

**Carbon Accounting in the Arboriculture Industry;
Reduction of Greenhouse Gas Emissions from
Tree Surgery**

by

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A thesis submitted in partial fulfilment for the requirements for the degree of
M.Sc (by research) at the University of Central Lancashire

January 2013

Declaration

I declare that no material contained in the thesis has been used in any other submission for an academic award and is solely my own work.

Tom Luck

Abstract

Increasing atmospheric concentrations of greenhouse gases (GHG) have been directly attributed to human activity; burning fossil fuels, land use change e.g. deforestation and energy production. Current practices in arboriculture rely heavily on fossil fuel based equipment to maintain trees in urban areas; removing carbon sinks (trees) and emitting CO₂ during management practices. Therefore, it has been suggested that the arboriculture industry may make a disproportionately large contribution to GHG emissions when compared to the size of the sector.

The study sought to identify the contribution of arboriculture to anthropogenic (GHG) emissions and provide recommendations for reduction. Assessment of the industry was achieved using a case study approach of a tree surgery company Down to Earth (DTE) based in Sevenoaks, Kent. The structure of CO₂e (carbon dioxide equivalent) quantification methods followed the top-down approach - BS ISO 14064:2006; using secondary data to measure CO₂e emissions and primary data for assessment of daily activity optimisation. The results, based on project boundaries included direct emissions from sources owned or controlled by the company – 101.2 tonnesCO₂e yr⁻¹, indirect emissions from energy use – 5.2 tonnesCO₂e yr⁻¹, and indirect emissions owned or controlled by other organisations – 98.9 tonnesCO₂e yr⁻¹. Results suggested that the arboriculture industry releases 7 times more CO₂e emissions yr⁻¹ than other similar-sized service sectors. This was mainly attributed to the use of plant and heavy-duty vehicles and the removal of carbon storing biomass. The study suggested that changing current practices could reduce GHG emissions from arboriculture by between 12% and 18%.

In 2011 DTE provided 719 tonnes of wood chip to a renewable electricity generation plant, substituting coal use avoiding the release of 1,062 tonnesCO₂e. Therefore, although arboricultural activities emitted 235.50 tonnesCO₂e, this figure was more than offset (825.58 tonnes CO₂e) by the avoided emissions achieved in power

generation. By providing a renewable feedstock for the generation of electricity it is suggested that the arboriculture industry may, in the future, achieve carbon positive status and its practices seen as the management of a renewable energy crop.

Acknowledgements

I would like to thank Glen Morris for funding the project and the employees at Down to Earth Trees for their cooperation.

With special thanks to my supervisory team David Elphinstone and Mark Johnston. And most of all, Christopher Lowe my director of studies, thank you for your constant support.

I would particularly like to show my appreciation to Bertie and Sue Luck, thank you. Also to Mark Brewster and my family for their support.

And crucially, Catheee.

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List of Abbreviations

AA	Arboricultural Association
Bhp	Break horsepower
CV	Calorific value
CO ₂	Carbon dioxide
CO ₂ e	Carbon dioxide equivalent
CMA	Carbon management accounting
CFCs	Chlorofluorocarbons
CMD	Clean development mechanisms
DEFRA	Department for Environment, Food and Rural Affairs
DTE	Down to Earth Trees Ltd
EF	Emission factor
FSB	Federation of Small Businesses
GWP	Global warming potential
GHG	Greenhouse gas
HGV	Heavy-goods vehicles
IPCC	Intergovernmental Panel on Climate Change
kW h	Kilowatt-hour
LCA	Life cycle assessment
CH ₄	Methane
MC	Moisture content
N ₂ O	Nitrous oxide
ODS	Ozone-depleting substances
PAS	Publicly available specification
SME	Small and medium enterprises
UNFCCC	United Nations Framework Convention on Climate Change
WRI	World Resources Institute

1 Introduction

In recent years overwhelming evidence for the existence of climate change has been presented (IPCC, 2007; Kumazawa and Callaghan, 2012; UNFCCC, 1992). Global climate change has been initiated by the relatively fast release of carbon dioxide (CO₂) stored within fossil fuels, and from land use change (Lingl et al., 2010). International agreements have been made in an attempt to mitigate the potential effects of increasing greenhouse gas (GHG) emissions; which predominantly include carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) (IPCC, 2007a).

Advances in communication technology and new media have meant that, information and research on climate change is readily available to the public. Society is increasingly environmentally and ethically aware, necessitating large, publically visible organisations to show commitment to reducing GHG emissions. Some organisations are required to quantify and reduce their GHG emissions, while others reduce it voluntarily for economic or environmental reasons, or to gain competitive advantage.

GHG quantification and reduction requirements, however, have not yet been applied to small and medium sized enterprises (SMEs), defined as an organisation with fewer than 250 employees (FSB, 2011). In the UK SMEs constitute 99% of all enterprise and 43% of private employment (BIS, 2008), potentially contributing significantly to national and global GHG emissions.

Arboriculture is the cultivation and management of trees in an urban environment. Ninety-four percent of arboriculture companies employ less than 100 people (Lantra, 2011); therefore fall under the SME category. Managing trees requires an abundance of heavy machinery, many of which rely on fossil fuels. The range of task complexity within arboriculture necessitates a variety of equipment for different operations; the larger and more complex tasks require more machinery to be transported to the task location and used, consequently causing an increase in GHG

emissions. Therefore it is suggested that arboriculture uses more fossil fuel based equipment and machinery than other businesses of similar size and structure and may make a significant contribution to GHG emissions.

International bodies have developed recognised standards to guide organisations through the quantification process, such as BS ISO 14064, GHG Protocol and PAS 2050. The application of these standards to various business types and niche industries has yet to reach maturity, raising questions of integrity (Pieragostini et al., 2012; Olson, 2010; Bowen and Wittneben, 2011). Assessments of GHG emissions from organisations have been carried out by auditing firms, primarily on large publically visible organisations (Bowen and Wittneben, 2011). The standards do not discuss methods of GHG reduction; they have therefore been developed by carbon auditing firms. The reductions recommendations provided to businesses are generic advice on office based energy savings, reduction in business travel (flights, trains) and diverting waste from landfill. There are no studies based on organisation specific GHG reductions, incorporating business specific activities and equipment. Moreover, little research exists on the GHG emissions of arboricultural practices or processes. The majority of related published research in arboriculture has focussed on emissions affecting human health (e.g. Volckens et al., 2007; Ålander et al., 2005).

Trees sequester and store CO₂ from the atmosphere eventually releasing it back during decomposition, therefore making tree growth and subsequent death a carbon neutral process. It is suggested that the use of fossil fuel based machinery to remove the carbon rich biomass may be adding to climate change; however, management practices can prolong the life of trees and extend the duration of CO₂ storage, possibly offsetting the impact of fossil fuel usage (Nowak et al., 2002). Furthermore, developments in renewable energy technologies show that the use of wood biomass in energy production can also mitigate a proportion of fossil fuel usage (DEFRA, 2008). Therefore the utilisation of biomass from arboricultural practices in

energy production may create a situation where the industry is considered to be managing and conserving a renewable energy source.

This project seeks to address some of the themes discussed and determine the impact of the arboriculture industry on GHG emissions.

1.1 Study Aims and Objectives

The aim of the project is to investigate the potential for reducing GHG emissions in the UK arboriculture industry. This will be achieved by undertaking a case study of a tree surgery company and will focus on the following objectives:

1. Determine the company's annual GHG emissions, through investigation and application of current methods of quantification e.g. international standards, carbon management accounting and life cycle assessment.
2. Identify areas where improvements can be made and provide company and industry specific recommendations for reducing GHG emissions.
3. Where applicable the project will apply and build on the applicable international standards, outlining gaps in working practices associated with the current guidelines on reductions of anthropogenic GHG emissions.

1.2 The Case Study Organisation

The case study organisation is a tree surgery company called Down to Earth Trees Ltd (DTE), situated 25 km south of London, in Sevenoaks. Founded in 1980, DTEs role within the arboriculture industry currently incorporates: urban forestry; tree planting; contracts for local councils carrying out a range of work from street trees, parks and schools; contractual work including site preparation for construction; and private work ranging from gardens to small woodlands.

DTE have 23 employees, including management, administrators, surveying staff, groundsmen, climbing arborists and mechanics. According to The Federation of

Small Businesses (FSB) DTE falls under the category of a 'small' business (10-50 employees), within the SME category (FSB, 2011), however DTE employs more staff than 83% of the arboriculture industry (Lantra, 2011). Therefore it should be noted that the generic company size description used by the FSB may be misleading when referring to DTE in the context of this study.

DTE is an AA approved contractor, the criteria to receive this status requires: said company to have been trading for at least 2 years, the manager to have at least 5 years of experience, appropriate insurance, rigorous site safety, records of completed work, office support, and health and safety procedures (AA, 2011). The AA approval places DTE on a similar functioning level as 2,000 (AA, 2011) other approved contractors in the UK, allowing the study to be widely applicable. The company is also well established, allowing scope for implementing carbon emission reductions without being detrimental to its' financial stability.

Like many tree surgery companies, DTE employ receptionists to handle requests for incoming work and manage paperwork. There is also a team of surveyors who drive daily to locations carrying out tree inspections or quoting; location routing is organised manually.

The company has 9 working vehicles, 8 heavy goods vehicles (HGV) and 1 light goods vehicle (LGV). The working vehicle will contain a crew of 2 to 3 arborists, power and hand-tools, and job specific equipment. It may also tow a chipper if required; this allows processing of small diameter wood into woodchips, which are usually stored in the body of the vehicle for the duration of the day. Depending on operation duration, vehicles will visit one location for several days until the task is complete, alternatively some smaller tasks will take hours, allowing vehicles to visit multiple locations in one day.

The chipped arisings (woody biomass) are usually removed from site and stored at base until a woodfuel biomass company collects them. Timber too large to chip is either processed by DTE into firewood, and if unsuitable for firewood then is handed to a local farm owner where it is burned locally in a woodfuel system. Arisings from procedures that create unwanted waste (e.g. stump grindings) are accumulated and removed for landfill waste.

The project will be based around this case study company and will use a combination of *in situ* data collection and historical data.

2 Literature Review

2.1 Introduction:

This selected literature review will initially assess current research surrounding the mechanics of climate change and the international and organisational methods of mitigation before reviewing the status of arboriculture in the UK

2.2 Climate Change

The term greenhouse gas (GHG) derives from the characteristic of certain gasses allowing solar energy through the atmosphere to the Earth's surface but denying the converted energy (longwave infrared radiation) exit, trapping it within the atmosphere (Hardy, 2003; Coley, 2008). GHGs with noteworthy concentrations consist of water vapour, carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) (Hardy, 2003; Coley, 2008).

2.2.1 Evidence:

Historically, global temperature has fluctuated naturally over millions of years (Coley, 2008). Ice core research has displayed a positive correlation between atmospheric CO₂ concentrations and global temperature (Hardy, 2003). This relationship is displayed in figure 1, suggesting that the carbon cycle appears to be acting as a thermostat to normalise temperatures on Earth (Coley, 2008).

Recent human-induced (anthropogenic) climate change has, called for a redefining of the phrase. The United Nations Framework Convention on Climate Change (UNFCCC)(1992) defined climate change as 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is, in addition to natural climate variability, observed over comparable time periods.' Human activities produce several GHGs that contribute to climate change; CO₂, CH₄, N₂O, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs),

chlorofluorocarbons (CFC-11 and CFC-12) and sulphur hexafluoride (SF₆) (Lingl et al., 2010; UNFCCC, 1988; IPCC, 2007a).

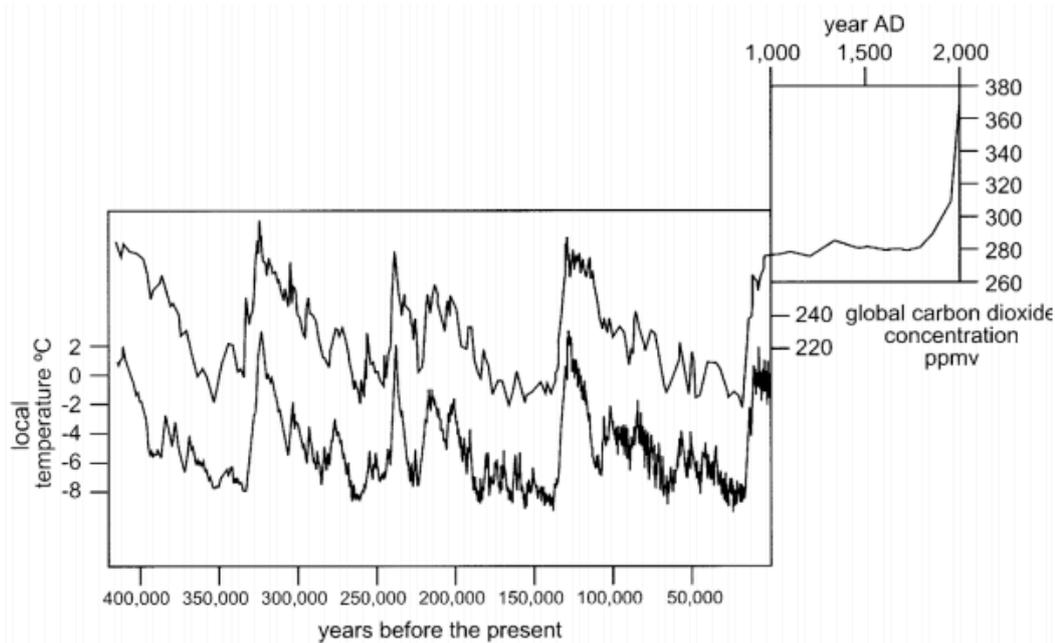


Figure 1: A display of the correlation between temperature (bottom line) and carbon dioxide concentration (top line) (Adapted from Coley, 2008, p94).

The main human activities that contribute to anthropogenic GHG emissions are – burning fossil fuels, land-use change, energy production, natural gas distribution and landfill (IPCC, 2007a; Lingl et al., 2010; Hardy, 2003). Burning fossil fuels is the dominant anthropogenic contributor to GHG emissions (Hardy, 2003), with CO₂ contributing 56.6% (IPCC, 2007b), however, CO₂ is also released naturally through deforestation and decay of biomass (17.3%) (IPCC, 2007b). Fossil fuels are composed of decomposed organic matter, formed over millions of years through intense pressure and heat; because of this time scale they are considered a non-renewable resource. Fossil fuels comprise of coal, petroleum and natural gas, all are high in carbon and methane, which are released into the atmosphere when combusted.

2.2.2 CO₂ and Other Greenhouse Gasses

Radiative forcing is a measure of the influence a factor (e.g. CO₂ or CH₄) has in adjusting the balance of incoming and outgoing energy in the Earth-atmosphere system (IPCC, 2007b). It is an index of the importance of the factor as a potential mechanism for climate change (IPCC, 2007b). Radiative forcing is measured in watts per square metre (W m⁻²) and figure 2 shows the relative contribution of various factors to the composition of the atmosphere. When radiative forcing from a factor or group of factors is assessed as positive, the energy of the Earth-atmosphere system will eventually increase, leading to a warming of the system (IPCC, 2007a).

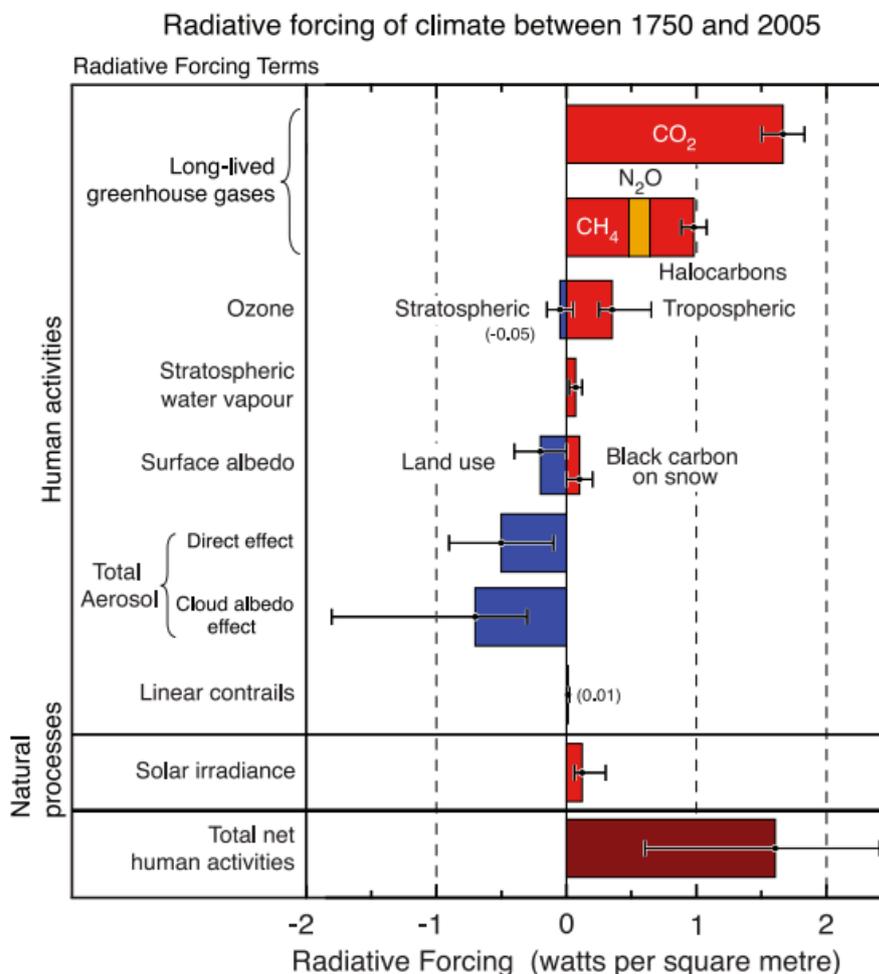


Figure 2: A summary of the principle factors of the radiative forcing of climate change. The values reflect the total forcing in 2005 relative to the start of the industrial era (1750). (adapted from IPCC, 2007a).

