Estimating the Climate Value of Bicycling in Bogotá, Colombia, using a Shadow Pricing Methodology

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13th December 2009

MSc Thesis

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Abstract

The reduction of CO_2 emissions forms one of the largest challenges of the current era. Sustainable transport projects aim at reducing emissions by (1) 'Avoiding' motorized mobility, (2) 'Shifting' motorized mobility to zero-emission alternatives or (3) 'Improving' efficiencies in the current transport system. Especially bicycling is suitable for 'Shift' projects because bicycles have a zero-emission value. Development of bicycle projects, however, is hampered caused by a lack of insight in the economic benefits arising from bicycling. With the introduction of the Clean Development Mechanism (CDM) and the Voluntary Carbon Markets (VCM) an extra stimulus for sustainable development, in the form of additional project revenues produced by the sale of CO_2 emission reduction credits (CERs) is created. Little scientific research has been conducted to the appraisal of the CO_2 reduction potential of bicycling. This research explores the possibilities of the CO_2 assessment of bicycling by the development of the Shadow Traffic Model.

The Shadow Traffic Model is a traffic evaluation model based on the economic principle of shadow pricing. Bicycle mobility represents a CO_2-sink in which each bicycle trip is a potentially emitting trip when made with a motorized transportation mode. Shadow pricing enables the estimation of the value of this CO_2-sink resulting in the Climate Value of Bicycling. The Shadow Traffic Model substitutes bicycle trips by their most likely alternative transportation modes, based on the choice probability distributions given by modal splits specified to trip length, socio-economic background and purpose combinations. This results in the Shadow Traffic Performance of bicycling. Subsequent emission modeling with transportation mode specific emission factors results in the Climate Value of Bicycling. When traded on the CDM and VCM carbon markets this climate value represents an monetary asset.

Application of the Shadow Traffic Model to the case study Bogotá, Colombia, a city with a bicycle modal share of 3.3 % on a total of 10 million daily trips, results in a Climate Value of Bicycling of 55.000-62.000 tCO_2 per year corresponding with an economic value of \$ 1.1-1.3m when traded on the carbon markets. A hypothetical increase in the bicycle modal share to 15 % leads to a value of 0.35 $MtCO_2$ per year representing an annual carbon finance revenue of \$ 7.1m.

Acknowledgments

The writing of this chapter of my Master Thesis symbolizes the end of my graduation process, my years as a student of the University of Twente and simply a fantastic period of my life. During the writing of this thesis I came to learn a lot about myself, the people that surround me and the social mechanisms of a researcher. But this report could not have been realized without the help of a lot of people. I would like to take this opportunity to thank them all.

First of all I would like to thank my supervising committee chaired by Martin van Maarseveen and consisting of Mark Zuidgeest, Jaap Rijnsburger and Jeroen Verplanke. Especially I would like to thank Mark Zuidgeest for all his time and feedback despite his outrageous schedule. Jaap Rijnsburger, for all his inspiring comments on my work and bicycling in general and for giving me the opportunity to travel to Bogotá, Colombia, to experience the case study with my own eyes. Martin van Maarseveen, for his clear and thought-out view on my research and Jeroen Verplanke for his reasoned comments on my work.

In Bogotá I owe Carlos Moreno a huge thanks for all his help in arranging meetings and letting me enjoy Bogotá. Olga Lucía Sarmiento at the Universidad de los Andes for her advice and assistance and allowing me to participate in their extensive bicycle field survey. At the Universidad de los Andes I would also like to thank Roberto Zarama for giving me the opportunity to stay at his department and Andrea Maldonado and Eduardo Behrentz for providing my vital data for my research. I would also like to express my gratitude for la Secretaria de Movilidad de Bogotá D.C. and especially Adriana Parra Casallas and Jhon Fernando Pesca for giving me the opportunity to use their data set for my research, without their assistance this report could not have been made. Finally I want to heartily thank Gloria Garavito and the whole Garavito family for making me feel at home in Bogotá and making me want to go back to their beautiful city and country.

At ITC I want to thank Frans van der Bosch, Petra Weber and Emile Dopheide for their assistance and advice. I want to thank Jacco for the good times we spent at our MSc Room. All CANners Flavia, Eddie, Deepthi, Janice, Himani and Alphonse for their good advice, help and great coffee breaks. I also want to thank Sally Ocana and Juan Francisco Sanchez for helping me out with their language and their good fun. At the University of Twente I want to thank Kasper van Zuilekom for his good advice and push in the right directions and Tom Thomas for always being willing to advice me on statistical matters.

Finally I deeply want to thank my family and friends for supporting me and giving me good reasons to get out of my work and have a good time.

Roel

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Chapter 1

Introduction

The reduction of GHG emissions is proving to be one of the largest global challenges of the present century. Road transportation plays an important role in this process due to its large share in GHG emissions. Since many non-Annex 1 countries are developing at a high rate, future abatement strategies should not only contain strategies for western countries but should have a distinctive focus on sustainable development in developing and emerging countries. The concept of carbon finance through the Clean Development Mechanism (CDM) or the Voluntary Carbon Markets (VCM) addresses this focus by providing an instrument for Annex-1 countries to invest in sustainable projects in non-Annex 1 countries to meet their own reduction commitments. Within the CDM, up to 1st of March 2009 only 7 of the 1424 approved CDM projects are developed in the transportation sector while transportation remains one of the largest contributors to GHG emissions.

The goal of sustainable transportation projects is to (1) Avoid mobility, (2) Shift mobility to sustainable modes of transportation or (3) Improve efficiency of current mobility. Avoid strategies aim at reducing the need for mobility by land use planning. Shift strategies aim at modal shifts from motorized modes of transportation to zero-emissions modes such as bicycling or walking. Improve strategies consist of vehicle and fuel technologies or effective public transportation systems. In developing and emerging countries the general emphasis is still to increase private motorized transportation because of the lack of strong stakeholders promoting sustainable methods of traveling. In particular it seems illogical that bicycling is still under invested in developing and emerging countries while (*a*) it is a cheap mode of transportation and can be obtained by even the poorest; (*b*) the investment costs are much lower than for private motorized traffic infrastructure; (*c*) in dense and congested urban areas the bicycle is as time-effective as motorized traffic; (*d*) it's a zero-emission mode of transportation [OECD, 2004, TRB, 2006]. The problem with bicycle initiatives is the absence of a strong political argument backed by powerful stakeholders. This problem is caused by a lack of insight in the economic benefits arising from bicycle projects such as avoided congestion, increased traffic safety, increased user health and most importantly avoided GHG emissions. A quantifiable and verifiable evaluation framework for the GHG reduction potential of bicycle projects is necessary to promote this type of zero-emitting mode of urban transportation. It also improves the chance of carbon finance through the approval for the CDM or the VCM. Therefore also the chance of actual implementation of bicycle projects in developing and emerging countries improves, stimulating the sustainable development of urban transportation systems.

Little scientific research has been conducted to the appraisal of the CO_2 reduction potential of bicycling.

It is still unknown what the value of current bicycle mobility of an enclosed region would be in terms of avoided CO_2 emissions. This is obviously the first step to be made before an appraisal methodology for bicycle projects can be made. The research proposed in this document therefore aims at developing an evaluation framework for the assessment of avoided CO_2 emissions of cycling, making this research a unique and valid contribution to urban transportation science.

But how can the CO_2 emission reduction potential of bicycling be assessed? The problem is that bicycling has an intrinsic zero-emission value making it difficult to attribute carbon financing to this transportation mode. There has been little scientific research conducted to the appraisal of the CO_2 reduction potential of bicycling. Although general cost-benefit analysis have been performed on an academic base [Litman, 2004, Foltýnová, , CCE, 2004, Sælensminde, 2004, Lind, 2005, Lind et al., 2005, BMVBS, 2008, Saari et al., 2005, Macdonald, 2007, Krizek, 2004, Cavill et al., 2009, Ploeger and Boot, 1987]. The current state-of-the-art of bicycle appraisal generally ignores the CO_2 reduction potential of bicycle projects. Only the researches by Browne, Gotschi and Wittink include CO_2 emissions as an individual entry in their cost-benefit analysis [Browne et al., 2005, Gotschi, 2008, Wittink, 2000]. In these researches the CO_2 reduction potential of bicycling projects is calculated by making an impact assessment of a bicycle project and multiplying the difference in vehicle kilometers traveled by a certain (economic) CO_2 emission factor. The results of these studies showed very low CO_2 reduction potentials predominantly caused by the low scale of a bicycle project. This indicates that either the economic factor or the scale of the projects needs to increase. With the introduction of the CDM and the VCM, CO_2 emission sale has become much more economically attractive. Second when looking at bicycling from a city-wide scale instead of a corridor the significance of the CO_2 reduction potential increases [Browne et al., 2005].

