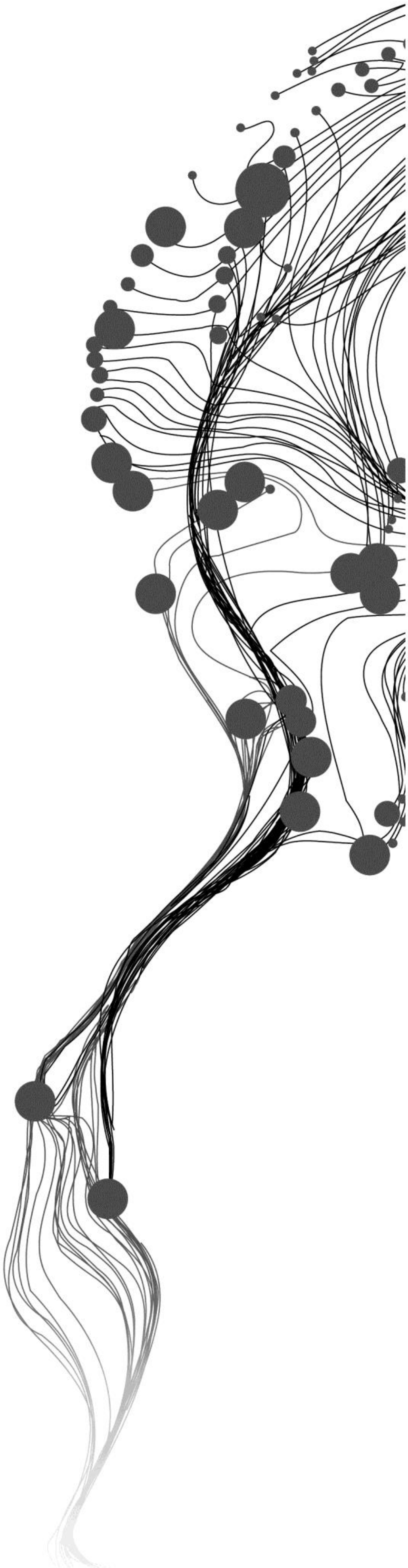
TRAVEL EMISSION PROFILES
Case Study:
Overijssel, The Netherlands

ZOYA SODHI
May, 2013

SUPERVISORS:
Dr. J. (Johannes) Flacke
Dr. S. (Sherif) Amer



TRAVEL EMISSION PROFILES
Case Study:
Overijssel, The Netherlands

ZOYA SODHI
Enschede, The Netherlands, May, 2013

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

SUPERVISORS:
Dr. J. (Johannes) Flacke
Dr. S. (Sherif) Amer

THESIS ASSESSMENT BOARD:
Prof. Dr. Ir. M.F.A.M. (Martin) van Maarseveen (Chair)
Dipl. Ing. Johannes Lückenkötter
(External Examiner, Technische Universität Dortmund)

ABSTRACT

Carbon emissions from personal travel have increased steadily in the country of The Netherlands. To reduce these emission levels, specific carbon reduction targets have been set within the Kyoto Protocol and agreed upon within the European Union for their medium long term period by 2020. To achieve these carbon reduction targets not only emissions produced from personal travel are important but also identifying the 'emitters' and analyzing 'how much' do these emitters contribute, is essential. This research describes an emission calculation framework to calculate carbon emissions using travel pattern related characteristics for profiling carbon dioxide emissions from personal travel across all modes of travel concerned with road transportation.

A case study application of the methodology integrating the sample based Mobility Survey Netherlands (MON) dataset provides an enhanced understanding of the extent to which individual travel patterns marked by household size and structure, car ownership, age, gender, education, paid work, income and geographical location impact on carbon emissions. Car travel significantly dominates the overall carbon dioxide emissions. Conversely, public transport accounts for a marginal share of emissions on an average basis. There is a highly unequal distribution of emissions amongst the population. The lowest emitters account for 17% of the total individuals and contribute 0.5 kg/day emissions per person on an average while the highest emitters account for only 2% of the total individuals contributing 18.5 kg/day CO_2 emissions per person on an average. Therefore the lowest emitters were typically non-car owners, individuals within the age group of 50-65 years, mostly female, comprising of lower education, working for less than 12 hours per week, earning less than 7500 Euros/year as their personal net income and residing mostly in lowly urbanised areas. On the other hand, highest emitters were car owners, aged between 25-35 years, mostly males who were highly qualified, earning equal to or more than 30000 Euros/year as their personal net income and residing in strongly urbanised areas.

ACKNOWLEDGEMENTS

Foremost, I would like to pay my sincere gratitude to my supervisors Dr. Johannes Flacke and Dr. Sherif Amer, for giving me the freedom to undertake a topic of my own interest and guide me through the process of undertaking the MSc research in the right stride. Heartfelt gratitude to my family for their undying concern and especially my two dearest friends at ITC, Parya Pasha and Ahmed Eissa for all their support, encouragement and motivation.

TABLE OF CONTENTS

1. Introduction 7
    1.1. Background 7
    1.2. Justification 8
    1.3. Research Problem 10
    1.4. Research Aim 11
    1.5. Research Objectives and Questions 11
    1.6. Case Study 11
    1.7. Conceptual Framework 12
    1.8. Research Methodology 13
    1.9. Thesis Structure 14
2. Literature Review 15
    2.1. Travel Growth 15
    2.2. Travel Patterns 15
    2.3. Travel Induced Carbon Emissions 20
    2.4. Travel emission calculation 22
    2.5. Travel Emissions in relation to socio-economic characteristics 26
    2.6. Conclusion 29
3. Methodology 30
    3.1. Description of the dataset 30
    3.2. Relevant units of analysis 33
    3.3. Methods used to undertake the analysis 33
    3.4. Conclusion 47
4. Results 48
    4.1. Travel Patterns 48
    4.2. Travel Emission Profiles 53
    4.3. Travel emission profiles related to socio-economic characteristics 58
    4.4. Conclusion 60
5. Conclusion and Discussions 62
    5.1. Addressing research objectives and questions 62
    5.2. Shortcomings of the study 63
    5.3. Recommendation for future studies 64
List of references 65
Appendix A: Description of Travel Variables 68
Appendix B: Travel Patterns 70
Appendix C: Characteristics of Car-based movements 72
Appendix D: Spatial variation of travel patterns 73
Appendix E: Travel emissions profiles related to socio-economic chracteristics 79

LIST OF FIGURES

Figure 1: Clean and Efficient (Schoon en Zuinig) policy programme of The Netherlands............................7
Figure 2: Case Study Area...11
Figure 3: Conceptual Framework...12
Figure 4: Research Methodology...13
Figure 5 ASIF framework...23
Figure 6: Emission quintiles by age and gender..27
Figure 7: Geo spatial analysis of household location and individual CO2 emissions by all travel modes....29
Figure 8: Basic structure of the MON dataset..31
Figure 9: Levels of analysis...31
Figure 10: Process of preparation of dataset for this research...32
Figure 11: Indicate missing values..32
Figure 12: Workflow to analyze selected MON dataset (2005-2009)...34
Figure 13: SPSS syntax for reclassifying mode of transport...35
Figure 14: SPSS syntax for reclassifying motive of travel...36
Figure 15: SPSS syntax used for recomputing Trip Distance..37
Figure 16: SPSS syntax used for recomputing Household size..38
Figure 17: SPSS syntax used for recomputing Household structure...39
Figure 18: SPSS syntax used for recomputing Age Class..39
Figure 19: SPSS syntax used for recomputing Education..40
Figure 20: SPSS syntax used for recomputing personal net income...41
Figure 21: Emission calculation framework..42
Figure 22: SPSS syntax for computing CO_2 Emission Factor..44
Figure 23: SPSS syntax used to calculate Travel Carbon Emissions..45
Figure 24: SPSS syntax used to calculate Travel Carbon Emissions in kilograms (kg)...............................45
Figure 25: SPSS syntax used to calculate Travel Carbon Emissions in Mtons..45
Figure 26: Ranking the emissions into quintiles...46
Figure 27: Pearson's Chi Square (x2) Tests..46
Figure 28: Example of Chi Square Test...47
Figure 29: Reclassified Modes of Transport for different motives (movement level)...............................49
Figure 30: Distribution of actual values for trips, movements, persons, households across municipalities 50
Figure 31: Relative share of modes of transport of all movements for each municipality........................51
Figure 32: Relative share of motives of transport of all movements for each municipality......................52
Figure 33: Average emissions produced per person by all modes of travel across municipalities.............54
Figure 34: Average emissions produced per person by carbon emissive modes across municipalities........55
Figure 35: Relative share of modes of transport of all trips for each municipality....................................55
Figure 36: Average Car Trip Distance KM across municipalities..55
Figure 37: Average Emissions per Person per Day distributed over degree of urbanization......................56
Figure 38: Relative share of emissions produced by Car and Public Transport...57

LIST OF TABLES

Table 1: Research Objectives and Questions ... 11
Table 2: Characteristics of Travel pattern ... 16
Table 3: Emission factors ... 25
Table 4: Years of MON dataset ... 32
Table 5: Computation of Reclassified Movement Mode ... 35
Table 6: Computation of reclassified movement motives ... 37
Table 7: Reclassified Age groups ... 39
Table 8: Highest completed education ... 40
Table 9: Personal net Income classes ... 41
Table 10: Trip modes of carbon emission calculation ... 42
Table 11: Carbon Emission Factors ... 42

1. INTRODUCTION

1.1. Background

In recent times, the transport sector is a major focus of concern for the environment around us and in terms of prospects for sustainable development. It continues to grow rapidly and further proliferates in the years to come. Environmental consequences from the transport sector appear to be difficult to control with the projected growth. In particular, this sector has proved to be the fastest growing contributor to greenhouse gas emissions including carbon dioxide (CO,), nitrogen oxides (NOx), carbon monoxide (CO), volatile organic compounds (VOCs) and others (Acutt & Dodgson, 1996). Moreover the share of emissions generated by the transport sector in the total greenhouse gas emissions is expected to increase between 30 and 50% by 2050 (Hoen et al., 2009).

With an 18% share in the year 2008, the transport sector is considered as a significant emitter in the total share of greenhouse gas production within The Netherlands (European Environment Agency, 2010). An increase of 36% was observed in the total carbon emissions generated from the sector of transport between the year 1990 and 2008 (Netherlands Environmental Assessment Agency, 2010). This increase can be attributed to two main reasons: higher consumption of fuel and subsequent increase in emissions produced from road transport. The carbon emissions increased by more than 35% between the years of 1990 and 2008 from road transportation (European Environment Agency, 2010). In actual figures, road transportation accounts for 38.5 metric tonne (Mton) of carbon emissions or makes up for 18.9% of the total emissions generated by the Dutch economy in year 2008 (Rossum & Schenau, 2010). The emissions from road transport comprise of road vehicles as that of cars, cabins, lorries, delivery vans, buses, mopeds and motorbikes (Rossum & Schenau, 2010). In the same year of 2008, other chief modes including emissions produced from water transport account for 7.9 Mton CO_2 emissions, or 3.9% of the total share of Dutch economy. The modes in this sector incorporate seagoing shipping, inland navigation and fisheries. Increasing share of air traffic, accounts for 14 Mton CO_2 emissions, or 6.8% of the total share of Dutch economy in same year 2008 (Rossum & Schenau, 2010).

To reduce these emissions, the Dutch climate policy aims to meet its targets as set in the Kyoto Protocol in achieving carbon emission reductions for the medium long period (2020) as has been decided upon with the European Union. The target set within the Kyoto Protocol was at 6% reduction in carbon emissions during the period of 2008-2012 in the case of Netherlands. Alternatively, certain specific

Key factor		**Schoon en Zuinig**
Fuel efficiency	1	Biofuels (first generation)
	2	Biofuels (second generation)
	3	CNG
Vehicle efficiency	4	CO_2 emission legislation passenger cars and vans
	5	Fiscal measures
	6	CO_2 emission reduction freight vehicles
	7	Innovation programme 'Car of the future'.
	8	Innovation in public transport
Driving efficiency	9	Public awareness campaign (eco-driving)
	10	Exploring modal shift towards energy efficient transport
Distance travelled	11	Road pricing passenger cars
	12	Road pricing freight
	13	Mobility management

Options 7, 8 and 10 are mainly research and demonstration programmes. These options are not discussed in this report, since no assessment of their effectiveness is currently available.

Figure 1: Clean and Efficient (Schoon en Zuinig) policy programme of The Netherlands

targets have been agreed by the Netherlands within the European Union (Statistics Netherlands, 2012). The Clean and Efficient (Schoon en Zuinig) Dutch climate policy has set 13 to 17 Mton CO_2 reductions as the target for the sector of transport by year 2020. Certain measures undertaken by the Dutch government have been highlighted in Figure 1 in order to achieve these set emission reduction targets (Hoen et al., 2009).
The key factors as mentioned in the above Figure 1 highlight the main aspects of carbon emission reduction in order to achieve the set targets for the year 2020. As a result, leading to 30% emission reduction from the base year of 1990 levels to year 2020, emissions from transport sector to be reduced by 13-17 Mton and reduction in consumption of energy by 2% (Hoen et al., 2009).

Thus, transport sector is a significant emitter of The Netherlands and carbon reduction targets have been set to mitigate these emissions. However, as can be understood from above, the chief sector within transport that leads to higher emissions is that of road transport. Key factors have also been considered within the Dutch climate policy as that of vehicle efficiency and distance travelled (see Figure 1) to mitigate these emissions level. Apart from freight transportation, emission reduction from road transport is focussed on passenger cars (see Figure 1) as assessed by the Dutch climate policy. Ever since 2005 the total number of cars have grown over a million and in 2012 approximately 7.9 million cars were registered within the country (Central Bureau of Dutch Statistics, 2012). However, in particular, CO_2 emissions increased by 29% from the 1990 levels resulting from the use of road vehicles by households. The reasons for this increase can be attributed to several factors encompassing increasing growth in population, higher ownership of cars, traffic intensity (number of kilometres driven per car) and a CO_2 emission factor (emissions produced per kilometre driven). If we consider actual figures there were three cars per ten Dutch inhabitants in the year 1990 while the number had increased to four cars per ten Dutch inhabitants in the year 2012. Many households in the present scenario, own a second car that is used for making primarily short trips (Statistics Netherlands, 2012).

Thus we can say, that the main focus in order to achieve the set targets for emission reductions has been placed on vehicle technology fixes through fuel efficiency, vehicle efficiency and implementing economic instruments including road pricing for vehicles (see Figure 1). However, to mitigate these carbon emissions at a personal level, it is essential to identify the "emitters" encompassing different sections of the society and analyze "how much" is the contribution of these population segments. This debate is thus hampered by the insufficient available information on the distribution of the CO_2 emissions among the population segments. In particular this refers to the emission distribution on daily and yearly travel activity at the personal level. However, this insufficient data makes development of policies difficult (Brand & Boardman, 2008). Thus, this research aims to address this part of the debate and studies the CO_2 emission distribution from personal travel across different modes of transport and in different segments of the population.

1.2. Justification

Transportation since long before has caused environmental problems, especially global warming from carbon dioxide, which is an outcome of continuous growth in personal travel and its associated environmental costs (Schafer & Victor, 1999). So far, personal travel in terms of passenger kilometres travelled is constantly increasing and being associated with consecutive shifts towards motorized transportation modes (Frändberg & Vilhelmson, 2011).

However, not much substantive information is available on the composition and distribution of carbon emissions resulting from the personal travel, particularly at disaggregated levels of individual and household level which forms the basis of this research. Travel activity pattern is important to derive carbon emissions at the personal level (Brand & Preston, 2010). Brand et al. (2013) highlighted the various determinants of personal travel and in particular trip distances which resulted in suggesting that variations can be observed in travel patterns based on socio-economic, demographic and personal characteristics. Some of these characteristics include mode choice, income, employment status, housing tenure and car ownership which proved to be greatly associated to the carbon emission levels (Brand et al., 2013). Travel patterns also vary according to characteristic features highlighting whether more trips are undertaken with people who have access to car and travel further in comparison to those who do not have one. Thus socio-economic characteristic as that of income is strongly related with car access. Income relates to the number of trips made and the subsequent distance travelled (Brand & Preston, 2010).

Brand and Preston (2010) stresses on the volume of car travel which forms a key strategic component for carbon emission reductions including other approaches of vehicle technology fixes and fuel switching. As Brand et al. (2013) suggests if more and more car trips are replaced by using zero emission modes of walking and cycling, the transport emission reduction targets are achievable.

Recently, there has been a growing body of literature in analyzing, 'who' is adding on to the rising emissions, what is the emission profile of this segment of population (Brand & Boardman, 2008). These include studies by Hillman and Whalley (1983), Banister (1993), Hughes (1993), Greening et al. (1997), Anable et al. (1997) and more recently, Greening (2004), who have been successful in identifying different subgroups of the population. These have been defined by a range of socio-economic, demographic and personal characteristics that contribute to emissions from personal motorised transportation and will be of key concern in this research.

The topic of this study is of prime concern in transportation planning and initiates an explorative effort to analyze travel pattern related carbon emissions.

From a planning perspective, transportation plans take under consideration carbon emission mitigation. Practitioners address the aspect of emissions through several key elements that exist within the transportation plans. These elements directly integrate emissions by clearly addressing carbon emissions, and indirectly by mentioning the elements of transportation that are associated to carbon emissions.

Mitigation of carbon emission can easily be incorporated as a stand-alone goal in plans of transportation. Planners can indirectly integrate this by laying stress on linkages between existing goals of transportation plans and emissions. Increasing emissions from transport sector are significant long term trends considering VMT (vehicles miles travelled) growth, fuel switching, traffic congestion etc. performance measures can be helpful in assessing whether the emission objectives are met or not. These measures are unique to undertake low carbon strategies (for example, CO_2 emissions per capita, petroleum use per VMT, percent of alternative fuel vehicles) or linked to conventional transportation planning goals as that of traffic congestion or air quality (example, transit mode share, average vehicle occupancy). These performance measures can therefore be used in evaluating the present system, comparing and selecting possible alternatives, and measuring the plan progress throughout its phase of implementation (ICF International, 2008).

As an example, among many roles of transport planners, they assist the transport agencies in reducing the amount of on-road travel, initiating shifts in passenger trips from car to public transport use, walking and biking. They assist these agencies to the extent that they are in a state to provide more modal options and thereby improve the ease of transfers between the transport modes. This will result in passengers being able to choose an alternative mode for at least a part of each journey. Thus multimodal transportation systems need to be organized so as to initiate shorter travelling distances and fewer trips by car. However private car travel is inaccessible for many individuals belonging to low income, elderly groups and children. The systematic provision of alternatives enhances the mobility of population groups and thereby helps in carbon emission reductions (ICF International, 2008).

In recent times many transportation plans incorporate carbon mitigation in a hierarchical policy structure (Vision – Goals – Policies – Strategies). The position of these emissions differs from plan to plan within a particular structure. Some plans incorporate a stand-alone goal related to it whereas the other plans include policies linked to carbon mitigation under one or many goals. Finally, few plans also include performance measures that are based on these emissions and may include various travel characteristic features that also form a part of this study (ICF International, 2008).

1.3. Research Problem

With an 18% share in the year 2008, the transport sector is considered as a significant emitter in the total share of greenhouse gas production within The Netherlands (European Environment Agency, 2010). An increase of 36% was observed in the total carbon emissions generated from the sector of transport between the year 1990 and 2008 (Netherlands Environmental Assessment Agency, 2010). This is primarily attributed to the subsequent CO_2 emissions increased by more than 35% between the years of 1990 and 2008 from road transportation (European Environment Agency, 2010). On-road transportation seems to be the highest net contributor to climate change. This is because vehicular emissions contribute to the rising CO_2 levels which is considered as a strong greenhouse gas and equally important air pollutant (Olivier et al., 2011).

However, to mitigate these emissions a target was set within the Kyoto Protocol at 6% reduction in carbon emissions during the period of 2008-2012 in the case of Netherlands. Alternatively, certain specific reduction targets between 13 to 17 Mton by year 2020 have been agreed by the Netherlands within the European Union (Statistics Netherlands, 2012). The main focus in order to achieve the set targets for emission reductions has been placed on vehicle technology fixes through fuel efficiency, vehicle efficiency and implementing economic instruments including road pricing for vehicles, thus laying stress on passenger vehicles that account for a major element in the road transport emissions (Hoen et al., 2009).

But nonetheless not much effort has been put to address carbon emissions at a personal level. With an emphasis to make passenger car travel carbon friendly it is equally important to understand the travel pattern of these passengers. Typically, for personal travel, individuals differ in the distance travelled, mode use and purpose for a journey. These are characteristics features that ultimately describe a travel pattern and each of these differ in its influence on carbon emissions. Thus what is unknown yet is the distribution and composition of these personal travel induced emissions.

To achieve carbon reduction targets not only emissions produced from personal travel are important but also identifying the 'emitters' and analyzing 'how much' do these emitters contribute, is essential. Thus, another aspect that is unknown yet is which segments of the population make up for higher emission levels by studying their socio-economic composition.

Hence the main problem that this research will address is, '*How travel patterns at individual and household level contribute to carbon emissions and can be identified through associated socio-economic characteristics*'.

Further, the findings of this research may assist the transport sector in developing their carbon mitigation policies. The usefulness of studying various characteristics of travel patterns operate as environmental indicators of vehicular emissions that would prove to be helpful in environmental monitoring and policy assessment for the transport sector (Stead, 1999). In addition, travel emission profiles at different levels of personal travel including individual or household can be used in developing information, measurement and forecasting tools that may be used (a) to assess and monitor policies and strategies of transport sector (b) raise awareness, feedback and advice to individuals and households (c) aggregate emissions forecasting (Brand & Boardman, 2008). To be able to target those individuals and households with a higher share of car ownership and thus provide possible alternatives to commute by car while assisting in planning policies that focus on reducing commuting distances which may provide an effective approach in achieving the set carbon mitigation targets (Brand et al., 2013).

1.4. Research Aim

To address the research problem, the main aim of this research is, **'To identify emission profiles on the basis of observed personal travel patterns, and to relate these to socio-economic and spatial characteristics of individuals and households in the province Overijssel'**.

1.5. Research Objectives and Questions

To reach the main aim of the research, following objectives and questions have been considered:

OBJECTIVE		RESEARCH QUESTION
1	To review and conceptualize personal travel and its relation with carbon emissions	• What are the relevant characteristics to describe travel patterns? • How can travel patterns be related to carbon emissions? • Are travel related carbon emissions associated with specific socio-economic characteristics?
2	To develop a methodology to describe travel patterns, calculate carbon emissions and relate these with socio-economic characteristics	• Which of the methods reviewed for travel and socio-economic characteristics will be adopted based on the available disaggregated dataset? • Which method is the most suitable to calculate carbon emissions?
3	To analyze the calculated travel pattern related carbon emissions	• How are travel emission profiles related to the socio-economic composition of a household, including income, education, economic activity, age, gender and car ownership? • How travel pattern related emissions are spatially distributed?

Table 1: Research Objectives and Questions

1.6. Case Study

For this research, Overijssel, a province situated in the central-eastern part of the country of The Netherlands was selected as the case study area (See Figure 2). The case study area has been selected based on the availability of the dataset (Mobility Survey Netherlands) which will meet the requirements for studying the research aim and objectives. A brief description about the province continues in the paragraphs to follow.

In terms of demographic statistics, the population of this province comprises of over one million inhabitants with a population density of 342 inhabitants/km^2. It consists of 25 municipalities of which Zwolle, Deventer, Enschede, Hengelo and Almelo constitute 46.8% of the total population (Provincie Overijssel, 2013d).

In terms of the state of travel and transport, Overijssel has experienced considerable growth over the past 25 years in the total number of kilometres travelled by its inhabitants which increased by around 40% in 2010 as compared to 1985 (Provincie Overijssel, 2013c). Out of these passenger kilometres travelled more than three quarters have been made by car as a driver or passenger (Provincie Overijssel,

Figure 2: Case Study Area

2013c). Substantial growth has been projected by the government in the number of private and commercial vehicles, motorcycles and mopeds in the coming years (Dutch Daily News, 2011). Bicycles on the other hand, are usually preferred to cover shorter distances and since 2011 the potential share of electric bicycles is growing significantly (Provincie Overijssel, 2013a). Public transport including train and bus services are also potential transport alternatives and are of popular use by its inhabitants along with non motorized mode of walking. With such a variety in the modes of travel that people could opt for, car and bicycles are seen as more popular modes of transport within the province (Provincie Overijssel, 2013c).

1.7. Conceptual Framework

The conceptual framework of this research (see Figure 3) incorporates three principal concepts of travel patterns, travel emissions profiles and its associated socio-economic characteristics. The first concept is to reach to the aim of the research by describing the concept of travel pattern, identifying its main characteristics (e.g.: mode, motive, and distance travelled) on the basis of a literature study. The second concept concerns carbon emissions. It will be explored how carbon emissions can best be estimated on

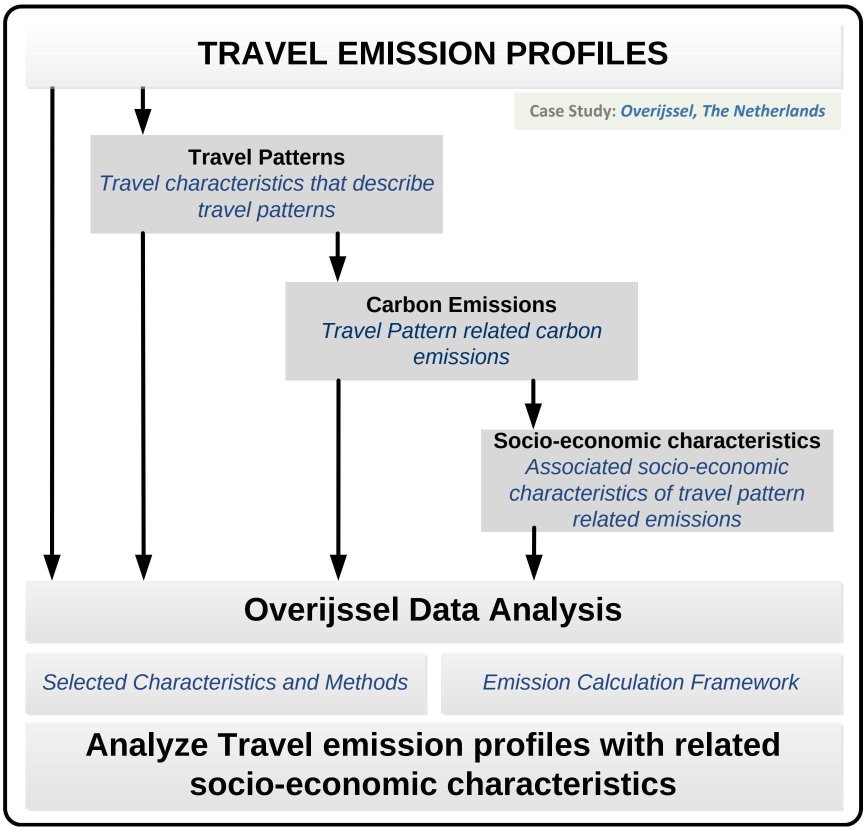


Figure 3: Conceptual Framework

the basis of selected travel characteristics. This exploration is again based upon literature. The third concept identifies "who" contributes "how much" to the emission levels and thus aims to associate specific socio-economic characteristics with travel induced carbon emission levels. All the three concepts are furthermore empirically undertaken using a sample based dataset of the case study area of Overijssel, The Netherlands.

To conclude we can say that the conceptual framework highlights what are the travel patterns, how do these travel patterns influence carbon emissions to generate travel emission profiles and further how these travel emission profiles relate to socio-economic characteristics in identifying who are the emitters contributing to higher travel emissions levels.

1.8. Research Methodology

The research methodology (see Figure 4) explains the workflow for the study and mentions the concepts highlighted in the conceptual framework. As explained in the figure below the research objectives and questions are addressed by undertaking a literature study on the three main concepts of travel patterns, carbon emissions and related socio-economic characteristics. Each of these will study, the travel characteristics defining travel patterns, methods for carbon emission calculation and methods and characteristics to derive socio-economic composition of emissions. Thus, these concepts will be analyzed using a sample data set for the case study area of Overijssel and the selected methods from literature will be implemented to analyze travel emissions profiles with related socio-economic characteristics.

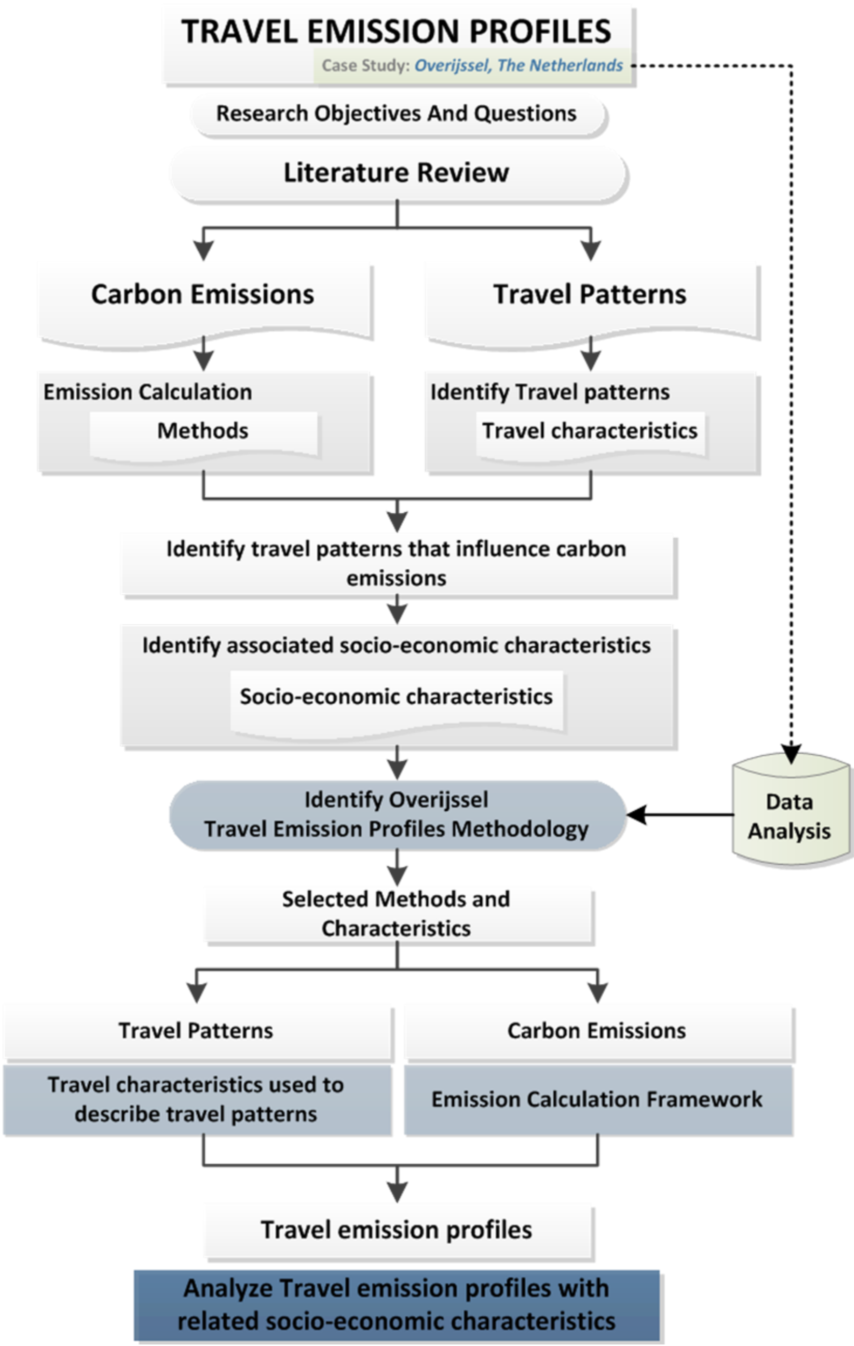


Figure 4: Research Methodology

1.9. Thesis Structure

The research is divided into five chapters that are briefly described here.

Chapter 1:

This provides an overview of the research topic of 'Travel Emission Profiles' constituting the background and justification of the topic; research problem, aim, objectives and questions, conceptual framework, a concise introduction to the case study area, relevance of the study and thesis structure.

Chapter 2:

This comprises literature review on the principal concepts of the study i.e. travel patterns, travel emissions and related socio-economic characteristics. It ranges from how personal travel patterns can be defined; what travel characteristics will it include; how does it affect emissions in turn, specifically why carbon emissions; what are the methods to calculate carbon emissions and which methods can be used to relate socio-economic characteristics to carbon emissions.

Chapter 3:

This comprises of three distinct sections. Section I focuses on the available sample dataset (Mobility Survey Netherlands) to be used for the study highlighting the description of the dataset, Section II focuses on units of analysis and Section III explains the methods used to undertake analysis; constituting the methods used to analyze travel patterns (using travel characteristics from Chapter 2), the procedure of estimating travel related carbon emissions and methods used to analyze travel emission profiles with related socio-economic characteristics.

Chapter 4:

This represents the results generated by applying methods (from Chapter 3) using the statistical and spatial approaches to analyze travel patterns, its related travel emission profiles and socio-economic characteristics based on the available sample dataset.

Chapter 5:

This comprises of conclusions and discussion of the study that highlights completion of research objectives and questions in the allocated time frame, shortcomings of the study and recommendations for future studies.

2. LITERATURE REVIEW

The debate on lowering carbon emissions from travel and transport has reached an imperative and crucial stage. Personal travel contributes a significant proportional share in these emissions as indicated previously. In this chapter extensive literature explains how are personal travel patterns described, which travel characteristics have been considered important in describing a travel pattern, in-depth knowledge on travel induced carbon emissions, methods to calculate these emissions and further which methods are best suitable in identifying the socio-economic composition of these emissions.

2.1. Travel Growth

Travel highlights activity participation, interrelationships of trips and movements and interactions amongst members of the household. Human activity is an output of actions that satisfy needs and travel fulfils these needs by participating in various activities. Individual travel patterns are determined subsequently by such involvement in distinct activities (Schafer & Victor, 1999).

Changing lives, rising incomes, inability of efficient provision of public transport have all led to continuous rising of yearly mileage per vehicle (Anable et al., 1997). Nonetheless, the car constantly remains the main mode of travel for all journey purposes. Although a change can be witnessed in the patterns of journeys with different modes of transport, but there still persists an insatiable demand for travel by car which leads to unsustainable volumes of traffic and congestion, posing environmental concerns in many areas (Anable et al., 1997).: In the year 2006, personal travel accounted for an average of 34 kilometres daily within the European Union, out of which 26 kilometres were travelled by passenger cars alone (Eurostat, 2009).

Thus it is not surprising that the number of cars in EU-27 grew at an average yearly rate of 2.4 % from 1990 to 2006. While the number of cars continued to expand, transport alternatives also grew of buses and coaches with a yearly average of 0.7% and developments in the rail transportation. Although when compared with cars it is considerably lower but may help to initiate a modal shift in the years to come (Eurostat, 2009).

In May 2007, a survey published modes of transport preferred for travelling by EU citizens from a variety of options including public transport and non-motorized including cycling and walking. 81% of the citizens declared having a car in their household and a majority of 51% named it as their chief mode of travel. This was followed by use of public transport (21%), walking (15%), cycling (9%) and the motorbike (2%) (Eurostat, 2009). However, it has been recognized that cars make up for the largest and most environmentally damaging subsector of transport and thereby effective policies should be implemented to mitigate its detrimental effects (Fergusson et al., 1989).

