The Climate Value of Cycling in The Netherlands: searching for explanatory variables

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March, 2013

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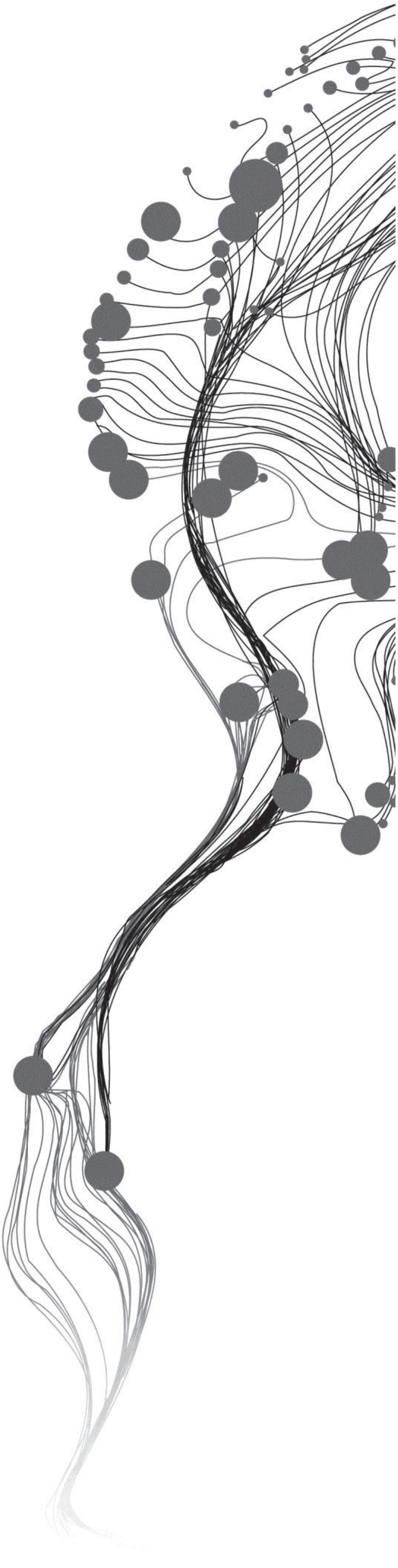

The Climate Value of Cycling in The Netherlands: searching for explanatory variables

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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

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ABSTRACT

Sustainable transport development calls for non-motorized travel modes that cause less or even no greenhouse gas emission. Bicycle as a non-emission travel mode has been gaining increasing attentions in terms of its contribution to CO_2 saving. As a bicycle friendly country, The Netherlands has a high level of bicycle share but still lack of studies looking at the climate perspective. A model Climate Value of Cycling (CVoC) calculates the most likely substitution mode for each bicycle trip and estimates the additional CO_2 emissions caused by induced traffic if cycling would no longer be possible. The induced CO_2 equals to the the total amount of avoided CO_2 emission by bicycle which is its climate value. This study explains the CVoC score by considering three urban and regional domains: socio-economic character, urban form and infrastructure. A list of explanatory variables is chosen under each domain to observe whether the primary modes share and the probability to choose the most likely alternative modes can be driven by the extent of these explanatory variables. The interpretations of the links between explanatory variables and CVoC scores provide urban planners a better understanding of the climate value of bicycle and plan for more sustainable transport system.

ACKNOWLEDGEMENTS

I will always believe that learning urban planning in ITC, University of Twente, is the most beautiful accident that I ever had.

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1. INTRODUCTION AND BACKGROUND

1.1. Challenge of sustainable development

In year 2010, the number of cars on Dutch roads passed the limit of eight million. On December 31 there were 8,002,579 passenger cars, reports from BOVAG (2010). This unrestrained increase in motor vehicle use has led to major problems for local governments, such as traffic congestion, air pollution and a growing impact on global climate change. In the same year, total greenhouse gas emissions in the Netherlands increased by approximately 6% compared to the 2009 emission level, report from CBS (2009). Apart from the expanding economy and growing populations, that causes the GHG emission from increased fuel combustion related to energy production and space heating. But mainly, the transportation sector responsible for nearly 80 percent increase of the greenhouse gas emissions since 1990 (Graveland & Schenau).

Based on the statistics above and together with some studies and project in the European Union, it is said that "in the EU, transport is the only sector that has increased its CO_2 emissions since 1990" ("Regions 202020," 2010). Local governments are responsible to address the problems of motor vehicle use and promote a more sustainable transportation system by taking actions such as minimize motor vehicle use, encourage transit use and promote non-motorized transport (NMT) use.

Apart from the transportation sector that is a leading and growing contributor to GHG emissions, the land use patterns in the urbanized areas are also significantly responsible for that growth(de Chazal & Rounsevell, 2009). Due to the rising trend of urbanization, cities may reshape and extend their physical size. Many of the farmlands, wetlands, forests, and deserts have been transformed into human settlements during the process of urbanization (Wu, Zhang, & Shen, 2011). Most major metropolitan areas face some driven problems such as urban sprawl: loss natural vegetation and open space, and a general decline in the extent and connectivity of forests or farmlands(Arribas-Bel, Nijkamp, & Scholten, 2011). The public only identifies these problems in the aspect that residential and commercial development replaces undeveloped land around them, ignoring the effects of climate change. Meanwhile, these problems can be generally attributed to increasing population. One hundred years ago, approximately 15 percent of the world's population was living in urban areas. Today, the percentage is nearly 50 percent. In the last 200 years, world population has increased six times, stressing ecological and social systems (USGE, 1999). These land-use change related problems reduced the amount of forest land available to absorb CO_2 and boost greenhouse gas emission.

1.2. Relationships between urban transport, land use and climate change

The relation between urban transportation, land use and climate change has been known for long, but is increasing getting attention in contemporary literatures. In Figure 1, the flow which represents movement of goods, services, and people is determined by both the transportation system and the land use patterns. This flow happened by using different types of transportation. And the variety of land use causes people's movement by using transportation. The changes that occur in land use in one hand, through the type of transportation and on the other hand, through the resources consumed in providing that transportation service. Simultaneously, transportation system in the flow also changes itself over time. Once the transportation get modification or a new service developed, land use change will also appear together with the flow. These interactions in the transportation system and land use contribute to climate change and further determine the degree of greenhouse gas emissions. And in return, climate change will have impacts on both transportation system and land use.

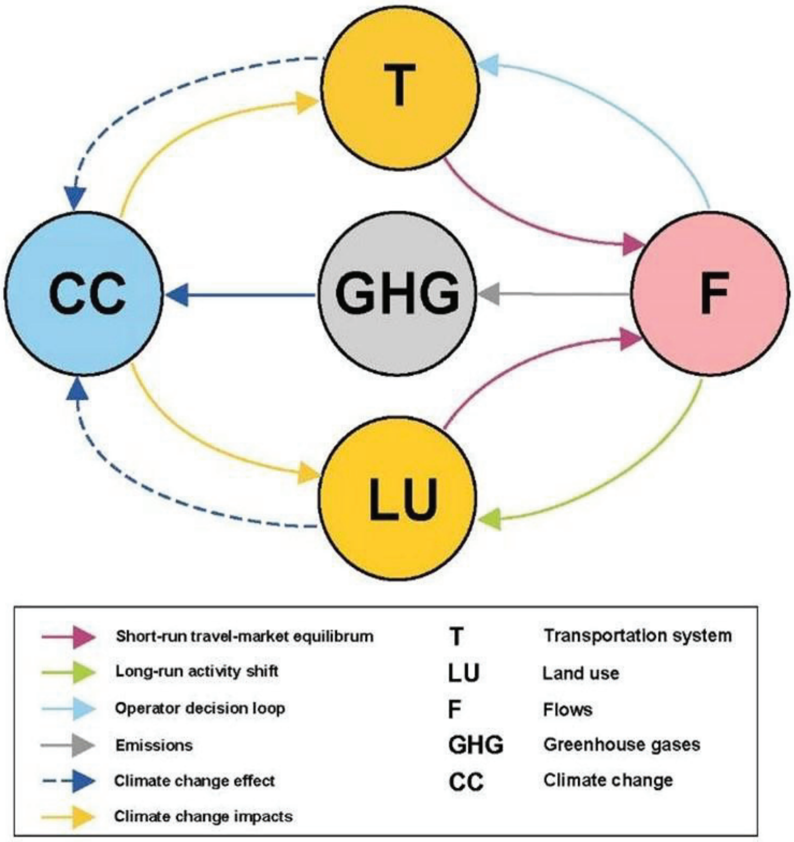


Figure 1 Urban transportation, land use, and climate change interactions.
Sources: adapted from Manheim (1979)

1.3. Environmentally sustainable transport development

In the transport sector, mobility is the fundamental living necessity of the 21st century and it brings access to primary services and leisure. But today, current patterns of provision and consumption of mobility are unsustainable and cities all over the world suffer from high levels of traffic related congestion, air pollution and even the degradation of communities and social dysfunction(UITP, 2010).

Addressing the issue of climate change is a key topic for all and for transport in particular. It has significant impacts on the environment, accounting for between 20% and 25% of world energy consumption and carbon dioxide emissions. Greenhouse gas emissions from transport sector are increasing at a faster rate than any other energy using sector. At present CO_2 from transport are growing mainly due to the sheer increase of the number of trips made. Road transport is also a major contributor to local air pollution and smog.

The environmental impacts of transport can be reduced by enhancing the role of public transport or electric rail and more sustainably, by improving the walking and cycling environment in cities. As a non-motorized transport mode, cycling is a very efficient and effective mode of transportation and optimal for short to moderate distances. Bicycles provide various benefits compared to other motor vehicles: including exercise, being an alternative to the use of fossil fuels, with no air or noise pollution, contributing to reduced traffic congestion, easier parking, and access to both roads and paths. The many advantages meet the requirements of environmentally sustainable transport development.

1.4. Justification

1.4.1. Carbon emissions from the transport sector

The study on Dutch emission factors of car traffic reported in Boer, L.C., Brouwer, F.P.E, and Essen (2008) shows that the car ranks first among all vehicles, with a rate of 0.188. It shows that the CO_2 that emitted by car is the highest among the GHG. Moreover, the actual amount of emissions is not only reflected by the amount of car ownership but also by how frequency of car usage, how far the car trip cover. From the National Mobility Survey(MON) in The Netherlands, in the most recent 3 years episodes between 2007 to 2009, it can be seen that among all the travel modes (adjust by aggregation), the car is responsible for most travel.

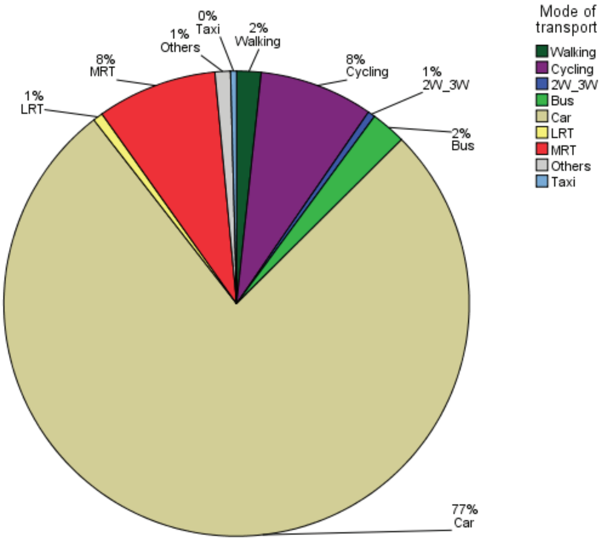


Figure 2 Percentage of trip length by each travel mode from MON

A study by SWOV (2010) reported that today, more than 200 billion kilometers are travelled each year. And the increase in mobility in the last ten years has been due almost entirely to the car.

On the other hand, sustainable travel modes that cause less carbon emission such as bus or tram have not increased in use significantly.

1.4.2. Call for more sustainable travel mode

In order to provide a more sustainable development, which focuses on the environment friendly development, a sustainable transport system is highly required.

Unlike motorized vehicles, non-motorized transport (NMT) options such as the bicycle do not emit greenhouse gas emissions or local air pollutants. It causes virtually no noise or air pollution and consumes far less non-renewable resources than any motorized transport mode. Every increase in NMT therefore leads to a direct decrease in emissions.

Therefore, bicycle systems are getting worldwide interest by planners and engineers because of its many advantages for the user and the environment. Apart from alleviating air pollution, as a traditional transport mode, bicycles provide high levels of accessibility to locations; reducing traffic congestion, reducing parking demand, user cost saving, energy conservation, mobility for non-drivers, health promotion ("the only energy cycling requires is provided directly by the traveller, and the very use of that energy offers valuable cardiovascular exercise" (Ralph Buehler & Pucher, 2008)), and most of all – promote sustainable urban development (Todd & Litman, 1994). While it is a convenient, enjoyable, and efficient way to make short trips – 40 percentage of all trips in the United States are two miles or less – and it does not emit

CO_2, policymakers are increasingly turning to promoting cycling as a way to meet GHG reduction targets (Flusche, 2010).

1.4.3. Value the benefits of cycling

However, valuing cycling from an environmental perspective thus has a lot of benefits, but also comes with a lot of challenges. Some quantitative studies look at cycling from the perspective of safety or resources saving. While due to the lack of information of travel distance and travel time by using the bicycle, the value of cycling is difficult to measure by only look at the amount of bicycle trips. A model is developed that aptly uses the term Climate Value of Cycling (CVoC) to quantify the amount of avoided CO_2 gas emissions to represent its contribution to the sequestering CO_2 emissions (Roel Massink, Zuidgeest, Rijnsburger, Sarmiento, & Maarseveen, 2011), while other studies mainly have emphasized on other aspects of cycling rather than its climate value.

This model assesses the climate value of bicycle by calculating how much emission the substituted modes cause. On one hand, it calculated the avoided CO_2 of using a bicycle. On the other hand by detecting what are the substituted modes it can provide insight in the risk of unsustainable development if cycling levels are not maintained.

1.5. Problem ststement

The climate value of cycling model quantifies the benefit of using bicycles in view of carbon dioxide savings. However, since cycling is an individual mode, people's behaviour of choosing or not may be influenced by other aspects such as socio-economic background, the availability of other transports facilities or the surrounding urban environment.

Figure 1 in section 1.2 already showed that the CO_2 emissions result from the interaction between transportation flows and land use. In order to understand CVoC in more comprehensive way, the link between CVoC and other urban and regional domains should be considered.

1.5.1. What this study will do

This research seeks to find urban planning interpretations that can well explain Climate Value of Cycling.

Through finding out the factors that can make the climate value different, urban planners can have a better understanding of climate value of bicycle and contribute to a more sustainable urban development. Thus, the selection of these factors in this research should keep the goals of urban planners in further plans in mind. In order to reach this goal, a set of "explanatory variables"-- used in a relationship to explain or to predict changes in the values -- that come from different urban and regional domains will be selected to provide interpretations. These explanatory variables act as a bridge to explain the climate value under different urban and regional aspects. This can provide insight for urban planners to find out or predict the focus points of sustainable development.

1.6. Research objectives and questions

Valuing cycling helps urban planners and decision makers to enhance the role of cycling in urban and regional plans, especially in view of the discussion about low carbon development. Knowing the climate value of cycling cities, regions or countries can switch to low carbon transport futures by employing the right transport policy measures, these tools can help urban management to reach sustainability thought various strategies like modal shift, and specifically shift to and encouraging cycling mode. It should be considered that the current situation is not sustainable and transport must contribute fully to achieving carbon reduction targets (Banister, 2011).

Regarding what has been discussed above, the main aim this research seeks to address is:

"To fill-in the knowledge gap of explaining CVoC through the major urban and regional planning domains like urban form, infrastructure and socio-economic characteristics."

1.6.1. Objectives and questions

The main objective of this research is to explain the Climate Value of Cycling in The Netherlands through a set of urban and regional explanatory variables.
Based on the main objective, the following table lists the related sub-objectives and research questions.

Objective	Research Questions
To short-list relevant urban and regional indicators that could explain CVoC	▪ Which urban and regional domains could well explain the CVoC? ▪ What would be suitable explanatory variables (EV) for each underlying domain?
To process the selected urban and regional explanatory variables	▪ Which data is required to process the selected indicators? ▪ How to obtain EVs? (What kind of spatial analysis is required to be employed?) ▪ How to map and visualize the selected indicators?
To model the CVoC for different classes of the selected urban and regional explanatory variables	▪ Which data is required to calculate CVoC? ▪ How to link the MON data (PC4) with the maps of the selected urban and regional indicators? ▪ How to calculate the CVoC?
To analyze the relations between CVoC and the urban and regional domains	▪ How to classify selected explanatory variables? ▪ How to correlate the explanatory variables with the CVoC score?
To draw inferences on the relation between CVoC and the urban and regional factors	▪ How to interpret the observed correlation? ▪ What policy lessons we can draw through?

Table 1 Research objectives and questions

1.7. Conceptual framework

Based on literature review, three urban and regional domains are selected to explain Climate Value of Cycling. The interpretations can be addressed from the primary bicycle share and the probability to choose the alternative travel modes if bicycle is absent. Therefore, a better understanding of the climate value of bicycle will be established to provide an overview of whether the current transport system is sustainable by considering the impacts of primary modes share and the substituted travel modes.