Bicycle projects are developed for two reasons: *(1)* to accommodate current bicycling by providing decent facilities and *(2)* to expand bicycling by improving and increasing bicycle facilities. In most countries the amount of bicycle trips decreases due to economic growth and related increasing demand for motorized transportation. In terms of climate control current bicycle mobility can be seen as a 'sink' of CO_2 emissions; each bicycle trip is a potential, motorized and emitting trip and therefore each bicycle trip has a value in terms of avoided CO_2 emissions. Regarding the current trend of capitalizing CO_2 emission reductions through carbon finance, the CO_2-sink of bicycle traffic has an economic value. Thus, besides transport and environmental arguments, accommodating and preferably expanding the size of the CO_2-sink of bicycle traffic has a strong economic argument. This is a general conclusions which counts for both developed as developing countries. Regarding carbon finance in Non-Annex 1 countries, projects that increase the size of the CO_2-sink of bicycle traffic should be facilitated by the CDM or VCM.

In order to estimate the economic potential of the CO_2-sink of bicycle traffic, evaluation methodologies have to be applied. Traditional cost-benefit analysis evaluate the future economic effects of different investment scenarios. They also request large amounts of data on various variables to make the traffic estimations and subsequent cost-benefit analysis. In Non-Annex 1 countries data is not as widely available as in the Western world therefore more simple methodologies are required to assess the these projects. This research therefore investigates the possibilities of estimating the size of the CO_2 emission reduction potential of bicycling by using a economic related methodology of shadow pricing. Although a shadow price model still requests a fair amount of data the model is less complex and more transparent then a traditional traffic model combined with a cost-benefit analysis. This leads to the following research objective:

To develop and apply a shadow price methodology - based on bicycle trip substitution by other transportation modes - for the calculation of the monetary value of avoided CO_2 emissions of bicycling in medium-sized to large cities in Non-Annex 1 countries.

This report discusses the Shadow Traffic Model development and the application of the model on the study case of Bogotá Region (Colombia). In Chapter 2 the research design is outlined. Chapter 3 discusses the background and meta-problem of assessing bicycle mobility which formed the basis of the research design by giving a framework of the GHG problems, abatement strategies, carbon finance in the transportation sector and evaluation studies of bicycle projects. Chapter 4, 5 and 6 describe the model development and study case analysis. Finally in 7 and 8 the research is discussed and concluded.

Chapter 2

Research Design

This chapter discusses the Research Design of this research. It is developed based on assessment of the literature as discussed in the previous chapter. It aims to provide a solid base CO_2 evaluation of bicycle mobility in medium sized to large cities in Non-Annex 1 countries.

2.1 Research Assumptions

2.1.1 Scope of research

The scope for this research is the development of an evaluation framework to determine the economic value of the CO_2-sink of bicycle traffic in a framed area such as a medium-sized to large city. Subsequently this methodology can be used to determine the CO_2 value of proposed bicycle projects. With this framework carbon finance opportunities of bicycle projects in the CDM or the VCM can be identified. The development of such an evaluation framework should therefore be based on a predefined dataset describing the (technical) traffic performance in an urban transportation network in terms of traffic volumes, trip lengthts and modal splits. This entails that an impact assessment of a bicycle project in an urban transportation network falls outside the scope.

2.1.2 Methodology

Section 3.3.2 discusses the various bicycle evaluation frameworks which are found in scientific literature. In short the following three methodologies can be applied:

1. Benefit Analysis: Evaluate the benefits of bicycling by quantification of a fixed set of benefit categories.

2. Cost-Benefit Analysis: Evaluate the costs and benefits of bicycling by quantification of a fixed set of cost and benefit categories.

3. Shadow Price Method: Evaluate the value of (isolated aspects) of bicycling by calculating the shadow price.

The first two methodologies are traditional for a general economic evalation of transportation projects. The last methodology is not often been used and academic base for the shadow pricing in transportation modeling is absent. But this method is especially interesting when analyzing the CO_2 emission reduction potential of bicycle projects. This is caused by the fact that bicycles do not possess tailpipes and therefore do not produce any CO_2 emissions. The advantage of a shadow price methodology is that it allows to define a value to these bicycle trips. Subsequently this methodology can be used in assessing the value of proposed bicycle projects. Prof. P. Rietveld from the Spatial Economy Department of the VU University of Amsterdam stated that although the shadow price method is not solid for the complete economic evaluation of bicycling it can be used for isolated aspects such as the CO_2 value of bicycling [Rietveld, 2009]. Based on the opportunities of the shadow price methodology and the expert opinion of Prof. P. Rietveld the shadow price methodology is selected as the model approach.

2.1.3 Geographic scale of research

The research by Browne et al. and communications with leading CDM and transport developers Grütter Consulting indicate that small bicycle projects are not feasible for the CDM or VCM because their carbon offset is to thin. A bicycle project should at least consist of a city wide network in order to produce enough CERs for feasible exploitation of the CDM project. The geographical scale of this research is therefore the evaluation of bicycle traffic in a medium-sized to large city. In order to comply with the conditions of the CDM this project also has to be located in a city in a Non-Annex 1 country.

2.1.4 Carbon Finance

In the context of this research the term carbon finance means the finance of sustainable projects through either the sale of Certified Emissions Reduction Credits in the CDM or Voluntary Emissions Reduction Credits in the VCM.

2.1.5 Case study

The assumptions on the geographical scale of the research defines the framework of the case study. To evaluate bicycle traffic, and the implications for the CO_2 emissions, information on the number of trips specified to transportation mode, socio-economic status and purpose of the trip should be readily available. The case study will be used to validate the developed modeling framework. The city of Bogota (Colombia) is the main case study. The reason for this selection is the availability of local representatives of the I-CE, the vast bicycle network implemented in the city and the potentially high amount of data available.

2.2 Research Objective

Based on the above stated research problem and assumptions the following research objective is defined:

To develop and apply a shadow price methodology - based on bicycle trip substitution by other transportation modes - for the calculation of the monetary value of avoided CO_2 emissions of bicycling in medium-sized to large cities in Non-Annex 1 countries.

2.3 Research Questions

Based on the general objective the following main research question is defined. This question represents the core of this research.

What is the monetary value of CO_2 emissions avoided by bicycle traffic in medium sized to large cities in non-Annex 1 countries when using a shadow pricing method?

Decomposing the main research question leads to the definition of the sub research questions. By answering these questions the main research question is answered as well.

1. *How to apply the shadow price concept to the monetary CO_2 evaluation of bicycle traffic?*
2. *How to define current traffic performance in terms of distribution per mode, trip distance, origin-destination matrices and number of movements in a medium sized to large city in a non-Annex 1 country?*
3. *How to use travel behavior characteristics to appraise alternative travel modes to bicycling in the frame of the shadow price methodology?*
4. *How to determine the CO_2 costs or benefits based on traffic data such as the distribution per mode, trip distance, origin-destination matrices and number of movements?*
5. *How to define a hypothetical traffic performance including the distribution per mode, trip distance, origin-destination matrices and number of movements in a medium sized to large city in a non-Annex 1 country in the case that all bicycle trips are replaced by other modes?*
   (a) *What are the first order effects of replacing all bicycle traffic with other transport modes?*
   (b) *What are the second order effects of replacing all bicycle traffic with other transport modes?*
6. *How can the Shadow Traffic Model be applied for other cities than the case study?*

2.4 Research Model

The research model gives a structured overview of the research objective and research issue and is given in Figure 2.1 on page 23.

2.5 Research Methodology

The research methodology gives the outline of the research strategy. The goal is to answer the research questions and thereby reaching the general objective. The research model in Figure 2.1 gives a structured overview of the research process. As can be seen the research is divided in four sections: theoretical framework, concept development, case study and result. The numbers shown in the figure correspond to the research question as stated in Section 2.3. In this chapter the research strategy for each section is discussed.

2.5.1 Theoretical Framework

The theoretical framework argues the academic base of this research. The goal of the theoretical framework is to answer the first four research questions and thereby providing a base for the concept development. The sources used in this section are scientific documentation, project documentation and expert interviews.