It is important to differentiate between GHGs, as equal quantities can have different levels of warming potential; this is shown in figure 3. Moreover, the lifetime of the gas in the atmosphere affects its resultant concentration and warming potential. Each GHG has a characteristic that defines its Global Warming Potential (GWP), or CO₂equivalent (CO₂e). For example a molecule of CH₄ or N₂O can trap 21, or 310, times more heat than one molecule of CO₂, respectively (Hardy, 2003; IPCC, 2007a). CO₂, however, has a higher atmospheric concentration compared to other GHGs. CO₂ is responsible for around 60% of anthropogenic climate change (Barrett, 2004b), 15-20% is caused by CH₄ and 20% from N₂O, CFCs and tropospheric ozone (Hardy, 2003). Therefore the major anthropogenic GHGs have been assigned a CO₂e, this combined with the global concentration figures and emissions rates provides a holistic view of each GHGs contribution to climate change.

Greenhouse gases	Chemical formula	Preindustrial concentration (ppbv)	Concentration in 1994 (ppbv)	Atmospheric lifetime (years) ^a	Anthropogenic sources	Global Warming Potential (GWP) ^b
Carbon dioxide	CO ₂	278,000	358,000	Variable	Fossil-fuel combustion Land-use conversion Cement production	1
Methane	CH ₄	700	1,721	12.2 ± 3	Fossil fuels Rice paddies Waste dumps Livestock	21 ^c
Nitrous oxide	N ₂ O	275	311	120	Fertilizer Industrial processes Combustion	310
CFC-12	CCl ₂ F ₂	0	0.503	102	Liquid coolants Foams	6,200–7,100 ^d
HCFC-22	CHClF ₂	0	0.105	12.1	Liquid coolants	1,300–1,400 ^d
Perfluoro-methane	CF ₄	0	0.070	50,000	Production of aluminum	6,500
Sulfur hexa-fluoride	SF ₆	0	0.032	3,200	Dielectric fluid	23,900

Note: ppbv = parts per billion volume; 1 ppbv of CO₂ in the Earth's atmosphere is equivalent to 2.13 million metric tons of carbon (www.cdiac.esd.ornl.gov, accessed on December 10, 2000).

^aNo single lifetime for CO₂ can be defined because of the different rates of uptake by different sink processes.

^bGlobal Warming Potential (GWP) for 100-year time horizon.

^cIncludes indirect effects of tropospheric ozone production and stratospheric water vapor production.

^dNet GWP (i.e. including the indirect effect due to ozone depletion).

Figure 3: The global warming potential, or CO₂ equivalent of the main anthropogenic greenhouse gasses (adapted from Hardy, 2003).

2.2.3 Carbon Dioxide

Since the start of the industrial revolution (circa 1750) CO₂ increases have caused the largest radiative forcing (IPCC, 2007a). Global industrialisation has increased the burning of fossil fuels causing an increase in atmospheric CO₂ concentrations. David Keeling's research monitoring atmospheric CO₂ has produced evidence that climate change is linked to an increase in burning of fossil fuels. Figure 4 shows atmospheric data collected at Mauna Loa (Hawaii) from 1958 to 2012. The red curve shows monthly CO₂ data and the black line shows seasonally corrected data (IPCC, 2007b). Recorded atmospheric CO₂ concentrations between 1958 and 2012 increased by 20% (Tans and Keeling, 2012). Ice core records show CO₂ levels remained within 280 ± 20 parts per million (ppm) 10,000 yr before the present up to 1750 (UNFCCC, 1992; Indermuhle et al., 1999); currently they are 392 ppm (Tans and Keeling, 2012), therefore CO₂ have increased 29% since pre-industrial levels. 'Keeling's curves' have become well known and indicate that humans are changing the GHG composition of the atmosphere.

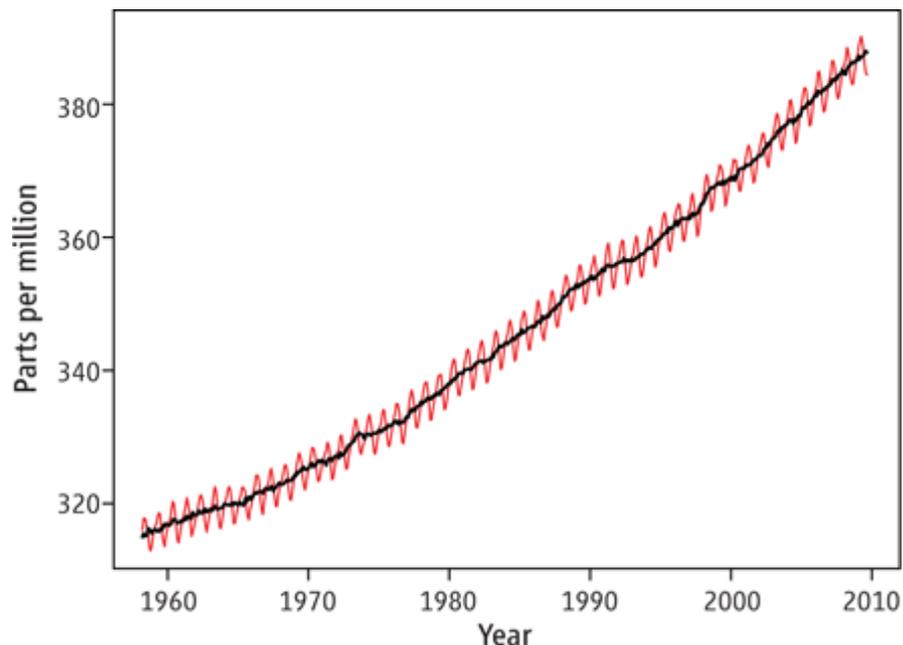


Figure 4: Levels of atmospheric CO₂; red line showing the levels of CO₂ recorded at Mauna Loa (adapted from McCarthy, 2009).

2.2.4 Other GHGs of Importance

Methane is the second-largest contributor to climate change, with an anthropogenic GHG contribution of 14.3% (IPCC, 2007a). Over the last 650,000 years, ice core records show that abundances of CH₄ have ranged from 400-700 parts per billion (ppb), compared to present concentrations of 1774.62 ± 1.22 ppb¹ (IPCC, 2007a). The atmospheric concentration of CH₄ has increased by 150% since 1750 (Hardy, 2003), and 30% from the last 25 years (IPCC, 2007a). Methane is produced from the breakdown of organic matter in the absence of oxygen, a natural process that occurs, for example, in wetland soils, swamps and natural coastal sediments (Hardy, 2003). Around half of the current CH₄ released is anthropogenic (Hardy, 2003), from activities including livestock production, natural gas extraction, coal and oil production and distribution and solid mass landfill sites (IPCC, 2007a; Hardy, 2003).

Nitrous oxide (N₂O) emissions, are thought to have contributed approximately 6% to anthropogenic induced climate change (Barrett, 2004b). N₂O is emitted by human activities such as fertiliser use and fossil fuel burning (IPCC, 2007a).

CFCs and other ozone-depleting substances (ODS) are GHGs, which contribute to the radiative forcing of the climate (Velders et al., 2007), and were found to cause stratospheric ozone depletion (Houghton, 2004). The Montreal Protocol (1987) was developed to control the production and consumption of CFCs and halons, two powerful groups of ODS (Oberthür, 2001). By 1998, the Protocol had been successful in reducing global production and consumption of these ODS by approximately 85%, compared to pre-protocol levels (Oberthür, 2001). The Montreal protocol is widely considered to be one of the most successful cases of worldwide co-operation on environmental issues.

¹ It is important to not the difference between ppm and ppb.

2.3 Action to Tackle Climate Change

The awareness of climate change has initiated scientific research to understand the mechanics of the problem from a molecular to a global scale. This research has led to international collaboration in an attempt to manage the global climate.

2.3.1 United Nations Framework Convention on Climate Change Mitigation

The Framework Convention on Climate Change (UNFCCC) was signed by over 160 countries (Houghton, 2004 p254) at the UN conference on Environment and Development held in Rio de Janeiro 1992. During the same year the Intergovernmental Panel on Climate Change (IPCC) was formed to collect information on what was known and unknown, and what could be done to pre-empt or mitigate for climate change (Barrett, 2004a). The UNFCCC provided context for international action regarding the issue of climate change, recognising the reality, as well as the uncertainties associated with current predictions. The convention agreed that action to mitigate effects of climate change was necessary and that this movement needed to be led by developed nations.

2.3.2 The Kyoto Protocol 1997

Following the UNFCCC further agreements were reached, the Kyoto Protocol was signed in 1997 and adopted in 2005 (Finus, 2008). The protocol specifies maximum emission levels for Annex I countries (developed countries), including dates by which the levels must be met; calculated relative to 1990 emission levels (Barrett, 2004a). The overall reduction in GHG emissions was agreed at 5% lower than 1990 levels, by 2008-12 (UNFCCC, 1988). The use of targets and timetables was the key difference between the Kyoto Protocol and the UNFCCC. The Kyoto Protocol remains the most comprehensive international agreement to date, endorsed by 195 parties (UNFCCC, 2012).

Its effectiveness, however, has been debated since its initiation due to the multi-dimensional uncertainties that surround it. From an economic perspective, the protocol is designed to tackle climate change by establishing an efficient regulatory framework that sets an international 'price' on GHGs (Grubb, 2003). Conversely, for many environmentalists the problem is largely scientific, and therefore should not follow conventional economics. Helm (2003) stated that scientists should determine the 'correct' level of emissions then this level should be imposed through direct intervention and suggested that moral philosophy, not economics, should provide the necessary intellectual input. Helm's view appears myopic in reality, as although scientific evidence will provide the basis for policy implementation, the implementation of the policy will be based on individual Parties resources. Böhringer (2003) proposed that for rational decision-making in climate change policy, a balance needs to be made between costs of GHG emission abatement and the benefits of the avoided disagreeable consequences of climate change. Böhringer (2003) suggests that a cost-benefit analysis provides a framework for measuring all positive and negative policy impacts, including resource use in the form of monetary costs and benefits. This economic perspective describes an achievable goal, as it allows parties to work within their governments' resources, creating achievable targets through applicable methods. This method, however, may not achieve the initial goal described by the UNFCCC as the GHG reduction decisions would be financially based, rather than target based. The application of economics to climate change causes problems in itself; economists do not agree upon the methodology for valuing the potential effects of climate change, for example extinction of species (Böhringer, 2003).

Due to the interdisciplinary nature of the problem, flexibility mechanisms were put in place. These measures include emissions trading, clean development mechanisms (CDM) and joint implementation. Emissions trading is the ability for two parties, which are subject to emissions control, to exchange part of their emissions

commitment (Grubb, 2003). CDM extends the emissions reduction flexibility to Non-Annex I Parties (developing countries) in order to exploit the availability of low-cost emissions abatement. Joint implementation implies a similar idea to CDM by allowing cross-border investments between countries, however it allows the host country to abate some of its own emissions commitment and it is applicable only to Annex I Parties (Grubb, 2003).

2.3.3 Kyoto integrity

The core problem with the protocol is – in order to ratify it, an Annex I Party must agree to reduce its GHG emissions to a specific level, by a set date, regardless of cost (McKibbin and Wilcoxon, 2002). Therefore the world's largest GHG emitters, such as USA and China, are not committed to the current protocol due to the potentially large expense (McKibbin and Wilcoxon, 2002; Böhringer, 2003; Helm, 2003; Kumazawa and Callaghan, 2012). The lack of ratification means that the global target of 5% reduction is not legally binding for the USA; a country that emits 25% of the world's emissions (Kumazawa and Callaghan, 2012).

The protocols effectiveness relies on the collaboration of all industrialised and developing countries to set emission targets; however, Non-Compliance Parties are not accountable for their GHG contribution, adding reduction burden upon Annex I Parties. The importance of unilateral ratification is reflected within the methods of the protocol; it implies only a moderate reduction and adjustment cost when considering internal-party changes; however, when parties collaborate and utilise the flexible mechanisms, scope for greater global reduction is possible.

The Kyoto Protocol clearly has flaws, however, the task of globally reducing GHGs, whilst ensuring it remains politically and economically viable for the diverse range of nations, is complex. The protocol is to be reviewed at the end of the first commitment (2008-2012), from here it is assumed that the opinions of the reviewers

will be heard. The severity and speed at which GHGs are increasing necessitated global change, however, it appears that the Kyoto Protocol was too ambitious too early, leaving the biggest emitters out.

The fundamentals of the protocol are considered sound – basing GHG reduction quantities on scientific evidence, as opposed to economic availability or political ease. The Kyoto Protocol must be seen as a first step towards addressing global climate change, with the hope that the impending review produces more watertight regulations. The introduction of the protocol has aided worldwide public comprehension of the magnitude of climate change, instigating research across countries, industries and organisations to reduce GHGs.

2.4 Assessing GHG Emissions

This section will aim to look into current methods for calculating GHG emissions at a company level. The section assesses the credibility and applicability of both governmental standards and commercial methods.

Carbon management accounting (CMA) is the assessment and calculation of CO₂e, emitted during regular processes carried out by an organisation; using the results to provide managers with information assisting them in short and long-term CO₂e reductions. Various tools for environmental and sustainability accounting have been developed and applied; however, little research has been conducted on the practice of collecting, managing and communicating carbon-related information within companies (Burrill et al., 2011). These advances have, so far been aimed at large, visible and usually publicly listed companies that are required to report their carbon performance (Bowen and Wittneben, 2011). CMA uses a top-down approach, which involves breaking down the company's processes and activities to reveal the individual subsections, each subsystem is then refined in more detail. This provides CO₂e output of the company as a whole, with detailed information regarding the subsections.

In contrast, Life cycle assessment (LCA), uses a bottom-up approach which consists of amalgamating all individual base elements of a company (e.g. the environmental impact of producing rubber for tyres) to create subsections in detail, these subsections are linked together to form further subsections, until the top level system is formed. This method systematically calculates the environmental impact of a product or service over its' whole life cycle. LCA considers various environmental impacts including climate change, eutrophication, acidification, toxicological toll on human health and ecosystems, depletion of resources, land use, noise and others (Rebitzer et al., 2004).

LCA has two main objectives; (1) to quantify the environmental performance of a product² from 'cradle-to-grave', i.e. considering the entire life cycle of the product; extracting and processing the raw materials; manufacturing, transportation and distribution; use, reuse, maintenance; recycling and disposal (Pieragostini et al., 2012); (2) to aid decision makers to choose between alternatives. The international standard for LCA describes the applications as; identification of improvement possibilities, decision making, choice of environmental performance indicators and market claims (BS ISO 14040, 1997).

2.4.1 Methodological approaches

The key aspect of CMA is the weighted importance between monetary concerns and physical CO₂e reductions. A study by Burritt et al. (2011) stated the overall aim is to reduce CO₂e emissions, therefore basing reductions on the physical emission units should provide the best results, however, carbon reductions require investments, either in technology or training and education. Burritt et al. (2011) concluded that although companies are constrained by monetary limitations, physical data is necessary in the CMA process; therefore both monetary and physical information are required for a comprehensive CMA.

² In LCA the concept of a *product* refers not only to the material products, but also to services.

The first step involves setting the goal of the project, and compiling a GHG inventory. Following this the range (scope) of analysis should be considered, which depends of the purpose of the study. A company determines its scope by setting organisational boundaries, in terms of other businesses or operations that contribute to the running of the company (WRI, 2004; BS ISO 14064-1, 2006). It then sets operational boundaries, which involves identifying emissions related to operations. These are then classified as direct and indirect emissions and the scope of the indirect emissions is decided (WRI, 2004; BS ISO 14064-1, 2006). Scope 1 includes only direct emissions (e.g. fuel use); scope 2 includes indirect emissions from any use of purchased electricity, steam or heat; scope 3 is the broadest, including all other indirect emissions, such as extraction, production and transportation of purchased materials and fuels, all outsourced activities and waste disposal (Wakeland et al., 2012; WRI, 2004). Utilising these three scopes provides a comprehensive framework for managing and reducing direct and indirect emissions. According to BS ISO 14064-1, (2006) once the inventory boundaries and base-year have been established, companies generally calculate GHG emissions using the following steps:

1. Identify GHG emissions sources and sinks
2. Select a quantification methodology
3. Selection and collection of GHG activity data
4. Selection or development of GHG emission or removal factors
5. Calculation of GHG emissions removals

The BS ISO 14064-1 (2006) and GHG Protocol (WRI, 2004) both provide fundamental guidance for methods such as GHG quantification, monitoring and reporting. The BS ISO 14064-1 (2006) lacks specific methods and procedures needed to measure GHG for SME's, consequently many can only follow the applicable

aspects. This is also true for government-produced publications PAS 2050 and 2060, which expand on the information described in the LCA based ISO 14040. The PAS 2050 guide is more comprehensive, although predominantly offers information about product LCAs and is therefore of little relevance to service industries. In contrast, the GHG Protocol provides more general information, creating applicability to a wider range of businesses. BS ISO 14064 (2006) and GHG Protocol (WRI, 2004) have no mention of LCA, which allows for wider use but a less holistic calculation.