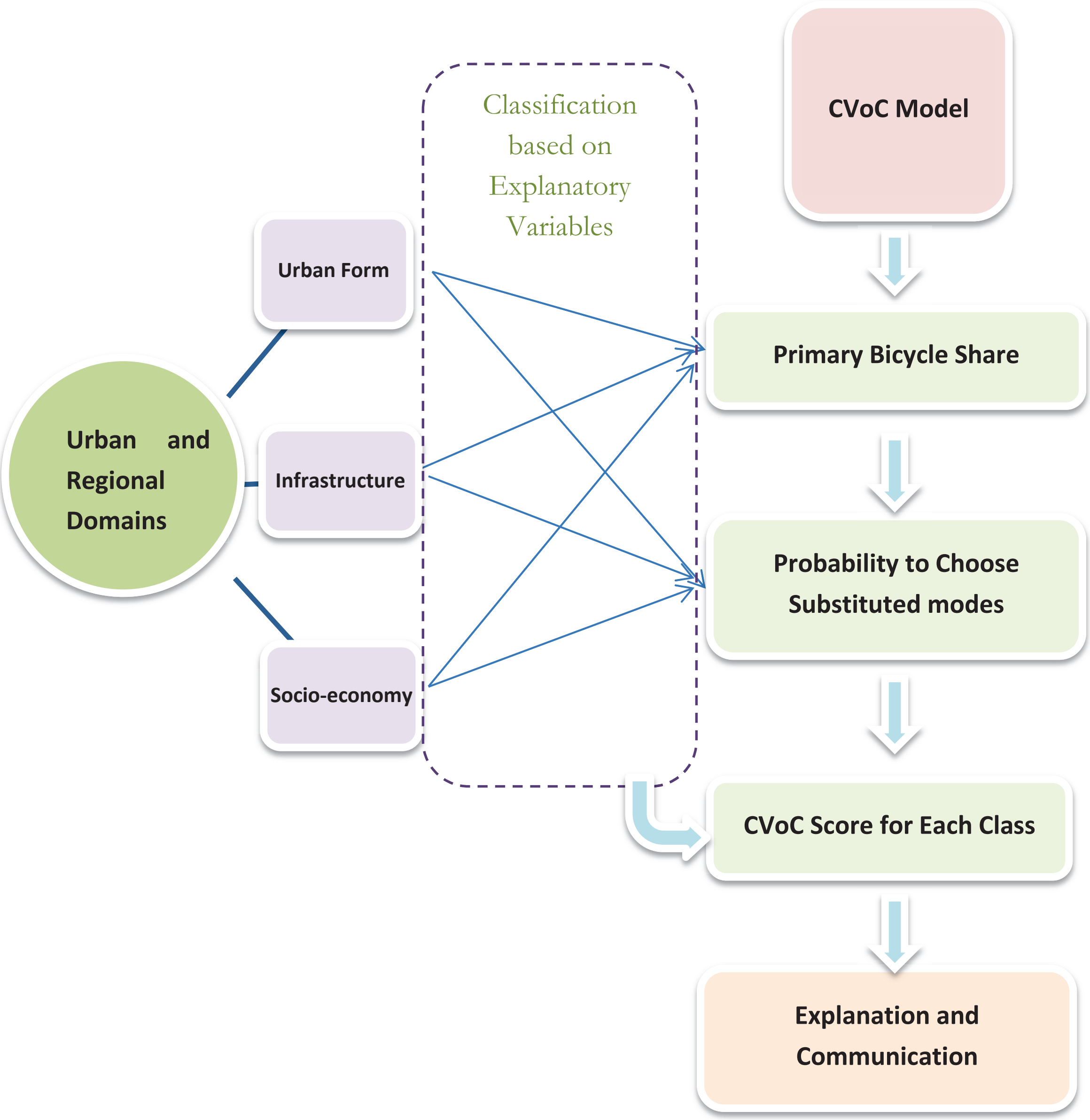


Figure 3 Conceptual Framework

2. LITERATURE REVIEW

2.1. Cycling in The Netherlands

In The Netherlands, cycling is very popular, with favourable conditions of terrain and infrastructure for cycling, with more bikes than inhabitants. The Dutch use bicycles as a means of transportation for commuting to and from work as well as for daily errands. One of the curious facts of the Netherlands shows that nearly 85 percent of the population own at least one bicycle. The bicycle use among Dutch is highly regular and often daily. There are about 16 million bicycles in The Netherlands, slightly more than one for every inhabitant. There are about 1.3 million new bicycles sold every year (Mobycon, Fietsberaad, & Ligtermoet, 2009).

From a policy aspect point of view, in the Netherlands, non-motorized modes of transport are at the center of transport policy. And it has an established tradition as a utilitarian transport mode (Ralph Buehler & Pucher, 2008).

Due to its contribution in relieving heavy traffic; its friendliness to the environment and the healthy life style it promotes, the Netherlands has been famous for its cyclist friendly urban design and policies.

Similar with the bicycle policy plan “Choosing for Cyclist: 2007-2010” in Amsterdam, large cities have started to try to increase bike parking spots, decrease bicycle theft, improve traffic safety, complete bike network and advocate young people to bike more. Since more funds would be invested from governments that focus on bicycling projects. Further urban planning would build up to a more bicycle friendly environment.

In this bicycle friendly environment, the benefit of using bicycle can be highly represented. The advantage of assessing the CVoC in the Netherlands is that it helps to measure the performance in terms of avoided greenhouse gases. It is particularly interesting since Dutch cities are known to have a good performance in cycling and so far there is no systematic assessment of cycling in terms of its climate value for the Netherlands.

2.2. What is Climate Value of Cycling

The modeling framework Climate Value of Cycling developed by Roel Massink et al. (2011) is to calculate the most likely substitution mode for each bicycle trip and estimate the additional CO_2 emissions caused by induced traffic if cycling would no longer be possible. The methodology uses data on the current modal shares of cycling mobility, the competition of cycling with other transportation modes, and CO_2 emission factors to calculate the climate value of cycling (Roel Massink et al., 2011). The amount of avoided CO_2 emissions can be calculated and are used to derive the CVoC when the main input data – trip length frequency distributions being ready.

2.2.1. Applicability in the Netherlands

By considering the situation in the study area, there are three aspects that need to be considered when calculating the probability of substitution mode. They are trip makers’ socio-economic strata, trip purpose and trip length. Assuming that people within the same trip distance class behave similarly, if the socio-economic background and travel purpose are the same, this group of people is also expected to choose the similar alternative travel mode if the bicycle is taken out of the choice set.

Luckily, there is a MON data (see description in 3.2.1) available that records the mentioned information for each observed trip maker that provides data for CVoC calculation. However, the parameters inside the CVoC model can be directly or indirectly influenced by other factors those are assumed, further explaining the CVoC values. Also for urban planners, there should be an urban concept to support the reason why the difference of CVoC value. Thus, instead of adjusting the model, to explain the CVoC value better is a need for correlating CVoC with some external parameters.

2.3. Previous study on the Climate Value of Cycling

In the in a recent research by Chen (2012) the climate value of cycling was assessed under different urban forms by using a quantitative and statistical approach. He chose three urban form dimensions which are density, diversity and design, and detected the correlation with different CVoC scores. The unit CVoC represented the marginal value of CVoC by passenger kilometre travelled. He found that the relationship between urban dimensions and unit CVoC is not linear but has a specific trend. These slight correlations can be caused by the following reasons:

Firstly, the spatial unit in his research is the Dutch municipality. However, the extent of the urban dimensions for each city can be diverse. Since the CVoC model observes substitute trips, there can be a gap to interpret the travel behaviour in one municipality by using samples of individual trip, which may cause the problem of "ecologic fallacy".

In addition, for more than 400 Dutch municipalities, the number of trips assigned in each one was limited. If choosing the most likely alternative travel mode by considering trip purpose and socio-economic background, some trip bins contained very few or even no records that might lead to the calculation of number of substituted trips returned zero. So in order to avoid this situation, only trip length was considered as parameter. It means trips that in the same bin size would shift to similar alternative modes. This method keeps the model simple but possibly led to a loss of credibility of the alternative modes.

2.4. The CVoC explanation this research search for

In order to support the interpretation of CVoC better, some explanatory variables under different urban and regional domains that try to consider every dimension of sustainable transport development would be applied in this research. By looking at a set of non-locational explanatory variables, the concept of CVoC can gain better understanding from insights.

2.5. Urban and regional domains

2.5.1. Urban form in transport sector

In urban environment, mobility has been formed by the capacity of transport infrastructure, such as the road network, public bus routes and railway lines. Urban form in the context of an urban transportation system is the spatial imprint on the urban network. The evolution of urban form has generally led to changes in transportation. The more the urban form has been altered, the more radical the change in transport technology, and vice versa (Rodrigue, 2013). For instance, what kind of travel modes people choose to satisfy their basic mobility are highly depend on the city considered, also cause the trips numbers varies. Study shows that walking account for 88% of all movements inside Tokyo while this figure is only 3% for Los Angeles(Rodrigue, 2013). Urban transportation is thus associated with a spatial form which varies according to the models being used (Badland & Schofield, 2005).

Meanwhile, the land development related urban sprawl in metropolitan areas of the US have been blamed for causing high levels of automobile travel, and thus for air quality problems(Handy, Cao, & Mokhtarian, 2005). A longitudinal analysis of changes in travel behaviour and changes in the built environment shows significant associations, even when the attitudes of trips have been considered, the causal relationship can still be provided (Handy et al., 2005). Also, studies show that the amount of urban land allocated to transportation is often correlated with the urban design or density level. The urban form domain therefore has impact on the transportation development itself as well as people's travel behaviour.

2.5.2. Infrastructure in the transport sector

In addition, to talk about transportation, infrastructure plays a main role to support it. The density of traffic spots and the availability of travel mode choices can be a significant affect for people to choose their favourable travel mode. Active travel is associated with good pedestrian and cycling infrastructure. Even in the place that walking and cycling are relatively uncommon but is facilitated in areas with less physical barriers and better infrastructures (McCartney, Whyte, Livingston, & Crawford, 2012). The accessibility to pedestrian or road space in some disorganised urban form can be the reason of cycling shares. The sustainable travel mode calls for more attempts to create spaces specifically for bicycles in urban areas, with reserved bicycle lanes and public parking facilities.

2.5.3. Social economic domain in transport sector

Last but not least, the socio-economic characteristic can also be the factor that influence travel behaviour. Study shows that travel patterns among different socio-economic groups are diverse according to the different characters of trip makes. There is a trend that people with relatively older age or persons with low incomes and women in general do not travel extensively while the middle-aged group, persons with high incomes and men travel much more and farther. Cars are the dominant transportation mode for all population groups. Public transportation is mostly used by young people and women (Carlsson-Kanyama & Lindén, 1999).

With the fast urban development, household structural dynamics in terms of socio-economic characteristics such as income, car ownership and composition have assumed different dimensions. Such changes have ensured an ever increasing demand for travel (Koushki, 1988).

2.6. The explanatory variables under each domain

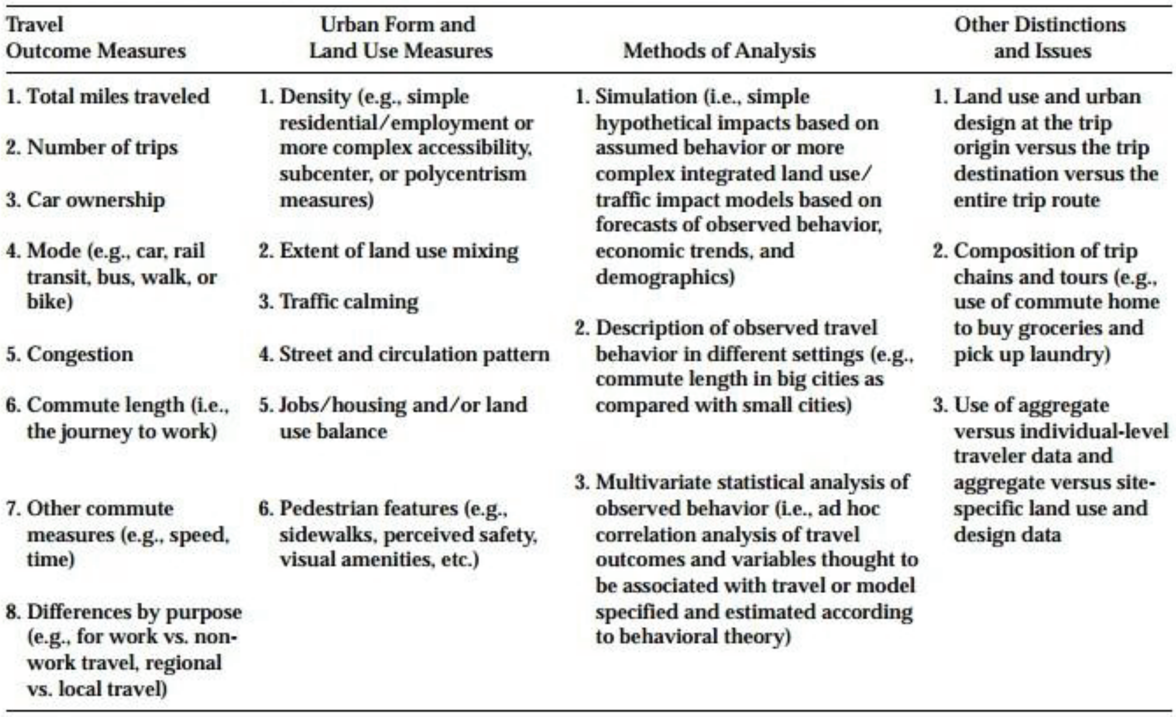
Since the mode of transportation demand is influenced by various factors such as availability of facilities, level of motorization, urban structure, pace of economic growth, local culture, and so on. The following urban and regional domains are considered to support explanatory variables' selection. They are urban form domain, infrastructure and socio-economic character.

2.6.1. Urban form domain

From the review of past studies, most aspects considered important on urban form are the distance to city center, structures of neighborhood, density of development, land uses mix, provision of local facilities and accessibility to public transport (Stead & Marshall, 2001). Different studies have examined impact of above urban form variables on travel patterns such as trip length, modal split, and transport energy consumption and so on.

Several researches pointing out the fact that travel patterns and therefore fuel consumption and pollution are strongly related to land use and the degree of "compactness" of cities, which means urban transportation and sustainable urban form are particular regard to the concept of 'compact city' (Jenks & Burgess, 2000). And the measurements of compactness met various studies such as population density, employment density or density of development and distance to city center. However, the challenge to choose "compactness" as index is that the compact city form is not confined just to distances, shapes or densities. Land use mix, provision of facilities and proximity to activity centers also comprise aspects of compactness(Narayan Sarlashkar, 2009).

Table 2 lists some other previous studies of urban form and transport, divided into four categories. Most attention has been on the first two columns as effect and cause, respectively.



Travel Outcome Measures	Urban Form and Land Use Measures	Methods of Analysis	Other Distinctions and Issues
1. Total miles traveled	1. Density (e.g., simple residential/employment or more complex accessibility, subcenter, or polycentrism measures)	1. Simulation (i.e., simple hypothetical impacts based on assumed behavior or more complex integrated land use/traffic impact models based on forecasts of observed behavior, economic trends, and demographics)	1. Land use and urban design at the trip origin versus the trip destination versus the entire trip route
2. Number of trips	2. Extent of land use mixing	2. Description of observed travel behavior in different settings (e.g., commute length in big cities as compared with small cities)	2. Composition of trip chains and tours (e.g., use of commute home to buy groceries and pick up laundry)
3. Car ownership	3. Traffic calming	3. Multivariate statistical analysis of observed behavior (i.e., ad hoc correlation analysis of travel outcomes and variables thought to be associated with travel or model specified and estimated according to behavioral theory)	3. Use of aggregate versus individual-level traveler data and aggregate versus site-specific land use and design data
4. Mode (e.g., car, rail transit, bus, walk, or bike)	4. Street and circulation pattern		
5. Congestion	5. Jobs/housing and/or land use balance		
6. Commute length (i.e., the journey to work)	6. Pedestrian features (e.g., sidewalks, perceived safety, visual amenities, etc.)		
7. Other commute measures (e.g., speed, time)			
8. Differences by purpose (e.g., for work vs. non-work travel, regional vs. local travel)			

Table 2 List of Outcomes, Questions, and Methods in Studies of Urban Form and Travel
Source: Crane (2000)

The concept of density in urbanism is frequently used to describe the relationship between a given area and the number of certain entities in that area (Wikipedia). These entities can be people, dwellings, services, or floor space. Not only a result of city development, density is currently a tool used to analyse problems, and further, to an instrument applied to offer improved solutions for sustainability analysis. More recently, minimum densities are argued for to support utilities and public transport, and as part of the solution to produce more sustainable urban environments with potential for vital human interaction ('urbanity')(Berghauser Pont & Haupt, 2009).

However, one of the problems of defining density in operational terms is the relatively weak relationship between density and building type. The same density can be obtained with radically different building types, and the same type can be used to obtain different densities (Lozano & Eduardo, 2006). For instance, Figure 4 illustrates three areas with 75 dwellings per hectare, but the population density in each situation would be different.

In this research, an established relationship between measures of the physical structure (e.g. building density) and the use/activity (e.g. population density) of the settlement is assumed. Based on the concept discussed above, both population density and building density would be observed in this research.