1. *How to apply the shadow price concept to the monetary CO_2 evaluation of bicycle traffic?*

To obtain a general idea on the concept of shadow pricing academic literature provides the basis for the conceptual model. Based on research papers provided by McKinsey and Company [McKinsey, 1986] and Ploeger [Ploeger and Boot, 1987] and engineering insight this question can be answered. By answering the second, third and fourth research question a gain in understanding in the mechanics of traffic performance evaluation (2), choice modeling (3) and CO_2 emission calculation (4) is intended. Chapter 3 provides this information.

2.5.2 Concept Development

The concept development is the main part of this research and consists of the evaluation framework development. This part aims at answering the fifth research question.

5. *How to define a hypothetical traffic performance including the distribution per mode, trip distance, origin-destination matrices and number of movements in a medium sized to large city in a non-Annex 1 country in the case that all bicycle trips are replaced by other modes?*
   (a) *What are the first order effects of replacing all bicycle traffic with other transport modes?*
   (b) *What are the second order effects of replacing all bicycle traffic with other transport modes?*

The theoretical framework forms the basis of the conceptual model development. Chapter 4 on page 41 and Figure 4.1 on page 44 give a description of the Shadow Traffic Model for the calculation of the monetary value of CO_2 emissions avoided by bicycling.

2.5.3 Case study

The case study consists of the selection of a suitable case study and the evaluation of this case study with the evaluation framework development. The selection of the case study is dependent on the possibilities provided by the ITC, the I-CE and their respective partners. Additionally this case study has to comply with the data conditions stated in the concept development stage. The city of Bogotá in Colombia is adopted as case study for this research.

2.5.4 Result

The final part of this research tries to find an answer to the main research question.

- *What is the monetary value of CO_2 emissions avoided by bicycle traffic in medium sized to large cities in non-Annex 1 countries when using a shadow pricing method?*

By analysis of the theoretical framework, the development of the evaluation framework and the results from the case study, the monetary value of CO_2 emissions avoided by bicycle traffic can be assessed. Subsequently a discussion of the results should provide information on the further developments of the model in the frame of carbon financing through the CDM or the VCM and the applications of the model in other cities in non-Annex 1 countries.

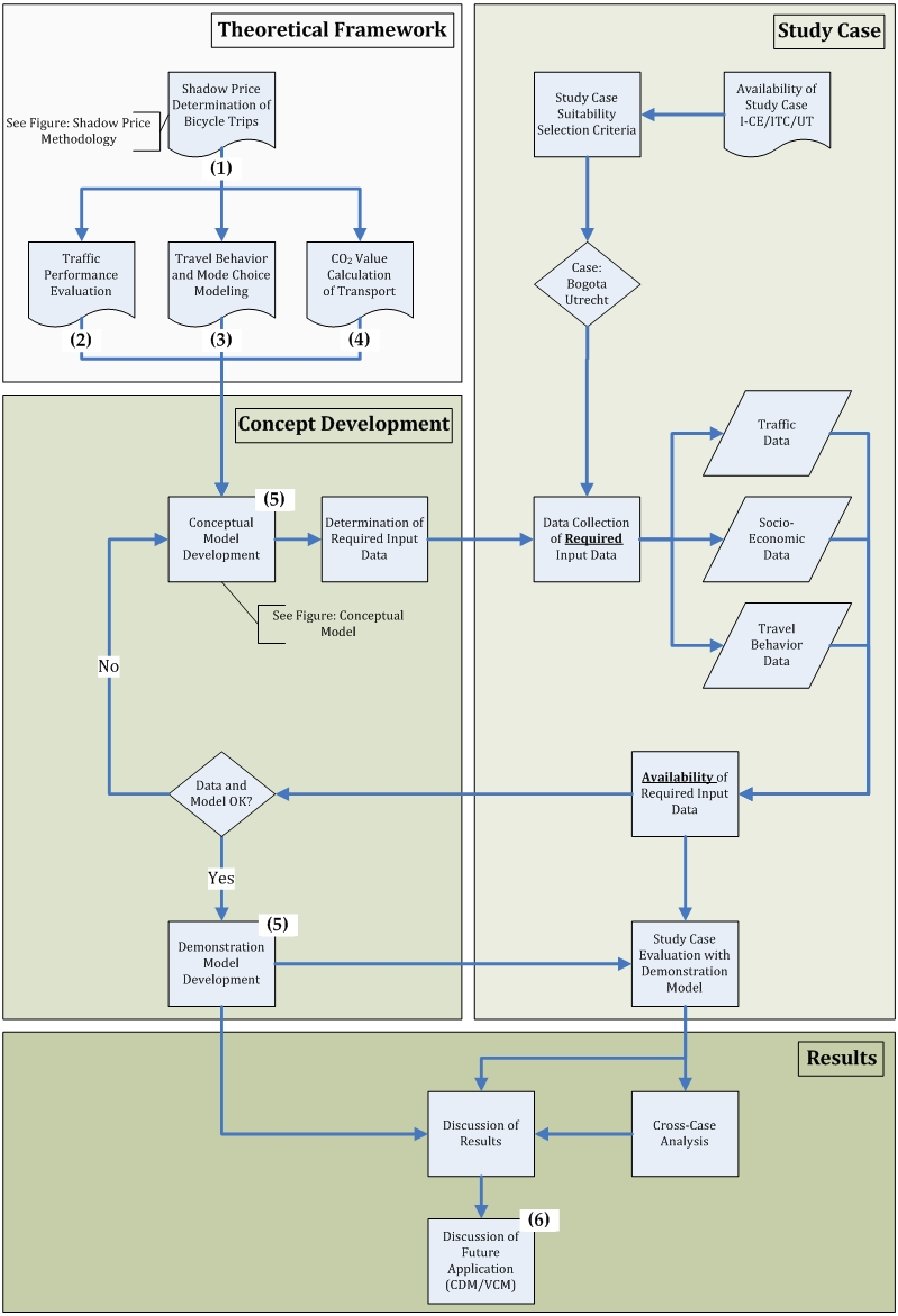


Figure 2.1: Research Model

Chapter 3

Literature Review

This chapter discusses the available literature on the subject of Greenhouse Gas (GHG) abatement in the road transportation sector by the implementation of bicycle projects. The first section handles on the background of the GHG problems and the possible abatament scenarios for the road transportation sector. The second section introduces the concepts of carbon finance, the Clean Development Mechanism and the Voluntary Carbon Markets. A state-of-the-art review of evaluation frameworks of bicycle projects is discussed in the third section. Finally a summary of the most important subjects is given in the fourth section.

Because CO_2 emissions are the most important and most spoken of GHG emissions, the terms GHG emissions and CO_2 emissions are used interchangeable with each other in this document.

3.1 Meta Problem of Climate Change Abatement

The problem of climate change caused by the emission of greenhouse gases (GHG) is one of the largest global problems of today. There are four major GHG, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and ozone (O_3). The emissions of carbon dioxide (CO_2) causes the largest problems. The significance of the problem of GHG emissions is captured within the Kyoto Protocol. This protocol to the United Nations Framework Convention on Climate Change (UNFCCC) was initially adopted in Kyoto on 11 December 2005. The ultimate objective of the UNFCC is [UN, 1992]:

"*the stabilization of greenhouse gas concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system*"

For 'Annex 1 countries[1]' the Kyoto Protocol defines binding commitments to reduce their collective emissions of GHG to a reduction of 5.2 % compared to the 1990 level. The limitations differ per country and range between 0% for Russia to 8% for European Union countries. Besides that a general commitment for all countries exists, this includes the non-Annex 1 countries.

The Kyoto Protocol is the driving force behind the reduction of GHG. The Kyoto Protocol defines 'flexible

[1]Annex 1 countries are the industrialized countries that were members of the OECD (Organization for Economic Co-operation and Development) in 1992, plus countries with economies in transition (the EIT Parties), including the Russian Federation, the Baltic States, and several Central and Eastern European States.

mechanisms' such as Emissions Trading, the Clean Development Mechanism and the Joint Implementation which allow Annex 1 countries to meet their GHG commitments by purchasing 'emission reduction credits' (also known as 'carbon credits') from other countries. In short this means that non-Annex 1 countries don't have a binding commitment in reducing emissions but a financial incentive to establish emission reducing projects in order to create carbon credits which can be sold on the international market.

The transportation sector is one of the major contributors to the emission of GHG especially the emission of CO_2. Figure 3.1 gives an overview of the CO_2 emissions by sector in 2004.

