Department of Mechanical and Aerospace Engineering

Utilising a Travel Survey to Calculate Greenhouse Gas Emissions from Commuting at the University of Strathclyde

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A thesis submitted in partial fulfilment for the requirement of the degree

Master of Science

Sustainable Engineering: Renewable Energy Systems and the Environment

2014

Copyright Declaration

Signed: James Copeland Date: 05/09/2014

Abstract

Following the recognition of peak oil and anthropogenic climate change we face the challenge of reducing our energy consumption and greenhouse gas (GHG) emissions. This could be achieved through various energy efficiency and renewable energy technologies but it is also important to realise that the cheapest and most effective way to save energy is not to use it in the first place.

A very significant amount of energy is consumed as a result of the transportation of goods and people and this is an area where there is a lot of scope for reductions in GHG emissions. One way to identify and consequently realise these reductions is through carbon foot printing: recording, analysing, reporting and managing emissions.

This thesis examines and investigates methods of calculating Scope 3 GHG emissions from the transportation sector. In particular the rarely reported category of commuting emissions is investigated in the setting of a large city-centre organisation (the University of Strathclyde). A quantitative estimation for the GHG emissions from commuting has been calculated via a spreadsheet model. Commuting GHG emissions were estimated to be 6610 Tonnes CO_2 equivalent per year. This is potentially equivalent to ~5% of the total carbon footprint of the university. Using the model, a sensitivity analysis was performed to check the robustness of the methods used to attain this estimate. This calculation has been performed utilising data from a recent travel survey at the University as well as information regarding staff and student postcodes (Postcode Analysis). Potential emissions reductions have also been investigated by modelling various mode shifts and behavioural changes that could be possible. This is followed by discussion of the practicalities of implementation of these measures. It has been determined that there are significant potential emissions reductions through encouraging rail transport and reducing the amount of days staff and student attend the university.

Different methods and procedures for calculating transportation emissions have been compared and discussed, resulting in recommendations for further investigation in this area or for anybody wishing to perform their own analysis. Background research focuses on carbon inventory practises at University institutions and previous literature results are compared to what has been identified in this project.

Acknowledgements

I would like to thank my project supervisor and course director Dr Paul Strachan for guidance during this thesis. I would also like to thank Mr Dean Drobot, energy manager from University estates, for providing me with access to travel survey results and other information relevant to this thesis.

I would also like to thank all of the staff and students involved in the running and teaching of the Renewable Energy Systems and the Environment course at Strathclyde which I have very much enjoyed taking part in over the past year.

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1. Introduction

1.1. Reporting GHG Emissions

Following the recognition of peak oil and anthropogenic climate change, sections of society have shifted towards a more sustainably minded paradigm to try and avoid the potentially devastating problems caused by these issues. Evidence of this shift can be seen to include the advancement of cleaner and more efficient technologies alongside efforts to reduce the overall consumption of fossil fuels and other rare natural resources. The latter is most often promoted through decisions made by individuals, organisations and governments. There have been legal and advisory targets and restrictions set by agreements such as the Kyoto protocol which expired in 2012 and the Climate Change Act (UK only). The UK Government recently announced that under the Companies Act 2006 (Strategic and Directors' Reports) Regulations 2013, quoted companies are required to report their annual green house gas (GHG) emissions in their directors' report. (Carbon Trust, 2013) For one to actually know if improvements are being made and targets being met there is a need for quantitative measurement and analysis to be performed. GHGs responsible for radiative forcing are the key quantities used to measure and determine a "carbon footprint", the most common method used to quantify an accumulated effect on potential global warming being described as "carbon footprinting". The term is concisely summarised by Wiedmann (2009), "Carbon footprinting – an attempt to capture the full amount of greenhouse gas emissions that are directly and indirectly caused by an activity or are accumulated over the life stages of a product".

Throughout this report GHG emissions will be discussed in terms of "CO_2 equivalent" (CO_2e). This being the concentration of CO_2 that would cause the equivalent level of radiative forcing as a set type and concentration of greenhouse gases such as are methane, nitrous oxide and perfluorocarbons. These all have a greater effect on radiative forcing than CO_2 but are far less prevalent. See appendix table I for the global warming potential of various greenhouse gases. (UNFCCC 2007)

Carbon footprinting or carbon reporting is a vital step for companies/organisations to address creating reductions in GHG emissions. By recording and reporting missions it is possible for companies to set targets and enforce carbon management strategies to help reduce emissions in the future. The UK Department for Environment, Food and Rural Affairs (DEFRA) has estimated that reporting will contribute to avoiding four million tonnes of CO2e emissions by 2021. (Carbon Trust 2013)

Aside from regulatory and legal purposes there are other benefits organisations can gain from recording and reporting their carbon footprints. It can be beneficial for company credentials as stakeholders and customers are increasingly expecting organisations, both large and small, to report Scope 3 emissions. Reporting can also help organisations reorganize processes and in turn become more efficient.

There are guidelines for carbon reporting that have been set by the World Resource Institute (WRI) and WBCSD in the GHG Protocol (WRI and WBCSD, 2004). Reporting boundaries have been set and classified into three categories:

Scope 1 – Direct GHG emissions from onsite burning of fuels or chemical production. For example, gas for heating and fuel used in fleet vehicles.

Scope 2 – Indirect GHG emissions created from creation of purchased electricity. These emissions are physically located where the electricity is generated (if non-renewable).

Scope 3 (optional) – Other Indirect GHG emissions from a broad range of sources that result as a consequence of the company's activities. Examples are emissions from production of purchased or sold goods, transportation of services or commuting of staff.

Conventionally only Scope 1 and 2 emissions have been reported; this is partly due to the complications and wide boundaries involved in calculating Scope 3 emissions as well as actual legal requirements. More recently it is being recognised that carbon footprints are only robust if they incorporate all three scopes of emissions. (Matthews et al 2008) conclude that Scope 1 and Scope 2 only account for 26% of total supply chain emissions on average for all 491 economic sectors in the US. This obviously ignores a considerable part of the equation and because of this lack of knowledge organisations will not be able to carry out the most financially effective emission mitigation strategies. As organisations move to pursue emission inventory activities to set a baseline for their carbon footprints they tend to look to legal protocol for guidance on setting carbon reporting boundaries but these results show that this can lead to significant underestimation in footprint determination if they ignore Scope 3 emissions. Large sources of emissions generated across supply chains (and downstream) should be targeted first if they are the most significant. Setting very basic boundaries for carbon reporting can lead to misleading information regarding how “green” or eco-friendly an activity, product or service is. When a company or organisation make a claim about an aspect of their carbon footprint it should always be considered which Scopes or emissions are actually being subject to reporting.

1.2. Regulation / Law

The government advises that all “quoted” companies are required to report GHG emissions and should aim to measure and report on their significant Scope 3 emissions. (Carbon Trust, 2014)

As described by Defra: “If you have a simple organisational structure and own 100% of the assets that you operate, it is straight-forward: you would report on the impacts from everything that you own and operate.” (Defra boundary descriptions, 2013)

A JMP report describes that “Central government departments, executive agencies and the National Health Service are committed to reporting their scope 3 business travel emissions to Her Majesty’s Treasury from financial year (FY) 2011/12.” (JMP 2012) With regard to the private sector, the Carbon Disclosure Project (CDP) can give a helpful benchmark to review emissions reporting activities of UK and international companies against. (JMP 2012)

1.3. Transport Emissions

Within Scope 3 emissions Transport and Travel will normally contribute a large proportion. This can range from emissions from commuting and business travel to delivery of goods and services.

A document produced by the Scottish Government regarding GHG emissions states that in 2011 Transport emissions comprised just over a quarter (25.3% , 13Mt$C0_2$) of Scotland's total emissions. 72% of these emissions came from road transport while 40% came from specifically car transport (Low Carbon Scotland, 2013). This is a significant proportion and obviously an area where progress can be made towards realising the government's commitments in reducing emissions. For many different organisations transport can be a major source of emissions and costs but to manage these emissions they need to be measured in the first place and continuously afterwards. Transport was the largest emitting sector aside from energy production and from 1990 to 2011 emissions from transport did not reduce while many other sectors saw reductions. (Scottish Gov 2011) Average vehicle emissions per distance have fallen steadily as a result of improved engine efficiencies but these gains have been counteracted by increased car ownership and travel (Low Carbon Scotland 2013). It could be observed that the developed world has an obsession with the motor car and as economic conditions improve car ownership increases. Currently this phenomenon can be seen in the rising economies of China and India (Dargay and Gately, 1999). The most favoured form of domestic passenger transport is also the most polluting and (Mackett, 2000) reported that a quarter of all car journeys made in the UK were less than two miles in distance and this is generally a walkable distance. This is clearly not appropriate and action is required; research supports that transport solutions should be related to car dependence and the roots behind this. This could involve more focus on land-use changes and broader trends such as teleworking and other lifestyle effects. (Anable and Boardman, 2005) The above information indicates that reducing transport emissions requires action in the form of behavioural change (societal adaption) alongside technological innovation, especially in the short term. (Anable and Boardman, 2005) conclude that policies to effect behaviour change and change travel habits were as important if not more important than technological solutions when addressing transport emissions. A large-scale commercial deployment of electric vehicles it far from being realised, in 2012 electric vehicles made up only

0.14% of car and van sales globally (Cluzel 2013). The necessary short term behavioural adaptions required to reduce emissions should be driven on a large scale through policy change and investment.

The Scottish Government has proposed four decarbonisation activities to reduce emissions from transport:

1) Decarbonising vehicles;
2) Road network efficiencies;
3) Sustainable communities;
4) Business engagement around sustainable transport.