2.2. Travel Patterns

Satisfying human needs from basic to needs for self-fulfilment is a fundamental state of human existence. (Maslow, 1943). The need to travel can't be met in situ (Becker et al., 2008). To be able to meet these needs, people should cover distances. The way these movements take place will largely depend upon a variety of individual factors such as attitudes and opportunities, and places of activities distributed over space. An underlying principle in the research for transportation states that demand for travel is derived from the need to take part in activities that are spread over time and space (Basmajian, 2010; Mokhtarian et al., 2001). This leads us to the question of how does movement of people and their activities derive a travel pattern.

In recent times, the vast growth in personal travel can be attributed to a number of characteristics including rising car ownership, falling car occupancy levels and increasing average trip lengths (Brand & Boardman, 2008). With increasing research in this field of study, many studies as described below use different characteristics to define a travel pattern. As explored by Stead (1999) characteristics as that of journey distance, journey frequency, travel time, and modal share have been used to describe a particular pattern of personal travel (see Table 2). According to Stead (1999), most of these characteristics have been defined in terms of modes of transport like car, foot, public transport, cycle and described by their distances, purpose (as work or non work related), time of travel and frequency in terms of number of journeys made. Similarly, travel characteristics as that of travel distance, mode of transport, journey frequency and travel time have been used to understand and examine travel patterns (Stead & Marshall, 2001). In few other studies, travel patterns have been described through a daily activity being performed which includes a variety of components as that of activity type, duration, location, mode choice and transition (Kitamura et al., 1997). These studies focus on how people tend to spend their time and recently the spatial component of urban activity patterns have been studied with activity locations. Thus the term of 'activity patterns' is synonymously used with the term of 'travel patterns' (Hanson & Hanson, 1981). Characteristics of these travel activity patterns incorporate frequency of travel for different motives or purposes, travel time and distances travelled for different purposes and mode of transport used (Hanson & Hanson, 1981).

Characteristics	Travel pattern examined
Journey distance	Travel distance by all modes
	Total work distance by all modes
	Total non-work distance by all modes
	Travel distance by car
	Average journey distance
Journey frequency	Number of journeys by all modes
	Number of journeys by car
	Number of journeys by public transport
	Number of journeys by foot
	Number of journeys by cycle
Travel time	Travel time by all modes
	Travel time by car
	Average journey time
Modal share	Proportion of journeys made by car
	Proportion of journeys made by public transport
	Proportion of journeys made by foot
	Proportion of journeys made by cycle

Table 2: Characteristics of Travel pattern

Source: Stead (1999)

Thus, to summarize from these above mentioned studies, travel patterns of an individual or household can be attributed to a number of key characteristic features. These encompass frequency, mode use, distance travelled, purpose (activity), travel time and location which will describe the personal travel pattern for this research. Therefore, each of these travel characteristics will be further explored in detail.

2.2.1. Mode of travel

In recent decades, greater importance has been placed on automobile modes of travel than public transport. The automobile mode i.e. car primarily serves shorter urban and commuter necessities (Penner et al., 1999). Kingham et al. (2001) suggests that even though many of these car journeys could be taken by foot, bicycle or bus but instead people still increasingly use cars. Also, Banister (2005) believes that *"car is both socially and spatially divisive as it allows cities to spread with the consequences that all people have to travel much longer distances than before, with space becoming something that you want to pass through rather than to stop in"*. But more recently used alternative modes of transport to cars are fast growing rapidly in the form of zero carbon emitting walking and cycling and electric buses/trains/trams and metros (Banister, 2005). To critically analyze which mode of transport emits higher carbon emissions it is important to take into account multiple determinants as mentioned in the paragraphs as under.

The mode of car has the most significant influence on carbon emissions. Cars produce the largest emission levels. A household having the total number of cars have a significant influence on the household's carbon emissions. It thus helps in assessing the individual or household travel emission profile. Therefore, car ownership acts as an important determinant influencing emissions.

The emissions induced by different modes of transport can be distinguished based on their fuel type. In comparison to petrol vehicles, diesel vehicles have considerably lower carbon emissions produced per kilometre travelled. This is because diesel engines are comparatively more efficient and thus have a lower impact on emissions (Department for Transport, 2013). Alternative fuel types of LPG and CNG run vehicles, mostly converted from petrol fuelled vehicles tend to fall between the CO_2 performance of petrol and diesel vehicles. This is because LPG and CNG vehicles have lower carbon content while a higher content of energy by mass of fuel. On the other hand, CNG vehicles have even lower carbon emissions than LPG, mostly comparable to emissions of diesel run vehicles (Department for Transport, 2013).

Another major determinant of mode of transport used to influence emissions is that of engine size and temperature. Vehicles with larger engines consume more fuel and emit more carbon dioxide. Calculations by (Gover et al., 1994; Stead, 1999) suggest that vehicles with large engines produce at least 50% more emissions of carbon dioxide than vehicles with small engines operating under similar driving conditions. There is often a large difference between the most and the least efficient vehicles within each engine size range. For example, the fuel consumption of various petrol cars with a 1.3 l engine can range from 11.8 to 18.5 km/l: a difference of 57% (Sorrell, 1992). Factors such as turbo charging, fuel injection, vehicle weight and two/four wheel drive are quoted as reasons for this large variation.

On the other hand, engine temperature influences emissions when it is cold and thereby tends to increase emissions (Gover et al., 1994). This is correct for both petrol and diesel engines. Fuel efficiency is likely to be 25% lower under cold conditions. High emissions under cold conditions can be expected for around the first 3 km of the journey (Eggleston, 1992). A large proportion of pollutants are produced under cold conditions as large share of journeys are made by car and it is important to highlight that most car journeys begin from cold-starts (Gover et al., 1994).

Vehicle speed also majorly affects emissions produced that vary across different modes of transport. At low speeds, high emission levels are the consequence of ineffective engine conditions. According to Anable et al. (1997), cars are usually designed to operate most efficiently at road speeds between around 80 and 95 km/h for petrol cars and between around 65 and 80 km/h for diesel cars.

Emissions varying across all modes of transport are largely influenced by vehicle occupancy and the age of the vehicle. Simple calculations have shown that the emissions of carbon dioxide per passenger-kilometre from a medium sized car carrying two passengers are similar to those of a minibus carrying three passengers (Stead, 1999). Vehicle age on the other hand influence emissions in two ways Anable et al. (1997). Firstly, age is often a substitute for the general state of maintenance—the older the car, the less well maintained it is likely to be. Secondly, age is related to vehicle technology—newer cars are likely to have more fuel-efficient features. Thus as vehicle age increases emissions also likely to increase.

There can be many other determinants of travel influencing different modes of transport and thereby have an effect on the carbon emissions generated from these modes. It basically explains on what basis the emissions generated from different modes are dependent on and thus varies in their emission levels.

These have been defined primarily to understand the different determinants that influence emissions generated from mode of travel and will not necessarily be used in this study.

2.2.2. Purpose of Travel

In everyday life, people engage in four main roles: the household/family role, the work/career role, the interpersonal/social role, and the leisure/recreation role. These roles can be transformed into standard trip or journey purpose categories incorporating shopping, personal business, work, social and recreation. The priority that the individual holds in carrying out each of these activities is considered important in determining the time that is allocated to each of these purposes, how frequent the activity has been undertaken and the distance one is willing to travel for the purpose (Hanson & Hanson, 1981).

Many studies have represented a higher share of car use for work related purposes and considerably lower use of public transport and bicycle use. However if transport access improves with a good network of bicycle paths, people have shown willingness in their travel by bicycle for their work purposes (Kingham et al., 2001).

In most cases, leisure travel amalgamating shopping, social and recreational activities are mainly associated with using one's car, with all the well known effects of it inducing higher emissions. Also studies have shown that places of social interaction are well accessible by public transport but still private transport is more dominant in these areas (Schlich et al., 2004). In activities as that of sports, the share of people travelling by public transport is considerably less and most people prefer to use private transport or non-motorized exclusively. Despite a higher dominance of privately used modes of transport in general, it does not hold strong for all purposes of travel and people and may vary significantly (Schlich et al., 2004).

2.2.3. Distance Travelled

Increasing travel is a product of the distances travelled in terms of vehicle kilometres travelled. It is important to note that the destination one wants to travel to, its accessibility, route to be chosen and mode of travel taken, are all factors that affects the distances travelled. Distances travelled over space grew considerably as society became increasingly associated with the use of car with people located further from workplace and school and to access basic amenities and leisure facilities (UK Energy Research Centre, 2009).

Developing faster travel alternatives as that of public transport leads to longer travel distances and offer much lower emissions per passenger when compared to private cars (UK Energy Research Centre, 2009). Studies have proved that taking the bus for longer distances have led to the lowest emissions of all public transport alternative modes (McDermott, 2012). However, this is not the case for inner city travel by the bus as many traffic jams, detours, pit-stops may arise, producing inconsistency in the engine speed and temperature leading to higher emissions. The least carbon intensive mode of travel to cover distances is ultimately the electric trains as they emit even lesser emissions and are developing at a rapid pace in comparison to those powered by coal that produces more emissions (McDermott, 2012).

We can thus state, that the distances travelled are also highly dependent on mode of travel.

2.2.4. Travel time

The variable of travel time is considered as a significant variable in describing a pattern of personal travel and in assessing travel induced emissions (Stead, 1999). The individual accounts for his/her feasibility in travelling at different time intervals of the day, mostly during off-peak and peak periods (Department of Transport, 2012).

2.2.5. Frequency

The individual takes into account whether or not the purpose for which the journey or trip is being made is worthwhile or not. The aggregation of all micro decisions of an individual determines the number of trips or journeys that will be undertaken (Department of Transport, 2012). The frequency of journeys or trips also depends upon the different modes of transport that has been used (Stead, 1999).

2.2.6. Geographical Location

Individual and household travel emission profiles are examined and analyzed based on geographical location, which can effect emissions greatly. Brand and Boardman (2008) highlight that the variation in average emissions produced by rural areas stand different in urban area. While average emissions from car travel are higher in rural, average emissions from air travel are higher in urban areas. This component helps in analyzing geospatial analysis of travel emissions, representing the location of highest and lowest emitters and distribution of modal share for all individuals (Brand & Preston, 2010).

Many other factors such as driving style, catalytic converters, vehicle type also act significant in affecting emissions. Driving style incorporating the effects of overall speed, acceleration, deceleration has considerably different impacts on emission levels. In previous studies it has been stated that 10 to 15% of fuel can be saved by avoiding faster acceleration and change of gear use (Stead, 1999). It was thus reported that 'expert driving' can directly reduce 9% in fuel used in driving conditions in an urban area while 10% can be reduced under driving conditions in a suburban area or 24% fuel reduction in the case of motorway driving compared to the 'usual' driving style (Stead, 1999).

Conclusion: Thus to summarize we can say that travel patterns have been described by using various travel characteristics as explained above but all of them will not be used in this study due to limited time frame and availability of the sample dataset. However in this research we will describe travel patterns based on six main characteristics of mode of transport used, purpose, distance travelled, travel time, journey frequency and geographical location. Each of these have been stated important in the study of travel patterns relating to carbon emissions, as can be understood from above. Thus these characteristics will be explored further in detail and empirically analyzed in the following chapter based on the case study area of Overijssel.

However, to be able to describe a travel pattern it is important to understand how such kind of a dataset will be collected to study these distinct patterns. In many studies Brand and Boardman (2008) highlight that data for travel activity was collected from National Travel Survey (NTS) in the UK. These surveys aim to collect data at a disaggregated level such as households or individuals in a timeframe pertaining to a week. However, the disadvantage with such a dataset excludes international travel and gives information only on trips made within a country. Similarly, within the Netherlands, there is the Dutch National Travel Survey (NTS) providing data on individuals, households, their journeys and trips for the past three decades. Uptil the year 1993, NTS has recorded data for almost 10,000 households, 20,000 individuals and more than 80,000 trips. In the year 1994 and 1995 NTS was further extended to be able to include more respondents, including children younger than 12 years who were earlier excluded from the dataset (Susilo & Stead, 2008). Consequently, the Dutch NTS dataset was collected since 1978 until 2003 (DANS, 2007). However, in continuation to the Dutch NTS dataset, a new dataset was introduced referred to as the Mobility Survey Netherlands (MON) that became functional from 2004-2010 and forms the sample data for this research (DANS, 2007).

Alternatively, Brand and Boardman (2008) and Brand and Preston (2010) in the UK, proposed a new method for data collection using traditional paper-and-pen-based and web-based surveys including all transportation modes and information on air travel to provide a more holistic and complete picture of travel activity at the disaggregated levels of households and individuals based on weekly and yearly estimates.

In some other studies, the information collected through surveys was much more centric on the journey purpose of travel activity. Brand et al. (2013) used surveys to particularly assess travel activity based on five distinct journey purposes. These included to and from work; to and from school or place of study; in the course of business; for shopping and personal business; and for visiting friends or relatives or other social activities.

Further, the data analysis for these travel patterns are based on their travel characteristics as described in the studies. To state an example, Brand and Boardman (2008) concluded the chief modes of travel of air and car covering the largest distance travelled. If we analyse geographical location, respondents travelled less by car and air (73%) residing in medium and large urban areas as compared to respondents residing in small and rural areas (87%). On the other hand, respondents travelled much higher by public transport (rail, bus, coach, taxi) residing in large and medium urban areas. This reflects good provision of public transport. Additionally, to gain confidence in the estimates of the study, a comparison was made with the national statistics of the average distance travelled per person, so as to highlight if the estimated travel activity figures compare well.

Similarly, in a study that was conducted in analyzing the travel patterns in The Netherlands, stated that there was substantial change in the patterns of personal travel between 1990 and 2005 (Susilo & Stead, 2008). Between the period of 1995 and 2005 the average distance travelled per person per day, speed of travel undertaken and travel time changed significantly as analyzed from the Dutch NTS dataset. Average trip distance by public transport (bus/tram/metro) and bicycle experienced a decline by 30% and 15% respectively between the time period of 1995 and 2005. On the other hand, average trip distance by motorcycle experienced an increase by more than 50% during the same time period. What considerably changed is the average number of trips that decreased by 14% over the same period and travel related carbon emissions experiences an increase on average by 16% within the same time period. Thus the increase in per capita can be primarily attributed to decreasing travel distances by bicycle and public transport while increasing travel distances by more carbon emissive modes such as motorcycle for specific frequent trips (Susilo & Stead, 2008).

2.3. Travel Induced Carbon Emissions

Transport constitutes the fastest growing sector and major source of emissions, especially those related to the accumulation of greenhouse gases in the atmosphere. Climate change, the subject of increasing concern world-wide, is the result of carbon dioxide and to a lesser extent other greenhouse gases such as nitrogen oxides, CFCs and methane building up in the atmosphere and limiting the amount of heat that can escape. Carbon dioxide is produced wherever fossil fuels are burned. The quantity of carbon dioxide emitted is directly related to the carbon content of the fuel, primarily from the private use of transport (Anable et al., 1997).

The transport sector within the Netherlands constitutes civil aviation, road transportation, railways and water-borne navigation. Emissions that are produced from domestic aviation make up for 'civil aviation' constituting air travel of arrival and departure within the country. Similarly, emissions produced from domestic inland navigation accounts for 'water-borne navigation'. 'Railways' and 'Road transportation' constitute emissions produced from fuel sold to both these sectors within the country (Netherlands Environmental Assessment Agency, 2010). A brief of emissions produced by all these sub-sectors of transport have been explained below.

Dutch national emissions in the year 2008 comprised of 206 Mtons CO_2 equivalent, about 3% below the carbon emissions produced in year 1990 (European Environment Agency, 2010). The transport sector is accountable for 18% of total greenhouse gas emissions produced within the country (European Environment Agency, 2010). Between the period of 1990 and 2008, the total emissions from the transport sector increased by 36% in the year 2008 (Netherlands Environmental Assessment Agency, 2010). This increase is mainly attributed by increasing fuel consumption and subsequent increase in emissions produced from road transport. In the year 1990, road transport contributed 16% of carbon emissions while it increased to 20% in 2008. Major proportion of this increase in emissions is due to increasing diesel use. Diesel run vehicles increased by 76% due to tremendous growth in freight transportation along with the increasing number of passenger run diesel cars and light duty vehicles. This resulted in increasing share of diesel in fuel sales to road transportation during the period of 1990 and 2008 (Netherlands Environmental Assessment Agency, 2010).

Emissions produced from rail transportation accounted for 0.1% in the share of total greenhouse gas emissions in between 1990 and 2008 (Netherlands Environmental Assessment Agency, 2010). This significant decline is due to decreasing diesel consumption in rail traffic and increasing share of electric locomotives from 10% to 22% over the same period (National Institute for Public Health and the Environment, 2011). Emissions produced from civil aviation was also less than 0.1% in the share of total greenhouse gas emissions between 1990 and 2008 (Netherlands Environmental Assessment Agency, 2010). Emissions produced from water-borne navigation were also relatively low in the share of total greenhouse gas emissions and is primarily because of emissions induced by inland shipping (National Institute for Public Health and the Environment, 2011; Netherlands Environmental Assessment Agency, 2010).

Implications of emissions from transport

Transport sector is one of the fastest growing sectors and is projected to grow further, thereby constituting a major source of emissions. Greenhouses gases such as carbon dioxide and to a lesser extent nitrogen oxides, methane, chlorofluorocarbons etc. building in the atmosphere, limits the fraction of heat that can escape, thereby resulting in climate change, a grave concern worldwide.

As we already know, carbon dioxide is one of the most abundant greenhouse gases and is not always regarded as an air pollutant as it has no effect on the health of humans in comparison to other greenhouse gases. However, it is responsible for 50% of global warming due to its increasing concentration levels and longer lifetime. This gas is a product of burning of fossil fuels. The quantity of CO_2 emitted in the atmosphere is directly associated with the carbon content of the fuel. The extent of petroleum products used by the transportation sector has augmented considerably, mostly from private transport. As a result, energy consumption from road transport alone acts as a major contributor to CO_2 emissions, producing over a fifth of the total production. (Anable et al., 1997).

International agreements started to take up emission reduction as a serious challenge which began with 1992 Earth Summit when 150 countries signed for CO_2 emission reduction strategies. Wherein emissions from domestic, industrial and commercial started to decline, transport continued to grow further (Anable et al., 1997). Royal Commission on Environmental Pollution (1994) proposed that specific targets should be implemented relating to the sector of transport to reduce CO_2 emission levels. However, newer means and technologies in the form of vehicle and fuel technologies have been a major improvement in tackling vehicular emissions. In lieu of the same, the European Commission (EC) has enforced limits to comply with pollution standards for all the cars sold after a specific date. These standards imply that a vehicle may emit a certain amount of pollutant per kilometre travelled (Royal Commission on Environmental Pollution, 1994).

An effective way to reduce these emissions is by reducing the amount of fuel used in vehicles. Although motor vehicles have become a lot more efficient, still the kilometres travelled and mode of transport used to cover those distances, is the root cause of increased use of fuel and carbon emissions. However, as trends overtime are undergoing changes in vehicle design and make, coupled with high traffic growth, emissions produced from road transport seem to be an intractable problem (Anable et al., 1997).

With the newer technology of catalytic converters for motor vehicles, emissions will significantly reduce in the short term of greenhouse gases like nitrogen oxides, carbon monoxide, hydrocarbons etc. But it will rise again in the longer term, once the growth in vehicle use increases. The principal reason for this is that short journeys with cold-starts undertaken by motor vehicles, has an effect on the catalyst performance, during which emissions only increase and not improves with this technology (Hughes, 1993).

However, low carbon intensive improvements in technology and transport infrastructure in the form of battery operated electric vehicles, transition to alternative fuel use like bio fuels, modal shifts to public transport use needs to be acted upon strongly for faster emission control. Hence, the main emphasis in the calculation of emissions from personal travel has been placed on this carbon dioxide gas.

2.4. Travel emission calculation

This section explores the different kinds of dataset used in various studies along with different methods that have been used to calculate travel pattern related carbon emissions. Brand and Boardman (2008) and Brand and Preston (2010) developed a tool for emission calculation that consisted of series of interconnected spreadsheets and databases. It was designed to integrate data of travel activity with emission factors for each greenhouse gas pollutant for different modes of transport vehicle and travel characteristics. Local emissions factors were collected from national sources pertaining to a country's national agencies.

Susilo and Stead (2008) used a computer programme COPERT to calculate emissions developed for the European Environment Agency using NTS information for each trip characterized by its mode, distance, fuel type, vehicle age, fuel type, occupancy and speed. Carbon emissions were thus estimated based on these characteristic features. Each vehicle type had an equation that differed in its age, fuel type, travel speed etc. Emission calculation resulted in 17 different equations based on vehicle type and age as used within the study. In case of emission calculation for public transport, only travel characteristics of mode and distance were used with typical emission factors for the country of Netherlands.

Thus, this collected dataset is further used to calculate the carbon emissions using various methods as proposed in different studies by Zegras (2007), Anable et al. (1997) and Stead (1999).

Zegras (2007) proposed the ASIF framework for emission calculation. This framework is basically used in transportation energy use incorporating a function based on total activity (A), mode share (S), fuel intensity (I), and fuel type (F) (thus, ASIF). Many factors have an influence on each of these components of the ASIF framework (see Figure 5). It should be noted that in the author's study this framework is applied on passenger transportation whereas the framework as mentioned in the study applies analogously to the freight transportation.

The first component, activity (A) as seen in Figure 5 acts as the driving force for transport emissions. For activities to be undertaken trips need to be made and thereby distances have to be travelled. These are influenced by demographic factors such as age, gender, income, economy and its composition which may have an impact on, for example, the different types of trips that are made; urban form and size, which may affect the total distances travelled and distribution of activities undertaken (Zegras, 2007).

The second component of mode share (S) within the framework (see Figure 5), have an influence on emissions and energy use as different modes of transport have different emission rates, for example walking, bicycle that produce no emissions. There are various multiple factors in this component that also play a significant role. To state an example, income has an influence on car ownership which results in determining the available transport modes. Provision of infrastructure can have an effect on the one's willingness to opt from different available modal options, dictate certain specific transit options. Quality of services available plays a significant role, likewise relative (out-of-pocket) costs. Urban form in terms of land use mixing and design factors in terms of local street patterns also play an important role (Zegras, 2007).

The third component of fuel intensity (I) highlights fuel consumption per work (passengers moved). Like the above two components multiple factors also play an important role in influencing this component including technological factors such as engine type, vehicle age etc. Vehicle technology fixes have been a conventional area of focus for research, also encouraged by government standards. Driving conditions such as start-and-stop consumes more fuel, thus effecting fuel intensity (Zegras, 2007).

The last component of fuel choice (F), plays a significant role as carbon emission concentrations in exhaust vary by fuel type. Emissions of natural gas differ from that of diesel, gasoline. However in the electricity-powered transport, emissions are dependent upon fuel sources combustion technologies, distribution and transmission losses. On the other hand, 'renewable' fuels have the capacity to reduce net carbon emissions (Zegras, 2007).

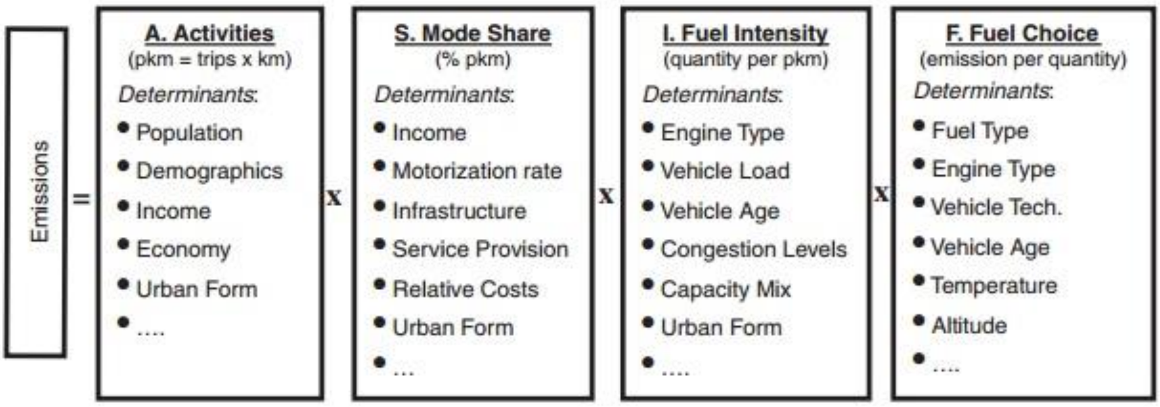


Figure 5 ASIF framework

While we have understood this framework, the use of ASIF framework has primarily been used for transportation energy use and emission calculation (Zegras, 2007). Hunter and Zegras (2011) used this framework in assessing the relationship between built environment and travel emissions. Also as can be seen above (see Figure 5) the factors influencing the four major components of this framework highlight urban environment characteristics related to their travel and socio-economic behaviour. However, it has not been widely used to calculate travel pattern emissions, which is the focus of this research and therefore makes this method less suitable in regard to this study.

In broader terms, there are two accepted methods of calculating travel pattern related emissions from a given set of input factors based on travel characteristics elaborated as discussed by Anable et al. (1997) and Stead (1999). As mentioned by the authors, the difference between the two models is that the former, works from an end calculation of fuel consumption whereas the latter, considers travel patterns in more detail and combines this information with figures relating to emission levels for the various components in a single travel profile.

2.4.1. The official fuel consumption method

This method calculates total fuel consumption from each vehicle used by combining distance figures for each category of speed with corresponding official statistics for miles per gallon (or litres per 100 kilometres). It uses a conversion factor which is based on the average carbon content of each litre of fuel, all of which is assumed to be released to form carbon dioxide which states (Anable et al., 1997):

- 1 litre of petrol = 2.42 kg of CO_2
- 1 litre of diesel = 2.64 kg of CO_2

This method was particularly used to derive carbon dioxide emissions from car-based travel which may differ in my research as it aims to calculate emissions from different modes of travel but the method of calculation can be adopted.

2.4.2. The emissions factor method

This method (Anable et al., 1997; Stead, 1999) uses a single emissions rate for each pollutant (as carbon dioxide, nitrogen oxide etc.) and vehicle category dependent on the types of vehicle operation and expressed in terms of the volume of emissions produced per kilometre travelled:

Emissions (g) = emissions factor (g/km) x vehicle kilometres per year (km)

These factors are derived from the results of on road testing programmes and are not derived from artificial test procedures, but from tests carried out on real life driving cycles. The emissions factors, which result, represent the most up to date and comprehensive set of data available for the vehicle stock. The basic data are published in an ETSU report (Anable et al., 1997; Gover et al., 1994) and can be seen in the table below. According to the accumulated data, a detailed breakdown of emissions levels for a number of pollutants was obtained by dividing the vehicle fleet into nine sections as follows (see Table 3):

- Three types of vehicles - petrol cars without catalysts, petrol cars with catalysts and diesel cars
- Three engine sizes - small (<1,4 litre); medium (1.4 - 2.0 litre) and large (> 2.0 litre)

For each section, fuel use and emissions factors are given for different speed conditions. The incorporation of these factors together involves the synthesis of the generated data on individual travel profiles, which provides an estimation of total kilometres travelled by each vehicle under each operating speed condition, with the relevant emissions factor. The basic structure of the method is thus based on four main parameters (see Table 3):

- Vehicle characteristics - technology, fuel, engine size
- Vehicle emission characteristics - speed profiles
- Annual distance travelled across speed profiles
- Emissions factors

Thus, both these above methods involve travel input assumptions and the use of generated data across larger sections. At the outset, it is difficult to choose which method will be applied in this research as elements of both seem to be important and may generate significant results in calculating travel pattern related emissions. This decision shall be taken once a clear understanding on the travel characteristics is obtained from the selected sample dataset as discussed in the following chapter.

CAR FUEL USE AND EMISSION FACTORS									
CAR TYPE	CAR SIZE	CAR SPEED	L/100km	g/km					
				CO_2	CO	HC	NOX	PM	SO_2
Petrol non-cat	Small	Cold	10.302	165	38.1	5.56	1.8	0.04	0.076
		<40 mph	7.0378	129	18.77	2.25	1.78	0.04	0.052
		40-65 mph	5.3678	116	5.14	0.7	2.12	0.04	0.04
		>65 mph	6.9362	146	9.46	0.75	3.69	0.04	0.051
	Medium	Cold	11.77	206	34.53	5.31	2.27	0.04	0.087
		<40 mph	8.2654	161	17.01	2.15	2.25	0.04	0.061
		40-65 mph	5.6196	123	4.46	0.7	2.44	0.04	0.042
		>65 mph	7.826	171	6.89	0.75	3.97	0.04	0.058
	Large	Cold	16.676	321	34.98	5.26	3.14	0.04	0.123
		<40 mph	12.098	251	17.23	2.13	3.11	0.04	0.09
		40-65 mph	6.7231	154	1.76	0.46	2.6	0.04	0.05
		>65 mph	9.9894	226	4.32	0.75	4.68	0.04	0.074
Petrol +CAT	Small	Cold	7.9531	161	14.32	1.2	0.8	0.01	0.059
		<40 mph	6.3934	145	3.06	0.24	0.34	0.01	0.047
		40-65 mph	4.8804	114	0.49	0.05	0.36	0.01	0.036
		>65 mph	6.5282	152	1.01	0.05	0.53	0.01	0.048
	Medium	Cold	10.39	216	16.05	1.1	0.63	0.01	0.077
		<40 mph	8.5379	195	3.43	0.22	0.27	0.01	0.063
		40-65 mph	6.5399	153	0.55	0.05	0.14	0.01	0.048
		>65 mph	8.9997	210	1.13	0.06	0.2	0.01	0.067
	Large	Cold	13.454	281	20.22	1.3	1.01	0.01	0.1
		<40 mph	11.065	253	4.32	0.26	0.43	0.01	0.082
		40-65 mph	8.5034	199	0.69	0.06	0.18	0.01	0.063
		>65 mph	11.78	275	1.42	0.07	0.26	0.01	0.087
Diesel	Small	Cold	5.5129	143	0.72	0.09	0.44	0.24	0.046
		<40 mph	4.5707	119	0.51	0.07	0.38	0.12	0.038
		40-65 mph	3.712	97	0.26	0.03	0.34	0.09	0.031
		>65 mph	5.7379	150	0.35	0.04	0.62	0.15	0.048
	Medium	Cold	6.6741	173	0.77	0.14	0.72	0.34	0.056
		<40 mph	5.5328	144	0.54	0.11	0.63	0.17	0.046
		40-65 mph	4.4767	117	0.27	0.05	0.55	0.11	0.038
		>65 mph	6.9626	182	0.37	0.06	0.95	0.2	0.058
	Large	Cold	8.9997	234	0.85	0.17	0.98	0.36	0.076
		<40 mph	7.4752	195	0.6	0.13	0.85	0.18	0.063
		40-65 mph	6.0381	158	0.3	0.06	0.75	0.13	0.051
		>65 mph	9.3973	246	0.41	0.07	1.28	0.22	0.079

Table 3: Emission factors

2.5. Travel Emissions in relation to socio-economic characteristics

This section identifies distinctive groups of the society and how they may contribute to the rising problem of travel emissions. A consensus seems to have been developed overtime, considering socio-economic profiles important for explanation of travel patterns, thus analyzing the *'emitters'* of highly induced travel patterns from the previous section (Stead, 2001). Socio-economic characteristics add to the complexity of comparing travel patterns in different areas and induced emission levels. Travel patterns differ in regard to demographic characteristics such as age, gender, economic activity etc. In many studies as described below, these have been examined at individual and household level to assess specific travel emission profiles (Anable et al., 1997).

Brand and Boardman (2008) collected data through postal paper-and-pen based surveys on various socio-economic characteristics such as household location, structure, income, occupation, age, gender, vehicle ownership and choice of transport mode and analyzed their impact on emissions. This information was further used to translate it into associated socio-economic travel emission related profiles using methods that varied among many studies. Brand and Boardman (2008) and Brand and Preston (2010) ranked the respondents in a continuous distribution where the smallest value was selected to represent rank 1 for the lowest emitters according to carbon emissions levels. The ranking of emissions were performed in order to rank each individual or household on a scale of 'high' to 'low emitters'. These emissions were ranked and grouped into emission quintiles and deciles representing group of a fifth of a total case and a tenth of the total. Similarly, Susilo and Stead (2008) made groups of travel emissions into five quintiles with an addition of a sixth quintile that represented zero emission travellers, which were also identified with their study.

Further, to identify who are the high and low emitters, the population is segmented based on socio-economic characteristics and multivariate analyses are undertaken to perform the analysis. These analysis are the Pearson's Chi Square tests, alternatively also called $\mathcal{X}^2$ tests (Brand & Boardman, 2008). These tests are used to assess if there exists a possible relationship between emission defined by emission quintiles and socio economic characteristics such as gender, age, income etc and if there exists, how strong is the relationship between the two. The null hypothesis highlights that there is no relationship of significance exists while alternatively there might also be a relationship of significance. For every test that was undertaken, the total $\mathcal{X}^2$, degrees of freedom, $\mathcal{X}^2$ probability and critical $\mathcal{X}^2$ of the actual and expected frequencies were calculated. In some other studies as that by Brand et al. (2013) multivariable regression models have also been used to identify the relationship between travel emissions and socio economic characteristics.

Thus the socio-economic composition of the sample shows if that sample is representative of the country population in terms of age structure, gender and economic activity and other related factors or characteristics using the above given methods. This socio-economic composition of the population was further analyzed by grouping the emissions into quintiles and analyzing their associated characteristics. Brand and Boardman (2008) highlighted that 20% of respondents in the highest emission quintile resulted in producing 61% of emissions while less than 1% of emissions were generated in the lowest emission quintile. The subsequent average emissions from personal travel activity in the highest emission quintile was 16.6 ton per person per year while in the lowest emission quintile, it was 0.19 ton per person per year. Similarly, in the top emission decile, representing 10% of the sample, resulted in 43% of the emissions while lowest emission decile was accountable for only 0.1% of the emissions. thus the individuals belonging to the top emission decile were typically the in between the age groups of 30 and 40 years, full time work or at university and earning £30k or more. On the other hand, individuals in the lowest emission decile were typically women, younger children between the ages of 6-17 years or older people than 75 years who are non-car drivers and low income residents of less than £10k p.a.

A sample of how these emission quintiles will look like in relation to all the associated socio-economic characteristics is presented (see Figure 6) below (Brand & Boardman, 2008):

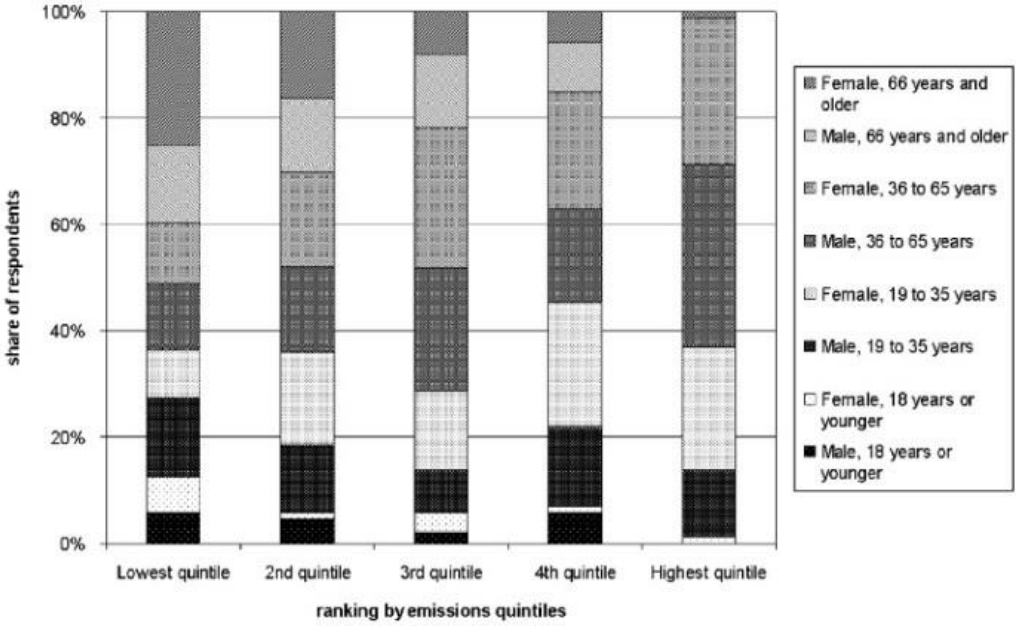


Figure 6: Emission quintiles by age and gender

However, as Susilo and Stead (2008) studied not only the highest and lowest emission quintile but also a zero emission category which stood fairly stable over the time period of 1990 and 2005. Thus it concluded in highlighting that 13% of individuals were accountable for 60% of transport induced emissions. When the socio-economic groups were compared, the individuals were typically the same type of emitters as expected: higher share of men over women, higher income groups, individuals with access to car (private vehicle was used for 85% of all trips). Interestingly the zero emission travellers within the country were mostly women.