The wide application of these standards and guidelines is beneficial to a number of companies, although their use across organisational fields causes methodological-confusion. This is discussed by Bowen and Wittneben (2011) who have shown that carbon accounting is an immature process, which progressively reduces uncertainty and increases accuracy across organisational fields, by independent development at different levels, such as molecular, organisational and societal. Olson (2010) discusses the challenges and opportunities of independent GHG accounting; whilst approaching the subject from a financial accounting perspective. Olson (2010) describes the current standards as complex and unclear, and their main flaw is having non-standard boundaries. Olson (2010) goes on to suggest that 'while standards are developed for classifying different sources of carbon emissions into one of three "scopes", there is still potential for discrepancies across industries and jurisdictions.' The author maintains that an established protocol for carbon reporting is vital for providing transparency and the addition of independent validation provides enhanced credibility (Olson, 2010).

The validation or verification process in CMA allows GHG emission reports to be assessed by internal and/or external verifiers. The verification process requires the introduction of the 'materiality' concept. Information is considered material if, by its inclusion or exclusion, it can be seen to effect any decisions or actions taken by users (WRI, 2004). A material discrepancy is an error that results in a reported quantity or

statement being substantially different to the true value or meaning (WRI, 2004). Therefore for a verifier to express an opinion on data or information they would need to form a view on the materiality of the identified errors or uncertainties. The concept of materiality requires a value judgement, the point at which a discrepancy becomes material (material threshold), which is usually pre-defined with the project company (BS ISO 14064-1, 2006). The material threshold provides guidance to verifiers on what may be an immaterial discrepancy, allowing them to concentrate their work on areas that are more likely to lead them to materially misleading errors (WRI, 2004). The validation or verification procedures are important in gaining external credibility, allowing clients to have more choice between environmentally credible organisations. It is potentially this 'green' credibility goal that is initiating organisations to compete for public attention.

Principles and guidelines on standardised LCA methodology were developed during the creation of BS ISO 14040 (2006). LCA has been applied by governmental and non-governmental organisations and a wide range of industries, either autonomously or with the aid of research institutes or consultants (Rebitzer et al., 2004). For the use of LCA within the public sector, a degree of transparency within the research is suggested by BS ISO 14040. Pieragostini et al. (2012) show that this is due to the subjectivity component in several aspects of LCA, such as system boundaries, goal definition and scoping, and the fact that the LCA results are often determined by limited data from unreliable sources. Subjectivity within LCA activities meant that BS ISO 14040 did not include a valuation procedure (similar to the validation or verification process for CMA); however, this often becomes necessary in LCA to gain credibility (Pieragostini et al., 2012). This is due to the possibility that the user might manipulate the outcome by choosing a method that gives a desired result. This can be remedied by continual development of methodology and critical reviews of studies.

Little attention has been given to LCA within transportation and logistics, in spite of transportation being a major polluter in society (Baumann and Tillman, 2004;

Abukhader and Jönson, 2003). Engine technology and fuels development have led to cleaner combustion and reduced SO₂, NO_x, CO and particulate emissions, but not CO₂ emissions as long as fossil fuels are used (Baumann and Tillman, 2004). A study by Vanek and Morlok (2000) showed that the freight transportation sector has had the fastest growth in energy use compared to all other sectors from 1970 to 1995. Vanek and Morlok (2000) also state that transport emissions may be small for many product groups, but are considerable for food products, wood products and clothing; due to the relative heavy-weight of the products.

Ultimately, the bottom-up approach used in LCA requires summing estimates of emissions associated with specific processes. The method of estimating the environmental impacts across an inventory of processes suffers from 'truncation error' leading to serious underestimation of the total in many situations (Nässén et al., 2007; Berners-Lee et al., 2011). The truncation occurs from the unavoidable omission of steps and processes in order to make the task achievable. LCA defines the system it is assessing by a limited number of steps and these often provide a satisfactory estimate; however, there will always be a bias as additional underlying steps will be omitted (Berners-Lee et al., 2011). This problem becomes exaggerated the further from a single, simple manufacturing process the task becomes.

CMA is a top-down approach process, using input-output analysis to separate the total known emission into different sectors. This approach has the advantage of utilising published global figures, however the disadvantage of creating a static description, incapable of reflecting or expressing the details of different management strategies (Berners-Lee et al., 2011).

Carbon management accounting is designed specifically for quantifying the carbon emissions of regular processes carried out by an organisation. The use of LCA may be applicable to aspects of organisational quantification, however the practicality

of carrying out a bottom-up process on complex systems requires multiple biased omissions. The use of CMA provides information aiding short and long-term decision-making and providing managers with a stable platform from which to reassess their emissions with relative simplicity.

2.5 Arboriculture

In general, trees develop in harmony with their environment above and below ground, however, conflicts with people and property can be caused by the process of growth and dieback, or the effects of damage caused by severe weather, pests or diseases (BS 3998, 2010). Equally, human activities can cause problems; activities affecting the growth or structural integrity of trees, or change the trees surroundings by demolition or construction leading to increased wind exposure. These interactions have potential to cause serious implications to health and tree lifespan and/or the safety of people and property (BS 3998, 2010). The prevention or resolution of potential implications can be achieved through tree management.

A qualitative survey by Lantra (2011) defined the size and scope of the trees and timber industry as, primarily the establishment, care, maintenance and management of individual trees, woodlands and forests. The survey results showed there to be 14,253 businesses, and 98,658 employees in the trees and timber industry, in the UK (Lantra, 2011). Within the arboriculture sector this includes 4,548 businesses with 23,766 employees; and the forestry sector includes 1,528 businesses and 11,716 employees (Lantra, 2011).

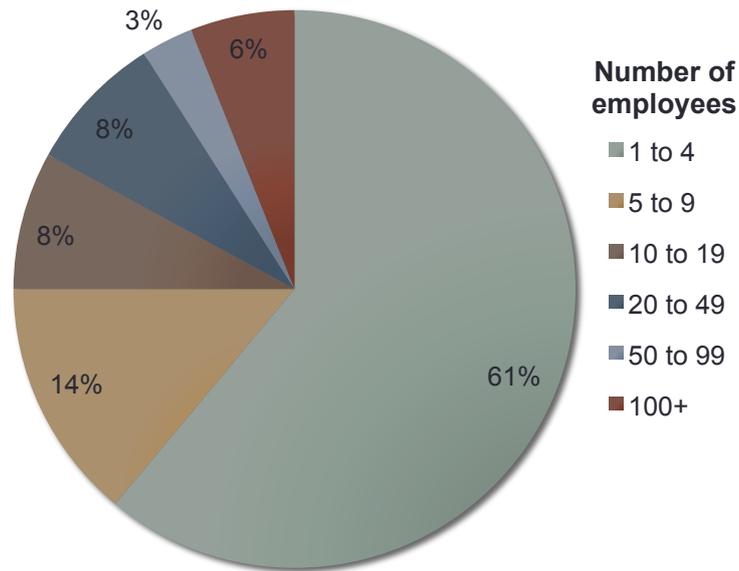


Figure 5: Percentage contribution of UK businesses in the trees and timber industry by size (adapted from Lantra, 2011).

The data shows that over 60% of companies within the trees and timber industry have fewer than 5 employees.

2.5.1 Arboricultural Operations and GHG Emissions

Healthy trees are well established in their immediate surroundings. They create structurally sturdy platforms, attempting to provide foliage with optimum light for growth. The woody structure is dense and heavy, creating difficulties for humans to manage them efficiently without aid of technology.

Many arboricultural operations rely heavily on fossil fuels: through the daily use of large engine HGVs, a variety of two-stroke equipment (e.g. chainsaws) and non-road diesel engine machinery. Two-stroke engines are small, handheld, petrol powered, spark ignition engines, which emit a variety of pollutants; carbon monoxide (CO), CO₂, nitrogen oxides (NO_x), hydrocarbons (HC) and particulate matter (PM) (Volckens et al., 2007). Most hydrocarbon emissions from 2-stroke engines result from

unburned or partially burned fuel that resides within the cylinder during the exhaust/intake stroke and exits the engine before the next compression/power stroke begins (Nuti, 1998). This process, known as scavenging loss, causes a proportional increase in fuel consumption (Volckens et al., 2007). This low fuel efficiency combined with the abundance of two-stroke equipment in the industry may contribute considerably to total CO₂e output.

The size and complexity of the task is directly linked to the number of additional machinery that is needed. The felling of a single middle-aged tree with no surrounding obstructions (i.e. utility wires, targets below the tree etc.) may take a crew of 3 and one vehicle less than a day to complete, yet, the removal of a large over-mature tree with multiple obstructions may require a crane or mobile elevated work platform (MEWP), with additional vehicles to transport arisings back to base. The range of task complexity within arboriculture necessitates a range of equipment for different operations. The larger and more complex tasks require more machinery to be transported to the task location, consequently causing exponential increase in CO₂e emissions.

Wood chippers are essential in the arboriculture industry, as many urban areas in which work is carried out are unsuitable for wood storage. Practically, chippers are essential to facilitate transport of arisings from location to base as they significantly reduce the volume of arisings. A study by Van Belle (2006) stated that chippers' fuel consumption is based on the diameter of the arisings processed; large diameter timber requires significantly higher torque, but has lower fuel consumption per kg wood chipped. The study used varying diameter wood to assess fuel consumption, stating that the chippers processed more kg hr⁻¹ of woodchips from large diameter wood compared to small. The kg woodchips⁻¹ hr⁻¹, however, was predictably higher from large diameter wood, as the hydraulic rollers that feed the arisings into the chipper move at a set speed, so more kg of solid large diameter timber is processed than lighter small diameter wood. The study used kg woodchips⁻¹ hr⁻¹ to display the chippers

productivity, however this will inevitably favour large diameter wood due to its' heavier weight. A more balanced representation for productivity would be weight of arisings before chipping, that way the density of the arising type would not mislead the chipper productivity.

Trees store carbon in their tissue during photosynthesis, a process called carbon sequestration. The rate of sequestration is based on factors such as tree maturity, size and life span (Nowak et al., 2002). The majority of tree surgery involves removing either a proportion or all of the woody biomass sequestered within a tree. A study by Nowak et al. (2002) speculated that increased maintenance could increase tree life span and therefore increase the potential for carbon sequestration; however, the study went on to show that an increase in maintenance could lead to an increase in fossil fuel use and associated CO₂ emissions. The authors concluded that tree maintenance could have a negative effect on carbon budgets (amount sequestered by the tree compared to CO₂ released through burning fossil fuels) unless tree maintenance led to increased lifespan, but, there is no empirical evidence to support the assumption that tree maintenance enhances carbon sequestration rates and storage.

Once a tree has died, or biomass is removed from a tree it begins to decompose, releasing CO₂. The rate of CO₂ released through decomposition of dead woody biomass is influenced by the characteristics of the wood, fate of the wood (e.g. chipped, burned, left standing etc.), and local soil and climatic conditions (McPearson and Simpson, 1999). Many tree surgeons use wood chippers to process the majority of the wood on site to prepare for transportation. A study by Fedele et al. (2007) showed that highest amounts of CO₂ were released immediately after chipping, decreasing exponentially until CO₂ was undetectable at 40 hours. Woodchips have a larger surface area than unprocessed timber causing them to decompose relatively quickly. McPearson and Simpson (1999) 'conservatively estimate' (due to a lack of supporting

data) that when trees are removed and mulched 80% of the stored carbon is released to the atmosphere as CO₂ in one year. McPearson and Simpson (1999) state that fallen forest trees can take at least 30 to 60 years completely disappear, with stored carbon transferred into decomposing organisms, soil humus and the atmosphere (as part of the carbon cycle). These studies show how the rate of CO₂ released differs significantly between the fates of arisings.

Biomass as a renewable energy source is considered carbon neutral as it absorbs the same amount of CO₂ during its' growth as it releases when burnt for fuel. The benefits of using biomass as a resource are that it is sustainable, multipurpose and can be used to provide electricity, heat and liquid fuels (Coombs, 2008). The biomass woodfuel market relies on several considerations: fuel cost, calorific value, moisture content, security of supply, biomass content and contaminants (DEFRA, 2008). The fuel cost must be considered in conjunction with availability of the fuel type (i.e. waste wood, forestry arisings and biomass crops). Waste wood arises from the construction and demolition industry and generation of municipal solid waste and is therefore unpredictable in terms of tonnages and sources, and materials are often mixed with other types of waste (DEFRA, 2008). Waste wood generally has a low moisture content (18-25%), therefore from an energy production perspective is preferable to forestry arisings and biomass crops (moisture content ~40%) (DEFRA, 2008); however, the security of supply of forestry arisings and biomass crops are preferable to investors for long-term contracts. This is because the tonnage and composition of forestry arisings and biomass crops are more consistent than waste wood. DEFRA, (2008) predict an increase in demand for forestry arisings and biomass crops, thereby affecting their price in the future.

UK electricity is mainly produced from gas, coal and nuclear (41, 29 and 18%, respectively); generation from hydro, wind, oil and other fuels is 10%, with imports 2% (DECC, 2012). Arisings from arboriculture can be used as a renewable energy source

for electricity generation for biofuel power stations, or through a process called 'co-firing', by mixing the biomass with coal or natural gas (Al-Mansour and Zuwala, 2010). Coal has the most intensive CO₂ emissions per kW h (kilowatt hour) in electricity production; therefore substitution of coal with carbon neutral biomass has the potential to reduce emissions (Al-Mansour and Zuwala, 2010).

The energy that can be gained from various fuels is based on their calorific value (CV); woodchips and coal have a CV of 3,890 and 6,570 kW h tonne⁻¹, respectively (DEFRA, 2012). The kW h tonne⁻¹ can be used to calculate the amount of electricity that can be generated from the woodfuel, for example, 10 tonnes of woodchips produces 38,900 kW h. To create the same energy ,38,900 kW h, from coal would require 5.92 tonnes of coal, therefore 10 tonnes of woodchip substitutes 5.92 tonnes of coal.

Coal has a higher CV and therefore produces more electricity per kg than woodfuel, however it releases up to 5 times more fossil CO₂ during electricity generation (Evans et al., 2010). Coal releases 0.37988 kgCO₂e kW h⁻¹, compared to woodchips that release 0.01579 kgCO₂e kW h⁻¹ (DEFRA, 2012). The woodchip CO₂ emissions are not included as the CO₂ released is equal to CO₂ stored within the lifetime of the biomass (DEFRA, 2012). The CO₂e emissions include CH₄ and N₂O, released from the transportation, distribution, refining, and storage of woodchips.

The role of forestry arisings for reducing atmospheric CO₂ was studied by Schlamadinger and Marland (1996b). The authors assessed the potential reduction focussing on; storage of carbon in forest products; storage of carbon in the biosphere; and use of biofuels to displace fossil-fuel use. Carbon within wood products is only stored for the products lifetime, the CO₂ avoided by not using fossil fuels are forever (Schlamadinger and Marland, 1996). The study concluded that over a long period greatest saving in atmospheric CO₂ is derived from replacement of fossil fuels with

renewable woodfuel and the replacement of fossil fuel intensive products with wood products (Schlamadinger and Marland, 1996). A similar study by Ford-Robertson (1996) estimated that the CO₂ emissions from harvesting and logging processes equated to 3% of CO₂ sequestered from the atmosphere during the growth of the plantation.

The UK has a forest cover of 12%, or 3 million ha (FC, 2011) equating to 0.05 ha capita⁻¹. McKay (2006) showed that forest cover in the UK is lower than in many other European countries (Finland, 4.083 ha capita⁻¹, Sweden 2.96 ha capita⁻¹, Germany 0.428 ha capita⁻¹ and EU27 0.312 ha capita⁻¹). Finland and Sweden are utilising their biomass resources, and have installed biomass energy plants to take advantage of the abundant local fuel supply (Al-Mansour and Zuwala, 2010).

A study by McKay (2006) assessed the current potentially operational available woodfuel resources in the UK, the results are displayed below.

Product	England	Wales	Scotland	Britain
A - Arboricultural arisings	313	18	10	341
A - Poor quality stemwood	94	113	70	278
A - Stem tips (<7 cm diameter)	14	12	5	31
A - Branches	225	116	68	410
B - Sawmill conversion products	29	40	17	86
B - Stemwood 7–14 cm diameter	30	61	13	103
B - Short rotation coppice	13	0.6	0.2	14
Total (odt)	718	360	183	1263

Table 1: Available British woodfuel sources, displayed in thousand oven dried tonnes (odt) yr⁻¹.
A –residue³, B – non-residue (adapted from McKay, 2006).