(Chapman 2007) discusses the tendency of academia to focus on long-term technological solutions when short-term behavioural change is crucial to achieving emissions reductions that are required in the transport sector. On this note, this thesis will predominantly concern efforts in the fourth category, in line with the addressing some of the issues previously mentioned. This will be investigated in the setting of a University institution, particularly the University of Strathclyde situated in the city centre of Glasgow.

Measuring and assessing a Transport carbon footprint can reveal valuable management information on travel patterns and traveller behaviour. This information can then be a key contributor to informing travel policies and methods of procurement. There is a wide range of positive effects that can result from measuring and reporting Scope 3 Transport emissions at an organisation such as a University:

1) Potential to save money alongside carbon reductions. This can be directly from fuel costs or otherwise.

2) Deepen understanding of underlying demand for transport – address safety issues.

3) Promote alternative methods of employment (mobile working).

4) Improve procurement and management of travel.

5) Promote active travel and in turn individual health and wellbeing.

6) Improve intra organisational communication and engagement in carbon reducing actions.

7) Organisations credentials and image – Increase corporate responsibility.

(JMP 2011)

A Defra sponsored study demonstrated that environmental management systems generally delivered cost savings and new business trades for the majority of the study's small and medium sized enterprises. (Hillary and Burr, 2011) After measuring Scope 3 emissions it is typical to discover that distribution and logistics emissions are particularly high. Relevant personnel can then work with suppliers to find more efficient routes, or select new suppliers based on efficiency

1.4. Commuting

It has been determined that 10% of total emissions in Scotland have been attributed to originating from car transport (Low Carbon Scotland, 2013) and commuting activities are a regular and frequent contributor to this statistic. The purpose of commuting is often even a driving factor behind car ownership so it is logical that commuting will contribute a significant amount to GHG emissions. These commuting emissions have been shown in several studies to be up to around 20% of total organisational emissions. (Klein Banai 2008) (Scottish Environment LINK, 2013)

This thesis will focus on attempting to estimate emissions from commuting, an area shown to be significant regarding overall emissions and one which has not been traditionally addressed at organisations. This is also an aspect of transport at Strathclyde where there is availability of interesting activity data in the form of travel survey results and distances commuted. The University of Strathclyde is now located in one densely built / compact area and this makes it a location where all staff and student will be commuting to more or less the same destination, meaning that the institution can be treated as one location.

An obvious and simple method to reduce emissions is modal shift towards public transport systems as well as zero emitting (at point of use) modes such as walking and cycling. Potential mode shifts for commuting at Strathclyde and their effects on emissions will be quantitatively analysed in this report. Strategies to encourage these modal shifts will also be discussed.

1.5. Universities

Universities are generally large institutions with many employees and even more students. Naturally organisations of this size will have a considerable carbon footprint which can potentially be reduced through actions following monitoring and reporting. A report (Zhang 2009) compared 12 studies of Universities GHG emissions and the average was determined to be 7.39 Tonnes CO_2 e per member of the community per year. It could be argued that as institutions of learning, development and innovation universities should strive to lead in the field of carbon reporting and demonstrate best practice in terms of boundaries set and robustness of methodology used. To do so requires a structure in place to source high quality scope 3 travel data and carry out the following necessary analysis. This thesis will look at the monitoring procedure (facilities) in place at the University of Strathclyde and provide suggestions for future improvements

2. Literature Review

This section will continue to review and discuss recent research in conducting transport related GHG inventories, with particular respect to the category of commuting. Although Scope 3 –Transport emissions are not generally reported several authors have explored methods to try and quantitatively estimate the commuting emissions at various organisations. Methods used and to what extent assumptions are made tend to depend on what level of data is available. There are several general tools available to help calculate carbon footprints at institutes but the comprehensive nature of the inventories used means that the transportation sector is aggregated and little depth is given to specifically capturing commuting aspects. Emissions inventories are constructed at various scales with the scopes covered and methods used varying greatly as has been discussed previously. The following studies demonstrate this:

Butazzoni and Zyla 2003, attempt to calculate transport emissions and discuss the challenges faced in the transport section of an emissions inventory. Alongside owned fleet emissions and business travel they unusually also considered scope 3 emissions from commuting at Yale University (Butazzoni 2003). Travel emissions were estimated utilising various data such as vehicle mileage, monetary expenditure and personnel data. This data was sourced from various record keeping departments at the university. Emissions were then calculated utilising external parameters such as km travelled per cost. Data regarding business travel is mostly travel expenditure based so emissions are calculated through various assumptions and generalisations.

To try and quantify the commuting emissions at Yale University they used simulation and uncertainty analysis tools. Postcode data was analysed for residences of staff and students. Emissions were then determined using the postcodes to calculate distance travelled, assuming mode of transport depended on the scale of these distances. Where distances appeared implausible they were replaced with an undisclosed “assumed” address. Working patterns and attendance were also assumed depending on the distance from the University. These assumptions bring uncertainties in various stages of the calculation and the more assumptions made the higher the uncertainty is in the final quantification.

The authors come to several conclusions and provide some strategies to increase the quality of commuting emissions estimations. This includes the need for consistent travel study templates with ascertaining standard travel questions and formats for reporting, specific to organisation type. This would capture organisation specific behavioural data and reduce uncertainties in emissions calculations due to assumptions. Regarding Postcode data it would be beneficial to have as precise and current data on employee and student term time residences. Vehicle-specific data should be obtained; this could be via parking department, permit allocator or questions in travel survey.

They also highlighted the need for availability of accurate general data on transportation and commuting behaviour on a more local level such as local averages for vehicle occupancy and modes of transport taken. Following the various calculations they determined commuting to make up 7.15% (21,015 T CO2e) of all Yale emissions, with most of these emissions stemming from staff commuting due to the majority of students residing on campus. It should be noted that this was with large uncertainties of up to +297%/-69% in the case of student commuting category.

An NHS England study undertaken attributed 4% of all emissions to staff commuting; this is still a significant amount considering the scale of energy being consumed at sites such as hospitals. Transport in total was determined to contribute 18% of all emissions, again highlighting the considerable portion of GHG’s emitted due to Transport (NHS 2008).

One method to capture (large scale) transport behaviour and modes is through the distribution and review of travel/commuting surveys, this is done at many institutions and organisations but detailed emissions analysis and calculations are mostly excluded. The University of Leicester completed a Staff Commuting transport-related carbon emissions analysis, (UoL, 2010). They used results of a travel survey to determine the commuting emissions of staff at the University. Figures for the total population were calculated by factoring up results, assuming the same mode split for surveys unreturned. Average distances travelled by each mode were used for this upscaling also. Some worst case scenarios were assumed throughout analysis to maintain robustness of results. To quantify emissions the latest conversion factors from Defra were used. Values for CO_2 equivalent were used to take into account all GHG’s. When not known conversion factors for average vehicle size with average fuel type was assumed. For 3541 staff the authors estimated the CO2e emissions to be 3870.78 T per year, this is roughly 1.09 T per member of staff per year. Worth mentioning is the finding that 80% of these emissions were deemed to be sourced from single occupancy vehicles, an area often highlighted in emissions inventories.

The University of Illinois also conducted an investigation into commuting emissions as part of a bigger GHG inventory project (Klein Banai et al 2008). They used data from a travel survey as a basis for their analysis and determined that 16% of total emissions from the University were from commuting. Like other studies the results from the survey were then up scaled to represent the whole population. Emissions factors used were attained from the “Carbon Campus Calculator” - a general tool available for emissions calculations. The survey also showed that reductions car parking permits from previous years are very probably due to the introduction of a free public transport pass. This study highlights the facility of a travel survey to allow emissions calculation s as well as to inform decision makers about the reasons behind certain patterns or shifts.

A study in Montreal took a more complex approach to quantifying commuting emissions following a travel survey from McGill University (Mathez et al. 2012). Their approach was to propose and develop a methodology to calculate emissions which would also allow them to identify the specific origins and causes of emissions so the largest sources of pollution could be identified. The authors also took seasonality into account. They then go on to discuss the value of the information discovered in the context of policy and strategy to promote emissions reductions. The study was heavily primarily based upon results from a travel survey conducted as well as analysis using GIS software. GIS was used to determine the distances commuted. As with the study at Leicester the results from the respondents were expanded to represent the entire University population, with some alterations made giving weightings depending on the correspondence of respondents addresses to total population postcodes that were on record. The project highlights the fact that staff are responsible for significantly more emissions per person than students and the fact that emissions are higher in the colder seasons when active travel is reduced. It is also concluded that flexible working can contribute notably to emissions reductions.

Limitations of the Mcgill study discussed include the uncertainties involved in attributing emissions per distance travelled due to unknown speeds and acceleration/

deceleration patterns. The aspect of seasonality variation was investigated in little depth and this is expected to have an effect in a location such as Montreal. These limitations will affect overall GHG emissions determined but should not detract from general conclusions reached regarding key study findings.

An Edinburgh University a footprinting study into the Universities “community” footprint was conducted. This study included emissions for the three main categories of “Energy”, “Travel” and “Goods and Services”. This footprint related to energy and goods consumed in the Students own residences and did not include Scope 1 emissions from university buildings. This is because the footprinting study considered the university community rather than the institution. Transport was shown to make up almost a quarter of the total community carbon footprint, with the largest proportion of this originating from “personal and leisure” travel. However this derivation is limited by the fact that data for travel emissions was based on national averages. As far as commuting is concerned the Edinburgh University Travel Survey 2007 estimated emissions from staff and student commuting to be 0.07 tonnes CO2e per student and 0.41 tonnes per staff per year, most of this originating from cars and trains. This commuting value seems quite low compared to other University study results and could be due to the central location Edinburgh University and density of student population. Again as found in other studies staff had a much higher travel footprint compared to students as would probably be expected because of the close proximity to the University of much of the popular Student areas for accommodation.

