och ekosystem runt om i världen. För att motverka klimatförändringar måste åtgärder för att minska växthusgaserna i atmosfären genomföras. Gräsytor kräver kontinuerlig skötsel, såsom klippning, bevattning och gödsling, vilket är energikrävande och ger upphov till utsläpp av växthusgaser. En stor del av världens städer består av gräsytor som bidrar med positiva effekter till samhället genom att bland annat förbättra luftkvaliteten, dämpa översvämningar och lagra in kol i marken och på så sätt reducera atmosfärens koldioxidhalt. Den nuvarande kunskapen om miljöpåverkan från gräsyteskötsel är bristfällig och fler studier behövs för att bestämma ytornas klimatpåverkan.

Syftet med studien var att bestämma energianvändning och klimatavtryck ur ett livscykelperspektiv för gräsytor med varierande skötselintensitet. De valda ytorna var bruksgräsmattor och slåttermarker som sköts av Uppsala kommun samt de två golfklubbarna Upsala GK och Sigtuna GK, vars ytor delades upp i green, tee, fairway och ruff. Energianvändningen och klimatavtrycket bestämdes genom en inventering av nuvarande skötselåtgärder. Detta gjordes genom intervjuer med greenkeepers på golfklubbarna, ansvariga på Uppsala kommun samt ansvariga för gräsyteskötsel på entreprenadföretag upphandlade av kommunen. Dessutom inhämtades information från litteraturen och databaser. Baserat på inventeringen utfördes beräkningar på energianvändning och klimatavtryck ur ett livscykelperspektiv.

Resultatet visade att greener hade den högsta energianvändningen och det största klimatavtrycket, som i fallande storleksordning följdes av tee, fairway, ruff, bruksgräsmattor och slåttermarker. Greenerna bidrog med 20 % av golfbanornas totala klimatavtryck, trots att de bara utgör 3 % av golfbanans totala area. Den totala energianvändningen var störst för golfbanorna, med 16.5 GJ ha^{-1} $år^{-1}$ för Upsala GK och 13.0 GJ ha^{-1} $år^{-1}$ för Sigtuna GK. Den lägsta energianvändningen resulterade från bruksgräsmattor och slåttermarker där 3.0 och 0.5 GJ ha^{-1} $år^{-1}$ krävdes för respektive gräsyta. Även för klimatavtrycket så var det större för golfbanorna med 1.33 Mg CO_2-ekvivalenter (CO_2e) ha^{-1} $år^{-1}$ för Upsala GK och 0.94 Mg CO_2e ha^{-1} $år^{-1}$ för Sigtuna GK, jämfört med bruksgräsmattorna vars klimatavtryck var 0.2 Mg CO_2e ha^{-1} $år^{-1}$ och slåttermarkerna med 0.03 Mg CO_2e ha^{-1} $år^{-1}$. Klippning, bevattning och produktion av gödningsmedel var de skötselåtgärder som hade högst energiförbrukning. De skötselåtgärder med det största klimatavtrycket var klippning, produktion av gödningsmedel samt de emissioner som uppstod till följd av gödslingen.

Detta projekt var en del av ett multidisciplinärt forskningsprogram där resultaten kommer att användas för att bestämma nettoutsläppsbalanser för gräsytorna när potentialen att lagra kol i marken har bestämts. Förslagna åtgärder för golfbanorna var att reducera gödselgivorna av kväve och öka dokumentationen av använda resurser. Det rekommenderas att öka användandet av hybrider och elektriska maskiner både inom kommunens gräsyteskötsel och på golfbanorna.

Nyckelord: klimatavtryck, livscykelanalys, energi, gräs, skötsel

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POPULÄRVETENSKAPLIG SAMMANFATTNING

Klimatförändringar är en av vår tids största utmaningar och påverkar både människor och ekosystem över hela världen. Koncentrationerna av växthusgaserna koldioxid, metan och dikväveoxid, även kallad lustgas, i atmosfären är nu högre än någonsin, vilket medför ökade temperaturer i luft och hav. Följderna av en global uppvärmning är klimatförändringar och för att motverka detta måste växthusgaserna i atmosfären reduceras. En sektor som ger upphov till växthusgasutsläpp, men som inte har studerats ingående i Sverige är skötseln av gräsytor.

Gräsytor förekommer över stora delar av världen i form av bland annat trädgårdar, parker, kyrkogårdar, sportfält, golfbanor och vägrenar. Genom att etablera gröna ytor i en stad kan flertalet positiva effekter åstadkommas för människors välbefinnande, så kallade ekosystemtjänster. Gräsytor minskar förekomsten av föroreningar i en stad och förbättrar således luftkvaliteten, vilket är fördelaktigt för medborgarnas hälsa. Andra positiva effekter är att de renar vatten och dämpar översvämningar samt att gräsytor ofta utgör stora rekreationsområden i staden. En viktig aspekt att ta hänsyn till när man behandlar ämnet global uppvärmning är gräsytors förmåga att lagra kol i marken, vilket minskar halterna av koldioxid i atmosfären. Genom fotosyntesen tar gräset upp koldioxid som lagras i form av organiskt material i jorden under en lång tid. Gräsytor har varierande potential att utföra kolinlagring, vilket främst beror på markens initiala kolhalt då gräsytan anlades.

För att sköta gräsytor krävs kontinuerligt underhåll, vilket varierar i intensitet beroende på dess användning. I denna studie har bruksgräsmattor, slåttermarker och golfbanor uppdelade på green, tee, fairway och ruff studerats i Uppsalaområdet med avseende på energianvändning och klimatavtryck ur ett livscykelperspektiv. De bruksgräsmattor och slåttermarker som inkluderades i studien bestod enbart av de vilka Uppsala kommun ansvarar för underhållet av, vilket motsvarade 400 hektar (ha) bruksgräsmattor och 176 ha slåttermarker. Två golfklubbar jämfördes, Uppsala GK som bestod av 76 ha och Sigtuna GK som hade 53 ha underhållna gräsytor. Bruksgräsmattor ska ha en gräslängd på 8-10 cm och klippas högst 15 gånger om året. Detta kan jämföras med slåttermarker som endast klipps två gånger om året. På golfbanorna däremot underhålls gräsytorna intensivt och förutom daglig klippning på greenerna omfattas skötseln av bevattning, gödsling, vertikalskärning, luftning, dressning och applicering av bekämpningsmedel. För att utföra dessa skötselåtgärder åtgår resurser, vilka under produktions- och användningsfasen orsakar utsläpp av växthusgaser och kräver energi. Till exempel är produktionen av gödsel en energikrävande process och därtill avges lustgas när kvävet i gödseln omsätts i marken.

En inventering av vilka resurser skötselåtgärderna omfattades av gjordes genom intervjuer och kompletterades med uppgifter från tidigare studier. Intervjuerna genomfördes med greenkeepers på Upsala GK och Sigtuna GK, ansvariga på Uppsala kommun samt ansvariga för gräsyteskötsel på entreprenadföretag upphandlade av kommunen. Inventeringen låg sedan till grund för beräkningar av total energianvändning och klimatavtryck från gräsyteskötseln. Resultatet visade att greener hade den högsta energianvändningen och det största klimatavtrycket, som i fallande storleksordning följdes av tee, fairway, ruff, bruksgräsmattor och slåttermarker. Greenerna bidrog med 20 % av golfbanornas totala klimatavtryck, trots att de bara utgör 3 % av golfbanans totala area.

När energianvändningen summerades för hela golfområdet, visade det sig att golfklubbarna hade en signifikant större energiförbrukning med 16,5 GJ ha^{-1} $år^{-1}$ för Upsala GK and 13,0 GJ ha^{-1} $år^{-1}$ för Sigtuna GK, jämfört med bruksgräsmattorna och slåttermarkerna som krävde 3,0 och 0,5 GJ ha^{-1} $år^{-1}$. Den totala energianvändningen för skötseln av gräsytor inom Uppsala kommun beräknades till 1200 GJ $år^{-1}$ för bruksgräsmattorna och 90 GJ $år^{-1}$ för slåttermarkerna, vilket totalt motsvarar den genomsnittliga energiförbrukningen hos 65 svenska personbilar under ett år.

Även klimatavtrycket var större för golfbanorna med 1,33 ton CO_2 ha^{-1} $år^{-1}$ för Upsala GK och 0,94 ton CO_2 ha^{-1} $år^{-1}$ för Sigtuna GK, jämfört med bruksgräsmattorna vars klimatavtryck var 0,2 ton CO_2e ha^{-1} $år^{-1}$ och slåttermarkerna med 0,03 ton CO_2e ha^{-1} $år^{-1}$. Det totala klimatavtrycket för skötseln av gräsytor inom Uppsala kommun beräknades till 83 ton CO_2 per år för bruksgräsmattorna samt 5,7 ton CO_2 per år för slåttermarker, vilket kan jämföras med golfbanornas totala klimatavtryck på 101 ton CO_2 per år för Upsala GK och 49 ton CO_2 per år för Sigtuna GK. Det är alltså dessa mängder kol som måste lagras in i marken varje år för att gräsytorna ska kunna bedömas som klimatneutrala. Huruvida markerna har potential att kolinlagra dessa halter återstår för forskarna i Lawn-projektet, vilket denna studie är en del av, att avgöra.

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1. INTRODUCTION

Climate change caused by anthropogenic activity is currently one of the major challenges in the world (IPCC, 2014). The atmospheric concentrations of greenhouse gas (GHG) emissions, including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), are now higher than ever before, resulting in rising global temperatures with severe implications for both humans and ecosystems (IPCC, 2014). To mitigate climate change large and sustained reductions of greenhouse gas emissions are required.

Lawns cover a significant part of urban areas around the world, in terms of private gardens, public parks, cemeteries, athletic fields, golf courses and along roads etc. (Ignatieva, 2014). Recent research has shown several advantages of establishing green areas in cities, with functions such as air quality improvements, flood mitigation, microclimate regulation as well as serving as recreational areas (Loram *et al.,* 2007; Currie and Bass, 2008; Huang *et al.,* 2008). Moreover, an important ecosystem service derived from the grass is the potential to sequester carbon and hence reducing CO_2 in the atmosphere (Qian and Follett, 2012). However, the management of lawns generally involve frequently maintenance activities, such as mowing, irrigation and fertilisation, which consume energy and emit GHG emissions to the atmosphere.

The Swedish Parliament has in the environmental objective “Reduced Climate Impact” adopted a vision that aims for zero net emissions of greenhouse gases to the atmosphere by 2050 (Environmental Objectives Portal, 2012). To achieve this vision, actions taken by the Swedish municipalities are important. The municipality of Uppsala fulfil this vision by aiming to have a zero net carbon footprint, with zero greenhouse gas emissions from energy use and transports in the municipality by 2050. Consequently an intermediate target is to have a fossil free machine park in the municipality by 2023 (Uppsala municipality, 2014).

To provide optimal grass quality at a golf course additional management practices are required, such as vertical cutting, dressing and aerification. The playable areas have different grass heights and thus the management intensity varies, yet all activities require energy and discharge GHG emissions (US EPA, 2005). The Swedish Golf Federation (SGF) has around 600,000 members playing golf on more than 35,000 ha (Strandberg, 2006). Uppsala is the municipality in Sweden with the largest area of golf courses covering almost 590 ha (Statistics Sweden, 2013). SGF is relating its environmental work to the Swedish environment objectives and hence aims to reduce the climate impact from golf courses (SGF, 2015).

Despite the large distribution of lawns in the world, the existing knowledge about environmental impact from the management is limited. To be able to reduce climate impact from lawn management and to develop sustainable management activities for the future more research is required. This study is a part of a multidisciplinary Lawn project focusing on researching lawns as a social and ecological phenomenon to improve sustainable urban planning, design and management.

1.1. OBJECTIVES

The objective of the study was to evaluate energy use and carbon footprint from urban lawn systems with different management intensities through a life cycle perspective. The lawns included in the study were utility lawns and meadow-like lawns, with management under responsibility of Uppsala municipality, and two golf courses divided into greens, tees, fairways and roughs. The following research questions were examined in the study:

- What is the total energy use per hectare for each lawn type and how is the energy use distributed between the different management activities?
- What is the carbon footprint per hectare for each lawn type and how is it portioned between different activities?
- What is the total required carbon sequestration to obtain a carbon neutral lawn management for each lawn type?
- How can the management be improved in order to reduce the energy use and the carbon footprint?

2. BACKGROUND

In the following chapter relevant aspects related to lawn management, life cycle assessment and urban green areas are being presented.

2.1. LIFE CYCLE ASSESSMENT

Life cycle assessment (LCA) is a quantitative method used for analysis of environmental aspects and potential environmental impacts in the life cycle of a product or service: from extraction of raw materials, to production, use and disposal (Lindahl *et al.*, 2001; Baumann and Tillman, 2004). The International Organization for Standardization (ISO) has developed international standards for life cycle assessments presented in the ISO 14040-series, issued from 1997 onwards (Baumann and Tillman, 2004). The standards can be considered as a framework to give guidance on a general level (Röös, 2013).

Results from an LCA can be used for decision making, identification of possible environmental improvements, selection of environmental performance indicators and marketing (ISO 14040, 2006). Furthermore, an LCA is a comprehensive method that avoids sub-optimization and burden shifting e.g. shifting the burden between the life cycle stages or between different environmental impacts (Röös, 2013). Besides LCA there are several environmental assessment tools available focusing on other aspects, such as economical and social aspects. Hence additional environmental management techniques should be considered to be able to use the most appropriate assessment technique for the prevailing situation (ISO 14040, 2006).

2.1.1. LCA procedure

The LCA methodology consists of four phases: goal and scope definition, inventory analysis, impact assessment and interpretation (Figure 1). Initially, the purpose of the assessment and the studied system are decided on. System boundaries, functional unit and other critical modelling choices are also determined in the first phase. Secondly, the inventory phase proceeds, including data collection and inventory of inputs and outputs of the system (ISO 14040, 2006). In the impact assessment phase, the results from the inventory are reviewed and potential environmental impacts are evaluated to describe environmental consequences. This is made by a classification of the inventory flows into the environmental impact categories: resource use, human health and ecological consequences, which can be divided into several sub-categories such as global warming, acidification and eutrophication, among others. Subsequently, the impacts are characterized to one common unit by using conversion factors (Baumann and Tillman, 2004). Lastly, in the interpretation phase the results are presented and evaluated considering completeness, sensitivity and consistency. In this phase, conclusions are drawn and recommendations are given (Lindahl *et al.*, 2001). To test the robustness of the conclusions, evaluations such as sensitivity analysis, uncertainty analysis and data quality assessment, can be made.

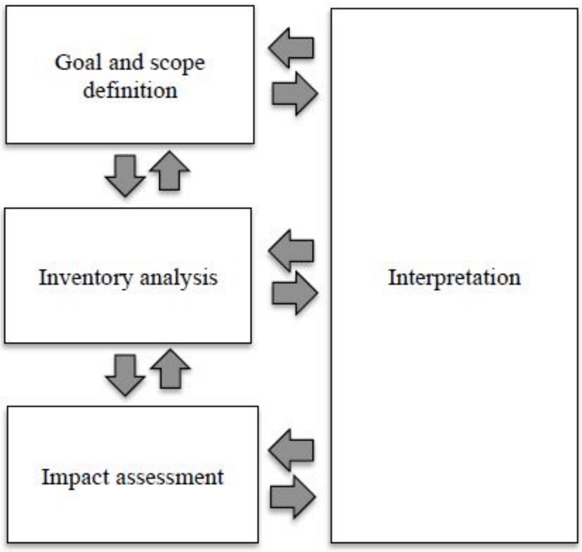

Figure 1 The life cycle assessment procedure (After ISO 14040, 2006).