The data in table 1 shows that the largest woodfuel resource in England is arboricultural arisings (material derived from gardens, parks and roadsides), with waste branch wood from forests providing the next highest contribution. The study assumed that the availability of branch wood from forestry and arboricultural arisings would remain a reliable woodfuel source as they are byproducts of practices, as opposed to stemwood which derives from poor management. McKay (2006) states that the forest cover per capita is too low to supply the UK's population, necessitating the utilisation of waste biomass; the study shows arboricultural arisings are abundant.

The arboriculture industry both removes carbon sequestering biomass and prolongs the life of trees through maintenance, whilst using machinery that is heavily fossil fuel reliant. The assessment of current literature has shown there to be a gap in knowledge surrounding the potential reduction in arboricultural GHG reductions, but the potential for nationwide utilisation of an abundant renewable energy source. The

³ I.e. waste byproduct.

literature has highlighted methods of quantifying GHG at a company level to assess the current impact; these methods will be discussed in the following chapter.

3 Methodology:

3.1 Introduction:

The main aim of the project is to calculate the current GHG (when quantifiable GHG will be referred to as CO₂e) emissions from the working operations of arboricultural practices, achieved by adopting a case study approach. BS ISO 14064-1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals (2006) will be applied as structure for GHG quantification. Highlighted areas of intense GHG emissions will be considered for reduction recommendations. The acquisition of detailed and accurate data will be key when assessing the potential decrease in GHG emissions for operations and processes. The research objectives, as stated in the introduction are:

1. Determine the company's annual GHG emissions, through investigating and application of current methods of quantification e.g. international standards, carbon management accounting and life cycle assessment.
2. Identify areas where improvements can be made and provide company and industry specific recommendations for reducing GHG emissions.
3. Where applicable the project will apply and build on the applicable international standards, outlining gaps in working practices associated with the current guidelines on reductions of anthropogenic GHG emissions.

Carbon accounting is a well-known practice, however its' application to a service organisation is not well documented. This induces setbacks due to the lack of literature, but provides scope for industry specific innovation. LCA will not be included in the GHG assessment for reasons discussed in section 2.4, however its application for the comparison of products provides holistic results; potential areas of LCA application for future research will be highlighted.

3.2 Definition of Project Boundaries

The BS ISO 14064-1 (2006) standard requests an inventory of the organisations GHG sources and sinks falling into categories between scope 1 and 3, which are defined below. Figure 6 shows the project boundaries, all of which are GHG sources. The study assessed the GHG emissions from the operations within the project boundaries.

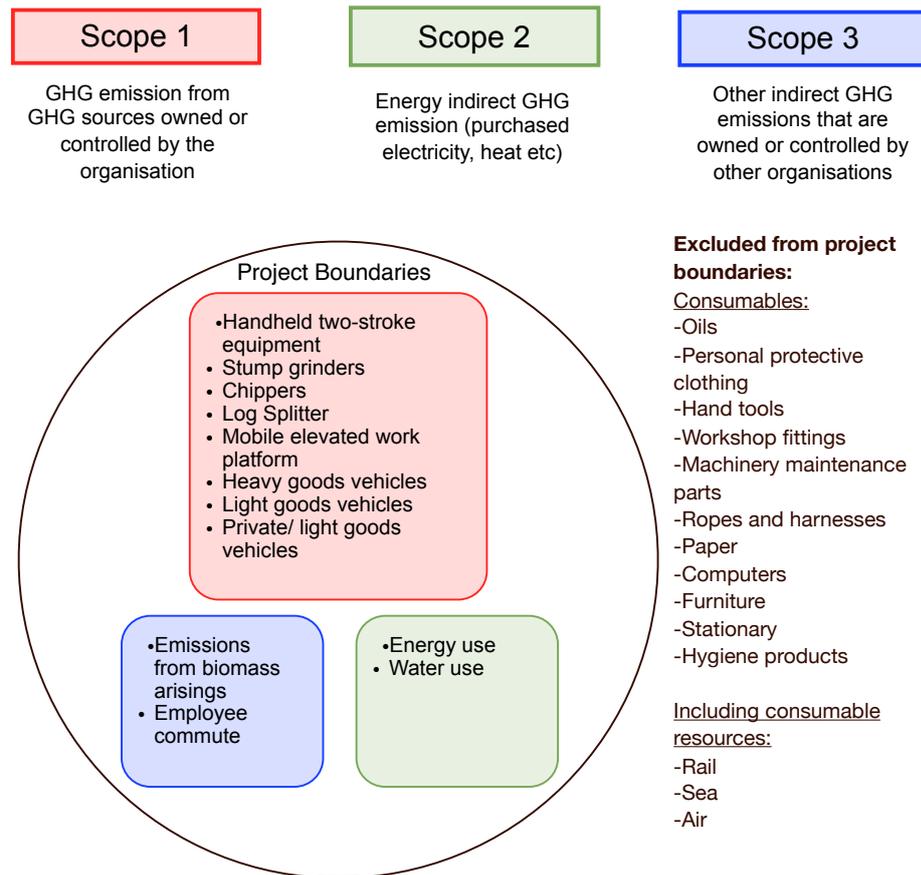


Figure 6: GHG sources associated with DTE, those that are included in the circle are within the project boundaries.

3.3 Research Strategy

The research strategy that will be adopted is a case study as the company is a single entity. Access to the company to collect primary data and to company records to obtain secondary data has been approved by the company director.

3.4 Data Collection Methods

The literature highlighted methods for reporting GHG emissions at an organisational level. The literature review showed the most applicable method to be based on a top down CMA approach, based on the methods described in BS ISO 14064-1 (2006).

3.5 Selection of Quantification Methods

Primary data was gathered during an *in situ*, 2-week data collection period in March 2012. Secondary data was obtained from historical records, using 2011 as the base year. It was necessary to choose a base year as close to current as possible as the company's employees, number of vehicles and machinery fluctuate regularly.

3.6 Primary Data Collection Methods

This involved time in the company office observing operations, joining crews during their daily routine, which provided an insight into current working practices, allowing observations to be made regarding streamlining operations. It also provided an opportunity to speak to employees about current practices and any potential efficiency improvement ideas they had.

This data provided information on the daily operations undertaken by the company, providing comparisons between individual machines and processes, highlighting areas for GHG reduction recommendations.

3.6.1 Vehicles

Business travel was measured daily using the vehicles odometers. The vehicle driver was asked to record the odometer reading and job reference on the 'vehicle form' (see appendix 1), each day before leaving base. The job reference allowed data about location and type of operation, to be linked with each vehicle.

The locations of daily jobs were recorded electronically to observe vehicle movement and calculate the most efficient route from base-to-task; this was done using online software called 'Map a List'. The software uses a geographical information system provided by Google. The electronically calculated route was then compared with the odometer reading. This provided information on route efficiency to provide company and vehicle specific logistics information.

The odometer readings were multiplied with vehicle type specific emissions factors based on $\text{kgCO}_2\text{e km}^{-1}$ from (DEFRA, 2012). The emission factors were based on vehicle type, weight and average load. This figure was converted to an annual figure, providing a comparison against the secondary data.

3.6.2 Non-road Diesel Engines

Tests were carried out under normal working conditions to replicate how the machinery is typically used to provide customised machine specific fuel consumption data. A long strip of card called a 'dipstick', was marked with a red line at one end to show the depth that the dipstick was to be put into the tank; the other was inserted into the fuel tank causing the liquid to stain the card. This stain was then labelled 'FL' (fuel level), showing the level of fuel in the tank before use. After use, the dipstick was reinserted into the tank to the red line and removed to display a second stain, showing the reduced level of fuel in the tank. A measuring jug was used to pour fuel back into the tank, checking the fuel tank levels regularly with the cardboard dipstick, until the fuel was back to the 'FL' marked line. The amount of fuel poured into the tank was then

documented along with the runtime of the machine and job reference to provide fuel usage data linked to operation type, make and model.

'Dipstick' Method Diagram

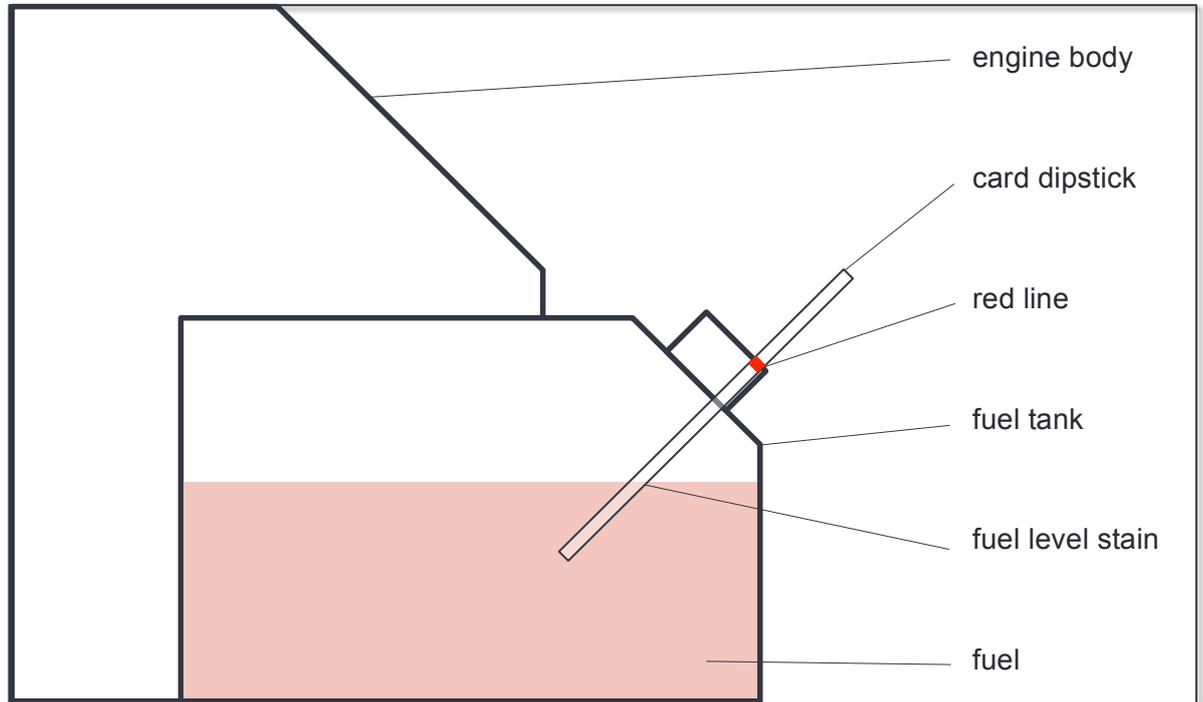


Figure 7: Diagram of the dipstick being inserted into the fuel tank of a non-road diesel engine.

Errors considered

The combustion of fuel during the use phase of the experiment will reduce the quantity of fuel in the tank. This could rearrange the weight of the machine, altering the distribution of fuel and changing the level of fuel that stains the card. This effect will be minimal as all machines tested weigh over 700 kg, meaning the redistribution of weight will be insignificant. The type of card used for the experiment had previously undergone tests to assess their structural integrity and absorption during liquid exposure. The card chosen for the experiment was 1 mm thick compressed card, due to its' minimal porosity and ridged structure.

The non-road machines are equipped with hour-meters, which record the duration each machine is turned on for; this provides daily and 2-week use figures. The fuel consumption data was multiplied by the diesel emission factor $3.1073 \text{ kgCO}_2\text{e l}^{-1}$ (DEFRA, 2012), displaying GHG emissions data for the individual machines.

3.6.3 Chippers

Six chippers were tested, ranging from 22-72 break horsepower (Bhp). Due to uneven ground surfaces on most sites, the chippers were not moved for the duration of the experiment; this was to ensure that the distribution of fuel in the tank would not change. This ensured high accuracy for the 'dip-stick' method, but meant that the recording times for the chippers could only extend to around 30 minutes run-time, as the chipper often needed to be re-positioned.

The chippers were run under normal working conditions, ensuring the employees usual work methods were recorded. Once the chipper had been used for a minimum of 30 minutes, (longer if there was no need to move it) the machine was then switched off and the dipstick inserted to check fuel used.

Variables considered

The type of arising – There are 3 main types of arisings associated with tree surgery: brash, small diameter branches mainly composed of foliage; medium; and large diameter timber. The company's chippers have wood diameter capacities ranging from 15.2 to 20 cm and standard practice is to chip as much of the arisings as possible. Therefore, during some operations large quantities of brash and medium diameter timber (up to between 15.2 to 20 cm in diameter) are processed, however large diameter timber is not. Fuel consumption rates for non-road diesel engines are unpredictable due to the varied engine speed and torque experienced during the use phase (Lindgren, 2005; Hansson et al., 1999). Therefore the data received from

primary experiments on non-road diesel engines will be used for comparison of use and not for the annual CO₂e contribution.

Idling time - It is standard procedure to position the vehicle and chipper close to where the tree operation is being undertaken, this reduces the distance the arisings need to be dragged before chipping, speeding up the job. During some operations a lengthy drag is unavoidable, therefore employees have two options with regards to chipping: 'continuous'; leaving the chipper idling and bringing one load of arisings at a time to feed into the chipper or 'batch chipping'; leaving the chipper off and bringing several loads next to the chipper, to be processed quickly in one session. These methods were assessed, but the conclusion was that it depended mostly upon the number of employees involved in the operation and distance from operation chipper, therefore methods ranged widely.

3.6.4 Stump Grinders:

The company owns and uses 2 stump grinders, 1 large tracked diesel engine and 1 lightweight petrol engine. The petrol grinder uses fuel that is added to the fuel card of the users vehicle, the fuel use was therefore calculated with the other petrol driven two-stroke engines.

The dipstick method was used to collect data from the large stump grinder. The stump grinder was operated for long periods of time and could be driven to flat ground. This enabled the experiment runtime to be longer providing a more precise average.

Variables considered

Most stump grinding procedures are carried out in the same way; the stump is cut with a chainsaw to a level as near the ground as possible, then the cutting disc on the grinder is moved over the stump removing shavings of wood with each pass. Variables that may have affected the results include hardness or diameter of wood, and distance between target stumps. The hardness and diameter of the stumps were

an unavoidable variable, however the experimental period covered a range of tree species and diameters, minimising its effect on the data.

The distance between target stumps was an issue to consider for the large tracked chipper as the machine's engine powers the tracks, moving it between stumps. The hour-meter begins when the machine is turned on; therefore the time taken to manoeuvre between stumps was included.

3.6.5 Two-stroke Equipment

While on location with a working crew the necessary two-stroke equipment were filled with two-stroke petrol, then poured into a jug to measure the capacity, it was then used and the duration of use time was measured. If the piece of equipment was not used until empty then the fuel remaining was measured, thus providing fuel consumption hr^{-1} . Observations were recorded regarding operator habits and methods, type of equipment use (e.g. large diameter timber, long periods of saw tick-over time etc.).

3.6.6 Arisings

The carrying capacities of vehicles were calculated, using dimensions to calculate the vehicle body volume. Upon return to base employees were asked to estimate the arisings in the body of the vehicle based on percentage of capacity. This percentage was then calculated with the individual vehicles volume capacity, providing m^3 of arisings. Some arisings have diameters that are too large to chip; these are transported to base whole and estimated with the woodchips, then separated. Arisings that are too large for the chipper are stacked in a pile, which is either used for a local woodfuel system, or is processed and sold as firewood.

The average weight of 1 m^3 of woodchips is between 300-400 kg (Biomass Energy Centre, 2011), this figure was used to convert the m^3 of woodchips into tonnes. The total tonnes of arisings was then multiplied by the woodchip emissions factor 61.41

kgCO₂e tonne⁻¹ (DEFRA, 2012), showing the CH₄ and N₂O release from the transportation, refining, distribution and storage of woodchips for use as biofuel.

3.7 Secondary Data Collection Methods

The annual emission data for the company was gathered using secondary data obtained from organisational reports. The use of secondary data was important as it had a high level of accuracy and would allow for future annual comparisons.

3.7.1 Vehicles

Each vehicle has a fuel card which, when processed during refueling, records the amount of petrol and diesel obtained. The fuel cards are specific to individual vehicles; therefore they provided itemised and highly accurate fuel consumption data. The PAS 2050 Guidelines (2008) and DEFRA (2012) suggest that gaining fuel input data and combining it with distance travelled and vehicle information provides the most accurate results. DEFRA (2012) state that CO₂ emissions from fossil fuels are essentially independent of application, assuming full combustion; i.e. the same amount of CO₂ is released regardless of how it is combusted, however, CH₄ and N₂O vary to some degree for the same fuel type, depending on use (DEFRA, 2012). Therefore the vehicles have been assigned different GHG emission factors depending upon their type, weight and average load (DEFRA, 2012). The vehicle specific conversion factors will be applied to the vehicles annual fuel consumption, providing an annual CO₂e emissions figure. The emission factor provided by DEFRA (2012) includes indirect emissions associated with the extraction and transport of fuels as well as the refining, distribution, storage and retaining of finished fuels (also known as well-to-wheel) (DEFRA, 2012).