JMP Consultants have provided a report to The Higher Education Funding Council for England as a guide regarding the measuring of Scope 3 Transport GHG emissions (JMP 2012). Their key findings include: HEI’s are not generally reporting scope 3 travel emissions and if they are it is often from different starting points and with different levels of effort. To lead by example HEI’s need to source high quality data and determine emissions in an efficient and effective manner, however they should be wary of rushing into increasing their reporting boundaries when there is not the necessary structure in place do so properly. This could present the risk of strategic decisions being made due to incomplete or poor quality reporting outputs.

Specific to Commuting travel JMP recommended that although it was optional every effort should be made to report these emissions and Staff and Student categories should be reported and calculated separately. They advise that this category will be the most challenging to capture but stress that the significance of commuter travel should not be underestimated and its inclusion in reporting would display leadership to the public and private sectors.

From these various studies we can see that what is included and not included in Transport emissions inventories greatly varies and there is no “accepted norm”. Emissions omitted or included in reports often depend on what data is available but boundaries chosen sometimes depend on “authors” of the report and what they decide is relevant or necessary for their purposes. This obviously shows a need for national or international guidelines for a monitoring and reporting framework/structure.

3. Objectives Summarised

This report examines and investigates methods of calculating Scope 3 Green House Gas (GHG) emissions from the Transport sector, particularly those as a result of large amounts of people commuting to a specific location. Following a literature review it is apparent that commuting contributes to a significant proportion of overall emissions and this is an area that is rarely reported on potentially due to lack of any standard guidelines and recommended methodologies or benchmarks. This research will focus on carbon inventory practice at University institutions. The main objectives of this thesis are as follows:

1) To complete a specific analysis and estimation of commuting emissions at the University of Strathclyde using data that is available from a recent travel survey and Postcode analysis.
2) Potential commuting emissions reductions will then be investigated alongside testing the robustness of the methods used to calculate these emissions.
3) Discussion and suggestions will be provided on the effectiveness of travel surveys as a method to capture carbon emissions.

4. Methodology

4.1. Transport Categories and Data Sources

For overall reporting the University of Strathclyde should consider all travel and or transport caused by the presence of the institution. Work-related travel covers staff (and students) travelling to and from their job (the commute) and staff travelling during the course of the working day (business travel).

Transport emissions at Strathclyde (or any organisation) could be split into the following 3/4 categories.

Owned Vehicle Emissions – Scope 1:

This category consists of the emissions from Strathclyde owned and operated vehicles including estate vehicles, department fleet etc. Records should exist of fuel purchased for these vehicles and at Strathclyde and I was able to access a record of expenditure on the motor vehicle fleet. This data used with relevant conversion factors could be projected to a quantitative value for emissions, making assumptions about vehicle and fuel type.

Work related emissions – Scope 3:

Trips taken for work related purposes out with organisation owned vehicles. It should be noted here that Strathclyde University does not always have any direct control over transport mode selected but nonetheless can have an influence. This includes department trips to conferences and travel for research purposes. Normally such travel will be paid for by the University and hence tracked in some kind of system. Trips paid for by other institutions would be classified under their own Scope 3 emissions.

Staff and Student Commuting – Scope 3:

This travel covers staff and students commuting to Strathclyde University from their residences. These modes are determined by choice of the individual but are counted under the footprint of Strathclyde University as the organisation is undeniably at the root of the cause for transport. This category could also include trips home made by students from term time residences and has done so by other studies. Data available to me at Strathclyde regarding this category includes generalised results from a transport survey at the University and postcodes for staff and student residences. Postcode information indicates where people are commuting from on an average day.

Contracted vehicles:

This would include vehicles leased (not owned by Strathclyde University) for class trips, sports teams, campus shuttle buses etc. This is a hard area to capture as there is little relevant data available and it could be presumed that emissions from delivery of products/services are classified under other companies "Scope 1" emissions.

The main source of data for my analysis was a travel survey conducted at the University of Strathclyde between 20th March and 11th May 2014. Discussion and analysis of any assumptions made will be covered later in this report. See on page 27 for a list of assumptions made to calculate the base case scenario.

The summary of responses to the survey give an accurate account of the "usual main" mode of travel used to commute and of distance travelled within specific ranges, with varying uncertainties. The response summary that I had access to only contained data for distance ranges rather than exact distances, for example distance travelled within a quoted range such as "1-2 mile" or "20 + miles". For base case analysis the median of the given range was taken as the distance commuted but the effects of using the minimum and maximum extremes will be explored and discussed later (assumption 4).

Emissions calculated for the purposes of this thesis will regard direct emissions only. This means that emissions factors used will only consider emissions at point of use, ignoring upstream or downstream emissions in a vehicles lifecycle. Therefore transport modes of walking and cycling can be considered "zero carbon" modes. Technically this is not true as active travellers need to consume more calories or ride a bike produced in a carbon intensive factory but it can be assumed that food displacement is negligible and commuters would own these bicycles regardless of the presence of the University. The same argument stands for carbon emitting vehicles.

4.2. To Calculate Distance Commuted Per Day

Method 1

Total distance travelled by all staff and student respondents per commute was calculated for a day of full attendance. This was done by taking the number of staff/students travelling within a specific distance range and multiplying with the median of that range. These products for all ranges were all summed to give total distance travelled per commute. For the purposes of calculating GHG emissions we are only interested in distances travelled by modes that create emissions i.e. not bicycle or walking. To take this into account it was assumed that respondents travelling by foot or bicycle would be commuting distances in the lower ranges (assumption 2). This meant that for emissions calculations all staff respondents from the 0-1 and 1-2 mile ranges and 2% from the 2-4 mile range were omitted (because 6% of staff cycle or walk so this amount had to be omitted from distance responses). From the student respondents 40% cycle or walk so all journeys (26%) from the 0-1 mile range and 14% from the 1-2 mile commute range were omitted (26% + 14% = 40%) .

To take weekly attendance into account the total emission creating distance travelled per commute of full attendance ($D_{emissions\ FA}$) was multiplied by the attendance factor for each individual day and summed up for a week and multiplied by a factor of two. For example:

Emission creating distance travelled per week by staff, ($D_{emiisions\ week}$)

$$\begin{aligned} D_{emissons\ week} = {} & (0.93 \times D_{emissions\ FA}) + (0.95 \times D_{emissions\ FA}) \\ & + (0.94 \times D_{emissions\ FA}) + (0.93 \times D_{emissions\ FA}) \\ & + (0.87 \times D_{emissions\ FA}) + (0.4 \times D_{emissions\ FA}) \\ & + (0 \times D_{emissions\ FA}) \times 2 \end{aligned}$$

Here the factor of 2 takes into account the two commutes per day.

Method 2

Another method to arrive at the same result is:

Emission creating distance travelled per week by staff, ($D_{emiisions\ week}$)

$$(D_{emission\ week}) = \text{Average Distance per Commute} \times \text{Total commutes per week} \times 0.85$$

Here the factor 0.85 takes into account the 15% cycling and walking staff commuters who do not create direct emissions and the "Total commutes per week" takes into account attendance. The Average Distance per Journey is calculated by:

$$\text{Average Distance per Personal Commute} = \frac{D_{\ emissions\ FA}}{\text{No. of Emission creating commuters}}$$

The same methodology was followed for Student response values.

Method 3 – Postcode Analysis

This method uses post code analysis rather than information from the travel survey regarding distances commuted to work. A list of Student and Staff postcodes of residence were attained from the HR department and analysed. Using an online tool called "Batch Geocoder & Converter", (Mapsdata) all the postcodes were converted to co-ordinates and Easting and Northing quantities. This data was then entered to excel and the shortest distance between them calculated using the Haversine Formula. This model approximates the Earth as a perfect sphere but for the relatively small distances in question gives acceptable accurateness for the purpose. The co-ordinates output by the internet programme were compared against Google Earth co-ordinates and were identical to 4 significant figures for ten post codes checked, this was seen to validate the tool.

Many postcodes were a large distance from the University and this will be due to Students and Staff having their second or "non term time" residences registered as their details. Some of these locations were as far as Lerwick, Aberdeen and various areas in England. It was deemed very unlikely that a person regularly commutes over 50miles/80.5km so commutes of over this distance were removed from the set and these values replaced with the average of the remaining commutes. The assumption here is that these people during term stay in a closer location to the University. This assumption was also analysed in sensitivity analysis. Obviously journeys are rarely in a direct line and this was taken into account in the calculation analysis, multiplying by factors increasing total distance by 20%. For random postcodes the same journey was entered into google maps to see how the direct distance varied from the route-distance a car or bus would take have to take.

So from the postcode analysis there is a value attained for total distance commuted on a full attendance day. This figure can then be altered for attendance and split between various modes as described later

4.3. To calculate GHG emissions per mode per year

To attain an emissions value for one year it has been assumed that Students would attend university for 32 weeks in a year and staff for 45 weeks in a year.

To calculate emissions for a given time period, the basic general equation is:

$$\text{Emissions (kg)} = \text{Activity data (km or litres or £)} \times \text{Conversion Factor} \left(\frac{\text{kgCO}_2\text{ e}}{\text{km travelled or litre fuel consumed or £}} \right)$$

In this case using the data available and standardised conversion factors from (DEFRA 2013) guidelines, the activity data is distance travelled per year and the conversion factor in the form of kg CO_2e per km/mile travelled.

From the data available to me I only had information on the % of respondents taking a particular mode of travel and the % of respondents travelling in a distance range. I did not have any information regarding which modes of transport corresponded to which distances travelled. This leads to assumption that after walking and cycling modes have been accounted for, the rest of the calculated distance travelled will be spread equally between the other modes. These modes are single occupancy car, passenger in car, car driver, bus, subway and train. For example, if 13% journeys are taken by train then 13% of total distance (minus walking and cycling distance) travelled will be by train.