2.1.2. Carbon footprint

Since the pre-industrial era anthropogenic greenhouse gas (GHG) emissions have increased, leading to higher concentrations in the atmosphere (IPCC, 2014). Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are the key GHGs of concern, since they are chemically stable and long-lived gases that are efficient in trapping heat and are emitted in large volumes (IPCC, 2006; IPCC, 2007). Additional GHGs are ozone (O_3), hydrofluorocarbons (HFCs), chlorofluorocarbons (CFCs), perflourocarbons (PFCs) and sulphur hexafluoride (SF_6) (US EPA, 2014). Water vapour (H_2O) is an essential GHG, but the emissions due to anthropogenic activities cause a negligible contribution to climate change (IPCC, 2007).

CO_2 is the major contributor to global warming and is thus considered the most important GHG. It is mainly emitted from combustion of fossil fuels and industrial processes, but also deforestation and biomass burning are large contributors (IPCC, 2007; IPCC, 2014). CO_2 can be removed from the atmosphere by photosynthesis and soil storage, a phenomenon called carbon sequestration, which is an important measure of climate change mitigation (Kätterer *et al.,* 2013). However, some soils, e.g. organic soils, can act as a carbon source by rapidly oxidising carbon into carbon dioxide and emitting it to the atmosphere (Röös, 2013). CH_4, as the second most prevalent GHG, is produced by natural biological processes in areas such as wetlands, but also through anthropogenic activities including rice agriculture, waste management, raising of ruminant animals and fossil fuel industries (IPCC, 2007; Röös, 2013; US EPA, 2014).

N_2O is a potent GHG emitted naturally from soils by nitrification and denitrification. The processes produce N_2O as an intermediate in the reaction sequence of denitrification as well as a by-product in the nitrification process (IPCC, 2006). N_2O can also be emitted through anthropogenic activity such as fossil fuel combustion, wastewater management and from fertilised soils, where the emissions can be divided into direct emissions and indirect emissions (IPCC, 2006; US EPA, 2014). Direct emissions are produced when N_2O is formed in soils by increased nitrogen levels, mainly caused by added nitrogen or change in management practices that enhances nitrogen mineralisation. The sources of indirect emissions are volatilisation of nitrogen in forms of ammonia (NH_3) Nitrogen oxides (NO_x). Another pathway to indirect emissions is leaching and runoff of nitrogen from land into waterways (IPCC, 2006). The manufacture of mineral fertilisers is also contributing to N_2O-emissions, but also large emissions of CO_2 due to the great amount of natural gas used in the Haber-Bosch process for the production of ammonia (Kool *et al.,* 2012).

Throughout the life cycle of a product or a service GHGs are emitted and removed, thus one variant of an LCA is to calculate the carbon footprint. Carbon footprint is the total amount of GHG emissions caused by a product or a service during its life cycle, and can be used as a tool to determine its contribution to climate change (Galli *et al.,* 2012; Röös, 2013). Compared to a complete LCA less data and modelling are needed when calculating carbon footprint, which reduces both time and resource use (Röös, 2013). The reason for that is mainly that the calculations are limited to only include the impact category global warming.

International technical specifications have been developed to set requirements for the quantification and communication of carbon footprint (ISO 14067, 2013). Opinions of which GHGs that should be included in the calculations differ and several suggestions have been proposed. Generally, the frequently used GHGs in carbon footprint calculations are CO_2, CH_4 and N_2O (Röös, 2013). This practice has been questioned by Wright *et al.* (2011), who suggest that only CO_2 and CH_4 should be included, to make the method cost-effective and practical. Another suggestion is to include only carbon dioxide in the calculations with the purpose to reduce the data collection, even though important GHGs are deliberately left out (Wiedmann and Minx, 2007).

To determine the carbon footprint the global warming potential (GWP) has to be considered. The GWP is an index of the radiative forcing of a GHG relative to that of carbon dioxide over a time horizon. The radiative forcing is defined as the change in net irradiance e.g. the difference between incoming solar radiation and outgoing longwave radiation measured in Watts per m^2 (IPCC, 2007). GHGs have different GWP values depending on their efficiency to absorb longwave radiation and the atmospheric lifetime of the gas (IPCC, 2007; US EPA, 2014). Since CO_2 alternate between the atmosphere, oceans and land biosphere, it is lacking a specific lifetime (IPCC, 2007). For other gases in the atmosphere the lifetime is defined as "the time it takes for a perturbation to be reduced to 37% of its initial amount" (IPCC, 2007, FAQ 10.3).

The UN Intergovernmental Panel on Climate Change (IPCC) has developed the GWP values that are used in carbon footprint calculations and continuously update the values (Table 1). In a study made by Gillett and Matthews (2010) it was investigated whether climate-carbon feedbacks in response to emissions of non-carbon dioxide gases should be included in the calculations of GWP values. Climate-carbon feedback describes the changes in the properties of land and ocean carbon cycle, due to climate change. The results showed an increase of the GWP values for CH_4 and N_2O with about 20% for the 100-years interval, and therefore a suggestion of including climate-carbon feedbacks in the calculations were made.

Table 1 The atmospheric lifetime and global warming potential (GWP) for carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) for a time horizon of 20 years and 100 years with climate-carbon feedbacks (cc fb) included and not included (IPCC, 2013)

Gas	Lifetime (years)	GWP_{20}		GWP_{100}	
		With cc fb	No cc fb	With cc fb	No cc fb
CO_2	-	1	1	1	1
CH_4	12.4	86	84	34	28
N_2O	121.0	268	264	298	265

The calculation of carbon footprint is the total GWP from the GHGs, expressed as CO_2-equivalents (CO_2e) (Equation 1).

$$Carbon\ footprint\ (kg\ CO_2e) = m_{CO_2}\ x\ 1 + m_{CH_4}\ x\ GWP_{CH_4} + m_{N_2O}\ x\ GWP_{N_2O} \quad (1)$$

where m is the amount of respectively GHG in kg, and GWP is the GWP-value for respectively GHG. Generally, a time interval of 100 years is chosen for carbon footprint calculations (ISO 14067, 2013).

2.2. ECOSYSTEM SERVICES RELATED TO URBAN GREEN AREAS

Urban green areas are ecosystems, which provide several benefits for human populations, which can be defined as ecosystem services. The services can be both on a local and global scale and benefit humans either directly or indirectly (Bolund and Hunhammar, 1999). A derived local ecosystem service from vegetation is a reduction of air pollution, which improves air quality and thereby also the health of humans living in urban areas. In a study made by Currie and Bass (2008) the air pollution mitigation by green roofs were examined, with results showing that grass had an important impact of air quality. Another local effect caused by urban green areas is the microclimate regulation. This has been studied by Huang *et al.* (2008) and the results showed decreased local air temperatures for lawns compared to bare concrete cover during both day and night.

Further benefits from urban green areas are improved water treatment and flooding mitigation, since urban green spaces decrease surface water run-off and infiltrate the water (Loram *et al.,* 2007). Furthermore, turfgrass provides soil erosion control and dust stabilization, which protects important soil resources (Beard and Green, 1994). However, the highest valued ecosystem service from urban green areas is probably the recreational value, which invites to play, rest and stress reliefs (Bolund and Hunhammar, 1999). Mitchell and Popham (2007) concluded that a higher proportion of green spaces in an area was correlated with better health, though other parameters could affect the results, such as the degree of urbanity and income deprivation. Urban green areas can also contribute with aesthetic and cultural values to the city (Bolund and Hunhammar, 1999).

2.2.1. Carbon sequestration

Carbon sequestration is an important ecosystem service since CO_2 is captured from the atmosphere by photosynthesis and stored in a stable form as soil organic matter (SOM) for a long time (Qian and Follett, 2012). However, several aspects will determine if carbon sequestration will be performed in a soil, such as management activities, biomass input, climate conditions and characteristics of the soil (Röös, 2013). In SOM, soil organic carbon (SOC) constitutes 58% of the mass. Further plant nutrients in the SOM storage are nitrogen, phosphorus, sulphur and potassium among others (Qian and Follett, 2012). The initial state of SOC in the soil determines if the applied management practices will increase or decrease the carbon storage in the soil, therefore it cannot be concluded that all soils will sequester carbon (Kätterer *et al.,* 2013). The potential to store carbon will decrease with time if management and environmental factors are lacking, since the soil will reach carbon equilibrium (Röös, 2013).

Turfgrass is known for its dense shoots and a developed root system, which gives it a potential for carbon sequestration (Wang *et al.,* 2014). If turfgrass has an input of irrigation and fertilisation, a high root and shoot biomass productivity is expected and hence a high carbon input into the soil is possible (Qian and Follett, 2012). Another factor that can enhance carbon in turfgrass is the recycling of clippings after mowing. In a study by Qian *et al.* (2003) the long-term effects of clipping and nitrogen management in fertilized turfgrass was examined. The results showed that returning clippings after mowing for 10 to 50 years increased both soil carbon sequestration and nitrogen sequestration and hence reduced the required fertilisation rates. This has also been proven by Falk (1980), who concluded that organisms can quickly degrade the small pieces resulting from mowing and nutrients will efficiently be available for the ecosystem by recycling the clippings to the lawn.

In general, turfgrass is constructed on the top of subsoil, which initially has low SOC. This, together with turfgrasses being perennial, productive and managed with minimal tillage result in a high potential for turfgrass to sequester carbon (Qian and Follett, 2012). According to Qian and Follett (2012) many studies have shown that the carbon sequestration for turfgrasses mainly occurs in the top layer of the soil and significantly decreases with depth. They also concluded that the carbon sequestration for turfgrass is significant during 25-30 years after construction, with values between 0.34 to 1.4 Mg ha^{-1} $year^{-1}$. The carbon sequestration for a golf course has been studied by Bartlett and James (2011) and was determined to 1 ± 0.14 Mg CO_2e ha^{-1} $year^{-1}$ for each playable area.

2.3. LAWN MANAGEMENT

Green areas require regularly management such as mowing, fertilizing, irrigation and pesticide application, which requires energy and emit GHGs to the atmosphere. However, for golf courses additional management activities are performed. In the following chapter, the management for utility lawns, meadow-like lawns, hereafter called meadow lawns, and golf courses is presented.

2.3.1. Utility lawns

In Sweden, lawns in parks maintained by the municipalities cover 20,600 ha, where the largest part (55%) consists of utility lawns (Swedish municipal alliance, 2002). A utility lawn should be robust to be able to withstand everyday use, yet be well-groomed, fast drying with an equal surface and green colour (Thisner, pers. comm.). Utility lawns can be found in parks, gardens, cemeteries and sport fields (Figure 2).

Figure 2 A utility lawn in a housing area in Uppsala, Sweden (Photo: Wesström, 2014).

In a Swedish guideline for turfgrass management by Persson (1998) it is specified that a utility lawn should be mowed 10-16 times per year with a maximum grass height of 8-10 cm. However, the mowing frequency will differ depending on the geographical location of the lawn, since the growing season varies within Sweden. Furthermore, the guideline suggests trimming 5-7 times per year, fertilisation once a year and reparation and edge cutting when needed (Persson, 1998). Irrigation and application of pesticides are usually not performed on a utility lawn. During fall, leaves should be collected, removed with a leaf blower or recycled to the lawn with a mulching mower to avoid underlying grass to get damaged (Thisner, pers. comm.). Clippings of turfgrass produced from mowing, can also be recycled with a mulching mower (Qian and Follett, 2012). Cutting height and mowing frequency affect the turfgrass plant, where no more than 30-40% of the blade area should be removed when mowing to avoid harming the plant and delay regrowth (Beard, 1973; SGF, 2001).

2.3.2. Meadow lawns

A meadow lawn consists of tall grass and is defined by its required management activity, which is cutting once or twice per year (Figure 3). It is not associated with specific grass or flower species since meadow lawns can grow on soils that are both rich and poor in nutrients, and hence attract various species. For instance, clay soils, which often are highly nutritious, are vegetated by Cow parsley (*Anthriscus sylvestris*), Turkish Wartycabbage (*Bunias orientalis*) and Russian comfrey (*Symphytum x uplandicum*), among others (Wissman, pers. comm.).

According to Persson (1998) clippings should be removed after cutting. This is agreed by Wissman (pers. comm.), who states that the cut grass otherwise will be shadowing other species and thus inhibit the vegetation growth. Furthermore, some species growing on meadow lawns perform nitrogen fixation, where atmospheric nitrogen (N_2) is converted to NH_3, and will continuously contribute with nutrients to the lawn, if not removed. Initially nutritious lawns will then receive an excessive load of nutrients.

Figure 3 A meadow lawn in Uppsala, Sweden
(Photo: Wesström, 2014).

2.3.3. Golf courses

A golf course generally consists of 18 golf holes, where each hole includes several playable parts: green, tee, fairway and rough (Figure 4). The tee is where the golfer is initiating the game and is an area with short grass (8-10 mm). There can be several tees at one hole indicating different distances to green (SGF, 2001). The fairway is the largest part of the golf course with a 10-15 mm grass height. Around the fairway is the rough, which can be divided into semi-rough and rough, with heights 20-35 mm and 35-60 mm respectively (SGF, 2010). The green is where the player finishes the game and has a grass height of 3-5 mm. The fringe is surrounding the green with a 0.5-2 meter width and a grass height of 8-15 mm (SGF, 2001). Additionally, a golf course consists of practice areas and other areas with no management activities such as lakes, nature reserves and unplayable grounds (US EPA, 2005).

Due to the different grass heights, the playable areas are managed with different intensities and devices, but in general greens and tees require the most intense maintenance (US EPA, 2005). Golf courses can be divided into different categories depending on its location and natural setting. The most common types are links courses, which are located near the coast with a medium intense maintenance, and parkland courses, which are inland, surrounded by forest and require intense management (Bartlett and James, 2011).

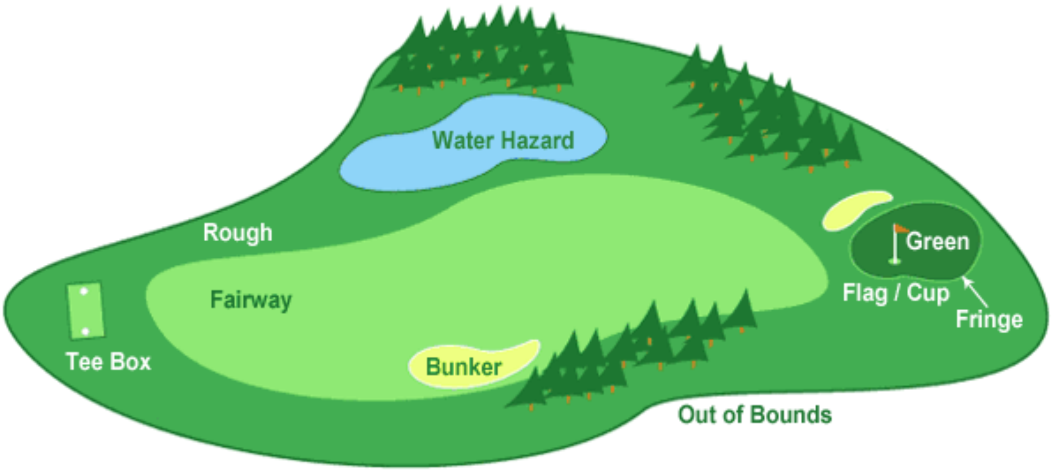

Figure 4 The typical layout of a hole on a golf course with the different parts displayed (The city of Calgary, 2014, with permission).

The mowing frequency varies between the green, tee, fairway and rough on a golf course. In general greens are mowed six times per week with a sharp mower that removes the clippings, due to aesthetic reasons and to avoid ball interference. It is of importance that the mowing is performed in different directions each time to prevent the grass from growing in one specific direction (SGF, 2001). Tees should be mowed three times per week, while the mowing frequency for fairways is at least two times per week (SGF, 2001).