Thus based on the above discussions, following are the important socio-economic characteristics that share a significant relationship with travel emissions as highlighted by Brand and Boardman (2008) in his study in the UK:

Income: In terms of carbon emissions produced from all personal travel, a quarter of individuals within the highest emission quintile constituted the highest income group (4£40k per person p.a.) while three quarters of individuals within the lowest emission quintile constituted the lowest income group (o£10k per person p.a.).

Economic activity/Occupation: In the top emission quintile, about three quarters were in work, while four-fifths of individuals within the lowest emission quintile were not in work.

Gender and travel by private vehicles: In the highest emission quintile, two-thirds of individuals were male for car travel only, while conversely two thirds of individuals in lowest emission quintile were females. In highest emission quintile, the higher proportion of men were mostly in full time employment, between the age groups of 36 and 65 years, income of £20k and residing in households with higher than average car availability.

Age: In the highest emissions quintile two-thirds of individuals (all travel) were aged between 36 and 65 years old, while in the lowest emissions quintile two-fifths of individuals were aged 66 years or older.

Household composition and size: Households with single person represented highest average carbon emissions per person (16% high than average of the sample) primarily because of higher emissions than average from air travel. On the other hand, households comprising of three individuals represented lowest average emissions level per person.

Car ownership: Emissions produced from car travel resulted to be highest from households which have access to two cars or more at almost twice the average of the sample.

Thus we can say, to gather knowledge of the households who are responsible for excessively higher emission levels is easily identifiable through these socio-economic characteristics in identifying distinctive groups of society that contribute to these travel emission profiles and measures can be undertaken to promote effective carbon reduction strategies amongst this fragment of the population.

We can conclude by summarizing, travel characteristics and its impact on emissions have been identified in the research by Brand and Boardman (2008). These include characteristics features that are indicative of higher income groups, employed in work, female in pensionable age , middle age group, smaller households sizes, higher car ownership etc. household location significantly influenced emission production with higher than average emissions produced from car travel in rural areas while conversely in urban areas higher than average emissions by air travel was observed.

Methods such multiple regression models and Pearson's Chi Square tests (χ^2) have been used for highlighting results that present significant relationship between emissions produced from travel activity and socio-economic characteristics particularly income, economic activity, age, household size and car availability (Brand & Boardman, 2008; Brand & Preston, 2010).

Above all, it is the composition and distribution of certain travel related characteristics that causes higher carbon emissions and the individuals and households that are producing them, which act as prominent contributions to the literature and thus will be applied in this study.

Multimodal, socio-economic groups and geographical location specific information on disaggregated levels of individuals and households seldom exist together. The approaches and methodologies that have been tested in studies mentioned in the above sections set an example of multi-output; a type of adaptable yet possibly policy-centric methods which needs to be further developed and should be employed nationally if the forecasting and measurement of travel activity patterns and their associated carbon emissions are to develop into a serious effective aspect of carbon mitigation policies and assessment strategies.

Further spatial analysis using the technology of GIS mapping of carbon emissions can demonstrate the association between carbon emission levels and location of individuals and households, thereby a tool visualizing the location of highest and lowest emitters, modal break up for each individual or household etc. To state an example, a mapping exercise of the City of Oxford is presented in the figure below (see Figure 7) showing a raster map overlaid with average emissions produced per person for all travel using pie charts in the study conducted by Brand and Preston (2010). Higher emissions have been represented by larger pie chart sizes. Concentric pie charts represent multiple numbers of respondents from the same household. As estimated in the quantitative statistical analysis, emissions produced from individuals residing in larger urban areas seem to be dominated by air travel (cyan) and car travel (red). Some notable exceptions have also been presented with rail (yellow) and bus (blue) users, thereby residing in good provision of public transport services.

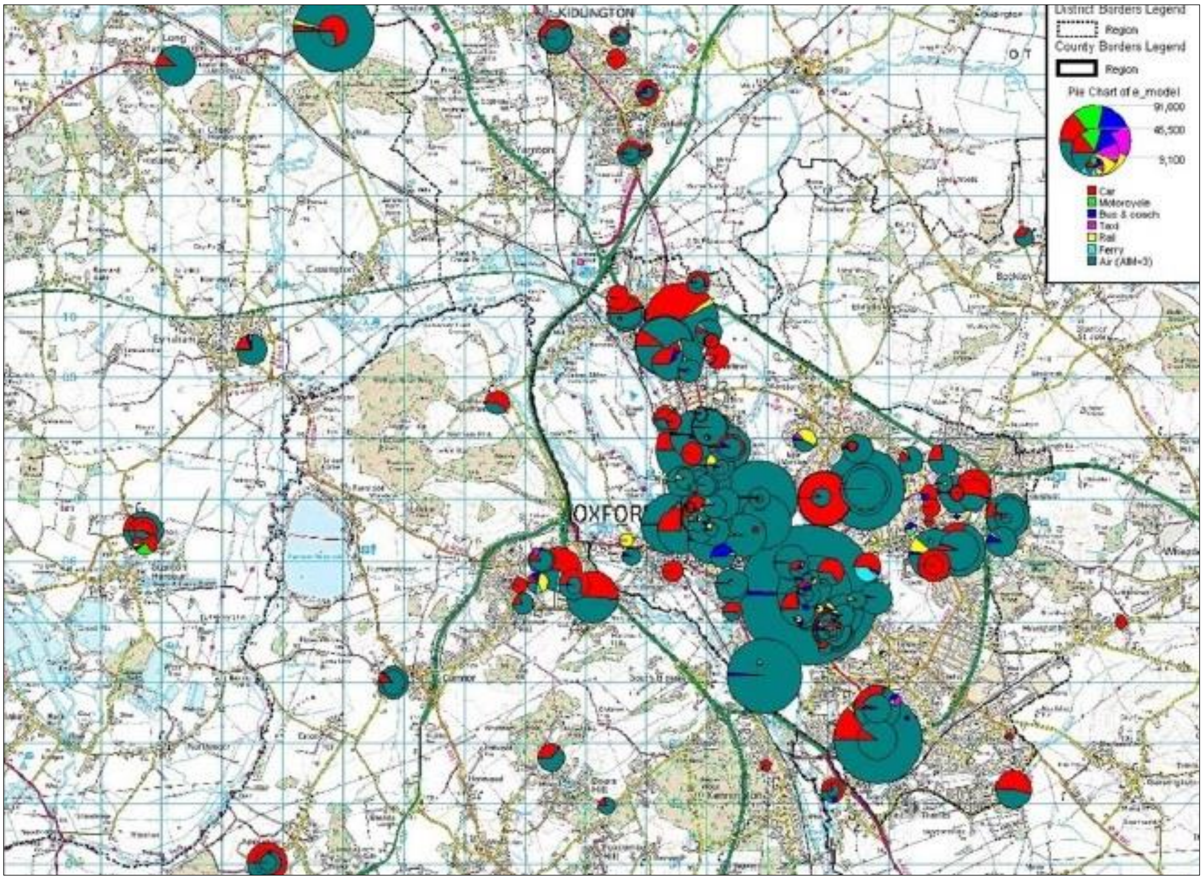


Figure 7: Geo spatial analysis of household location and individual CO2 emissions by all travel modes

This research will thus result in producing a good understanding of the composition and distribution of carbon emissions from personal travel at the different disaggregated levels using methods as learnt from literature. A basic analysis of identifying different travel patterns will be identified through univariate analysis of the different travel characteristics that will define a pattern. Then emissions will be calculated through one of the given methods in literature depending upon the feasibility of the dataset. Emission factors to be used in the calculation will be collected from secondary sources. Further socio-economic characteristics will be identified. Multivariate regression analysis will be undertaken to see the how emissions varies across different population segments by classifying the individuals and households into five groups in the form of quintiles or deciles and represented spatially. By representing insights in socio-economic profiles of travel pattern related emissions, this research will result in giving clues as to who is contributing in producing significant proportion of emissions.

2.6. Conclusion

This chapter presents detailed understanding on the three major concepts of the study using extensive literature. The concept of travel patterns described for this research is based on specific travel characteristics including mode, motive, distance, travel time, frequency and geographical location. Various methods have been presented to calculate carbon emissions based on the travel pattern characteristics and the official fuel consumption method or emissions factor method will be used to calculate these emissions based on the availability of the sample dataset as explored in the next chapter. To be able to relate these travel pattern induced emissions, multivariate analysis will be undertaken using the calculated emissions levels and socio-economic characteristics as discussed in the following chapter.

3. METHODOLOGY

This chapter discusses the methodology framework and strategy to profile climate change related carbon emissions from individual and household travel activities across all transport modes, broken down into movement and trip patterns. Most travel studies requiring detailed information on distances travelled, trip and movement profiles, rely upon a direct measurement approach, that of the daily or weekly travel diary. This is true for larger national surveys such as the Mobility Survey Netherlands (MON) and was thus the dataset selected to study individual/household induced CO_2 emissions in the province of Overijssel.

It is clear that the degree of complexity adopted in any approach depends largely on the required amount and intended use for the data. As it will be seen below, the level of detail of data needed for input into the calculation of emission profiles from travel is potentially very high given the number of characteristics that define the travel patterns.

Thus, the structure of the chapter is as follows:

- Description of the MON dataset
- Discussion of the relevant units of analysis
- Methods used to undertake analysis

3.1. Description of the dataset

Mobility Survey Netherlands (MON) dataset has been organized by the Ministry of Transport and National Water Centre for Transport and Shipping. The purpose of the MON dataset is to extract information about continuous daily movements of the Dutch population. It is a national database where data is obtained through a written and telephonic survey based on a random sample of the population. The surveys thus result in two final outputs of database and table book. The database contains all the MON results of the standard survey comprising of a number of variables highlighting the daily movement of the Dutch population as mentioned before. The table book contains the explanation of the variables.

The main objective of the survey is to record travel behaviour in the form of trips and movements at household and person level. These travel behaviour consist of travel variables such as transport modes used, motives, duration, distance travelled etc. Other detailed information such as socio-demographic variables of the person/household who makes the trip/movement have also been provided. Also, some limited information on vehicle characteristics has also been provided. A spatial element is also provided in the dataset at three different scales of zonal, municipal and postcode level. Following this brief description, a basic structure of the dataset can be seen below encompassing these aforesaid elements within the MON dataset and will suffice the interest of addressing the research objectives of this study.

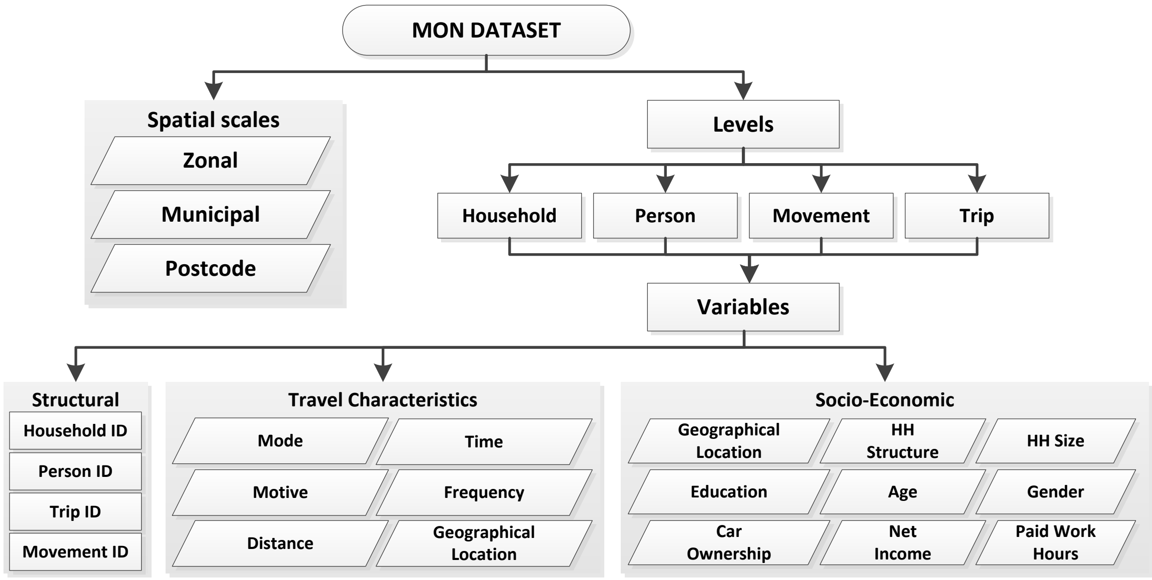


Figure 8: Basic structure of the MON dataset

Thus, from the above structure (See Figure 8) of the MON dataset, it is clear that the information provided in the dataset comprises of two distinct elements. The first element consists of data in terms of variables at four different levels and the second element consists of data to be able to represent spatially. Let us briefly try and understand this structure in further detail.

The four different levels of household, person, movement and trip comprises of different travel and socio-economic variables which represents the key focus of this research. These will be studied with the support of four structural unique ID numbers that are based on the four different levels containing information on the different aforementioned variables. Taking forward this approach of using the structural unique ID numbers is important as certain variables are distributed over each level and aggregations need to be made based on these unique ID's to derive any interrelationships between the variables or among different levels. Thus to obtain valuable information, the structural unique ID numbers play the most important role in generating results from the dataset.

The spatial element on the other hand in simple terms assists in spatially representing information available within the dataset. However spatial scales as we can see are distributed over three scales: postcode, municipal and zonal. Out of the three spatial scales the postcode level is the lowest scale following the hierarchy of municipal and zonal which is the highest scale after aggregating the information to be represented at each level separately.

As we now already know that the dataset consists of variables at four levels: household, person, movement and trip, we further try to understand the relationship between these levels as highlighted in the figure (see Figure 9). These terms are understood as:

- Household: A household consists of one or more persons who lives alone or together in a house and share their daily necessities.
- Person: A member of the household.
- Movement: A journey or part of a journey with a motive (a particular purpose).
- Trip: A part of a movement.

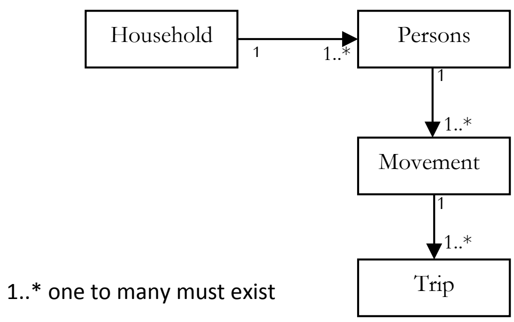


Figure 9: Levels of analysis

Thus we can say that the data in terms of variables provided at the household level is the highest level whereas data available at the trip level is at the lowest level.

The MON dataset has been studied for different set of years: 2004, 2005, 2006, 2007, 2008, and 2009 and recently for the years 2010 and 2011 (See Table 4). Each year's data is structured based on the four levels of analysis – household, person, movement, trips consisting of 129 variables. As we have learnt previously that to generate any outputs from the dataset, it is essential to study the variables with the support of structural unique ID numbers which are Household ID (hhid), Person ID (persid), Movement ID (verplid) and Trip ID (ritid), the availability of which might differ in all the years as the MON is updated with newer information each year sampling more households and persons with their movement and trip information. It is thus clear from Table 4 that in the year 2004 structural unique ID numbers are missing for person, movement and trip. Similarly, in the years 2010 and 2011 these structural unique ID numbers are seen missing in the case of household alone. Therefore, it becomes difficult to conduct analysis and generate outputs in these years. Even then, the dataset available from 2005-2009 seems more complete with all the structural unique ID numbers and is therefore selected as the dataset of this study (see Figure 10). The total sample size thus represents 59805 trips of 55536 journeys by 16817 individuals living in 7161 households in all 25 municipalities for the selected case study area of Overijssel. It is also important to note here that in each different year from 2005-2009, the travel and socio-economic variables that were selected, were based on the literature as discussed in chapter 2. However variables those were subject to address the research objectives were scrutinized and selected for the study to be able to address the primary aim of the research.

Year	Household	Persons	Movements	Trips
jaar	hhid	persid	verplid	ritid
2004	16670	-	-	-
2005	14697	14697	14697	14697
2006	13498	13498	13498	13498
2007	13257	13257	13257	13257
2008	10789	10789	10789	10789
2009	7564	7564	7564	7564
2010	-	9428	8943	8943
2011	-	8238	7812	7812

Table 4: Years of MON dataset

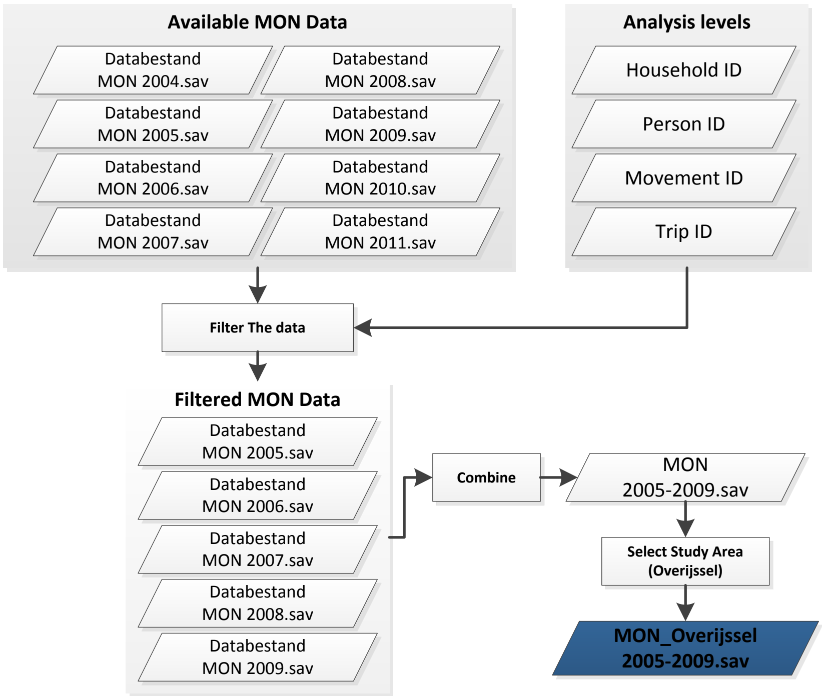


Figure 10: Process of preparation of dataset for this research

It is important to note that within the dataset certain variables contain missing values. Some of these variables will be used in the study as that of travel variables including mode, motive, distance travelled etc. Thus, a very important step is to draw upon a transparent and consistent way of coding these existing missing values. The use of coding these missing values will be that once they consist of an arbitrary value, they will not be

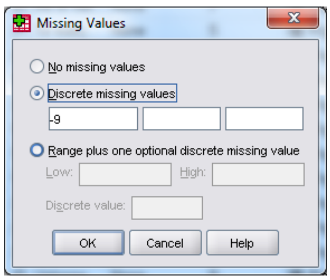


Figure 11: Indicate missing values

treated as 'true values' and therefore will not be included during the process of generating results and analysis. There are certain values for coding these missing values. Mostly used values are that of 99, 9999, -9 and –8 and are all arbitrary values (SPSS). In this study we have used –9 as the standard missing value. Therefore, once this value is given to the selected missing values in the dataset, and is mentioned in the variable consisting of these missing values with the help of the window display as shown above (see Figure 11); these values will not distort the dataset any further and will not be included in the analysis.

3.2. Relevant units of analysis

This section represents the units of analysis that have been selected to carry out the process of generating results and analysis which will be discussed in Chapter 4 in elaborate detail. However, for this research, units of analysis include all the four levels of the sample dataset: trip, movement, individual and household.

In this research, the unit of calculation used for calculating carbon emissions is at the trip level. For every trip, carbon emissions have been calculated and thus form the mainstay of this study. Data for each trip contains information on mode, duration, distance and other related factors. It is important to note that once the carbon emissions have been calculated at the trip level, further analysis can be easily carried out with related variables at movement, person or household level to reflect the travel emission profiles with related socio-economic characteristics. Therefore emissions calculated at the trip level which is the lowest level (given in the MON dataset) allows aggregations to higher levels (movement, person & household) to represent relationships among variables given at different levels.

As we already know, that a trip is a part of a movement with a travel motive, thus movement forms an important unit for representing the analysis. Variation at this level highlights multimodal trips within one movement studying their purpose of travel for that one single movement. Also, a movement specifies personal travel in the amount of time taken to travel a given distance.

However, the individual and household level analysis assists in relating socio-economic characteristics with the emission analysis. It supports just and fair reflections of the emissions induced and facilitates in identifying a particular segment of population responsible for higher emission levels. For instance, travel patterns for each mode of transport used are linked to person and household characteristics such as number of individuals within the household, age, gender, occupation etc.

3.3. Methods used to undertake the analysis

The following section explains the methods to be used to undertake analysis by beginning with a workflow that guides how to process the information available within the selected MON dataset (see Figure 10) to be able to use in this study. The workflow describes how the MON dataset is used to analyze the principal concepts of this study. These principal concepts encompass describing and representing travel patterns, calculating and representing travel emission profiles and associating travel emission profiles to related household socio-economic characteristics. Thus, the methods mentioned in the sections to follow will help in analyzing the research of the study based on these principal concepts.

3.3.1. Workflow to undertake analysis

This section deals with how to process the information we have obtained in the form of the MON dataset (see Figure 10). It explains the workflow of the dataset that will be followed based on the research aim and objectives to be addressed. The following diagram (see Figure 12) gives a very brief overview of how this workflow will function using the data as provided within the sample (MON) dataset.

As can be seen from Figure 10 firstly the final dataset has been prepared to be used for the study. As previously explained the MON was undertaken for many years but the data encompassing information from the years of 2005-2009 have been filtered and selected for this study consisting of all the four structural unique ID numbers of Household (ID), Person (ID), Movement (ID) and Trip (ID) which forms the basis of the analysis levels. The datasets of all the five years from 2005 to 2009 is further combined into one dataset 'MON 2005-2009' (See Figure 10). Again as the research is focussed on the case study area of Overijssel, it is filtered from MON 2005-2009 and is now the final dataset which is used for generating outputs and results in addressing the aforesaid research aim and objectives. This dataset consists of selected travel and socio economic variables to be used for generating the outputs and the selection of these variables are dependent on the literature as explained in Chapter 2. These variables have been empirically identified using the selected MON dataset to analyze travel patterns using the travel variables (see Figure 12). Further to calculate emissions representing these travel patterns, an emission calculation framework has been designed which calculates travel emissions and helps in generating travel emission profiles (see Figure 12). Finally, these travel emissions profiles are analyzed by using related individual and household socio-economic characteristics which have been selected previously using the selected MON dataset based on literature described in Chapter 2 (see Figure 12). Thus the results generated by this workflow aims to address the principal concepts of this study of representing travel patterns, calculating and representing travel emission profiles and further associate these travel emission profiles to household socio-economic characteristics. Each of these has been explored further in the following sections.

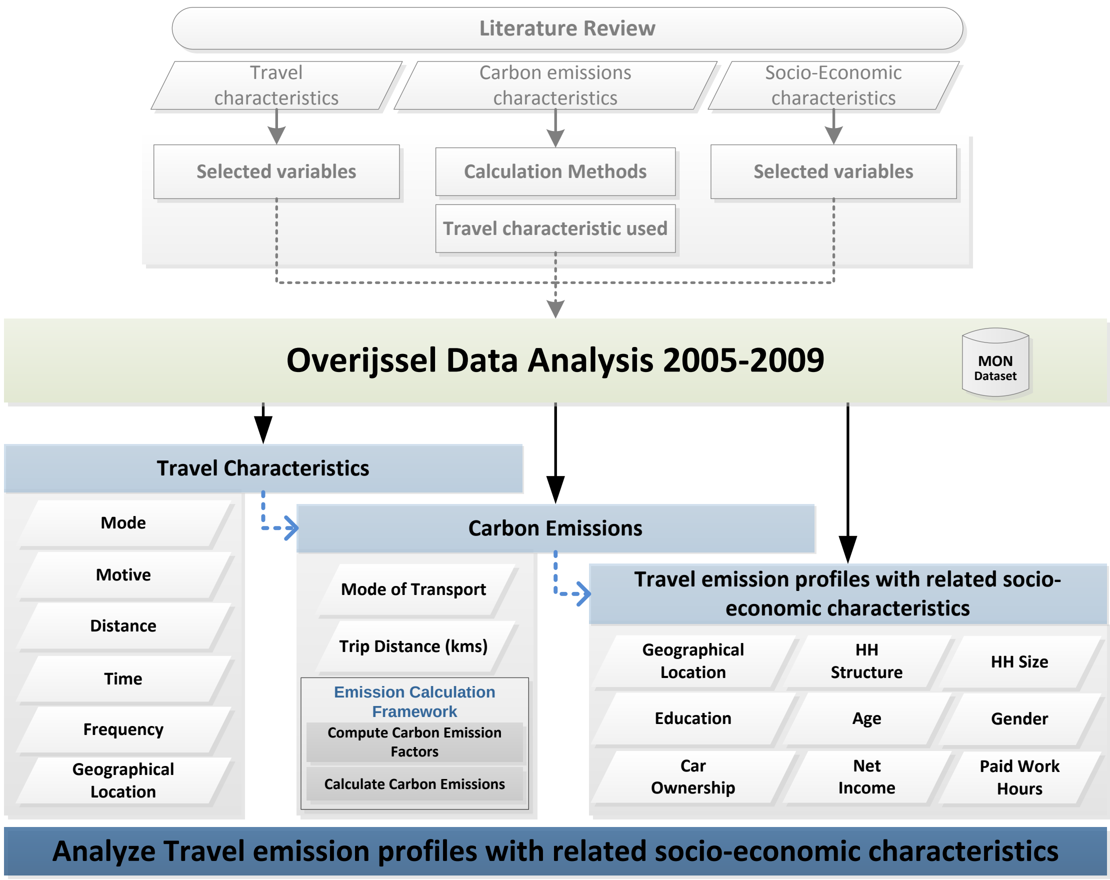


Figure 12: Workflow to analyze selected MON dataset (2005-2009)

3.3.2. Description of travel variables

This section describes the reclassification of selected travel characteristics to define a travel pattern according to literature. These include mode of travel, motive (purpose), distance travelled, travel time, journey frequency and location. These are available in the dataset in the names of *vv* (Trip mode of transport), *hv* (Movement mode of transport), *kmotief* (motive), *afstr* (trip distance), *afstv* (movement distance), *rsdduur* (travel time) and *sted* (Degree of Urbanization). To understand how these will be used in analyzing travel patterns from the dataset we try and understand each of them separately in the following sections.

Mode of transport: Mode of transport indicates use of different modes of travel for making a trip or a movement. As given in the dataset there are two distinct variables for trip modes of transportation (*vv*) and movement modes of transportation (*hv*). Each consists of a descriptive set of modes as explained in Table 5. These have been reclassified for this study to understand chief modes used for the trips and movements undertaken. To be able to compute this new variable, which comprises of the reclassified modes, the following syntax has been used in the software of SPSS for the movement level (see Figure 13). A similar syntax was also created for the trip modal level (see Appendix A).

```
IF  (vv = 1) MovementMode=1.
EXECUTE.
IF  (vv = 2 | vv = 9) MovementMode=2.
EXECUTE.
IF  (vv = 5 | vv = 17 | vv = 16 | vv = 7 | vv = 6) MovementMode=3.
EXECUTE.
IF  (vv = 3 | vv = 4 | vv = 8) MovementMode=4.
EXECUTE.
IF  (vv = 10 | vv = 11 | vv = 12 | vv = 13 | vv = 14 | vv = 15 | vv = 18 | vv = 19 | vv = 20 | vv =
21 | vv = 22 | vv = 26) MovementMode=5.
EXECUTE.
```

Figure 13: SPSS syntax for reclassifying mode of transport

Thus, the numbers displayed in the syntax (see Figure 13) are the corresponding mode class numbers transforming from the original to the reclassified movement modes (See Table 5).

Table 5 represents the different modes of transport at the movement level according to the information provided in the MON dataset and the reclassified modes that will be used in this study. A similar table has also been created for reclassified trip modes (see Appendix A). The reclassified modes have been derived by reordering the original mode class categories. In the first instance, it is clear that the reclassified modes of walking, bicycle, public transport and car have the higher frequencies and are the most common means of travel for

Classified Movement Mode (Head Transportation)	MON Mode of Transport (hv)	Frequency	%
-9	.	2833	5%
Walking	Te voet	8412	15%
Bicycle	Fiets	15845	30%
	Fiets als passagier	588	
Public Transport	Bus	337	2%
	Tram/Metro	10	
	Trein	734	
	Touringcar	59	
	Besloten busvervoer (schoolbu	53	
Car	Bestuurder auto	17578	46%
	Passagier auto	7931	
	Taxi	189	
Other	Snorfiets	102	2%
	Bromfiets	157	
	Motor	70	
	Traktor	44	
	Bestelauto	54	
	Vrachtauto	49	
	Boot (lijndienst/veerdienst)	48	
	Vliegtuig	15	
	Kinderwagen	136	
	Skates/Skeelers/Step	48	
	Gehandicaptenvervoermiddel	154	
	Anders	90	
Total		55536	100%

Table 5: Computation of Reclassified Movement Mode

movements. The reclassified modes therefore, represent a combination of mode categories (See Table 5) for fair distribution of the dataset. Private transport represents variation in the different modes used as of walking, bicycle, car and will be studied as separately used unique modes of travel in analyzing travel patterns as the relatives frequencies of each are high. Public transport on the other hand represents a combination of modes of travel i.e. bus (including private school/company bus, coach), train, tram/metro. They are not being analyzed as separate modes due to lower relative frequency and keeping in mind the key concern of this study that focuses on travel patterns by private and public transport use.

However as mentioned previously, the research primarily emphasizes on private and public use of travel as of car, bicycle, walking, bus, train, tram/metro. This may appear to provide an incomplete overview of different modes of travel excluding air travel, navigation etc. A simple reason for this selection is the limited information available in the data source.

The variable *hv*, as also mentioned previously, consists of the above mentioned 26 different modes and have been reclassified for our study into five modal classes. It also comprises of some missing values as can be seen in Table 5 which will be laid stress on later in the chapter so as to avoid distorting the analysis.

However, there is yet another variable *khv* within the dataset (see Appendix A) comprising of similar modes as that of the original variable *hv*. In the *khv* variable, the original modes have been combined together to form just 8 different mode classes of walking, bicycle (including bicycle and bicycle as a passenger), car driver, passenger car, bus/tram/metro, train, mopeds and others (rest of the remaining). Thus, meaning that the original mode class (*hv*) comprising of 26 modes have been combined together to form just 8 modes in the variable of *khv,* existing already within the dataset. Similarly there was also a *kvv* variable for trip modes of travel that had been combined together the same 8 modal classes (see Appendix A). The reason of mentioning this is that as the dataset already consists of a simpler classification of modes, there could have been a possibility to select *khv* variable over *hv* variable for reclassification. But the reason that the *khv* variable was not selected (for both trip and movement) is because it categorized the modes of 'taxi', 'private bus transport (school/company bus)' and 'coach' in 'others' (modes) (see Appendix A) which may have an effect on emissions and would be excluded if this variable was taken under consideration for reclassification. Thus, this would have resulted in losing some data that could have been a part of car and public transport and displayed inaccurate results in emission analysis from different modes. Therefore, the variable of *khv* and *kvv* was "not" taken under consideration and the reclassification of movement modes as seen in the Table 5 has been based on the *hv* variable.

```
IF  (kmotief = 1 | kmotief = 2)  TravelPurpose_Movement=1.
EXECUTE.
IF  (kmotief = 5)   TravelPurpose_Movement  =2.
EXECUTE.
IF  (kmotief = 4)   TravelPurpose_Movement  =3.
EXECUTE.
IF  (kmotief = 6)   TravelPurpose_Movement  =4.
EXECUTE.
IF  (kmotief = 8 | kmotief = 7)   TravelPurpose_Movement  =5.
EXECUTE.
IF  (kmotief = 3)   TravelPurpose_Movement  =6.
EXECUTE.
IF  (kmotief = 9)   TravelPurpose_Movement  =7.
EXECUTE.
```

Figure 14: SPSS syntax for reclassifying motive of travel

Motive: Motive represents the activity or purpose of travel specifically for a movement. The variables that represented motives of travel within the dataset were two of them: *motief* and *kmotief*. The earlier one (*motief*) included a more descriptive set of motives (see Appendix A) while the latter (*kmotief*) displayed combinations of some motive classes from the earlier one. Thus the reclassification of motives for this study was done using the *kmotief* variable. The above shown SPSS syntax was used to reclassify the motives from the *kmotief* variable. Thus the numbers displayed in the syntax are corresponding to the below given table (Table 6).

Classified Movement Motives	MON Mode of Transport (kmotief)	Frequency	%
-9	.	2833	5%
Work	Van en naar het werk	8408	18%
	Zakelijk bezoek in werksfeer	1729	
Education	Onderwijs/cursus volgen	4918	9%
Shopping/Errands	Winkelen/boodschappen doen	10615	19%
Visit/Stay	Visite/logeren	7971	14%
Social Recreation	Sociaal recreatief overig	6656	23%
	Toeren/wandelen	5880	
Services/Personal Care	Diensten/persoonlijke verzorging	2078	4%
Other	Overige	4448	8%
Total		55536	100%

Table 6: Computation of reclassified movement motives

Thus as we can see from (Table 6) the *kmotief* variable consists of 9 distinctly different motives of travel and have been further reclassified into 7 in the new variable. As can be seen, *to and from work* and *business trip working atmosphere* have been combined together into one class as they both represent work related purpose. Also, *touring/hiking* and *social recreation* has been combined to form one class as both represent social recreation (activities). However all the other classes represent the same as in *kmotief* variable. The table also represents missing values (Table 6), which will be laid stress on later in the chapter to avoid distorting the analysis undertaken by the use of these variables.

Distance travelled: This includes covering travel distances within The Netherlands, in our case Overijssel (case study area). It includes two distinct variables that will be used in the study. These are distances at trip and movement level which are seen in the dataset as *afstr* (trip distance) and *afstv* (movement distance). Again, we already know that trip is a part of a movement, as previously mentioned. Both will be used for travel pattern analysis but the trip distance in particular will also be used to calculate carbon emissions. However both the variables consist of missing values which will be laid stress on later in the chapter to avoid distorting the calculation and analysis undertaken by using these variables.

Thus, the variable of trip distance of *afstr* has been further computed into a new variable as it was given in hectometres (hm) in the dataset and was converted to kilometres (km) in the new variable. The syntax used in SPSS for this computation can be seen below (see Figure 15).

```
COMPUTE   TripDistance_KM =afstr * 0.1.
EXECUTE.
COMPUTE   MovementDistance_KM =afstr * 0.1.
EXECUTE.
```

Figure 15: SPSS syntax used for recomputing Trip Distance

From the above figure it can be seen that converting hectometres to kilometres indicates multiplying 0.1 to the variable of *afstr* as 1 hectometre = 0.1 kilometre and there by all the values in the new variable represent distance at trip level in kilometres. Similarly, the movement distance has also been converted from hectometres (as given in dataset) to kilometres as can be seen in the above syntax.