Using this logic and the relevant UK Government conversion factors for Company Reporting, (Defra and DECC 2014), emissions per mode have been calculated through the following steps:

$$\text{Distance travelled per mode per week } (D_{/\text{mode}/\text{ week}}) = D_{\text{emissions week}} \times \text{Proportion of respondents travelling by that Mode}$$

Note that the proportions of respondents used here are not the same as from original survey results. We need to take into account that walking and cycling modes have been omitted so the remaining distances are completed by a smaller set of people. Ratios need to be adjusted so as all the respondents travelling by the remaining modes makes up 100% of the new set.

$$\text{Emisions } CO_2 \text{ e per year per mode} = D_{/\text{mode}/\text{ week}} \times \text{Conversion Factor} \times \text{No. Weeks Commuted}$$

Conversion factors used for multiple occupancy car modes were divided by a factor depending on scenario chosen. For a conservative estimate the default was taken to be that all multiple occupancy commutes have two people in the car in total.

Finally the results needed to be up scaled for the full university population, the sample size of respondents is large enough for this to be statistically representative to a level shown in table 2.

Final output per mode expressed in form of tonnes of $C0_2$ e, this corresponds to the conversion factors used and conventional yearly reporting. See table 1 below for the conversion factors used for calculations and the following sensitivity analysis performed. For more detailed conversion factors see appendix II.

Table 1- Emissions Factors (Defra 2014)

	Mode	Car (unknown fuel)	Bus	Subway (Glasg0w Specific Figure)	Train (National Rail)	Coach
Conversion Factor (Kg $C0_2e$ /mile)	Low Emissions Scenario	0.2520	0.0472 (coach)			
	Default	0.3049	0.1634	0.1278	0.0763	0.0472
	High Emissions Scenario	0.4006				

Methodology Diagram

The diagram below summarises the methodology described and shows where the assumptions and uncertainties that are analysed later enter the calculation process.

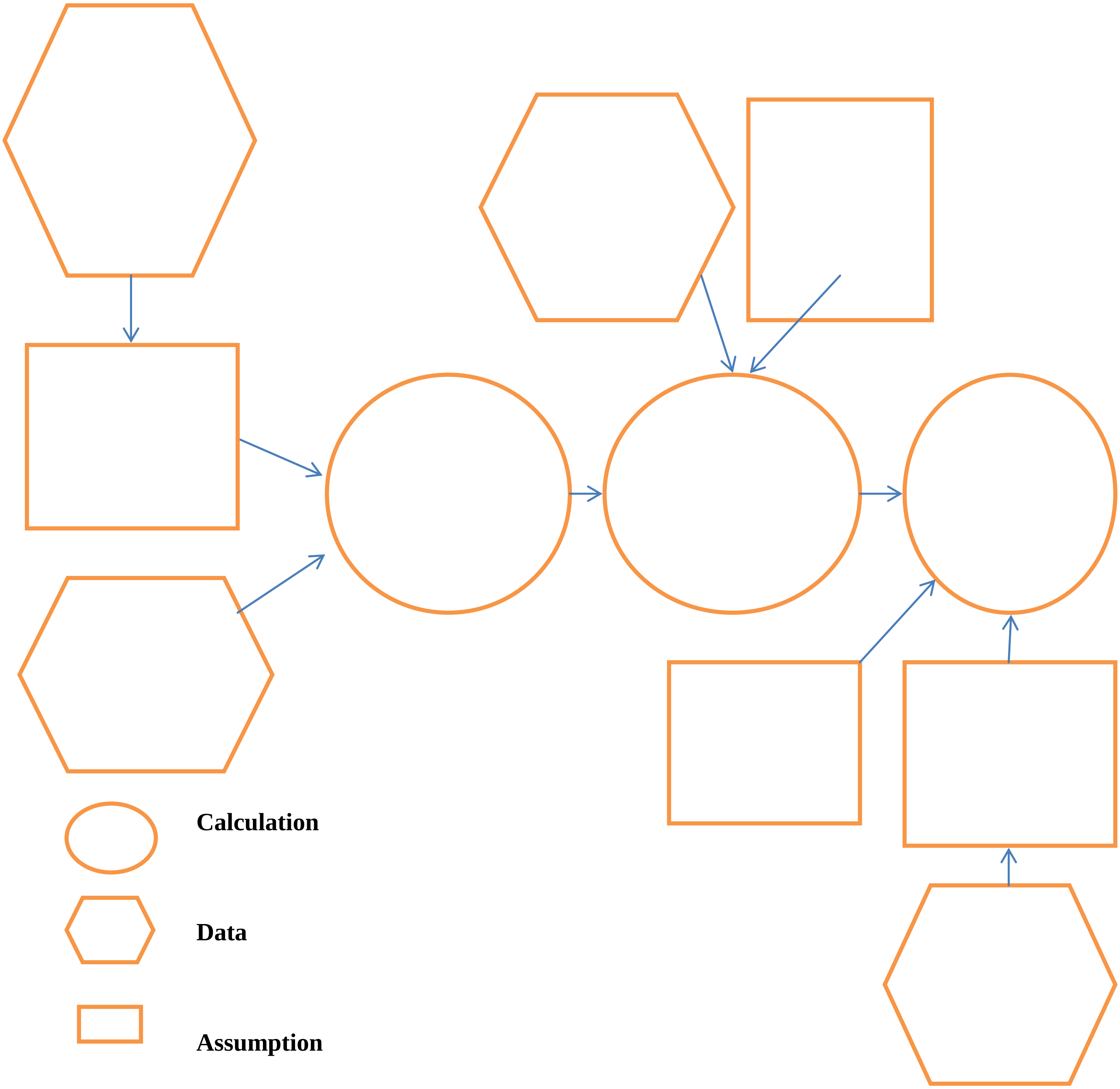

Figure 1- Methodology Diagram

4.4. List of Assumptions Made

1) 1% of students and 6% staff travel home via a different mode than from arrival. These low proportions meant that for calculations it can be assumed that people take the same transport to and from the University. It should also be noted that a more common swap is likely to be between different modes of public transport causing little effect. This is partly due the impracticalities of leaving a bicycle or vehicle on campus overnight.

2) It was assumed that all walking and cycling commuters were in the 0-1 and 1-2 mile distance intervals. These relevant shares of journeys taken were subtracted from the totals distance before the emission calculation process.

3) It was assumed that the rest of distances travelled are spread equally over each different modes of transport.~(ie – if 13% journeys are taken by train then 13% of total distance travelled will be by train). This is analysed later but can be justified by the fact if subway is removed it is quite intuitive that car, train and bus are equally as likely to travel longer distances. The spread of conversion factors for different modes would also have an averaging out effect on emissions.

4) It was assumed that for a commute within a distance interval, the average distance travelled will be the median of that interval range. This effect of this assumption is also analysed by taking extreme values and following through with emissions calculations.

5) It was assumed that in shared car the total occupancy for bases case scenario will only be two persons.

6) It was assumed that respondents who replied as saying they travelled by bus could be represented under the conversion factor of "average bus". Realistically some of these respondents will be travelling in coaches (with significantly smaller conversion factors) but there was only the response option of "bus" in the travel survey.

7) It was assumed that respondent's estimations regarding their normal weekly attendance at the University was representative of actual attendance. Number

of weeks a year of attendance for staff and students was also assumed to a realistic quantity

5. Results and Discussion

5.1. Survey Response

The travel survey had a response rate of 8% for students and 36% for staff. For the large number of staff and students in question these responses can be viewed as being representative of the whole population. See Table 2 below for response rates and confidence intervals for the sample size where 50% gave a specific answer.

Table 2- Response rate and confidence intervals for survey sample (Strathclyde Travel Plan 2013)

	Total Population 2013/2014	Sample Size	Response Rate (%)	95% Confidence Interval for 50% (+/-%)
Staff	2805	996	36	3.1
Student	15706	1208	8	2.8
	18511	2134	12	2.1

The table above shows the response rates achieved from staff and students in the travel survey. Confidence intervals are given for the sample sizes where 50% gave a certain viewpoint. For example, the table demonstrates that the staff sample size of 996 would allow us to be 95% confident that where 50% gave a particular response, the true figure would be within the range of 46.9% - 53.1%.

5.2. Attendance Analysis

The summary of survey results also included information regarding weekly attendance. This data was attained from asking staff and students for their normal weekly attendance patterns. See Table 3 below for the response results.

Table 3 - Normal weekly attendance patterns for staff and students

	Mon	Tues	Wed	Thurs	Fri	Sat	Sun	Total personal commutes per week (2 per day)
Attendance								
Staff %	93	95	94	93	87	4	0	
No. Staff	926	946	936	926	867	38	0	9283
Student %	86	89	79	86	78	9	6	
No. Students	1039	1075	954	1039	942	109	72	10461

1% of students and 6% of staff indicated that they travel home via a different mode of travel than from arrival but for the purpose of this analysis it was assumed that people used the same method of transport at all times (assumption 1). It was also assumed that two commutes were made per day of attendance.

5.3. Distance Commuted Per Day

Before emissions are calculated we need to know what distances are commuted and this was calculated as described in the methodology. Below is a bar chart summarising the survey results for distances commuted by staff and students.