The most important nutrients to add to the golf course grass are nitrogen (N), phosphorus (P), potassium (K), but also magnesium (Mg), iron (Fe) and sulphur (S) can be added. Different grass species require different amounts of nutrients and pH levels and therefore the amount of fertiliser needed depends on the grass type and the construction material. For every grass field a fertiliser program is formed, where greens and tees follow a similar program. If clippings are recycled to fairways they require less fertiliser than greens and tees, since nutrients are returned with the clippings. In addition, greens, tees and fairways should be irrigated, specifically during May to June in Sweden due to dry conditions. Early in the season the roots of the turfgrass are limited in their capacity to take up water and therefore irrigation can be advantageous at that time to enable plant uptake from the blades (SGF, 2010). The amount of irrigation water needed is determined by precipitation and evaporation. In general, roughs are neither fertilised nor irrigated.

Another management practice to perform on a golf course is aerification. Aerification is made to avoid compression and increase the oxygen in the ground, which can occur due to the pressure from machines and players. Furthermore, it will improve the surface layer of accumulated organic matter and fine particles, which allows water and fertilisers to reach deeper (Brame, 1999). There are two main types of aerification; shallow-tine aerification and deep-tine aerification. Shallow-tine aerification is performed with knifes of varied lengths, but at deepest 0.2 m. For deep-tine aerification, however, the depths are between 0.05-0.4 m. To receive the best result the aerification program should alternate between aerification methods adjusted for existing conditions. Greens should be shallow-tine aerated fortnightly during playing season and tees should be deep-tine aerated three to four times during a season. Additionaly, fairways should both be shallow-tine aerated and deep-tine aerated once per season (SGF, 2001).

Vertical cutting is a management activity performed on greens, tees and fairways to avoid the grass from growing horizontally. Moreover, vertical cutting enhance shoot growth and consequently a more dense grass field will develop (SGF, 2010). To receive a firm surface and to protect root necks greens, tees and fairways are top dressed. This will improve the grass quality, the experience for the player and the resilience of the plant. Generally, sand or a mix of sand and soil are used with a grain size between 0.1 – 1 mm for greens and tees, and up to 6 mm for fairways. Top dressing should be performed every third week on greens, weekly on tees and fairways when needed. In combination with vertical cutting and top dressing, reseeding is recommended to improve the quality of the grass surface (SGF, 2001).

Usually, the usage of pesticides is limited on a golf course. If vertical cutting and aerification is performed well, weeds can be controlled without application of herbicides. Fungus, however, can be a problem causing diseases, such as snow mold and can be controlled with fungicides during fall to decrease the risk of an attack (SGF, 2010). Dry patches are brown spots that are dry after irrigation and also caused by fungus. The disease can be treated with surfactant, which increases the plants ability to keep water and nutrients (SGF, 2001).

To increase the sustainability on golf courses and reduce the environmental impacts, Golf Environment Organisation developed an international environmental certification system in 2009, called GEO certification. The certification verifies that the environmental work on the golf course follow appropriate international standards and are currently applied on 100 golf courses around Europe (SGF, 2015).

2.3.4. Machines and fuels

The machine park for a utility lawn and a golf course consists of machines with varying power and size, such as tractors, ride-on mowers, utility vehicles, pedestrian mowers and hand-powered units. Generally, the machines have combustion engines, including two-stroke engines and four-stroke engines, which are operated by diesel or petrol. Four-stroke engines emit fewer GHG emissions and require half the fuel consumption compared to two-stroke engines (Priest *et al.,* 2000). This is due to the fact that two-stroke engines have a high power output and combust fuel twice as fast as four-stroke engines (Caple, 2008). On the other hand they benefit by having a low weight and a simple design compared to heavy and complicated four-stroke engines (Aspen, 2015). To ensure a reliable and satisfied machine park it is important to maintain the machines by washing, lubricating, repairing and sharpening the knives (SGF, 2001).

On a golf course grass with high quality is required and hence modern and efficient machines are needed. To a large extent, geographical location and landscape design will determine the machine park needed at the golf course (Caple, 2008). There are two types of commonly used machines for mowing a golf course; cylinder mowers and rotary mowers. When using a cylinder mower a high quality cutting is received with a low fine cut. This is due to a knife cylinder, which cut the grass against a bottom blade, resulting in an even cut and hence a fast restoring process for the grass. The quality of the cutting depends on the number of knifes in the machine and the rotation speed of the cylinder. A cylinder mower can be used on greens, tees and fairways (SGF, 2001). For roughs and semi-roughs, a rotary mower is more preferable since it works with a high intensity, which gives the grass a coarse cut (SGF, 2001). According to Caple (2008), a cylinder mower is more energy efficient than a rotary mower, resulting in a 50% increase in fuel consumption for a rotary mower. The efficiency of the mowers depends on the velocity of the machine and the engine speed. A velocity of 6.5- 10 km h^{-1} is recommended for golf course mowers. To get a more uniform cut and more consistent playing surface, the mower for greens, tees and fairways can be equipped with groomers, consisting of steel knifes to lift the grass before cutting (Toro, 2015). Since a golf course has additional management activities compared to utility lawns and meadow lawns, special machines such as aerators and top dressers, are needed and are usually combined with a tractor. For fertilisation different types of spray machines are used since liquid fertiliser is more common to use on a golf course than granular fertiliser (SGF, 2001).

Generally machines for lawn management are fuelled with diesel or petrol, but alternative fuels such as electricity and biofuels are increasing in popularity (Caple, 2008). Electrical mowers run by rechargeable batteries, which reduce the available operational time for mowing compared to diesel mowers. Therefore they are popular for residential use, but recent developments in battery technology are increasing the electrical products on the lawn management market. Electrical green mowers are currently available on the market, but it is more common to use hybrid mowers (Nilsson, pers. comm.). A hybrid mower can run on both electricity and diesel and hence increase the operational time, yet deliver the same quality of cutting and power output (Nilsson, pers. comm.). Biofuels are derived from living matter, often crops, and include bioethanol, biodiesel, vegetable oils and biogas among others. Bioethanol is most commonly produced from food crops, such as corn, sugar cane and wheat, whilst biodiesel is usually produced from vegetable oils, but also from animal fats (Demirbas, 2009).

The production of biofuels is based on renewable sources, yet there are issues that have to be considered. Producing biofuels is an expensive process and further research has to be made to make the production cost-effective (Demirbas, 2009). Furthermore, biofuels are currently violating land and crops used for food production, resulting in possible land-use changes and consequently discharge of emissions. Operational problems can occur when biodiesel are acting as a filter blocker and swelling in cold temperatures (Caple, 2008). Biodiesel can be blended with diesel to reduce emissions, but still manage cold weather and have a decent price. The most common blend is B20, containing 20% biodiesel and 80% diesel. Pure biodiesel, B100, has lower energy content than B20, but have on the other hand lower emissions (AFDC, 2015). Toro, a producer of lawn management equipment, have several diesel machines available that can be used with biodiesel B20.

An environmental alternative fuel is Aspen alkylate petrol, a substitute for petrol which is synthetically produced and contains significantly less aromatic hydrocarbons compared to standard petrol (Aspen, 2015). In a study by the Swedish Environmental Research Institute (IVL) (2008) alkylate petrol was concluded to give lower risks to negative environmental impact. Alkylate petrol was developed to improve the working conditions and health for foresters. It can be used in small machines such as mowers, trimmers, chainsaws and leaf blowers (Aspen, 2015).

Another alternative fuel is Ecopar, which is a synthetic diesel produced from natural gas. In a study by Lindgren *et al.* (2011) it was concluded that Ecopar cause lower emissions of aromatic hydrocarbons. However, compared to Swedish Environmental Class 1 diesel, the emissions regarding work operation character were equally for both fuels. Ecopar can be used in all types of machines and vehicles where standard diesel can be used (Ecopar, 2015).

2.4. PREVIOUS STUDIES OF CARBON FOOTPRINT FROM LAWN MANAGEMENT

The knowledge about GHG emissions from lawn management is limited, especially regarding Nordic conditions. In a Master thesis by Hansson and Persson (2012), the environmental impact from golf courses was determined by an LCA. The identified resources having a significant environmental impact were petrol, diesel, electricity, fertiliser, herbicides and sand, where diesel, nitrogen fertiliser and sand had the largest contribution to global warming potential.

Bartlett and James (2011) modelled the balance between carbon sequestration and GHG emissions from golf course management. The study included two golf courses in the United Kingdom, one links course and one parkland course. Input data were received from former studies of emissions from agriculture and lawn management. Greens and tees contributed with 16% of the emissions even though they only cover 3% of the golf course. The reason for that was mainly due to the use of nitrogen fertiliser. To determine the emission balance, the area of trees was vital since trees, vegetation and roughs acted as carbon sinks. The results showed that at the parkland course a negative balance was obtained, where the emissions were offset by the carbon sequestration. For the links course, however, the net balance became around zero, mainly due to the lesser amount of trees.

A similar study was made for urban turfgrass in Hong Kong by Kong *et al.* (2014), where the carbon footprint from turfgrass management was determined as well as the carbon sequestration. Five urban lawns were included in the study and the management activities was researched with questionnaires. The carbon sequestration was analysed by collecting soil samples from the lawns at different depths. The time since the turf establishment had an impact on the result, where three lawns acted as carbon sinks, all three years of age. Between 5 to 24 years was the estimated time for the carbon storage to be offset by the emissions. Two of the lawns acted as a carbon source and had a turf age of 15 and 25 years.

In California, USA, the sequestration and GHG emissions in ornamental lawns were studied by Townsend-Small and Czimczik (2010). The management included weekly mowing and mulching, combined with irrigation and fertilisation. N_2O fluxes were measured with a static flux chamber and the results showed that fertilised lawns emitted significant quantities of N_2O, but was offset by carbon sequestration. However, due to large emissions of CO_2 from the management, it was concluded that the GHG emissions were larger than the carbon sequestration.

Another study on lawns performed in the United States by Selhorst and Lal (2013) showed that the required time for carbon sequestration to offset GHG emissions from mowing and fertilisation was between 66 and 199 years. Soil samples were collected at 16 locations throughout the whole country, which resulted in varied sequestration rates between sites. It was concluded that more efficient management practices was required to receive greater climate change mitigation potential.

3. MATERIAL AND METHODS

The energy use and carbon footprint from lawn management in this study was determined from a life cycle perspective. Global warming and energy use were the chosen impact categories with the functional unit stated as the management of 1 ha of lawn during one year. A literature review was performed, to receive information about environmental advantages and disadvantages of lawns, required management activities as well as former research in the field. Subsequently, an inventory of utility lawns, meadow lawns and golf courses was made through interviews in the Uppsala region, Sweden. Additional information was received from the literature and databases.

The carbon footprint was calculated by using the results from the inventory and given emission factors from previous studies regarding the different activities performed during lawn management. Emissions of CO_2, N_2O and CH_4 were calculated and converted to CO_2e. The energy use was determined similarly, by using the inventory results and existing energy data of primary energy and electricity derived from other studies. The data was taken from reliable and well-researched sources and was compared with results from other studies.

3.1. SYSTEM BOUNDARIES

The studied system included lawn management, maintenance of equipment and production of purchased inputs e.g. fuel, fertiliser and pesticides (Figure 5). Transport of equipment between sites was excluded, except for the golf courses where the fuel consumption was reported in cycles. A cycle was identified according to Caple (2009) as the work required to perform an activity, i.e. mowing, on a specific lawn type. Hence the fuel needed to transport the equipment between the lawn types was not considered.

Production of equipment, construction of lawns, waste management and end of life treatment of equipment was not accounted for. Generally, lawns are used for a long time and to receive relevant results for the study, the entire lifetime was not taken into consideration. Studies have shown that the use phase of a vehicle has the largest environmental impact compared to all other life cycle stages (Castro *et al.,* 2003). Thus the same result was assumed for machines associated with lawn management and therefore the production and waste handling of machines was not considered. Emissions of greenhouse gases from composted or returned clippings were omitted in the study due to the absence of data regarding concentration of total solids (TS) in the grass. Also emissions associated with the soil waste from vertical cutting at the golf courses were excluded from the study.

Since the study was limited to include the grass management additional lawn activities, such as snow removal, were excluded. It was assumed that the required resources for maintenance of the lawn management equipment were the same for all lawn types, since similar machines are used and this aspect probably will have a low impact on the results

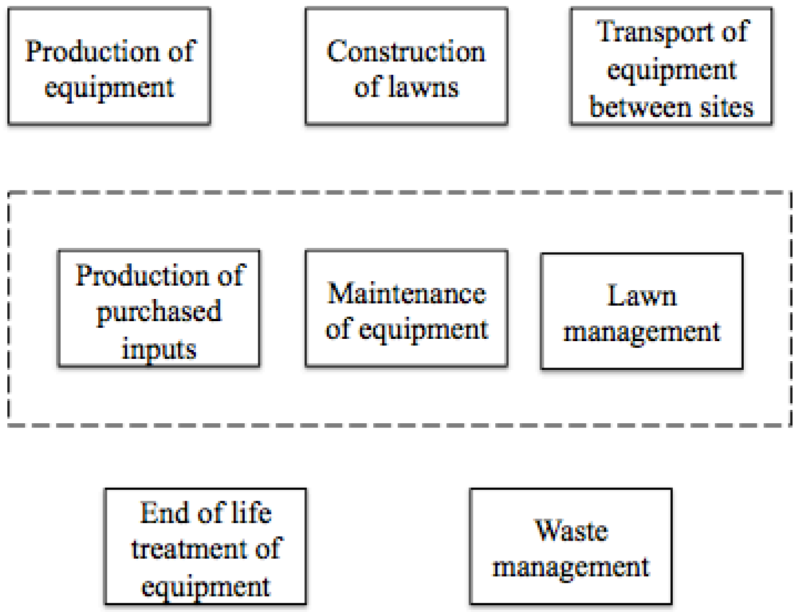

Figure 5 System boundaries for the study, where the activities within the dashed line were included for all lawn types.

The selected sites for collection of inventory data were geographically limited to the Uppsala region, Sweden. The reason for that was to include similar climate conditions for the studied lawns and to be able to perform personal interviews with greenkeepers, stakeholders and lawn caretakers. The golf courses were chosen due to previous involvement in the Lawn project to enable the results to be considered in other parts of the project. The subcontractors were chosen with the requirement that they were managing lawns on behalf of Uppsala municipality. A limited amount of subcontractors fulfilled that demand and therefore only two were selected.

3.2. INTERVIEWS

The inventory was performed through semi-structured interviews with greenkeepers at the two golf clubs Upsala GK and Sigtuna GK as well as stakeholders at Uppsala municipality and lawn caretakers at the two subcontractors Maskinringen Mälardalen and Vallgårda Entreprenad AB. To be able to validate the given information, one parallel interview was performed with the company Sweax, performing lawn management for housing cooperatives and private properties. The interviews consisted of open-ended questions, with a possibility to add supplementary information if needed.

All the interviewed managers had a central role in the management activities. In the inventory of utility lawns and meadow lawns, information was given by Per Westerlund and Viviann Blomgren from Uppsala municipality. Furthermore, Bo Gustavsson from Maskinringen, Sören Vallgårda from Vallgårda Entreprenad AB and Per Lidfors from Sweax were interviewed. Information about management practices at golf courses was provided by Leif Paulsson from Upsala GK and Henrik Johansson from Sigtuna GK, unless otherwise is stated. Literature was used as input data when additional information was needed.

3.3. INVENTORY OF UTILITY LAWNS

There are around 400 ha of utility lawns in Uppsala, which are managed by the municipality (Hedblom, pers. comm.). The management of the lawns is procured between the municipality and a subcontractor (Westerlund, pers. comm.). The geographical location of the lawns regulates the procurement, where adjacent lawns are managed by the same subcontractor (Blomgren, pers. comm.). According to the administrative regulations of the procurement some environmental aspects are demanded. The petrol consuming machines should be equipped with an engine that fulfils the emission requirements from EU, US Environmental Protection Agency (US EPA) or the California Air Resources Board (CARB) Step 1 or cleaner (Westerlund, pers. comm.). The petrol should be of environmental quality, equivalent with Aspen. Diesel machines should be certified accordingly to emission regulation EU Step 3. Furthermore, applying chemical pesticides to utility lawns are prohibited. The subcontractor is responsible to dispose pollutants and manage recycling of resources, as well as in collaboration with the municipality minimize the environmental effect.