Thus, the calculated trip distance (kms) will be used for calculating carbon emissions which will be at grams/kilometre (g/km) wherein distances in kilometre will be necessary. As trip level is the smallest level of analysis given in the dataset, once the emissions are calculated at the smallest level, any information provided at other levels (movement, person, household) can be easily aggregated from the smallest unit to generate significant results. More details on emission calculation are discussed in later part of the section.

Travel time and Geographical location: For the variables of travel time and geographical location the original variables as given in the dataset were used as there was no requirement for reclassification. These variables were *rsdduur* and *sted*. It is important to mention here that *rsdduur* represents travel time (in minutes) within the Netherlands, in our case travel time for distances covered for movements within Overijssel. On the other hand, *sted* represents degree of urbanization categorized into strong urban, few urban, poor urban and no urban. This variable is given at the municipality level and will be further aggregated to produce travel pattern analysis. The variable of *sted* has also been used in the analysis of socio-economic characteristics and discussed in more detail in the next section.

3.3.3. Description of socio-economic variables

This section describes the reclassification of selected socio-economic characteristics as available within the dataset to identify socio-economic composition of travel pattern induced emissions. These variables have been selected based on literature from Chapter 2 and will be used for individual and household based emission analysis. These include household size (*aantpers*), household structure (*hhlft4*), car ownership (*pauto*), age (*leeftijd*), gender (*geslacht*), highest completed education (*opleid*), paid work hours (*betaaldw*), personal net income (*inkomen*) and degree of urbanization (geographical location) (*sted*). The aforementioned variables are available at different levels and need to be reclassified to produce valuable outputs. To understand how these will be used in identifying the socio-economic composition from the dataset we try and understand each of them separately in the following sections.

Household size: The variable used to highlight household size, is *aantpers*, which depicts the number of individuals within the household in the selected MON dataset. The values represented within the variable according to the given dataset consist of 1-10 people within the household and is available at the person level within the dataset. For the ease of interpretation of results this was reclassified into four classes. According to the syntax below (see Figure 16), class 1 comprises of 1-2 people within a household, class 2 comprises of 3-4 people, class 3 comprises of 5-6 people and class 4 comprises of more than six people within a household.

```
IF  (aantpers_first = 1 | aantpers_first = 2) HHsize=1.
EXECUTE.
IF  (aantpers_first = 3 | aantpers_first = 4) HHsize=2.
EXECUTE.
IF  (aantpers_first = 5 | aantpers_first = 6) HHsize=3.
EXECUTE.
IF  (aantpers_first  > 6) HHsize=4.
EXECUTE.
```

Figure 16: SPSS syntax used for recomputing Household size

Household structure: The variable used to highlight household structure is *hhlft4* which indicates number of family members living within a household above 18 years of age. This means that all the people living within this variable will be able to legally hold a driving license to drive a car and can thus contribute to emissions. This brings us to the focus of this research. However the values represented in the variable consist of 1-9 members and have been further reclassified into four distinct classes for ease of interpretation. The following syntax (see Figure 17) represents class 1 comprising 1-2 people above 18 years of age within a household, class 2 comprising of 3-4 people, class 3 comprising of 5-6 people and class 4 comprising of more than 6 people above 18 years of age within a household.

```
IF  (hhlft4_first = 1 | hhlft4_first = 2) HHstructure=1.
EXECUTE.
IF  (hhlft4_first = 3 | hhlft4_first = 4) HHstructure=2.
EXECUTE.
IF  (hhlft4_first = 5 | hhlft4_first = 6) HHstructure=3.
EXECUTE.
IF  (hhlft4_first  > 6) HHstructure=4.
EXECUTE.
```

Figure 17: SPSS syntax used for recomputing Household structure

Car Ownership: The variable of *pauto* highlights the number of cars a person owns. The values within the variable include of *yes* and *no*, thus highlighting whether or not a person owns a car. This variable significantly assists in identifying the contribution of emissions produced at a person based level using the mode of car, which generates higher levels of emissions. However there was no requirement of reclassification for this variable.

Age: The variable of *leeftijd* represents age of individuals from 0 to 99 (numeric values). For ease of interpretation this variable was reclassified into six classes as computed in the following SPSS syntax (Figure 18). These include Class 1 which represents 0-18 years of age for individuals highlighting children, class 2 represents 18-25 years of age, class 3 represents 25-35 years of individuals highlighting working class, class 4 represents 35-50 years of age group highlighting working class, class 5 represents 50-65 years of individuals and class 6 represents individuals above 65 years of age, highlighting the retired age group. This can also become clearer in Table 7.

```
IF  (leeftijd  < 18) AgeClass=1.
EXECUTE.
IF  (leeftijd  >=  18 & leeftijd  25) AgeClass=2.
EXECUTE.
IF  (leeftijd  >=  25 & leeftijd  35) AgeClass=3.
EXECUTE.
IF  (leeftijd  >=  35 & leeftijd  50) AgeClass=4.
EXECUTE.
IF  (leeftijd  >=  50 & leeftijd  65) AgeClass=5.
EXECUTE.
IF  (leeftijd  >= 65) AgeClass=6.
EXECUTE.
```

Figure 18: SPSS syntax used for recomputing Age Class

Classified Age Groups (AgeClass)	Frequency	%
0-18	3776	22%
18-25	1089	6%
25-35	1824	11%
35-50	3818	23%
50-65	3572	21%
>65	2738	16%
Total	16817	100%

Table 7: Reclassified Age groups

Gender: The variable *geslacht* represents the gender of an individual. This comprises of values highlighting whether the individual is a male or a female. The variable has however not been reclassified and used for interpretation as originally given within the dataset.

Highest completed education: The variable of *opleid* as given within the MON dataset highlights the highest completed education of an individual. The categories within this variable had been reclassified for ease of analysis and interpretation. The following SPSS syntax (Figure 19) had been used to reclassify the original *opleid* variable.

```
IF (opleid = 1 | opleid = 2) Education=1.
EXECUTE.
IF (opleid = 3) Education=2.
EXECUTE.
IF (opleid = 4) Education=3.
EXECUTE.
IF (opleid = 0 | opleid = 5 | opleid = 6)
Education=4.
EXECUTE.
```

Figure 19: SPSS syntax used for recomputing Education

Classified Highest Completed Education	MON Highest Completed Education (opleid)	Frequency	%
Lower Education	BO/LO	2327	39%
	LBO/VGLO/LAVO/MAVO/MULO	4255	
Middle Education	MBO/HAVO/Atheneum/Gymnasium/MMS/HBS	4422	26%
Higher Education	HBO/Universiteit	2715	16%
Others	Jonger dan 12 jaar	2505	18%
	Overig	48	
	Onbekend	545	
Total		16817	100%

Table 8: Highest completed education

According to Table 8 the reclassified classes represent lower education, middle education, higher education and others. All the classes are corresponding to the above given SPSS syntax. It is important to mention here that the 'others' class includes children younger than 18 years old and some unknown data within the variable.

Paid work hours: This variable constitutes the total number of paid working hours for an individual. The variable *betaaldw* highlights these paid work hours in four classes of less than 12 hours per week, between 12-30 hours per week, equal to or more than 30 hours per week and unknown data within the variable. It therefore highlights the amount of time an individual spends in one week in his/her occupational service that incurs income. It therefore has a direct relationship to the income one earns. This variable thus did not require any reclassification and was used in its original way of representation as available in the dataset.

Personal net income: The variable *inkomen* represents income classes of individuals. These have been given in Euros per year according to the MON dataset. The classes within this variable have been reclassified using the following SPSS syntax (Figure 20).

```
IF (inkomen = 0 | inkomen = 1 | inkomen = 7) Income=0.
EXECUTE.
IF (inkomen = 2) Income=1.
EXECUTE.
```

```
IF (inkomen = 3) Income=2.
EXECUTE.
IF (inkomen = 4) Income=3.
EXECUTE.
IF (inkomen = 5) Income=4.
EXECUTE.
IF (inkomen = 6) Income=5.
EXECUTE.
```

Figure 20: SPSS syntax used for recomputing personal net income

Classified Income classes	MON Personal net income (inkomen)	Frequency	%
No income	Jonger dan 12 jaar	2505	45%
	Geen eigen inkomen	2379	
	Onbekend	2665	
< 7 500	< 7 500	1232	7%
7 500 - 15 000	7 500 - 15 000	2681	16%
15 000 - 22 500	15 000 - 22 500	2163	13%
22 500 - 30 000	22 500 - 30 000	1697	10%
>= 30 000	>= 30 000	1495	9%
Total		16817	100%

Table 9: Personal net Income classes

According to Table 9 these income classes have been reclassified into five income classes of no income, less than 7500 Euros, between 7500 – 15000 Euros, between 15000 – 22500 Euros, between 22500 – 30000 and more than or equal to 30000 Euros. These values are corresponding to the ones mentioned in the above given SPSS syntax. Income is very important determinant of emission analysis and has a major influence on emission induced.

Degree of Urbanization (Geographical location): The variable of *sted* highlights degree of urbanization in five distinct classes. These include highly urbanised or more (*zeer sterk stedelijk*), highly urbanised (*sterk stedelijk*), moderately urbanised (*matig stedelijk*), lowly urbanised (*weinig stedelijk*) and not urbanised (*niet stedelijk*). However within the dataset, only the name of highly urbanised or more (*zeer sterk stedelijk*) class has been given with no value in the dataset and therefore have not been considered in carrying out the analysis for this study. Thus only four classes have been considered for this study excluding the class of highly urbanised or more (*zeer sterk stedelijk*). Within the dataset this variable is given at the municipality level and thus will be aggregated at different levels for carrying out analysis. The variable thus highlights the geographical location of individuals and households in their place of stay. It had not been reclassified as the original variable of *sted* which is representative for the analysis and interpretation.

Thus, all the above mentioned variables have been used in generating results in Section 4.3.

3.3.4. Methods used to calculate carbon emissions

This section deals with the most eminent part of the thesis constituting the process of calculation of carbon dioxide (CO_2) emissions.

To carry out the process of calculating CO_2 emissions, we follow the framework as designed in (Figure 20). According to this framework, the emission calculation is based on the travel characteristics of the mode of transport (as given in the MON dataset). But as previously explained, we will use the 'Reclassified modes of transport' representing sustainable and unsustainable modes (see Table 10).

It represents sustainable modes of walking and bicycle combines together, unsustainable modes of car, bus, train, tram/metro. However, as bicycles and walking are zero emission modes, we will not consider them in the emission calculation and analysis process. Thus, as described in the framework (See Figure

21) the modes of car and public transport are going to be of prime focus in this section for emission calculation.

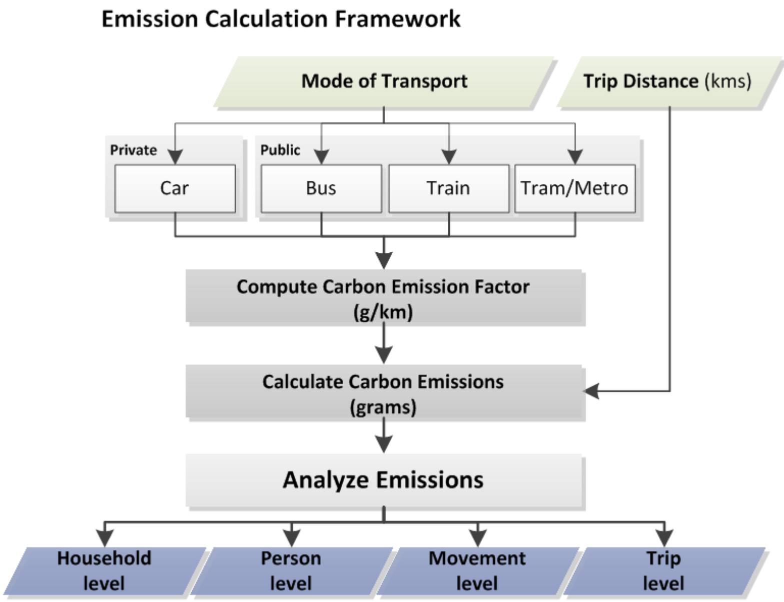


Figure 21: Emission calculation framework

Thus, as the emission calculation is based on the mode of transport; the next step involves assigning a carbon (CO_2) factor value for each mode. While assigning a carbon factor value for each mode highlighting car and public transport a number of sources were considered (see Table 11). It is important to note here that public transport can be understood by the modes of bus, train and tram/metro as can be seen in Figure 21 but this is only for the emission calculation as each mode consists of a different carbon factor (see Table 11) and will be considered as a whole (public transport) in case of the emission analysis. Thus the public transport modes of bus, tram/metro and train have been considered because they form the mode class of public transport together according to the reclassified modes mentioned earlier (see Appendix A). Thus, as seen from the Table 11 carbon (CO_2) factor values were collected from different sources for four different modes of transport i.e. car, bus, tram/metro and train.

Classified Trip Mode Emissions (CO2TripModes)	Frequency	%
-9	2900	5%
Sustainable Modes	27702	46%
Bus	713	1%
Tram/Metro	27	0%
Train	923	2%
Car	26495	44%
Others	1045	2%
Total	59805	100%

Table 10: Trip modes of carbon emission calculation

Mode	Type		CO_2 factor 1995 g/rkm (1) (2)	CO_2 factor 1995 g/rkm (2)	CO_2 factor 2010 g/rkm (1) (2)	CO_2 factor 2012 (2)	
Car	Including refining	Stad	129	283	**108**	Average petrol Car (3)	201.08
		Average		213		Average diesel Car (3)	185.2
						Average LPG Car (3)	212.97
Bus	Including refining	City bus	137	104	**125**	110	
		Intercity	100	76	**91**		
Tram			68	59.3	57	60	
Metro			67	59	**56**		
Train	Stop trains		77	69.9	72	50	
	Intercity's		49	44.9	46		
	Average		63	56.8	**58**		

(1) Include Fuel and Electricity Production
(2) g/rkm - CO_2/passenger kilometre
(3) g/km - CO_2/vehicle kilometre

Table 11: Carbon Emission Factors

Based on the above table (see Table 11), the following paragraphs explain how these modes have been assigned a carbon (CO_2) factor and based on what source of information. As can be seen in the table (See Table 11) carbon factor values have been displayed for three different years 1995, 2010 and 2012.

The CO_2 factors mentioned for the years of 1995 and 2010 are applicable to The Netherlands distinctly and have been collected from National Institute for Public Health and the Environment (1997). On the other hand, the CO_2 factors mentioned for the year of 2012 is based according to Department for Environment Food and Rural Affairs (2012) in the United Kingdom (UK). The CO_2 factors based on The Netherlands, given in the years of 1995 and 2010 include factors mentioned according to CO_2 emitted per passenger kilometre travelled by the respective modes of transport. But there is a minor difference one set of CO_2 factors in year 1995 include fuel and electricity production for all modes while it is absent in the other set of carbon factors of the same year, thus minor differences can be seen in the carbon factors which are higher in the former one than the latter except for the mode of car. Also the CO_2 factors mentioned in 2010 based on The Netherlands, include fuel and electricity production for all modes, thereby experiencing a declining trend in comparison to the factors mentioned in the year of 1995 (including fuel and electricity production). A major reason for this decrease in the emission factors can be improved use of fuel and electricity production that has a lesser impact on emissions in comparison to the earlier one (used in 1995).

As we proceed to the year of 2012, based on UK CO_2 factors, we can observe a further declining trend in the emission factors in all modes except for car which has a sub categorization based on fuel type and consists of a carbon factors based on the fuel type. If we observe closely, there is not much difference between the different fuels type CO_2 factors for the car (See Table 11) and thus one CO_2 factor can be selected for the mode of car for this study.

Therefore, the most suitable CO_2 factors that are thus selected to be used for calculating carbon emissions are that based on The Netherlands for the year 2010 (including fuel and electricity production). As this is applicable distinctly to The Netherlands itself and is the closest to the MON dataset in use (2005-2009) using figures for 2010 is the most appropriate. It is thus important to note here that within this year there is one CO_2 factor for the mode of car, two CO_2 factors for the mode of bus, one factor each for Tram and Metro and three factors for Train (see Table 11). Thus in our selection, we will consider only one CO_2 factor for each mode except for that of bus where two factors will be considered. The bus consists of a CO_2 factor for city bus and intercity bus which have different impacts on the emissions. A city bus induces higher emissions in comparison to an intercity bus. This is because a city bus covers shorter distances experiencing traffic jams, halts at regular intervals thereby affecting changes in speed and engine temperature (mentioned previously in Chapter 2) which induces more emissions. An intercity bus on the other hand covers longer distances and we assume drives at a more constant speed, thereby affecting considerably lower emissions.

In the case of tram and metro, only one CO_2 factor has been selected (see Table 11). This is because, firstly there is a marginal difference between the two factors and secondly they have been clubbed together as one mode class according to the MON dataset. In the case of train (see Table 11), only one factor that highlights the average is taken under consideration as there is no information available in the MON dataset highlighting stop trains or intercity trains for which the factors have been given in the table and are thus ignored.

In the case of car, there already exists one CO_2 factor which will be considered for emission calculation (see Table 11). But interestingly if we look closely at the emission factors for a car, it is lower than the emission factor for the city bus (See Table 11). This can be discussed from two viewpoints: firstly some reports and studies show that on a per passenger/kilometre basis a city bus induces more particulate matter and other pollutants than cars (Department for Environment Food and Rural Affairs, 2012), which may be inclusive in the CO_2 factor but there has been no mention in the source. And secondly, the CO_2 factor given for the car is based on an average car and not defined by the fuel type with which it may vary drastically.

Thus, as the CO_2 factors have been selected based on the year of 2010 with each mode representing one carbon factor as explained above (see Table 11), this is computed in the MON dataset in the form of a new variable to further calculate emissions. But before computing the new variable of *CO2EmissionFactor*, another variable was computed of 'CO2TripModes' that included sustainable modes, bus, tram/metro, train, car and others. This was computed solely for carbon emission calculation and was computed from the original mode of transport MON variable of *vv* (see appendix A). It is however, very important to mention that it is totally different from the 'Reclassified Modes' including walking, bicycle, public transport, car and others (as mentioned in Section 3.3.2, highlighting travel characteristics). This reclassified modes could however not be used in the emission calculation due to the mode class of bicycles and walking which are zero emission modes and includes public transport as one complete class (see appendix A). Whereas for the emission calculation we require breakdown of the public transport modes and thus was computed again from the original MON variable (applicable only for emission calculation).

Thus, following is the SPSS syntax used to compute this new variable containing the carbon factors for each mode of transport, based on the new computation of bus, tram/metro, train, car and others (see Figure 22).

```
IF  (CO2TripModes = 2 & TripDistance_KM <  5) CO2EmissionFactor=125.
EXECUTE.
IF  (CO2TripModes = 2 & TripDistance_KM >=  5) CO2EmissionFactor=91.
EXECUTE.
IF  (CO2TripModes = 3) CO2EmissionFactor=56.
EXECUTE.
IF  (CO2TripModes = 4) CO2EmissionFactor=58.
EXECUTE.
IF  (CO2TripModes = 5) CO2EmissionFactor=108.
EXECUTE.
```

Figure 22: SPSS syntax for computing CO_2 Emission Factor

Thus, from the above figure, we can see that for each mode of transport (newly computed) one CO_2 factor has been assigned based on the explanation mentioned above. The mode of bus (2) has two CO_2 factors to be assigned to the dataset according to the collected source: city bus and intercity bus (see Table 11). However the MON dataset has no information on these two categories of buses and we assume that a bus covering a trip distance of less than (<) 5 km is a city bus and a bus covering a trip distance of more than (>=) 5 km is an intercity bus. Thus as seen in the figure above, the mode of bus (2) with distance less than (<) 5 km has a CO_2 factor assigned of 125 g/rkm (city bus) whereas with a distance of more than or is equal to (>=) 5 km has a CO_2 factor of 91 g/rkm according to Table 11. The mode of tram/metro (3) has a CO_2 factor of 56 g/rkm. The mode of train (4) has a CO_2 factor assigned of 58 g/rkm and that for the mode of car (5) has a CO_2 factor of 108 g/rkm (grams/passenger kilometre) as can be seen in the SPSS syntax above.

Thus, once the variable of CO_2 Emission Factor has been computed within the MON dataset, the final step involves calculating the carbon emissions. However, according to literature mentioned in section 2.4, two different methods have been mentioned to calculate carbon emissions. Amongst both the methods, the method that was used for calculating emissions was the 'emission factor method' (see section 2.4.2) and not the 'official fuel consumption method' (see section 2.4.1). The simple reason for selecting the former method is that it uses a carbon (CO_2) factor based on certain travel characteristics (see section 2.4.2), in our case only the mode of transport due to limited information available in the MON dataset. In the second method, it uses distance figures for each speed category and the amount of fuel used per vehicle (see section 2.4.1); both of which is not the information provided in the MON dataset.

Thus, according to the emission factor method, the following equation is used to calculate carbon emissions, according to the information provided in the MON dataset. Thus the equation below uses the MON variables in its representation of calculation, based on equation used for calculation in the emission factor method (see section 2.4.2).

Emissions (g) = CO2EmissionFactor (g/km) x TripDistance_KM

The above equation thus represents emissions (in grams) as an output of multiplying CO_2 factor (based on the mode of transport as seen in (Table 11) with the trip distance (in km). It is thus important to mention that the emissions are calculated at the trip level which is the smallest unit of analysis within the MON dataset. Thus the SPSS Syntax used to calculate the carbon emissions into a new variable (CO2Emissions_G) within the MON dataset can be seen below (see Figure 23).

```
COMPUTE CO2Emissions_G=CO2EmissionFactor * TripDistance_KM.
EXECUTE.
```

Figure 23: SPSS syntax used to calculate Travel Carbon Emissions

The calculated carbon emissions (in grams) were further converted from grams to kilograms into a new variable (CO2Emissions_Kg), for analyzing results that can be seen in the next chapter and this conversion in the SPSS syntax can be seen below (see Figure 24).

```
COMPUTE CO2Emissions_Kg=CO2Emissions_G * 0.001.
EXECUTE.
```

Figure 24: SPSS syntax used to calculate Travel Carbon Emissions in kilograms (kg)

Thus the calculated carbon emissions (in kg) were further converted into metric tonnes (Mtons) into a new variable (CO2Emissions_T), for analyzing results on a yearly basis specifically as will be seen in the next chapter and this conversion can be seen in the SPSS syntax below(see Figure 25).

```
COMPUTE CO2Emissions_T=CO2Emissions_Kg * 0.001.
EXECUTE.
```

Figure 25: SPSS syntax used to calculate Travel Carbon Emissions in Mtons

Thus, the carbon emissions have been calculated in kilograms at the lowest level of analysis which is the trip level within the MON dataset. This allows higher level aggregations (household, person and movement) for analyzing relationships of emissions with different travel and socio-economic variables that are present at different levels within the dataset.

3.3.5. Methods used to analyze emissions in relation to socio-economic characteristics

As previously described in Chapter 2 socio-economic characteristics have been considered important for the explanation of travel patterns and can also help in identifying ‘who’ are the individuals that are responsible for emissions and ‘how much’ do they contribute.

As Brand and Boardman (2008) and Brand and Preston (2010) suggested the individuals were ranked in a continuous distribution from the smallest to the largest value; thus the smallest value will be assigned 1 (lowest emitter). This can be seen in the figure below (see Figure 26). The calculated carbon emissions were ranked and grouped into emission quintiles. Quintiles represent groups of a fifth of total.

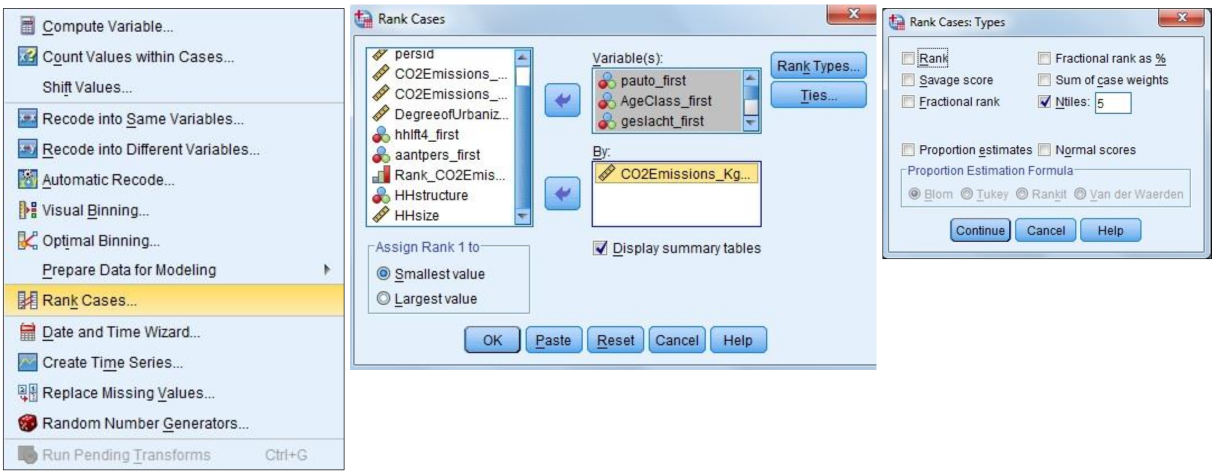
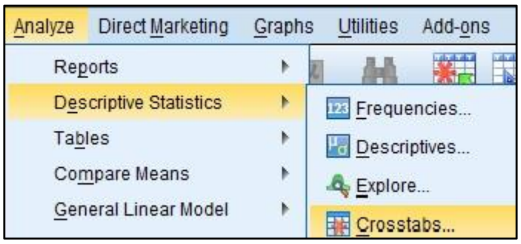


Figure 26: Ranking the emissions into quintiles

Further, to identify who are the high and low emitters, the population is segmented based on socio-economic characteristics and multivariate analyses are undertaken to perform the analysis. These analysis constitute the Pearson's chi square (χ^2) tests which were performed in order to find out whether or not there is a relationship between socio-economic characteristics (household size and structure, car ownership, age, gender, education, income, paid work hours, degree of urbanization) and emissions levels (defined by quintiles) and, if so, how strong is the relationship between them. This method has been taken from literature and was used in a study conducted by Brand and Boardman (2008). The process of undertaking Chi Square tests will become clearer from the figure below by quoting an example (see Figure 27).



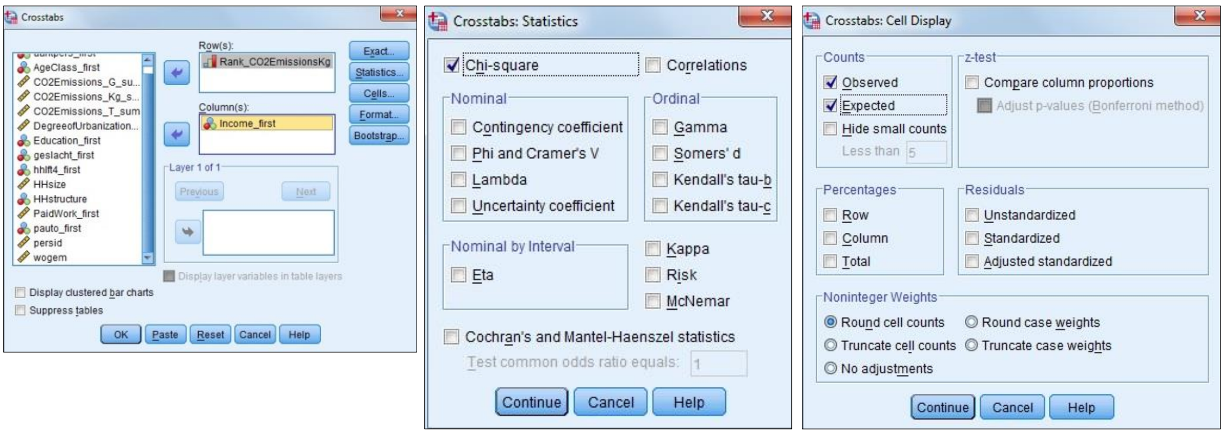


Figure 27: Pearson's Chi Square (x2) Tests

Pearson's chi square tests are used to analyze an association or relationship between two categorical variables (Field, 2009). Thus, once the emissions are ranked from the previous step into a new variable, it becomes categorical in terms of five emission quintile groups. So to assess the relationship using these tests the ranked emission variable and any other socio-economic variable represent the two categorical variables. It tests if both the categorical variables are independent. If the significance value, generated by the Chi Square test is small (Sig. should be less than .05) then the hypothesis is rejected of variables being independent and gain confidence that both the variables are related (Field, 2009). To quote an example, as given in the Figure 28 the value of chi square statistic is 381.467, which has a corresponding degree of freedom 20, thus the value is highly significant as $p<0.001$ (.000 is interpreted as <0.001) (Field, 2009), indicating a definite relationship between the two categorical variables.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	381.467[a]	20	.000
Likelihood Ratio	369.345	20	.000
Linear-by-Linear Association	307.493	1	.000
N of Valid Cases	9111		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 116.63.

Figure 28: Example of Chi Square Test

Also important for the test, is underneath the chi square table there are several footnotes relating to the assumption that the expected count should be greater than 5. If the expected count is less than 5 then more data needs to be collected for undertaking the test (Field, 2009). Thus, the results of these tests have been explained in Section 4.3.

3.4. Conclusion

The chapter highlights the availability of the MON dataset and how different elements of the dataset have been used in this research. The different travel and socio-economic variables of the dataset have been described that will be used in the producing analysis of the study. A carbon emission calculation framework has been designed in order to calculate emission with the input of travel characteristics and emission factors collected from various sources. In order to relate the calculated emissions to socio-economic characteristics, multivariate analysis have been undertaken in the form of Pearson's Chi Square tests that is used to identify a significant relationship between the emissions and categorical socio-economic characteristics such as household size and structure, car ownership, age, gender, income, education.

4. RESULTS

This chapter represents the analysis of the principal concepts in three distinct sections by describing a travel pattern, analyzing its impact on carbon emissions and identifying the individuals and households contributing to these emissions. Travel patterns are based on frequency of travel for different purposes, mode of transport used, travel time, distances travelled, and geographical location which have been described in terms of trips and movements.

These resultant travel patterns are further translated into emission profiles. These travel emission profiles are related to specific socio-economic characteristics as that of household size and structure, income, age, education, occupation, gender and car ownership to identify the highest and lowest emitters. In order to gain confidence in the analysis of the study, the results have been compared to provincial statistics of Overijssel and other related studies.

4.1. Travel Patterns

Travel pattern, at its very basic, is described in two forms of trips and journeys in this study. As mentioned previously a trip is the smallest unit of analysis and a journey with one or more trips with a motive is described as a movement. However, a pattern can be studied for each of these, to identify the popular modes of transportation used by the residents of Overijssel. Among the chief modes (see Appendix B), almost half of all the trips were made by zero emission (sustainable) modes of transport, 17% of which were made by walking covering an average distance of 0.9 kms. 29% of the trips were made by bicycle to cover a distance of 2.9 kms, on an average. In contrast, 44% of the other half of trips was made by car to cover an average distance of 17.1 kms. Thus we can say, to travel shorter distances, walking and bicycle is preferred over car which is used to cover much longer distances. Also, as we know public transport is an alternative for long distance travelling, only a miniscule 3% of trips were made by this means of transport to cover an average distance of 33 kms. One possible explanation for such a small proportion of public transport users, can be that the people who were surveyed for this sample dataset were more frequent car users. The rest 2% of trips were made by other modes (see Appendix A), about 5% trips had missing data.

Although similar travel pattern can be seen with the movements contained in the sample dataset of Overijssel, yet smaller differences have been observed by analyzing average distance and time travelled (see Appendix B). As trips, almost half of all the movements were also undertaken by zero emission (sustainable) modes of transport of which 15% were made by walking to travel an average distance of 0.9 kms in an average travel time of 12.3 minutes. While 30% of movements were made by bicycle to travel an average distance of 2.9 kms in 13.5 minutes. In comparison, 46% of the movements were made by car to travel much longer distances, an average of 17.2 kms in 22.1 minutes. As far as use of public transport is concerned, only 2% of all the movements are made by it to cover an average distance of 48.8 kms in 68.9 minutes. The rest 2% of the movements were made by other modes (see Appendix A), about 5% movements had missing data. These above statistics when compared with provincial statistics highlighted some similarities in the form of 30% movements made by bicycle, 47% by car and 2% by public transport (Provincie Overijssel, 2013b). However, when compared with distances, cycling and walking were usually used to travel shorter distances (Provincie Overijssel, 2013b).

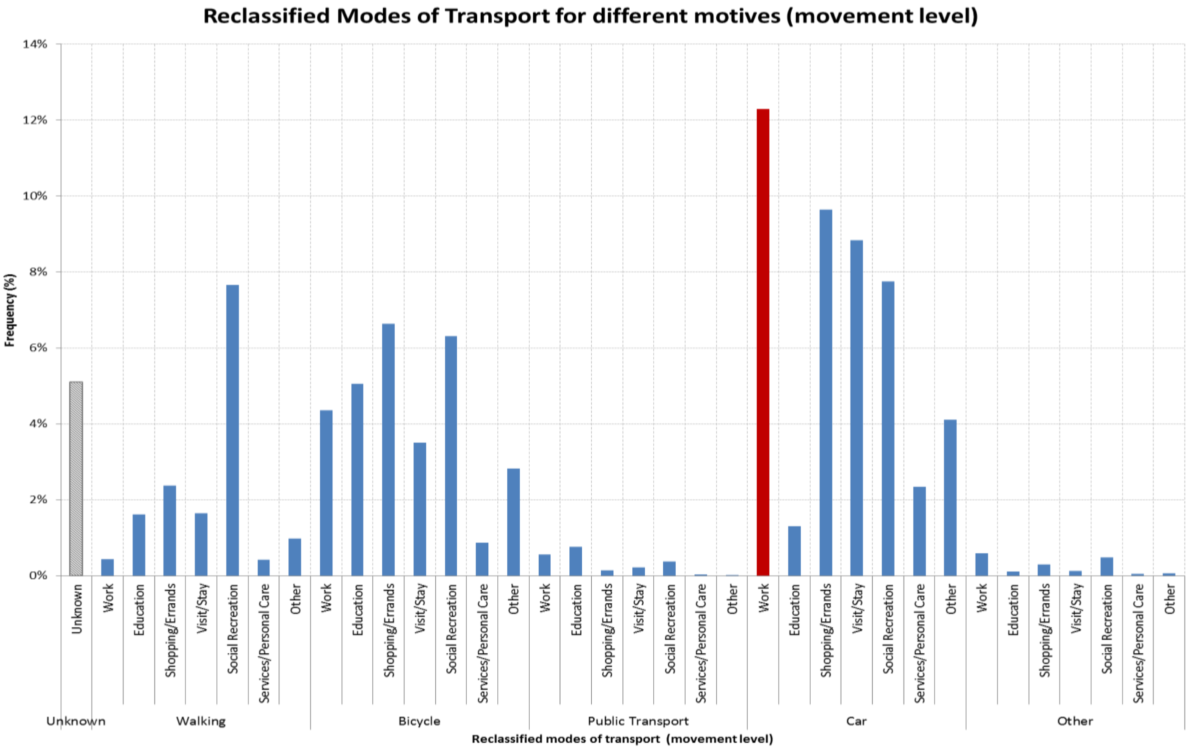


Figure 29: Reclassified Modes of Transport for different motives (movement level)

It is thus clear from the above that the travel patterns undertaken for both trips and movements have a predominance of the use of car as their chief mode of transport. What is not known yet is, amongst all the movements, what purpose are car movements made for so often and have been explored below.