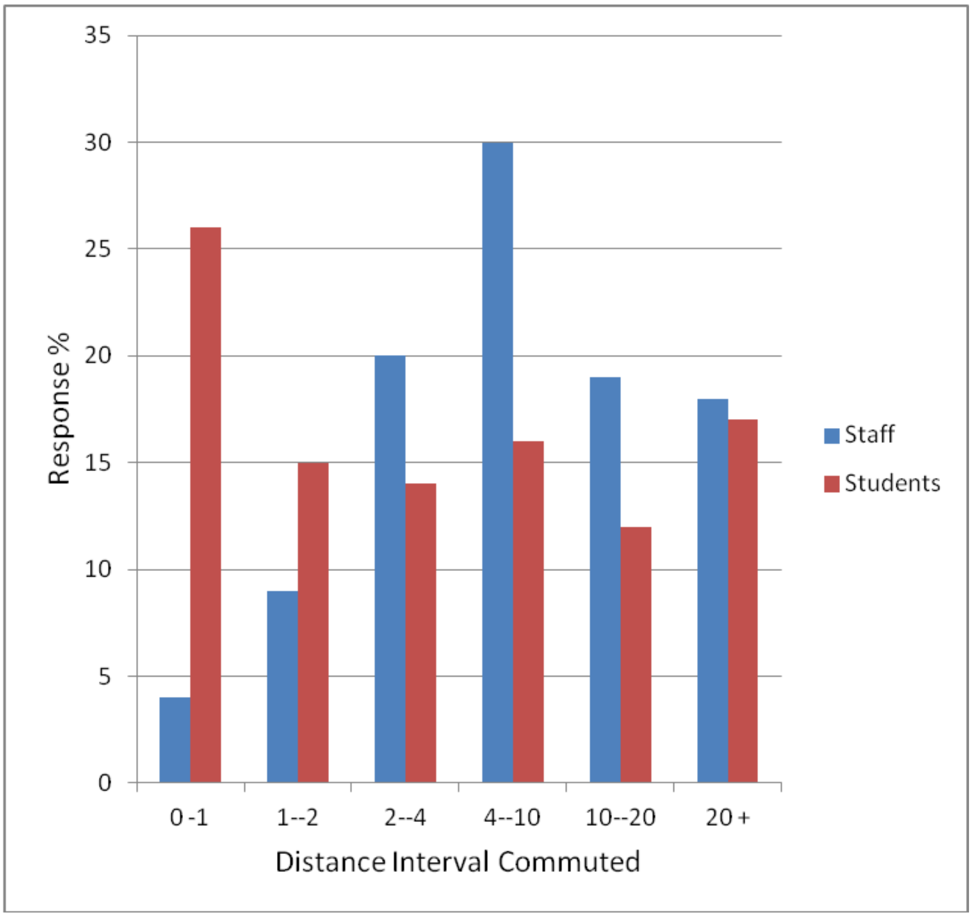

Figure 2- Distance interval commuted by staff and students

This chart shows us there are a bigger proportion of students living closer to the University. This is expected and makes sense with the added knowledge from the survey that a lot more students walk as a commuting mode.

Using the postcode analysis method gives a similar value to Methods 1 and 2 described in the methodology. Below are the values estimated for total distance commuted by all the staff and student population. It should be noted that these are the values before they have been altered to take into account only emission creating miles travelled.

Table 4 - Distances calculated by different methods

Method Used	Travel Survey Analysis Method	Postcode Analysis Method (accounting for + 20% as commute is not shortest route)
Distance commuted per day for full attendance day (nearest Mile)		
Student	265500 +/- 35.5%	306000
Staff	61500 +/- 35.3 %	79000

These results are quite similar indicating that both methods of analysis are probably giving a realistic value. This is expected as the survey results I had access to have been derived from student responses regarding postcodes that they travelled from. This further indicates that the responses from the travel survey can be treated as representative of the whole population. It also to some extent legitimises the assumption that the average distances travelled by each commuter are the medians of ranges responded. Uncertainty regarding the travel survey values is due to the data I had indicating only these ranges of distance travelled rather than an exact figure. The extreme values of the range for each response were modelled giving values of +/- 35.5% compared to using the medians.

While calculating distances using postcodes, it was decided to ignore postcode distances that were over 50miles from Strathclyde due to the presence of so many unrealistically far away postcodes registered as “term time address”. These distances were then replaced with the average value of all the remaining postcode distances. To analyse the effect of the choice of 50 miles as this limit, the value was altered to 60 and 70 miles. The effect of this was to increase the total distance value by 1% and 4% respectively. Even with larger limits these values are within the large uncertainty range of the travel survey method. Emissions calculated using distances from the Postcode analysis method would fall within the uncertainty values of the survey method values. To determine distance travelled more accurately different computer programmes could be used, taking into account actual road and rail route distances.

It was decided not to include student holiday trips home under commuting distances, there is lot of uncertainty surrounding these values and it can be argued that these trips are due to the individual’s choice rather than the presence of the University.

5.4. Emissions

Calculated Commuting Emissions

Following the methodology described previously with mentioned assumptions and chosen “most likely” baseline scenario values I have arrived at an estimated value for the yearly GHG emissions due to commuting at the University of Strathclyde.

This value is 6610 Tonnes of CO_2 equivalent per year from Staff and Students combined.

This figure seems sensible considering the size of the University and in comparison to other studies. The table below summarises some of the findings from studies discussed in the literature review section and compares them to emissions estimated in this study.

Table 5- Comparison of Commuting Emissions Studies

Study / Location		Total Commuting Emissions (Tonne CO_2e / year)	Emissions per person (Tonne C02e / year / person)
Strathclyde	Staff	1980	0.71
	Student	4630	0.30
Leicester (University of Leicester, 2010)	Staff	3870	1.04
	Student	N/A	N/A
Yale (Butazzoni and Zyla, 2003)	Staff	13500	1.08
	Student	1700	0.15
University Illinois (Klein-Banai , 2010)	Staff	22000	1.91
	Student	21000	0.97
University of Edinburgh (Transition Edinburgh University, 2009)	Staff	Not included	0.63
	Student	Not included	0.18

Comparing the results from Strathclyde shows that the value attained is sensible. Strathclyde is in the lower end of the scale considering emissions per person than the most other Universities. This would make sense as Strathclyde is in an extremely central location with good public transport links. The very low value for Yale students will be due to the fact that most students there actually live on campus rather than in the surrounding areas. On the other hand the University of Illinois is historically known as a “commuter campus” and this explains its much higher quantity for emissions per person (Klein-Banai , 2010). Edinburgh University is in an extremely central location in a city centre with little parking provisions, this can partly explain the very low values attained in that study. It is important to note that there are many limitations in making comparisons such as these. Amongst many factors different universities may use different fuels, be in very differing climates and consider different reporting boundaries. For these reasons caution should be taken when comparing these values across different studies.

A further breakdown of the calculated emissions will be provided below relevant to the information that was available.

Staff/Student Share of Emissions

Table 6 - Emissions per year staff/student breakdown

	Emissions CO_2 e per year (tonne)	Emissions CO_2 e per year per person (2 d.p)
Staff	1978	0.71
Students	4630	0.30
Staff and Students	6608	0.36

We can see that staff have a much higher commuting footprint per person than students and this is as would be expected with many students residing in halls and city centre accommodation. Staff are also generally part of a more wealthy demographic and thus will also be more likely to own and use personal transport (cars) than students.

Assuming Strathclyde has a total emissions quantity of the average of several others calculated by other authors (7.29 TCO_2 e per person)(Zhang et. Al, 2009), this would mean that around 5% of total emissions at Strathclyde are due to commuting.

To put this in context, a 20% reduction in commuting emissions would reduce total emissions by 1%. However, these figures should be taken with caution as studies used to attain the average used different calculation techniques and were not consistent in what they included under their emission scopes. If anything this is probably an underestimate of the significance of commuting as studies averaged to attain the total emissions value where all from the US and likely to have more emissions per person than Strathclyde. Nonetheless these figures do indicate that a sizeable proportion of emissions can be attributed to commuting.

Modal Share of Emissions

Below is a bar chart showing the modal shares of staff and students for their normal method of commute to the University of Strathclyde.

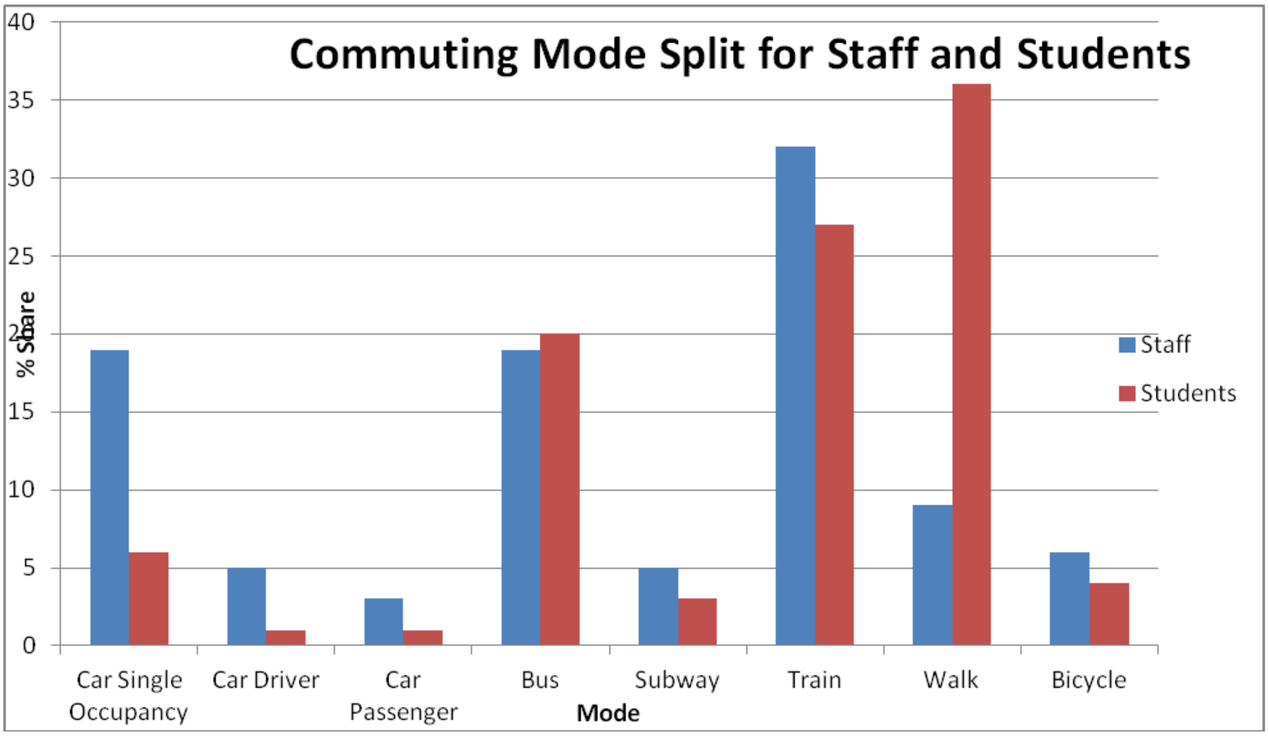

Figure 3- Commuting mode split for staff and students

Below are charts of the calculated yearly emissions broken down into the transport commuting modes that they originate from.