Usually, the utility lawn management season starts in May and finish in mid-October (Westerlund, pers. comm.). According to the regulations, the management has to include mowing, trimming, leaf blowing, leaf mulching and edge cutting, which require resources and emit GHG emissions (Figure 6). Mowing should be performed with a rotary mower with a frequency that is high enough to keep a grass height of 8-10 cm during the season, in general with a maximum frequency of 15 times per year. Grass clippings should normally not be collected. Leaves should be cut at site to return nutrients to the grass continuously during fall. Every other mowing routine should be followed by trimming around trees, fences, flowerbeds etc. Other management practices, such as edge cutting should be performed when necessary. Fertilisation and irrigation, however, are normally not being performed for utility lawns. The management activities deviate from the regulations during new establishments of grass areas, to preserve the lawn a guarantee management with extended activities is performed during three years (Westerlund, pers. comm.).

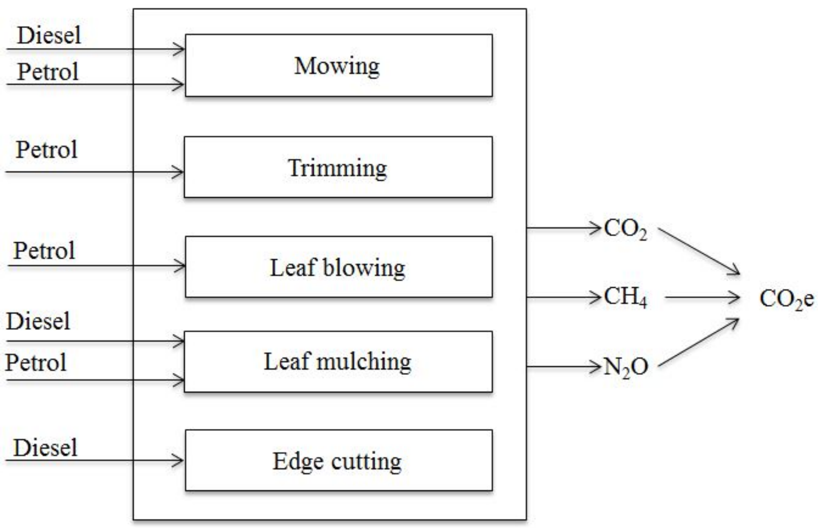

Figure 6 Flowchart of the lawn management activities performed on utility lawns with resources and output emissions displayed.

Maskinringen and Vallgårda perform mowing with a riding rotary mower with a width between 1.80 m and 3.20 m (Table 2). Sweax, however, uses a tractor, TransPro 54, for mowing, which is complemented by a pedestrian mower, Klippo, to be able to access all grass areas. Using a Transpro for lawn mowing is an uncommon practice. All companies leave the grass clippings on the lawn after mowing.

Table 2 Fuel type, fuel consumption and frequency for mowing of utility lawns

Contractors	Fuel	Average fuel consumption ($l\ ha^{-1}$)	Mowing frequency (occasion $season^{-1}$)	Annual fuel consumption ($l\ ha^{-1}\ year^{-1}$)
Maskinringen	Diesel	6	12	72
Vallgårda	Diesel	4	10-12	40-48
Sweax	Diesel	13	16	208
	Petrol	1.1	16	17.6

All contractors perform trimming but since it has a fuel consumption less than 5% of the fuel consumption for mowing, it is considered negligible. Leaf mulching is performed during fall with the same machine as used for mowing (Table 3). The maintenance of machines required 7 L ha^{-1} $year^{-1}$ motor oil and hydraulic oil (Lidfors, pers. comm.). Leaf blowing was estimated to 21 L ha^{-1} $year^{-1}$ (Lidfors, pers. comm.), but was neglected in the study due to uncertainties in the estimations. Often leaves are blown from roads and pathways, and it is therefore uncertain whether it should be included in lawn management or not. Since edge cutting was performed when needed, difficulties in the fuel consumption estimations occurred and were therefore neglected from the calculations.

Table 3 Fuel type, fuel consumption and frequency for leaf mulching of utility lawns

Contractor	Fuel	Average fuel consumption ($l\ ha^{-1}$)	Mowing frequency (occasions $season^{-1}$)
Maskinringen	Diesel	6	3
Vallgårda	Diesel	4.4	5
Sweax	Petrol	5.7	5

3.4. INVENTORY OF MEADOW LAWNS

Meadow lawns were established in 1960s and 1970s in Uppsala and currently 176 ha are managed by the municipality. Mowing is the sole management activity performed on meadow lawns, yet it emits GHG emissions (Figure 7). The mowing frequency is two times per year, once before Midsummer (mid-June) and once in August. It is not considered when the species are in blossom (Westerlund, pers. comm.) as this practice could inhibit the pollination (Wissman, pers. comm.).

Forage harvester and a tractor connected to a towed disc mower are the two types of machines used for cutting meadow lawns in Uppsala. The estimated diesel consumption per mowing time is 8 L/ha for Maskinringen and 5 L/ha for Vallgårda. The clippings are being left on the lawns after mowing. According to Westerlund (pers. comm.), the meadow lawns were considered trivial and were lacking interesting flora during procurement, and hence no effort to remove clippings are being made nowadays. However, Blomgren (pers. comm.) argues that it is due to the matter of costs. The resources needed for maintenance of the machines could not be estimated.

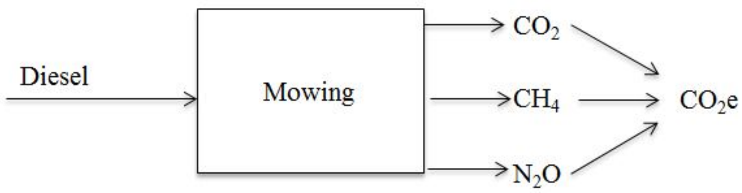

Figure 7 Flowchart of the lawn management activity performed on meadow lawns with resources and output emissions displayed.

3.5. INVENTORY OF GOLF COURSES

Upsala GK is located in Uppsala County and built its first golf course in 1938 (Upsala GK, 2015). Today it is a parkland course that got GEO certified in 2013, which consists of one 18-hole course and two 9-hole courses. Sigtuna GK built its 18-hole course in 1972 and is located outside Sigtuna, 33 km from Uppsala, in Stockholm County (Sigtuna GK, 2015). It currently has an area of 70 ha, including one 18-hole course, one 6-hole course and four practice greens (Table 4). Similarly, it is a parkland course and became GEO certified in 2014. The length of a golf season depends on the weather. It was stated by the golf clubs that in general a season is from May 1 to October 31 (26 weeks) for Upsala GK and April 1 to mid-October (28 weeks) for Sigtuna GK.

Table 4 The areas of the playable parts at the golf courses Upsala GK and Sigtuna GK

	Green (ha)	Tee (ha)	Fairway (ha)	Mowed rough (ha)
Upsala GK	2.5*	1.5	22	50
Sigtuna GK	1.5**	1	10	40

* Greens: the 18-hole course is 1 ha and the 9-hole courses are 1.5 ha
** Greens: the area of the 6-hole course is included

The lawn management on a golf course is very intense compared to the other lawn types and includes mowing, irrigation, fertilisation, application of pesticides, vertical cutting, aerification, top dressing, reseeding and leaf blowing (Figure 8).

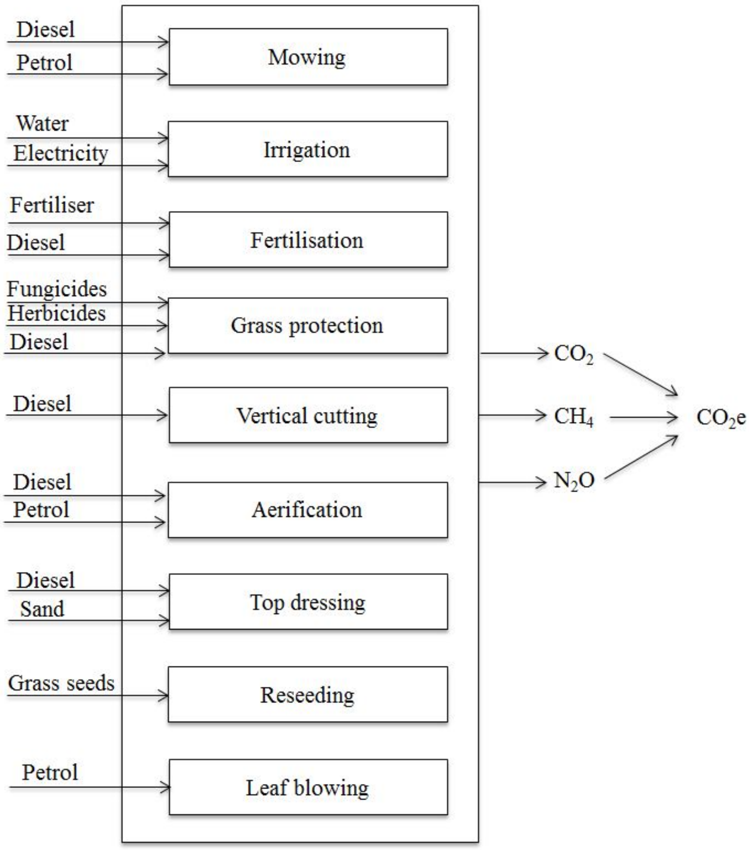

Figure 8 Flowchart of the lawn management activities performed on a golf course with resources and output emissions displayed.

Mineral fertilisers are applied on both golf courses, but depending on the duration of the season the applied amounts differ from year to year. Sigtuna GK follows a specific fertiliser program where the amount of products added to the greens and tees every week is preordained. The fertilisation rarely deviates from the program and 2013 was considered a representative year for the fertilisation at Sigtuna GK, hence the input data was from this year. At Upsala GK the amount of applied fertilisers is determined by the greenkeeper and a representative year was considered in the given data. At Upsala GK, Indigrow and Ecoturf are commonly used fertilisers, while Sigtuna GK uses Everris, Scotts, Headland Amenity and Compo.

The irrigation frequency is determined by the precipitation, but in general greens, tees and fairways at Sigtuna GK are irrigated three times per week. The roughs, however, receives no irrigation water. Similar irrigation routines are applied at Upsala GK, where greens, tees and fairways receive water at equal frequency and roughs are omitted. The water used at Sigtuna GK is pumped from lake Mälaren and distributed with an underground irrigation system, complemented with a hose when necessary. At Upsala GK, irrigation water is pumped from a nearby pond, which also receives the drainage water from the golf course. There are four pumps of the model Grundfos CR30-80 at Sigtuna GK, with an electricity consumption of 0.5 kWh m^{-3} (Johansson, P., pers. comm.) and five pumps of the model Grundfos CR32-6 at Upsala GK. CR 32-6 is 5-10% more efficient than CR30-80 and hence an electricity consumption of 0.45 kWh m^{-3} was estimated for Upsala GK (Johansson, P., pers. comm.).

Total estimated annual water consumption was 45,000 m^3 and 25,000-30,000 m^3 for Upsala GK and Sigtuna GK, respectively. Distributed on the different golf course parts the assumptions for water consumption were based on the stated fairway water use by Sigtuna GK of 17,000-20,000 m^3/year. An average amount of 18,500 m^3/year was assumed, which correspond to 67% of the total water use at Sigtuna GK. Hence the same percentage was assumed for irrigation of fairways at Upsala GK. Due to information given by the greenkeepers, the remaining water, 33% of the total water use, was divided equally on greens and tees at Upsala GK. For Sigtuna 60% of the remaining water was consumed on greens and 40% was used to irrigate tees.

Fungicides and herbicides are used on both golf courses, while insecticides are not being used. Commonly used fungicides are Sportak, Headway, Medallion and Amistar and a typical applied herbicide is Starane 180. For the application a tractor with a spray is used at Upsala GK with an estimated diesel consumption of 3 L/ha. The same fuel consumption was assumed for Sigtuna GK.

Reseeding is annually performed at both courses. It was estimated that a yearly amount of 30 kg seeds is used at Sigtuna GK, but was assumed to have negligible environmental effect and was hence not considered. Leaf blowing is performed continuously during fall with a back mounted unit consuming petrol at both golf courses. The fuel consumption was estimated to be 200 L per year for Upsala GK, but since leaf blowing is not limited to only blow leaves from the grass but also from roads and pathways it was neglected.

Machines are maintained regularly at both golf courses during the year by using motor oil, hydraulic oil, water and degreaser (Figure 9). Daily washing and continuously degreasing are performed at both courses. In addition motor oil and hydraulic oil is used frequently throughout the season (Table 5). The annual consumption of water and degreaser for maintenance could not be estimated and were omitted from the study.

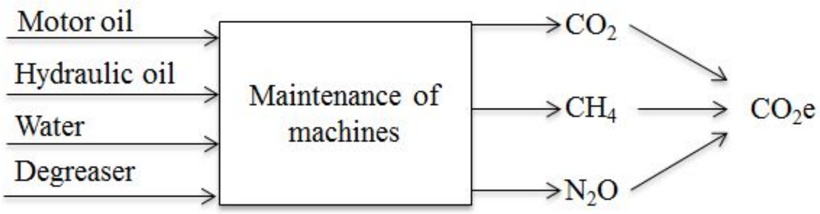

Figure 9 Flowchart of the required resources for maintenance of machines used for lawn management and output emissions.

Table 5 Annual amounts of maintenance resources for machines used at Upsala GK and Sigtuna GK

Golf course	Motor oil (l year^{-1})	Hydraulic oil (l year^{-1})
Upsala GK	60	150
Sigtuna GK	150	160

At Upsala GK the alternative fuel Aspen is used for the all petrol machinery, whereas at Sigtuna GK it is only used for small machines, such as the leaf blower and the trimmer. The synthetic diesel Ecopar is used for greens and tees at Upsala GK, while all other diesel machinery, at both courses, consumes standard diesel.

3.5.1. Greens

Greens are intensively managed with a mowing frequency of seven times per week at Upsala GK and five to six times per week at Sigtuna GK during a season. An average mowing frequency of 5.5 times per week was assumed for Sigtuna GK. Off season the frequency is reduced to three times per week before winter, thus an additional six times was included in the mowing frequency to include off season mowing (Table 6). The fuel consumption at Sigtuna GK varied between four to six litres per mowing time, whereas for Upsala GK it was measured by Caple (2008) and average fuel consumption was determined. At Sigtuna GK a green mower consuming diesel is used (Figure 10), whereas at Upsala GK a petrol mower is used, complemented with a diesel mower 10 times per year. The grass clippings are collected by the mower at both golf courses and put to compost or spread out on other grass areas.

Table 6 Fuel type, fuel consumption and frequency for mowing of greens at Upsala GK and Sigtuna GK

Golf club	Course	Fuel	Mean fuel consumption (l ha^{-1} occasion^{-1})	Mowing frequency (occasions season^{-1})
Upsala GK	18-hole	Petrol	4.3	188
	18-hole	Diesel	8.5	10
	9-hole	Diesel	2.1	188
Sigtuna GK	All	Diesel	3.3	160

Figure 10 The riding cylinder mower Greenmaster 3250-D from Toro used at Sigtuna GK for greens (Photo: Wesström, 2014).