Car travel makes for the largest 12.3% of all the movements to travel to 'work' (see Figure 29) covering an average distance of 23.9 kms in an average travel time of 28.3 minutes (see Appendix B). Alternatively, a much smaller 4.4% of movements have been made by bicycle for 'work' to cover an average distance of 3.7 kms in 15.7 minutes on average. Among other purposes, 'shopping' by car makes up for 9.6% of all the movements (see Figure 29) to travel an average distance of 7.8 kms in 13.8 minutes. What comes closer to an alternative mode for 'shopping', is the use of bicycle (6.6% movements) to travel an average distance of 1.9 kms in 9.5 minutes, however to travel much shorter distance as compared to that of a car. To travel for 'social recreation' by car, 7.7 % of all movements have been made to cover an average distance of 18.7 kms in 24.7 minutes. While an equivalent proportion of movements have been made for the same purpose to travel by walking but a rather shorter distance of 1.2 kms in 16.5 minutes, on an average (see Appendix B). However, a comparatively larger proportion of all movements of 8.8% have also been made by car for 'visit/stays' covering an average distance of 23.2 kms in 25.9 minutes. Interestingly, only 1.3% of all movements have been made for 'education' by car which is to travel a longer distance of 10 kms in 17.9 minutes on an average. While 5.1% of all movements have been made by bicycle for 'education' to travel a much shorter distance of 3.3 kms in 15.2 minutes on an average.

Thus, "*work-based car movements*" (see Figure 29) account for the most significant proportion of passenger travel pattern. As we already know from above that car based movements account for almost half of all the movements made within Overijssel, it would be interesting to understand some of the characteristics features of these movements.

4.1.1. Characteristics of Car-based movements:

From the given sample, it can be said that more than half of the movements made by cars, are older than 2002 (see Appendix C). In particular, the highest 18% of all movements made by cars have been bought between the years of 1997 to 1999, indicating that already the car has been 6-8 years old since the year of sample collection (2005) which makes the condition of the car inefficient and more carbon emissive.

However, how carbon emissive is a car depends a lot on the fuel type of the car. Diesel run vehicles have significantly lower carbon emissions when compared to petrol run vehicles. This is because the diesel engines have higher efficiency and hence have a comparatively lower impact on emissions (Department for Transport, 2013). Thus while almost half of these car based movements were being run on gasoline (47%), thereby a much greater contribution to increasing emissions can be observed. Diesel run journeys (18%) are much lower in comparison and a marginal proportion on LPG (3%) which emits even lower emissions (see Appendix C).

Thus, to summarize we can say that the movements made by the use of cars in Overijssel are to a large extent older than 6 six years, running comparatively higher on gasoline, thus making the car pollute more and have a higher probability to contribute to greater emissions.

4.1.2. Spatial variation of travel patterns:

As we have explored travel patterns by trips and movements in the previous section, it becomes important to understand how these have been distributed across municipalities spatially. Overijssel embodies 25 municipalities, representing total number of trips, movements, persons and households displayed by different colours by pie charts within each municipality (see Figure 30).

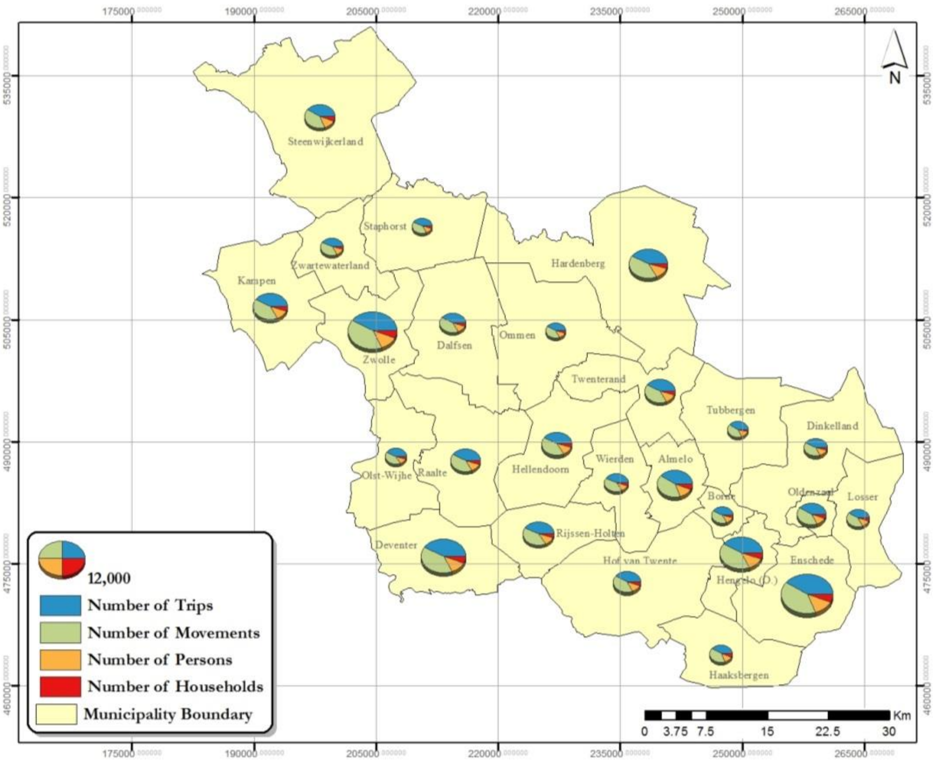


Figure 30: Distribution of actual values for trips, movements, persons, households across municipalities

As can be seen, the city of Enschede and the capital city of Zwolle have the highest sample size with similar figures in the number of trips, movements, individuals and households (see Appendix D). While a comparatively lower sample size can be observed for the municipalities of Deventer, Hengelo and Hardenberg. However municipalities of Almelo, Hellendoorn, Kampen, Raalte, Twenterand, Steerwijkerland and Rijssen-Holten have considerably lower sample sizes in comparison to the above mentioned (see Figure 30). Even smaller sample sizes can be observed for the rest of the municipalities of Borne, Dalfsen, Haaksbergen, Losser, Oldenzaal, Ommen, Staphorst, Tubbergen, Wlerden, Hof van Twente, Olst-Wljhe, Dinkelland and Zwartewaterland.

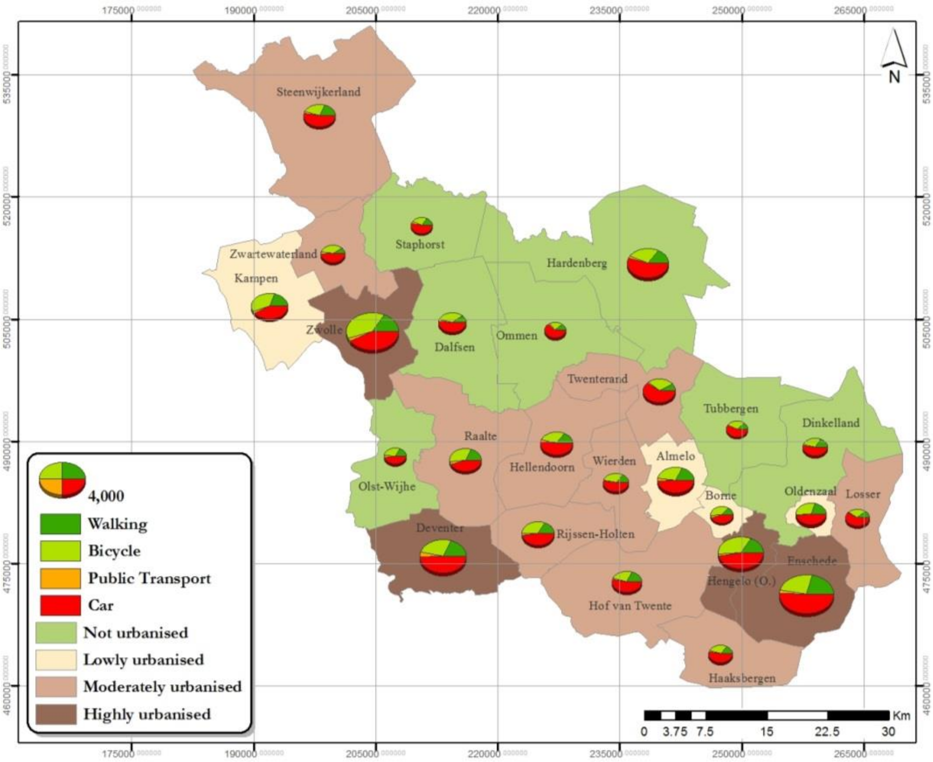


Figure 31: Relative share of modes of transport of all movements for each municipality

The map above (see Figure 31) represents travel patterns described by the relative percentage of the different modes of transport for movements for each municipality. This distribution has been represented across geographical areas of urbanization. These areas (see 3.3.2) have been displayed using different colours while the modes of transportation have been displayed by pie charts representing walking (dark green), bicycle (light green), public transport (orange) and car (red). The size of pie charts differs across each municipality due to the sample size as available within the MON dataset.

It can be evidently seen that there is a predominance of car use in all geographical areas along with a high bicycle use and proportionally less but significant use of walking for personal travel. While public transport is comparatively a much smaller share (see Appendix D). But variations amongst the use of these modes of travel can be observed within different geographical areas of urbanization. However some of the noteworthy examples have been discussed below.

While the not urbanised areas constitute higher share of car use as can be seen in Hardenberg where 51% of all movements are made by car, but also 27% movements by bicycle and 14% by walking are made. The city of Dalfsen accounts for 47% of its movements by car, 34% by bicycle use and 9% movements by walking mode.

Lowly urbanised area of Almelo, constitutes 45% movements by car in comparison to a lower 28% by bicycle use and 16% by walking. On the other hand, Kampen accounts for 39% of movements by car, slightly lower 33% of movements by bicycle use and 18% by walking.

Among the moderately urbanised areas, Haaksbergen accounts for 48% of all movements by car, while 29% by bicycle and 13% by walking respectively. The city of Raalte constitutes 42% car travel while 32% bicycle use and 17% of walking mode of transport. Twenterand comprises of wide variations, 55% of car travel while a comparatively lower 28% of movements by bicycle and even lower 8% movements by mode of walking.

The distribution of transportation modes within the highly urbanised areas of Zwolle, Deventer, Hengelo and Enschede, differed greatly in their mode share use. One of the prominent reasons could be because of a comparatively much higher sample size. Zwolle being the capital city of Overijssel, had almost an equivalent share of movements by bicycle (37 %) and car use (40%) with a smaller 15% of movements by walking. On the other hand, Deventer comprised of 46% movements by car, 27% by bicycle and 17% movements by walking. The largest city of Enschede accounted for 46% movements by car, 25% movements by bicycle and 19% movements by walking. In the city of Hengelo, car travel is used for 45% of all movements, 33% by bicycle and 15% by walking (see Appendix D).

Thus we can conclude that unlike the 'typical' idea of understanding that an urban area has greater alternatives to different modes that can be used for travel and are however absent in rural areas; the province of Overijssel stands different based on this sample dataset. Differences between the modes used for travelling can be seen among the different geographical areas of urbanization but there exists a consistency which highlights that almost half the movements are made by car while the rest are primarily distributed between walking and a higher share of bicycle use across all geographical areas (Figure 31).

Therefore we can say that the variable of geographical location is not of greater significance in describing the travel pattern variations. This can be validated by a study that was conducted by Timmermans et al. (2003) on 'Spatial context and the complexity of daily travel patterns: an international comparison'. However, it might be an important component in highlighting emission variation resulting from these travel patterns as explored in the next section.

Thus further is becomes important to identify the different motives (for all movements) within every municipality. The relative share of motives have been displayed by pie charts using different colours: work (blue), education (light blue), shopping (light green), visit/stays (yellow), social recreation (orange) and services/personal care (red). These pie charts differ in size due to the difference in sample size.

As seen in the map (Figure 32), the motives for which movements are made distinctly differ from each

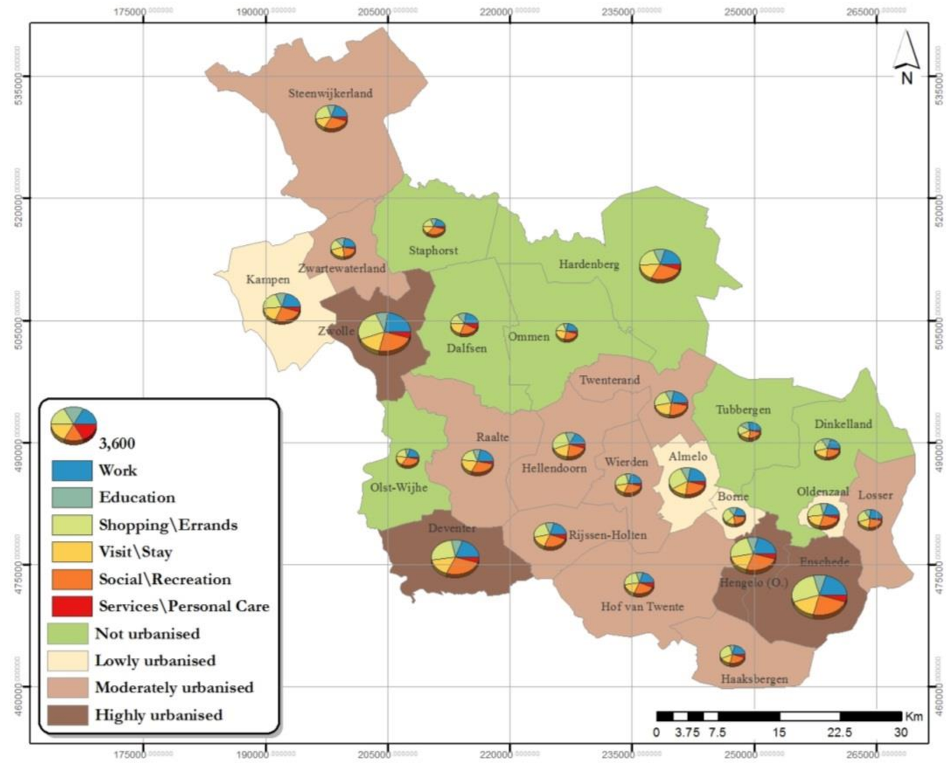


Figure 32: Relative share of motives of transport of all movements for each municipality

other but to understand these spatial variations some eminent examples include highly urbanised areas of Zwolle, Deventer, Hengelo and Enschede; moderately urbanised area of Haaksbergen, lowly urbanised areas of Almelo and Kampen, and not urbanised area of Hardenberg.

It is clear from the map that movements in Zwolle are undertaken highest for shopping (21%) and work related travel (20%) with significant proportion of visits (13%). In the case of the urban area of Deventer, social recreational activities account for the highest share (24%) in comparison to shopping (21%) and work related travel (16%). In Hengelo, movements are undertaken primarily for social recreational activities (24%), 20% for shopping and 18% of work related purposes. On the other hand Enschede experiences a similar proportion of travel for social recreational activities (21%) and shopping (21%) while a marginally smaller percentage share for work related travel (17%) (see Appendix D).

Among the moderately urbanised area of Haaksbergen, 23% of its movements are undertake for shopping, a similar proportion of 22% for social recreation activities and 19% movements for work related travel. Conversely, the lowly urbanised areas of Almelo, undertake 22% of travel for shopping and similar proportions for work (18%) and social recreational activities (19%). While Kampen, comprises of highest social recreational travel of 25% and 18% of work related travel. It also shares similar proportions of shopping (17%) and travel for visits (15%). On the other hand, the not urbanised area of Hardenberg comprises of movements mostly made for social recreational activities (25%), while 18% for work related travel and significant proportions of travel for shopping (16%) and visits/stays (14%) (see Appendix D).

Thus holistically we can say that more commonly travel is undertaken for work related, shopping, visits and social recreational activities with a smaller proportion for education and even smaller for services/personal care.

4.2. Travel Emission Profiles

This section spatially analyses the emissions produced from the above mentioned travel patterns on an average per person across the municipalities to identify the lowest and the highest emitters, as undertaken in studies conducted by Brand and Preston (2010) in UK.

Average travel emissions per person per year for the province of Overijssel is 2.1 tonnes of carbon emissions. This has been estimated by analyzing the average emissions per person per day as 0.0058 tons (5.8 kg) which was further multiplied to 365 days (assuming one year). This emission figure of 2.1 tonnes emitted per person in one year represents emissions produced by only carbon emissive means of transportation as that of car and public transport. This emission figure can be validated by the report published by International Transport Forum (2010). However the emission figure is validated based on the per person emission in the year 2007 according to the report.

The emissions have been calculated based on the trip level and all the results discussed in this section are thus based on trip level. An emission value per person (on an average) has been calculated for each municipality but for the ease of analysis these emission values have been put together in three classes to distinctly identify lowest, middle and highest emitters. Thus, the emission values have been classified based on the '*natural breaks classification method*', where similar values that cluster together are placed into a single class and the differences between the classes occur where there is a gap between clusters (ArcGIS Desktop Help, 2006).

However, the emissions have been calculated based on the modes of car and public transport as the modes of walking and bicycle are zero emission modes. It is thus important to mention that there is a wide difference between the average emissions produced per person for each municipality, when considering all modes of travel and only emissions produced by car and public transport. What happens is that in the emissions produced by all modes, the use of walking and cycling modes lowers the overall emissions produced, and can thus be misleading in identifying the emission production. This can be seen in Figure 33 below, displayed with the emission classes and total sample size of each municipality. As the focus of the research is concerned with identifying *who* are the individuals that contribute to emissions and *how much* is their contribution, we focus on average emissions produced per person, only by the carbon emissive modes of car and public transport. Thus as can be seen in Figure 34 the emission distribution varies from the previous Figure 33 highlighting only the individuals that contribute to carbon emissions, in terms of sample size and emissions.

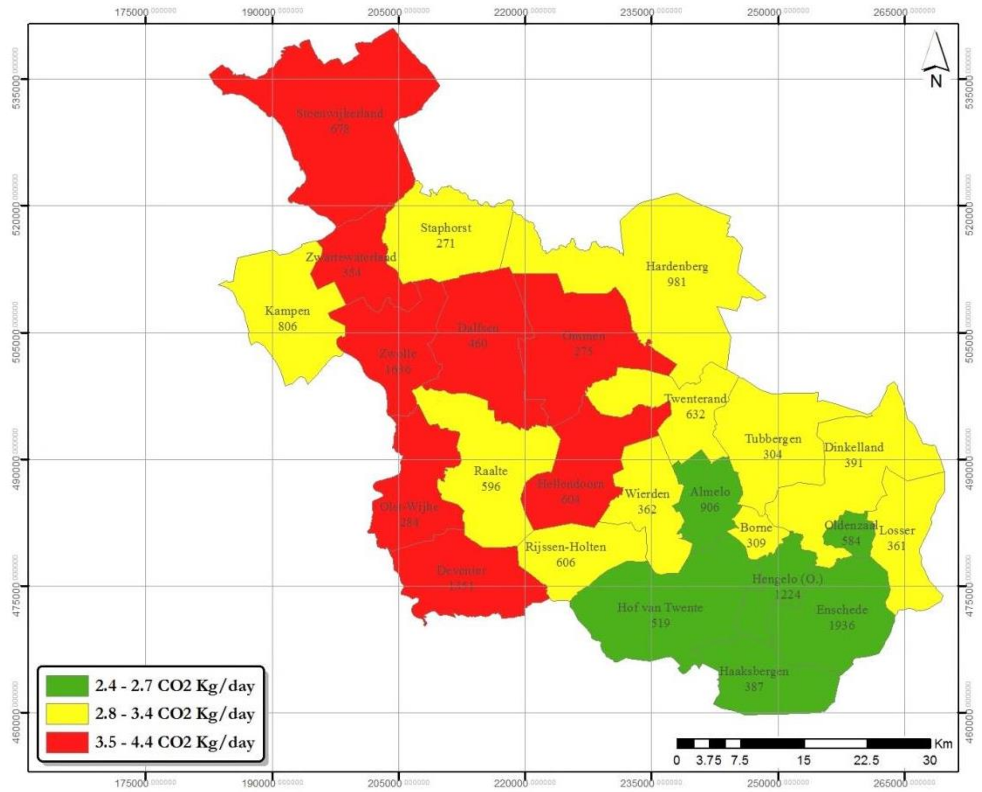


Figure 33: Average emissions produced per person by all modes of travel across municipalities

The map below differs greatly between the average emissions produced per person per year, classified into three classes, represented by different colours: 4.4 to 5.4 kg/day (green) is the lowest emission class, 5.4 to 6.3 kg/day (yellow) is the medium emissions class and 6.3 to 7.3 kg/day (red) is the highest emission class. Thus Figure 34 we can say that the west part of the province produces highest emissions whereas the east part of the province produces lowest emissions.

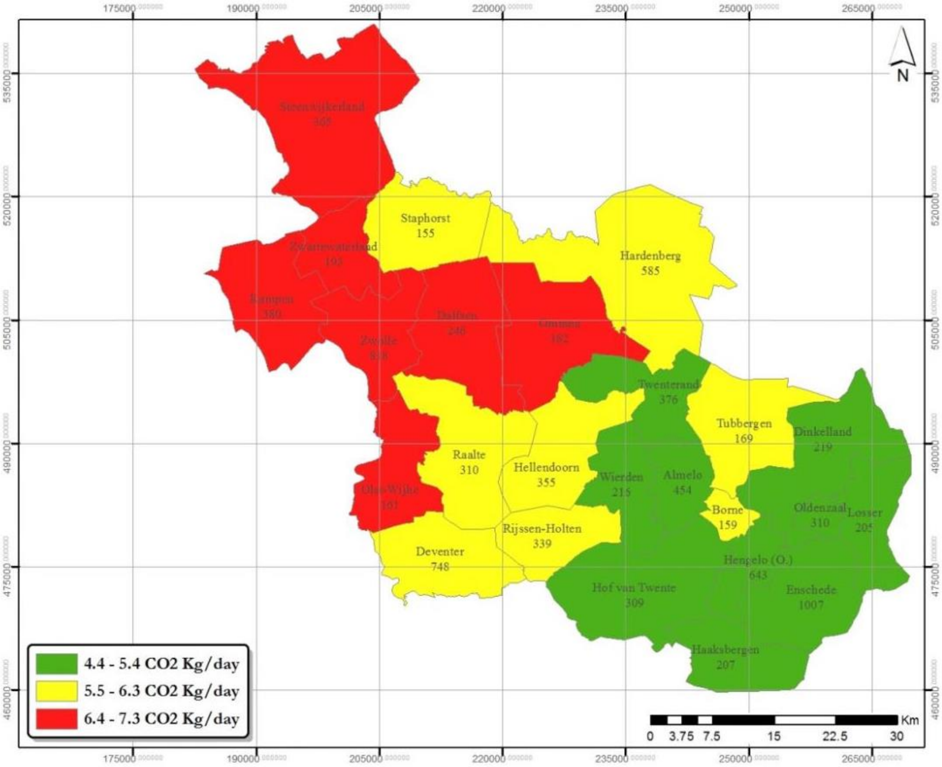


Figure 34: Average emissions produced per person by carbon emissive modes across municipalities

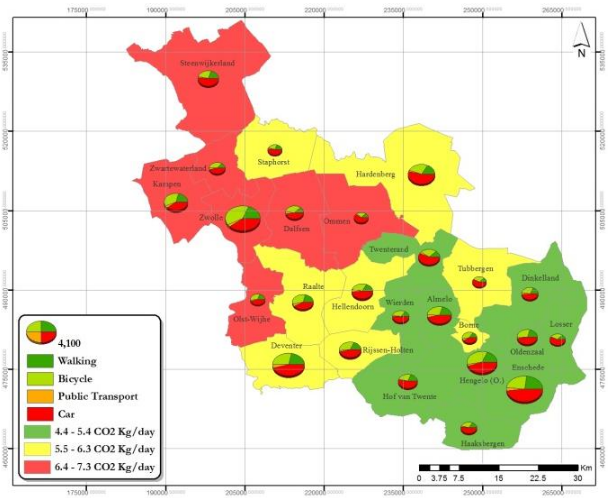


Figure 35: Relative share of modes of transport of all trips for each municipality

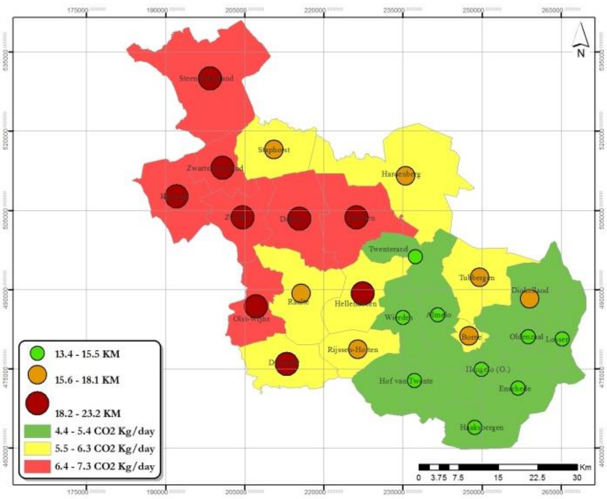


Figure 36: Average Car Trip Distance KM across municipalities

We can try and understand the reason behind such a wide variation between the east west gradient through the chief mode of transport that has been used for each municipality and then analyze the average travel distance covered by this mode of transport. This is because the emissions as previously mentioned have been calculated based on different modes and their distances travelled. Figure 35 represents the different modes of transport used for trips on an average including walking, bicycle, public transport and car. If we see Figure 35, there is a vast predominance in the relative share of trips made by car across each municipality. Thus it will be interesting to analyze the average distance travelled in each municipality by the mode of car as seen in Figure 36, where three distinct classes represent the average distance travelled for each trip. These classes range from the lowest average distances 13.3 to 15.4 km/trip, 15.4 km to 18.0 km/trip and highest 18.6 to 23.1 km/trip. The classes have been classified using the Natural breaks classification method (as explained previously). However, the distances travelled by car for each trip differs greatly for each municipality in Figure 36 resulting in stark differences in their emission distribution on an average per person. We can see that all the lowest average distances travelled by car for each trip fall in the lowest emission class that are in the east part of the province while all the highest average distances fall in the highest emission class that are seen in the west part of the province. To make this clearer, we try to quote some examples as under.

In the west part of the province the capital city of Zwolle constitutes 40% of trips made by car (see Figure 35) where the average distance travelled by car falls in the between 18.0 to 23.1 km/trip, thus highest average distance resulting in highest emission class of 6.4-7.3 kg/day CO_2 on an average per person. On the other hand, in the east part the largest city of the province Enschede, comprises of 48% of trips made by car and have an average travel distance between 13.9 to 15.4 km/trip, thus lowest average distance resulting in lowest emission class of 4.4-5.4 kg/day CO_2 on an average per person.

Similarly, if we see the city of Kampen in the west part of the province neighbouring with the capital city, constituting 40% of trips by car and results in higher average distances travelled ranging between 18.0 to 23.1 km/trip. This results in producing highest emissions on an average per person between 6.4-7.3 kg/day CO_2. Whereas if we see the city of Almelo in the east part of the province constituting 47% of trips by car and travelling an average distance between 13.9 to 15.4 km/trip by car, thereby resulting in lowest emissions on an average per person between 4.4-5.4 kg/day CO_2.

As we know the average emissions produced per person it is imperative to understand the location of these individuals. The map below (see Figure 37) represents the average emissions produced per person across all the municipalities distributed geographically over degree of urbanization. These geographical areas can be observed in four different areas (see 3.3.2), each represented by a different colour: highly urbanised (dark brown), moderately urbanised (light brown), lowly urbanised (light pink) and not urbanised (green).

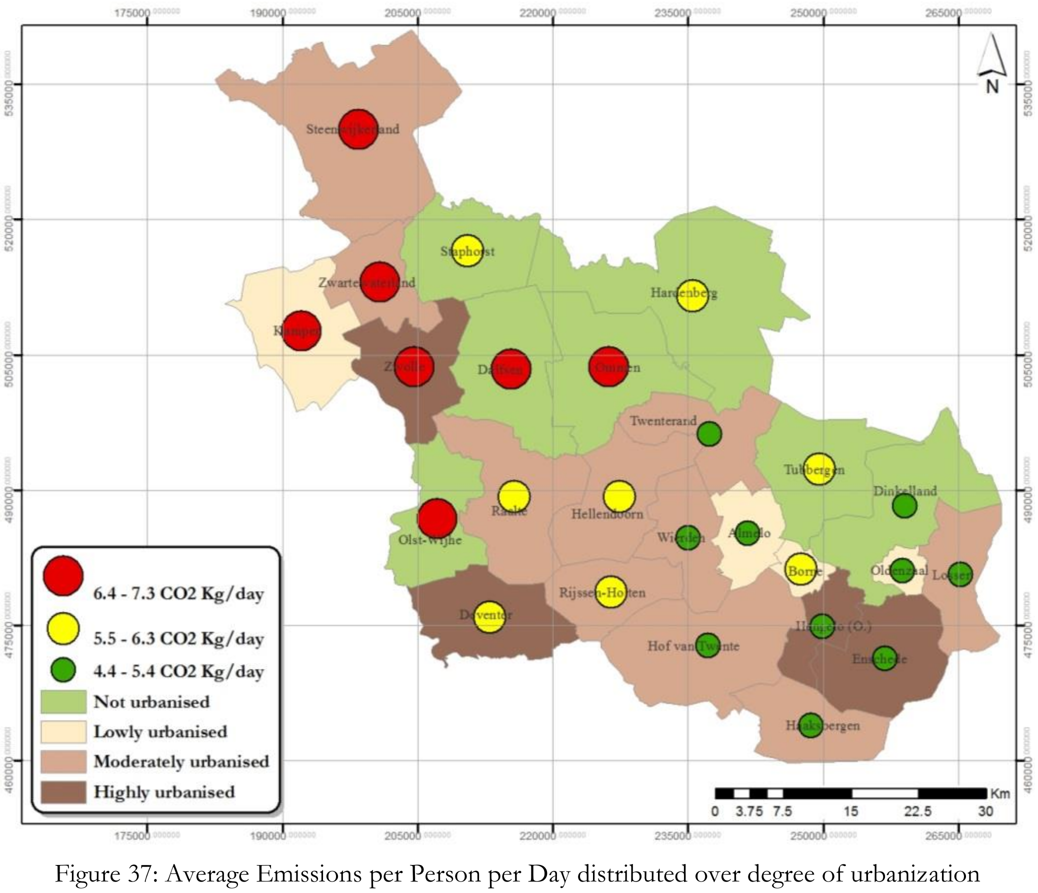


Figure 37: Average Emissions per Person per Day distributed over degree of urbanization

According to the distribution (see Figure 37), lowest emitters can be seen in the east part of the province. These cover the major portion of moderately urbanised areas of Twenterand, Wierden, Hof van Twente, Haaksbergen and Losser, lowly urbanised areas of Almelo and Oldenzaal and not urbanised area of Dinkelland. Interestingly highly urbanised areas of Hengelo and the largest city of the province, Enschede contain individuals producing the lowest emissions on an average per day.

On the other hand, the medium emitters are spread across the moderately urbanised areas of Raalte, Hellendoorn and Rijssen-Holten, lowly urbanised area of Borne, not urbanised areas of Staphorst, Hardenberg and Tubbergen. It is noteworthy to visualize the highly urbanised area of Deventer fall under this category.

Thus the highest average emissions produced per person belong to the west part of the province. These comprise of the not urbanised areas of Dalfsen, Ommen and Olst-Wijhe, moderately urbanised areas of Zwartewaterland and Steenwijkerland including the lowly urbanised area of Kampen. However the capital city of the province is a highly urbanised area and the individuals residing in this area contribute to the highest number of emissions.

Based on the above emission variations, we try to explore the contribution of emissions produced by the different modes of transportation. As walking and bicycle modes are zero emission modes, therefore they have been excluded in this variation and thus only comprises of modes producing emissions such as that of car and public transport. It should be noted that public transport includes travel by bus, train, tram/metro as mentioned previously in section 3.3.4. Thus the map below, represents relative share of emissions produced by modes of car and public transport. These have been displayed by pie charts where the size of each pie chart represents the emissions share of a particular municipality.

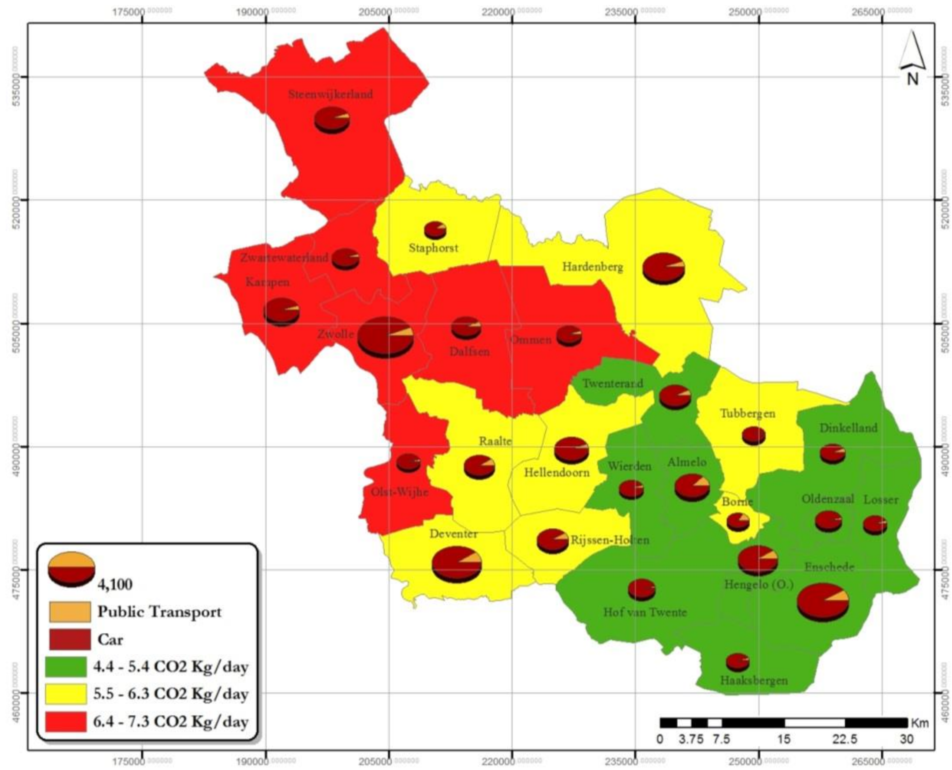


Figure 38: Relative share of emissions produced by Car and Public Transport

It is of no surprise that there is a vast predominance of emissions produced from car travel than public transport (see Figure 38). In the capital city of Zwolle, 94% emissions are produced by car and if we take into account the number of number of trips within this city, it comprises of only 40% (see Appendix D) thereby resulting in higher emissions. Similarly in the city of Enschede, 92% of the emissions are being produced by car that results from 48% of the trips made. In the case of Deventer, a similar scenario can be observed, where 91% of the emissions are produced from car use and the trips made by car account for only 46%. Thus we can say that almost half of all the trips made within each of these municipalities account for their largest percentage share of emissions production.

Further to identify 'who' are producing these travel emissions, their socio-economic composition will be explored in the next section.

4.3. Travel emission profiles related to socio-economic characteristics

This section aims to identify the "emitters", who are responsible for emitting the carbon emissions levels. The emissions produced by the individuals have been ranked into five distinct groups (quintiles) on a range of low to high emissions, to identify the average emissions produced per person on an average. The socio-economic composition of each of these quintiles will be identified based on the emission levels and the characteristic features such as geographical location, household size and structure, vehicle ownership, age, gender, highest completed education, total number of working hours and personal net income.

The lowest emission quintile consists of 17% of the total individuals and produce 0.5 kg/day of carbon emissions on an average. The second emission quintile consists of a higher proportion of total individuals 29% and contributes 1.5 kg of emissions on an average per day. A small proportion (3%) of individuals in the third emission quintile contributes 3 kg/day of emissions. The fourth emission quintile constitutes almost half, 44% of all the individuals producing 5.9 kg/day of emissions on an average. However, this quintile instead has the maximum influence on the sample average of 5.8 kg/day of emissions per person (see section 4.2). Thus, if the emissions of this quintile group can be controlled in particular then the average carbon emission contribution can become lower thereby mitigating the effects of travel patterns. If the numbers are compared to the highest emitters, only a miniscule 2% contribute 18.5 kg/day. However it should be noted that the rest 5% consists of missing data as the emissions have been calculated based on modes of transport used (trip level) which contains this missing data (see Appendix A).