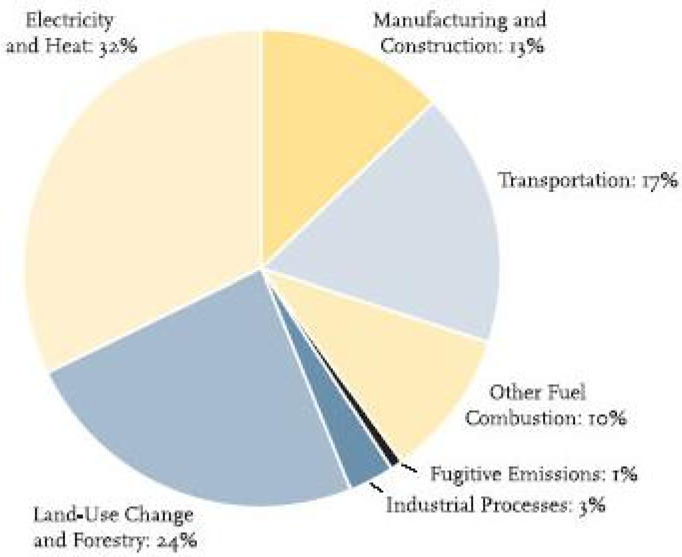


Figure 3.1: Global CO_2 emissions per sector in 2006 [WRI, 2006]

Figure 3.1 illustrates that the transport sector has a dominant role in the emission of CO_2. The transport sector consists of all road, water and air transport. When analyzing the specific contributions of each subsection it becomes clear that road transportation is the largest emitter of CO_2. In 2005 the share of road transporation was 73 % (Figure 3.2).

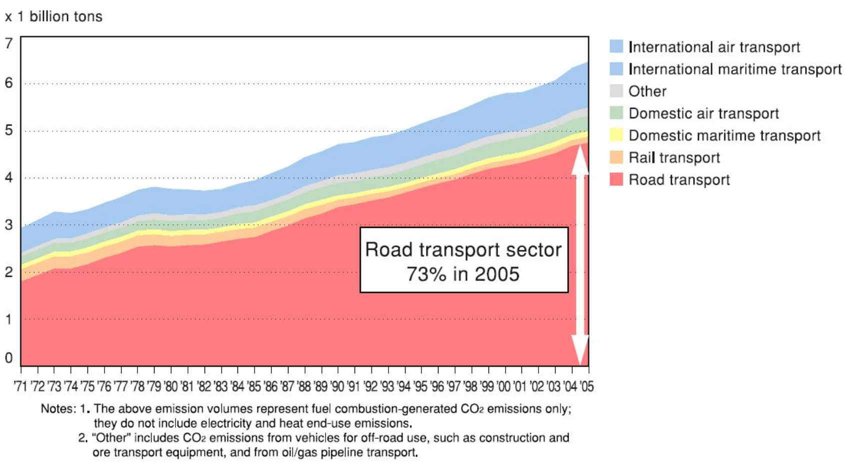


Figure 3.2: Global CO_2 emissions in the transport sector [IEA, 2007]

The increase in CO_2 emissions is primarily caused by the increasing growth in the global urban population and the increased motorization of the global urban population. While in Western countries urban growth remains stable the emerging and to a lesser extent the developing economies undergo periods of great economic change resulting in significantly higher urban growth rates. This economic growth results in increased use of private motorized transportation. The following figure shows the projected increase in global CO_2 emissions from motorized vehicles for the period of 1990-2020 estimated by the OECD in 2000:

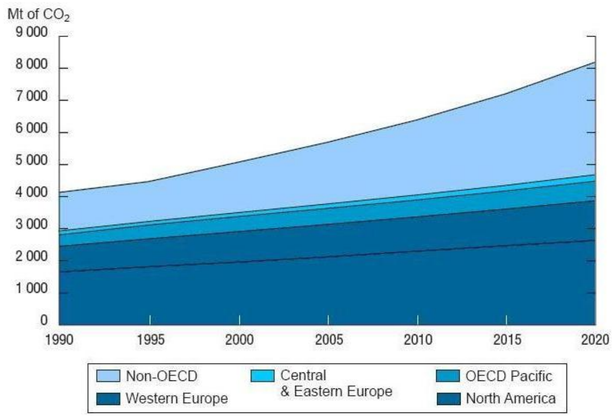


Figure 3.3: Global CO_2 emissions from motor vehicles, 1990-2020 [OECD, 2001]

Although more than half of the CO_2 emissions remains to be emitted in western countries Figure 3.3 indicates the significant growth of CO_2 emissions in emerging and developing countries. These countries are the non-OECD which corresponds with non-Annex 1 countries. This projected growth is propelled by the enormous estimated growth of population and their mobility needs. This trend defines the importance of abatement of road transportation emissions on a global level but with extra attention to emerging and developing countries.

3.1.1 Abatement Strategies

The Briding the Gap Intitiative, started after COP14 in Poznan by GTZ, TRL, Veolia Transport and UITP, also defines transport as one of the important climate change contributors. In their "Common Policy Framework on Transport and Climate Change" they state the following about abatement strategies concerning transportation[the Gap, 2008]:

"A central theme in the discussions on the position of transport in a post 2012 climate agreement is the need to deal with transport as a sector in its own right and not as a sub-sector of the energy sector as is currently the case. Treating transport as a sub-sector of the energy sector puts an undue emphasis on technological solutions and tends to underplay the importance of the "Avoid and Shift" part of the "Avoid - Shift - Improve" approach. Much more so than in the energy sector there are possibilities to limit emissions in the transport sector through behavioral change and through reducing the need for mobility through better land use planning. "Avoid and Shift" oriented strategies often result in a negative cost for the society as a whole and a larger focus on "Avoid" and "Shift" can change the perception of costs and benefits of mitigation in the transport sector."

"Avoid - Shift - Improve" provides the hierarchy of best abatement strategies, that is (1) to avoid (motorized) transportation by clever land use planning, (2) to shift motorized transportation to non-motorized transportation by clever land use planning and behavioral changes and finally (3) to improve technology leading to more efficient motorized transportation.

In general these strategies are divided into direct and indirect measures. Indirect measures aim at changing the behavior of travelers and to induce an "avoid/shift" by land use planning or through stimulation of GHG reduction projects by providing financial opportunities. The Kyoto Protocol and its flexible mechanisms Emissions Trading, the Clean Development Mechanism and Joint Implementation are examples of indirect measures. Direct measures aim at direct abating or mitigation of emission at their sources. This can be an "avoid/shift" through mobility reduction programs or modal shift programs or an "improve" such as vehicle and fuel technology improvements,

Avoid and Shift Strategies

These strategies aim at reducing GHG emissions by reducing the growth of motorized transportation or by redistributing traffic demand over mode, space and time. These instruments consist of motorized transportation reduction policies and development of efficient alternatives to private automobile transportation.

Land-use policies and location efficiency are tools that aim at sustainable futures. Land-use patterns have significant impact on the demand for mobility. By effective planning the demand for transportation can be influenced. Integration of transport planning and urban planning is therefore inevitable. For example, compact urban areas decrease the demand for mobility and increase the effectiveness of public transportation. The city of Curitiba, Brazil, is a good example of this integration where a bus rapid transit system is integrated in a linear city model. This resulted a public transportation system with a higher modal share and lower fuel consumption per vehicle than in comparable cities [Smith, 1998]. The high performance of the transportation network in Curitiba is mainly caused by the effective public transportation system.

This indicates the importance of an effective public transportation system. By supplying an effective public transportation system the accommodation of the current modal share of public transportation and/or a modal shift from motorized transportation to public transportation could be induced. The emission of GHG decreases when the modal share of public transportation rises because average emissions per (passenger) vehicle kilometer traveled (VKT) are much lower when traveling by bus, light rail or metro compared to private motorized transportation. Projects such as TransMilenio in Bogotá show a decrease in GHG emissions and provide a more reliable transportation network which also improves the livability of the city. The economic benefits of the abated GHG emissions is calculated at $ 56 million for the year 2006. This means a very substantial economic benefit compared to the investment realized [Grütter, 2007].

In combination with public transport investments the development of non-motorized transport options increases the effectiveness of an urban transportation network. Urban bicycle networks prove to be an effective alternative to private motorized transportation in urban areas. Research by Gotschi to bicycle and walking projects in the United States show that even modest investments could lead to an annual reduction of 70 billion VKT in the United States [Gotschi, 2008]. Although Gotschi might be a bit optimistic in his predictions the general conclusion of his work is that bicycle investments result in a positive balance. In developing countries, investments in bicycle infrastructure proves to be an effective tool for reducing GHG emissions. Wittink et al. performed case studies in three cities in South-America (Bogota), Africa (Morogoro) and Asia (New-Delhi) and concluded that the benefits of the bicycle investments outweigh the costs of implementation [Wittink, 2000]. The direct economic value is gained from improved safety and travel time costs. Although the reduction in emissions is also stated as benefit no monetary term could be applied.