Fertilisers are applied continuously throughout the season on all greens (Table 7). At Upsala GK the applied amounts of nitrogen and potassium vary between 180 kg/ha, year and 200 kg/ha, year, hence an average value of 190 kg/ha, year was assumed. Liquid fertilisers are used on greens at Upsala GK, while Sigtuna GK uses both liquid and granulated fertilisers. Granulated fertilisers are slow released fertilisers, which can supply the plant during a longer period of time compared to liquid fertilisers. The application is performed manually and thus no fuel is needed for this management practice.

Table 7 Amounts of nitrogen (N), phosphorus (P) and potassium (K) added by fertilisation of greens during a representative year for Upsala GK and Sigtuna GK

Golf club	N (kg ha^{-1} $year^{-1}$)	P (kg ha^{-1} $year^{-1}$)	K (kg ha^{-1} $year^{-1}$)
Upsala GK	190	80	190
Sigtuna GK	214	37	139

The annual water consumption for irrigation of greens resulted in 7,425 m^3 for Upsala GK and 5,400 m^3 for Sigtuna GK according to previous assumptions.

Fungicides are applied with the same frequency and amounts at both golf courses, while herbicides are never used on greens (Table 8). It was assumed that the fungicide Sportak EW was used on both courses. Sportak EW has the active ingredient Perkloraz 450 g l^{-1} (Swedish Chemicals Agency, 2015).

Table 8 Fungicide application frequency and amount of applied fungicides on greens for Upsala GK and Sigtuna GK

Golf course	Application frequency (occasions season^{-1})	Amounts of applied fungicides (l ha^{-1} occasion^{-1})	Amounts of active substance (kg ha^{-1} season^{-1})
Upsala GK	3	1	1,35
Sigtuna GK	3	1	1,35

Vertical cutting varies in frequency between the courses (Table 9). The fuel consumption, however, was assumed to be equal since Caple (2008) had measured consumption rates at Upsala GK, and Sigtuna GK was unable to estimate their fuel consumption for vertical cutting.

Table 9 Cutting frequency and fuel consumption for vertical cutting on greens at Upsala GK and Sigtuna GK, with the fuel consumption rate measured by Caple (2008)

Golf course	Fuel	Cutting frequency (occasions season^{-1})	Average fuel consumption (l ha^{-1} occasion^{-1})
Upsala GK	Diesel	8	10.9
Sigtuna GK	Diesel	14	10.9

Deep-tine aerification is performed two times per year at Sigtuna GK with additional aerification a few times during the year. At Upsala GK deep-tine aerification and hole pipe aerification are accomplished six times per year. Therefore it was assumed that the two golf courses had the same aerification frequency (Table 10). For the fuel consumption, Sigtuna GK was unable to estimate the consumption and thus the same fuel consumption and working velocity as stated by Upsala GK was assumed. The used machine is a Toro Procure 648 walk behind aerator, which consumes petrol.

Table 10 The annual frequency of deep-tine aerification and hole pipe aerification, as well as the required fuel for the activity on greens at Upsala GK and Sigtuna GK

Golf club	Fuel	Frequency (occasions season^{-1})	Work time (h ha^{-1})	Fuel consumption (l h^{-1})
Upsala GK	Petrol	6	10	5
Sigtuna GK	Petrol	6	10	5

Both golf courses perform top dressing at a similar frequency. Since no estimation of the fuel consumption of top dressing could be made at Sigtuna GK, it was assumed to be equal to the stated consumption by Upsala GK (Table 11). Sand is delivered from Broby Sand AB in Katrineholm, Sweden, 160 km from Upsala GK and from Sand & Grus AB Jehander and Rimbo Jord & Maskiner AB, located 50 km from Sigtuna GK.

Table 11 Top dressing frequency, amounts of applied sand and the required fuel for greens at Upsala GK and Sigtuna GK

Golf club	Fuel	Frequency (occasions season^{-1})	Amounts of sand (tonnes ha^{-1} season^{-1})	Work time (h ha^{-1})	Fuel consumption (l h^{-1})
Upsala GK	Diesel	13	120	2.4	10
Sigtuna GK	Diesel	14	187	2.4	10

3.5.2. Tees

Tees are mowed three times per week at both courses (Table 12), by a riding mower consuming diesel (Figure 11). Additionally, four mowing regimes were included in the mowing frequency to include off-season mowing. The grass is collected by the mower and spread out on other playable parts e.g. roughs, or composted.

Table 12 Fuel type, fuel consumption and frequency for mowing of tees at Upsala GK and Sigtuna GK. The fuel consumption for Upsala GK was measured by Caple (2008)

Golf club	Fuel	Mean fuel consumption (l ha^{-1} occasion^{-1})	Mowing frequency (occasions season^{-1})
Upsala GK	Diesel	10.5	82
Sigtuna GK	Diesel	8	88

Figure 11 The riding cylinder mower Baroness 315 used for cutting tees at Sigtuna GK (Photo: Wesström, 2014).

At Sigtuna, the fertilisation follows a program, similar to the program used for greens. At both courses only granulate fertilisers containing N, P and K are applied (Table 13). The application is performed manually and thus no fuel is needed for this management practice.

Table 13 Amounts of nitrogen (N), phosphorus (P) and potassium (K) added by fertilisation of tees during a representative year for Upsala GK and Sigtuna GK

Golf club	N (kg ha^{-1} $year^{-1}$)	P (kg ha^{-1} $year^{-1}$)	K (kg ha^{-1} $year^{-1}$)
Upsala GK	220	40	220
Sigtuna GK	176	27	108

The annual water consumption for irrigation of tees resulted in 7,425 m^3 for Upsala GK and 3,600 m^3 for Sigtuna GK according to previous assumptions.

At Upsala GK, fungicides follow the same application frequency and applied amounts as on greens (Table 14). It was assumed that the fungicide Sportak EW was used with the active ingredient Perkloraz 450 g l^{-1} (Swedish Chemicals Agency, 2015). Sigtuna GK, however, never applies fungicides on tees and neither of them uses herbicides on tees.

Table 14 Fungicide application frequency and amounts of applied fungicides on tees for Upsala GK and Sigtuna GK

Golf course	Application frequency (occasions $season^{-1}$)	Amounts of applied fungicides (l ha^{-1} $occasion^{-1}$)	Amounts of active substance (kg ha^{-1} $year^{-1}$)
Upsala GK	3	1	1,35
Sigtuna GK	0	0	0

Vertical cutting is an activity performed solely at Sigtuna GK, with a frequency of three times per year. The fuel consumption was assumed to be equal as when performed on greens.

Once a year deep-tine aerification is being performed at Sigtuna GK (Table 15). The aerification frequency is slightly higher at Upsala GK, probably due to a routine of both deep-tine aerification and knife aerification. Because of two management practices, both a petrol consuming walk behind aerator and a diesel consuming tractor are being used. Since the fuel consumption at Sigtuna GK was unavailable, a similar machine regarding fuel consumption and work time, as for the deep aerification at Upsala GK was assumed being used.

Table 15 The annual frequency of aerification, work time and the required fuel for tees at Upsala GK and Sigtuna GK

Golf club	Fuel	Frequency (occasions season^{-1})	Work time (h ha^{-1})	Fuel consumption (l h^{-1})
Upsala GK	Petrol	3	5.33	5
	Diesel	3	3	3
Sigtuna GK	Petrol	1	5.33	5

At Sigtuna GK tees are top dressed every other month, whereas at Upsala GK that frequency is once a year (Table 16). As before, no estimation of fuel consumption could be made at Sigtuna GK therefore it was assumed to be consistent with the fuel consumption and work time at Upsala GK. Sand is purchased from Swerock Vendels Grus, Sweden, 30 km from Upsala GK and from Sand & Grus AB Jehander and Rimbo Jord & Maskiner AB, located 50 km from Sigtuna GK.

Table 16 Top dressing frequency, amounts of applied sand and the required fuel for tees at Upsala GK and Sigtuna GK

Golf club	Fuel	Frequency (occasions season^{-1})	Amounts of sand (tonnes ha^{-1} season^{-1})	Work time (h ha^{-1})	Fuel consumption (l h^{-1})
Upsala GK	Diesel	1	33.3	5.33	10
Sigtuna GK	Diesel	3	40	5.33	10

3.5.3. Fairways

Fairways are mowed three times per week at both golf courses (Table 17). At Upsala GK, however, half of the mowing regimes are performed with a groomer (Caple, 2008). In addition, the mowing frequency was increased by four times to take off-season mowing into account. At Sigtuna GK a riding mower is used for mowing fairways (Figure 12). The grass clippings are not collected on fairways.

Table 17 Fuel type, fuel consumption and mowing frequency for fairways at Upsala GK and Sigtuna GK. The fuel consumption is measured by Caple (2008) for Upsala GK and Johansson, H. (pers. comm.) for Sigtuna GK

Golf Club		Fuel	Mean fuel consumption (l ha^{-1} occasion^{-1})	Mowing frequency (occasions season^{-1})
Upsala GK	Groomers	Diesel	2.44	41
	No groomers	Diesel	1.67	41
Sigtuna GK		Diesel	3	88

Figure 12 The riding cylinder mower Jacobsen 4677
used for mowing fairways at Sigtuna GK
(Photo: Wesström, 2014).

Fertiliser is applied on fairways continuously during the year (Table 18). For this management practice a machine consuming diesel is used with an annual assumed fuel consumption of 10 L/ha.

Table 18 Amounts of nitrogen (N), phosphorus (P) and potassium (K)
added by fertilisation of fairways during a representative year for
Upsala GK and Sigtuna GK

Golf club	N (kg ha^{-1} $year^{-1}$)	P (kg ha^{-1} $year^{-1}$)	K (kg ha^{-1} $year^{-1}$)
Upsala GK	160	40	160
Sigtuna GK	89	12	40

Irrigation water amounts were assumed to be 30,150 m^3 at Upsala GK and 18,500 m^3 at Sigtuna GK due to previous assumptions.

Herbicides are applied at both golf courses, once a year at Sigtuna GK and every other year at Upsala GK (Table 19). Fungicides are applied once a year solely at Upsala GK while herbicides are applied at both golf courses. It was assumed that the fungicide Sportak EW and the herbicide Starane 180 were used with the active ingredient Perkloraz 450 g l^{-1} and Fluroxipyrn (1-methylheptylester) 259,4 g l^{-1} (Swedish Chemicals Agency, 2015).

Table 19 Fungicide and herbicide application frequency and amounts of applied fungicides on fairways for Upsala GK and Sigtuna GK

Golf course	Type of pesticide	Application frequency (occasions season^{-1})	Amounts of applied fungicides (l ha^{-1} occasion^{-1})	Amounts of active substance (kg ha^{-1} year^{-1})
Upsala GK	Fungicides	1	1	0.45
	Herbicides	0.5	1.5	0.19455
Sigtuna GK	Fungicides	0	0	0
	Herbicides	1	1.5	0.3891

Vertical cutting is not performed on fairways at neither golf course. Aerification, on the other hand, is performed with a tractor consuming diesel (Table 20). The fuel consumption and working time at Sigtuna GK was assumed to be the same as for Upsala GK.

Table 20 The annual frequency of aerification, work time and the required fuel for fairways at Upsala GK and Sigtuna GK

Golf club	Fuel	Frequency (occasions season^{-1})	Work time (h ha^{-1})	Fuel consumption (l h^{-1})
Upsala GK	Diesel	3	0.55	3
Sigtuna GK	Diesel	2	0.55	3

At Upsala GK fairways are top dressed once a year, whereas at Sigtuna GK the activity is not being performed (Table 21). Sand is purchased from Swerock Vendels Grus, Sweden, 30 km from Upsala GK.

Table 21 Top dressing frequency, applied sand and fuel consumption for fairways at Upsala GK and Sigtuna GK

Golf club	Fuel	Frequency (occasions season^{-1})	Amounts of sand (tonnes ha^{-1} season^{-1})	Work time (h ha^{-1})	Fuel consumption (l h^{-1})
Upsala GK	Diesel	1	30	1.81	10
Sigtuna GK	-	0	0	0	0

3.5.4. Roughs

Roughs require the least management practices at a golf course. Mowing is performed once a week during season (Table 22), with a mower consuming diesel (Figure 13). The clippings are left on the ground after mowing. No other management practice is performed on the roughs, except for application of herbicides once every other year with 1.5 L/ha, time at Upsala GK to prevent dandelion growth.

Table 22 Fuel type, fuel consumption and mowing frequency for roughs at Upsala GK and Sigtuna GK

Golf club	Fuel	Fuel consumption (l ha^{-1} $occasion^{-1}$)	Mowing frequency (occasions $season^{-1}$)
Upsala GK	Diesel	6	26
Sigtuna GK	Diesel	6	28

Figure 13 The rotary mower Baroness 2800B used for mowing roughs at Sigtuna GK (Photo: Wesström, 2014).

3.6. GENERAL INPUT DATA

Throughout the calculations of carbon footprint and energy use general data has been used (Appendix I). For all carbon footprint calculations GWP values from IPCC (2013) was used with a time horizon of 100 years and climate-carbon feedbacks included. It was assumed that the standard petrol and standard diesel used during lawn management were petrol mixed with 5% ethanol and diesel mixed with 5% biodiesel of Fatty Acid Methyl Ester (FAME), since they are the most commonly sold types of fuel in Sweden (Värmeforsk, 2011). The energy content in the standard fuels where received from the Swedish Petroleum and Biofuels Institute (SPBI).

Emissions to air during production, distribution and combustion of the fuels were derived from Miljöfaktaboken (Värmeforsk, 2011). It contains a detailed summary of emission factors for fuels and energy sources based on other published studies. The data is corresponding to Swedish conditions and cover the total environmental impact through a life cycle perspective, from raw material extraction to processing, transportation and conversion. It was assumed that the electricity used at the golf courses was Swedish electricity mix, and hence primary energy factors and emission factors were collected from the same study. The energy in the Swedish electricity mix derives mainly from nuclear power and hydropower.

The production and distribution of the alkylate petrol Aspen is similar to standard petrol (Karlsson, pers. comm.). Thus Aspen was assumed to have the same primary energy content and emission factor for the production and distribution phase as standard petrol. The emissions of CO_2 from the combustion will decrease with 15% compared to standard petrol (Karlsson, pers. comm.), but since no research has been made on Aspen yet, the emissions from the combustion were assumed the same as for standard petrol. For Ecopar the CO_2 emissions during combustion were calculated using the fuel composition and the lower heating value. All other emission factors were assumed the same as for standard diesel since further research in the area was unavailable. The energy content in Ecopar and Aspen were calculated to 9.69 and 8.53 kWh l^{-1}, respectively.

In a study by Brentrup and Pallière (2008), reference data for European fertiliser production and use from 2006 were presented. An LCA was made on the production phase, from raw material extraction to the product at plant gate. Information for the study was derived from members of the European Fertiliser Manufacturers Association (EFMA), complemented by data from the literature. The fertiliser products used at Sigtuna GK for nitrogen fertilisation contain a mix of urea, ammonium and nitrate (Appendix II). Hence the primary energy consumption value was chosen for the product Urea ammonium nitrate (UAN). For fertilisation of phosphorus and potassium primary energy consumption values for the products Triple Super Phosphate and Muriate of potash were chosen. It was assumed that the same types of fertilisers were used at Upsala GK.

The carbon footprint of different fertiliser products in different region in the world has been determined by Kool *et al.* (2012). The study was conducted from a life cycle perspective, from cradle to gate of the fertiliser plant. Western Europe was the chosen region, with solely use of natural gas for fertiliser production and emissions from the production, transport and leakage of natural gas included in the study. The average carbon footprint determined for liquid UAN, Triple Super Phosphate and Potassium chloride were chosen to match the fertilisers used at Sigtuna GK.

Additional direct N_2O emissions due to application of synthetic nitrogen fertilisers to the soil was assumed to be 1% of applied nitrogen amounts, according to IPCC (2006). Indirect N_2O emissions, due to volatilisation of ammonia, were neglected since they were assumed to be significantly smaller compared to the direct emissions.