3.7.2 Non-road diesel engines

An on-site red diesel container supplies all non-road diesel engines. It is refilled when necessary, providing the company with invoices throughout the year. The GHG

emissions are calculated by multiplying data by the diesel emission factor 3.1073 kgCO₂e l⁻¹ (DEFRA, 2012).

3.7.3 Two-stroke:

The two-stroke machinery consists of 50 chainsaws ranging from 2.4-8.7 Bhp, 9 hedge trimmers, 9 blowers, 2 brush cutters and 2 long reach combination engines. All 72 pieces of equipment have similar engine design, only differing in displacement and Bhp.

Annual CO₂e figures for two-stroke machinery was calculated by using the annual litres of petrol (figures ascertained from fuel cards) in conjunction with petrol emission factor 2.6670 kgCO₂e l⁻¹ (DEFRA, 2012). No publications were found regarding the GHG emissions of two-stroke engines, which was a limitation as two-stroke and four-stroke engines differ in combustion methods. Due to lack of research on the subject of GHG emissions of two-stroke engines, or the subsequent effect that lost petrol/oil fuel mixture has on the composition of the atmosphere, scavenging loss will not be included in the calculations (see section 2.5.1 for description of scavenging loss). Instead an assumption was made that the petrol is completely burned or has evaporated, releasing CO₂ into the atmosphere.

3.7.4 Woodchips

The company stockpile their woodchips at base until near holding capacity, at which point a renewable energy company collects the woodchips using an HGV vehicle. The woodchips are loaded onto the vehicle where they are weighed and an invoice provided showing the weight of woodchips loaded. Collection of woodchips is on an ad hoc basis and therefore invoices are provided irregularly throughout the year.

The total tonnage of woodchips was multiplied by the wood chip emission factor 61.41 kgCO₂e tonne⁻¹ (DEFRA, 2012) to provide GHG emission figures. This is limited

to CH₄ and N₂O emissions from arisings⁴, which fall under scope 3 of BS ISO 10464 (2006); defined as ‘other indirect GHG emissions that are owned or controlled by other organisations’. The CH₄ and N₂O are released from the transportation, refining, distribution and storage of woodchips for biofuel.

Arisings that are too large for the chipper are stacked in a pile, which is either used in a local woodfuel system, or is processed and sold as firewood. There is no secondary data on this subject, therefore the difference between the primary and secondary data was used to provide an estimate to the amount of unprocessed arisings.

The calculation of the CO₂e emissions and the potential coal substituted for woodfuel was assessed using DEFRA (2012) emission factors (EF):

Woodchip emissions:

$$\text{Woodchip tonne yr}^{-1} \times \text{woodchip CV (3890 kW h tonne}^{-1}) = \text{kW h yr}^{-1}$$

$$\text{Woodchip EF (0.01579 kgCO}_2\text{e kW h}^{-1}) \times \text{kW h yr}^{-1} = \text{woodchip kgCO}_2\text{e yr}^{-1}$$

Coal emissions:

$$\text{Woodchips kW h yr}^{-1} \times \text{coal EF (0.37988 kgCO}_2\text{e kW h}^{-1}) = \text{coal kgCO}_2\text{e yr}^{-1}$$

3.7.5 Energy consumption

Utility bills from 2011 were acquired for the buildings in use by DTE. Energy usage (kW h) was multiplied by the 2010⁵ emission factor for consumed electricity of 0.49390 kgCO₂e kW h⁻¹ (DEFRA, 2012) to show the GHG emissions from electricity consumption.

⁴ CO₂ from biomass is carbon neutral as it releases the same amount of carbon that was stored during its lifetime.

⁵ Emission factors for 2011 are not available at time of publication.

3.7.6 Employee commute

The company provided each employees address, with information on the status of employment i.e. full-time or part-time, to calculate the number of days that individuals commute. The addresses were entered into the online software 'Map a List', which provided separate electronic route distances both to and from base. This figure was multiplied by the number of days each individual employee worked, providing annual commute distance. These figures were multiplied by an average petrol car emission factor of $0.20864 \text{ kgCO}_2\text{e km}^{-1}$ (DEFRA, 2012), displaying the GHG emissions of employee commute.

4 Results

4.1 Introduction

Primary and secondary datasets are displayed separately, followed by total annual GHG emissions.

4.2 Primary Data:

4.2.1 Vehicles:

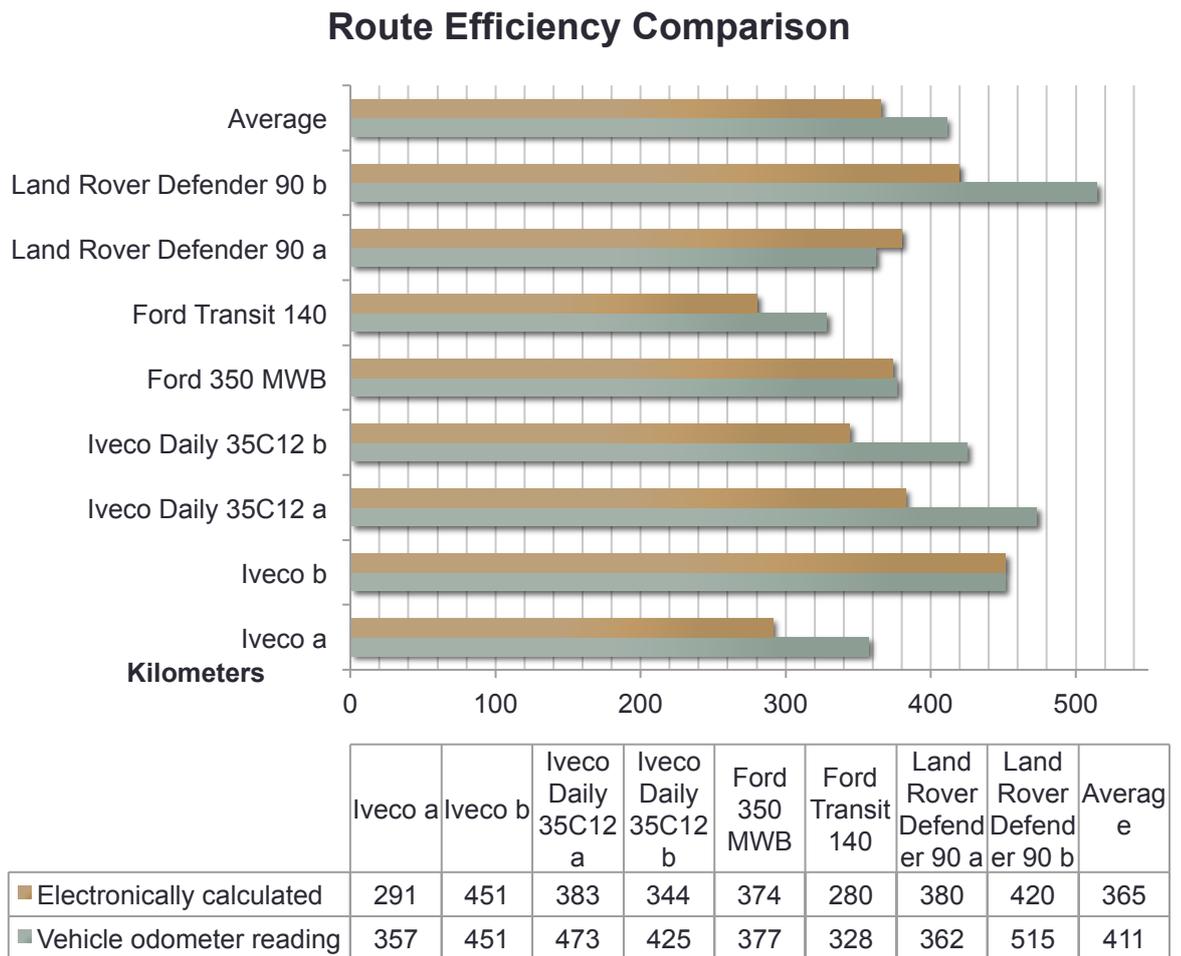


Figure 8: A comparison between the actual distance travelled and the electronically produced 'base to destination' distance of the working vehicles. **Route Efficiency Comparison**

Figure 8 and 9 are based on the vehicles odometer readings. The mean vehicle odometer reading was 66 km more than the electronically produced data. During the experimental period 2 vehicles (NX56FWS and VU06TXN) were used privately, consequently no electronic data could be calculated for these journeys.

Mean Undocumented travel was 33 km vehicle⁻¹ week⁻¹, giving an annual value of 1,690 km. Undocumented travel for the 8 working vehicles was 13,520 km yr⁻¹.

Working and Surveying Vehicle Distance Comparison

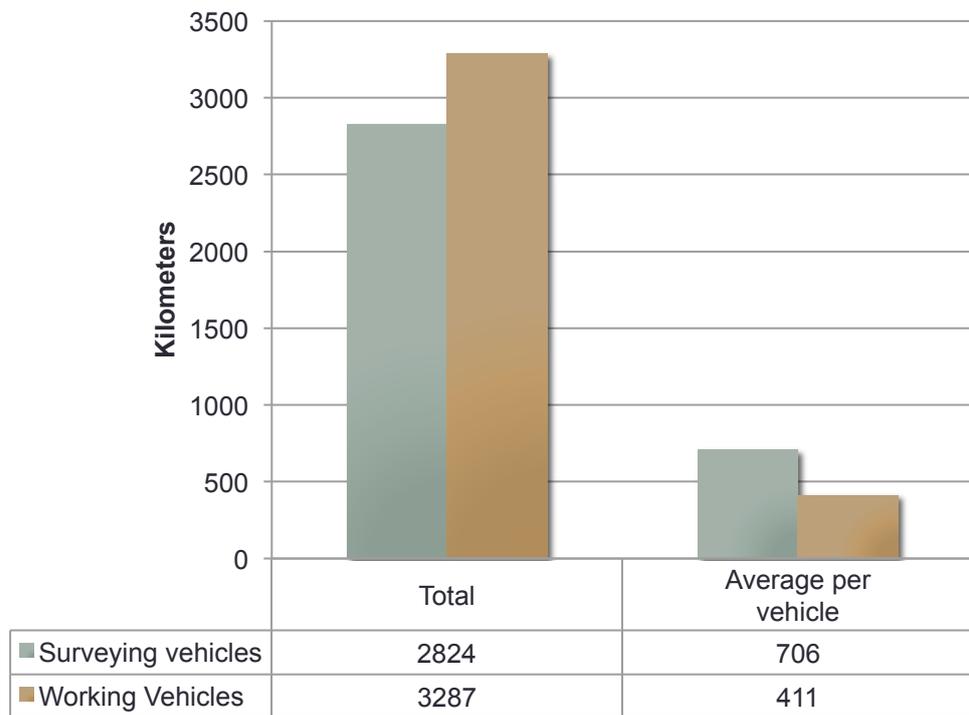


Figure 9: Total distance travelled by 8 working and 4 quoting vehicles during the experimental period.

Figure 9 shows the odometer readings that the 8 working vehicles travelled 463 km more than the 4 active surveying vehicles during the 2-week period. The working vehicles travelled an average of 41 km day⁻¹ and the surveying vehicles travelled 71 km day⁻¹. Based on the primary data the working and surveying vehicles travel

approximately 78,000 and 67,000 km yr⁻¹, respectively (based on 48 week working year).

Geographical Distribution of Working Vehicles During Experimental Period



Figure 10: The geographical spread of the working vehicles⁶, with the red balloon showing the location of the company. Rings represent working radius in 10 km increments

Figure 10 shows that the company operated within a 55 km range with the majority of work taking place in a 30 km radius of the company.

4.2.2 Non-road Diesel Engines

⁶ Note: working vehicles, not surveying vehicles.

Non-road Diesel Engine Fuel Consumption

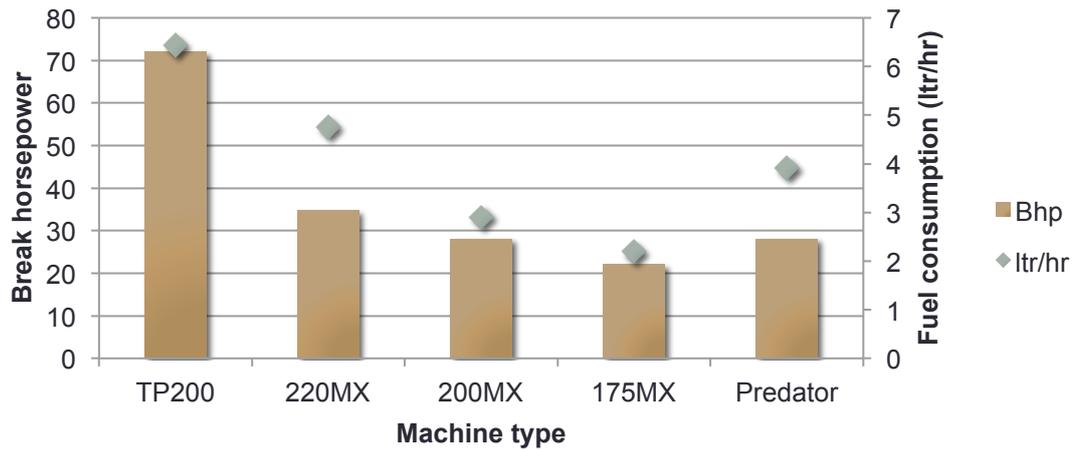


Figure 11: Machine type fuel consumption and Bhp for non-road diesel engines over the 2-weeks.

Two-week fuel consumption (figure 11) was acquired from 7 non-road diesel engines, consisting of 1-TP200 – 46.9 l, 2-TP200 – 9.6 l, 3-220MX – 33.3 l, 4-220MX – 28.6 l, 5-200MX – 17.4 l, 175MX – 9.7 l, and Predator – 20.2 l.

4.2.3 Arisings

Arisings Collected by Vehicle Type

Vehicle Type	Vehicle weight (kg)	2-week arisings (tonne)	TonneCO ₂ e
Iveco a	15000	24	1.5
Iveco b	13000	19	1.2
Iveco Daily 35C12 a	3500	3	0.2
Iveco Daily 35C12 b	3500	6	0.4
Ford 350 MWB	3500	4	0.2
Ford Transit 140	3500	4	0.2
Land Rover Defender 90 b	3500	2	0.1
Emission factor		TonneCO ₂ e per tonne	0.06141
2 week total		62	3.8
Annual total		1609	98.8

Table 2: Correlation between vehicle weight and arisings produced.

The arising data (Table 2) displays woodchips and unprocessed arisings collected during the 2-week period. The potential electricity generated from all arisings is 3,264,456 kW h yr⁻¹ (see section 3.7.4 for equation). This figure uses only the potential kW h available, as not all arisings are used for electricity generation.

Multiplying arisings kW h yr⁻¹ by coal emission factor (0.37988 kgCO₂e kW h⁻¹) shows that if all arisings were processed to woodchips and used as woodfuel then 2,380 tonnesCO₂e yr⁻¹ would not be released by burning coal.

4.2.4 Two-stroke equipment

Five types of two-stroke equipment were assessed with average fuel consumption of 0.52 ± 0.2 l hr⁻¹.

4.3 Secondary Data

4.3.1 Vehicles

Comparison of Diesel Use by Working and Surveying Vehicles

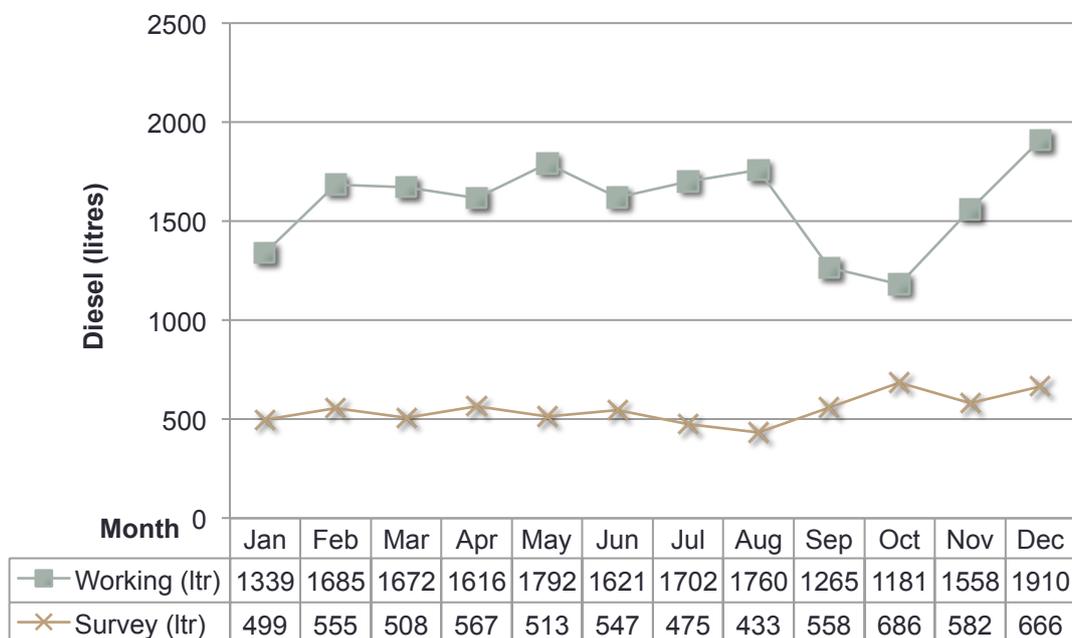


Figure 12: Monthly consumption (litres) of diesel fuel for working and survey vehicles.