The abatement strategies discussed here provide a solid basis for development towards a sustainable transport future. Vehicle and fuel technologies aim at reducing the (fossil) fuel consumption and tailpipe emissions. The objective of traffic demand strategies is to reduce the need for mobility by effective land use planning and improvement of sustainable modes of transportation in order to induce a modal shift. However most of the current investments are stimulating motorized transportation while zero-emissions possibilities like bicycling are overlooked. This is primarily caused by the investment strategies of many cities where road infrastructure investments are mainly made in new asphalt. These new roads are then directly taken over by the huge demand of commercial motorized transportation such as public transport in the form of minibuses or freight transport. In most cases these infrastructure investments don't include segregated bicycle paths or road markings. Because NMT modes are the most vulnerable they get overpowered by the demand of motorized transport such as the minibuses, carriers, vehicles or motorcycles. More investments in specific bicycle infrastructure such as segregated lanes and decent road marking are necessary for increased cycling. A lack of insight in the economic costs and benefits of such projects hampers these developments.

Avoid and Shift by Bicycling

In urban areas bicycling forms an effective mode of transportation for complete trips. In addition it plays in important role in the public transportation feeder network. Bicycling is therefore an essential link in a sustainable urban transportation system. Especially in urban areas in developing and emerging countries the bicycle mode proves its value because: (a) it is a cheap mode of transportation and can be obtained by even the poorest; (b) the investment costs are much lower than for private motorized traffic infrastructure; (c) in dense and congested urban areas the bicycle is as time-effective as motorized traffic; (d) it's a zero-emission mode of transportation [OECD, 2004, TRB, 2006].

Bicycle projects are developed for two reasons: *(1)* to consolidate the current amount of bicycle trips and *(1)* to increase the amount of bicycle trips. In most countries the amount of bicycle trips decreases due to economic growth and related increasing demand for motorized transportation. In terms of climate control the currently existing bicycle trip performance can be seen as a 'sink' of CO_2 emissions; each bicycle trip is a potential, motorized and emitting trip and therefore each bicycle trip has an intrinsic value in terms of avoided CO_2 emissions. Regarding the current trend of capitalizing CO_2 emission reductions through carbon finance, the CO_2-sink of bicycle traffic has an economic value. Thus, besides transport and environmental arguments, consolidating and preferably increasing the size of the CO_2-sink of bicycle traffic has a strong economic argument. This is a general conclusion which counts for both developed as developing countries. Regarding carbon finance in Non-Annex 1 countries, projects that increase the size of the CO_2-sink of bicycle traffic could be facilitated by the CDM or VCM. The size of the CO_2-sink of bicycle traffic therefore has economic value and potential.

Although bicycling provides sufficient benefits, implementation is generally hampered. For the further development of bicycling as a sustainable mode of transportation, empowerment of bicycle stakeholders is necessary. This empowerment is stimulated when the economic benefits of bicycle projects can be monetized with a solid evaluation framework. Appraising or monetizing of CO_2-sink of bicycle traffic strengthens the political argument towards implementation of bicycle projects because the benefits of bicycling become clearer.

Improve Strategies

Vehicle and fuel technology improvements possess the potential to reduce the future emissions of greenhouse gases. When looking to the introduction of the Internal Combustion Engine (ICE) it is acknowledged that it had major implications on the industry and energy resources. A similar effect could result from a shift to more sustainable vehicle and fuel technologies. Research by Ryan and Turton resulted in a comprehensive overview of promising technologies for the 21st century [Ryan, 2007]. On the short-term ICE vehicles can be upgraded with better combustions technologies such as petrol-fuelled direct homogeneous charged compression ignition (HCCI). Because of their higher efficiency HCCI engines can achieve higher efficiencies while releasing less emissions than present ICE. Improvements such as faster warm-up, especially in urban traffic, and exhaust treatment prove to be promising technologies in increasing the efficiency and decreasing the emissions of vehicles. Also the use of different fuels can reduce emissions of vehicles. It is estimated that fuels such as natural gas (CNG) produce approximately 30 % less, on a well-to-wheel basis, than petroleum or diesel [IEA, 1997]. One of the drawbacks of the use of natural gas is their unpractical fuel storage since they have to be stored in compressed cylinders either in gas of liquid (LNG) form. Another potential substitute of petroleum are alcohol and biofuels. The advantage of alcohol and biofuels is their higher octane rating and therefore better oxygenation which results in an improvement of combustion and emission quality. A drawback however is the production process of these fuels since inputs in their production produces CO_2 as well. Hall and Turton conclude that because of the lower yield in the production of biofuels and the competing demand of other land uses and the growth of biofuels are likely to make alcohol fuels more attractive for large-scale production than biofuels.

In the long-term different engine systems can provide the way towards sustainable land transportation. In particular the introduction of electric vehicles (EV) has great potential because of the lack of tailpipe emissions and direct impact on air quality. Further advantages of EVs are the independence of fossil fuels which enables great flexibility since electricity can be generated in a multitude of (sustainable) ways. Second, EVs are able to achieve much higher efficiencies than ICEs because they avoid thermodynamic losses related to the transition of chemical energy in the fuel to mechanical energy. One of the biggest problems is the storage and supply of electricity to the engine. Battery storage is the first option but is highly dependent on the future development of highly efficient storage carriers. The second option is the fuel cell vehicle (FCV) where electricity is directly generated on board of the vehicle. But similar prospects occur here since future developments will have to prove their worth.

3.2 Carbon Finance and the Transport Sector

The Kyoto Protocol is the most important stimulus for sustainable environmental development. To help Annex 1 countries reach their binding emission commitments the three 'flexible mechanisms' are established within the Kyoto Protocol. Emissions Trading allows Annex 1 countries to trade GHG emissions credits following the market value. Joint Implementation allows Annex 1 countries to meet their emission goals by investing in emission reduction projects in other Annex 1 countries as a substitute for investing in projects in their own country. While these two mechanisms only allow for inter-Annex 1 relations, the Clean Development Mechanism enables non-Annex 1 countries to participate in the global carbon market. Article 12.2 of the Kyoto Protocol regulates the objective of CDM as [UN, 1992]:

"*The purpose of the clean development mechanism shall be to assist Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist Annex I countries in achieving compliance with their quantified emission limitation and reduction commitments under Article 3*"

The impact of the CDM is therefore of a dual character, first it helps industrialized countries to meet their commitments and second it assists the host countries, mostly developing or emerging countries, to achieve their sustainability goals. The CDM can constitute an important revenue source for sustainable transport projects next to traditional income sources such as the Global Environmental Facility [Grütter, 2007]. Because host countries can sell the CERs resulting from projects, the feasibility and therefore the chance of implementation of such sustainable transport projects increases.
In order to participate in the CDM the project has to be approved by the UNFCCC Executive Board. The basic requirement for a CDM project is its additionality which means that the emissions resulting from the baseline scenarios are higher than the projected emissions in case of implementation of the project. In other words, it has to be proven that the project is additional and these emissions reductions are not expected to occur in the business-as-usual scenario. The existence of financial, technological or political barriers that will resolve in case of the CDM can be used as proof for this additionality. A discussion of the complete CDM project cycle is provided in Appendix A. Once a project is approved and registered by the CDM Executive Board the CERs it produces can be traded on the worldwide greenhouse gases market. The structure of the GHG market is shown in Figure 3.4:

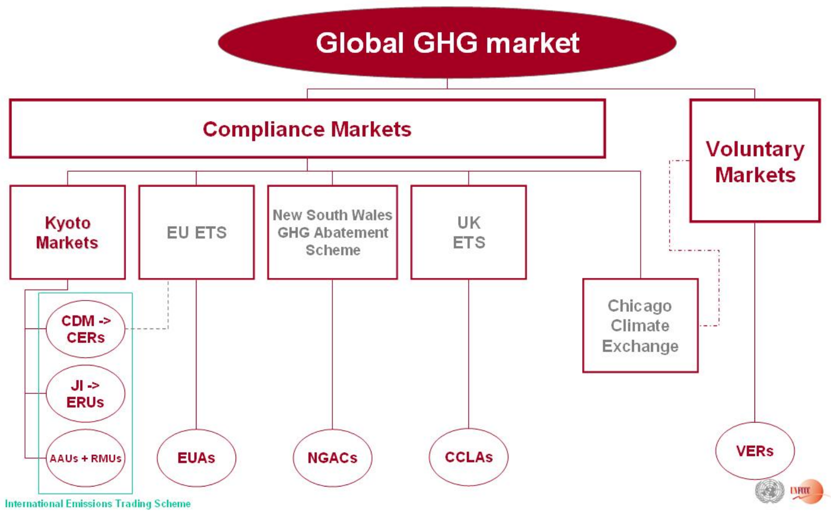


Figure 3.4: Structure of Global GHG Market [UNFCCC, 2008]