In an LCA by Bernesson (2004), the energy requirements for pesticide manufacturing were set at 198.1 MJ kg^{-1} active substance including packaging and transport. Moreover, the study presented the GHG emission factors for production of pesticides. These factors were used for energy and carbon footprint calculations for pesticides.

Motor oil and hydraulic oil was assumed to correspond to light fuel oil at regional storage, manufactured in Europe in the database Ecoinvent. Ecoinvent is one of the largest databases in the world consisting of life cycle inventory data, with transparent and current information (Ecoinvent, 2015). Emission data of the production and distribution of the oil was received from the database. The primary energy was not considered.

Emissions and energy use from transportation of sand to the golf courses were calculated with the Network for Transport Measures (NTM) calculation tool NTMCalc Freight Basic. The tool is developed by members and stakeholders within NTM and is an accepted method for emission calculation and environmental effects from goods and passenger transport (NTM, 2015). It was assumed that the transport was performed by a truck with trailer with a cargo capacity of 40 Mg.

4. RESULTS

This chapter will present the results regarding the calculations of energy use and carbon footprint for utility lawns, meadow lawns, greens, tees, fairways and roughs.

4.1. ENERGY USE FOR DIFFERENT LAWN TYPES

The largest energy use per hectare was determined for greens, followed by tees, fairways and roughs (Figure 14). Utility lawns and meadow lawns had the least energy consuming management of all lawn types. The average energy use was 16.5 GJ ha^{-1} $year^{-1}$ for Upsala GK and 13.0 GJ ha^{-1} $year^{-1}$ for Sigtuna GK. The energy use was expressed as primary energy in all calculations. The required energy for management of the whole courses was 1 250 GJ $year^{-1}$ for Upsala GK and 680 GJ $year^{-1}$ for Sigtuna GK.

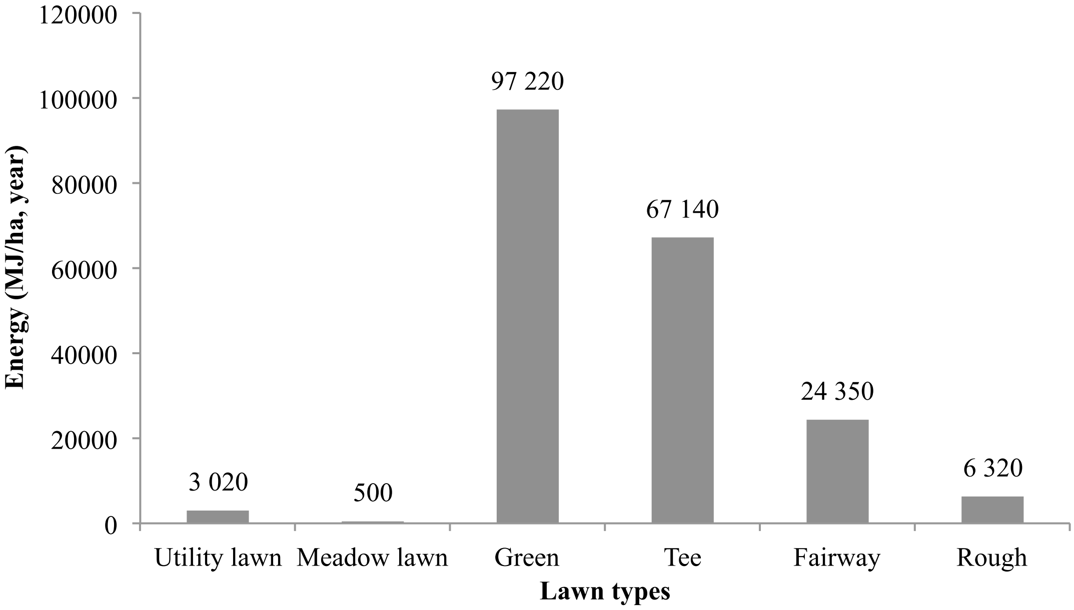

Figure 14 The average energy use expressed as primary energy caused by lawn management for different lawn types in the Uppsala region.

For the utility lawn management, Maskinringen reported larger energy consumption than Vallgårda (Figure 15). However, the leaf mulching activity at Vallgårda used a slightly higher amount of energy than Maskinringen. The total energy used by Uppsala municipality for management of 400 ha of utility lawns was 1 200 GJ $year^{-1}$.

The management of meadow lawns, with mowing as the only activity, resulted in an energy use of 620 and 390 MJ ha^{-1} $year^{-1}$ for Maskinringen and Vallgårda, respectively. The average total energy used by Uppsala municipality for management 176 ha of meadow lawns was 90 GJ $year^{-1}$.

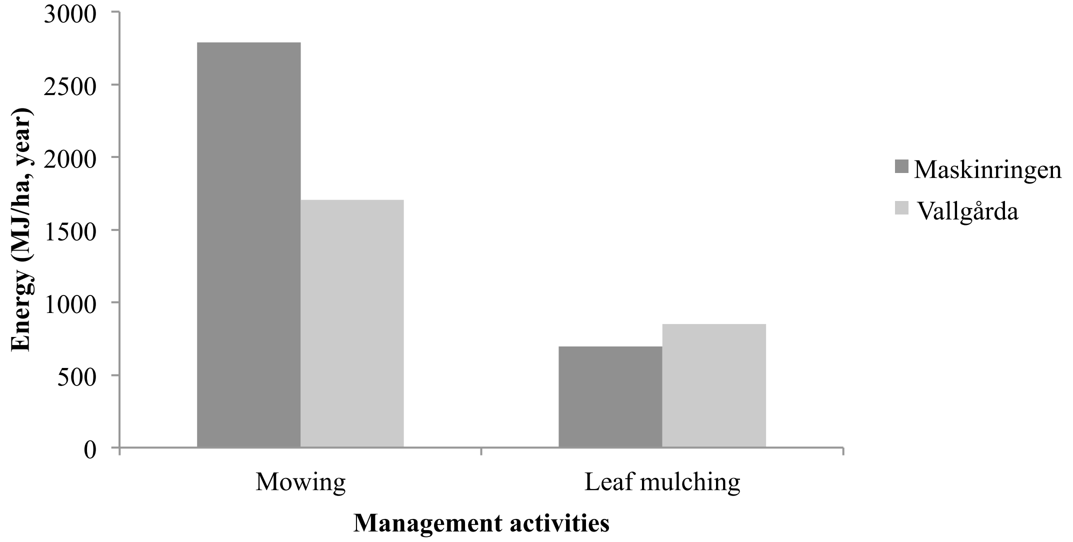

Figure 15 The primary energy used for lawn management of utility lawns during one year by the subcontractors Maskinringen and Vallgårda.

The energy use distributed on the different management activities showed that mowing and dressing were the most energy consuming activities performed on greens at both golf courses (Figure 16). The energy used for dressing was mainly due to the transportation of sand to Upsala GK. At Sigtuna GK, however, the transportation distance was smaller and thus a large part of the energy was due to the fuel consumption while performing the dressing. For the fertilisation, the consumed energy was the energy needed for the production of the fertiliser. The results showed that greens, which only contribute to 3% of the golf course area, consumed 19-21% of the total energy at the golf course during one year.

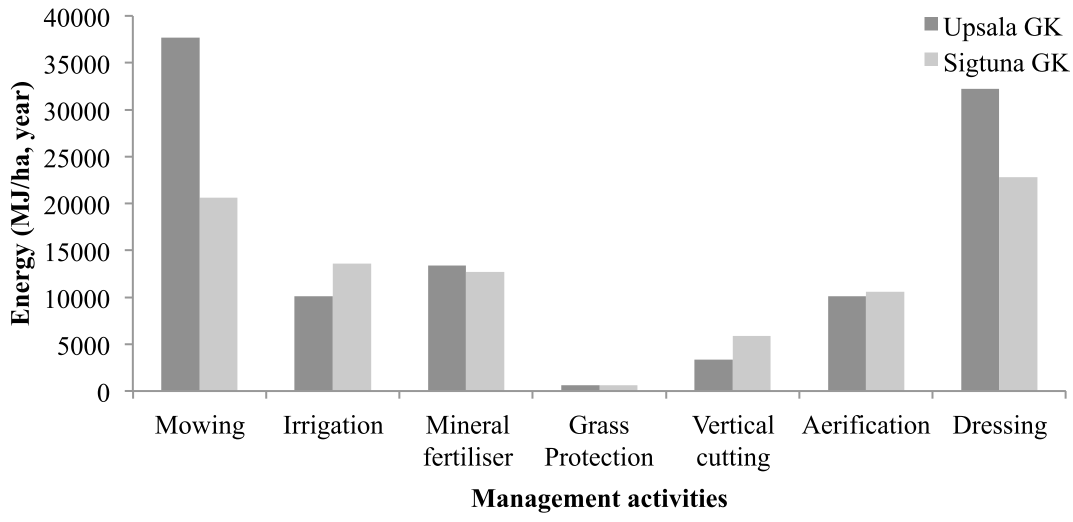

Figure 16 The primary energy used for lawn management of greens during one year at Upsala GK and Sigtuna GK.

Mowing, followed by irrigation and the manufacturing of mineral fertiliser were the activities consuming the most energy at tees (Figure 17). The management of tees caused 9% of the total energy used at the golf courses during a year. Even though, tees consist of a small proportion, only 2%, of the golf course.

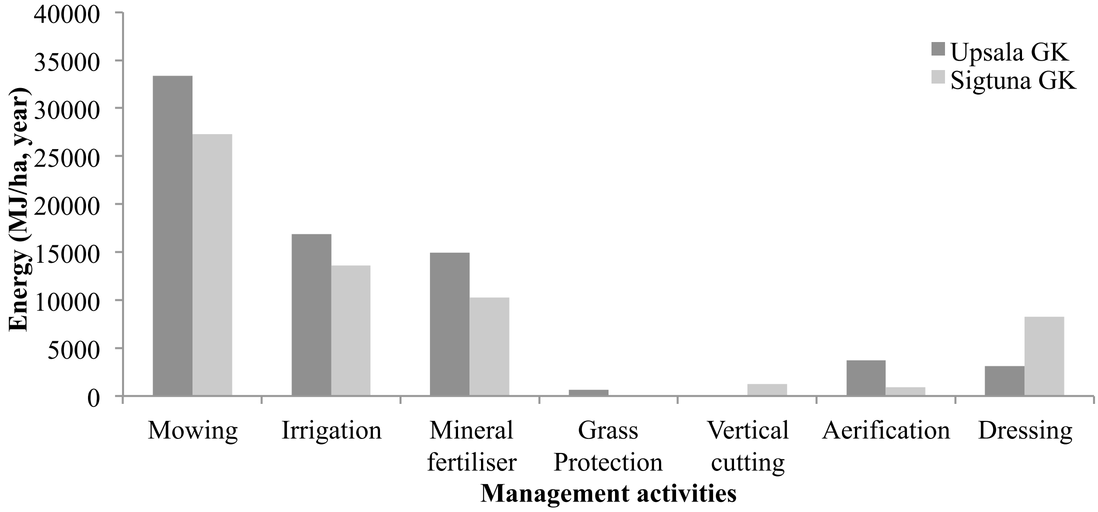

Figure 17 The primary energy used for lawn management of tees during one year at Upsala GK and Sigtuna GK.

A large proportion of the total energy consumed on lawn management was used on fairways, where Upsala GK used 45% of the annual energy and Sigtuna GK used 34% of the annual energy. However, a large part of the golf courses (19-28%) consist of fairways. Mowing, irrigation and fertilising were found to be the most energy consuming management activities at fairways (Figure 18). The energy used for mineral fertilisation on fairways consisted of both the energy needed for manufacturing of fertilisers (93-96%) as well as the energy needed for the fuel consumption (4-7%). Large differences between the two golf courses were observed, in particular for the energy related to the use of fertiliser due to different fertilisation rates between the courses.

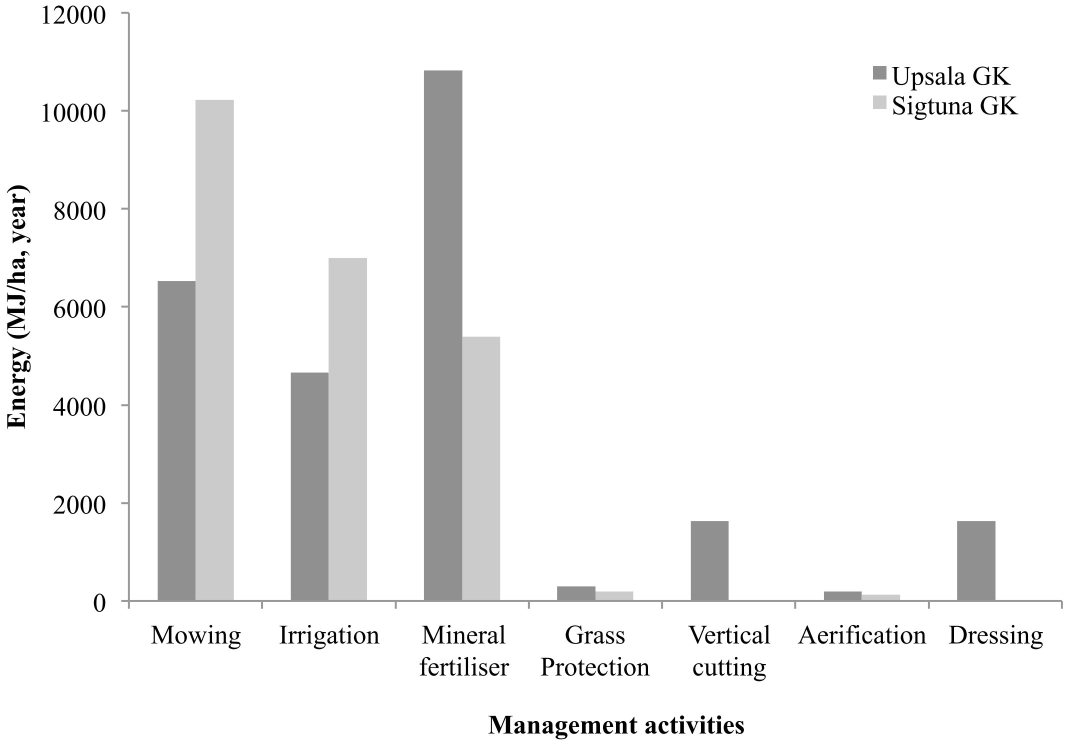

Figure 18 The primary energy used for lawn management of fairways during one year at Upsala GK and Sigtuna GK.

Mowing was the management practice at the roughs that consumed most energy with similar annual amounts at both courses (Figure 19). At Sigtuna GK, roughs were the most energy consuming area with 38% of the annual energy use, whereas at Upsala GK the consumption was slightly less (24%).