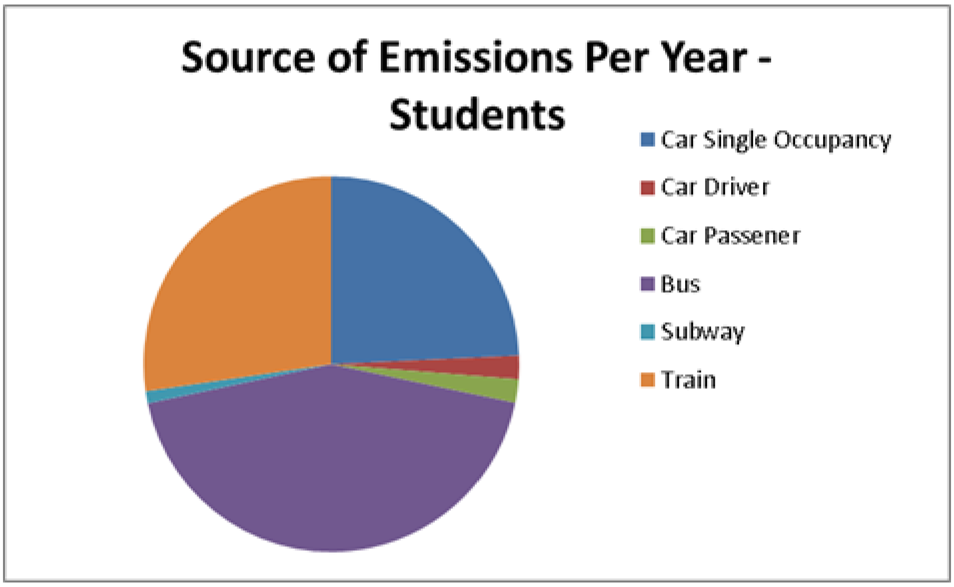

Figure 4 - Modal break down of emissions for students

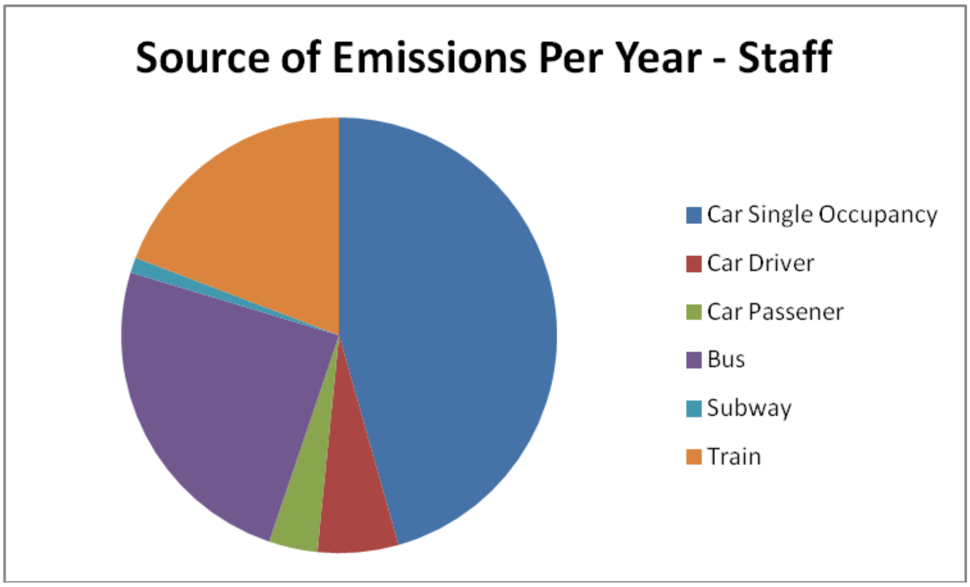

Figure 5 - Modal break down of emissions for staff

Findings of interest include that although only 19% of staff travel in a single occupancy vehicle (SOV), this generates around 46% of total staff emissions. This highlights the prominent role cars play in commuting emissions. For students this statistic shows an even higher ratio, 24% of emissions for 6% of the mode share. This is clearly an area where emissions reductions can be made and this potential will be investigated in the next section.

It can see that buses contribute more emissions than trains for staff and student populations even though they have a lower share of the mode split. This is due to the higher energy efficiency of trains (lower conversion factors). It is interesting to note that staffs are more likely to commute by train while students are more likely to commute by bus. This could potentially be due to the fact that rail travel is more expensive than bus travel and more affordable to staff who are generally financially more comfortable. The effect on emissions of a mode shift from bus to train will also be investigated in the following section.

Effects of Mode and Behaviour Shifts

This section presents alternative scenarios which can give some understanding into potential options that could contribute towards reducing the carbon footprint due to commuting. These scenarios are based on altering variables whose original values were collected by the travel survey.

Results show us that for the baseline scenario, staff and student populations combined, cars make up 46% of total emissions and single occupancy cars 38.3%. This is a large proportion especially considering that in total only 16.6% of staff and students commute by car. Taking this it consideration, it is evident that reducing car travel is a key area where emissions reductions can be made, especially if mode can be shifted to emission free walking or cycling. For longer distances, shifting from car to train can still bring about significant reductions. See table below for reductions possible from various mode shifts and to what extent.

Results from altering attendance show us the potential reductions that can be made from a shift to flexible working or telecommuting. Telecommuting is the option for people to work from home rather than physically attending the institution location. This has become more practical than ever with the advancement of internet speeds and digital technology.

Below is table displaying the effects of the various emissions scenarios discussed.

Table 7 - Effects of emissions scenarios

Alteration	**Details**	**Effect on total Emissions against Baseline Scenario (- %)**
SOV switch to shared car, active travel or train	If Strathclyde achieves 10% for staff single occupancy drivers.	3.2 shared car, 6.5 active travel, 4.8 train
Reduced Attendance (flexible working staff)	Staff flexible work 1 day a week. Reduce attendance factor to 0.8	6
Reduced Attendance (flexible working staff and student)	Staff and student flexible work 1 day a week. Reduce attendance factor to 0.8	20
¼ Bus users switch to Train	N/A	4.4
½ Bus users switch to Train	N/A	8.9

From these results we can see the large potential of emissions reductions through a range of options. If overall commuting trips were reduced by 20% this would give a 20% reduction in overall emissions (remember that the method used to commute emissions relies on distance travelled and this is assuming an equal spread of mode users cutting down on travel). Due to the nature of commuting requiring two journeys, in practice this would require 15656 less days of attendance at the University per week. To achieve this would take the equivalent of 85% of staff and students travelling one day less per week. With modern technology aiding the potential to telecommute this is more possible than ever. This potential agrees with a report by (Anable and Boardman 2005) which highlights telecommuting as an easily and quickly implemented method to influence early emissions savings from the transport sector on timescales not possible by advances in technology. An example of telecommuting could be video conferencing which also has the potential to create emissions reductions in the business travel category of inventories. Unconventional or "advanced" timetabling and longer working days can also contribute to making these reductions possible although 20% attendance reduction would be an ambitious target. A more realistic figure could be a 10% reduction in attendance giving 10% less commuting emissions, still a significant amount. This highlights the significance of allowing a flexible work schedule. There can also be other benefits to flexible working such as employee relations and time saving. A report by the Scottish government gives several case studies where emissions reductions through flexible working has been achieved (Scottish Gov, 2013).

It should be noted however that flexible working could lead to higher energy demands at the home location and this is an example of the kind of problems faced when setting carbon footprint boundaries and how complicated the whole issue can be.

Mode shifts from single occupancy car give emissions reductions to the various degrees shown. Most people driving on their own are probably not in a position to practically commute by active travel so a more realistic scenario would be the shift to car sharing or public transport. Strathclyde already has low proportion of single occupancy drivers so the scope for further reductions here is limited to about 10% if all SOV drivers were to switch to train. A report by (Atkins 2009) concluded that "Car Demand Management (Smart Measures) category has the greatest potential to reduce CO_2 emissions. In particular the potential for travel planning considerably exceeds that for all other policy options". This knowledge alongside the potential emissions reductions identified in this study indicate that reducing car use through travel planning is an effective method to reduce emissions.