The European Union Emissions Trading Scheme is the largest allowance-based GHG market in terms of activity [Violetti, 2008]. Of the Kyoto Markets the CDM market is the largest. The price of CERs differs from each project depending on the risk distribution on buyers/sellers. CERs can be exchanged with a 1:1 rate with EU Allowances (EUAs) which are marketable on the EU ETS market. Besides the compliance markets also a Voluntary Carbon Markets (VCMs) exist. This market aims at customers that want to environmentally neutralize their operations by purchasing Voluntary Emission Reduction credits (VERs). The VERs market is less regulated than the compliance markets. The regulations for projects to sell VERs are therefore less strict resulting in great opportunities for residential, institutional, commercial and industrial costumers to invest in sustainable projects [Hamilton and Hawn, 2007]. Because the VCMs are less regulated the quality of VERs sold can vary largely. The develoment of high quality VERs should be according to the principle of the CDM or recognised standards such as the Voluntary Carbon Standard (VCS) [Carbon-Accountable, 2009]. The VCS ensures that VERs sold can be trusted and have real environmental benefits by providing a robust and global standard for voluntary offset projects [VCS, 2009]. For the development of sustainable urban transport projects the sale of VERs can therefore also play in important role when CDM approval is not achieved.

As of the 1st March 2009 1424 CDM projects have been registered corresponding to an amount of 262 million CERs [URC, 2009]. Of this list, 7 projects fall within the transport scope. The TransMilenio Bus Rapid Transit project in Bogotá (Colombia) is approved as the only large-scale transport CDM project. The remaining projects are small-scale projects and involve fuel efficiency projects. The term large- and small-scale projects indicates whether or not the project exceeds 60.000 tonne CO_2 per year. For transport CDM projects the success rate from application to registration has been lower then average. Grutter states that this low success rate is caused by the methodological complexity of transport projects, especially concerning determination of baseline emissions, monitoring requirements and leakage effects [Grütter, 2007]. Projects with quantifiable and verifiable greenhouse gases reductions are more likely to be approved within the CDM. Browne et al. also identified these problems occurring with transport projects in their research to transportation and the CDM. They state that many important greenhouse gases reduction opportunities are missed due to the project-based approach of the CDM. Allowing a more policy- or sector-based approach will result in many more emission reduction opportunities [Browne et al., 2005]. The findings of both Browne et al. and Grutter indicate that further development is necessary for the integration of the CDM in transport projects. For this a structured evaluation framework is vital. A lot of opportunities exist, especially with non-motorized transportation. These modes produce no direct emissions and thus have a large potential of decreasing the emissions produced by the road transportation sector.

3.3 Evaluation Frameworks for Bicycle Projects

As discussed in section 3.1.1 a rigid evaluation of the CO_2-sink of bicycle traffic needs to be developed to strengthen the political argument for the implementation of bicycle projects. This section discusses the available scientific literature on the economic evaluation of bicycling and specific projects. The goal of this preliminary literature review is:

"*To review the available scientific literature on the economic evaluation of bicycling projects with special attention to the inclusion of the CO_2 emission reduction potential of bicycling projects.*"

3.3.1 Costs and Benefits of Bicycle Projects

The costs and benefits of bicycling can be estimated on different levels. First the individual level the costs of bicycling are determined in terms of time spent traveling and relating opportunity costs when this time was spent differently and the costs for purchase and maintenance of the bicycle. The benefits of bicycle on the individual level are first of all the benefits of being at the destination of the trip. Second, individual health benefits arise from the physical exercise of bicycling.

For policymakers the individual costs and benefits are less important than the aggregated results in terms of social costs and benefits. Especially the CO_2 costs and benefits are important regarding the scope of this literature review. The (social) benefits of bicycling are the decreased pressure on the motorized infrastructure network decreasing the potential of traffic congestion. Also the health benefits of a population with high physical activity (through bicycling) improves the public health and decreases costs to the health system [Cervero et al., 2009]. Bicycling also results in CO_2 emission benefits because bicyclists do not use motorized transportation and therefore reduce CO_2 emissions. The (social) costs of bicycling are related to the infrastructure investments and maintenance. Although these costs are relatively cheap compared to infrastructure for motorized transportation they do produce CO_2 emissions which should be included in the complete assessment of a bicycle project. For the city of Bogotá, Colombia, infrastructure investment costs are estimated at $ 130.000 per kilometer [C40, 2009].

3.3.2 Estimation of Bicycle Costs and Benefits in Current Literature

The inclusion of the CO_2 emission reduction potential is important since it indicates the opportunity of integration with the CDM. The focus of the literature review was therefore to a large extent on finding literature including this aspect. In total sixteen different papers were reviewed. Appendix B provides a complete overview of the reviewed literature and summarizes the key aspects and conclusions. The findings can be divided into four types of research: literature review, benefit analysis, cost-benefit analysis and shadow price methods. Table 3.1 summarizes the literature review by assigning the findings into their appropriate category.

The general approach of the evaluation methodologies is to define a baseline scenario and to compare this to the scenario in case of implementation of the bicycle project. In general CO_2 emissions are not one of the key aspects in the currently available evaluation methods of bicycle projects. The focus of most evaluation methods lies mainly on the increased traffic safety, increased health and reduced congestion. The two literature reviews didn´t even include an evaluation of CO_2 emissions nor air pollution [Krizek, 2004, Cavill et al., 2009]. The objective of both researches was to review and interpret literature that evaluates economic benefits of bicycle projects. Cavill et al. focuses especially on health effects of increased bicycling. Three papers did include the effect of bicycling on air pollution but didn´t include CO_2 emissions in their evaluation methodologies [Lind, 2005, Saari et al., 2005, Macdonald, 2007]. Furthermore argumentation for the values used in these papers is absent. Six papers included CO_2 emissions into a general term for reduced air pollution [Foltýnová, , CCE, 2004, Litman, 2004, Sælensminde, 2004, Lind et al., 2005, BMVBS, 2008]. The general approach in these methodologies is to define an economic cost for each VKT attached to air pollution and to combine this term with the number of reduced VKT as a result of the bicycle project. Only three papers specifically discuss the effects of bicycling on CO_2 emissions [Wittink, 2000, Browne et al., 2005, Gotschi, 2008]. It is important to note that Wittink is the only one to include both costs and benefits in the analysis.

Type of Research	**CO2 Emissions Included**	**CO2 Emissions Included in General Term**	**Only Air Pollution**	**No CO2 Emissions or Air Pollution Included**
Literature Review				(Krizek, 2004; Cavill, 2009)
Benefit Analysis	(Browne, 2005; Gotschi, 2008)	(Litman, 2004)		
Cost-Benefit Analysis	(Wittink, 2000)	(Foltýnová; CCE, 2004; Saelensminde, 2004; Lind, 2005; BMVBS, 2008)	(Lind, 2005; Saari, 2005; MacDonald, 2007)	
Shadow Price Methods				(Ploeger, 1987)

Table 3.1: Overview of Literature

The report compiled by Wittink in 2000 tries to explain the economic significance of cycling by performing cost-benefit analysis for four different cities based on project data provided by stakeholders [Wittink, 2000]. The study case of Amsterdam included CO_2 emissions as an independent benefit factor stating that fl.15,60 per 1000 avoided VKT could be gained. For the other cities an economic value for the GHG emissions avoided per VKT was calculated. This approach resulted in benefit/cost ratios of 1.5 for Amsterdam, 7.3 for Bogota (Colombia) and 20 for Delhi (India). For the Morogoro case no data was presented. But the large b/c ratios for cities in developing countries show the potential of bicycle projects as beneficial public investments.