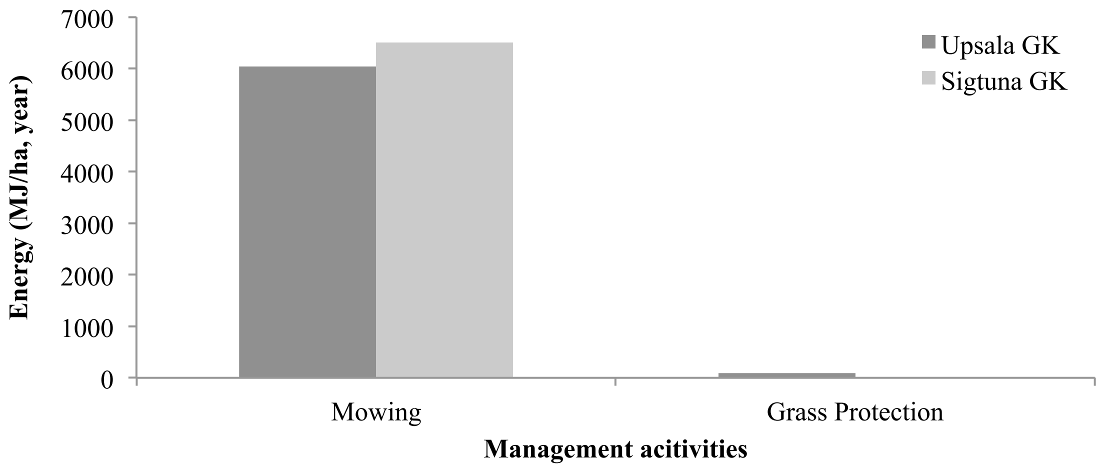

Figure 19 The primary energy used for lawn management of roughs during one year at Upsala GK and Sigtuna GK

4.2. CARBON FOOTPRINT FOR DIFFERENT LAWN TYPES

The results for carbon footprint followed the same distribution as for energy consumption with greens as the lawn type with the largest footprint, followed by tees, fairways and roughs (Figure 20). The smallest carbon footprint was caused by utility lawns and meadow lawns. For the two golf courses the carbon footprint was 1.33 Mg CO_2e ha^{-1} $year^{-1}$ for Upsala GK and 0.94 Mg CO_2e ha^{-1} $year^{-1}$ for Sigtuna GK. The roughs dominate the golf course area, which explain the rather low carbon footprint per hectare for the whole golf course.

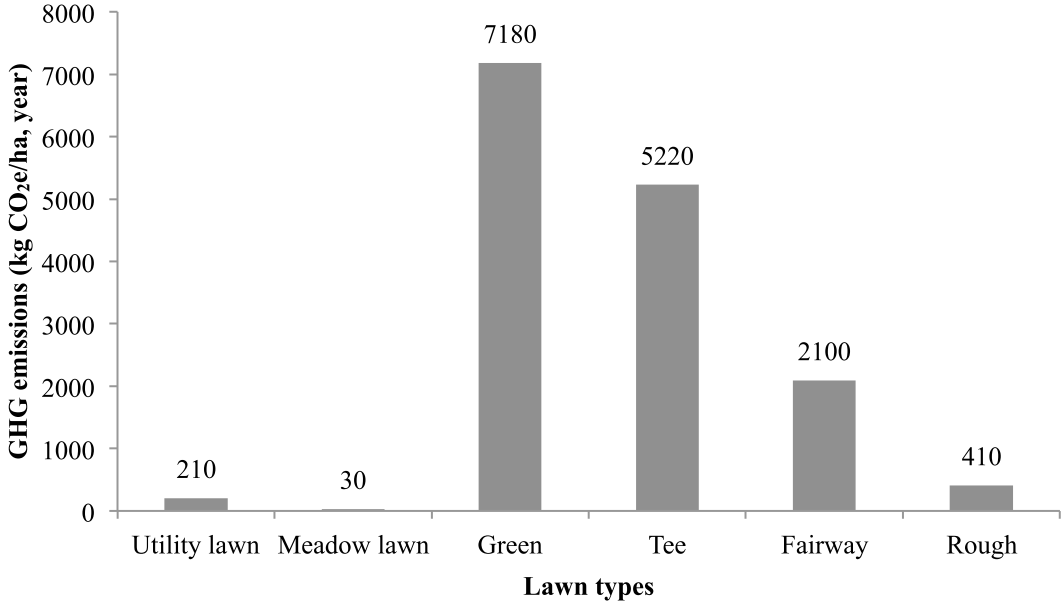

Figure 20 The average carbon footprint caused by lawn management for different lawn types in the Uppsala region.

The carbon footprint from utility lawn management was divided into mowing and leaf mulching, with a slightly larger carbon footprint derived from Maskinringen (238 kg CO_2e ha^{-1} $year^{-1}$) compared to Vallgårda (179 kg CO_2e ha^{-1} $year^{-1}$) (Figure 21). Maintenance of the equipment was included in the mowing emissions and caused 3-4% of the carbon footprint from mowing. The total carbon footprint from utility lawn management by Uppsala municipality was 83 Mg CO_2e $year^{-1}$.

The management of meadow lawns, with mowing as the only activity, resulted in a carbon footprint of 40 kg CO_2e ha^{-1} $year^{-1}$ for Maskinringen and 25 kg CO_2e ha^{-1} $year^{-1}$ for Vallgårda. The total carbon footprint caused by Uppsala municipality for the management of meadow lawns was estimated to 5.7 Mg CO_2e $year^{-1}$.

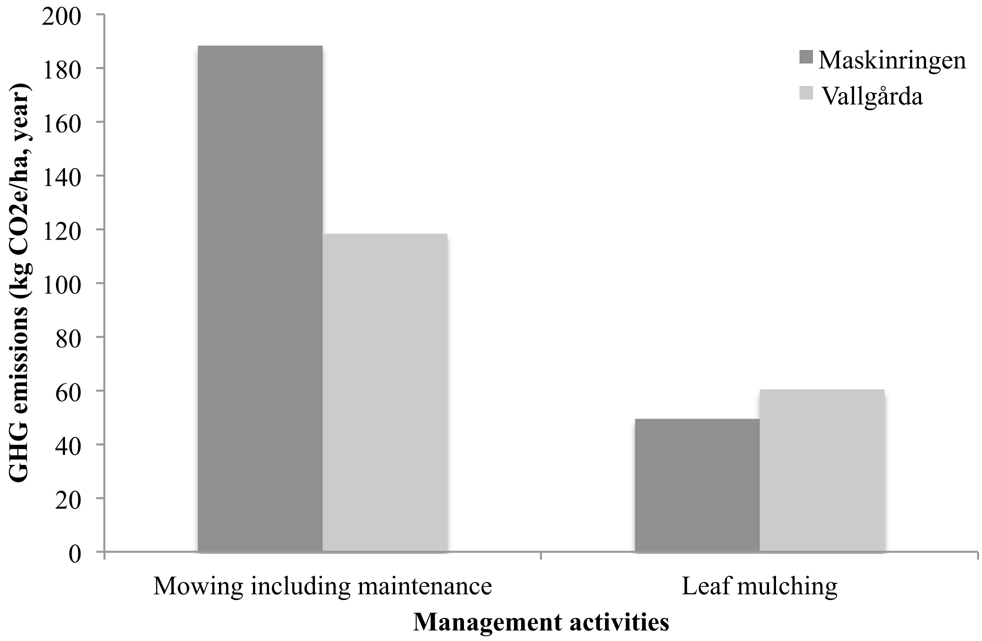

Figure 21 The carbon footprint caused by lawn management of utility lawns during one year by the subcontractors Maskinringen and Vallgårda procured by Uppsala municipality.

On greens, mowing, manufacturing of mineral fertiliser, soil emissions of N_2O and dressing were the management activities with the largest emissions of GHGs (Figure 22). A total carbon footprint from the golf courses was determined 101 Mg CO_2 $year^{-1}$ for Upsala GK and 49 Mg CO_2 $year^{-1}$ for Sigtuna GK. Of the total carbon footprint, 20% of the GHG emissions were caused by the management of greens, with greens consisting of only 3% of the total golf course area. 1% of the emissions from mowing were due to manufacturing of resources used for machine maintenance.

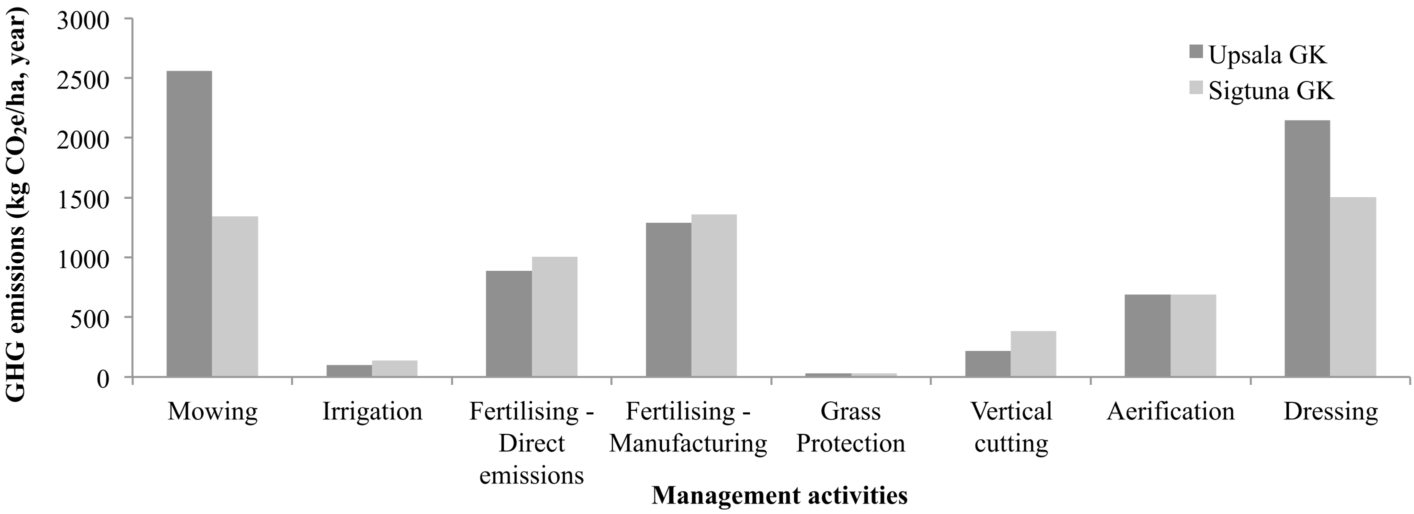

Figure 22 The carbon footprint caused by management of greens at Upsala GK and Sigtuna GK

Mowing and fertilisation (manufacturing and soil emissions of N_2O) were the two management practices with the largest carbon footprint at tees at both golf courses (Figure 23). Tees were the lawn type at the golf course with the smallest total carbon footprint, where 8% of the total GHG emissions were emitted from Upsala GK and 10% of the total GHG emissions were emitted from Sigtuna GK.

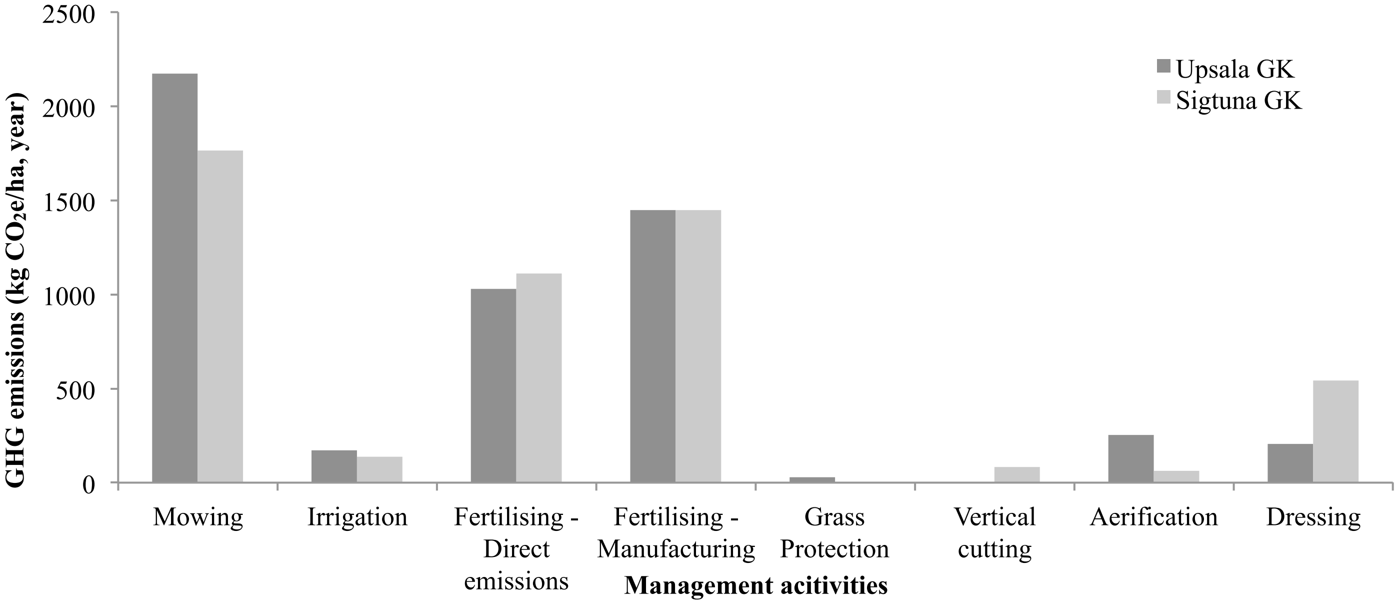

Figure 23 The carbon footprint caused by management of tees at Upsala GK and Sigtuna GK.

The emissions due to manufacturing of fertiliser and soil emissions of N_2O, together with mowing were the largest contributor of GHG emissions at both Upsala GK and Sigtuna GK (Figure 24). The emissions from the fuel consumption due to fertilisation was included in the manufacturing calculations, but only contributed to 2% (Upsala GK) and 4% (Sigtuna GK) of the manufacturing emissions. At Upsala GK 53% of the total GHG emissions were emitted from the fairways, whereas at Sigtuna GK the emissions attributed to fairway management were only 35%. Since golf courses constitutes of a large area of fairways, the total carbon footprint from fertilisation of fairways is 40% of the total emissions at Upsala GK and 20% of the total emissions at Sigtuna GK.

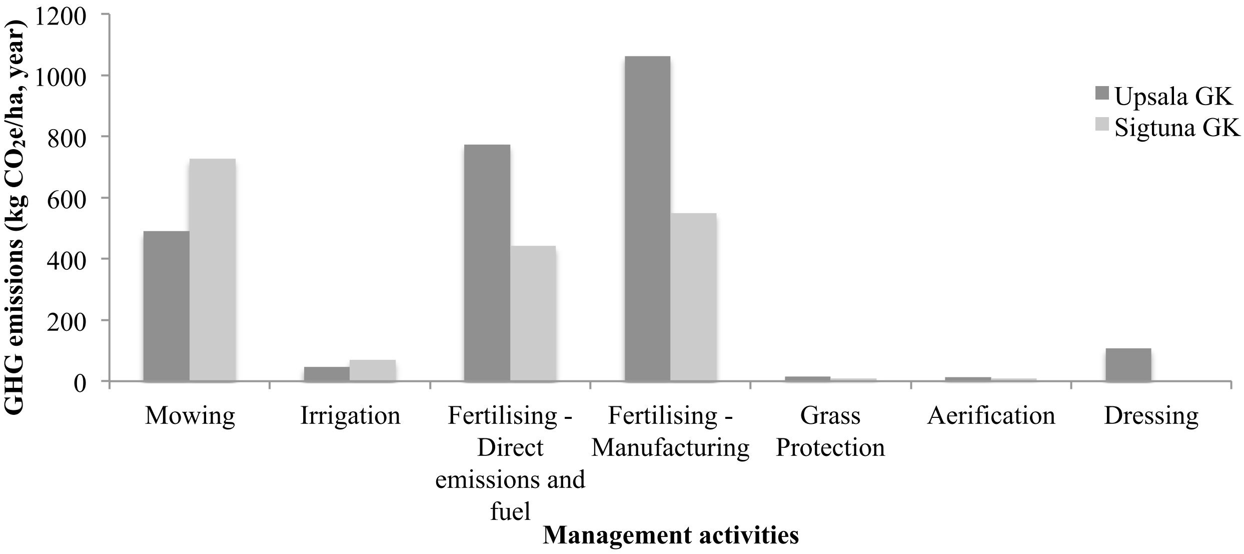

Figure 24 The carbon footprint caused by management of fairways at Upsala GK and Sigtuna GK.

Mowing was the only management activity emitting significant GHG emissions at the roughs (Figure 25). However, since roughs consist of a large part of the golf course, they emitted 20% and 35% of the total GHG emissions at Upsala GK and Sigtuna GK, respectively.