Mode switches from bus to train also show considerable commuting emissions reductions of almost 5% with a shift of 25% of bus users switching to train and this seems feasible. This could be argued to highlight the benefits of long term investment in rail infrastructure. This could bring increased accessibility and keep costs down for the public, to reduce transport emissions from commuting. These reductions could be realised because as fuel costs rise, public transport options will be more feasible and appealing to travellers. As mentioned previously, rail transport is currently more expensive than bus in Scotland and this could be a barrier to potential carbon savings. (Klein-Banai, 2010) reveal that parking permits sharply decreased after the implementation of a free transit pass, this points towards the idea that students may be more inclined to take different modes of transport if it is financially practical for them to do so. This also agrees with the Strathclyde travel survey results reveal that on being asked about the potential changes that would encourage them to use public transport, the main two identified responses were discount tickets for rail (46%) and discount tickets for buses (39%) (Strathclyde Travel Plan. 2013).

To help promote mode shifts or any other behavioural changes the university could potentially provide incentives or even barriers to achieve the desired effect. This could involve a myriad of things from providing bicycle shelters to decreasing the amounts of parking permits allocated. There are indications that parking measures at the University of Strathclyde has contributed towards a reduction in single occupancy drivers over the last few years (Strathclyde Travel Plan, 2013).

5.5. Discussion of Robustness / Sensitivity Analysis

It is important to address the robustness of these estimates calculated. Taking into account some of assumptions made and variability of certain quantities a sensitivity analysis has been performed. This has been done by taking values for highest and lowest emissions scenarios and comparing these with the assumed most likely scenario.

Descriptions and discussion of Sources of Uncertainty

Firstly maximum and minimum values from the distance travelled ranges were taken and the emissions calculations performed. For example minimum emissions scenario would model a 10 mile journey for everybody who responded in the survey that they travelled in the 10-20 mile distance range, as opposed to the median of 15 miles taken as the "most likely" scenario.

Information on exact car or bus type was not known. In the model there is the option to set the conversion factor for the car mode to "large car", "average car", or "small car". All these values are for the category of "unknown fuel" in the Defra Conversion factors data sheet. Extreme scenarios where all cars are either large are small was modelled. Conversion factors for vehicles depend on age and fuel type of vehicle but the uncertainty inherent in these variables will be far less than the extreme boundary parameters tested.

In the Defra conversion factors the category of "coach" has a much lower value than "average bus" but these two categories were not distinguished between in the travel survey. It is more probable that the majority of these responders will fall into the "average bus" category but both extremes where investigated where all respondents were entered to use one or the other.

There will be an error inherent in the answers given for normal weekly attendance and for this reason the amount of trips taken per week was altered by +/- 10% and investigated in the model. This alteration will also cover the take into account the assumption regarding the attributed 32 weeks attendance per year for students and 45 weeks for staff.

Reassuming that 15% of all staff in both categories actually walk or cycle in the 2-4 and 4-10 mile ranges rather than the shorter ranges shows the effect of the original assumption. Again it is completely unlikely that more respondents are walking 2-4 miles than 1-2 but the analysis shows us the effects of an extreme example.

Car occupancy for car sharing was assumed to be two for the baseline but this parameter has been analysed with a value of three.

There is also an uncertainty incorporated within the quoted conversion factors, emissions per distance travelled are not as accurate a quantity as if time taken for journey was also known or even better the exact amount of fuel consumed for the journey was known. These uncertainties will have smaller overall effects and will be absorbed into the uncertainties due to other parameters (such as size of car) under investigation.

There is also the important assumption made that after taking into account walkers and cyclists that the rest of total distances travelled by commuters are spread equally over each different mode of transport.~(ie – if 13% journeys are taken by train then 13% of total distance travelled will be by train). This will not be entirely representative but was necessary with the data available and modelling process employed. This assumption was investigated to some extent by analysis changing the weightings of distances travelled between buses and cars for Staff as an example. For example the car/ bus ratio 3:1 would be simulating that cars travel a distance 3 times greater than buses do for the same proportion of commuters.

A simulation has been run where all subway journeys were all in the 2-4 mile range As the total Glasgow subway length is 8m long this is a logical assumption than no subway journey would be >4 miles. This would have been more logical for inclusion in the baseline emissions scenario but it has little effect on overall emissions (-0.31%) so its omission is not important.

Realistically if there is an uneven distribution of distances between modes then the lower emitting modes such as Coach and Train will be travelling much of the longer distances. This means that the model I have run will generally give a conservative estimate.

Combining all parameters for "best" and "worst" case scenarios has been performed to estimate a final uncertainty value in the baseline value.

Effects of Uncertainties

Below is a table showing the variables discussed above and the effects on final emissions caused by altering these values between maximum and minimum parameters that I will describe and argue. In this table the effect on emissions indicated is from altering each parameter individually with all other parameters held at the baseline scenario.

Table 8 - Effects of altering parameters on baseline emissions scenario

Assumption / Uncertainty	Effect of extremes of parameter on overall commuting baseline emissions estimate (+/- %)	
	-	+
Distance Travelled in range responded	34.8	34.8
Car size	6.1	11
Average Bus or Coach	25.8	
Response given for weekly Attendance (and weeks yearly)	10	10
Walkers and cyclist in smallest distance range	22	N/A
Average Car Occupancy for shared Car	1.9	N/A
Subway journeys all 2-4 miles	0.3	N/A
Bus – Car weighting for share of distances. (Staff) (3:1) (1:3)	3.2	3.2
Maximum/ Minimum Scenario(All Parameters)	**64**	**73**

It can be seen that the uncertainty range is large and this can me mainly contributed to the uncertainty in distance travelled. It is worth noting that these uncertainties are lower than values determined in the similar Yale study and this is due to the better data regarding mode split available at Strathclyde, gained from the travel survey.

Simulation using extremes of all parameters except distance commuted gave values of + 28.4 / - 45.3 % from the baseline scenario, where the majority of the negative uncertainty value comes from the bus/coach assumption. This uncertainty due to the selection of either bus or coach can be eradicated completely by the simple determination of the exact mode used. In further surveys these two modes should be distinguished from each other. Even with just the raw data from the survey a sensible judgement could be made between the two based on the distance travelled.

All these parameter values used are assuming a worst or best case scenario which will in reality give very conservative estimates of the relevant uncertainties.

6. Conclusions

Following background reading it became evident that the calculation and reporting of GHG emissions from transportation is an area that is often overlooked despite the significant proportion of emissions that it contributes towards. Transportation contributes towards around one quarter of total Scottish emissions and specifically it was identified that there is a gap in the field of carbon reporting regarding the particular category of commuting within transportation. A literature review was conducted concerning the topic of commuting emissions and the methods employed to estimate these. Various studies revealed that commuting is a significant area of emissions in its own right. The work performed for this thesis further confirmed this, calculating an estimated 6610 Tones CO2 e emitted per year due to commuting at the University of Strathclyde. This averages out to 0.36 Tones CO_2 e per year per member of the university community. This value calculated is in a sensible range when compared to other similar studies. Assuming a sensible value for the total emissions at Strathclyde would mean that the commuting value determined makes up ~5% of total emissions.

Reporting boundaries that are set highly influence the overall proportion of emissions that transport and specifically commuting contribute towards. Different studies use different reporting boundaries and this makes it hard to compare across studies. For example some studies include students travelling home under commuting emissions while others do not. It is apparent that there is a great need for guidelines to be set for emissions reporting at organisations and Universities, this very much agrees with the literature.

At Strathclyde it was not possible to gain access to information regarding business travel but this is the type of data that it would be beneficial to have readily available. Without basic information on travel miles or expenses, business travel emissions calculations could not be carried out. When a member of staff or student completes a travel expense form some basic anonymous data regarding length of trip and transport mode should be logged and recorded. There is also the potential for a record to be made regarding reimbursed trips made by visitors travelling to Strathclyde, as has been done in one of the studies discussed in the literature study.

This thesis has demonstrated that using a travel survey is a fairly non-complex method that can be used to estimate GHG emissions from commuting. As for other categories of transport, accuracy of results relies heavily upon the level of detail of data that can be determined from the survey. Compared to other methods such as the sole use of post code analysis a travel survey can be more accurate as it is possible to determine exact modes of transport and attendance rather than assumptions based on distances or other criteria. The biggest source of uncertainty in the calculated emissions was from the “distance travelled” activity data. Obtaining as accurate as possible a figure for total distance travelled is key to improving the robustness of the method employed in this thesis. Another source of uncertainty than could easily be eliminated is the lack of distinction between bus and coach travel, as these modes have significantly different conversion factors.

Regarding the postcode analysis method, uncertainties can be reduced if up-to-date term time addresses are known. Current records have a large amount of data that had to be omitted and then reassumed due to unrealistically large commuting distances.

Aside from calculating emissions, if the right questions are asked a travel survey can also be good means of discovering how possible certain behavioural shifts may be. An example of this might be probing to discover how willing people may be to change their mode of transport and what might encourage them

A key behavioural change to promote emissions reductions has been shown to be attendance at the university. Analysis revealed that if 85% of commuters travel to the university one day less per week, this can reduce the total commuting emissions by 20%. This behavioural shift could be encouraged through methods of telecommuting and more flexible working hours.

Mode shift analysis performed showed that if 25% of bus users switch to train this can reduce commuting emissions by almost 5%. This could be used as an argument for the potential of long-term investment in rail infrastructure to contribute significantly to emissions reductions. A similar reduction of 5% can also be made if single occupancy staff drivers are reduced to 10% of total staff population and these drivers switch to rail transport.

It should be noted that even if estimated emission values are not accurate, effects of mode shifts and behavioural shifts are relative and so should still have value. Using a standardised method would still allow emissions values to be monitored and could provide the possibility for comparison with other organisations.