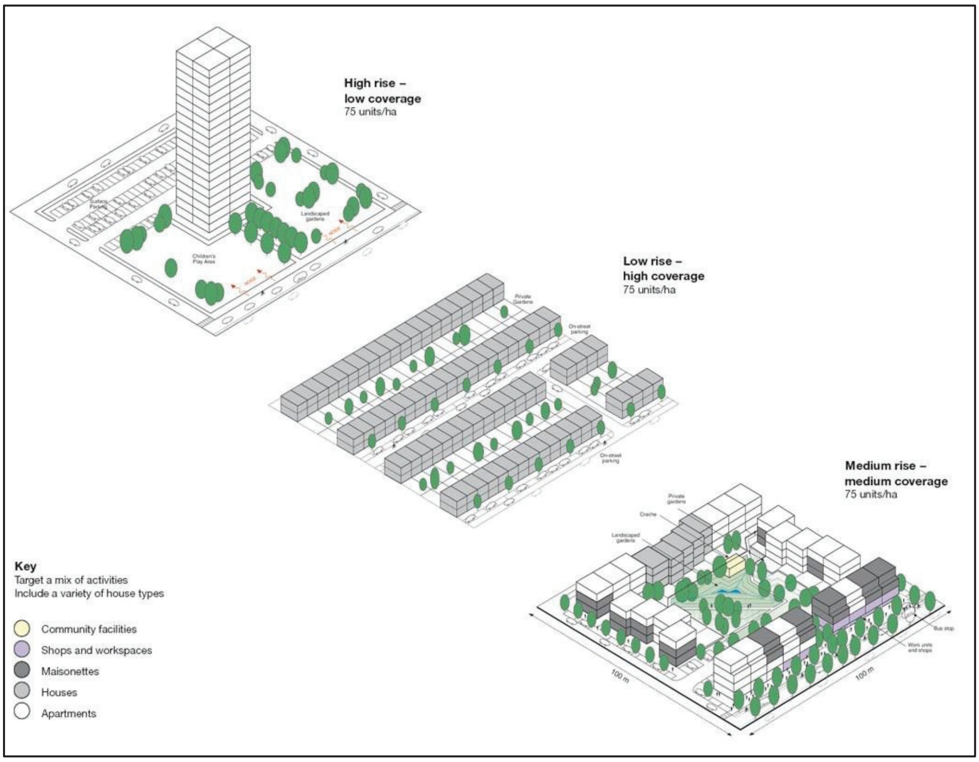


Figure 4 Relationship between density and urban form

Source: The Urban Task Force: Towards an Urban Renaissance. Taylor and Francis (1999)

2.6.2. Urban infrastructure

As a non-motorized transport mode, there are some limitations of using bicycles. The most obvious shortage is the travel time and distance cannot be long enough due to personal situation, together with the travel speed of cycling. Caulfield, Brick, and McCarthy (2012) focused on an empirical study of infrastructure features that affect the choice of whether to cycle. They found that in terms of infrastructure, regardless of the personal physical cycling condition, routes that without facilities or cycle paths are the least favourable cycle route types. For example, most cities in India lack pedestrian and bicycle lane facilities and the institutional and enforcement capability to sustain them as a viable and safe mode choice(Srinivasan & Rogers, 2005).

Based on the benchmarking project 'Fietsbalans' in The Netherlands, a clear relationship is found between bicycle use in municipalities and the quality of their infrastructure. More cycle tracks and more even roads are mentioned as the most important factors by people from 2 Danish cities in order to make people cycle more (Christian Ege & Thomas Krag).

Both cyclists and non-cyclists indicate that changes in the built-up environment would help them bicycle more (Moudon et al., 2005). Frequently mentioned environmental changes that can encourage cycling includes: more bike lanes and trails (mentioned by almost half of the respondents), good lighting at night (33%) and bicycle racks at destinations (31%). Dill and Carr (2003) also found that new bicycle lanes in large cities will be used by commuters. Krizek and Johnson (2006) investigated the effect of proximity to bicycle facilities and neighbourhood retail on urban cycling, controlling for individual, household and other characteristics. They found that bicycle use did not differ significantly by proximity to any bicycle facility, although people that live closer to these facilities are slightly more likely to use their bicycle.

On the other hand, the number of policy initiatives to promote the use of " bike-and-ride, or the combined use of bicycle and public transport for one trip", has grown considerably over the past decade as part of the search for more sustainable transport solutions(Martens, 2007). In The Netherlands where natural conditions and infrastructure are conducive, the bicycle is a potentially attractive access mode for railways since it allows travellers to avoid waiting at bus, metro or tram stops. Especially at the home end the bicycle has been going to play a main role as an access mode with a share of 35%. At the activity end the share is much shorter (Rietveld, 2000).

2.6.3. Social economic aspects

Cycling considers benefits of individual health, but the situation is not always equitable across socio-demographic groups (Ogilvie & Goodman, 2012). Cervero and Kockelman (1997) used travel diary data for 50 San Francisco Bay Area neighborhoods and found that socio-demographics have a larger influence.

The relevant personal characters are age, income, and physical abilities. For children and youngsters non-motorized transport tends to be relatively important. If focus on the factor of age, most studies found age has a negative effect on cycling (Xing, Handy, & Buehler, 2008);(Moudon et al., 2005). Younger people tend to cycle more than older. For children, their main mode of transport is bicycles (Wang et al., 2009), and students prefer cycling as their convenient travel modes. Rietveld and Daniel (2004) also found that a higher proportion of young people (15-19 years) and the presence of a school for higher vocational training include a higher bicycling share.

Meanwhile, people with low incomes may not be able to afford a car so that non-motorized transport modes such as walking or cycling become their favorable preferences. The frequent bike users are mainly high school students and academic institutions. In the USA university towns, the score of bicycle trips share is relatively high comparing with other modes (Gordon & Richardson, 1998). In addition, physical conditions (gradients) play an important role. Dimitriou (1995) mentioned that bicycles are not convenient with slopes higher than 4 percent. Of course weather conditions (temperature, wind, rain, snow) are another group of determinants of modal choice. This holds true both at the strategic level and at the level of daily varying travel patterns (Khattak & De Palma, 1997).

On the other hand, if the quality of bus and train service in the city is relatively low, such concerns appear to be universal amongst low-income residents regardless of location(Srinivasan & Rogers, 2005). Studies show that people from deprived areas are under-represented among users (Ogilvie & Goodman, 2012).

In some developing countries, the poor depend heavily on non-motorized transportation like walking and cycling for their primary mode of travel (Srinivasan & Rogers, 2005). However, it may not be true in some developed countries such as The Netherlands or Denmark. In conclusion, in this research, income and age would be two indicator to observe whether it associate with climate value of bicycle or not.

3. RESEARCH DESIGN AND METHODOLOGY

The CVoC model provides the value of saved CO_2 if choosing bicycle as travel mode. However, this value only evaluates the amount of CO_2 emission caused by different transport modes. How to associate CVoC with urban planning domains and further explain CVoC value in planning aspect of view and support decision making is the main purpose of this research.

Based on the literature review in the previous chapter, this research is aiming to explain the Climate Value of Cycling through a list of explanatory valuables from different urban domains. The interpretation of CVoC from the view of urban and regional domains can be framed through a list of explanatory variables. This chapter discusses the design of this research and the related methodologies for supporting the whole study.

3.1. Research assumption

3.1.1. Scope of research

Based on literature review in this research, a list of explanatory variables (EV in short) under three urban and regional domains is chosen, i.e. urban form, infrastructure and socio-economic domains. These explanatory variables help to classify The Netherlands into homogenous groups which can represent the level of each EV. The Climate Value of Cycling will be calculated for each class. After analysing the output, it is investigated whether there are effects of each level of explanatory variables on CVoC scores or the differences between explanatory variables themselves or not. The results provide a way of communication the importance of CVoC and may lead to policy recommendations.

3.1.2. Geographic scale

The structures of communities, districts or the whole municipality area can be influenced by transportation systems under different scales. And each scale comes to different transport infrastructure. For instance, one of the most significant impacts of transportation on the urban structure has been the clustering of activities near areas of high accessibility (Rodrigue, 2013).

As a bicycle friendly country, the coverage of bicycle use is almost the whole the Netherlands. In this study, the spatial extent is the entire Netherlands. Due to the limitation of bicycle travel distance and together with the big extent of study area, the spatial unit of in this research should be feasible and reasonable. In The Netherlands, postal codes are alphanumeric, consisting of four digits followed by a space and two letters (NNNN AA). Large cities are often divided into postal zones or postal districts. So it can also be a method for geographic zoning. There are in total 4007 4-digit post code areas in the Netherlands, and the average area of them is 8.70 km^2, which can be a suitable spatial unit for bicycle study. Also, it is a proper unit to represent MON data (see section 3.2.1 data preparation).

This study counts the number of trips by considering the departure point, which means for each PC4 area, the number of trips only count those have the same departure postcodes. Since the sample size is limited in each PC4 area, the input data for calculating CVoC value is a group of PC4 areas that have the homogenous character of each explanatory variable. The further analysis would be carried out based on these groups of PC4s.

3.2. Research Methodology

3.2.1. Data description and preparation

Based on the scope of research, there are two main parts that require data. One is for processing explanatory variables, and the other part is for running the Climate of Cycling model.

The parameters that are required in the CVoC modeling can get from Dutch Mobility Survey – MON (Moboliteitsonderzoek Nederland(Transport, 2011)). The MON is conducted on behalf of the Ministry of Transport, Public Works and Water Management to obtain information on the mobility of the Dutch: how, where, why and when do they travel? Researchers and policymakers in the area of transport and traffic make use of this information. As is a continuous survey and represents the daily travel behavior of Dutch, it keeps track of travel data for a particular day of the year. Data are collected on the transport movement of individuals, such as the reason for the movement, the place of departure and the destination, the transport mode, and how long and how far trips take. In addition, social and economic information on personal and household characteristics are recorded, such as household composition and size, as well as age, sex and education of the travellers. The survey allows statements about all movements with the exception of vacations that begin or end in the Netherlands, and for all inhabitants of the Netherlands except people in care homes. It provides adequate information about the daily mobility of the Dutch population (DANS, 2009; Ministry of Transport, 2010).

On the other hand, in order to streamline explanatory variables for each urban and regional domain, some other sets of spatial data such as socio-economic statistics, land use data, road network and infrastructures are required.

In the socio-economic domain, data mainly come from Statistics Netherlands -- CBS (in Dutch: Centraal Bureau voor de Statistiek). The information Statistics Netherlands publishes incorporates a multitude of societal aspects, from macro-economic indicators such as economic growth and consumer prices, to the incomes of individual people and households, which is a rich data source for collecting socio-economic characters(CBS, 2010).

For processing explanatory variables under infrastructure domain, the online resource Open Street Map (OSM for short) is available. It is a freely available and freely editable map that collected and stored in an accessible database about 5 years worldwide information on streets, rivers, borders, and areas. In this research, the OSM information is transferred into ArcGIS shapefile that subsequently for editing and analyzing. Together with Open Street Map, there is another open data available named "TOP10 Netherlands" (TOP10NL). The information included in this data set is areas of buildings, iso height line, railway and roads lines and areas, road intersection points and so on. These two data source can support processing explanatory variables under infrastructure and urban form domains.

As motioned in section 3.1.2, all these explanatory variables at the end are aggregated or disaggregated into the same spatial unit – PC4. The 4-digit postcode boundaries layer is available from secondary resource.

3.2.2. Model description

The model of "Climate Value of Cycling" is adapted from the framework by R. Massink (2009).

According to the model concept, CVoC calculates total avoided emissions by summation of all additional CO_2 emissions by the alternative transport modes. A behavioural model which builds on existing theories of the multinomial logit behavioural model is designed to estimate the most likely alternative mode for each bicycle trip (Roel Massink et al., 2011).

The original equations in Roel Massink et al. (2011)'s study:

1) The probability of choosing the most likely alternative modes:

$$P\big(X_{b,s,p}(m) = x_{b,s,p}\big) = \left[\frac{N_{b,s,p}^{m}}{\sum_{m=1}^{m} N_{b,s,p}^{m}}\right] \qquad \forall b, s, p$$

Where:

b : Trip length bin

s : Socio-economic strata

p : Trip purpose

$N_{b,s,p}^{m}$: Number of trips of mode m in subclass

This step assumes that if the bicycle is no longer a mode choice, what would be the probability to choose the alternative modes. The substituted modes can be selected from a sample space $M_{b,s,p}$. The assumption in this step is that the probability ratios of choosing one mode over the other keep same if bicycle mode is absent from choice set (Roel Massink et al., 2011). This is the main idea of multinomial logit model (Luce & Suppes, 1965a). R. Massink (2009) in his research chose trip length, trip purpose and socio-economic strata as the factors that cause the difference of modes shift. In the same trip bin, people with same trip purpose and socio-economic background trend to choose the similar alternative modes.

2) The total travel distance of these substituted modes m

$$\Delta PKT_m = \sum_{p=1}^{p}[\sum_{s=1}^{s}[\sum_{b=1}^{b}(F_{DT}^{s} * N_{b,s,p}^{bicycle} * \left[\frac{N_{b,s,p}^{m}}{\sum_{m=1}^{m} N_{b,s,p}^{m}}\right] * \mu_{b,s,p}^{m})]] \quad \forall m$$

Where:

$\Delta \mathrm{PKT_m}$: Induced traffic of mode m in subclass

$\mathrm{F_{DT}^{s}}$: Discouraged traffic factor specified per socio-economic strata

$\mathrm{N_{b,s,p}^{bicycle}}$: Number of bicycle trips in subclass

$\mathrm{\mu_{b,s,p}^{m}}$: Average trip length in subclass

This step calculates the total personal kilometers travelled by the sum of all substituted modes which is shifted from bicycle. It means if the bicycle is not available, the distance originally should be covered by bicycle is now assign to the alternative travel modes.

3) The Climate Value of Cycling

$$CV_{cycling} = \sum_{m=1}^{m} \Delta PKT_m \times EF_m$$

Where:

$\mathrm{CV_{cycling}}$: Climate value of cycling (kg CO_2)

EFm : Emission factor for mode *m* in kg CO_2/km

The last step is CVoC calculation. The distance that caused by substituted modes multiply the emission factor returns to the climate value of cycling.

3.2.2.1. Model parameters

Based on the concept of Climate Value of Cycling model, it assumes that trip makers with similar background information make similar mode choice. The MON data provides information for each trip in the database on gender, vehicle ownerships, number of bicycle owned and purpose of trips. During R. Massink (2009)'s research, he finally chose three parameters among many, they are socio-economic status, personal trip length and purpose. In order to have enough sample size for CVoC score, this research uses a stacked MON data set for calculation: from MON 2007 to 2009. And the information that used for calculating probability of alternative mode was readily available from mobility survey which formed the input database for this research. What the alternative travel modes to choose would depend on trip makers' socio-economic background and travel purpose that in the same trip bin.

In addition, due to the wide distribution of trip length, not all the trips would be selected for this study. Based on the cumulative trip length frequency distribution graph (see Figure 5), it can be seen that more than 90% of all trips made are less than 30 km. Since only less than 10% of trips are longer than 30 km, the trips distance longer than that are discarded. The 30 km is defined as "max bin". Subsequently within the max bin, the "bin size" is tested for 1 km, 2 km and 5 km. smaller bin size shows more details but requires more data while bigger size needs less data but cannot present the enough details. After comparing several tests, this research decided to choose 2 km as bin size.

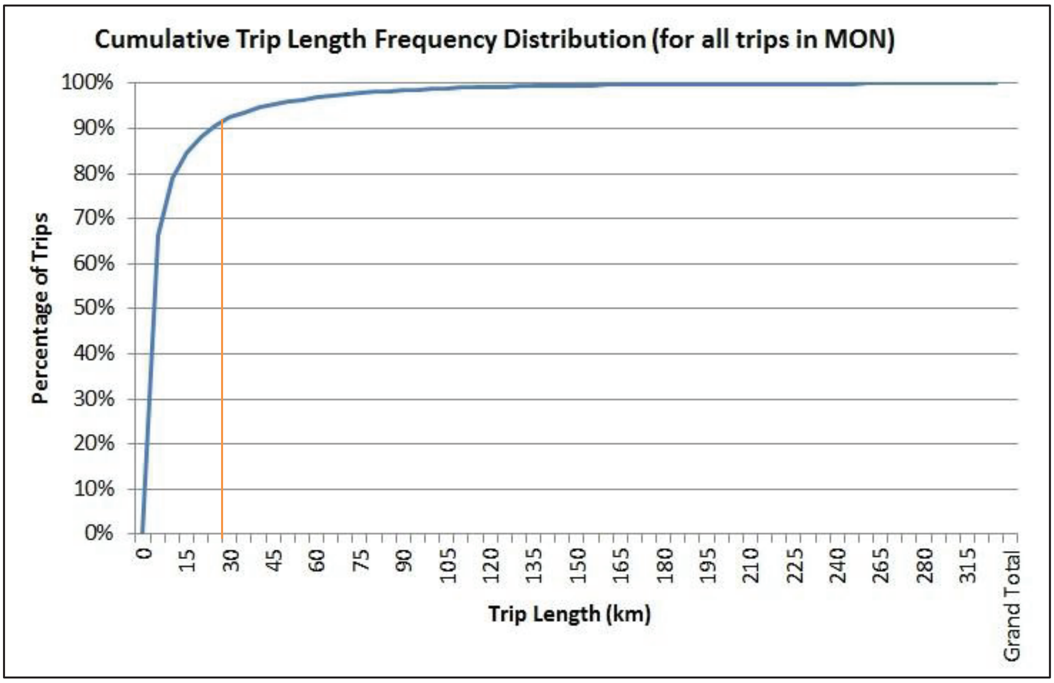


Figure 5 Trip Length Distribution for all trips in stacked MON

In addition, in order to streamline model parameters the travel modes are aggregated and conversed into an adapted form that can fit the model environment. There are in total 26 travel modes in the MON data. Within the trip length bin, not all of them are necessary to be considered and used to substitute bicycle trips. For instance, the Euclidian length of trips is much more than 30 km and also trips by boats cannot be replaced by other modes. So in this research, they are classified into 9 trip modes in total (see Table 3).