Working and surveying vehicles used a total of 19,101 and 6,589 l of diesel, respectively. The working vehicles had an average monthly fuel consumption of 1,592 l, while the surveying vehicles used 549 l. The 5⁷ surveying vehicles used an average of 1,318 l vehicle⁻¹ yr⁻¹ and the 10⁸ working vehicles used 1,910 l vehicle⁻¹ yr⁻¹. Using the diesel emission factor 3.1073 kgCO₂e l⁻¹ the working and surveying vehicles contributed 59.4 and 20.4 tonneCO₂e, respectively, to the company's annual emissions.

⁷ The primary data shows 4 surveying vehicles, 1 was not active during the two-week period.

⁸ The primary data shows 8 working vehicles: during the two week period 1 working vehicle was not in use; in 2011 1 working vehicle was sold.

Fuel Efficiency by Vehicle Type

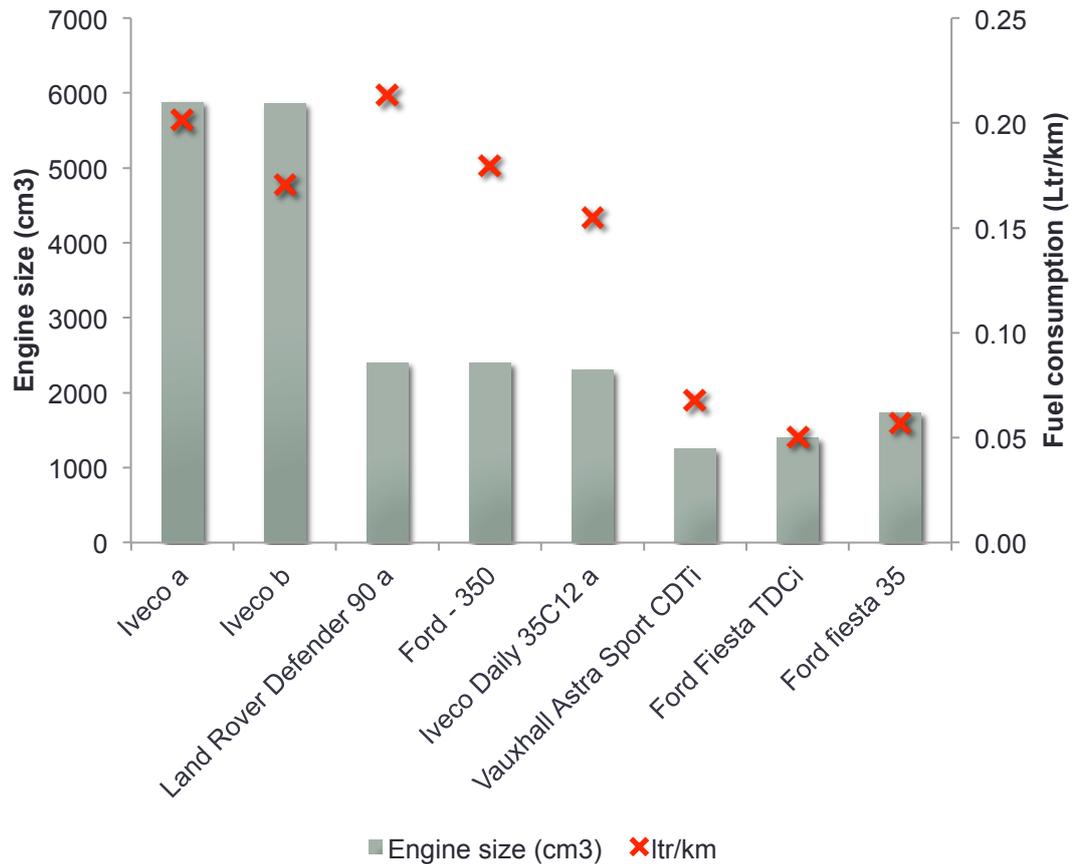


Figure 13: Fuel consumption per km travelled in 2011 with engine size of vehicle.

The working vehicles consist of Iveco a, Iveco b, Land Rover, Ford – 350 and Iveco Daily; weighing 15,000, 13,000, 2,400, 3,500 and 3,500 kg, respectively. The Land Rover had the highest fuel consumption. The surveying vehicles (Vauxhall Astra Sport CDTi, Ford Fiesta TDCi and Ford Fiesta 35) weigh 1,920, 1,585 and 1,585 kg, respectively.

4.3.2 Non-road Diesel Engines

Invoices from bulk deliveries of diesel from February, June and September 2011, showed that 2,200, 1,500 and 1,500 l of diesel had been used respectively, providing an annual consumption of 5,200 l. Using the diesel emission factor 3.1073 kgCO₂e l⁻¹ the annual emission contribution was 16.2 tonneCO₂e.

4.3.3 Two-stroke Equipment

Annual Petrol and Diesel Usage

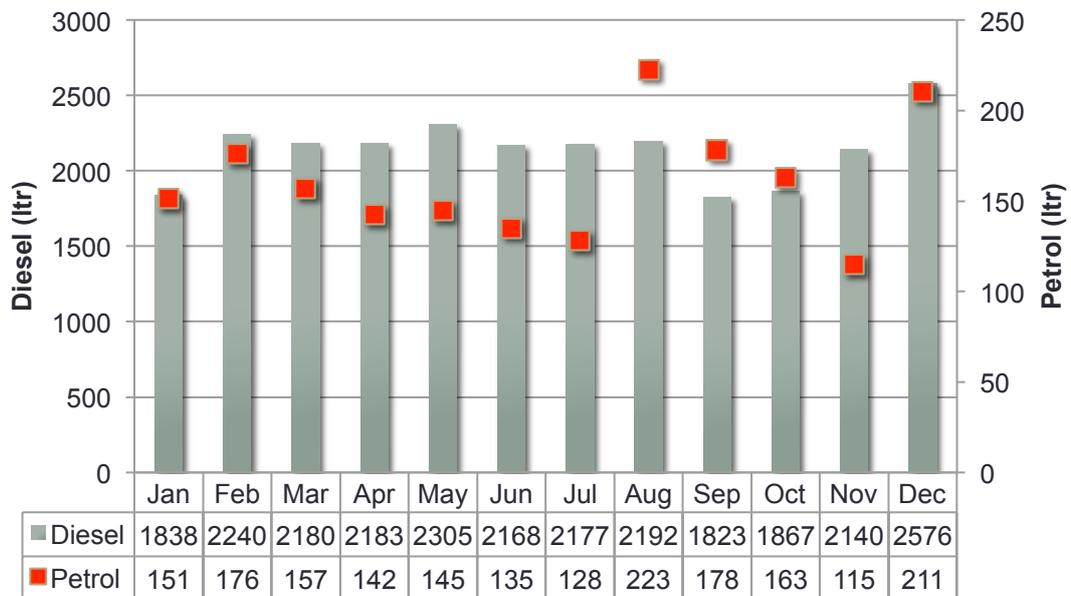


Figure 14: Relationship between diesel usage for vehicles and petrol usage for two-stroke equipment.

Total annual petrol used for two-stroke equipment was 1,923 l, with a monthly average of 160 l. This provided a 5.13 tonneCO₂e contribution figure, using the emission factor 2.667 kgCO₂e l⁻¹.

4.3.4 Woodchips

The total annual woodchip arising was 718 tonnes, with a monthly mean average of 59.9 tonnes. Using the calorific value for woodchips of 3,890 kW h tonne⁻¹ provided the figure 2,800,000 kW h yr⁻¹; multiplied by the woodchip emission factor 0.01579 kgCO₂e kW h⁻¹ showed the woodchips released 44.1 tonnesCO₂e yr⁻¹.

Multiplying woodchips kW h yr⁻¹ by the coal emission factor (0.37988 kgCO₂e kW h⁻¹) showed the emissions not released due to use of woodfuel to be 1062.1 tonnesCO₂e yr⁻¹. There was no relationship between wood chip data and diesel or petrol fuel usage, nor any trend between seasons.

4.3.5 Energy Consumption

The data collected from utility bills was provided in a single annual figure of 11,000 kW h, contributing 5.4 tonneCO₂e, based on 0.49390 kgCO₂e kW h⁻¹.

4.3.6 Employee Commute

The mean employee commute was 55.8 km, however, this figure includes the commute of a single employee who travels 695 km every 2 weeks. The median employee commute was 20.6 km. The total distance travelled by all employees, taking into account the number of days per year each employee worked during the base year is 143,890 km. Therefore the GHG contribution is 30.02 tonneCO₂e based on an 'average petrol car' emission factor of 0.20864 kgCO₂e km⁻¹. The average employee contributes an average of 1.31 tonneCO₂e yr⁻¹.

Placing employees in a band, illustrating their distance from DTE allows the introduction of the mode average. Table 3 shows the mode commute to be less than 10 km.

Employee Commute by Distance from DTE

	<10 km	10 - 20 km	20 - 30 km	30> km
Employees	11	5	5	2

Table 3: Employee commutes grouped by commute travel in 10 km increments.

4.4 Annual GHG Emissions

Total Emissions Released from DTE Activities in 2011

Output	Tonnes CO ₂ e	Units	Emission factor	Emission factor type
Working vehicles	59.4	19,101	3.1073	kgCO ₂ e/litre
Surveying vehicles	20.5	6,589	3.1073	kgCO ₂ e/litre
2-stroke machinery	5.1	1,923	2.667	kgCO ₂ e/litre
Non-road	16.2	5,200	3.1073	kgCO ₂ e/litre
Energy use	5.4	11,000	0.4939	kgCO ₂ e/kW h
Employee commute	30.02	14,3890	0.20864	kgCO ₂ e /km
Arisings	98.9	1,610	0.06141	kgCO ₂ e/tonne
Total tonnesCO₂e	235.50			

Table 4: Contribution of individual sectors; double horizontal lines separating scope 1, scope 2 and scope 3, respectively.

The annual GHG emissions were calculated from secondary data, with the exception of arisings, which were based on primary data. All emission factors were taken from DEFRA (2012).

CO₂e Contribution by Sector

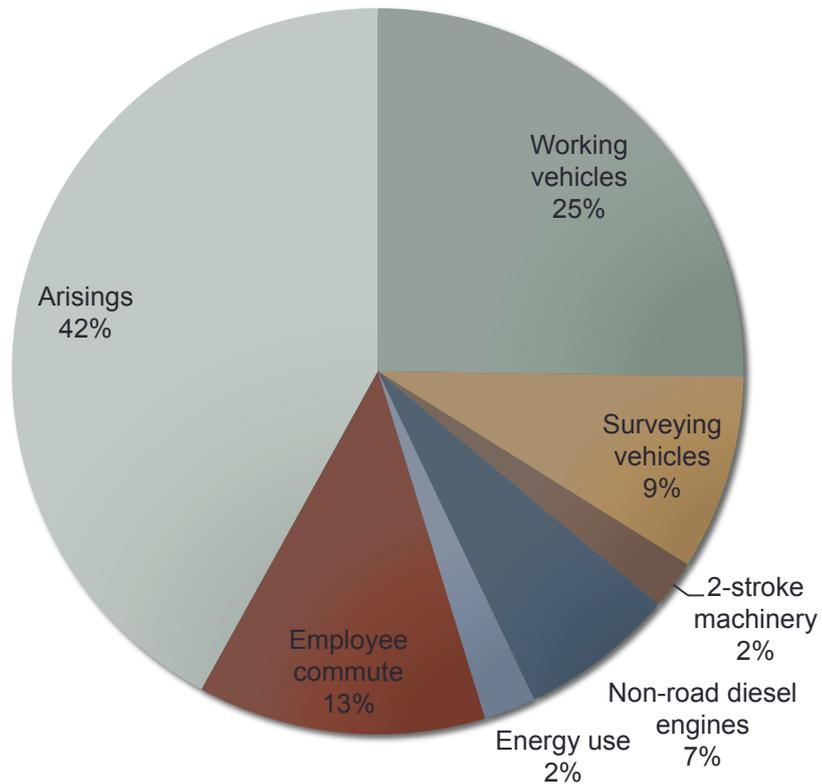


Figure 15: Percentage contribution of individual sectors of DTE, including three scopes.

The company vehicles contributed 34% of the annual emissions. The emissions from the arisings only consist of CH₄ and N₂O; the CO₂ emissions are not included as they are equivalent to the CO₂ stored during growth of the biomass (DEFRA, 2012). The arisings data is based on primary data as it shows emissions from all arisings yr⁻¹, rather than the total woodchips used for electricity generation.

Emissions from project boundary groups are; scope 1 -101.2 tonnesCO₂e yr⁻¹, scope 2- 5.4 tonnesCO₂e yr⁻¹ and scope 3- 128.9 tonnesCO₂e yr⁻¹.

5 Discussion:

This chapter will present primary and secondary data first with in-depth analysis of the collection procedures and results. Followed by the key findings from the study in relation to total GHG emissions from the case study company. Recommendations for reducing GHG emissions, where relevant, are listed throughout the chapter.

The research assessed current GHG emission released by a tree surgery company, (please refer to section 1.2 for information regarding the case study company) which was achieved by using quantification techniques from BS ISO 14064 (2006). The application of BS ISO 14061-1 (2006) to the case study company provided valuable structure through established techniques. The application of a standard that applies to all companies, however, is considered too generalised, therefore leaves too much flexibility when defining the boundaries of the project. The subjectivity surrounding the choice of boundaries and the complexity of the document ensures that the standard is not user friendly, with the prospect of obstructing a potential user. The separation of the standard into several business types (e.g. manufacturers, retail, wholesale, construction, transportation and leisure and hospitality) would allow the user to apply it unimpeded and would reduce subjectivity in boundary choice between business types.

The application of LCA to the study was excluded due to the bottom-up approach the method uses. Bottom-up processing produces an inventory of subsections to create a top-level system of the company; this process would have created a dataset specifically for DTEs vehicles, equipment and activities, thus creating difficulties when applying the process to other organisations in the industry. Therefore to fulfil the stated aim of industry level applicability the top-down approach of BS ISO 14064 (2006) was used. Machinery will always need replacing and recommendations have been made to apply LCA to guide purchase of equipment with the lowest overall environmental impact.

The BS ISO 14064 (2006) standard provided little information on the data collection procedures, an area that is clearly important to assessing GHG emissions. The projects use of the standard offers scope for company accreditation after completion of section 7 and 8.

5.1 Primary Data:

Primary data was collected to highlight potential areas of improvement based on daily operations. The stability and accuracy of the emissions calculated from primary data (see appendix 2) has demonstrated that if repetition of the project was necessary, then the use of historical secondary data may not be necessary.

5.1.1 Vehicles:

The comparison between vehicle odometer readings and electronically generated distances (figure 8) showed an average of 33 undocumented km vehicle⁻¹ week⁻¹. Undocumented travel could be due to: vehicles used to make journeys back to base to offload arisings; undocumented journeys to join other teams for support; differing routes to the electronic system for traffic avoidance or an accumulation of detours for employees. The results show that the vehicle type does not affect the difference between electronic and odometer distances; the 13 tonne HGV, Iveco b has identical distance figures and the considerably smaller, Land Rover Defender b shows a 95 km difference between the electronic and odometer reading.

Undocumented travel for the 8 working vehicles was 13,520 km yr⁻¹. Although it cannot be assumed that the difference between the two datasets is purely due to route inefficiency, the electronically produced data produces markedly lower annual travel figures.

Primary data was collected while the company was active to gain normal working operations data, meaning the data collection had to adapt to daily changes in work schedule. The employees filled in the vehicle forms whilst carrying out their

morning checks, before leaving base; however, moving locations is not always planned, staff would not always remember to add other locations to their vehicle sheet, causing discrepancies between odometer and route planner data. Figure 9 showed that the individual surveying vehicles travelled further on a daily and annual basis. Surveyors usually spend less time on location, allowing them to visit several clients in a single day.

During the 2-week data collection period notes were made regarding efficiency problems employees regularly encountered, as it has the potential to reduce energy use. The vehicle drivers described the current daily route planning method, which is done manually by employees who were familiar with the geography of the working area of the company. The point was raised that some vehicles cross paths when travelling to multiple locations, when it would reduce daily travel by ensuring each vehicle travels to locations as close together as possible. Figure 10 shows the working radius of the working vehicles over the two-week period. The distribution of the individual vehicles displays no pattern or grouping, showing a varied use of the different vehicle types. Two main clusters of activity are displayed on the map, 10 km south in Sevenoaks and 20 km northwest near Bromley.

However, the data set was limited as the collection period was too short to provide an annual overview of the working radius of the company, as some vehicles returned to the same location several times over the two-week period. Data collection over 2 months would have provided a more accurate working area of the company and individual vehicles.