Thus, it would be interesting to find out what is the socio-economic composition of these emission groups (quintiles) to further highlight a particular population segment that should be focussed upon to mitigate these induced emissions. Thus to identify who are the high and low emitters, Pearson's Chi Square (x2) tests (see section 3.3.5) were performed to discover if there is an association or relationship between emission levels and socio-economic characteristics and if so, to assess how strong is that relationship (see Appendix E). These tests have been used in previous studies by Brand and Boardman (2008) on 'Taming of the few—The unequal distribution of greenhouse gas emissions from personal travel in the UK'.

The socio-economic characteristics can be understood in detail as under:

Household Structure: Household structure in this study is indicative of the number of individuals aged 18 year or above in a household, as they are legally permissible to hold a driving license to drive a vehicle that may result in producing emissions; which is the key concern for this study. Among the lowest emitters, 22% of households composed between 1-2 individuals while in the second emission quintile 27% of households composed of equal to or more than 5 individuals (see Appendix E) In the third emission quintile 18% of the households comprised between 3-4 individuals. In the fourth emission quintile 24% of households comprised between 3-4 and more than 5 individuals. However amongst the highest emitters 18% of the households comprised of 3-4 individuals and almost same proportion for 1-2 individuals. Thus there exists a significant relationship ($p<0.001$) between household structure and emissions.

Household Size: The total number of individuals in a household varied across emission quintiles. In the first emission quintile 22% households consisted of 3-4 individuals in total while the same proportion for 5-6 individuals. In the second emission quintile 26% households comprised of 5-6 total individuals while 25% households comprised of more than 6 individuals in total. 18% households in the third emission quintile comprised of 1-2 individuals while the same proportion for more than 6 individuals. However in the fourth emission quintile, 20% households comprised of 1-2 individuals, the same proportion for 3-4 individuals and yet again the same share for 5-6 individuals in total. However the highest emitters constituted 20% of households having 1-2 individuals while the same share for more than 6 individuals in total. Thus, there exists a significant relationship ($p<0.001$) between the household size and emission levels.

Car Ownership: Lowest emitters comprise of 26% of the individuals who did not own a car while roughly 24% of the individuals in the second emission quintile did not own a car. However, in the third emission quintile 18% of the individuals own a car and the proportion become significantly high in the fourth emission quintile where 23% of individuals are car owners. However a slight decline can be observed in the highest emission quintile, where 21% of individuals are car owners. Thus the relationship proves to be significant as the significance level of the x2 tests stand as $p<0.001$.

Age: In the lowest emission quintile 19% of individuals are aged between 50-65 years while 17% are aged between 18-25 years. In the second emission quintile 22% of individuals are between the ages of 50-65 years and 20% between the age group of 18-25 years. However, 21% of individuals within the third emission quintile belong to the age category of 18-25 years. In the fourth emission quintile, 27% of individuals age between 18-25 years, 24% between 25-35 years and the same proportion between 35-50 years. This ideally makes up for the working class population. Amongst the higher emitters, 22% of the individuals are aged between 25-35 years. Thus, the factor of age and emissions share a significant relationship where $p<0.001$.

Gender: Amongst the lowest emitters 23% are females while a similar proportion in the second emission quintile can also be observed. In the third emission quintile, 19% individuals are females while the share of the male becomes higher in the fourth and highest emission quintile. While 21% males are present in the fourth emission quintile, a marginally lower 20% of females are also present in this group. However the highest emitters constitute of 24% of male population. Thus there exists a significant relationship ($p<0.001$) between gender and emission levels.

Highest Completed Education: In the lowest emission quintile, 22% of the individuals are lower educated. While in the second emission quintile 23% of the individuals are lower educated and 22% constitute middle education. 19% of individuals constitute lower education while 18% middle education in the third emission quintile. However, a sharp increase of 24% individuals who are highly qualified and 24% consist of middle education in the fourth emission quintile. The highest emitters include 29% of persons who are highly qualified. Therefore as $p<0.001$ we can say that a significant relationship exists between education and emissions levels.

Paid Work Hours: In the lowest emission quintile, 19% of individuals worked for less than 12 hours per week while, 18% worked between 12 to 30 hours per week. Second emission quintile comprised of 23% of individuals working for less than 12 hours while 22% worked between 12 to 30 hours in a week. 23% of the third emission quintile comprised of working hours between 12 to 30 hours per week. However in the fourth emission quintile 25% individuals worked for equal to or more than 30 hours/week while 24% worked between 12 to 30 hours/week and 23% worked for less than 12 hours/week. The highest emitters include 26% of individuals working for equal to or more than 30 hours/week. Thus there exists a significant relationship ($p<0.001$) between the two variables of paid working hours of individuals and emissions produced.

Personal Net Income: Among the lowest emitters, 23% of the individuals earn less than 7500 Euros per year while 25% of earn between 7500-15000 Euros/year in the second emission quintile. In the third emission quintile, 19% individuals earn between 15000-22500 Euros/year, 18% earn between 7500-15000 Euros/year and the same proportion (18%) less than 7500 Euros/year. However in the fourth emission quintile, 23% are earners between 22500-30000 Euros/year, 22% individuals earn between 15000-22500 Euros/year and the same share of individuals earn equal to or more than 30000 Euros/year. In the same quintile, 21% are earners between 7500-15000 Euros/year and 20% earn less than 7500 Euros/year. Amongst the highest emitters 31% of individuals earn equal to or more than 30000 Euros/year while 27% earn between 22500-30000 Euros/year. Thus by examining the x2 tests the relationship between income and emissions proves to be significant ($p<0.001$).

Degree of Urbanization (location): In the lowest emission quintile 23% of individuals reside in lowly urbanised areas while 21% reside in moderately urbanised and highly urbanised areas. 25% of the individuals reside in highly urbanised areas in the second emission quintile. In the third emission quintile 19% of individuals reside in moderately urbanised areas and 18% reside in lowly urbanised and highly urbanised areas. Interestingly, in the fourth emission quintile 24% of individuals reside in not urbanised areas, 23% reside in moderately urbanised areas and 20% reside in lowly urbanised areas. Amongst the highest emitters, 20% of individuals reside in highly urbanised areas and not urbanised areas. Thus the relationship between geographical degree of urbanization and emissions proves to be significant ($p<0.001$).

Thus to conclude, we can say, that the lowest emitters were typically non-car owners, individuals within the age group of 50-65 years, mostly female, comprising of lower education, working for less than 12 hours per week, earning less than 7500 Euros/year as their personal net income and residing mostly in lowly urbanised areas. On the other hand, highest emitters were car owners, aged between 25-35 years, mostly males who were highly qualified, earning equal to or more than 30000 Euros/year as their personal net income and residing in strongly urbanised areas. It should be kept in mind that while lowest emitters comprising 17% of total individuals produced on average 0.5 kg/day emissions per person; the highest emitters comprising of a miniscule 2% of the total individuals produced 18.5 kg/day CO_2 emissions per person. However the focus for carbon mitigation from travel emissions should be laid on the fourth emissions quintile group constituting 44% of the total individuals and producing an average of 5.9 kg/day emissions per person which in the long run increases the emission figure of 2.1 tonnes/year per person further up.

4.4. Conclusion

The travel pattern of Overijssel highlights that almost half of all the trips and movements are made by zero emission modes of walking and bicycle use while the other half almost makes up for car travel. Specifically, work-based car movements account for the most significant proportion of passenger travel pattern. Movements made by the use of cars in Overijssel are to a large extent older than 6 six years, running comparatively higher on gasoline, thus making the car pollute more and have a higher probability to contribute to greater emissions. The result of these travel patterns leads to 2.1 tonnes of carbon emissions per person per year on an average for the province of Overijssel. The west part of the province produces highest emissions whereas the east part of the province produces lowest emissions. There is a vast predominance of these emissions produced from car travel than public transport. In order to identify the emitters of these emissions, the lowest emitters constituted non-car owners, individuals within the age group of 50-65 years, mostly female, comprising of lower education, working for less than 12 hours per week, earning less than 7500 Euros/year as their personal net income and residing mostly in lowly urbanised areas. On the other hand, highest emitters were car owners, aged between 25-35 years, mostly males who were highly qualified, earning equal to or more than 30000 Euros/year as their personal net income and residing in strongly urbanised areas.

5. CONCLUSION AND DISCUSSIONS

This chapter summarizes the aim and purpose of the study which identified emission profiles on the basis of observed personal travel patterns which have been connected to socio-economic characteristics which will be addressed by the research objectives and questions. It also gives an overview of the shortcomings of the study and recommendations for future studies undertaken in the same aspect of travel emission profiles within the case study area.

5.1. Addressing research objectives and questions

5.1.1. To review and conceptualize personal travel and its relation with carbon emissions

The first research objective highlighted conceptualizing and operationalizing personal travel in relation to carbon emissions which mentioned two eminent research questions. The first one highlighted relevant travel characteristics that were needed to describe travel patterns in relation to carbon emissions. These incorporated studying literature on how travel patterns have been described by different authors and researches. Thus the travel characteristics that were to describe a travel pattern in this research were mode of transport, motive (purpose) of travel, distance travelled, travel time, frequency and geographical location.

The second research question highlighted on how travel patterns are related to carbon emissions which was addressed by highlighting the emissions produced by the transport sector within Overijssel constituting civil aviation, water borne navigation, rail and road transportation. It was however established that road transportation accounts for the highest increasing emissions since 1990 levels within the province and constitutes emissions produced from passenger vehicles, light duty vehicles and freight transportation.

The third research question was to analyze the association between travel related carbon emissions and specific socio-economic characteristics. This was addressed by gaining literature from various studies and in this study specific characteristics were undertaken to identify their association in terms of impact on emissions incorporating household size and structure, car ownership, age, gender, education, paid work, income and geographical location in terms of degree of urbanisation.

5.1.2. To develop a methodology to describe travel patterns, calculate carbon emissions and relate these with socio-economic characteristics

The second research question highlighted to develop a methodology to describe travel patterns, calculate emissions and relate these to socio-economic characteristics. This included two major research questions. The first one aimed at reviewing methods for travel and socio-economic characteristics which will be adopted based on the sample dataset. The travel variables as selected from the sample MON dataset for this study, based on literature, were reclassified to carry out the required analysis for the study. The socio-economic characteristics were also selected from the sample MON dataset and to identify a significant relationship with the carbon emissions multivariate analysis were explored based on literature. In this study, the method of Pearson's Chi Square tests was used to analyse this relationship using the emissions levels and the selected socio-economic characteristics.

The second research question aimed at identifying the most suitable method to calculate carbon emissions which was addressed by developing an emission calculation framework using the travel characteristics of mode of transport and distance travelled in emission calculation. Emission factors were collected from national sources based on the different modes of transport used within the country of the Netherlands. This calculation was based on the emissions factor method as it suited the most according to the availability of the dataset.

5.1.3. To analyze the calculated travel pattern related carbon emissions

The third and the final research objective aims at analyzing the calculated carbon emission levels which includes two eminent research questions. The first question aimed at identifying the relationship between the socio-economic characteristics and travel emissions. By undertaking the Pearson's Chi Square tests, significant relationships were identified between calculated carbon emissions and the socio-economic characteristics of household size and structure, car ownership, age, gender, education, paid work, income and geographical location in terms of degree of urbanisation. The lowest emitters constituted non-car owners, individuals within the age group of 50-65 years, mostly female, comprising of lower education, working for less than 12 hours per week, earning less than 7500 Euros/year as their personal net income and residing mostly in lowly urbanised areas. On the other hand, highest emitters were car owners, aged between 25-35 years, mostly males who were highly qualified, earning equal to or more than 30000 Euros/year as their personal net income and residing in strongly urbanised areas.

The second research question aimed at the spatial distribution of travel pattern related emissions. Average travel emissions per person per year for the province of Overijssel is 2.1 tonnes of carbon emissions. This has been estimated by analyzing the average emissions per person per day as 0.0058 tons (5.8 kg) which was further multiplied to 365 days (assuming one year). This emission figure of 2.1 tonnes emitted per person in one year represents emissions produced by only carbon emissive means of transportation as that of car and public transport. This emission figure can be validated by the report published by International Transport Forum (2010). However the emission figure is validated based on the per person emission in the year 2007 according to the report. The average emissions produced per person per year, were classified into three classes across the municipalities, represented by different colours: 4.4 to 5.4 kg/day (green) was the lowest emission class, 5.4 to 6.3 kg/day (yellow) was the medium emissions class and 6.3 to 7.3 kg/day (red) was the highest emission class. It was thus observed that the west part of the province produces highest emissions whereas the east part of the province produces lowest emissions.

5.2. Shortcomings of the study

This research faces shortcomings for broadly two main purposes. Firstly that it incorporates very limited travel characteristics in the study of travel patterns, restricted only to six travel characteristics including mode, motive, distance, time, frequency and geographical location due to limited timeframe. Secondly the emission calculation was limited to the use of two major travel characteristics of the mode of transport and distance travelled while emission calculation methods as mentioned in literature incorporated a number of vehicle characteristics, technology characteristics that were missing in the study due to the restraints of the dataset.

Also, in regard to the information available at the disaggregated levels of trips, the information on the motive for each trip made was not available and holds importance in analyzing the emission production at the trip level. Similarly the information available at the trip level for modes of transport includes comparatively very less samples for travel undertaken by public transport in comparison to car travel which might give an inaccurate picture for the modes of transport used by the respondents. This is also the case at the information available at the movement level for modes of transport used for personal travel. These limitations as provided within the dataset could have been useful if available for the emission analysis.

5.3. Recommendation for future studies

For future studies, these shortcomings should be taken under consideration as the study itself is a worldwide topic of concern and can have serious implications on the environment that sustains us. It is a way of enabling people to observe a distinctive association between the travel patterns that they follow which in turn produces emissions. This research is therefore aimed to identify the potential that exists for change in the existing travel patterns, for example: car dependent travel and amongst what groups of society, for example: high income groups. It gives a clearer picture of which groups of the society generate more emissions than the others and what steps and measures can be taken to reduce their contribution to the doubling levels. The study can act as an inventory for national and local policies, examining individual and household profiles. This will thus aid in developing effective strategies for less carbon intensive travel by means of improved technology and passenger transportation. Many studies in the past have been undertaken in this direction but recently it has gained much more importance, due to the widespread news of climate change and global warming, a major consequence of accelerating carbon emission levels.

LIST OF REFERENCES

Acutt, M., & Dodgson, J. (1996). Policy Instruments and Greenhouse Gas Emissions from Transport in the UK. *Fiscal Studies, 17*(2), 65-82. doi: 10.1111/j.1475-5890.1996.tb00243.x

Anable, J., Boardman, B., & Root, A. (1997). Travel Emission Profiles. Oxford, United Kingdom: Energy and Environment Programme.

ArcGIS Desktop Help. (2006). Classification methods Retrieved May 26, 2013, from http://webhelp.esri.com/arcgisdesktop/9.1/index.cfm?id=2473&pid=2470&topicname=Classification%20methods

Banister, D. (1993). *Transport, the environment and sustainable development*: Routledge.

Banister, D. (2005). *Unsustainable transport*: Routledge.

Basmajian, C. (2010). "Turn on the radio, bust out a song": the experience of driving to work. *Transportation, 37*(1), 59-84.

Becker, U., Böhmer, J., & Gerike, R. (2008). How to define and measure access and need satisfaction in transport. *Dresden Institute for Transportation and Environment (DIVU)*(7).

Brand, & Boardman, B. (2008). Taming of the few—The unequal distribution of greenhouse gas emissions from personal travel in the UK. *Energy policy, 36*(1), 224-238. doi: http://dx.doi.org/10.1016/j.enpol.2007.08.016

Brand, Goodman, A., Rutter, H., Song, Y., & Ogilvie, D. (2013). Associations of individual, household and environmental characteristics with carbon dioxide emissions from motorised passenger travel. *Applied Energy, 104*(0), 158-169. doi: http://dx.doi.org/10.1016/j.apenergy.2012.11.001

Brand, & Preston, J. M. (2010). '60-20 emission'—The unequal distribution of greenhouse gas emissions from personal, non-business travel in the UK. *Transport Policy, 17*(1), 9-19.

Central Bureau of Dutch Statistics. (2012). Traffic and transport Retrieved December 24, 2012, from http://www.cbs.nl/en-GB/menu/themas/verkeer-vervoer/cijfers/nieuw/default.htm

DANS. (2007). Mobility Survey Netherlands Retrieved May 14, 2013, from https://easy.dans.knaw.nl/ui/datasets/id/easy-dataset:33530

Department for Environment Food and Rural Affairs. (2012). 2012 Greenhouse Gas Conversion Factors Retrieved December 12, 2012, from http://www.defra.gov.uk/publications/2012/05/30/pb13773-2012-ghg-conversion/

Department for Transport. (2013). Cars and fuel options Retrieved May 13, 2013, from http://www.dft.gov.uk/vca/fcb/cars-and-fuel-options.asp

Department of Transport. (2012). Road Transport Forecasts 2011: Results from the Department for Transport's National Transport Model. UK.

Dutch Daily News. (2011). Dutch Road traffic nuisance serious but stable, *Dutch Daily News*. Retrieved from http://www.dutchdailynews.com/dutch-road-traffic-nuisance/

Eggleston, H. (1992). Pollution in the Atmosphere: Future Emissions from the UK. *LABORATORY REPORT*(LR 888 (AP)).

European Environment Agency. (2010). Climate change mitigation (Netherlands) Retrieved May 12, 2013, from http://www.eea.europa.eu/soer/countries/nl/soertopic_view?topic=climate%20change

Eurostat. (2009). Panorama of Transport.

Fergusson, M., Holman, C., & Barrett, M. (1989). ATMOSPHERIC EMISSIONS FROM THE USE OF TRANSPORT IN THE UNITED KINGDOM. VOLUME 1: THE ESTIMATION OF CURRENT AND FUTURE EMISSIONS.

Field, A. (2009). *Discovering statistics using SPSS*: Sage Publications Limited.

Frändberg, L., & Vilhelmson, B. (2011). More or less travel: personal mobility trends in the Swedish population focusing gender and cohort. *Journal of Transport Geography, 19*(6), 1235-1244. doi: 10.1016/j.jtrangeo.2011.06.004

Gover, M. P., Hitchcock, G. S., Collings, S. A., & Moon, D. P. (1994). *UK Petrol and Diesel Demand. Energy and Emissions Effects of a Switch to Diesel*. UK.

Greening, L. A. (2004). Effects of human behavior on aggregate carbon intensity of personal transportation: comparison of 10 OECD countries for the period 1970–1993. *Energy Economics, 26*(1), 1-30.

Greening, L. A., Schipper, L., Davis, R. E., & Bell, S. R. (1997). Prediction of household levels of greenhouse-gas emissions from personal automotive transportation. *Energy, 22*(5), 449-460.

Hanson, S., & Hanson, P. (1981). The impact of married women's employment on household travel patterns: A Swedish example. *Transportation, 10*(2), 165-183. doi: 10.1007/bf00165264
Hillman, M., & Whalley, A. (1983). *Energy and personal travel: obstacles to conservation*.
Hoen, A., Geurs, K., Wilde, H. d., Hanschke, C., & Uyterlinde, M. (2009). CO_2 emission reduction in transport: Confronting medium-term and long-term options. The Netherlands: Netherlands Environmental Assessment Agency (PBL) and Energy research Centre of the Netherlands (ECN).
Hughes, P. (1993). *PERSONAL TRANSPORT AND THE GREENHOUSE EFFECT. A STRATEGY FOR SUSTAINABILITY*.
Hunter, P. G., & Zegras, P. C. (2011). Mobility's Footprint: Household Travel, Local and Global Emissions, and the Built Environment in Santiago de Chile.
ICF International. (2008). Integrating Climate Change into the Transportation Planning Process.
International Transport Forum. (2010). REDUCING TRANSPORT GREENHOUSE GAS EMISSIONS: Trends & Data 2010 (pp. 15). Leipzig, Germany.
Kingham, S., Dickinson, J., & Copsey, S. (2001). Travelling to work: will people move out of their cars. *Transport Policy, 8*(2), 151-160. doi: http://dx.doi.org/10.1016/S0967-070X(01)00005-1
Kitamura, R., Chen, C., & Pendyala, R. M. (1997). Generation of synthetic daily activity-travel patterns. *Transportation Research Record: Journal of the Transportation Research Board, 1607*(-1), 154-162.
Maslow, A. H. (1943). A theory of human motivation. *Psychological review, 50*(4), 370.
McDermott, M. (2012). Planes, Trains, Automobiles (and Buses): Which is the Greenest Way to Travel Long Distance in the US? Retrieved January 31, 2012, from http://tlc.howstuffworks.com/family/plane-train-automobile-travel.htm
Mokhtarian, P. L., Salomon, I., & Redmond, L. S. (2001). Understanding the demand for travel: It's not purely'derived'. *Innovation: The European Journal of Social Science Research, 14*(4), 355-380.
National Institute for Public Health and the Environment. (1997). Energiegebruik en emissies per vervoerwijze. The Netherlands.
National Institute for Public Health and the Environment. (2011). Greenhouse Gas Emissions in the Netherlands 1990-2009. The Netherlands.
Netherlands Environmental Assessment Agency. (2010). Greenhouse Gas Emissions in the Netherlands 1990-2008: National Inventory Report 2010. Bilthoven, The Netherlands.
Olivier, J. G. J., Janssens-Maenhout, G., Peters, J. A. H. W., & Wilson, J. (2011). Long-term trend in global CO_2 emissions. The Hague.
Penner, J. E., Lister, D. H., Griggs, D. J., Dokken, D. J., & McFarland, M. (1999). Aviation and the Gobal Atmosphere (Vol. 2013). Cambridge, UK: Intergovernmental Panel on Climate Change (IPCC).
Provincie Overijssel. (2013a). Bicycle Use Retrieved May 13, 2013, from http://www.overijssel.nl/overijssel/cijfers-kaarten/staat-overijssel/regionale/bereikbaarheid/fietsgebruik/
Provincie Overijssel. (2013b). Car Use Retrieved May 13, 2013, from http://www.overijssel.nl/overijssel/cijfers-kaarten/staat-overijssel/regionale/bereikbaarheid/mobiliteit/autogebruik/
Provincie Overijssel. (2013c). Mobility Retrieved January 31, 2013, from http://www.overijssel.nl/overijssel/cijfers-kaarten/staat-overijssel/regionale/bereikbaarheid/mobiliteit/
Provincie Overijssel. (2013d). Population and Area Retrieved January 29, 2013, from http://www.overijssel.nl/overijssel/cijfers-kaarten/inwoneraantal/
Rossum, M. v., & Schenau, S. (2010). CO2 emissions on quarterly basis. The Hague: Statistics Netherlands, National Accounts Department.
Royal Commission on Environmental Pollution. (1994). Eighteenth Report: Transport and the Environment. London.
Schafer, A., & Victor, D. G. (1999). Global passenger travel: implications for carbon dioxide emissions. *Energy, 24*(8), 657-679. doi: http://dx.doi.org/10.1016/S0360-5442(99)00019-5
Schlich, R., SCHÖNFELDER, S., Hanson, S., & Axhausen, K. W. (2004). Structures of leisure travel: Temporal and spatial variability. *Transport Reviews, 24*(2), 219-237.
Sorrell, S. (1992). Fuel efficiency in the UK vehicle stock. *Energy policy, 20*(8), 766-780.
SPSS. Retrieved January 28, 2013, from http://homepages.vub.ac.be/~evdbussc/files/Data%20Management%20Sheet.pdf

Statistics Netherlands. (2012). Environmental accounts of The Netherlands: Greenhouse gas emissions by Dutch economic activities. The Hague.
Stead, D. (1999). Relationships between transport emissions and travel patterns in Britain. *Transport Policy, 6*(4), 247-258. doi: 10.1016/s0967-070x(99)00025-6
Stead, D. (2001). Relationships between land use, socioeconomic factors, and travel patterns in Britain. *Environment and Planning B: Planning and Design, 28*(4), 499-528.
Stead, D., & Marshall, S. (2001). The relationships between urban form and travel patterns. An international review and evaluation. *European Journal of Transport and Infrastructure Research, 1*(2), 113-141.
Susilo, & Stead, D. (2008). Individual CO_2 emissions and the potential for reduction in the Netherlands and the United Kingdom.
Timmermans, H., van der Waerden, P., Alves, M., Polak, J., Ellis, S., Harvey, A. S., Kurose, S., & Zandee, R. (2003). Spatial context and the complexity of daily travel patterns: an international comparison. *Journal of Transport Geography, 11*(1), 37-46. doi: http://dx.doi.org/10.1016/S0966-6923(02)00050-9
UK Energy Research Centre. (2009). What policies are effective at reducing carbon emissions from surface passenger transport? A review of interventions to encourage behavioural and technological change.
Zegras, P. C. (2007). As if Kyoto mattered: The clean development mechanism and transportation. *Energy policy, 35*(10), 5136-5150. doi: http://dx.doi.org/10.1016/j.enpol.2007.04.032

APPENDIX A: DESCRIPTION OF TRAVEL VARIABLES

1) Computation of Reclassified Trip Mode

Classified Trip Mode	MON Mode of Transport (vv)	Frequency	%
-9	.	2900	5%
Walking	Te voet	10216	17%
Bicycle	Fiets	16873	29%
	Fiets als passagier	613	
Public Transport	Bus	588	3%
	Tram/Metro	27	
	Trein	923	
	Touringcar	66	
	Besloten busvervoer (schoolbus/bedrijfsbus)	59	
Car	Bestuurder auto	18069	44%
	Passagier auto	8207	
	Taxi	219	
Other	Snorfiets	103	2%
	Bromfiets	164	
	Motor	70	
	Traktor	44	
	Bestelauto	54	
	Vrachtauto	56	
	Boot (lijndienst/veerdienst)	74	
	Vliegtuig	15	
	Kinderwagen	146	
	Skates/Skeelers/Step	48	
	Gehandicaptenvervoermiddel	178	
	Anders	93	
Total		59805	100%

2) Computation of Reclassified Motives (Variable Motief)

MON Movement Motives (motief)	Frequency	%
.	2833	5%
Van en naar het werk	8408	15%
Zakelijk bezoek in werksfeer	1651	3%
Vervoer als beroep	78	0%
Afhalen/brengen personen	3399	6%
Onderwijs volgen	4918	9%
Winkelen/boodschappen doen	10615	19%
Visite/logeren	7971	14%
Toeren/wandelen	5880	11%
Sport/hobby	3246	6%
Overige vrijetijdsbesteding	3410	6%
Diensten/persoonlijke verzorging	2078	4%
Meegaan met begeleider	552	1%
Overige	497	1%
Total	55536	100%

3) Computation of Reclassified Movement Modal Class – Variable Khv

MON Movement Mode classes (khv)	Frequency	%
.	2833	5%
Auto als bestuurder	17578	32%
Auto als passagier	7931	14%
Trein	734	1%
Bus/Tram/Metro	347	1%
Bromfiets/Snorfiets	259	0%
Fiets	16433	30%
Lopen	8548	15%
Overig	873	2%
Total	55536	100%

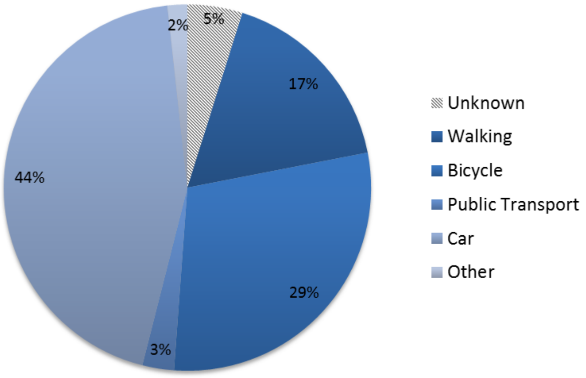
4) Computation of Reclassified Trip Modal Class – Variable Kvv

MON Trip Mode classes (kvv)	Frequency	%
.	2900	5%
Auto als bestuurder	18069	30%
Auto als passagier	8207	14%
Trein	923	2%
Bus/Tram/Metro	615	1%
Bromfiets/Snorfiets	267	0%
Fiets	17486	29%
Lopen	10362	17%
Overig	976	2%
Total	59805	100%

APPENDIX B: TRAVEL PATTERNS

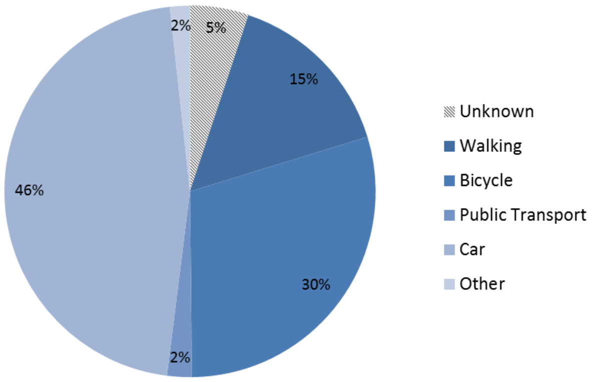
5) Travel patterns by Trips: Reclassified Modes of Transport (Trips)

Reclassified Modes of Transport (Trips)				
Value	Modes	Avg. Mode Distance (KM)	Frequency	%
-9	Unknown	.	2900	5%
1	Walking	0.89	10216	17%
2	Bicycle	2.92	17486	29%
3	Public Transport	33.56	1663	3%
4	Car	17.11	26495	44%
5	Other	17.05	1045	2%
Total			59805	100%



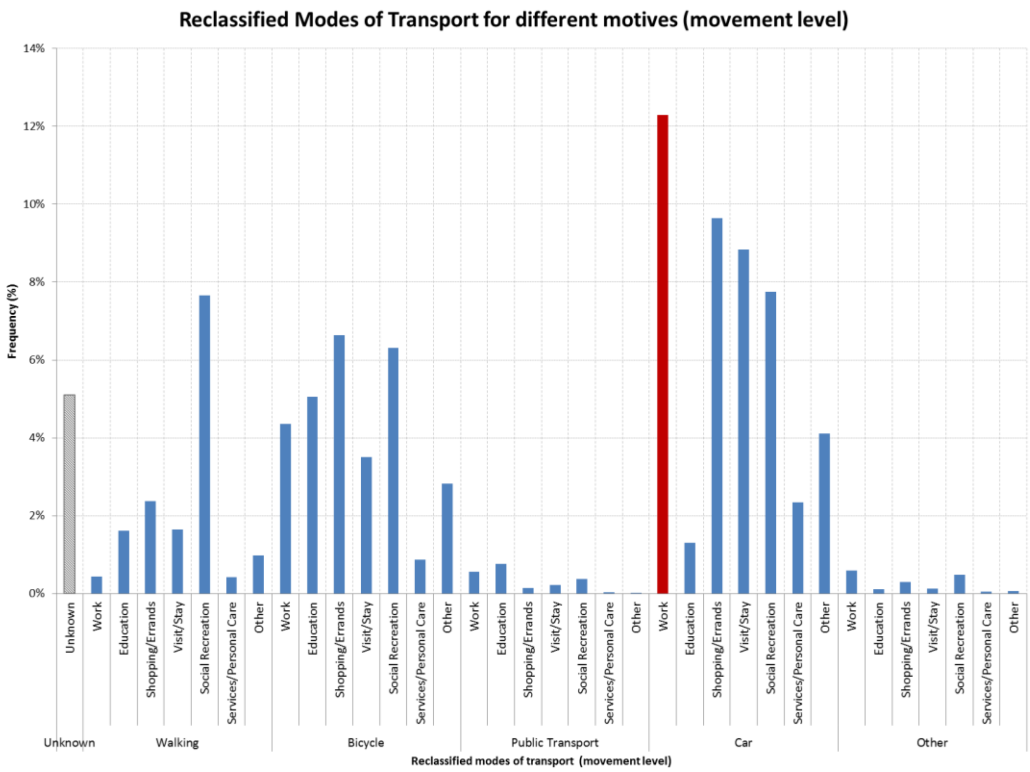
6) Travel patterns by Movements: Reclassified Modes of Transport (Movements)

Reclassified Modes of Transport (Movements)					
Value	Modes	Avg. Movement Distance (KM)	Avg. Movement Travel Time (Min)	Frequency	%
-9	Unknown	.	.	2833	5%
1	Walking	0.95	12.31	8412	15%
2	Bicycle	2.93	13.58	16433	30%
3	Public Transport	48.84	68.93	1193	2%
4	Car	17.20	22.14	25698	46%
5	Other	16.47	30.35	967	2%
Total				55536	100%



7) Travel pattern by all modes: Reclassified Modes of Transport for different motives (movement level)

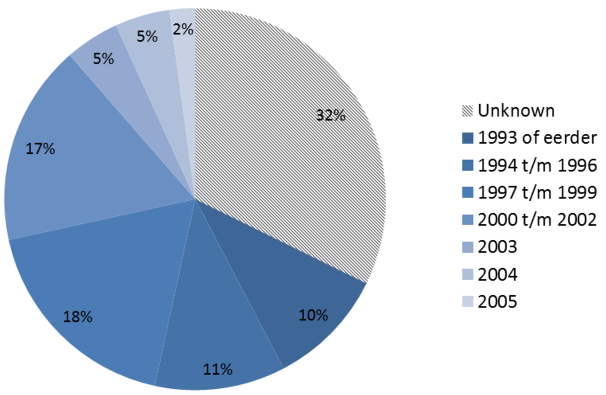
Modes	Motives	Avg. Mode Movement Distance (KM)	Avg. Movement Travel Time (Min)	Frequency %
Unknown	Unknown	.	.	5%
Walking	Work	0.75	8.89	0%
	Education	0.47	6.23	2%
	Shopping/Errands	0.70	9.43	2%
	Visit/Stay	0.62	8.08	2%
	Social Recreation	1.29	16.58	8%
	Services/Personal Care	0.58	7.77	0%
	Other	0.49	6.68	1%
Bicycle	Work	3.76	15.77	4%
	Education	3.38	15.26	5%
	Shopping/Errands	1.91	9.51	7%
	Visit/Stay	2.57	12.21	4%
	Social Recreation	3.99	18.76	6%
	Services/Personal Care	1.96	9.63	1%
	Other	1.63	8.11	3%
Public Transport	Work	43.27	59.66	1%
	Education	33.27	59.76	1%
	Shopping/Errands	28.37	45.56	0%
	Visit/Stay	68.38	85.26	0%
	Social Recreation	86.05	101.71	0%
	Services/Personal Care	33.83	61.35	0%
	Other	59.06	69.08	0%
Car	Work	23.90	28.32	12%
	Education	10.03	17.97	1%
	Shopping/Errands	7.89	13.80	10%
	Visit/Stay	23.24	25.93	9%
	Social Recreation	18.78	24.79	8%
	Services/Personal Care	11.49	17.71	2%
	Other	8.58	13.93	4%
Other	Work	27.46	34.97	1%
	Education	7.27	18.77	0%
	Shopping/Errands	2.25	12.99	0%
	Visit/Stay	5.14	15.35	0%
	Social Recreation	20.73	46.14	0%
	Services/Personal Care	3.24	13.76	0%
	Other	1.99	16.94	0%
Total				100%