The methods used in this study to calculate commuting emissions are applicable to any other single location organisation with similar data available. Any study should try to source conversion factors and other data that is as specific to the local area as possible.

Further Work

With access to raw data from the travel survey, rather than summarised, it would be possible to eliminate much uncertainty regarding distances travelled and the distance weighting for each mode. This more detailed data would also allow analysis of emissions corresponding to other variables of age, gender or job category within staff.

Knowing accurate postcodes and mode of travel for individuals would allow more precise calculation of distance travelled to be performed on programmes such as GIS. To calculate uncertainty ranges worst and best case scenarios have been used, however these give no indication as to what is actually most likely, a more statistical approach to the analysis would yield a uncertainty range more indicative of the true value.

Results from this study have the potential to compliment estimations for other categories of transport emissions at the University. This would allow a determination for transport emissions as a whole and this could be put into context of the whole carbon footprint of the university. A similar analysis as this could be beneficial following another travel survey in the future to observe how commuting emissions have changed over time.

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8. Appendixes

Appendix I - UNFCCC,2007

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69554/pb13773-ghg-conversion-factors-2012.pdf

Factors for Process Emissions - Greenhouse Gases Listed in the Kyoto Protocol							
Emission	Chemical formula	Amount Emitted per Year in tonnes	x	Conversion Factor (GWP) [1]	x	Unit conversion tonnes to kg	Total kg CO_2e
Carbon Dioxide	CO_2		x	1	x	1,000	
Methane	CH_4		x	21	x	1,000	
Nitrous Oxide	N_2O		x	310	x	1,000	
HFC-23	CHF_3		x	11,700	x	1,000	
HFC-32	CH_2F_2		x	650	x	1,000	
HFC-41	CH_3F		x	150	x	1,000	
HFC-125	CHF_2CF_3		x	2,800	x	1,000	
HFC-134	CHF_2CHF_2		x	1,000	x	1,000	
HFC-134a	CH_2FCF_3		x	1,300	x	1,000	
HFC-143	CH_3CF_3		x	300	x	1,000	
HFC-143a	CH_3CHF_2		x	3,800	x	1,000	
HFC-152a	CF_3CHFCF_3		x	140	x	1,000	
HFC-227ea	$CF_3CH_2CF_3$		x	2,900	x	1,000	
HFC-236fa	$CHF_2CH_2CF_3$		x	6,300	x	1,000	
HFC-245fa	$CH_3CF_2CH_2CF_3$		x	560	x	1,000	
HFC-43-I0mee	$CF_3CHFCHFCF_2CF_3$		x	1,300	x	1,000	
Perfluoromethane (PFC-14)	CF_4		x	6,500	x	1,000	
Perfluoroethane (PFC-116)	C_2F_6		x	9,200	x	1,000	
Perfluoropropane (PFC-218)	C_3F_8		x	7,000	x	1,000	
Perfluorocyclobutane (PFC-318)	c-C_4F_8		x	8,700	x	1,000	
Perfluorobutane (PFC-3-1-10)	C_4F_{10}		x	7,000	x	1,000	
Perfluoropentane (PFC-4-1-12)	C_5F_{12}		x	7,500	x	1,000	
Perfluorohexane (PFC-5-1-14)	C_6F_{14}		x	7,400	x	1,000	
Sulphur hexafluoride	SF_6		x	23,900	x	1,000	
Blends [2]							
R404A	52:44:4 blend of HFC-143a, -125 and -134a		x	3,260	x	1,000	
R407A	20:40:40 blend of HFC-32, -125 and -134a [3]		x	1,770	x	1,000	
R407C	23:25:52 blend of HFC-32, -125 and -134a		x	1,526	x	1,000	
R407F	30:30:40 blend of HFC-32, -125 and -134a [3]		x	1,555	x	1,000	
R408A	47:7:46 blend HCFC-22, HFC-125 and HFC-143a		x	2,795	x	1,000	
R410A	50:50 blend of HFC-32 and -125		x	1,725	x	1,000	
R507	50:50 blend of HFC-125 and HFC-143a		x	3,300	x	1,000	
R508B	46:54 blend of HFC-23 and PFC-116		x	10,350	x	1,000	
Total							**0**

Appendix II – Defra, 2013 Government GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors.

				Scope 3				Scope 3	All Scopes
Taxi, Bus, Rail and Ferry Passenger Transport Conversion Factors				**CO_2**	**CH_4**	**N_2O**	**Total Direct GHG**	**Total Indirect GHG**	**Grand Total GHG**
Method of travel		Vehicle km travelled (vkm)[1]	x	kg CO_2 per vkm[1]	kg CO_2e per vkm[1]	kg CO_2e per vkm[1]	kg CO_2e per vkm[1]	kg CO_2e per vkm[1]	kg CO_2e per vkm[1]
Taxi [2]	Regular taxi		x	0.21040	0.00005	0.00167	0.21212	0.02431	0.23643
	Black cab		x	0.24157	0.00005	0.00167	0.24329	0.04639	0.28968
Taxi [2]	Regular taxi		x	0.15029	0.00004	0.00119	0.15151	0.02886	0.18038
	Black cab		x	0.19871	0.00011	0.00056	0.19938	0.03548	0.23486
Bus	Local bus (not London)[3]		x	0.18433	0.00020	0.00135	0.18588	0.03540	0.22128
	Local London bus[4]		x	0.08566	0.00008	0.00056	0.08630	0.01645	0.10275
	Average local bus		x	0.14754	0.00016	0.00107	0.14877	0.02833	0.17710
	Coach [5]		x	0.03000	0.00007	0.00057	0.03064	0.00576	0.03641
Rail	National rail [6]		x	0.05340	0.00006	0.00303	0.05649	0.00815	0.06464
	International rail (Eurostar)[7]		x	0.01502	0.00001	0.00009	0.01512	0.00200	0.01712
	Light rail and tram [8]		x	0.07101	0.00003	0.00044	0.07148	0.00944	0.08092
	London Underground[9]		x	0.07313	0.00003	0.00045	0.07361	0.00972	0.08333
Ferry (Large RoPax) [10]	Foot passengers		x	0.01912	0.00001	0.00015	0.01928	0.00324	0.02252
	Car passengers		x	0.13216	0.00004	0.00102	0.13322	0.02243	0.15565
	Average (all passengers)		x	0.11516	0.00004	0.00088	0.11608	0.01954	0.13562
Total									

				Scope 1 OR Scope 3				Scope 3	All Scopes
Passenger Road Transport Conversion Factors: Cars (unknown fuel)				**CO_2**	**CH_4**	**N_2O**	**Total Direct GHG**	**Total Indirect GHG**	**Grand Total GHG**
Size of car	Total units travelled	Units	x	kg CO_2 per unit	kg CO_2e per unit	kg CO_2e per unit	kg CO_2e per unit	kg CO_2e per unit	kg CO_2e per unit
Average small car (unknown fuel)		miles	x	0.26659	0.00023	0.00166	0.26847	0.04781	0.31628
		km	x	0.16565	0.00014	0.00103	0.16682	0.02971	0.19653
Average medium car (unknown fuel)		miles	x	0.32224	0.00019	0.00187	0.32430	0.05863	0.38293
		km	x	0.20023	0.00012	0.00116	0.20151	0.03643	0.23794
Average large car (unknown fuel)		miles	x	0.43129	0.00016	0.00211	0.43356	0.07936	0.51292
		km	x	0.26799	0.00010	0.00131	0.26940	0.04931	0.31871
Average car (unknown fuel)		miles	x	0.32721	0.00019	0.00185	0.32926	0.05950	0.38876
		km	x	0.20332	0.00012	0.00115	0.20459	0.03697	0.24156
Total for average cars									

Table 18: GHG emission factors, electricity consumption and passenger km for different tram and light rail services

	Type	Electricity use	gCO_2e per passenger km				Million
		kWh/pkm	CO_2	CH_4	N_2O	Total	pkm
DLR (Docklands Light Rail)	Light Rail	0.1180	56.7	0.033	0.498	76	456
Glasgow Underground	Light Rail	0.1643	78.9	0.051	0.501	79.4	41
Midland Metro	Light Rail	0.1353	65.0	0.042	0.413	65.4	51
Tyne & Wear Metro	Light Rail	0.2053	98.6	0.064	0.626	99.3	304
London Overground	Light Rail	0.0871	41.8	0.027	0.266	42.1	645
Croydon Tramlink	Tram	0.0793	38.1	0.025	0.242	38.4	148
Manchester Metrolink	Tram	0.0787	37.8	0.024	0.240	38.0	228
Nottingham Express Transit	Tram	No data					
Supertram	Tram	0.1857	89.2	0.058	0.566	89.8	97
Average*		**0.1186**	**57.0**	**0.036**	**0.394**	**61.7**	**1970**

Notes: * Weighted by relative passenger km

Activity	Type	Unit	kg CO_2e	kg CO_2	kg CH_4	kg N_2O
Bus	Local bus (not London)	passenger.km	0.10946	0.10847	0.00009	0.0009
	Local London bus	passenger.km	0.08142	0.08082	0.00005	0.00055
	Average local bus	passenger.km	0.10155	0.10067	0.00008	0.0008
	Coach	passenger.km	0.02932	0.0287	0.00005	0.00057
Activity	Type	Unit	kg CO_2e	kg CO_2	kg CH_4	kg N_2O
Rail	National rail	passenger.km	0.04738	0.0471	0.00004	0.00024
	International rail	passenger.km	0.01212	0.01202	0.00001	0.00009
	Light rail and tram	passenger.km	0.06168	0.06118	0.00004	0.00046
	London Underground	passenger.km	0.06312	0.06261	0.00004	0.00047

Defra, DECC , 2014 - UK Government conversion factors for Company Reporting. Spread sheet