Vehicle Recommendations: Typically a surveyor drives to the client in an average-sized engine diesel vehicle, assesses the required task and moves on to survey another location or return to base to calculate a quote. If the quote is accepted then arrangements are made for the task to be carried out

and a working vehicle is sent to the location to undertake the task. The working vehicle may make a single or multiple visits depending on the complexity of the task.

Survey vehicle travel could be reduced by the use of an online estimating system to replace a proportion of the on-road surveying fleet. DTE would need a dedicated section of the company to run the online estimating system, as it would require a surveyor to manage the online applications and fully equipped working vehicles prepared to arrive on location with less knowledge regarding the task. The term estimate is used as there may be some information that is not obvious until arriving on location, therefore consideration should be given to providing a dedicated working vehicle with a range of equipment on board that is hired out to clients per hour.

The system would have to utilise video communication (where appropriate), digital photography, geographical information systems/aerial photographs and would require assistance from the client. Client cooperation may limit the use of the system to those who are willing and able to assist. Society is becoming more environmentally aware, potentially attracting some clients to the idea, however some clients may not be interested, have the computer literacy or have the practical skills required for aspects of the application e.g. the need to estimate the tree height or judge the walking distance from the task to nearest point of access.

Therefore the first aspect to consider when assessing the applicability of the task for online estimating will be the size, complexity of the task and clients' motivation. The online estimating system may be best used for smaller tasks such as hedge cutting, simple tree reductions, felling and removals. The system could also be applied to regular clients who request operations on an

annual basis; some task information may already be available. Furthermore the online surveyor could work from home, saving commuting emissions, and may be able to process more applications per day due to no business travel time.

Removing one surveying vehicle from use to carry out online estimating could reduce road travel by 17,040⁹ km yr⁻¹, equating to 3.19 tonnesCO₂e yr⁻¹ (based on average diesel car emission factor of 0.18702 kgCO₂e km⁻¹.)

Improving logistical efficiency will reduce wasted daily travel. There are online and offline computer software systems available that allow precision routing and scheduling for vehicle fleets; reducing or removing vehicles crossing paths. There are also several companies that provide ordinance survey based systems. A similar system utilised by an SME manufacturing company (Blackheath Products) saved 75% on planning time and 20% in vehicle mileage (Paragon Products, 2012). The installed system accommodated the delivery of multiple types of products, which could translate as multiple types of arboricultural tasks such a tree work, hedging, cable bracing, surveying etc.

These routing systems offer reductions in fuel and mileage ranging from 10% to 20% depending on the business size and type. Based on these reduction values DTE vehicle travel would be reduced by between 14,668 km yr⁻¹, and 36,670 km yr⁻¹. Diesel usage would be reduced by between 2,569 l yr⁻¹ and 5,138 l yr⁻¹, reducing GHG emissions by between 7.99 tonnesCO₂e yr⁻¹ and 15.98 tonnesCO₂e yr⁻¹.

To ensure the benefits of the logistical system are maximised, the use of an integrated global positioning system (GPS) is also suggested. Advanced

⁹ Figures based on primary data.

HGV specific GPS systems are available that provide efficient routing, excludes non-HGV access roads and provides live traffic information. Reduced time in traffic lowers fuel use and would ensure vehicles arrived at location quicker; increasing time spent carrying out operations.

The primary data indicated a maximum working radius of approximately 55 km. The company promote their services in Bristol, Southampton and Northampton, distances of 200 km, 125 km and 120 km, respectively and the company will carry out operations within this range if it is financially viable. The GHG emissions from one working vehicle and one surveying vehicle, travelling round trip to Bristol would be 0.47 tonneCO₂e. A suggested alternative to this could be to collaborate with other arboriculture companies in a region to facilitate a trading of work to minimise travel. Any collaboration would require trust and transparency between companies, but could be financially and environmentally beneficial.

The collection of vehicle movement data over a longer timescale would provide more detail on the working area of the company. This data could be used to make an informed decision regarding the creation a second company base, allowing vehicles to travel fewer kilometres to tasks, increase company coverage, reduce employee commutes (for some), and the choice of location could incorporate good public transport links for employees.

The use of LCA would be valuable for the purchasing of new, more fuel efficient vehicles. Primary data can be used to compare the efficiency of a vehicle owned by the company with potential replacement vehicles, using the vehicle specific data to compare the environmental impact of potential replacement vehicles over their full life cycle.

5.1.2 Non-road Diesel Engines

5.1.2.1 Chippers

The chipper data (figure 11) indicated that fuel consumption is directly proportional to the Bhp of the engine, which was expected. The machines differed in the maximum size diameter of wood they are able to process; the TP200s are <20 cm, the 220mx 200mx and 175mx are <16 cm. Higher Bhp engines usually have larger diameter processing capabilities which are necessary in arboriculture for processing and transporting large volumes of arisings. The use of chippers with larger engines (e.g. TP200) is warranted if the magnitude of the job requires it. It was noted that during the two-week period individual chippers were used with an array of working vehicles; showing good use of appropriate equipment.

Chippings Recommendations: There is very little research on handfed chipper fuel consumption characteristics (Van Belle, 2006). Spinelli and Hartsough (2001), carried out a study of chippers for large scale logging with mechanised harvesters, concluding that there was no universal procedure for the most efficient use of chippers; most operators are working with what they considered to be near-optimal configurations of their equipment.

Chippers are essential for maintaining tree surgery operations; as most customers are in urban areas, and cannot accommodate arisings; and they reduce the overall size of arisings, allowing for transportation of more arisings in a single journey, reducing return visits. Therefore, as there are no suitable alternatives, the continued use of chippers must be accepted with only general recommendations for fuel efficiency in arboriculture: reduce tick-over time by chipping arisings in batches, appropriate use of chipper size for task, ensure two sets of cutting blades are available for use, (allowing the sharpening of one set whilst the use of the other) and regular machine maintenance.

5.1.2.2 Stump Grinder

The Predator stump grinder had a higher fuel consumption in comparison to the matching Bhp 200mx chipper. Stump grinding is an important aspect of arboriculture as in most cases, clients who have trees removed want to utilise the space. Furthermore, some tree species will continue to grow if not ground out.

The process of stump grinding does not vary greatly within grinding operations, leaving little scope for streamlining activities. Currently, DTE organise stump grinding on a batch basis over a single day, allowing the grinder to be taken to multiple sites. The utilised machine is an appropriate size and power for the tasks it is applied to, therefore it is not recommended to downsize the equipment.

5.1.3 Arisings

Primary data for arisings indicated that larger vehicles were used for tasks that gathered more arisings, suggesting that the company utilises its larger vehicles appropriately. The chippers were not assigned to single vehicles; consequently it was not possible to correlate chipper use with arising quantities. No relationship exists between distance travelled and arisings.

The mean quantity of arisings was 30 tonnes week⁻¹, which is more than double the woodchip data (15 tonnes week⁻¹). Although the data is only representative of a 2 two-week period it highlights the large quantity of un-chipped arisings. Currently a proportion of unchipped arisings are used locally in a woodfuel energy system, minimising travel distances and therefore reducing the environmental impact. It is suggested that the use of local woodfuel energy systems should be developed and promoted.

Demand and prices for woodfuel are predicted to rise due to government policies and incentives which encourage the use of wood as renewable fuel (Confor, 2010; BioRegional Development Group, 2008). The rise in price for woodfuels may

change arboricultural arisings from being a burden to an asset. Processing more arisings to sell as woodfuel may be profitable whilst also replacing fossil fuels in heating and energy production. An assessment of woodfuel prices by English Wood Fuels (2012) showed that woodchips sold for commercial energy production are valued at £80 tonne⁻¹ for 40% moisture content (MC) and £40 tonne⁻¹ for 50% MC. Woodchips for domestic use require a lower leaf content and MC; woodchips at 20% and 30% MC can fetch £115 tonne⁻¹ and £100 tonne⁻¹, respectively (English Wood Fuels, 2012). The lower MC necessitates a drying process, which can be achieved through oven drying (active) or air-drying (passive), which requires a large amount of space. The on-site chipped arisings contain twigs and leaves which increases the amount of ash when burned and decreases the average particle size of the biomass, reducing its' efficiency, making it unsuitable for some domestic boilers (BioRegional Development Group, 2008). The unprocessed arisings contain no twig or leaf matter, therefore are a potential source of domestically accepted biomass.

Arisings Recommendations: There is a proportion of arisings collected that are not processed due to the large diameter of the wood. If the unprocessed arisings are chipped separately from the standard woodchips, then allowed to dry, they may be used for woodfuel on a domestic scale. This will require large machinery for chipping the unprocessed arisings. A suggestion would be to collaborate with other arboricultural companies, choose a location equidistant from each base to rent for the storage and drying of wood. The cost of the premises, installation of drying facilities, and whole-tree chipper hire could then be divided by the participants.

This process may become widely adopted in arboriculture due to the potential profits, stability of biomass resource and beneficial environmental output. There is already a market for domestic woodfuel, BioRegional

Development Group (2008) showed that there were 2,171 businesses purchasing woodfuel within a 25 km radius of central London.

5.1.4 Two-stroke Equipment

Two-stroke machinery suffers from scavenging loss, reducing the fuel efficiency of the engine, however, the quantities of fuel consumed are small in comparison to fossil fuel use in larger machinery. Observations showed that the small climbing saws (ms200) were used most frequently. All employees exhibited good practice in machine operation, switching off equipment when not in use. Equipment was well maintained whilst on location and at the base ensuring optimum productivity.

5.2 Secondary Data

5.2.1 Vehicles

Results have indicated that DTE surveying vehicles showed fairly constant consumption throughout the year, with an increase from August to November. The annual working vehicle fuel consumption decreased in August to September, followed by an increase from October to December. The increase in working vehicle use may be explained by the increase in surveying vehicle consumption (and associated increase in work) from August to November. The decrease in working vehicle consumption is inexplicable, however the increase in October may be due to increased demand for logs in the winter.

The working vehicles were the largest contributor of direct annual GHG emissions, responsible for 75% of diesel fuel consumption and released 59.2 tonneCO₂e yr⁻¹. The average vehicle fuel consumption for working and surveying vehicles, 1,910 and 1,318 l yr⁻¹, whilst the primary data showed the mean travel week⁻¹ for working and surveying vehicles was 205 km and 353 km, respectively. Highlighting the effectiveness of the smaller engine surveying vehicles.

Annual travel data was not available for all vehicles, however 3 surveying vehicles averaged 26,660 km vehicle⁻¹ yr⁻¹, compared to 6 working vehicles averaging 12,846 km vehicle⁻¹ yr⁻¹. The two large engine Iveco HGVs had comparable fuel efficiency to the 2400cc Land Rover Defender a, Ford – 350 and Iveco Daily 35C12 a. Individually, these 3 vehicles weigh approximately ¼ of the Iveco HGV and have less than ½ the engine power; therefore based on power to weight ratio, their fuel efficiency should be higher. The results showed, however, that their fuel consumption was comparable to the heavier, larger engine Iveco HGVs.

The Iveco HGVs have been restricted to 90 km/h (56 mph), which may explain the relative fuel efficiency. All vehicles under 7.5 tonne are legally limited to 112 km/h (70 mph), or 96 km/h (60 mph) if towing (Directgov, 2012). Therefore the Land Rover, Ford – 350 and Iveco Daily can travel up to 112 km/h, which can significantly increase fuel consumption. A study carried out by Everglade Services (n.d.) demonstrated that reducing the speed of a Ford Transit 350 from 112 km/h to 96 km/h reduced fuel consumption by 17.8%. This reduction in fuel consumption may explain the relatively low fuel consumption associated with the speed restricted Iveco vehicles.

Vehicle Recommendations: The amount of CO₂ released into the atmosphere by vehicles is directly linked to fuel use. The use of speed restrictors is an accepted method for reducing fuel consumption and is highly recommended. The restriction of speed lowers the consumption of fuel and prolongs the life of vehicle engines, tyres and breaks, therefore it is estimated that speed limiters can produce a 10% to 15% cost reduction when limiting speeds to 96 km/h (Bishop, 2008). Slower vehicles (if driven appropriately) may promote a better company image and cause fewer crashes and accidents (Bishop, 2008). A survey of 3,244 drivers using speed limiters showed that 76% of users agreed it had reduced fuel consumption (18% neutral) and 84% stated that it did not affect delivery time (16% neutral) (Bishop, 2008) .

There is no generic formula available to calculate the potential fuel saving by installing speed restrictors, due to the myriad of variables ranging from vehicle type, engine size, type of use (e.g. freight, urban etc.) and driver behaviour. As an indication, applying 17.8% fuel saving to the DTE working vehicles gives a reduction of 3,399 l yr⁻¹ and 10.6 tonneCO₂e yr⁻¹.

Driver behaviour is also an important factor influencing fuel use. Driver training courses are available, endorsing at least a 5% reduction; saving 3.99 tonneCO₂e yr⁻¹.

5.2.2 Non-road diesel engines

The non-road diesel engines used 5,200 l of fuel, equating to 16.2 tonnesCO₂e yr⁻¹. Direct reduction options for chippers and stump grinders are limited as they are essential equipment, with little scope for changing methods or type of equipment. Until advances in technology provide more efficient engines, they must continue to be used.

5.2.3 Two-stroke equipment

The annual use of petrol by two-stroke equipment showed a slight decline in consumption from February to May, which could be indicative of a reduction in work due to spring leaf flourish. The data showed an annual petrol use of 1,923.2 l, a small volume in comparison to the large engine equipment; the primary data indicated that this is due to the low fuel consumption per hour.

Two-stroke Equipment Recommendations: For speed and reduced human effort in arboriculture, high-powered tools are necessary for cutting wood, due to its high density. Two-stroke engines fulfil the criteria for arboricultural work of; a lightweight body, the capability of use at any angle, high Bhp and relative torques, durability (Ålander et al., 2005), ease of maintenance and an abundant source of energy. Small non-fossil fuel powered equipment is being

produced, however, at present they lack the power and longevity needed to carry out many labour intensive arboricultural tasks.

Advances in 2-stroke engines have been made, including modifications that provide an extra insertion of clean air into the piston to reduce scavenging loss. Chainsaws with this technology are reported to provide a 20% fuel reduction (Stihl, n.d.). When choosing new equipment the use of LCA can be advantageous in minimising the indirect GHG emissions released through the production process; as two similar products from different makes can vary in manufacturing methods.

However, at present the aim must be to promote practices that use less fuel. For example, promote the use of brooms to clear up chippings, and handsaws for deadwooding, thinning and pruning.

5.2.4 Energy Consumption

Energy consumption (mains electricity) contributed only 2% of the company's overall emissions.

Energy Consumption Recommendations: Electricity generation cannot be achieved on a small scale; however small woodfuel burners are available for installation. Throughout the DTE premises only the office is heated during the winter. Therefore a small log burner is suggested, replacing the electricity used for the radiators with renewable fuel.

There is a range of office based reductions available including: turning all equipment off overnight (24 kgCO₂ yr⁻¹ per employee); change from 100 watt light bulbs to energy saving bulbs (60 kgCO₂ yr⁻¹ per light bulb); recycling and office insulation. Most reductions in office energy use derive from change in behaviour, therefore educating office staff on the potential benefits both environmental and economic, whilst providing them with reduction guidelines

to assist will be the highly beneficial. The Carbon Trust provides tools and guides for employee education.

5.2.5 Employee Commute

The inclusion of the scope 3 employee commute contributes significantly to annual GHG emissions of DTE. The difference between the mean (55.8 km) and median (20.6 km) commute distances to DTE reflected a single employee commute of 695 km every 2 weeks. The mode showed that the majority of the employees commuted less than 10 km, however this does not accurately represent the average commute; if all 23 employees travelled 10 km to DTE on the 280 working days in the year then the total annual commute would be 64,400 km, which is less than half of the calculated total annual employee commute of 143,890 km. Using the same calculation for the median (20.6 km) shows the total annual employee commute to be 132,664 km, a more accurate representation. As this data set is not normally distributed the median is considered a more accurate representation of average employee commute, however the total GHG emissions include the outlying value.

Employee Commute Recommendations: A reduction in employee commute can be achieved by allowing employees to coordinate journeys straight to task location, pay or subsidise travel by public transport, and encourage and reward employees who use alternate methods of transport e.g. walk, cycle, carpooling and car sharing. Removing a single average annual commute of 6,256 km, by carpooling or sharing would save 1.3 tonnesCO₂e yr⁻¹. Estimating¹⁰ train and bus travel using the average annual commute would save 530.8 kgCO₂e and 941.3 kgCO₂e, respectively, compared to driving.

¹⁰ Estimation only as train and bus distance would vary from the average commute distance.

5.3 Annual GHG Emissions

The total annual CO₂e emissions for DTE in 2011 were 235.5 tonnes. This includes data from scopes 1 (direct GHG emissions from sources owned or controlled by the company), 2 (indirect GHG emissions from purchased heat and electricity) and 3 (other indirect emissions owned or controlled by other organisations), BS ISO 14064-1 (2006) describe including scope 3 emissions as optional, raising questions over the integrity of the standard, as the arisings contributed 42% of the GHG emissions.