APPENDIX C: CHARACTERISTICS OF CAR-BASED MOVEMENTS

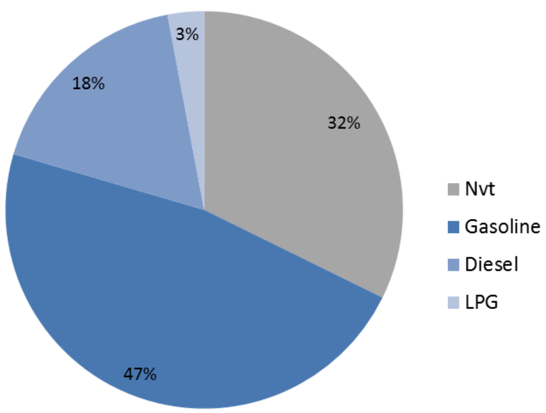
1) Age of Vehicle

Mode of Transport	Age of Vehicle	Frequency	%
Car	Unknown	8294	32%
	1993 of eerder	2583	10%
	1994 t/m 1996	2845	11%
	1997 t/m 1999	4671	18%
	2000 t/m 2002	4372	17%
	2003	1182	5%
	2004	1195	5%
	2005	556	2%
Total		25698	100%



2) Fuel Type car

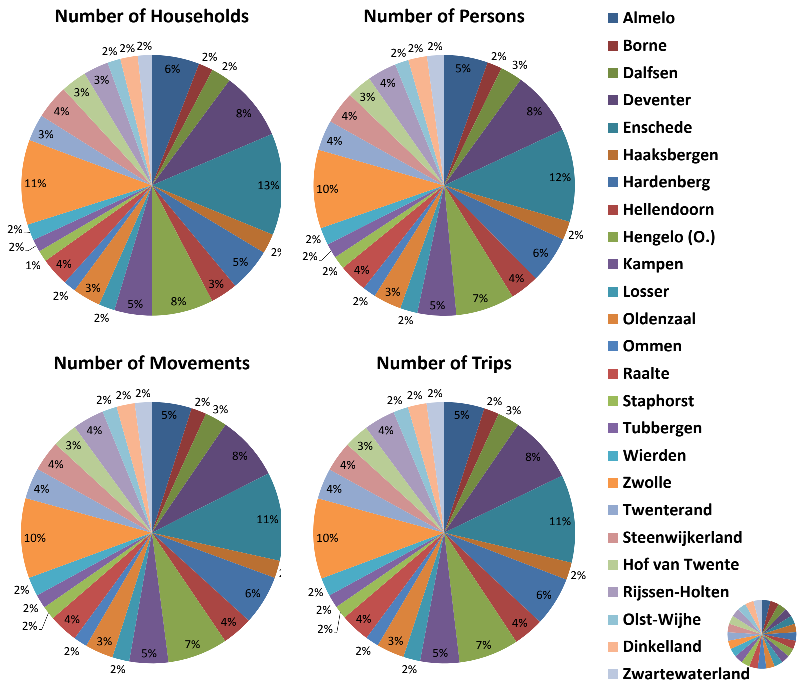
Fuel Type car		
Fuel Type	Frequency	%
Nvt	8294	32%
Gasoline	12144	47%
Diesel	4499	18%
LPG	761	3%
Total	25698	100%

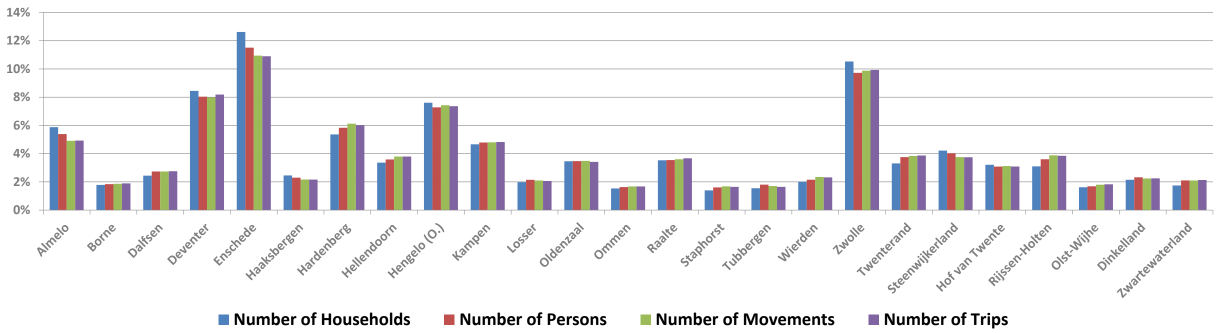


APPENDIX D: SPATIAL VARIATION OF TRAVEL PATTERNS

1) Distribution of Trips, Movements, Persons, Households across Municipalities

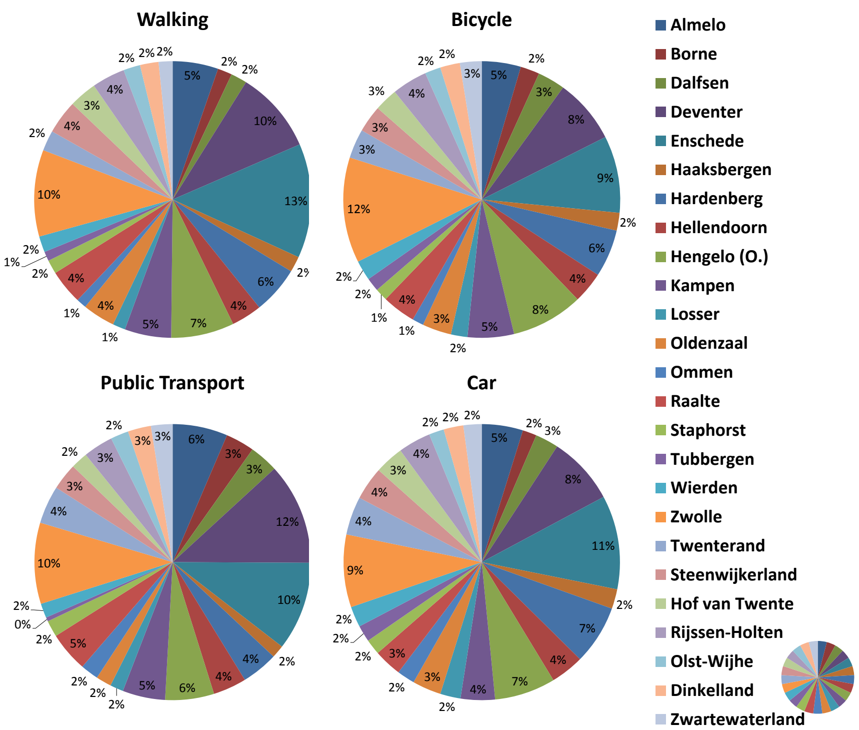
Municipality	Degree of Urbanization	Number of Households			Number of Persons			Number of Movements			Number of Trips			Total
		Frequency	Row %	Column %	Frequency	Row %	Column %	Frequency	Row %	Column %	Frequency	Row %	Column %	
Almelo	Lowly urbanised	421	6%	6%	906	13%	5%	2729	39%	5%	2968	42%	5%	7024
Borne	Lowly urbanised	128	5%	2%	309	12%	2%	1034	40%	2%	1114	43%	2%	2585
Dalfsen	Not urbanised	175	5%	2%	460	12%	3%	1521	40%	3%	1628	43%	3%	3784
Deventer	Highly urbanised	605	5%	8%	1351	12%	8%	4436	39%	8%	4938	44%	8%	11330
Enschede	Highly urbanised	904	6%	13%	1936	13%	12%	6080	39%	11%	6509	42%	11%	15429
Haaksbergen	Moderately urbanised	176	6%	2%	387	13%	2%	1203	39%	2%	1290	42%	2%	3056
Hardenberg	Not urbanised	384	5%	5%	981	12%	6%	3401	40%	6%	3651	43%	6%	8417
Hellendoorn	Moderately urbanised	241	5%	3%	604	12%	4%	2108	41%	4%	2249	43%	4%	5202
Hengelo (O.)	Highly urbanised	545	5%	8%	1224	12%	7%	4128	40%	7%	4433	43%	7%	10330
Kampen	Lowly urbanised	334	5%	5%	806	12%	5%	2669	40%	5%	2887	43%	5%	6696
Losser	Moderately urbanised	142	5%	2%	361	12%	2%	1167	40%	2%	1252	43%	2%	2922
Oldenzaal	Lowly urbanised	248	5%	3%	584	12%	3%	1936	40%	3%	2049	43%	3%	4817
Ommen	Not urbanised	110	5%	2%	275	12%	2%	932	40%	2%	985	43%	2%	2302
Raalte	Moderately urbanised	253	5%	4%	596	12%	4%	2003	40%	4%	2176	43%	4%	5028
Staphorst	Not urbanised	100	4%	1%	271	12%	2%	935	41%	2%	979	43%	2%	2285
Tubbergen	Not urbanised	111	5%	2%	304	13%	2%	947	40%	2%	977	42%	2%	2339
Wierden	Moderately urbanised	144	5%	2%	362	11%	2%	1304	41%	2%	1362	43%	2%	3172
Zwolle	Highly urbanised	754	5%	11%	1636	12%	10%	5486	40%	10%	5938	43%	10%	13814
Twenterand	Moderately urbanised	237	4%	3%	632	12%	4%	2129	40%	4%	2273	43%	4%	5271
Steenwijkerland	Moderately urbanised	302	6%	4%	678	13%	4%	2086	39%	4%	2227	42%	4%	5293
Hof van Twente	Moderately urbanised	230	5%	3%	519	12%	3%	1735	40%	3%	1839	43%	3%	4323
Rijssen-Holten	Moderately urbanised	222	4%	3%	606	11%	4%	2156	41%	4%	2303	44%	4%	5287
Olst-Wijhe	Not urbanised	116	5%	2%	284	11%	2%	1001	40%	2%	1108	44%	2%	2509
Dinkelland	Not urbanised	154	5%	2%	391	12%	2%	1245	39%	2%	1377	43%	2%	3167
Zwartewaterland	Moderately urbanised	125	4%	2%	354	12%	2%	1165	40%	2%	1293	44%	2%	2937
Total		7161	-	100%	16817	-	100%	55536	-	100%	59805	-	100%	139319

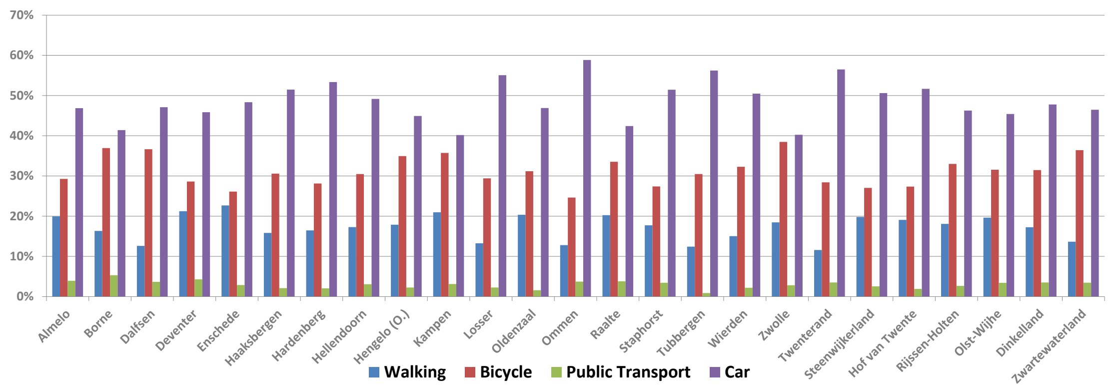




2) Distribution of Modes of transport of all Trips for each Municipality

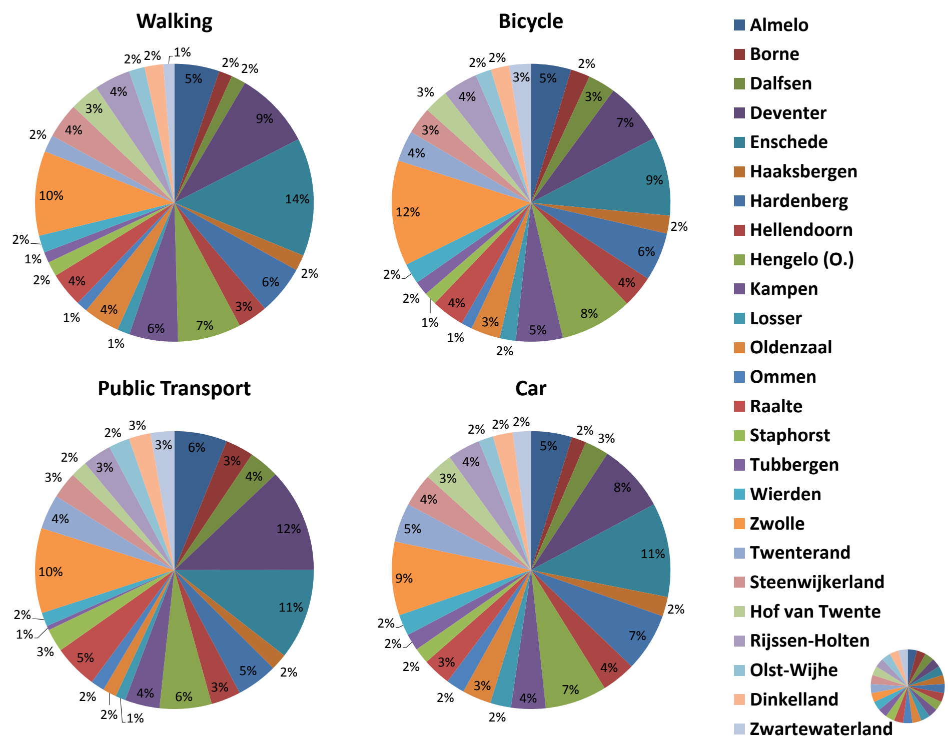
Municipality	Degree of Urbanization	Walking			Bicycle			Public Transport			Car			Total
		Frequency	Row %	Column %	Frequency	Row %	Column %	Frequency	Row %	Column %	Frequency	Row %	Column %	
Almelo	Lowly urbanised	**543**	20%	5%	**797**	29%	5%	**107**	4%	6%	**1276**	47%	5%	2723
Borne	Lowly urbanised	**172**	16%	2%	**389**	37%	2%	**56**	5%	3%	**436**	41%	2%	1053
Dalfsen	Not urbanised	**193**	13%	2%	**561**	37%	3%	**56**	4%	3%	**721**	47%	3%	1531
Deventer	Highly urbanised	**980**	21%	10%	**1321**	29%	8%	**198**	4%	12%	**2116**	46%	8%	4615
Enschede	Highly urbanised	**1365**	23%	13%	**1573**	26%	9%	**173**	3%	10%	**2912**	48%	11%	6023
Haaksbergen	Moderately urbanised	**188**	16%	2%	**363**	31%	2%	**25**	2%	2%	**611**	51%	2%	1187
Hardenberg	Not urbanised	**568**	16%	6%	**970**	28%	6%	**71**	2%	4%	**1840**	53%	7%	3449
Hellendoorn	Moderately urbanised	**364**	17%	4%	**642**	30%	4%	**65**	3%	4%	**1036**	49%	4%	2107
Hengelo (O.)	Highly urbanised	**752**	18%	7%	**1470**	35%	8%	**95**	2%	6%	**1889**	45%	7%	4206
Kampen	Lowly urbanised	**555**	21%	5%	**946**	36%	5%	**83**	3%	5%	**1064**	40%	4%	2648
Losser	Moderately urbanised	**152**	13%	1%	**337**	29%	2%	**26**	2%	2%	**631**	55%	2%	1146
Oldenzaal	Lowly urbanised	**387**	20%	4%	**593**	31%	3%	**30**	2%	2%	**892**	47%	3%	1902
Ommen	Not urbanised	**120**	13%	1%	**231**	25%	1%	**35**	4%	2%	**552**	59%	2%	938
Raalte	Moderately urbanised	**413**	20%	4%	**684**	34%	4%	**78**	4%	5%	**865**	42%	3%	2040
Staphorst	Not urbanised	**165**	18%	2%	**255**	27%	1%	**32**	3%	2%	**479**	51%	2%	931
Tubbergen	Not urbanised	**113**	12%	1%	**277**	30%	2%	**8**	1%	0%	**511**	56%	2%	909
Wierden	Moderately urbanised	**191**	15%	2%	**410**	32%	2%	**28**	2%	2%	**641**	50%	2%	1270
Zwolle	Highly urbanised	**1034**	18%	10%	**2154**	38%	12%	**158**	3%	10%	**2254**	40%	9%	5600
Twenterand	Moderately urbanised	**244**	12%	2%	**598**	28%	3%	**74**	4%	4%	**1189**	56%	4%	2105
Steenwijkerland	Moderately urbanised	**403**	20%	4%	**550**	27%	3%	**52**	3%	3%	**1030**	51%	4%	2035
Hof van Twente	Moderately urbanised	**331**	19%	3%	**475**	27%	3%	**33**	2%	2%	**897**	52%	3%	1736
Rijssen-Holten	Moderately urbanised	**395**	18%	4%	**721**	33%	4%	**58**	3%	3%	**1011**	46%	4%	2185
Olst-Wijhe	Not urbanised	**201**	20%	2%	**323**	32%	2%	**35**	3%	2%	**465**	45%	2%	1024
Dinkelland	Not urbanised	**221**	17%	2%	**403**	31%	2%	**45**	4%	3%	**612**	48%	2%	1281
Zwartewaterland	Moderately urbanised	**166**	14%	2%	**443**	36%	3%	**42**	3%	3%	**565**	46%	2%	1216
Total		**10216**	-	100%	**17486**	-	100%	**1663**	-	100%	**26495**	-	100%	55860

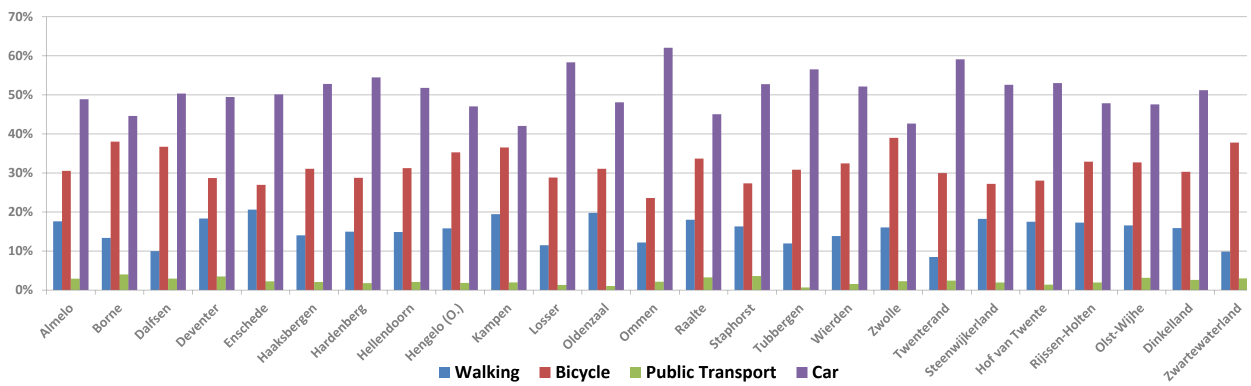




3) Distribution of Modes of transport of all Movements for each Municipality

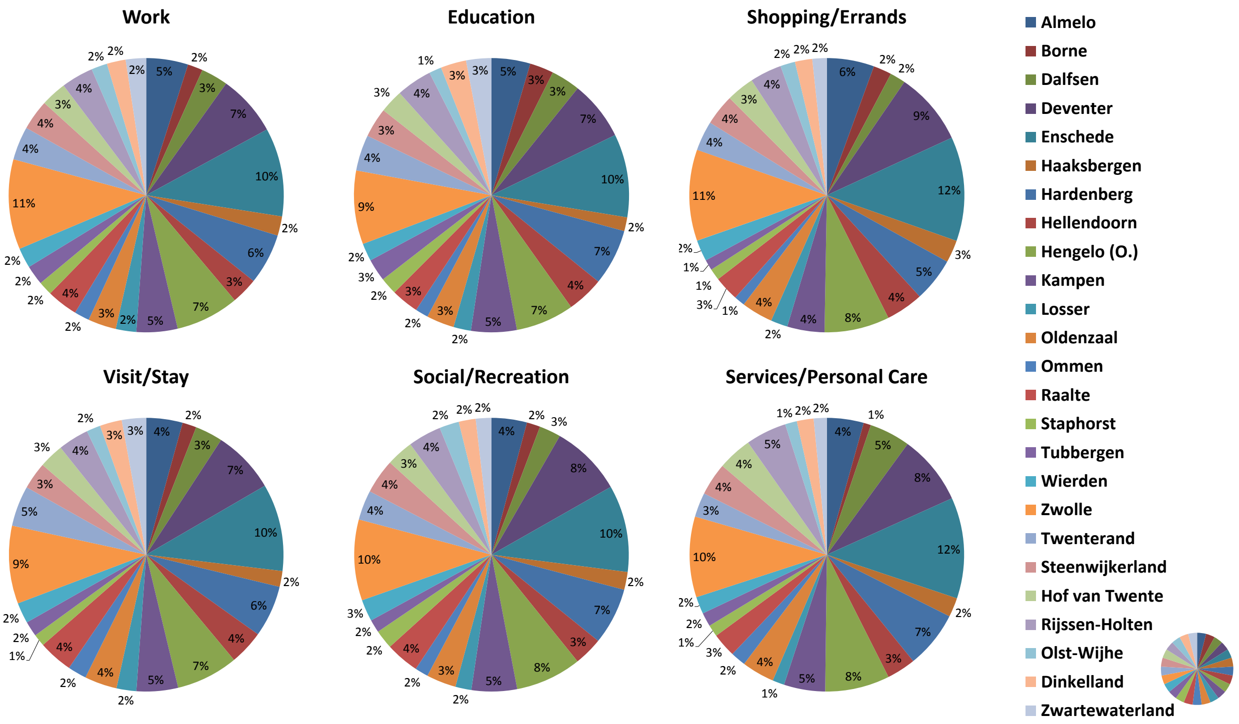
Municipality	Degree of Urbanization	Walking			Bicycle			Public Transport			Car			Total
		Frequency	Row %	Column %	Frequency	Row %	Column %	Frequency	Row %	Column %	Frequency	Row %	Column %	
Almelo	Lowly urbanised	439	18%	5%	761	31%	5%	73	3%	6%	1218	49%	5%	2491
Borne	Lowly urbanised	130	13%	2%	370	38%	2%	39	4%	3%	434	45%	2%	973
Dalfsen	Not urbanised	142	10%	2%	523	37%	3%	42	3%	4%	717	50%	3%	1424
Deventer	Highly urbanised	757	18%	9%	1185	29%	7%	144	3%	12%	2042	49%	8%	4128
Enschede	Highly urbanised	1157	21%	14%	1513	27%	9%	126	2%	11%	2815	50%	11%	5611
Haaksbergen	Moderately urbanised	155	14%	2%	343	31%	2%	23	2%	2%	583	53%	2%	1104
Hardenberg	Not urbanised	480	15%	6%	922	29%	6%	57	2%	5%	1746	54%	7%	3205
Hellendoorn	Moderately urbanised	293	15%	3%	615	31%	4%	41	2%	3%	1020	52%	4%	1969
Hengelo (O.)	Highly urbanised	618	16%	7%	1380	35%	8%	72	2%	6%	1840	47%	7%	3910
Kampen	Lowly urbanised	476	19%	6%	894	37%	5%	48	2%	4%	1029	42%	4%	2447
Losser	Moderately urbanised	122	11%	1%	306	29%	2%	14	1%	1%	619	58%	2%	1061
Oldenzaal	Lowly urbanised	355	20%	4%	558	31%	3%	19	1%	2%	864	48%	3%	1796
Ommen	Not urbanised	108	12%	1%	209	24%	1%	19	2%	2%	550	62%	2%	886
Raalte	Moderately urbanised	338	18%	4%	632	34%	4%	61	3%	5%	845	45%	3%	1876
Staphorst	Not urbanised	145	16%	2%	243	27%	1%	32	4%	3%	469	53%	2%	889
Tubbergen	Not urbanised	105	12%	1%	271	31%	2%	6	1%	1%	497	57%	2%	879
Wierden	Moderately urbanised	168	14%	2%	394	32%	2%	19	2%	2%	633	52%	2%	1214
Zwolle	Highly urbanised	828	16%	10%	2012	39%	12%	118	2%	10%	2201	43%	9%	5159
Twenterand	Moderately urbanised	167	8%	2%	590	30%	4%	48	2%	4%	1164	59%	5%	1969
Steenwijkerland	Moderately urbanised	346	18%	4%	516	27%	3%	37	2%	3%	997	53%	4%	1896
Hof van Twente	Moderately urbanised	286	18%	3%	458	28%	3%	23	1%	2%	866	53%	3%	1633
Rijssen-Holten	Moderately urbanised	353	17%	4%	672	33%	4%	40	2%	3%	978	48%	4%	2043
Olst-Wijhe	Not urbanised	153	17%	2%	302	33%	2%	29	3%	2%	439	48%	2%	923
Dinkelland	Not urbanised	183	16%	2%	349	30%	2%	30	3%	3%	590	51%	2%	1152
Zwartewaterland	Moderately urbanised	108	10%	1%	415	38%	3%	33	3%	3%	542	49%	2%	1098
	Total	8412	-	100%	16433	-	100%	1193	-	100%	25698	-	100%	51736

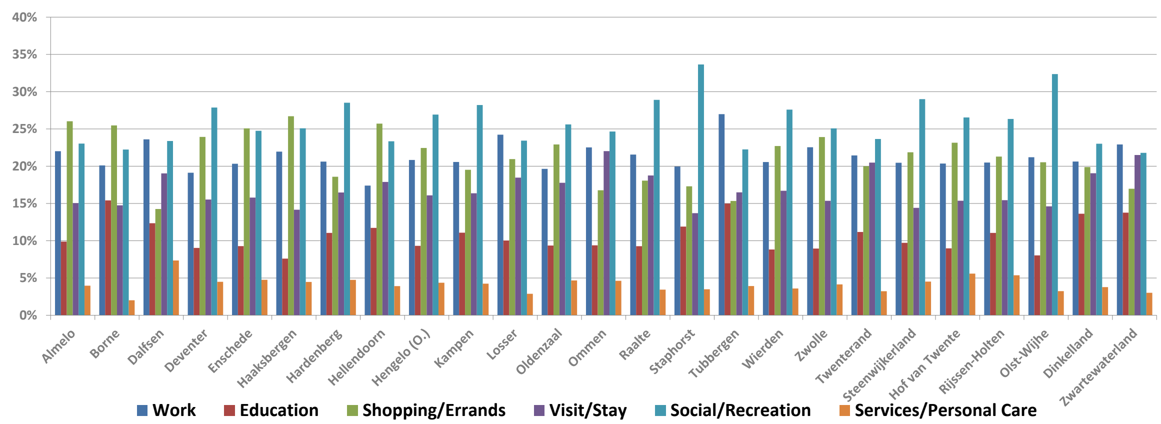




4) Distribution of Motives of transport of all Movements for each Municipality

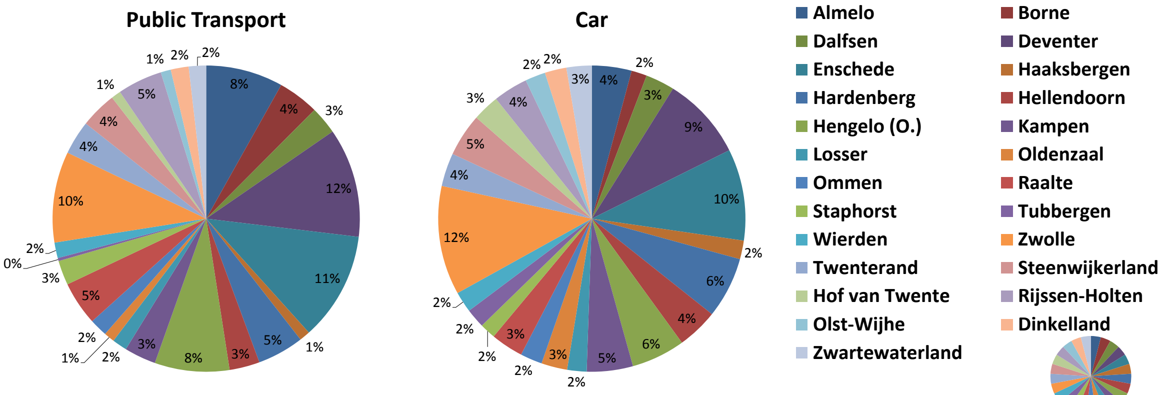
Municipality	Degree of Urbanization	Work			Education			Shopping/Errands			Visit/Stay			Social/Recreation			Services/Personal Care			Total
		Frequency	Row %	Column %	Frequency	Row %	Column %	Frequency	Row %	Column %	Frequency	Row %	Column %	Frequency	Row %	Column %	Frequency	Row %	Column %	
Almelo	Lowly urbanised	499	22%	5%	224	10%	5%	590	26%	6%	341	15%	4%	522	23%	4%	90	4%	4%	2266
Borne	Lowly urbanised	180	20%	2%	138	15%	3%	228	25%	2%	132	15%	2%	199	22%	2%	18	2%	1%	895
Dalfsen	Not urbanised	321	24%	3%	168	12%	3%	194	14%	2%	259	19%	3%	318	23%	3%	100	7%	5%	1360
Deventer	Highly urbanised	728	19%	7%	344	9%	7%	911	24%	9%	591	16%	7%	1061	28%	8%	171	4%	8%	3806
Enschede	Highly urbanised	1058	20%	10%	483	9%	10%	1305	25%	12%	822	16%	10%	1288	25%	10%	248	5%	12%	5204
Haaksbergen	Moderately urbanised	231	22%	2%	80	8%	2%	281	27%	3%	149	14%	2%	264	25%	2%	47	4%	2%	1052
Hardenberg	Not urbanised	608	21%	6%	326	11%	7%	548	19%	5%	486	16%	6%	841	29%	7%	140	5%	7%	2949
Hellendoorn	Moderately urbanised	316	17%	3%	213	12%	4%	467	26%	4%	325	18%	4%	424	23%	3%	71	4%	3%	1816
Hengelo (O.)	Highly urbanised	754	21%	7%	337	9%	7%	812	22%	8%	582	16%	7%	974	27%	8%	158	4%	8%	3617
Kampen	Lowly urbanised	490	21%	5%	264	11%	5%	465	20%	4%	390	16%	5%	672	28%	5%	101	4%	5%	2382
Losser	Moderately urbanised	244	24%	2%	101	10%	2%	211	21%	2%	186	18%	2%	236	23%	2%	29	3%	1%	1007
Oldenzaal	Lowly urbanised	336	20%	3%	160	9%	3%	392	23%	4%	304	18%	4%	438	26%	3%	80	5%	4%	1710
Ommen	Not urbanised	180	23%	2%	75	9%	2%	134	17%	1%	176	22%	2%	197	25%	2%	37	5%	2%	799
Raalte	Moderately urbanised	370	22%	4%	159	9%	3%	310	18%	3%	322	19%	4%	496	29%	4%	59	3%	3%	1716
Staphorst	Not urbanised	166	20%	2%	99	12%	2%	144	17%	1%	114	14%	1%	280	34%	2%	29	3%	1%	832
Tubbergen	Not urbanised	234	27%	2%	130	15%	3%	133	15%	1%	143	16%	2%	193	22%	2%	34	4%	2%	867
Wierden	Moderately urbanised	240	21%	2%	103	9%	2%	265	23%	2%	195	17%	2%	322	28%	3%	42	4%	2%	1167
Zwolle	Highly urbanised	1076	23%	11%	427	9%	9%	1141	24%	11%	733	15%	9%	1197	25%	10%	198	4%	10%	4772
Twenterand	Moderately urbanised	399	21%	4%	208	11%	4%	372	20%	4%	381	20%	5%	440	24%	4%	60	3%	3%	1860
Steenwijkerland	Moderately urbanised	362	20%	4%	172	10%	3%	387	22%	4%	255	14%	3%	513	29%	4%	80	5%	4%	1769
Hof van Twente	Moderately urbanised	306	20%	3%	135	9%	3%	348	23%	3%	231	15%	3%	399	27%	3%	84	6%	4%	1503
Rijssen-Holten	Moderately urbanised	382	20%	4%	206	11%	4%	397	21%	4%	288	15%	4%	491	26%	4%	100	5%	5%	1864
Olst-Wijhe	Not urbanised	190	21%	2%	72	8%	1%	184	21%	2%	131	15%	2%	290	32%	2%	29	3%	1%	896
Dinkelland	Not urbanised	224	21%	2%	148	14%	3%	216	20%	2%	207	19%	3%	250	23%	2%	41	4%	2%	1086
Zwartewaterland	Moderately urbanised	243	23%	2%	146	14%	3%	180	17%	2%	228	22%	3%	231	22%	2%	32	3%	2%	1060
	Total	10137	-	100%	4918	-	100%	10615	-	100%	7971	-	100%	12536	-	100%	2078	-	100%	48255

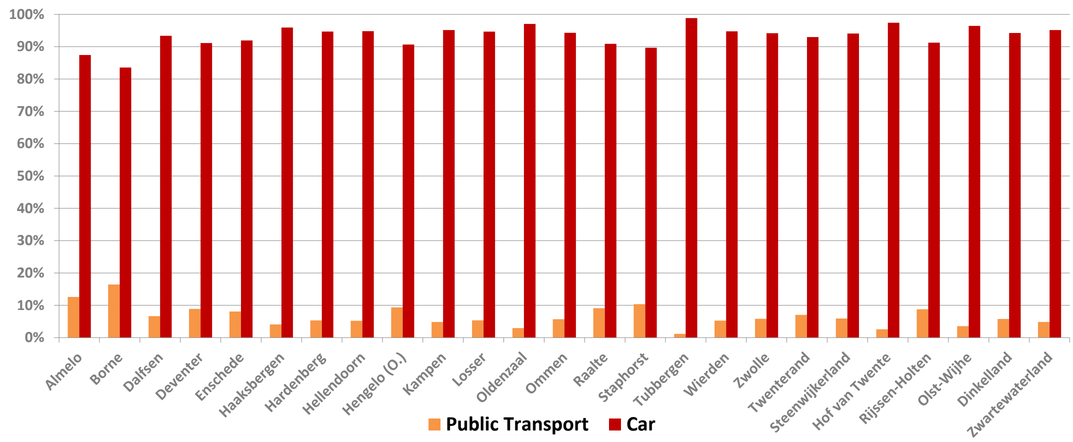




5) Distribution of emissions produced by Car and Public Transport for each Municipality

Municipality	Degree of Urbanization	Public Transport			Car			Total
		Emissions KG	Row %	Column %	Emissions KG	Row %	Column %	
Almelo	Lowly urbanised	**295**	13%	8%	**2046.1**	87%	4%	2340.7
Borne	Lowly urbanised	**157**	16%	4%	**797.3**	84%	2%	954.1
Dalfsen	Not urbanised	**106**	7%	3%	**1496.8**	93%	3%	1603.2
Deventer	Highly urbanised	**418**	9%	12%	**4291.1**	91%	9%	4709.3
Enschede	Highly urbanised	**416**	8%	11%	**4733.0**	92%	10%	5148.5
Haaksbergen	Moderately urbanised	**41**	4%	1%	**963.0**	96%	2%	1004.0
Hardenberg	Not urbanised	**178**	5%	5%	**3158.5**	95%	6%	3336.0
Hellendoorn	Moderately urbanised	**116**	5%	3%	**2109.0**	95%	4%	2224.6
Hengelo (O.)	Highly urbanised	**285**	9%	8%	**2768.9**	91%	6%	3054.3
Kampen	Lowly urbanised	**121**	5%	3%	**2377.1**	95%	5%	2498.2
Losser	Moderately urbanised	**56**	5%	2%	**1000.5**	95%	2%	1057.0
Oldenzaal	Lowly urbanised	**41**	3%	1%	**1335.1**	97%	3%	1375.6
Ommen	Not urbanised	**68**	6%	2%	**1130.1**	94%	2%	1198.4
Raalte	Moderately urbanised	**168**	9%	5%	**1673.8**	91%	3%	1841.6
Staphorst	Not urbanised	**94**	10%	3%	**814.9**	90%	2%	908.9
Tubbergen	Not urbanised	**12**	1%	0%	**996.8**	99%	2%	1008.5
Wierden	Moderately urbanised	**59**	5%	2%	**1072.3**	95%	2%	1131.8
Zwolle	Highly urbanised	**348**	6%	10%	**5634.6**	94%	12%	5982.8
Twenterand	Moderately urbanised	**130**	7%	4%	**1719.5**	93%	4%	1849.4
Steenwijkerland	Moderately urbanised	**139**	6%	4%	**2211.4**	94%	5%	2350.6
Hof van Twente	Moderately urbanised	**37**	3%	1%	**1382.4**	97%	3%	1419.2
Rijssen-Holten	Moderately urbanised	**171**	9%	5%	**1781.4**	91%	4%	1952.5
Olst-Wijhe	Not urbanised	**39**	4%	1%	**1046.9**	96%	2%	1085.5
Dinkelland	Not urbanised	**68**	6%	2%	**1116.1**	94%	2%	1184.3
Zwartewaterland	Moderately urbanised	**66**	5%	2%	**1300.3**	95%	3%	1366.6
	Total	**3629**	-	100%	**48956.7**	-	100%	52585.7