Code	Modes	Modes in MON (English)	Modes in MON (Dutch)
1	Walking	Walking; Pram	Te voet; Kinderwagen
2	Cycling	Cycling; Bicycle passenger; Motorcycle	Fiets; Fiets als passagier; Snorfiets; bromfiets
3	2W/3W	Motor/Scooter	Motor/Scooter
4	Car	Car driver; Car passenger	Bestuurder auto; Passagier auto
5	Taxi	Taxi	Taxi
6	Bus	Bus; Touring car; Private bus	Bus; Touring car; Besloten busvervoer
7	LRT	Metro	Tram/Metro
8	MRT	Train	Trein
9	Other	Tractor; Van; Truck; Boat; Skates; Airplane	Tractor, Bestelauto; Vrachtauto; Boot; Vliegtuig; Skeelers; Gehandicapten vervoermiddel

Table 3 Original modes in MON and conversion in CVoC model

As the purpose of CVoC model is to calculate the save CO_2 emission if using bicycle, for each travel mode, the CO_2 emission is calculated by multiplying the emission factor (see Table 4).

Code	Modes	Emission factor
1	Walking	0
2	Cycling	0
3	2W/3W	0.052
4	Car	0.153
5	Taxi	0.306
6	Bus	0.029
7	LRT	0.020
8	MRT	0.020
9	Other	0.044

Table 4 CO_2 emission factors per mode in kilogram (Boer et al., 2008).

3.2.2.2. Model input data

There are two main input data sets for the CVoC modelling.

One is National Mobility Survey- MON data. It provides the parameters' information of each trip. In order to avoid the problems that some PC4 areas do not have any MON records, the number of observations should big enough to cover all PC4 areas. In this research, a stacked MON is applied. The bar chart below shows the number of modes' records distributed by months from the latest three years of MON data (from MON 2007 to MON 2009).

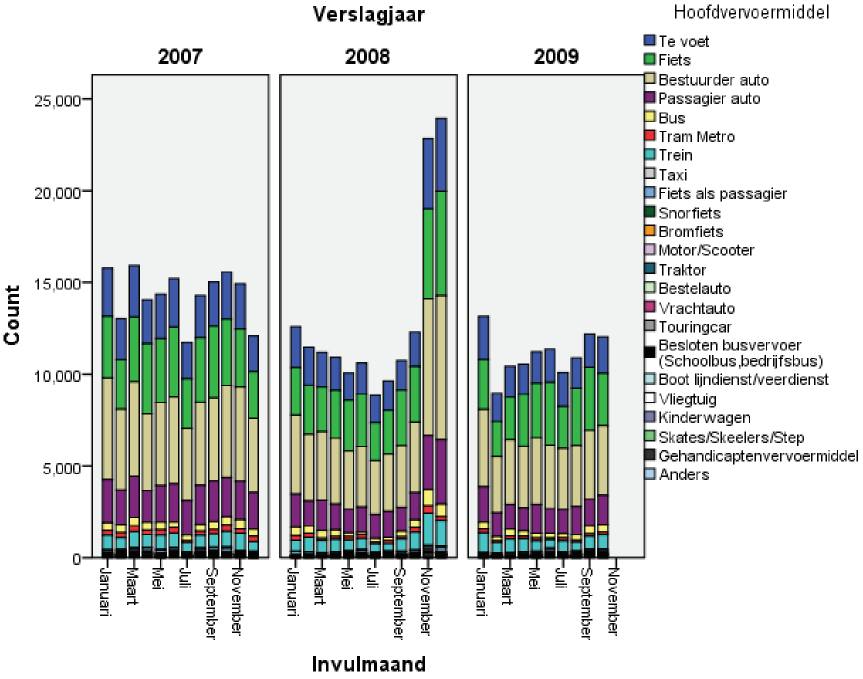


Figure 6 Stacked MON records distribution (Transport, 2011)

There are in total 437,968 records in stacked MON data. Each observation has the records of departure PC4 code and arrival PC4 code. In this research, the number of trips for each PC4 area only counts the trips that start from this PC4. Due to the records are not even distributed among all PC4 areas, also the amount of observations for single year may not big enough to represent the real trip behaviours, each trip will multiply the trip expansion rate. This expansion factors are weighted by considering the following aspects: urbanization, province, age group, household size, sex, fuel, life time of car, and the owner of the car (Transport, 2011). However, if the number of observations of people and trips are limited, the expansion rate will be large so the CVoC calculation may have low accuracy. In this case, the MON datasets of the latest three years (2007 to 2009) are stacked together to render more observations.

The other main input data is PC4 array. It is a matrix that transfers spatial classification into statistical matrix. Each row represents different classes of the explanatory variables, while the columns are the PC4 codes that belong to that class. In order to make the matrix 'squared', 'zero' values are added in each row except for the longest row.

3.2.2.3. Model output

Based on the mentioned model parameters, and together with two main input data sets, the CVoC model in total calculates 6 values for each mode under each indicator as output.

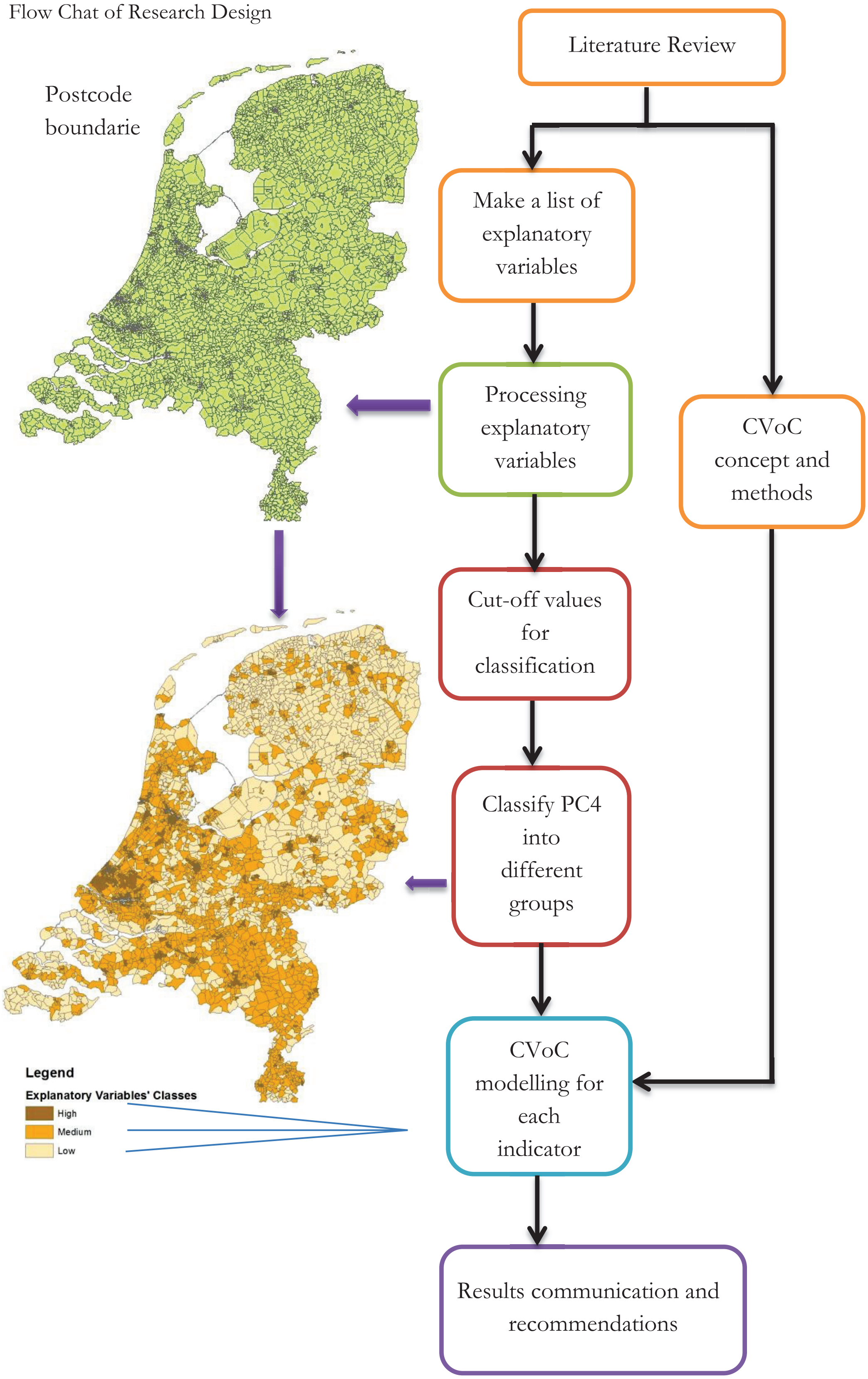
Output values	Explanations
Present Traffic Performances (Trips)	Number of trips made of each mode
Present Traffic Performances (PKT)	Personal kilometres travelled of each mode
Total Present CO_2 Emissions (tCO_2/year)	Tons of CO_2 emission per year
Climate Value of Cycling (Trips)	CVoC in number of substitute trips
Climate Value of Cycling (PKT)	CVoC in personal kilometres travelled
Climate Value of Cycling (tCO_2/year)	CVoC of CO_2 emission per year

Table 5 Output values of CVoC model

As shown in table above, the first three values return number of trips, personal kilometres travelled and CO2 emission for all the modes of trips. And the rest three return the values that if taking the bicycle mode out of choice set, what other travel modes' amount, PKT increase and how much CO_2 save which is the climate value of cycling.

3.2.3. Research design

Figure 7 Flow Chat of Research Design



From the chart we can see that the methodology includes five main steps (different colour of text outline). These steps will be further discussed below:

3.2.3.1. Concept development

The first step of this research is about concept development, which mainly based on literature review. It contains two main parts which are describing the concept of Climate Value of Cycling and forming a short-list of explanatory variables under the main urban and regional domains that can be supposed to well explain CVoC.

Table 6 shows the list of explanatory variables that is applied in this research.

In order to carry out further analysis, together with consulting experts, the cut-off values that used for classifying (group PC4 areas into different classes. i.e. High, medium and low) will also be considered.

3.2.3.2. Processing explanatory variables

The second step concerns the data collection and preparation. Processing explanatory variables needs a set of spatial and non-spatial data (mainly collected from secondary sources) which includes data from the transport sector, land use sector and social economic data (described in section 3.2.1 data description).

In order to develop explanatory variables in form of spatial layers collected and prepared data in previous steps would be used and different spatial analysis tools and methods such as overlaying, spatial join, etc. would be applied. The list of explanatory variables and their definition and general spatial analyses are listed in the following table:

URD	Explanatory Variables (Indicators)	Operationalisation
Social Economic	Percentage of Young	young age population/ total population
	Average Income Level	average annual income in 1000
Urban Form	Population Density	population/ area
	Percentage of Built-Up	built-up area/ total area
Infrastructure	Percentage of Bicycle Path	total length of bicycle lanes/ total length of roads
	Number of Public Bus Stops	sum the amount of bus stops per area
	Distance to The Nearest Train Station	distance from PC4 centriod point to the nearest train station

Table 6 The list of explanatory variables and their operationalization.

As discussed in 3.1.2 on geographic scale, the spatial extend for this study is the whole Netherlands and the spatial unit is 4-digit postcode boundary. So all the explanatory variables are aggregated or disaggregated into PC4 level.

3.2.3.3. PC4 areas classification

Due to the wide range of explanatory variables' values and for the purpose of simplify the level of EV; the third step is classifying all PC4 areas into homogeneous groups under different explanatory variables. Cut-off values from literature review are applied in this step.

Due to the limitation of data such as missing values or not enough records, some statistical methods are applied for choosing cut-off values apart from literature review. The following paragraphs describe the classification method that is based on statistical analysis:

From the available data (CBS), age is grouped into 5 groups, they are: 0-14; 15-24; 25-44; 45-64 and >65. Consider the people below 14 may be infants or too young to use bicycle, the group that consider as young age is people between 15 and 24 years old. The way to process percentage of young is sum total population that in 15-24 age range and then divided into total residents per PC4 area.

As shown in the histogram, the average percentage of young age in the Netherlands is about 11.45%. Based on the standard deviation, this explanatory variable is classified into 3 classes. Percentage below 8 is considered as low percentage while above 14 is high. So these two values were selected as cut-off. Almost 80% PC4 areas have the percentages of young age people between 8% and 14%.

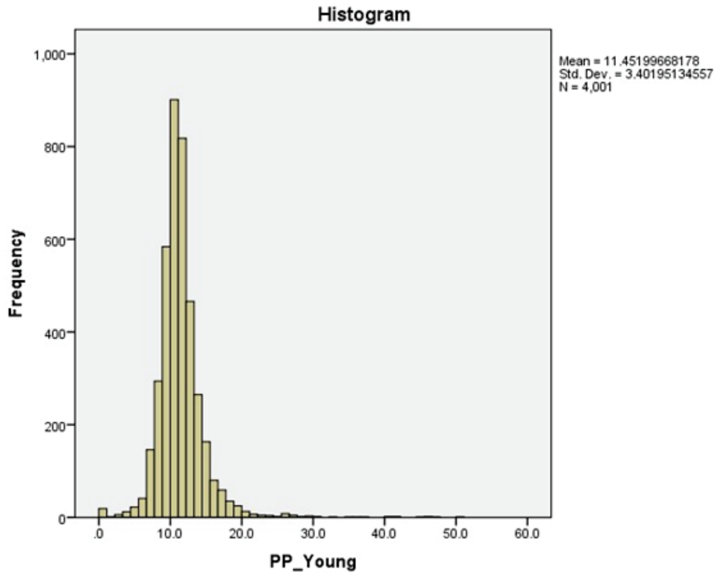


Figure 8 Histogram of the explanatory variable: percentage of young

The same method is applied for the explanatory variable: average income level. In order to consider all residents, the value selected in CBS data is the average net income divide by 1000 euro rounded off to 100 euro per person, which means the group of people that do not have income are also considered. And the average income value is later aggregated into PC4 areas.

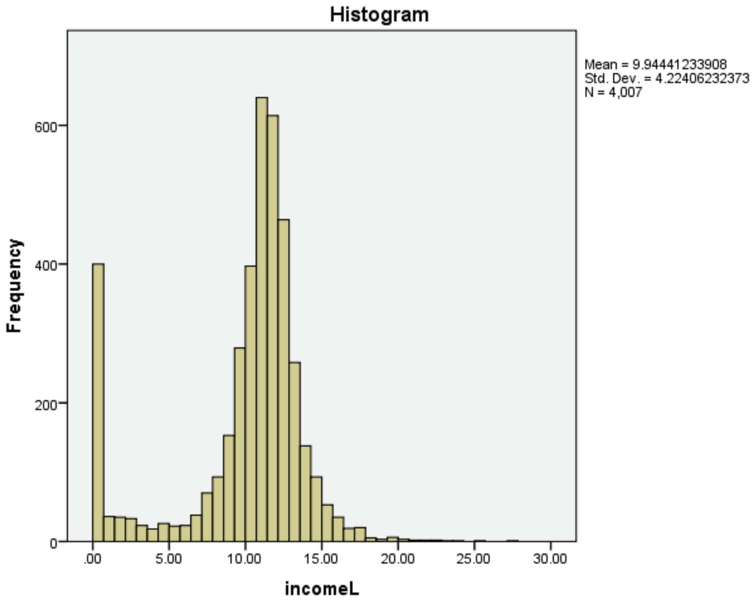


Figure 9 Histogram of the explanatory variable: average income level

For the explanatory variable in urban form domain: population density, the data was extracted from CBS data 2007. According to the World Bank Report (2007), population density in The Netherlands in 2007 was 485.27 (person per km^2). This value helps to classify population density into two groups: more than average and lower than average. But this way breaks the middle group. Based on the range of population density and its standard deviation, the cut-off values applied in population density round 30% upper and down from the average (see in Table 7).

The way to indicate bus stops was firstly sum the total number of bus stops inside each PC4 area and then divided into areas (km^2). This variable has a wide range (from 0 to 55.85) between high bus stops dense areas and low dense areas. This study firstly determined whether there is a bus stop per area or not. If the ratio is less than 1, it means for each square kilometre, there is no bus stop, while if more than 1, there is at least one bus stop per area. Then define how many bus stops per area are considered as "high" amount. Since the average PC4 area is 79.09 km^2, the upper threshold is 7 bus stops per area, which also fit the maximum of the standard deviation.