A study by AXA (2008) provided information about 3 companies with annual CO₂e emission data: a marketing consultancy company in central London with 11 full-time staff - 14.42 tonnes; a medium-sized car dealership in Somerset employing 50 staff - 72.06 tonnes; and a risk management solutions company in Dorset employing 60 staff - 93.94 tonnes; while DTE employ 23 members of staff and emits 235.5 tonnes. The 3 companies in the AXA study have average emissions of 1.44 tonneCO₂e yr⁻¹employee⁻¹ compared with 10.24 tonneCO₂e yr⁻¹employee⁻¹ for DTE. These calculations show that DTE has both higher annual CO₂e output and higher CO₂e emissions per employee compared to the 3 companies.

The majority of GHG emissions from the 3 companies were from employee travel, recycling and energy usage (AXA, 2008), indicating that the project boundaries included only scope 1 and 2. DTE's annual GHG emissions from scope 1 and 2 was 106.5 tonneCO₂e yr⁻¹, equating to 4.63 tonneCO₂e yr⁻¹employee⁻¹.

Lantra (2011) stated there were 23,766 employees in the arboriculture industry; if this figure is multiplied by DTE CO₂e emissions per employee this equates to a potential industry total¹¹ of 243,343 tonneCO₂e yr⁻¹. To make a comparison, the same number of employees (23,766) was multiplied by the 3 companies average CO₂e yr⁻¹ employee⁻¹ of 1.44, producing a total of 34,205 tonneCO₂e yr⁻¹.

¹¹ Making the assumption that their respective businesses function in a similar fashion.

This suggests that the arboriculture industry has the potential to have 7 times more GHG emissions than service businesses similar to those mentioned above. This figure is based on the assumption that other businesses without a reliance on fossil fuels have similar emission levels.

In 2011 DTE provided 718 tonnes of woodchips to a renewable energy electricity generation plant; the woodchips replacing use of coal in the generation process. Using formula discussed in the methodology it was calculated that the use of woodchips substituted 425 tonnes of coal, which would have released 1062 tonnes of fossil CO₂e. Therefore, providing what many arborists call 'waste' to be used for renewable energy prevented the release of substantially more CO₂e than was released by the company in production of arisings. This novel perspective is more comprehensible when the arboriculture industry is viewed as farmers of energy crops. If this view is adopted, it is possible to show that management of trees (energy crops) in 2011, released 235.5 tonnesCO₂e but that 1062 tonnesCO₂e emissions were avoided (offset), equating to a total emissions saving of 825.5 tonneCO₂e and as a result, DTE may be considered carbon positive.

During the experimental period it was noted that not all arisings were chipped and removed for electricity generation; the unprocessed biomass was used in local micro-generators, processed for logs and unusable arisings sent to landfill¹². If all available biomass were chipped for use in electricity generation the saving in coal emissions would equate to 2380 tonneCO₂e.

A study by Confor (2010), predicted that 'Demand for wood fibre will increase dramatically in Britain in the next 15 years'. The prediction is made due to financial incentives provided by government (renewable obligation certificates) to encourage a

¹² It should be noted that the unwanted arisings were not recorded, however their contribution on a daily basis is minimal; deriving only from unwanted stump grindings and biomass that is mixed with unsuitable chipping material e.g. gravel.)

move to renewable energy, instigating plans for wood energy plants (Confor, 2010). The study acknowledged that the contribution of arboricultural arisings is relatively small compared to the potential demand. However McKay (2006) showed that use of Britain's forests cover per capita is too low to meet predicted woodfuel demands. To do so would require changing the composition of forests, unbalancing natural ecosystems, or importing woodfuel. Therefore to support global GHG reductions all available resources requiring no substantial changes to ecosystems in Britain should be utilised. McKay (2006) highlighted these sources as arboricultural arisings, branch and small diameter stem by-products from forestry and waste from saw conversion products.

Summary of Key Recommendations

Sector	Recommendation	Criteria	Min tonne CO ₂ e	Max tonne CO ₂ e
Vehicles	Online estimating system	Remove 1 survey vehicle and 1 commuting employee.	4.5	
	Routing and scheduling software	10-20% reduction in all diesel fuel.	7.99	15.98
	Speed limiters	Applied to all working vehicles - 17.8% fuel saving	10.6	
	Driver training	5% fuel saving.	3.99	
	GPS	Reduces time in traffic – saves fuel and time		
	Second base	Increase working area while decreasing fuel use		
Employee commute	Carpooling	13% or 22% employees carpooling (3 or 5 employees)	2.6	6.5
Potential annual CO₂e Emissions reduction			29.68	41.49

Table 5: Recommendations that are considered to have the highest impact on GHG emissions.

The recommendations provided are mostly based on a reassessment of current working practices, based on areas highlighted by the results. The recommendations describe potential GHG emissions reduction of 12.6 and 18% from the total annual emissions, 235.50 tonnesCO₂e.

An important recommendation is to gain employee cooperation, as ultimately the fossil fuel based vehicles and machinery are at their disposal. It will require more than education of the environmental and economic benefits for employees to change their working practices, not only because established methods are usually at near optimum efficiency for well established companies but also because some alternatives may require more effort, and may therefore not come naturally.

6 Conclusions:

The quantification of GHG emissions established that the case study company produced substantially more CO₂e emissions in comparison to the companies discussed. The optional inclusion of scope 3 boundaries attributed 134.34 tonnesCO₂e yr⁻¹, however excluding this still provides 4.63 tonnesCO₂e employee⁻¹ yr⁻¹, compared to emissions from the companies discussed, 1.44 tonnesCO₂e employee⁻¹ yr⁻¹. Based on this data arboriculture releases more GHGs per employee than companies without such high fossil fuel dependency.

An economically viable arboriculture company relies on fossil fuel based equipment to replace time and labour intensive manual processes. It is therefore in the nature of the industry to utilise equipment powered by fossil fuels. The use of such equipment will continue until technological advances arise that supersede current attempts at utilising alternative renewable energy sources.

The reduction recommendations stated in the discussion are therefore based on changing company procedures and utilising existing fuel efficiency technology. The recommendations are considered economically and practically applicable, enabling the company to apply recommendations without significant financial outlay. I.e. there is no insistence that the vehicle fleet be replaced with fuel-efficient vehicles. This was important; to illustrate that a reduction in GHG emissions can be achieved at a level of low cost, high impact and subsequent reduction in operating costs in the long term.

BS ISO 14064 (2006) provided guidelines on assessment of current GHG emissions at company level, yet, there are no standards available regarding the *reduction* in GHG emissions. The government provides guidance on a range of generic GHG savings, however the information is mostly behavioural based, restricting its' potential effect. Reductions in direct emissions require processes optimisation and methods of work to be reassessed. If the international standards were sector focussed

then the GHG assessment could be applied to respective industries with relative ease and industry specific reduction recommendations could be developed.

This study has shown that company specific reduction methods are possible, which may be applicable to many companies within arboriculture that use heavy-duty or surveying vehicles and collect woodchips or arisings. These aspects of arboriculture are essential, therefore the recommendations could be applied throughout the industry.

The accuracy of primary (see appendix 2) data has suggested that the acquisition of annual secondary data may not be necessary for assessment of GHG emissions. This would allow companies to use these methods for GHG quantification and reductions, initiating an industry specific set of guidelines. The benefits of industry specific guidelines would be the availability of established data collection methods and recommendations, making GHG quantification and reduction a more manageable task. Industry guidelines could also determine the project boundaries of the assessment, allowing for accurate comparisons between companies.

Assessment of the company's use of arisings indicated that a proportion of it was used for electricity generation, offsetting GHG emissions from coal. Studies have shown that demand for renewable woodfuel is rising, both in the domestic and commercial sector (Confor, 2010; BioRegional Development Group, 2008). The UK's low forest cover ($0.05 \text{ ha capita}^{-1}$) requires utilisation of all biofuel available to meet demand. McKay (2006) highlighted arboricultural arisings as being the largest resource of wood residue available in England, and stating that 100% of the resource could be used without detrimental effect to UK ecosystems.

Arboriculture is the maintenance of trees in an urban environment; urban areas consume large amounts of energy and trees are a source of renewable energy. Most arboriculture companies are located near towns and cities due to the proximity of potential operations; this potentially places 4,548 arboriculture companies (Lantra,

2011) near future/current consumers of renewable energy. This would allow many companies to supply their respective local towns and cities with renewable fuel. Utilising arboricultural arisings as local woodfuel would reduce GHG emissions from domestic energy consumption and create a stable market for the arboriculture industry to profit from.

The information in this study has the potential to readdress the connotations associated with fossil fuel use in arboriculture. The application of the term 'farmers of energy crops' may initiate a reassessment of the function of tree maintenance. Moreover, the project demonstrates the potential for GHG emission and cost reduction on a well-established, optimised and fossil fuel intensive organisation.

7 Limitations and Further Research

The primary data was collected over 2 weeks while the company was active, with the employees carefully collecting most of the daily data. The employees' contribution over the data collection period was invaluable, enabling data collection to be carried out in multiple locations, simultaneously.

The chippers were utilised for appropriate tasks i.e. large chippers were used for tasks involving large volumes of wood. This meant that chippers were used with a combination of vehicles. The arising data was specific to each vehicle, therefore arising and chipper data could not be linked, making 'chipper productivity' (woodchips hr^{-1}) data not possible to attain. This could be addressed by labeling the chippers; the employee would write the identification number of the chipper on the vehicle form, daily. The addition of too many daily tasks, however, would increase the risk of employees overlooking other tasks; some data collection procedures were avoided due to this.

The two-week data collection provided comparable data to the secondary data, indicating the period successfully represented the annual data (see appendix 2). This 2-week duration was deemed adequate for the collection of vehicle km, arisings and non-road diesel engines. The working area data collected over the 2 weeks did not accurately represent the entire working area due to vehicles returning to the same location several times. The primary data was not collected over a longer period as the employees were asked to carefully collect much of the daily data; prolonging this process may have created a decline in data quality. A potential solution would be to collect the company area data using secondary methods, as the information for recommendations needs to be indicative of the working area over the year, not the two weeks.

It has been suggested that the maintenance of a tree prolongs its' lifespan; increasing the trees' capacity for sequestering carbon. A study by EIA (1998) stated that a 30 year hardwood with moderate growth speed sequesters $16.6 \text{ kgCO}_2 \text{ yr}^{-1}$ in an urban environment. If tree reduction (reducing overall tree canopy size) maintenance was carried out in 2 year intervals, the tree would sequester 33.2 kgCO_2 . The CO_2 emitted from fossil fuel used to maintain the tree may equate to carbon sequestration by the tree. There is, however, little information on the relationship between CO_2 exchange in trees and CO_2 release through fossil fuel intensive arboricultural management (Nowak et al., 2002). The effect maintenance has on the lifespan of a tree is under researched, allowing only for speculation.

8 Appendices

8.1 Appendix 1

Vehicle form

DOWN TO CO₂

Vehicle form							
Vehicle REG:							
	Job Ref:			Milometer reading:			% of body full
	Job: 1	2	3				
Example:	P 123	P 123	P 123				80%
Date:							
Monday 12th							
Tuesday 13th							
Wednesday 14th							
Thursday 15th							
Friday 16th							
Monday 19th							
Tuesday 20th							
Wednesday 21st							
Thursday 22nd							
Friday 23rd							

What to do:

Each morning before leaving the yard you will need to:

1. Fill in the **milometer** and **job reference** on the vehicle form.
2. Fill in the **hour reading** and the **job reference** of the **1st** job of the day on the chipper form.
3. If used, fill in the hour meter and job reference on the stump grinder.

Before offloading the arisings:

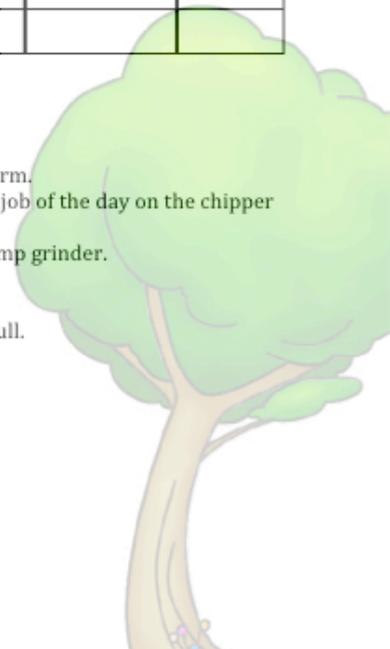
1. Crew leader should estimate the percentage of the body full.

Any problems or questions:

Contact Details:

Tom Luck: 07123456789

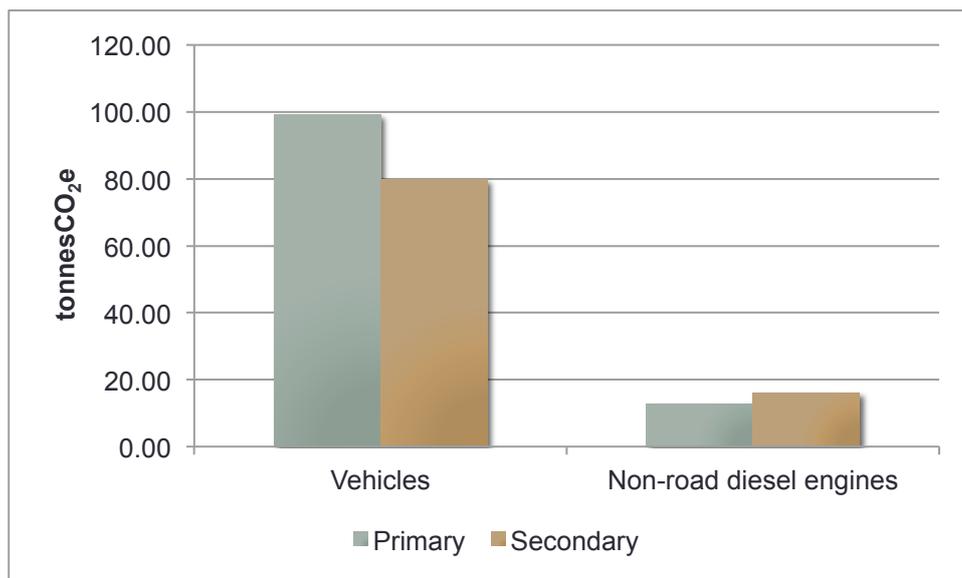
E-mail: tomluck4@gmail.com



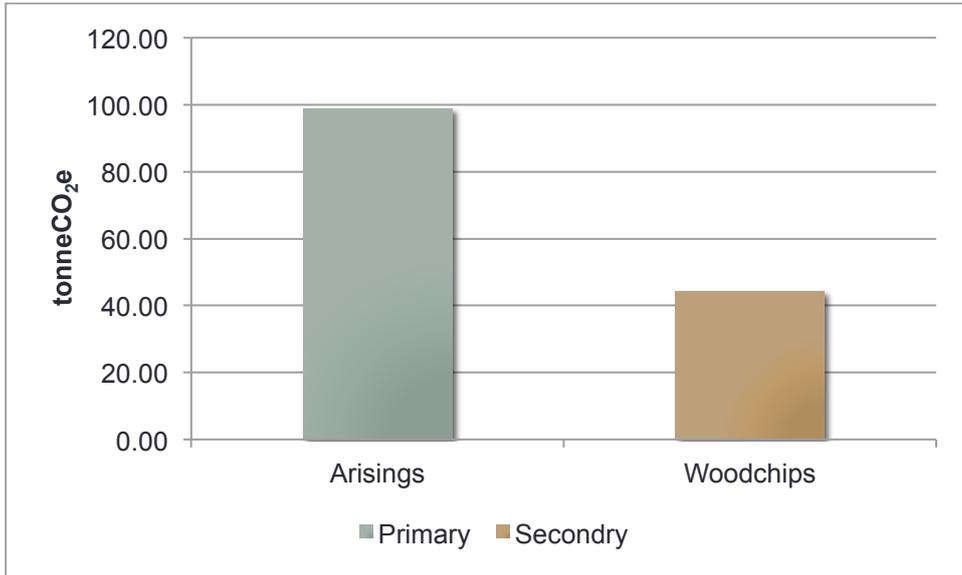
8.2 Appendix 2

Comparisons of primary and secondary data shows that the data collected over two weeks provided annual CO₂e emissions similar to the historical secondary data. This indicated that the data collected during the 2 week period was representative of the companies overall activities. It also shows that the methods if primary data collection described in section 3.6 may provide adequate data for GHG quantification. This allows GHG quantification to be applied to companies who do not have the benefit of historical fuel records.

The discrepancy between woodchips and arisings (appendices figure 2) may be a result of a high number of large-scale operations that took place over the 2-weeks, however, the primary and secondary results for the fossil fuels show the experimental period to consist of an average amount of work. Moreover, it would be unexpected for two weeks of operations to remove over twice the tonnage of arisings during work activities. As discussed, the difference between the two data sets is expected to be the amount of arisings that are unchipped.



Appendix figure 1: Primary and secondary data for vehicles and non-road diesel engines. All data is transformed to annual CO₂e emissions.



Appendix figure 2: Primary and secondary data for woodchips and arisings. All data is transformed to annual CO₂e emissions.

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