6) **Average CO2 emission per person for each emission group**

Emission group	Average emissions per person (kg/day)	Number of persons	%
.	.	7706	5%
1	0.5	1860	17%
2	1.6	1954	29%
3	3.1	1663	3%
4	5.9	1905	44%
5	18.6	1729	2%
Total		16817	100%

APPENDIX E: TRAVEL EMISSIONS PROFILES RELATED TO SOCIO-ECONOMIC CHRACTERISTICS

1) HH Structure: Number of Family Member above 18

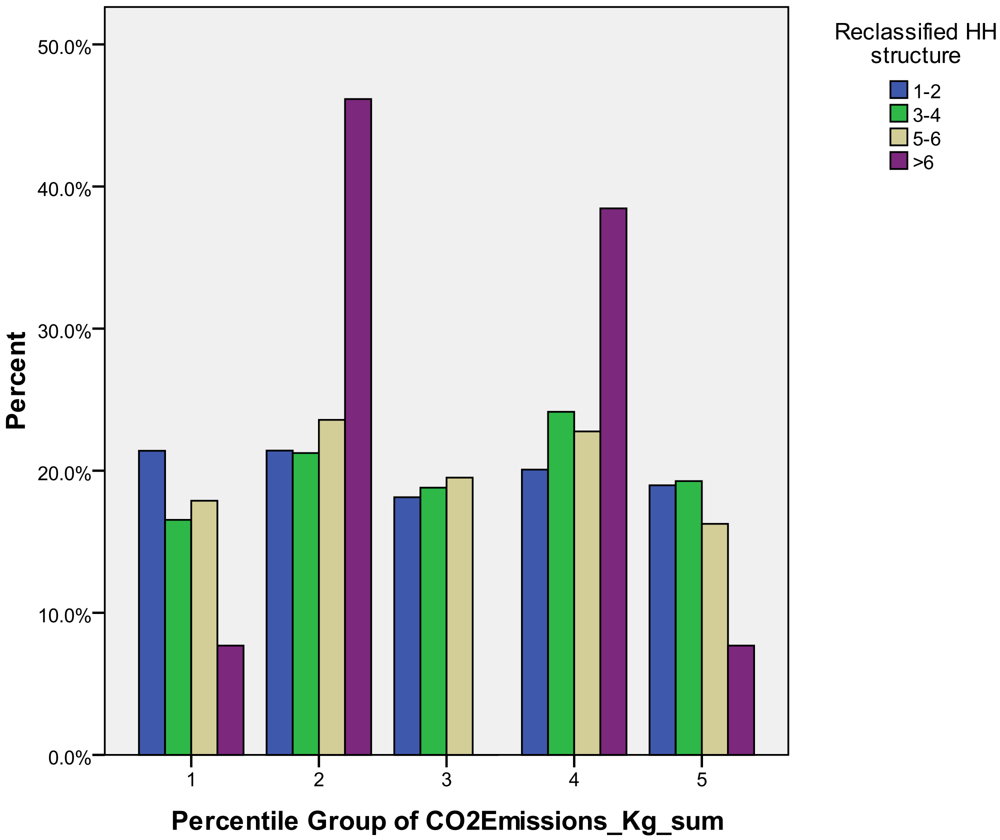
Percentile Group of CO2Emissions_Kg_sum * Reclassified HH structure Crosstabulation

			Reclassified HH structure				
			1-2	3-4	5-6	>6	Total
Percentile Group of CO2Emissions_Kg_sum	1	Count	1552	285	22	1	1860
		Expected Count	1480.5	351.7	25.1	2.7	1860.0
	2	Count	1553	366	29	6	1954
		Expected Count	1555.3	369.5	26.4	2.8	1954.0
	3	Count	1315	324	24	0	1663
		Expected Count	1323.7	314.5	22.5	2.4	1663.0
	4	Count	1456	416	28	5	1905
		Expected Count	1516.3	360.3	25.7	2.7	1905.0
	5	Count	1376	332	20	1	1729
		Expected Count	1376.2	327.0	23.3	2.5	1729.0
Total		Count	7252	1723	123	13	9111
		Expected Count	7252.0	1723.0	123.0	13.0	9111.0

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	38.928[a]	12	.000
Likelihood Ratio	41.044	12	.000
Linear-by-Linear Association	10.546	1	.001
N of Valid Cases	9111		

a. 5 cells (25.0%) have expected count less than 5. The minimum expected count is 2.37.



2) HH Size: Number of persons in household

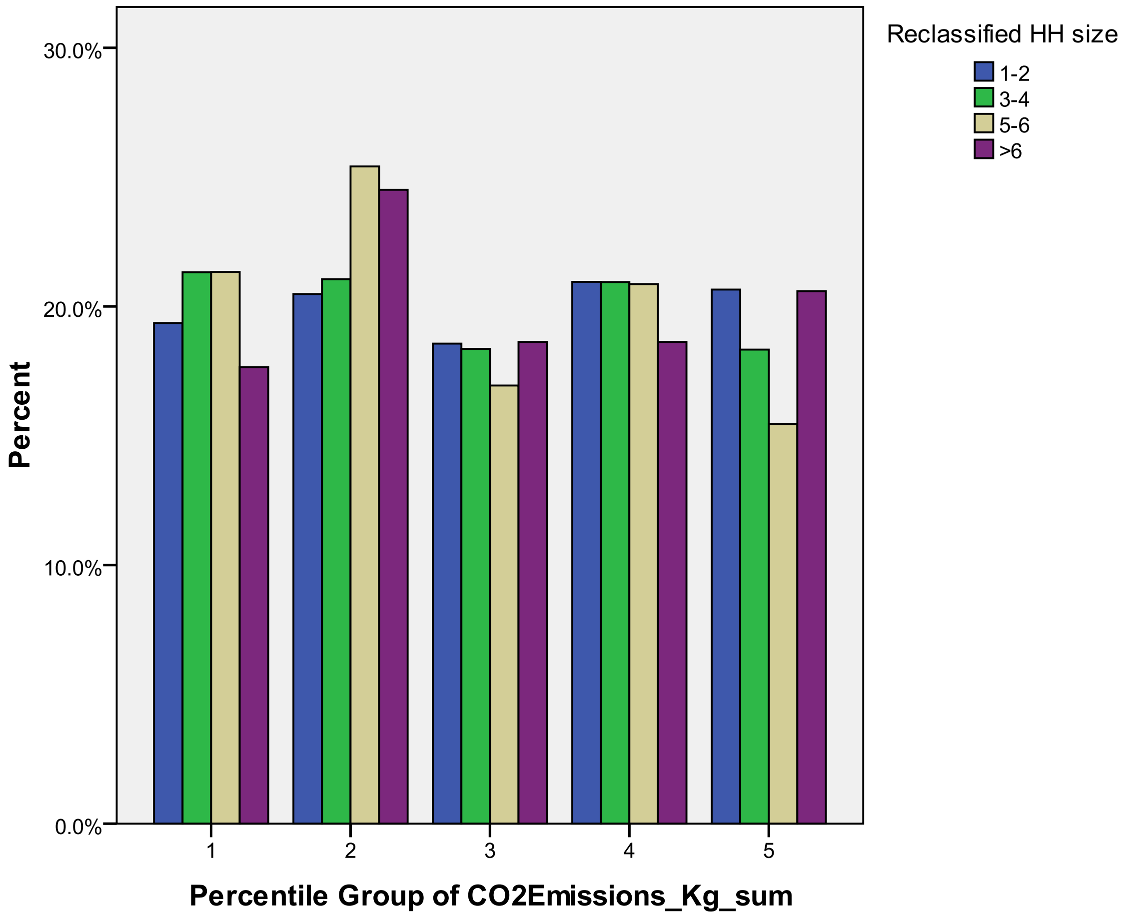
Percentile Group of CO2Emissions_Kg_sum * Reclassified HH size Crosstabulation

			Reclassified HH size				Total
			1-2	3-4	5-6	>6	
Percentile Group of CO2Emissions_Kg_sum	1	Count	778	792	272	18	1860
		Expected Count	820.5	758.4	260.3	20.8	1860.0
	2	Count	823	782	324	25	1954
		Expected Count	861.9	796.7	273.4	21.9	1954.0
	3	Count	746	682	216	19	1663
		Expected Count	733.6	678.1	232.7	18.6	1663.0
	4	Count	842	778	266	19	1905
		Expected Count	840.3	776.8	266.6	21.3	1905.0
	5	Count	830	681	197	21	1729
		Expected Count	762.7	705.0	242.0	19.4	1729.0
Total		Count	4019	3715	1275	102	9111
		Expected Count	4019.0	3715.0	1275.0	102.0	9111.0

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	33.374[a]	12	.001
Likelihood Ratio	33.332	12	.001
Linear-by-Linear Association	17.484	1	.000
N of Valid Cases	9111		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 18.62.



3) Person vehicle ownership

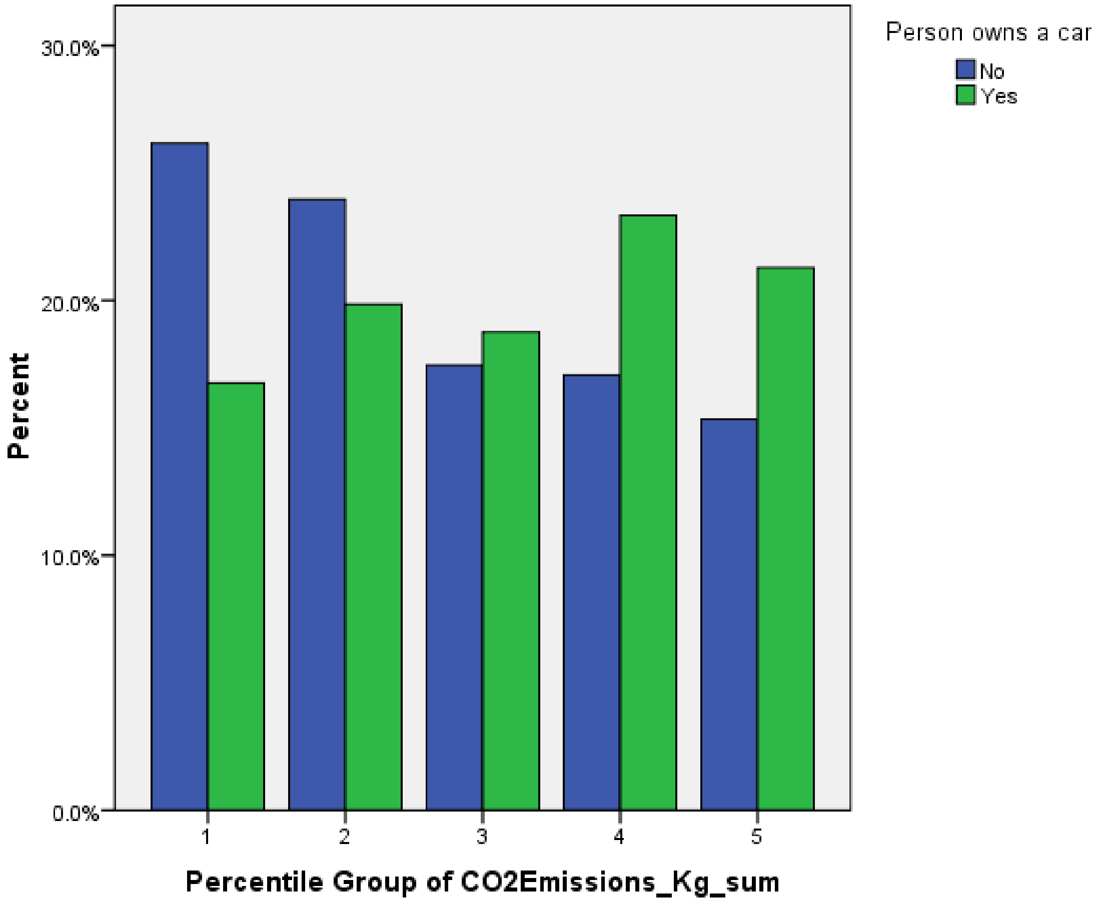
Percentile Group of CO2Emissions_Kg_sum * Person owns a car Crosstabulation

			Person owns a car		
			No	Yes	Total
Percentile Group of CO2Emissions_Kg_sum	1	Count	925	935	1860
		Expected Count	721.5	1138.5	1860.0
	2	Count	847	1107	1954
		Expected Count	757.9	1196.1	1954.0
	3	Count	617	1046	1663
		Expected Count	645.0	1018.0	1663.0
	4	Count	603	1302	1905
		Expected Count	738.9	1166.1	1905.0
	5	Count	542	1187	1729
		Expected Count	670.6	1058.4	1729.0
Total		Count	3534	5577	9111
		Expected Count	3534.0	5577.0	9111.0

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	194.064[a]	4	.000
Likelihood Ratio	193.758	4	.000
Linear-by-Linear Association	182.980	1	.000
N of Valid Cases	9111		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 645.05.



4) Age

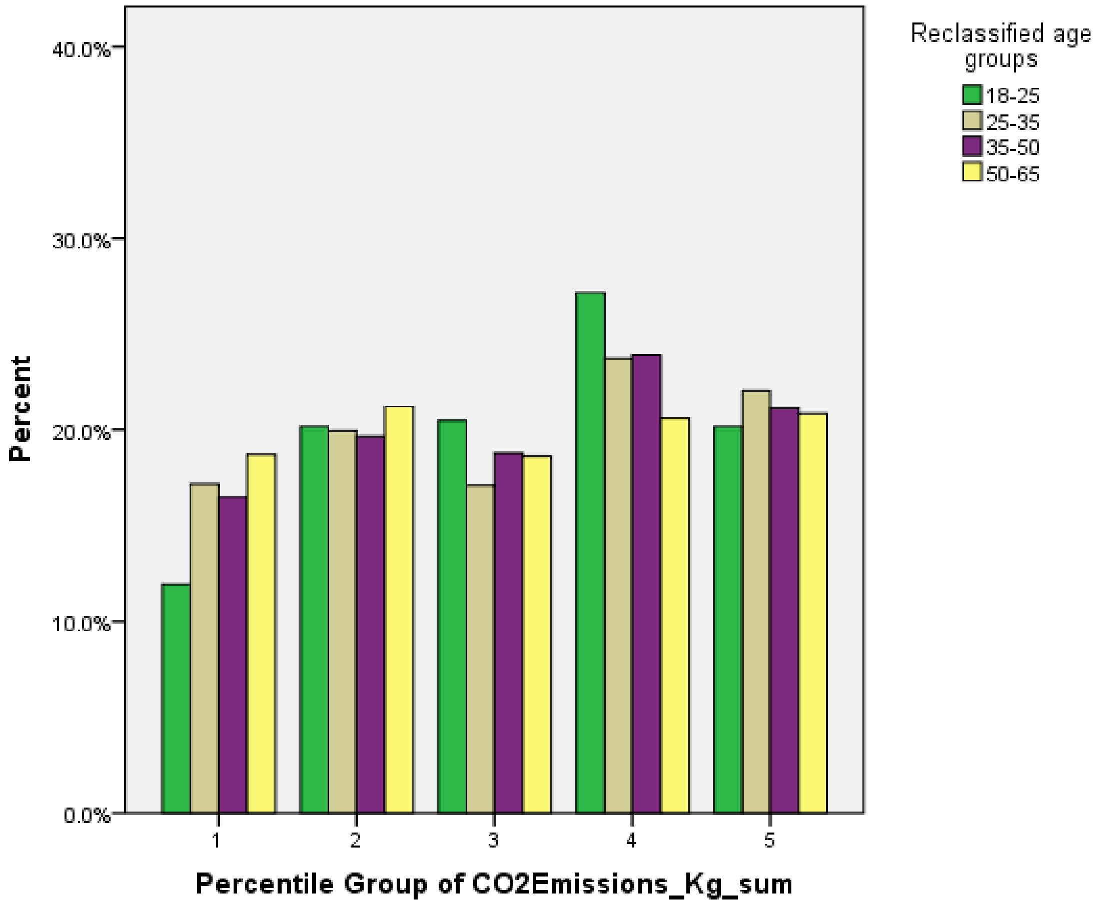
Percentile Group of CO2Emissions_Kg_sum * Reclassified age groups Crosstabulation

			Reclassified age groups						
			0-18	18-25	25-35	35-50	50-65	>65	Total
Percentile Group of CO2Emissions_Kg_sum	1	Count	483	77	212	414	402	272	1860
		Expected Count	296.8	131.5	251.9	512.0	438.7	229.1	1860.0
	2	Count	359	130	246	493	456	270	1954
		Expected Count	311.8	138.1	264.7	537.9	460.9	240.6	1954.0
	3	Count	236	132	211	471	400	213	1663
		Expected Count	265.4	117.5	225.2	457.8	392.2	204.8	1663.0
	4	Count	207	175	293	600	443	187	1905
		Expected Count	304.0	134.7	258.0	524.4	449.3	234.6	1905.0
	5	Count	169	130	272	530	448	180	1729
		Expected Count	275.9	122.2	234.2	475.9	407.8	212.9	1729.0
Total		Count	1454	644	1234	2508	2149	1122	9111
		Expected Count	1454.0	644.0	1234.0	2508.0	2149.0	1122.0	9111.0

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	330.312[a]	20	.000
Likelihood Ratio	325.840	20	.000
Linear-by-Linear Association	38.793	1	.000
N of Valid Cases	9111		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 117.55.



5) Gender

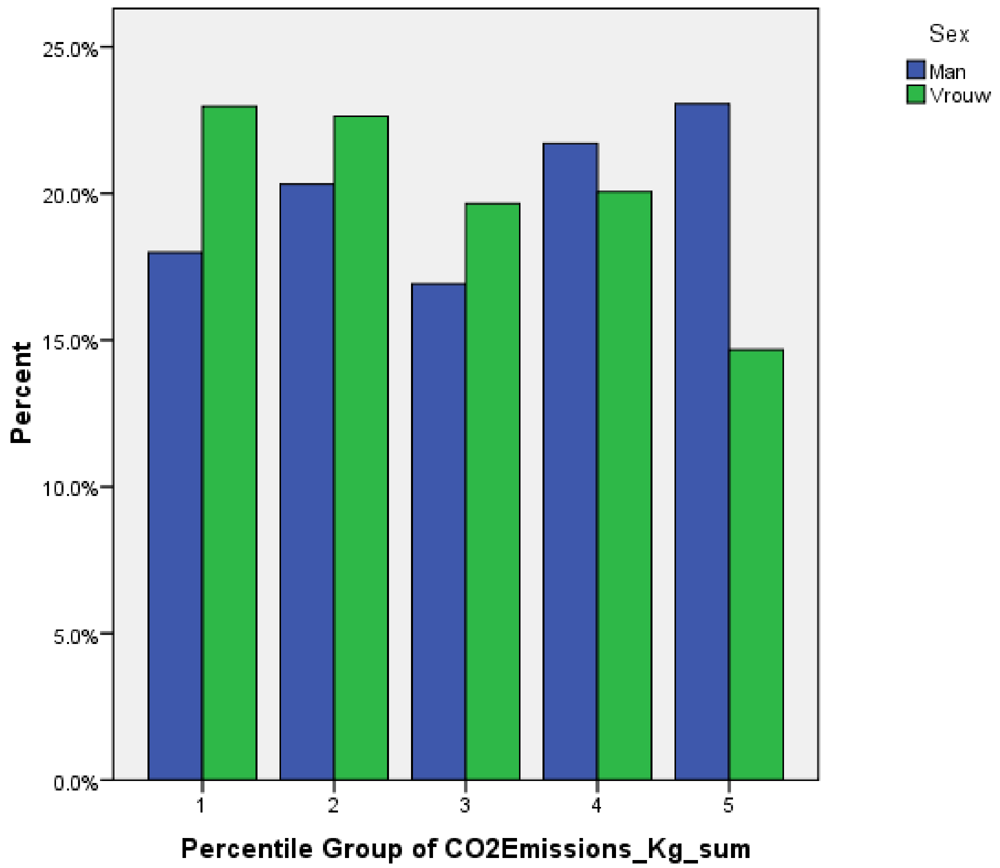
Percentile Group of CO2Emissions_Kg_sum * Sex Crosstabulation

			Sex		
			Man	Vrouw	Total
Percentile Group of CO2Emissions_Kg_sum	1	Count	841	1019	1860
		Expected Count	954.4	905.6	1860.0
	2	Count	950	1004	1954
		Expected Count	1002.6	951.4	1954.0
	3	Count	791	872	1663
		Expected Count	853.3	809.7	1663.0
	4	Count	1015	890	1905
		Expected Count	977.5	927.5	1905.0
	5	Count	1078	651	1729
		Expected Count	887.2	841.8	1729.0
Total		Count	4675	4436	9111
		Expected Count	4675.0	4436.0	9111.0

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	129.948[a]	4	.000
Likelihood Ratio	130.990	4	.000
Linear-by-Linear Association	107.292	1	.000
N of Valid Cases	9111		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 809.69.



6) Highest completed education

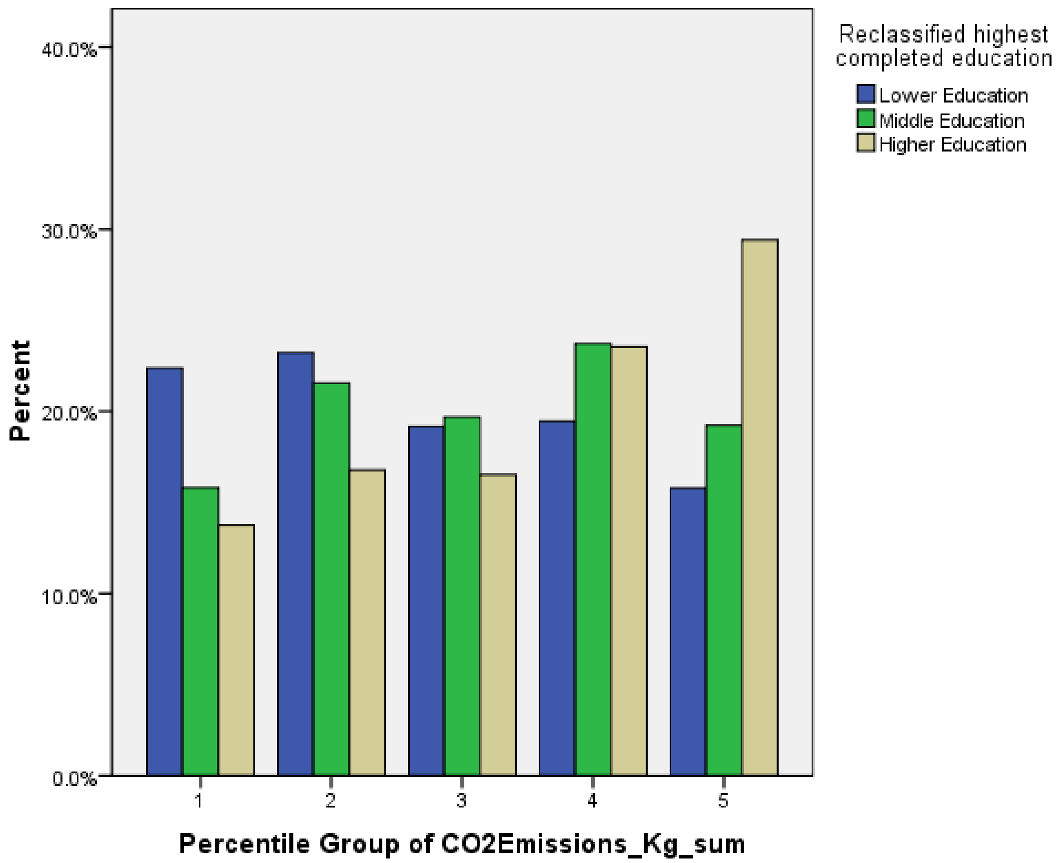
Percentile Group of CO2Emissions_Kg_sum * Reclassified highest completed education Crosstabulation

			Reclassified highest completed education				
			Lower Education	Middle Education	Higher Education	Others	Total
Percentile Group of CO2Emissions_Kg_sum	1	Count	674	448	258	480	1860
		Expected Count	614.7	578.6	383.2	283.6	1860.0
	2	Count	699	611	315	329	1954
		Expected Count	645.8	607.8	402.6	297.9	1954.0
	3	Count	577	558	310	218	1663
		Expected Count	549.6	517.3	342.6	253.5	1663.0
	4	Count	586	672	442	205	1905
		Expected Count	629.6	592.6	392.5	290.4	1905.0
	5	Count	475	545	552	157	1729
		Expected Count	571.4	537.8	356.2	263.6	1729.0
Total		Count	3011	2834	1877	1389	9111
		Expected Count	3011.0	2834.0	1877.0	1389.0	9111.0

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	463.654[a]	12	.000
Likelihood Ratio	444.319	12	.000
Linear-by-Linear Association	3.280	1	.070
N of Valid Cases	9111		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 253.53.



7) Paid work hours

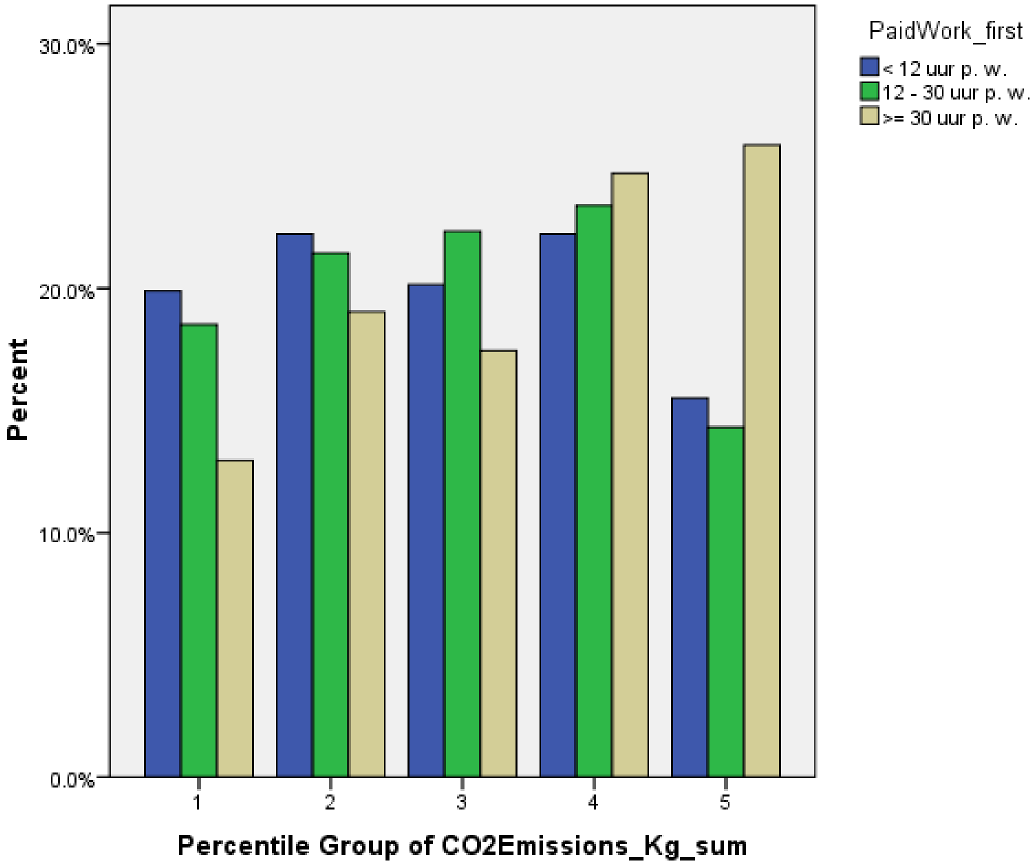
Percentile Group of CO2Emissions_Kg_sum * PaidWork_first Crosstabulation

			PaidWork_first				
			Unknown	< 12 uur p. w.	12 - 30 uur p. w.	>= 30 uur p. w.	Total
Percentile Group of CO2Emissions_Kg_sum	1	Count	1090	77	247	446	1860
		Expected Count	805.4	79.0	272.3	703.3	1860.0
	2	Count	926	86	286	656	1954
		Expected Count	846.1	83.0	286.1	738.8	1954.0
	3	Count	686	78	298	601	1663
		Expected Count	720.1	70.6	243.5	628.8	1663.0
	4	Count	656	86	312	851	1905
		Expected Count	824.9	80.9	278.9	720.3	1905.0
	5	Count	587	60	191	891	1729
		Expected Count	748.6	73.4	253.2	653.8	1729.0
Total		Count	3945	387	1334	3445	9111
		Expected Count	3945.0	387.0	1334.0	3445.0	9111.0

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	431.122[a]	12	.000
Likelihood Ratio	431.340	12	.000
Linear-by-Linear Association	360.806	1	.000
N of Valid Cases	9111		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 70.64.



8) Personal net income

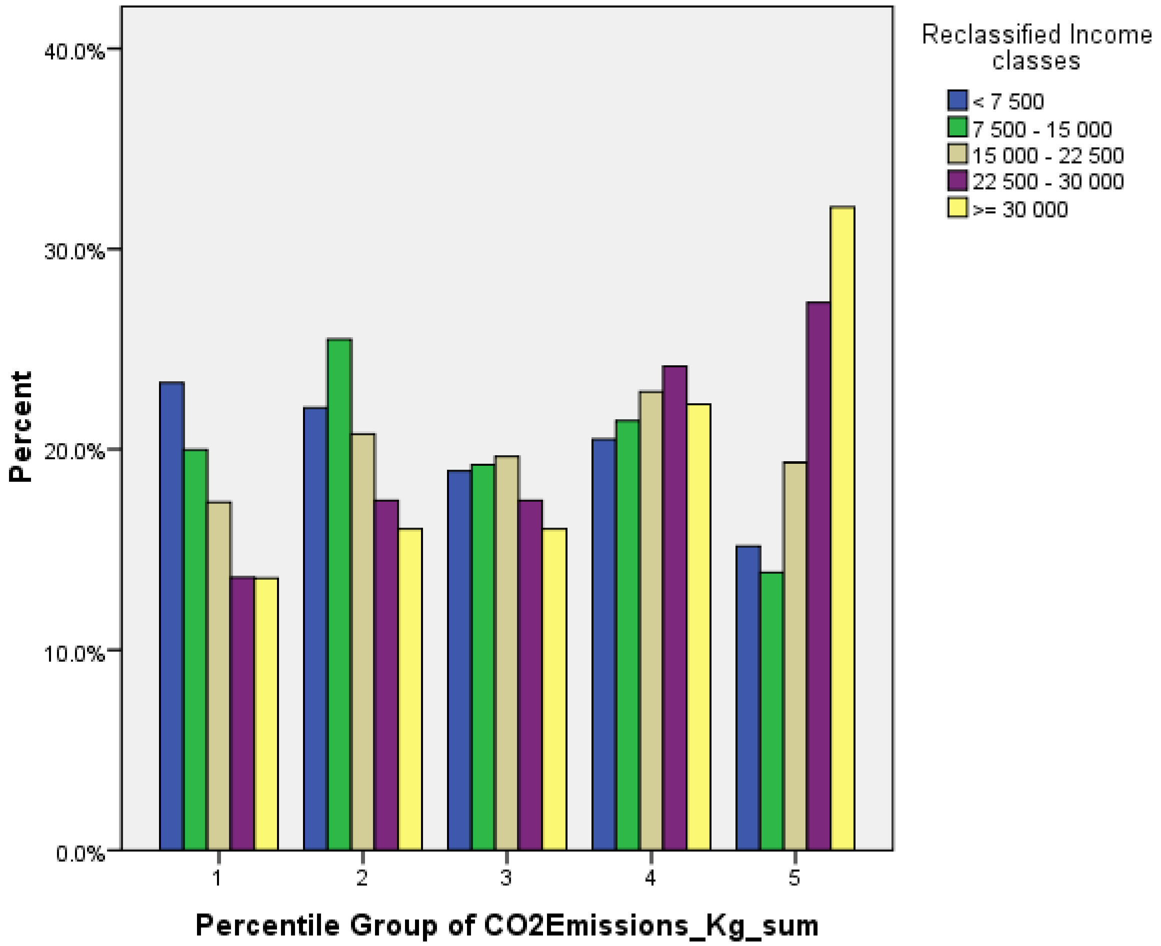
Percentile Group of CO2Emissions_Kg_sum * Reclassified Income classes Crosstabulation

			Reclassified Income classes						
			No income	< 7 500	7 500 - 15 000	15 000 - 22 500	22 500 - 30 000	>= 30 000	Total
Percentile Group of CO2Emissions_Kg_sum	1	Count	877	149	275	247	163	149	1860
		Expected Count	690.0	130.5	281.1	290.1	244.4	224.0	1860.0
	2	Count	782	141	351	295	209	176	1954
		Expected Count	724.9	137.0	295.3	304.8	256.7	235.3	1954.0
	3	Count	613	121	265	279	209	176	1663
		Expected Count	616.9	116.6	251.3	259.4	218.5	200.2	1663.0
	4	Count	621	131	295	325	289	244	1905
		Expected Count	706.7	133.6	287.9	297.1	250.3	229.4	1905.0
	5	Count	487	97	191	275	327	352	1729
		Expected Count	641.4	121.3	261.3	269.7	227.2	208.2	1729.0
Total		Count	3380	639	1377	1421	1197	1097	9111
		Expected Count	3380.0	639.0	1377.0	1421.0	1197.0	1097.0	9111.0

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	381.467[a]	20	.000
Likelihood Ratio	369.345	20	.000
Linear-by-Linear Association	307.493	1	.000
N of Valid Cases	9111		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 116.63.



9) Degree of urbanization (location)

Percentile Group of CO2Emissions_Kg_sum * Degree of Urbanization (municipality) Crosstabulation

			Degree of Urbanization (municipality)				
			Strong urban	Poor urban	Few urban	Non-urban	Total
Percentile Group of CO2Emissions_Kg_sum	1	Count	673	299	602	286	1860
		Expected Count	656.5	266.0	586.9	350.5	1860.0
	2	Count	812	268	542	332	1954
		Expected Count	689.7	279.4	616.6	368.2	1954.0
	3	Count	516	249	567	331	1663
		Expected Count	587.0	237.8	524.8	313.4	1663.0
	4	Count	556	267	666	416	1905
		Expected Count	672.4	272.4	601.1	359.0	1905.0
	5	Count	659	220	498	352	1729
		Expected Count	610.3	247.3	545.6	325.8	1729.0
Total		Count	3216	1303	2875	1717	9111
		Expected Count	3216.0	1303.0	2875.0	1717.0	9111.0

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	114.470[a]	12	.000
Likelihood Ratio	115.385	12	.000
Linear-by-Linear Association	22.860	1	.000
N of Valid Cases	9111		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 237.83.