The operation of processing percentage of built-up area is sum the footprint of buildings and then divided into PC4 area. However, it is difficult to define whether the density is high or low due to lack of data about floors of the building. Based on the mean and standard deviation, the percentage that higher than 15 is considered as high dense.

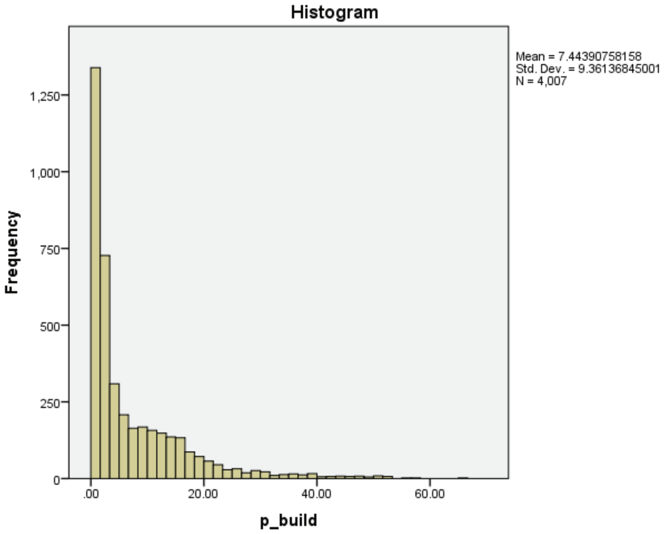


Figure 10 Histogram of the explanatory variable: percentage built-up areas

The last explanatory variable is the distance to the nearest train station. It measured the distance between centroid point of PC4 area and the nearest train station. The average area of all PC4 is approximately 80 km2, suppose the PC4 area is a circle, if there is a train station in this PC4 area, the farthest distance from the centroid point to it is equal to the radius which is around 5000 meter. If the distance is longer than 5000 meter, we suppose inside this PC4 area, there is no train station.

The following table shows the final cut-off values of each explanatory variable:

Code	Explanatory Variables	Low	Medium	High
1	Percentage of Young	(0, 8]	(8, 14]	>14
2	Average Income Level	(0, 9.28]	(9.28, 12.86]	>12.86
3	Population Density	(0, 189.61]	(189.61, 1276.58]	>1276.58
4	Percentage of Built-Up	(0, 2]	(2, 15]	>15
5	Number of Bus Stops per area	(0, 1)	[1, 7]	>7
6	Percentage of Bicycle Path	(0, 5]	(5, 22]	>22
7	Distance to The Nearest Train Station	(0, 1000]	(1000, 5000]	>5000

Table 7 The cut-off values for classifying each explanatory variables

3.2.3.4. CVoC modelling

The fourth step is the actual CVoC modelling. The software MATLAB 2009 is applied to run the large amount of data.

When the classifications are ready, export all the postcodes for each class (indicators). These PC4 codes are the input matrix of CVoC model: PC4 codes in column and each row represent one class. In order to make the matrix 'squared', 'zero' values are added in each row except for the longest row. In total, 7 explanatory variables multiply 3 classes for each return to 21 rows, and the biggest class contains 3187 PC4 codes. This 21*3187 matrix (PC4 array) is the input for CVoC modelling.

In addition, stacked MON data from 2007 to 2009 provides the model parameter includes trip length, trip purpose and social-economic profile of the trip maker. The final output calculates the average of these three years.

3.2.3.5. Result communication

The fifth step concerns analysing the results and communication. In this step, some statistical analysis tools such as SPSS and Excel will be applied for visualize the results in form of tables, charts and graphs. And further, present conclusion and recommendations.

4. DATA ANALYSIS AND RESULTS COMMUNICATION

4.1. Processing explanatory variables

Based on literature review, seven explanatory variables were selected under three urban and regional domains. These explanatory variables were supposed to have correlation with travel modal share and shift. The following maps show each explanatory variable in the spatial scale of PC4.

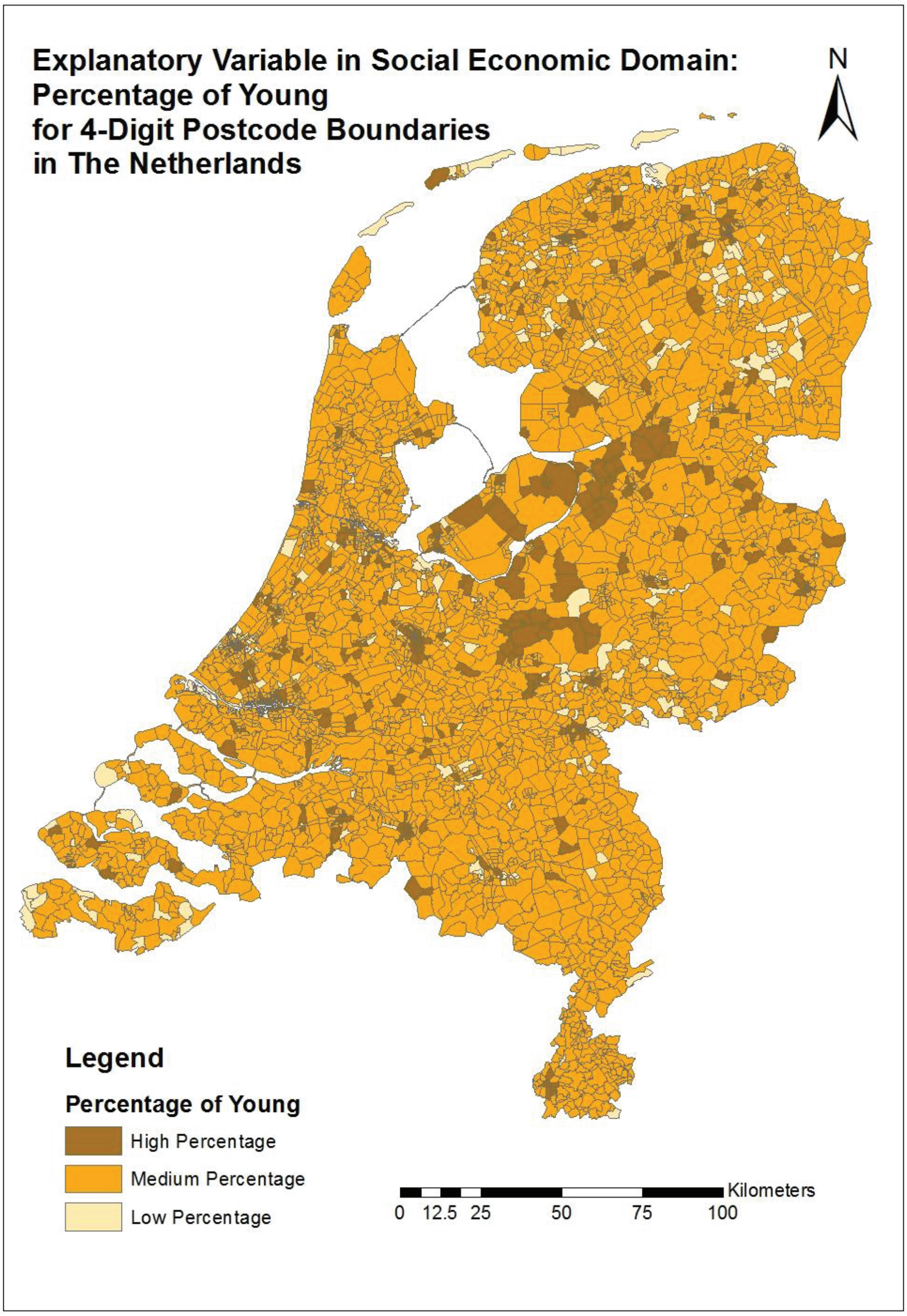


Figure 11 Explanatory Variables in Social Economic domain: Percentage of Young

The first map Figure 11 presents the explanatory variables in the social economic domain. From the map we can see that people in younger age are not so gathered to city centre. But with the PC4 areas that have educational institutions around, there are more distributions of young age people. The centre of The Netherlands gathers more young age people. However, the range of percentage is not so wide.

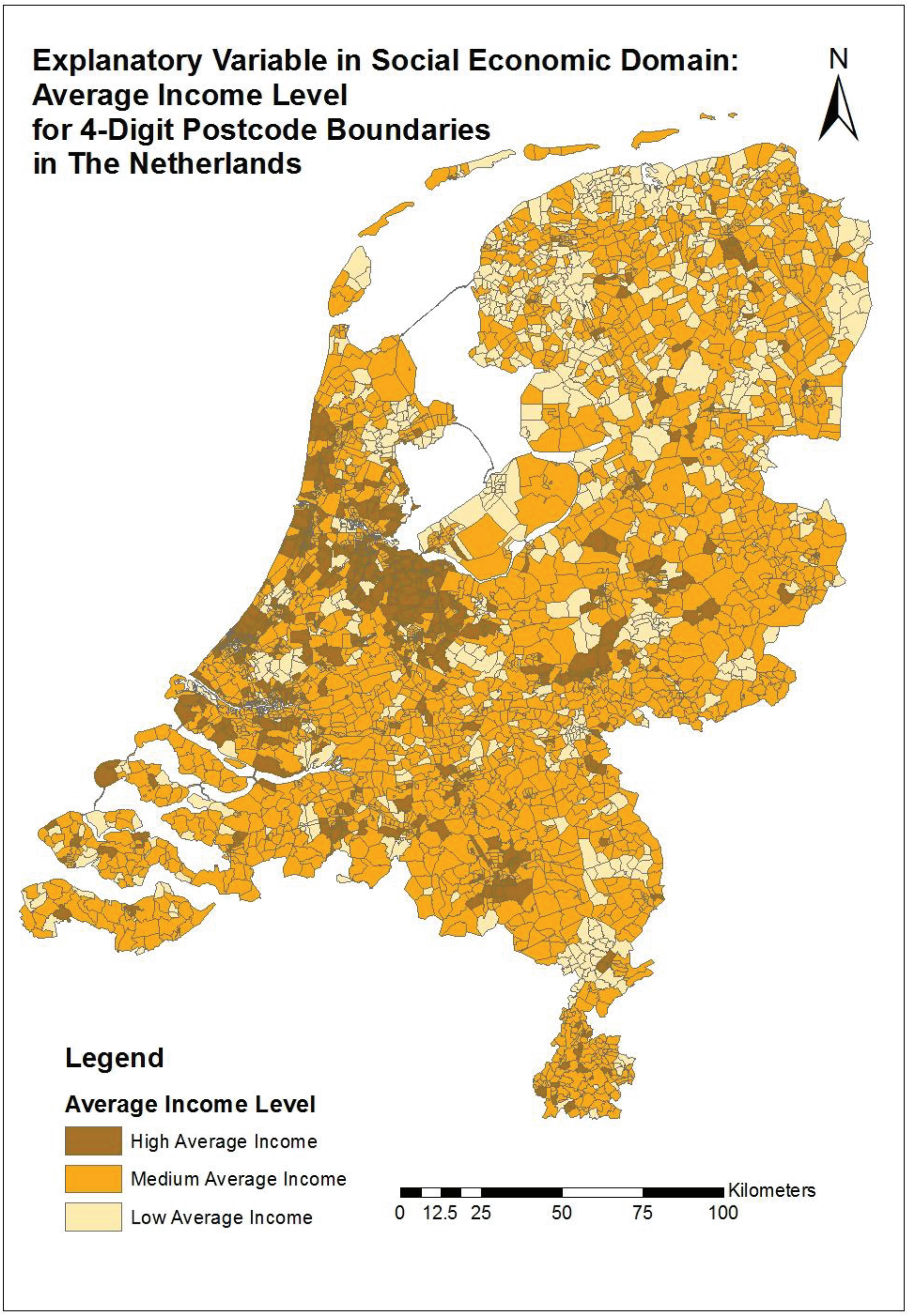


Figure 12 Explanatory Variables in Social Economic domain: Average Income Level

For the explanatory variable average income level which is in the unit of 1000 euro annually, the map shows that people live in south are relatively richer than those in north. And richer people are more gathered in the PC4 areas that located near city centre especially west part of The Netherlands.

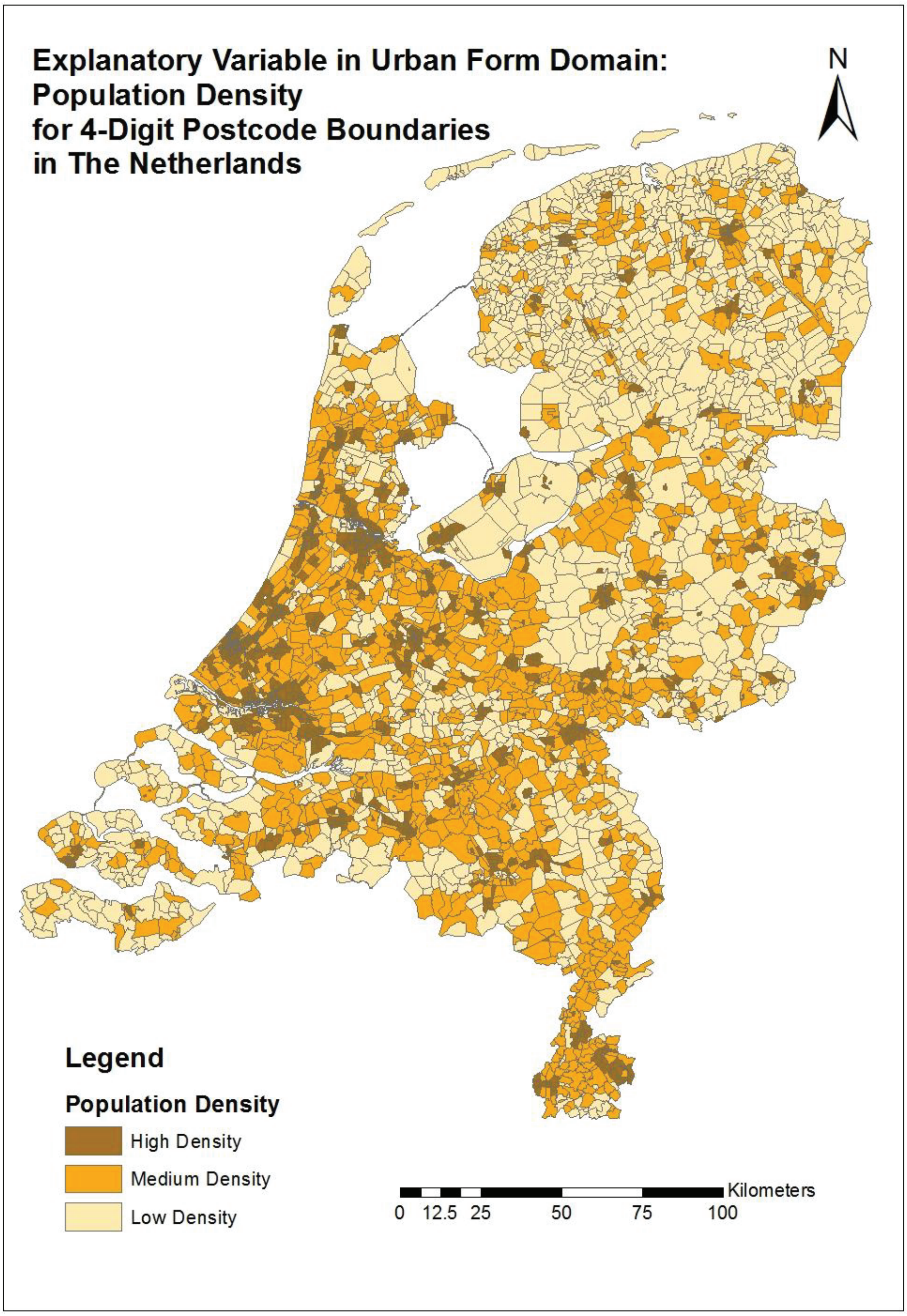


Figure 13 Explanatory Variables in Urban Form domain: Population Density

In the urban form domain, the spatial distribution of population density shows that PC4 areas in southwest of Netherlands are generally more dense than those in northeast. The range of value is high, from 0 to approximately 25000 per square kilometre. The densest places are located in Amsterdam, Rotterdam and Utrecht. Reports shows that over the past 49 years, population density in Netherlands reached a maximum value of 492.62 in 2010 and a minimum value of 344.75 in 1961 (CBS, 2010). The average population density in this map is 463.11. The data comes from secondary resource CBS in 2007.