In their report "*Getting on Track: Finding a Path for Transportation in the CDM*" Browne et al. examine the possible scenarios for using the CDM as a tool to promote sustainable transport in the transportation sector in Chile [Browne et al., 2005]. Among the five case studies two bicycle studies are examined, a bikeway and a comprehensive bicycle network. The methodology used consists of five steps:

1. Forecasting bicycle use by rough estimates and discrete choice modeling based on a revealed preference and stated preference surveying.
2. Baseline determination for four different scenarios: conservative, normal, aggressive and break-even.
3. Additionality assessment as an obligatory aspect of a CDM project.
4. Development of a monitoring approach by balancing robustness with practicality.
5. Calculation of avoided emissions by subtracting project emissions with baseline emissions.

The evaluation of both bicycle projects resulted in annual CER revenues of a negligible $ 735 for the bikeway project but a profit range of $273.000 - $996.000 for the comprehensive bicycle network. Obviously this analysis is by no means a complete cost-benefit analysis. Brown et al. do indicate that small bicycle projects such as individual bikeways produce insufficient carbon offset to establish a feasible CDM project. Bicycle projects with a larger scale such as a comprehensive bicycle network prove to give more opportunities of embedding in the CDM. The same is concluded by the company Grütter Consulting who are working on the transportation CDM market. They indicate that bicycle projects such as a bikeways are not profitable since the carbon offset created by the project is not enough to cover for the monitoring costs of the CDM [Grütter, 2009]. For the future development of the CDM and bicycle projects the scale of the project needs to be comprehensive.

The objective of Grotschi's research was to provide a quantitative assessment and an overall estimation of the monetary value of the benefits of current and future bicycling and walking facilities in the United States [Gotschi, 2008]. The report should help to strengthen the case for increased federal investment in bicycling and walking. The case setup is very broad and consists of three scenarios for the future of cycling in the complete United States. The approach of bicycling appraisal is considered and also applicable to smaller cases. The methodology is a benefit analysis based on projected modal shifts and VMT (Vehicle Miles Travelled) avoided. Several first and second order effects are investigated. Costs are not covered in this research. CO_2 emissions are monetized by evaluation of the criteria 'quantity of reduction' and 'cost per ton of CO_2 avoided'. In addition to the CO_2 savings from shifting short car trips to bicycle trips Grotschi stated the following other CO_2 benefits as second order effects of increased bicycling; CO_2 savings from improving public transportation; CO_2 savings from increased compactness of new development; CO_2 savings from congestion relief. The report continues to identify other important categories such as congestion relief and health effects. The results of the study case are rough estimates based on a broad scope so obviously the results should be interpreted with care. Total annual benefits range from \$10 bln in the modest scenario up to \$65 bln in more substantial scenarios. Although the costs for the bicycle projects is not included the benefits stated here can open up a political dialogue for increased investments in bicycle infrastructure.

The shadow price method used by Ploeger to estimate the economic value of bicycle traffic with the motive education used a different approach [Ploeger and Boot, 1987]. This method is based on the report of McKinsey and Company in 1986 which determined the economic value of traffic congestion by using a shadow price method comparing waiting time due to congestion with economic loss [McKinsey, 1986]. The main research question of the report by Ploeger was:

"*What would be the costs of public transport if all bicycle movements with the motive home - school were to be replaced by public transport*"

By using the principle of shadow pricing the economic value of the bicycle traffic with the motive home - school was estimated by calculating the additional costs to the public transport system if all bicycle trips home - school were to be facilitated by the public transport system. This resulted in an value of Fl. 1.3 billion (approximately E 600 million). Extrapolation to the complete traffic performance of bicycling this corresponds to a value of Fl. 5 billion (approximately 2.3 billion). This estimate was solely based on direct investment, maintenance and operating costs. External social costs caused by air pollution or CO_2 emissions were excluded from this research. Although the substitution assumptions made in this work are thinly backed, the general assumption of the attribution of an economic value based on a shadow price is valid and interesting. Critics claim that although this method is correct for the estimation of isolated aspects of traffic (such as the CO2 reduction potential) using it for determination of the economic value is principally wrong [2] Especially because bicycling has an intrinsic zero-value for CO_2 emissions, a shadow pricing approach can assign (economic) value to the CO_2-sink of bicycle traffic.

[2] According to P. Rietveld, professor spatial economics at the VU University of Amsterdam [Rietveld, 2009].

Although the state-of-the-art of economic evaluation of bicycle projects is not yet extensive, a decent base can be found in the current literature. The general evaluation approach is to calculate the avoided amount of VKT (or VMT) resulting from the implementation of a bicycle project. The exception to the general approach is given by the shadow price method. The economic appraisal is a result of combining this figure with economic information over traffic safety, health benefits, congestion relief and air pollution. With respect to CO_2 emissions and the integration with the CDM very few literature is available. Only three papers discuss the aspect of CO_2 emissions avoided by bicycling to a certain extent. For the strengthening of the political argument towards implementation of more bicycle projects more detailed evaluation frameworks need to be developed.

3.4 Applying Shadow Pricing in Transportation Research

For some goods or services it is difficult to determine their price or value. This is caused by nonexistence of a market for the good or service or that this market is imperfect. Analogical to economic concepts the trip between location A and B can be seen as a service. The different transportation modes represent the different markets in which the service 'trip between location A and B'can be traded. This results in the existence of a 'bicycle-mobility market'and a 'car-mobility market'.The different markets are related by cross-elasticity. A shift in costs and price on one mobility market also results in a shift on the other mobility markets. A practical transportation example of this principle is the implementation of congestion charging on the car-mobility market which results in the stimulation of other markets such as the public-transit mobility market or the bicycle-mobility market.

If markets would operate efficiently and thus be perfect of nature the value of the service, in this case bicycle-mobility, can be determined directly. However the bicycle-mobility market is distorted because individual choices are mostly based on self-interest without taking in to account the external effects caused by their choice. The choice for a car over a bicycle for a short distance trip is an example of this distortion.

In a perfect market the value of one unit bicycle-mobility (e.g. one bicycle trip from location A to B) is equal to the marginal social costs and the marginal social benefits of one extra unit bicycle-mobility. In reality the bicycle-mobility market is distorted causing divergence between the market value and the marginal social costs. The observed market value is therefore not the real market value. This also occurs in the transportation market where the emission of CO_2 caused by individual travel behavior is generally not integrated in the individual choice for transport mode. This means that the marginal social costs are not completely taken into consideration in the evaluation. It is possible to determine the market value of a service such as bicycle-mobility when it is traded on a market where the demand curve equals measured social benefits, and the supply curve meets measured social costs. The value resulting from such an approach is the shadow price. A trip on the bicycle market is therefore substituted by a trip on a different transportation mode market to still be able to assess the social costs and benefits of the trip. Figure 3.5 shows a graphic depiction of the shadow pricing principle applied to the estimation of the shadow price of a bicycle trip on the the Transportation Market.

The concept of shadow pricing can be used to determine the value of the CO_2-sink of bicycle mobility created by the avoided CO_2 emissions caused by bicycle traffic. Since bicycles have an intrinsic zero-emission value a change in the number of bicycle trips will not directly show in their emissions figures. When looking at the nature of these changes new information can be obtained. Because of the price-

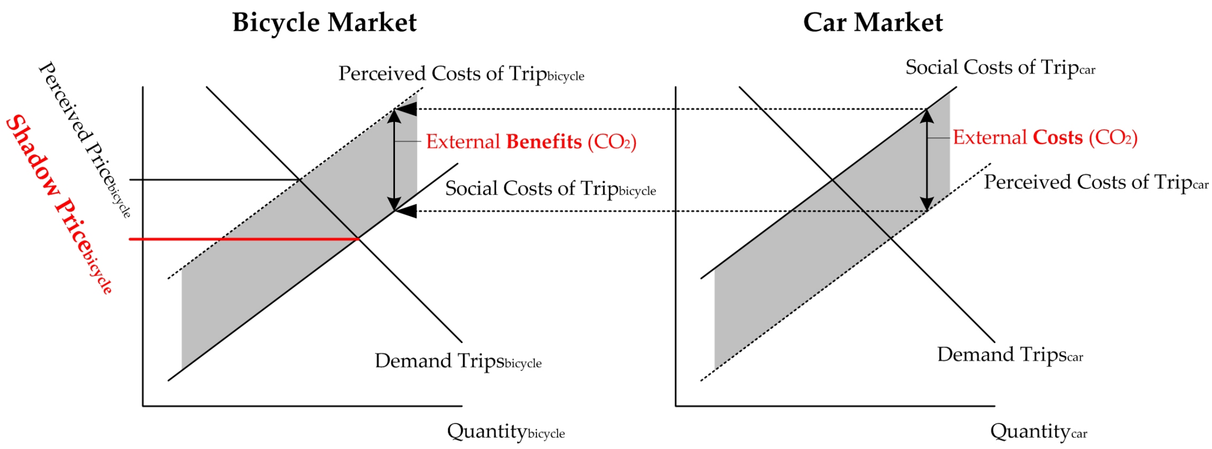


Figure 3.5: Shadow Pricing applied to the Transportation Market

elasticity on the transportation mode markets a change in the number of bicycle trips has an direct effect on the other transportation markets. A decrease in bicycle trips results in an increase on the other markets. When bicycle trips are substituted by trips made with motorized transportation modes the amount of CO_2 emitted will increase as well. Calculation of the additional CO_2 emissions caused by this substitution gives information on the CO_2 value of bicycle trips. Using this approach the total value of the CO_2-sink of bicycle traffic can be calculated.