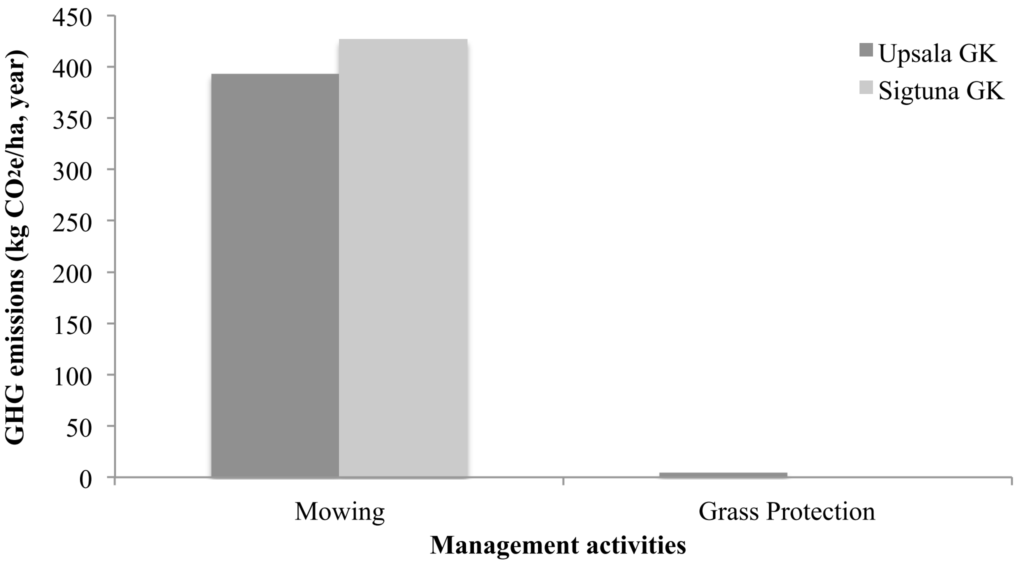

Figure 25 The carbon footprint caused by management of roughs at Upsala GK and Sigtuna GK.

5. DISCUSSION

Greens had the largest carbon footprint and energy use per hectare, followed by tees, fairways, roughs, utility lawns and meadow lawns. This was due to the decreasing intensity of management activities, where greens require a lawn with higher grass quality and hence more activities compared to utility lawns. The management activities consuming most energy were mowing, irrigation and manufacturing of fertiliser, whereas the activities with largest carbon footprint were mowing, manufacturing of fertiliser and soil emissions from application of fertilisers.

The average energy use per hectare was significantly larger for the golf courses (16.5 GJ ha^{-1} $year^{-1}$ for Upsala GK and 13.0 GJ ha^{-1} $year^{-1}$ for Sigtuna GK) compared to the utility lawns (3 GJ ha^{-1} $year^{-1}$) and meadow lawns (0.5 GJ ha^{-1} $year^{-1}$). The total energy used by the golf courses was 1 250 GJ $year^{-1}$ for Upsala GK and 680 GJ $year^{-1}$ for Sigtuna GK. For the lawns with management under responsibility of Uppsala municipality the equivalent amount was 1200 GJ $year^{-1}$ for utility lawns and 90 GJ $year^{-1}$ for meadow lawns. In Sweden, a passenger car drives on average 12 180 km annually, with an energy use of 33 GJ $year^{-1}$ per car, if fuelled with petrol (Swedish Energy Agency, 2013). Thus the total management of lawns by the municipality corresponds to the annual average energy consumption of 65 passenger cars.

In a study by Bartlett and James (2011), the carbon footprint was 0.7 ± 0.2 Mg CO_2e ha^{-1} $year^{-1}$ for a parkland golf course. Compared to this, the carbon footprint for Upsala GK (1.33 Mg CO_2e ha^{-1} $year^{-1}$) and Sigtuna GK (0.94 Mg CO_2e ha^{-1} $year^{-1}$) were larger, yet feasible. The larger carbon footprint at the golf courses around Uppsala could be due to the fact that dressing was not included in the study by Bartlett and James. Dressing, especially due to the transport of the sand, was shown to emit a considerable amount of GHG emissions. This was also concluded by Hansson and Persson (2012) that identified sand as a significant source of GHG emissions at golf courses. The management intensities vary amongst golf courses, which also can have an effect on the results and prevent the work to identify an average golf course management. Roughs and utility lawns have similar management activities, but differ in the duration of the mowing season. The total carbon footprint from utility lawns of 210 CO_2e ha^{-1} $year^{-1}$ can be compared with similar results from a study by Selhorst and Lal (2013) that determined the GHG emissions to 190 kg CO_2e ha^{-1} $year^{-1}$ from mowing of home lawns.

The total required carbon sequestration to obtain a carbon neutral golf course was 101 Mg CO_2 $year^{-1}$ for Upsala GK and 49 Mg CO_2 $year^{-1}$ for Sigtuna GK. For the utility lawns of 400 ha and meadow lawns of 176 ha it require 83 and 5.7 Mg CO_2e $year^{-1}$, respectively, to obtain a carbon neutral lawn. A higher carbon sequestration is expected at the golf course compared to the utility and meadow lawns since irrigation and fertilisation is continuously performed, which increases the root and shoot biomass and thus the carbon storage in the soil (Qian and Follett, 2012). In the study by Bartlett and James (2011), trees were determined to be a large sequester of carbon. Since Upsala GK and Sigtuna GK both are parkland courses, a significant amount of trees are available, which will enhance the sequestration rates.

Qian and Follett (2002) determined the average carbon sequestration rates from 15 golf courses to be 1 $\pm$ 0.14 Mg CO_2e ha^{-1} $year^{-1}$. The study also showed that the sequestration rates were increasing until 25-30 years after establishment, then the rates tended to reach equilibrium. The existing golf course at Sigtuna GK was built in 1972 (Sigtuna GK, 2015), while Upsala GK initial 18-hole course was built in 1965, but have had several renovations since then (Upsala GK, 2015). According to this, the potential for the golf courses to continuously sequester carbon today is low.

A high variability in carbon sequestration is expected for lawns due to differences in the initial carbon content when the lawns were constructed (Kätterer, pers. comm.). If the soil will sequester or emit carbon depends on the balance between production of organic material and degradation (Kätterer, pers. comm.). Other aspects determining the carbon sequestration are climate, soil properties and management activities. By recycling the clippings after mowing enhanced sequestration rates are expected, which increases the potential for utility lawns and meadow lawns to sequester carbon.

The lawn management of a golf course is often unique for the course due to its geographical and landscape layout. Therefore will these results not be applicable for all golf courses. The greenkeepers and lawn caretakers estimated the fuel consumption rates, which was used as input data in the study. These values include a larger uncertainty compared to if the values would have been measured, which was the case for the input data given by Caple (2008). Furthermore, assumptions regarding the irrigation were made that includes uncertainties in the amount of water being used at the both courses. For the utility lawns and meadow lawns only two subcontractors were interviewed, which can have an effect on the input data. Also, the results are specific for Uppsala and could vary among other municipalities in Sweden.

The management activities using the most energy on the golf courses were the activities performed on fairways and roughs, with mowing, irrigation and manufacturing of fertiliser as the most energy consuming. The largest carbon footprint at the golf course was also determined at the fairways and roughs with soil emissions and manufacturing of fertiliser as well as mowing as the largest emitters. But notable are also the greens, with large total GHG emissions and energy use although its area is small. Since the levels of fertilisation are high, in particularly on fairways at Upsala GK, one improvement could be to reduce the applied amounts of nitrogen fertiliser. A recommended fertilisation rate of nitrogen for fairways is 30-100 kg N ha^{-1} $year^{-1}$ (Edman, pers. comm.). The manufacturing of nitrogen fertiliser is an energy demanding process and causes a considerable amount of GHG emissions. In addition, applied nitrogen to soil enhances N_2O emissions. Therefore, reducing the carbon footprint related to fertilisation requires both the choice of a fertiliser produced according to best available technique, and a reduction of applied nitrogen fertiliser.

The greenkeepers have a large responsibility to maintain the golf course after the players' expectations. To improve the internal environmental work at the golf course it is recommended that the amount of used resources are documented. The documentation will help the greenkeeper to remember previous years management practices and where improvements can be made to benefit both the environmental work and the finances. The documentation can also function as a tool for determining the environmental impact at the golf courses and consequently ease the process to reach the environmental goals.

The GEO certification will continuously improve the environmental work at the golf clubs, but since a majority of the golf courses in Sweden are not certificated yet a tool for documentation could be a start to improve the internal environmental work. To invest in the environmental work and communicate it to the customers is beneficial for the golf courses and will invigorate their environmental image.

In 2012, the total CO_2 emissions to air from the usage of working machines in Uppsala municipality were 44 Gg due to combustion of fossil fuels (Swedish EPA, 2015). Compared with the total carbon footprint for utility and meadow lawns of 83 and 5.7 Mg CO_2e $year^{-1}$, the lawn management by the municipality represent a minor part of the working machines carbon footprint. Furthermore, compared to other studies on lawns around the world, Uppsala municipality demand fewer management practices, i.e. no irrigation and fertilisation, which has an environmental advantage. However, to achieve the goal of zero net carbon footprint every sector in the municipality must be improved. One possible improvement is to increase the environmental requirements in the procurements. In the procurements only Aspen is mentioned as a requirement, even though both subcontractors are using diesel for the mowing machines. By demanding the use of biodiesel or alternative fuels such as Ecopar, environmental impacts could be reduced. However, more research on alternative fuels has to be accomplished to conclude the reductions of energy and GHG emissions alternative fuels can provide.

Another management improvement to consider is to demand hybrid or electrical mowers, which is in accordance with the intermediate target to have a fossil free machine park in the municipality by 2023. This can also be an appropriate recommendation for the golf courses. By using hybrid mowers the emissions from the usage stage will be reduced. Furthermore, studies have shown that over the life cycle a significantly larger amount of pollutants are emitted from petrol powered mowers compared to battery and electricity powered mowers (Sivaraman and Lidner, 2004).

In the Lawn project, research about the utility lawns, the meadow lawns and the golf courses potential to sequester carbon is investigated, which in combination with this study will result in a net emission balance. Further studies could be to include more life cycle stages in the research. For instance the lawn construction phase usually involve land use change by the removal of existing vegetation to promote grass growth and change in management practices. Land use changes can cause GHG emissions or carbon sequestration depending on the change and is therefore an interesting aspect of the life cycle perspective.

6. CONCLUSIONS

The study concluded that greens had the largest carbon footprint and energy use per hectare followed by tees, fairways, roughs, utility lawns and meadow lawns. The management of greens caused 20% of the total carbon footprint at the golf courses, with greens consisting of only 3% of the total golf course area. The management activities consuming most energy were mowing, irrigation and manufacturing of fertiliser, whereas the activities with largest carbon footprint were mowing, manufacturing of fertiliser and soil emissions from application of fertilisers.

The energy use was the highest for the golf courses, with 16.5 GJ ha^{-1} $year^{-1}$ for Upsala GK and 13.0 GJ ha^{-1} $year^{-1}$ for Sigtuna GK. Lower energy use was determined for the utility lawns and meadow lawns, where 3 and 0.5 GJ ha^{-1} $year^{-1}$ were required for the lawn management, respectively. The carbon footprint of the golf courses was 1.33 Mg CO_2e ha^{-1} $year^{-1}$ for Upsala GK and 0.94 Mg CO_2e ha^{-1} $year^{-1}$ for Sigtuna GK, which were significantly larger compared to the utility lawns of 210 kg CO_2e ha^{-1} $year^{-1}$ and meadow lawns of 30 kg CO_2e ha^{-1} $year^{-1}$.

A recommended improvement is to reduce the applied amounts of nitrogen fertiliser, in particularly on fairways at Upsala GK. Another suggestion is to increase the documentation of used resources at the golf courses, which will consequently improve the internal environmental work. In the municipality, one possible improvement is to increase the environmental requirements in the procurements, for instance by demanding hybrid or electrical mowers. These types of mowers can also be suitable for the golf courses, since mowing was one of the management practices with the largest climate and energy impact.

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APPENDIX I – EMISSION AND ENERGY DATA

Table AI.1 Energy content in fuels (SPBI, 2014)

Fuel type	Energy content ($kWh\ l^{-1}$)
Petrol (5 vol% ethanol)	8.94
Diesel (5 vol% FAME)	9.77

Table AI.2 Emissions to air during production, distribution and combustion of fuels, for the greenhouse gases carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (Värmeforsk, 2011)

Fuel type	GHG	Production and distribution ($g\ MJ^{-1}$)	Combustion (person vehicle) ($g\ MJ^{-1}$)
Petrol (5 vol% ethanol)	CO_2	6.04	70
	CH_4	0.0334	0.016
	N_2O	0.00125	0.0012
Diesel (5 vol% RME)	CO_2	6.32	69.6
	CH_4	0.0328	0.00054
	N_2O	0.00104	0.002

Table AI.3 The primary energy factor during production and distribution of petrol (5 vol% ethanol) and diesel (5 vol% RME), where RME is a type of FAME (Värmeforsk, 2011)

Fuel type	Primary energy factor ($MJ\ MJ^{-1}$)
Petrol (5 vol% ethanol)	1.1
Diesel (5 vol% RME)	1.1

Table AI.4 The primary energy use and emissions of greenhouse gases (CO_2, CH_4 and N_2O) for electricity (Värmeforsk, 2011)

Electricity	Primary energy factor ($kWh\ kWh^{-1}$)	Emission factor ($g\ CO_2e\ kWh^{-1}$)
Swedish electricity mix	2.1	36.4
Nordic electricity mix	1.74	97.3

Table AI.5 The primary energy consumption for different fertiliser products based on European average from 2006 (Brentrup and Pallière, 2008).

Fertiliser product	Nurient content	Primary energy consumption (MJ kg^{-1} product at plant gate)
Urea ammonium nitrate (UAN)	32% N	15.23
Triple Super Phosphate	48% P_2O_5	6.39
Muriate of potash	60% K_2O	5.01

Table AI.6 The calculated carbon footprint (cradle to gate) for different fertiliser products in Western Europe, with minimum and maximum values between brackets (Kool *et al.,* 2012)

Fertiliser product	Carbon footprint
Liquid UAN (kg CO_2e kg^{-1} N)	5.77 (2.11-10.38)
Triple Super Phosphate (kg CO_2e kg^{-1} P_2O_5)	0.36 (-0.04-0.52)
Potassium chloride (kg CO_2e kg^{-1} K_2O)	0.56 (0.39-0.71)

Table AI.7 Emission factors for production of pesticides (Bernesson, 2004)

GHG	Emission factor (g kg^{-1} active substances)
CO_2	4921
CH_4	0.18
N_2O	1.5

Table AI.8 Emissions to air during manufacturing (production and distribution) of light fuel oil at regional storage (Ecoinvent, 2015)

GHG	Emissions to air (kg)
CO_2	0,24798
CH_4	0,0032828
N_2O	0,0015383

APPENDIX II – NITROGEN CONTENT IN PRODUCTS

Table AII.1 Nitrogen content in products used by Sigtuna GK (Jordelit AB, 2015)

Type	Product	Ammonia (%)	Urea (%)	Nitrate (%)
Granulated fertilisers	Sportsmaster municipal	4.3	10.7	
	Greenmaster Autumn Mg	1.8	4.2	
	Greenmaster NK	4	8	
	Compo Easygreen Mini 21	11		10
Liquid fertilisers	Headland Solufeed High N	2.6	22.4	4
	Headland Liqiuid Turf Hardener			10
	Turfite	7		
Iron products	Farmura ferrosol		15	
Biostimulants	Headland Seamac Ultra Plus			
	Headland Turfcomplex			
	Farmura Porthcawl			
Wetting agent	Primer Select			
	Revolution			