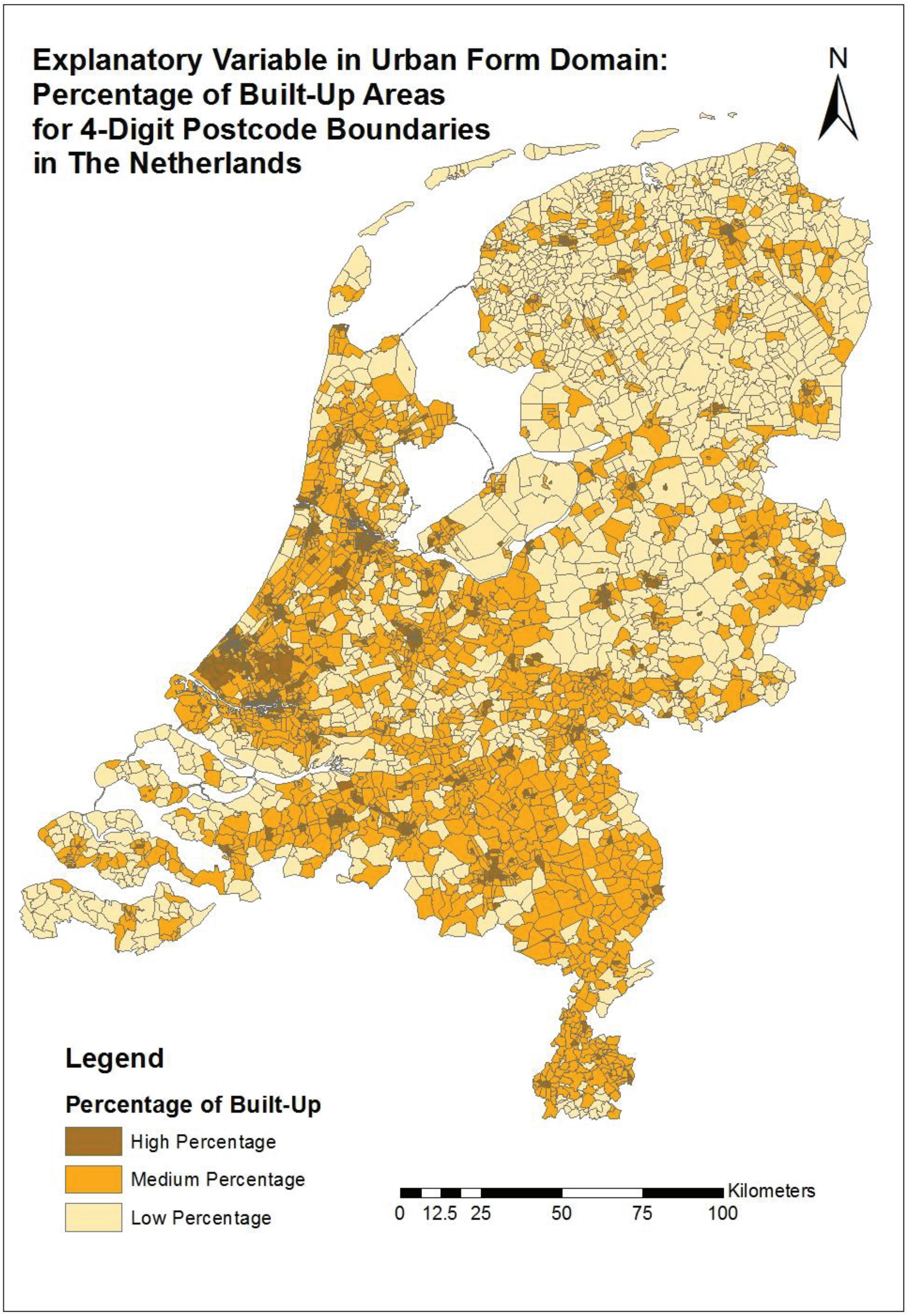


Figure 14 Explanatory Variables in Urban Form domain: Percentage of Built-Up

The distribution of built-up density is similar to population density. There are only some differences in southeast part of Netherlands. However, the range of percentage is not as wide as population density. The lower build-up density areas locate in north Netherlands, together with some parts in southwest.

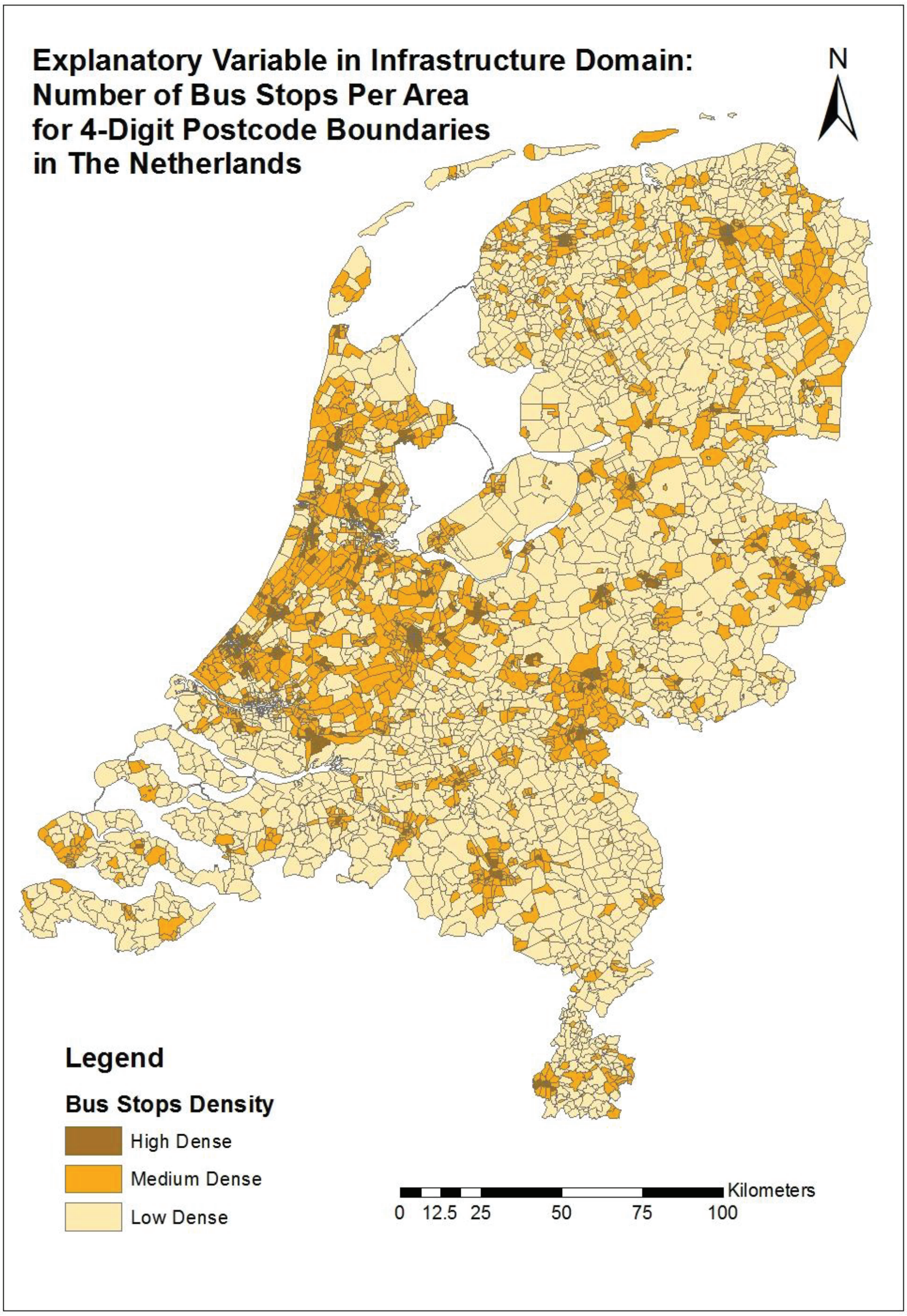


Figure 15 Explanatory Variables in Infrastructure domain: Number of Bus Stops per Area

For the infrastructure domain, there are three explanatory variables that related to bus tops, train stations and bicycle path. The first map in this domain detects the average amount of bus stops per area. It shows that the PC4 areas that closer to city centre with more urbanized development have more bus stops and vice versa. High availability suggests the area around Amsterdam, Rotterdam, Utrecht and Nijmegen.

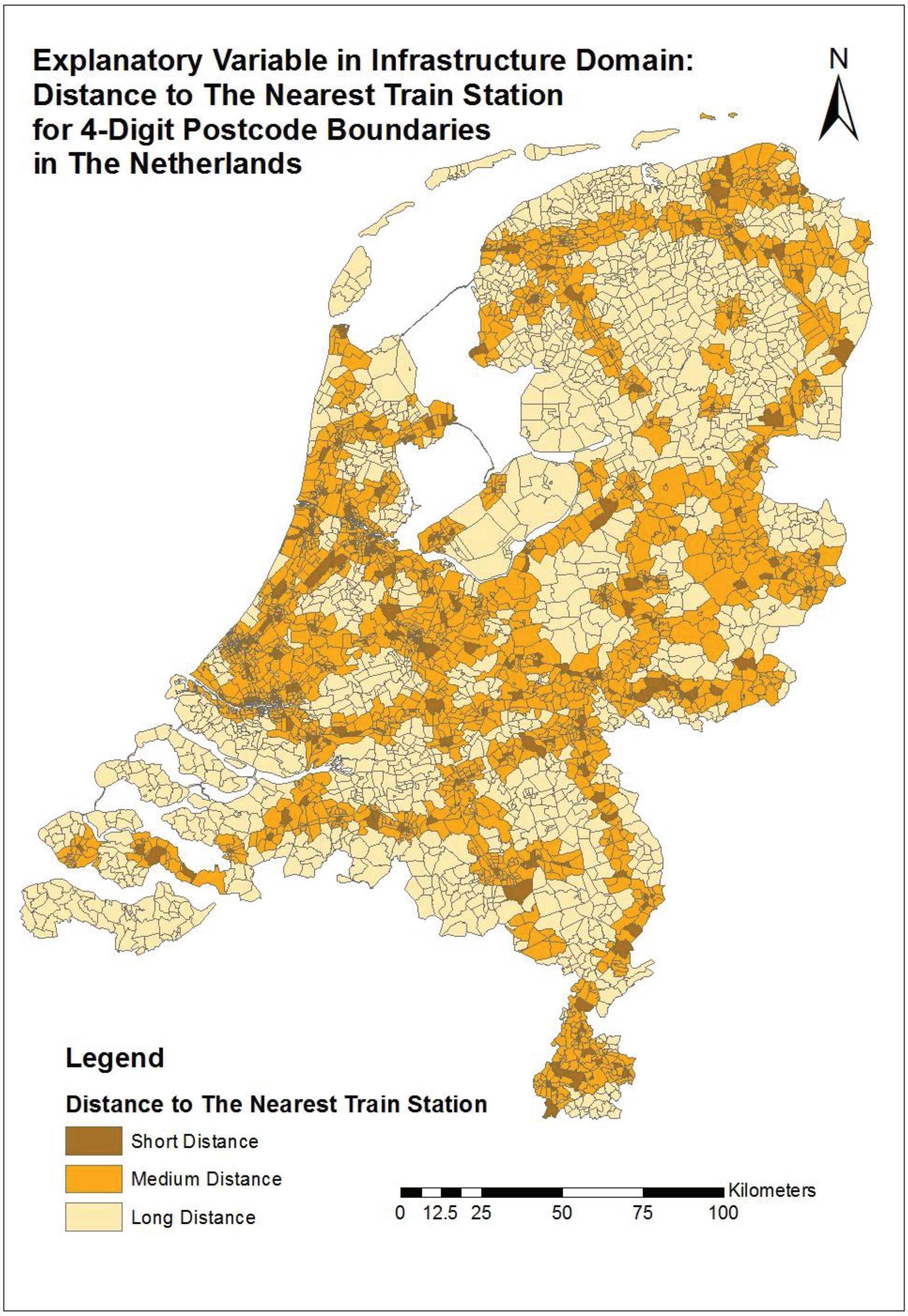


Figure 16 Explanatory Variables in Infrastructure domain: Distance to The Nearest Train Station

Different from the bus stops, the accessibility to train stations mainly depends on the rail locations. The Netherlands has a rail network approximately 2,800 kilometres in length with around 400 train stations. Most of them gather in centre part of Netherlands. Although the stations have high frequency allocation, in average, almost each 7 km has one station, the accessibility to reach it returns 5 km for all PC4s in average.

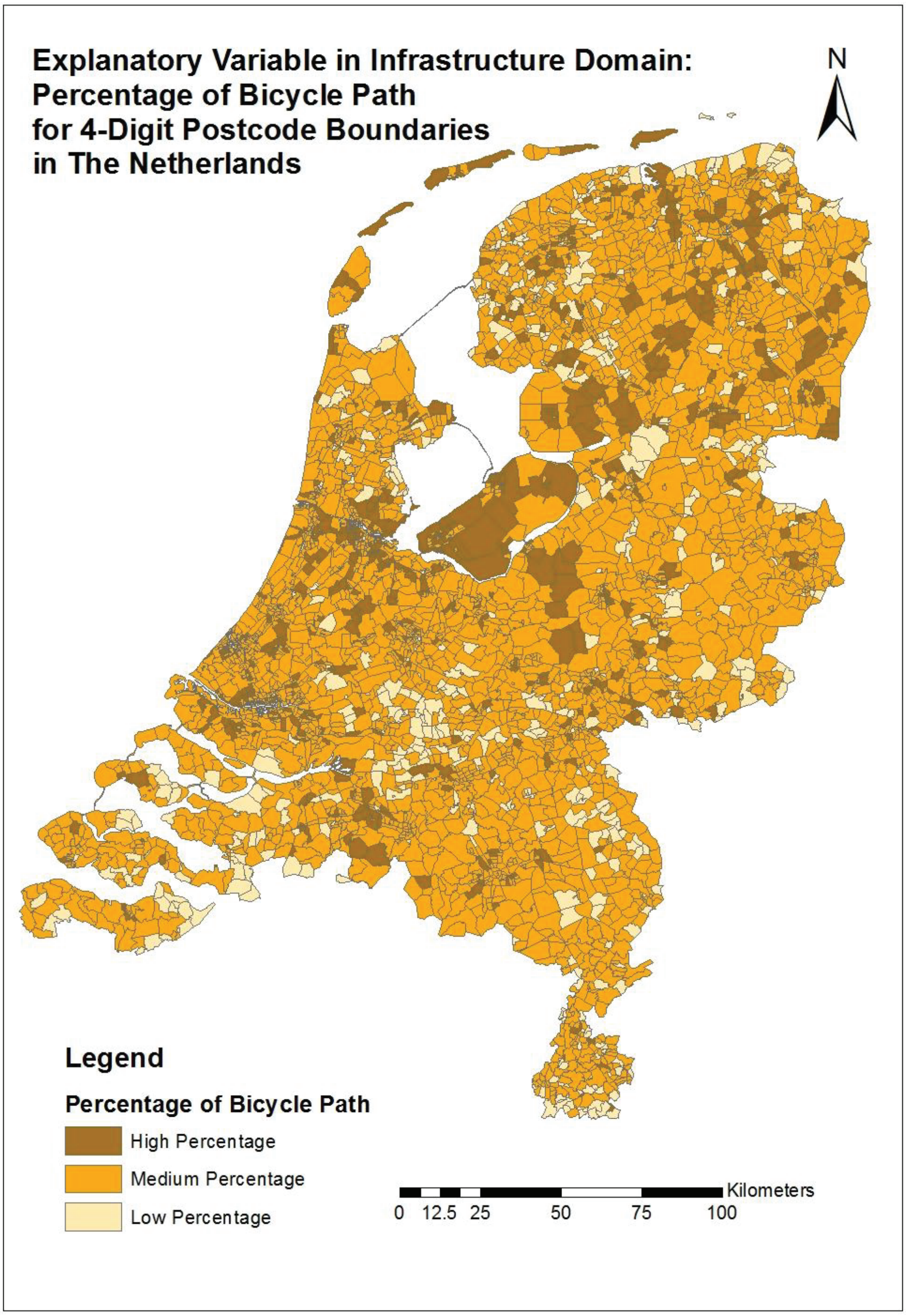


Figure 17 Explanatory Variables in Infrastructure domain: Percentage of Bicycle Path

The density of bicycle path is also related to urban design. The PC4 areas that have higher percentage of bicycle path, they are closer to city centre. But it is not as concentrate as bus stops or train stations dense areas. Since the Netherlands has a bicycle friendly environment, the range of value is not so wide, which means the difference between high percentage class and low is not so big.

4.2. CVoC modelling output

The CVoC modelling is executed in MATLAB. The model successfully calculated 437,968 trip records in stacked MON 07-09 that distributed in 3 homogenous classes of each explanatory variable. The output values are the average of these three years.

In CVoC modelling, the original travel modes are reclassified into 9 modes (see Table 3). The emission factors (see Table 4) from the CE-DELFT report (Boer et al., 2008) is applied for calculating CO_2 emission in each travel mode. The number of trips from each PC4 area is summarized by counting the trips that departure point belongs to that PC4 area. The total number of trip performance is extended by multiplying expansion rate. The trip bin size is set as 2 km, and the upper threshold of trip distance is 30 km. In order to compare the CVoC value in different level, the following indicators are calculated for each class of explanatory variables.

1) Total CVoC: Total induced emissions of carbon dioxide for the classes of EV based on all substituted cycling trips.
2) CVoC per Capita: Total CVoC divided by the total population of EV classes.
3) CVoC per Area: Total CVoC divided by the total PC4 areas of EV classes.
4) CVoC per Bicycle PKT: Total CVoC divided by the total bicycle kilometres travelled, which represents the amount of CO_2 saved by each unit of bicycle trip length.
5) National Standard: Total CVoC in The Netherlands divided the total population, total land areass and total bicycle kilometre travelled per year.

Table 8 CVoC in terms of area, capita and bicycle trips.below lists the value calculated for each class of every explanatory variable.

Explanatory Variables	Classes	Total CVoC per year [tons]	Total Area (km2)	Total Population	CVoC per Area per Year [tons/km2]	CVoC per Person [kg_year]	CO2 Each Bicycle PKT Save [kg year]
Percentage of Young	High	263097.40	3017.94	2588435	87.178	101.643	36.198
	Medium	1267087.57	29900.57	13076347	42.377	96.899	41.611
	Low	59846.23	1937.99	477446	30.881	125.347	41.572
Income Level	High	400860.38	3601.95	3440158	111.290	116.524	38.571
	Medium	1028688.33	23211.38	11135457	44.318	92.380	41.328
	Low	161039.40	8043.18	1566613	20.022	102.795	41.559
Population Density	High	840754.43	2664.73	8937174	315.513	94.074	38.678
	Medium	563650.95	12700.06	5542075	44.382	101.704	42.759
	Low	189685.84	19491.72	1662979	9.732	114.064	44.741
Percentage of Built-Up	High	479747.23	1178.96	4300892	406.923	111.546	37.622
	Medium	926917.96	14048.80	9794494	65.978	94.637	41.761
	Low	185416.83	19628.74	2046842	9.446	90.587	44.028
Number of Bus Stops per Area	High	340998.71	677.25	3072855	503.504	110.971	38.190
	Medium	773659.35	8563.38	7739153	90.345	99.967	40.945
	Low	476035.70	25615.87	5330220	18.584	89.309	41.998
Distance to Nearest Train Station	High	373254.49	19571.05	3986085	19.072	93.639	43.145
	Medium	921011.63	13741.94	9563206	67.022	96.308	40.843
	Low	298563.45	1543.52	2592937	193.431	115.145	37.518
Percentage of Bicycle Path	High	197747.63	4714.19	2267515	41.947	87.209	39.137
	Medium	1279215.50	25856.55	12652297	49.474	101.105	40.893
	Low	114497.94	4285.77	1222416	26.716	93.665	40.543

Table 8 CVoC in terms of area, capita and bicycle trips.

4.2.1. Compare between classes

From the column total CVoC per year, the difference between classes of each explanatory variable is clearly large. However, these can be different due to the extension of land area, population or number of trips.

For socio-economic domain, since the explanatory variables are related to personal background information, the CVoC unit that fit to observe whether there are correlations or not is by capita. This way quantifies the CVoC each individual creates.

Based on Table 8, the class with younger age people cause less CO_2 emission. The difference of capita CVoC between high percentage of young class and low percentage is 23.703 kg each year. There is a study calculated that 1 tree absorbs 24 kg CO_2 per year and the average lifetime of a tree is 40 years (Energyrace, 2008). One person in younger age each year saves CO_2 emission equal to the amount that one tree absorbs.

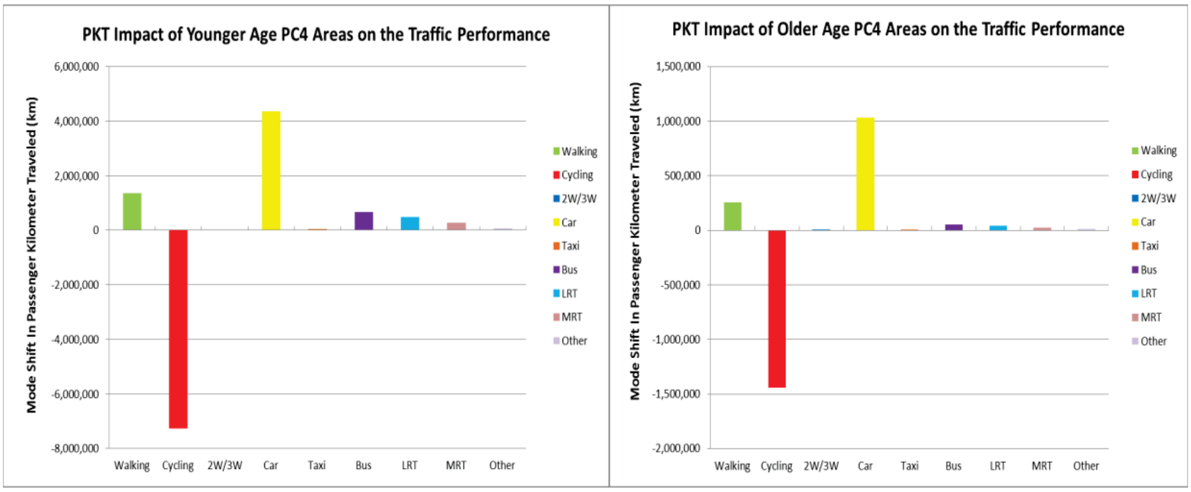


Figure 18 PKT impact of percentage of young on the traffic performance.

Figure 18 shows that originally, the bicycle trips distance in younger age group is 4 times higher than older age group. When bicycle is out of choice set, both young age and old age often choose car as their alternatives, but except car, young people tend to choose bus also some other public transport like metro or tram while older people prefer to use private vehicles such as car. It can be the reason that public transport is relatively costless. Students or the younger staffs that newly employed may not afford private car.

And for the explanatory variable: average income level, the difference between high and low is smaller, reaching 13.73 kg CO_2 per person, even the higher the income, the more personal CO_2 emission they cause. But the difference is not so obvious. In Figure 12, map shows that PC4 areas with high average income level located southwest of Netherlands and mainly near city centres. From Table 9, the relative bigger difference happened in the mode that shifts to walking. Since this study only considers the trips that the distance is less than 30 km and set 2 km as interval. Higher income people that live closer to city centre can have more accessibility to their destinations. So they trend to choose walking as their alternatives. Together with the map about allocations of bus stops density. The places near city centres have higher density of bus stops, which means there is more variety of modes choice such as bus or train. On the other hand, people with lower income live far from city centre, if bicycle is out of choice set, they should choose car or other public facilities instead.

EV class	walking	2w/3w	car	taxi	bus	LRT	MRT	Other
High	19.43%	0.32%	65.38%	0.64%	5.22%	5.16%	3.02%	0.83%
Low	16.70%	0.39%	71.45%	0.46%	4.35%	2.95%	2.28%	1.41%

Table 9 Percentage of PKT increase in each mode shift for high and low classes of average income level

An interesting thing happened on EVs in urban form domain. The way to observe the difference between urban form EV classes is comparing CVoC value on a land unit that can indicate the intensity of each square kilometre. There are big differences happened on both population density and building density: the higher the density, the more CVoC in unit of area. On one hand, it can be the reason that before mode shift, there are more trips happen. On the other hand, due to these areas mainly located around city centre which is more compact (see EV maps in Figure 13 and Figure 14) the alternatives in more compact areas can be more diverse. Chen (2012) used urban density hypothesis “the higher the density, the lower the unit CVoC”. The unit CVoC means total CVoC divided by the total cycling trips distance. In the last column in Table 8, the CVoC in each bicycle PKT in higher density class is around 7 kg lower than that in low classes, which is fit both population density and built-up density. But these different is not so strong.

The explanatory variables in infrastructure domain mainly consider trip makers' choice of mode.
Before modal shift, trip makers' decision which mode they will choose for travel is correlated with the infrastructure facilities availability.

Explanatory Variables	Classes	Total number of trips per day	Number of bicycle trips per day	Number of bus trips per day	Number of train trips per day	Percentage of bicycle trips	Percentage of train trips	Percentage of bus trips
Number of bus stops	High	29071	7900	1572	1043	27.17%	3.59%	5.41%
	Medium	63241	16484	1411	1295	26.07%	2.05%	2.23%
	Low	39128	9635	148	552	24.63%	1.41%	0.38%
Distance to train station	High	29650	7739	488	153	26.10%	0.52%	1.65%
	Medium	74107	19268	1732	1528	26.00%	2.06%	2.34%
	Low	27682	7013	859	1208	25.33%	4.36%	3.10%
Percentage of bicycle path	High	17682	4711	535	437	26.64%	2.47%	3.03%
	Medium	103963	24523	2337	2264	23.59%	2.18%	2.25%
	Low	9793	2018	207	188	20.61%	1.92%	2.12%

Table 10 Trip distribution of explanatory variables in infrastructure domain

Based on the highlighted part in Table 10, if there are more bus stops available, there would be more trips made by bus. The same situation happened in the PC4 areas that are closer to train stations: if the distance is lower, the probability to choose it becomes higher.
However, if taking bicycle out, the modes shift is not highly correlated with the facilities nearby. Even there are more bus stops or shorter distance to train station, the preference of trip makers' modes choice seems not dominated by the facilities available.
Choosing the number of bus stops per area as an example, it is assumed that there would be more trips shift to bus if there are more bus stops available. The bar chart in Figure 19 shows that in the PC4 areas that have more bus stops, there are more modes that shift to bus, but this trend is not so strong. Similarly, if the distance to train station becomes shorter, there would be more modes that shift to train.
However, even there is a trend that more modes shift to bus or train if they are more accessible, the percentage of the mode shifts difference remains low, only around 5% and 4% respectively. The difference between high class and low class is so small.
Detecting the percentage of bicycle path, there is also a slight difference of mode shift between the high percentage of bicycle path class and low percentage class. The distribution of modes share is similar, but the CVoC value per area (with more bicycle path) is higher than low class because before modes shift, there are more bicycle trips made if there are more bicycle path.

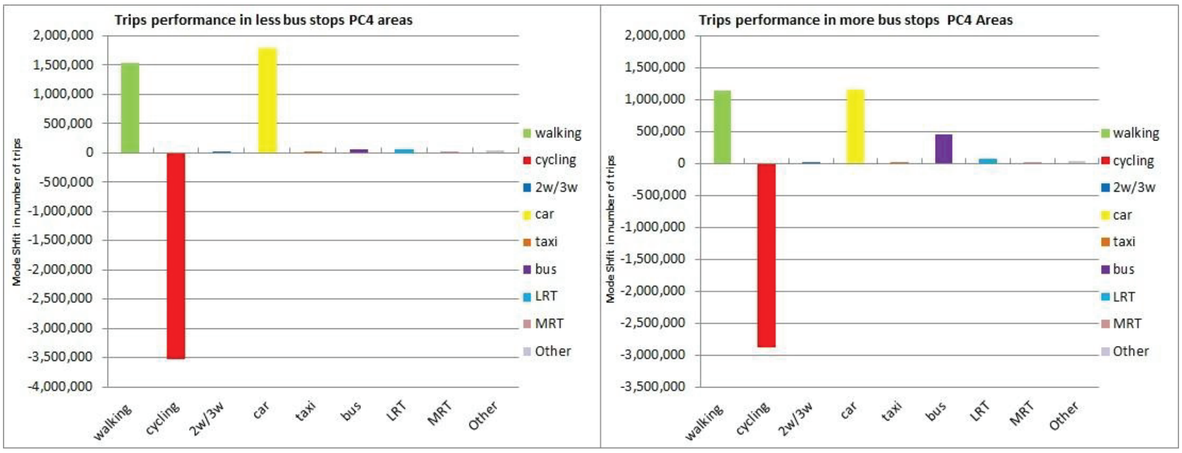


Figure 19 Trips performance in explanatory variable number of bus stops per area.

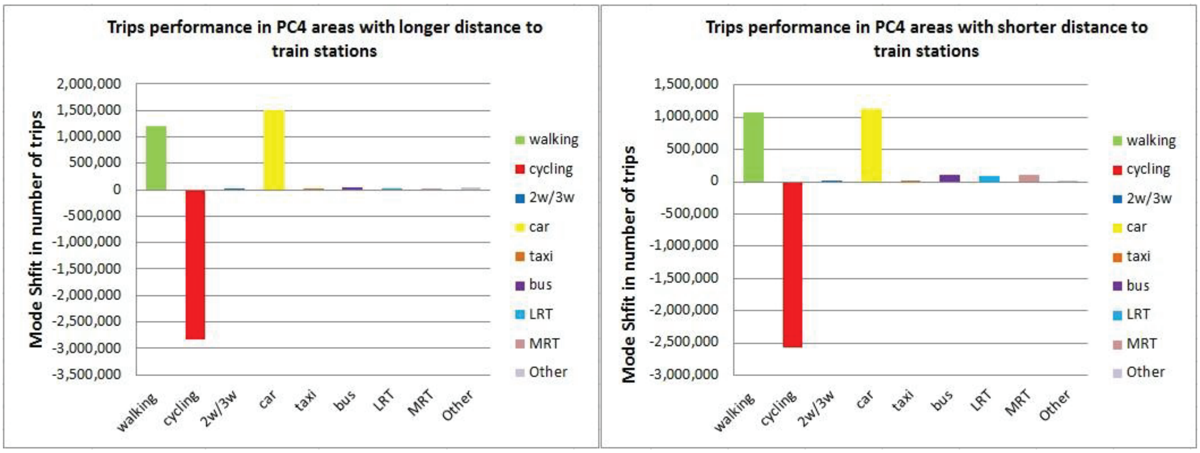


Figure 20 Trips performance in explanatory variable distance to the nearest train station.

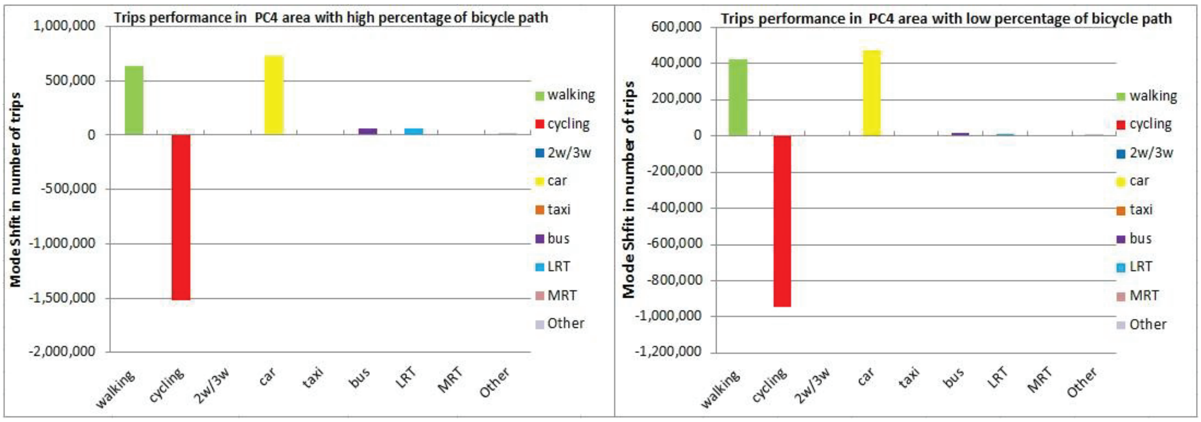


Figure 21 Trips performance in explanatory variable percentage of bicycle path

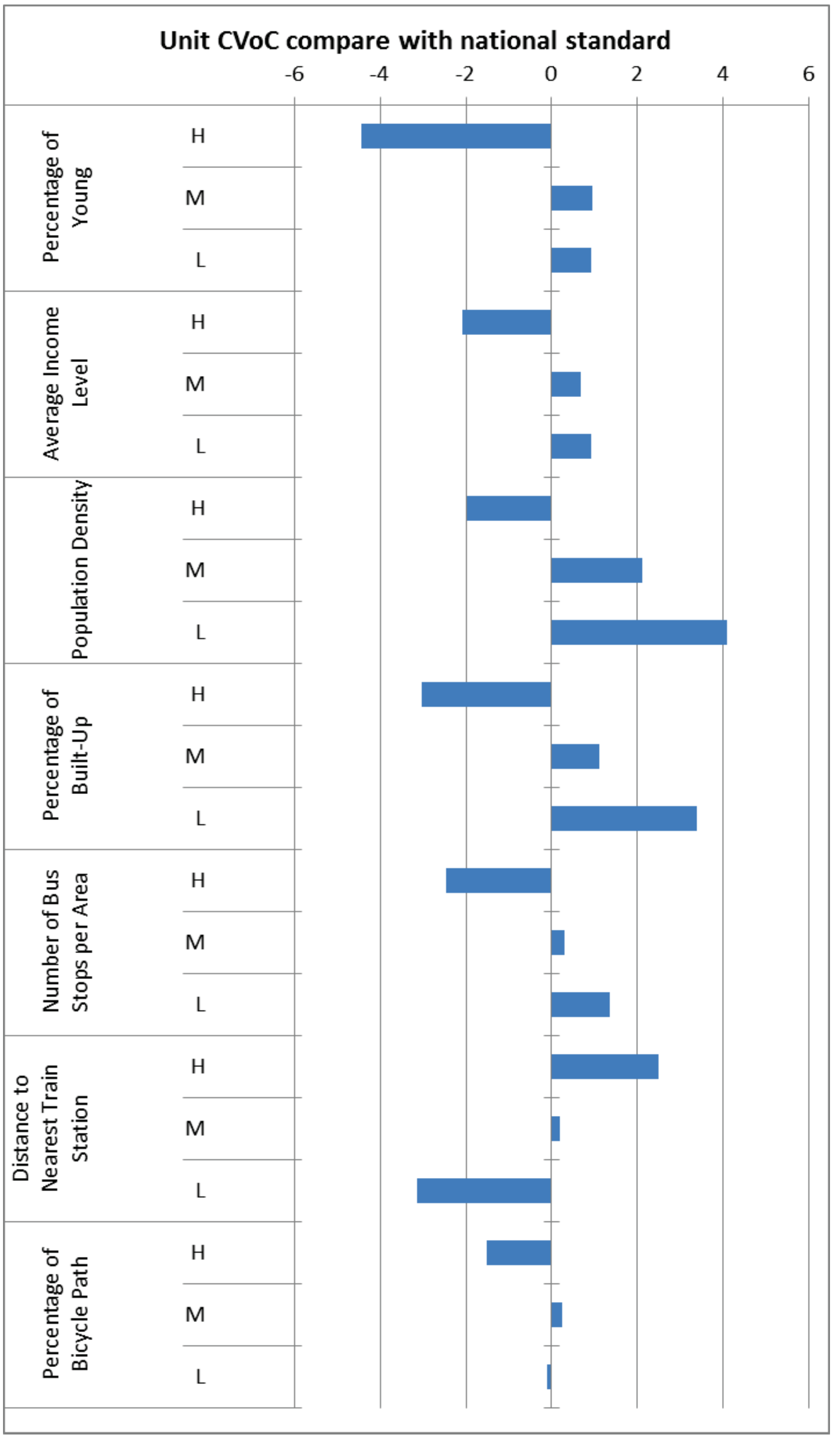


Figure 22 Unit CVoC compare with national standard

This chart shows the net unit CVoC –the climate value of cycling per kilometre-- as compared with the national standard. The bars that placed on left means lower than national standard while those located on right is higher than national standard. The lower unit CVoC suggests that if bicycle is out of choice set, the substituted modes cause less emission, which is more sustainable. From the chart the high percentage of young age class contribute more to saving CO_2 emission. Then comes to the urban infrastructure domain: if there are train stations nearby, the mode shift to train causes less emission. On the other hand, the low population density class cause the most CO_2 emission per kilometre travel. These PC4 areas located far away city centre, the main modes they shifted to is car.

Explanatory Variables	classes	CVoC in Capita	CVoC in Area	Original mode share	Unit CVoC	Bicycle share
Percentage of Young	H	L	H		L	H
	L	H	L		H	L
Average Income Level	H	H	H		L	H
	L	L	L		H	L
Population Density	H	L	H		L	H
	L	H	L		H	L
Percentage of Built-Up	H	H	H		L	H
	L	L	L		H	L
Number of Bus Stops per Area	H	H	H	H	L	H
	L	L	L	L	H	L
Distance to Nearest Train Station	H	L	L	L	L	H
	L	H	H	H	H	L
Percentage of Bicycle Path	H	L	H	H	L	H
	L	H	L	L	H	L

Table 11 Table link explanatory variables and CVoC score

Explanatory Variables	Explanations and potential policy response
Percentage of Young	People in age between 15 and 24 use bicycle more often than other age groups. And if without bicycle, they tend to choose the less emission travel modes. Moreover, if averaged by capita, the increased CO_2 is still low, which means the CO_2 emission can be maintained in areas with more young people.
Average Income Level	The income level seems not be a factor for whether choosing bicycle, the difference of bicycle share between high income class and low class is slight, only 1.5% difference. However, the CO_2 emissions cannot maintain in high income group after modal shift. Capita CO_2 emission is high in high income group.
Population Density	There are more bicycle shares in the PC4 area with high population density, and these areas provide more clean travel modes. But if averaged by area, more dense areas cause more CO_2 emission.
Percentage of Built-Up	Although the unit CVoC shows modes may shifts to sustainable way, the CO_2 emission in average area in these dense places cannot be maintained. The more compact of buildings the more CO_2 emission may occur.
Number of Bus Stops per Area	The places with more bus stops available are more favourable for trips by bus. And graph in Figure 19 shows that more modes would shift to bus if bicycle is not available. However, areas with high density of bus stops cause more CO_2 emission.
Distance to Nearest Train Station	More accessible to train stations causes more trips by train, and attracts more modes shift to train. However, the areas near train station in average cause more CO_2 emission than those far from station.
Percentage of Bicycle Path	The high level of bicycle path development attracts more bicycle use. But the difference is so slight that not so correlated with CVoC score. The distribution of modes shifts in high and low classes behave similar.

Table 12 Explanations and policy response to explanatory variables.

Combined the primary bicycle share and the unit CVoC can present the situation before and after taking bicycle out of choice set. In the following table, bicycle share means in total travel distance, the percentage of bicycle PKT. The higher bicycle share the more the distance travelled by bicycle. Together with unit CVoC, if the unit CVoC returns lower, the alternative modes cause less CO_2 emission which means the substituted travel modes are more sustainable. The following table shows the distribution of each class considering both bicycle share in PKT and unit CVoC.

Low Bicycle share & High Unit CVoC	High Bicycle share & High Unit CVoC
▪ High distance to train station	▪ Low percentage of young ▪ Low average income level ▪ Low population density ▪ Low percentage of built-up ▪ Low number of bus stops
Low Bicycle share & Low Unit CVoC	**High Bicycle share & Low Unit CVoC**
▪ Low distance to train station ▪ High population density ▪ High number of bus stops ▪ Low percentage of bicycle path	▪ High percentage of young ▪ High average income level ▪ High percentage of built-up ▪ High percentage of bicycle path

Table 13 Distribution of classes considering both bicycle share in PKT and unit CVoC

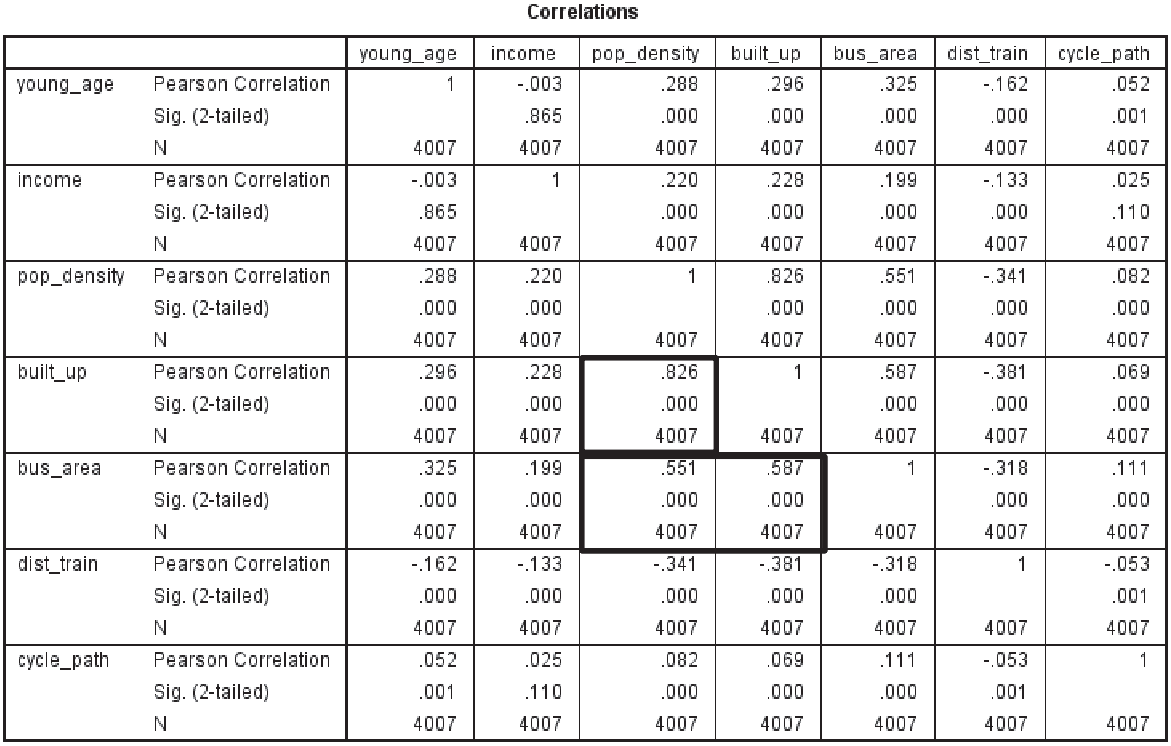
1) Low Bicycle share & High Unit CVoC
   The longer distance to the nearest train station placed in this category which thought to be the worse situation. In these areas, the bicycle use is not so frequent and the alternative travel modes cause more CO_2 emission.
2) Low Bicycle share & Low Unit CVoC
   EV classes in this category means even the bicycle PKT share is lower, the substituted modes that replace bicycle PKT cause less CO_2. They are positively correlated with climate value but call for more bicycle trips.
3) High Bicycle share & High Unit CVoC
   EV classes in this category shows that even there are more bicycle share, the CO_2 that bicycle per kilometre travel can save is less. The alternative travel modes instead of bicycle cause more CO_2 emission.
4) High Bicycle share & Low Unit CVoC
   The classes in this category represent an exemplary travel pattern. The bicycle kilometre travelled is high and each PKT save more CO_2 emission. The substituted modes in this category are sustainable in terms of its climate value.

5. DISCUSSION

5.1. Correlations within explanatory variables

By detecting the different behaviours of choosing travel modes, the explanatory variables can be a tool to link urban and regional domains and the CVoC score. However, it is still unavoidable that the explanatory variables under different urban and regional domains correlated with each other.

According to Table 14, except the relationships between income level and percentage of young age, income and percentage of bicycle path, other EVs are more or less correlated with each other. There are three pairs of explanatory variables that relatively stronger correlated. The most significant correlation can be seen between EVs in urban form domain. The Pearson correlation between population density and percentage of built-up is 0.826. It can be the reason that in more compact areas, population becomes larger than those less compact places. The other two strong correlations appear in the explanatory variable number of bus stops per area. Its correlations with population density and percentage of built-up are 0.551 and 0.587 respectively. The bus stops as urban infrastructure refers to the utilities required to operate the usable urban form effectively. More compact area can have more requirement of infrastructure. As a common urban facility, the distribution of bus stops is correlated with EVs in urban form domain.



Correlations

		young_age	income	pop_density	built_up	bus_area	dist_train	cycle_path
young_age	Pearson Correlation	1	-.003	.288	.296	.325	-.162	.052
	Sig. (2-tailed)		.865	.000	.000	.000	.000	.001
	N	4007	4007	4007	4007	4007	4007	4007
income	Pearson Correlation	-.003	1	.220	.228	.199	-.133	.025
	Sig. (2-tailed)	.865		.000	.000	.000	.000	.110
	N	4007	4007	4007	4007	4007	4007	4007
pop_density	Pearson Correlation	.288	.220	1	.826	.551	-.341	.082
	Sig. (2-tailed)	.000	.000		.000	.000	.000	.000
	N	4007	4007	4007	4007	4007	4007	4007
built_up	Pearson Correlation	.296	.228	.826	1	.587	-.381	.069
	Sig. (2-tailed)	.000	.000	.000		.000	.000	.000
	N	4007	4007	4007	4007	4007	4007	4007
bus_area	Pearson Correlation	.325	.199	.551	.587	1	-.318	.111
	Sig. (2-tailed)	.000	.000	.000	.000		.000	.000
	N	4007	4007	4007	4007	4007	4007	4007
dist_train	Pearson Correlation	-.162	-.133	-.341	-.381	-.318	1	-.053
	Sig. (2-tailed)	.000	.000	.000	.000	.000		.001
	N	4007	4007	4007	4007	4007	4007	4007
cycle_path	Pearson Correlation	.052	.025	.082	.069	.111	-.053	1
	Sig. (2-tailed)	.001	.110	.000	.000	.000	.001	
	N	4007	4007	4007	4007	4007	4007	4007

Table 14 Correlations between explanatory variables

6. CONCLUSION AND RECOMMENDATIONS

6.1. Explanation to Climate Value of Cycling

This research detected explanatory variables under three urban and regional domains, and explain their values with CVoC score by using different unit.

6.1.1. Social economic domain

By observing the climate value of cycling per capita, the results show that people with younger age (between 15 and 24) tends to use public facilities more than those in other age groups, but the modes shifts to car still plays the main preference. However, the unit CVoC value in younger age class is lower than other age classes, which means their modes shift cause less emission.

The income effect on capita CVoC shows slight correlation. Before modes shift, the bicycle shares in PKT in high income class and low income class are 8.25% and 7.76% respectively. And the distributions of assigning bicycle PKT to alternative modes are similar.

In general, the income level is not so correlated with bicycle share and the modal shift while age is a factor to cause difference in bicycle use and the choice of modes shifts.

6.1.2. Urban form domain

Both population density and building density keeps big difference between classes in CVoC per square kilometre. The high dense areas cause much more CO_2 emission per area. The difference between high and low classes of population density is distinguished; reach 305.781 tons per year. And the differences between built-up density classes are even eminent: reach 397.476 tons each year. If in one year, a tree absorbs 24 kg CO_2, there should be around 12500 trees plant per km^2 in high population areas. And for high building density areas, 16000 trees are required to deal with high CO_2 emission. The more compact areas cause more CO_2 emission. Urban form domain is this sense correlated with CVoC score in terms of density.

6.1.3. Infrastructure domain

The usage of public transport has the same trend with the availability of transport infrastructure. The percentage of trips made by bus in more dense bus stops area is higher than less bus stops area. Same situation in distance to the nearest train station: closer to train station leads to more train travel. The bicycle facility also influences the bicycle use. If the percentage of bicycle path is higher than 22%, the cycling share can reach 23.5%. But the difference between classes is not so illustrious since the range of value is not so wide.

If considering both bicycle share and CVoC score, the urban infrastructure domain does not have a unified explanation. Less distance to train station and more bus stops have positive correlation with unit CVoC but the bicycle share in these classes is low.

Based on the detections from each urban and regional domain, the classes that have more bicycles share in PKT have one or some characters as follow:

1) High Percentage of young age, high income;
2) Low population density, high built-up density;
3) Less bus stops available, longer distance to train station, more bicycle path.

On the other hand, the less CO_2 emission caused by modes shifts, or in other words, high climate value each bicycle kilometre travelled saved, have the following characters:

1) High Percentage of young age, high income;
2) High population density, high built-up density;
3) More bus stops available, less distance to train station, less bicycle path.

So in conclusion, the more bicycle share with high climate value have the characters of younger age, high income, more built-up areas and more bicycle path. The socio-economic domain can explain CVoC well while other EVs in urban form and infrastructure domain can also show the characters that correlated with CVoC scores.

6.2. Policy responses

Based on all the explanatory variables that applied for observations in this study, the distance travelled by car is the main share of total PKT, which occupied 77% of all travel distance. And this mode causes most CO_2 emission (0.188 kg/km) among all. Consider using public transportation, walking, or biking rather than private automobile. Most forms of public transportation have lower pollutant emissions per passenger than private vehicles. The policy response instead of simply calling for increasing usage of non-motorized travel mode can plan more environmentally sustainable transportation development by focusing on knowing the characters that favourable for bicycle user.

In socio-economic domain, age is a kind of personal character that cannot easily control. But based on the trend that young people are more willing to choose bus or train, further planning can on one hand, encourage older age group use bicycle more, on the other hand, allocating the public transport facilities by considering the climate value of bicycle. In addition, more focus on improving average income level can also contribute to decreasing the capita CVoC.

In urban form domain that considers both people and buildings, both high population and built-up density have low unit CVoC score but if assign the total CO_2 into area, the emission reaches so high. The environmentally sustainable planning can focus on the physical compact area in terms of population and buildings.

From the view of infrastructure, train stations allocation mainly depends on the spread of rail lines. The PC4 areas that have longer distance to train station not only have less bicycle share but also have high unit CVoC score. The requirement of connection to train stations can be one consideration of further planning. There is also a recommendation to balance the bus stops and bicycle use. The results show that even the mode shift to bus causes less emission, more bus stops lead to less bicycle use.

6.3. Recommendations

This research classifies the Dutch PC4 areas into homogenous groups, and test the CVoC scores in different groups that whether they can be well explained by each explanatory variable or not. Although the differences between classes are reasonable, it's unavoidable of some interactions among EVs.

The possible solution to avoid it is by partial correlation that simply compares the independent explanatory variables with CVoC score in which the effects of other variables are held constant. However, CVoC model gets the most likely alternative modes based on a specific amount of sample size, which limited the probability to calculate CVoC for each PC4. If this can be solved, the dependent CVoC score can be predicted by considering some combination of explanatory variables.

So for the further application of CVoC model, if there are rich sample size enough in PC4 level, a regression model can be applied to predict the depend CVoC score by regression coefficients.

On the other hand, the probability calculation that for choosing the most alternative modes keeps idea of multinomial logit model (Luce & Suppes, 1965b). The application of this independence of irrelevant alternatives in this research means the ratio of choosing each substituted modes keeps still if bicycle is present or absent from mode choice set. The idea of multinomial logit model should use Hausman test (Hausman, 1978) which is highly encouraged.

The selection of explanatory variables are mainly based on literature review, even it considered three urban and regional domains, due to the limitation of data, some potential aspects cannot be observed. Since the MON data records yearly, it limits the variation between seasons. For instance, it assumed that the younger age people may use bicycle more than older. People in age between 15 and 24 are mainly students. By observing the CVoC value each year, the difference between vocations and school time cannot be avoided. Moreover, travel in winter can be more convenient by private vehicle rather than bicycle or walking. Based on MON records, especially in 2008 (see Figure 6), there are around 40% observations recorded in winter. If further studies can distinguish the travel behaviour between seasons, the results can be more accurate.

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