3.4.1 Impact on the Travel, Transport and Traffic Markets

So what are the effects of this substitution of bicycling with other transportation modes? To answer this question first the transport and traffic market has to be analyzed. In his description of the relations between the transport and the traffic market Schoemaker defines three layers: travel patterns, transport services and traffic services [Schoemaker, 2002]. The mechanics of these markets are based on the aggregated results of individual travel choices of the users of the system. Based on the distribution of activities individual travelers construct their travel patterns, this is the first layer of Schoemaker's model. Because the travel patterns are based on the spatial distribution of land uses and relating activities another layer can be added on top, the land use distribution. This layer is added as the top layer (0) in addition to Schoemaker's three layer model (see Figure 3.6. The interaction between the location of activities and the travelers takes place on the *Travel Market*. The second layer in Schoemaker's model is that of the transportation services. The demand for transportation resulting from the desired travel patterns interacts with the supply of transportation modes on the *Transportation Market*. Finally the last layer in Schoemaker's model are the traffic services. On the *Traffic Market* the demand for traffic resulting from the transportation services layer interacts with the supply of traffic services, i.e. traffic infrastructure such as roads, public transportation systems, etc.

To analyze the effects the impact of the substitution of bicycle trips on the traffic markets, as given in Figure 3.6, has to be assessed. Three types of effects can be identified.

First Order Effects

The first order effects are direct result of the substitution of bicycle trips. Because bicycling is discarded as transportation mode, the supply of transport services changes. The demand for transportation re-

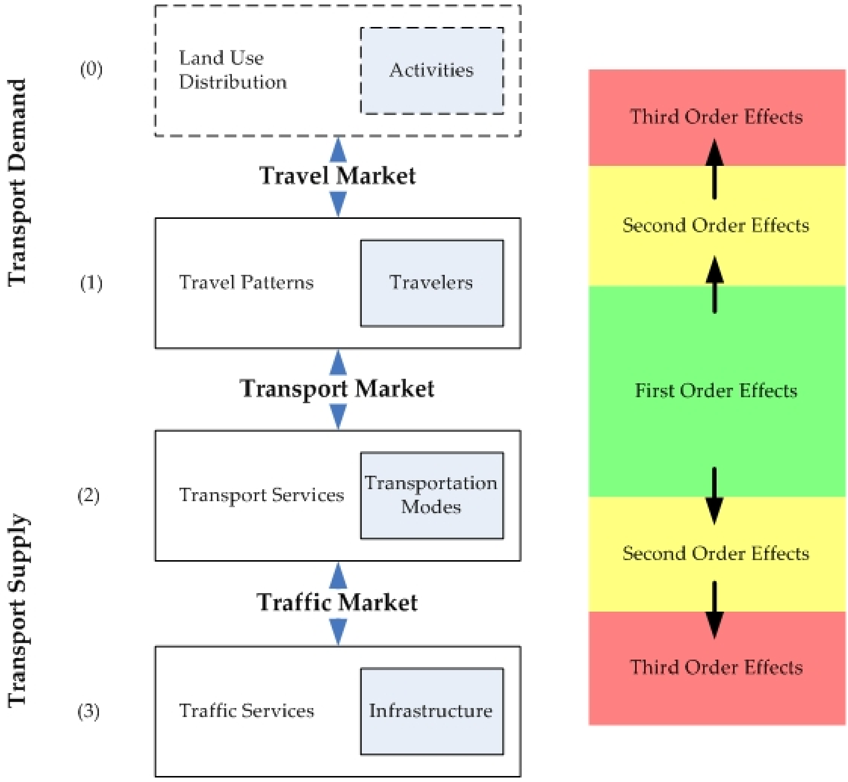


Figure 3.6: The Travel, Transport and Traffic Market (based on [Schoemaker, 2002])

mains the same, i.e. travelers still have their same travel patterns. The interaction between the supply of transport services and the demand for travel takes place on the *Transport Market*. Because the substitution is based on the current situation only two things can happen: (1) the trip is substituted by another transportation mode because the benefits of being at the destination is still exceed the costs related to the trip; (2) the trip is not being made anymore because the benefits of being at the destination underspend the costs related to the trip. On the supply side a (1) change in transportation services, caused by the different distribution of transportation modes resulting from the substitution, takes place. This leads to increased emissions of CO_2, increased congestion and deteriorating traffic safety due to higher speeds and larger speed differences between walking and motorized transportation modes. On the demand side a (2) change in travel patterns, because some trips are not required anymore, takes place. These are the first order effects of the shadow price methodology.

Second Order Effects

On the short-term the substitution has broader effects then a shift in transportation modes. On the demand side, individuals who are forced to use a different transport mode might change their travel pattern as well. For example if an individual uses a bicycle to shop at the local stores, the transition to the use of a motorcycle (for the same trip: shopping) might result in a new situation where the individual goes shopping at a larger supermarket in the outer parts of the city. According to Prof. Rietveld from the Spatial Economics Department of the VU Amsterdam this effect is indeed substantial[3]. On the short-term the substitution of bicycle trips therefore also impacts the *Travel Market*. On the supply

[3]From email conversation: "*Focus from modal shift calculation to the potential shift in travel destinations: e.g. if a bicycle trip is substituted by a car trip the neighborhood shops are presumably skipped and thus more kilometers are traveled; the absolute number of trips might decrease.*" [Rietveld, 2009]

side the substitution of bicycle trips results in a shift in transportation services. This means a shift in the demand for traffic and therefore has a significant impact on the *Traffic Market*. Because bicycle trips are substituted more motorized transportation modes are used resulting in an increased pressure on the traffic infrastructure. On the short problems will therefore occur on the *Traffic Market* because the traffic infrastructure supply cannot handle the traffic demand. These second order effects take place in the *Traffic Market* where the traffic services interact with the transport services.

Third Order Effects

On the long-term the substitution of bicycle trips also has a significant impact on the land use distribution and traffic services. On the demand side a changes travel patterns can create a change in demand of activities on the long-term. Because travelers use different transportation modes then the original bicycles, their radius of action changes as well. This leads to a change in land use patterns. Increased use of cars can lead to a more dispersed land use pattern while increased use of walking will lead to a more compact land use pattern [Schoemaker, 2002]. On the long-term the substitution of bicycle trips thus has an impact on the land use distribution. On the supply side of transportation the changes in the transport and traffic market also lead to a change in the supply of traffic services. Due to a change in transport services the demand for different traffic infrastructure changes as well. Increased demand for car infrastructure leads to more and broader roads while increased demand for public transportation results in expansion of the public transportation system. On the long-term traffic services thus changes as a result of the substitution of bicycle trips.

In this research only the first order effects are discussed because the aim of this research is to provide a solid base for the shadow price methodology in transportation research. Including the second and third order effects are to complex to account for in this MSc research. This means that only the CO_2 emissions caused by the first order effect are included in the Climate Value of Bicycling as proposed in this document.

3.5 Summary

The emission of greenhouse gases remains one of the biggest challenges of our era. The importance of reducing the emissions is established in the Kyoto Protocol which defines binding commitments for Annex 1 countries for reducing their collective GHG emission to a reduction of 5.2 % compared to the 1990 level. As shown in Figure 3.1 and Figure 3.1 the road transportation sector is on the of largest emitters of GHG. Furthermore the enormous growth that most developing and emerging countries are currently experiencing puts more pressure on the atmospheric environment. It is estimated that in 2020 almost half of the CO_2 emitted from motor vehicles will come from vehicles driving in non-OECD countries (Figure 3.3). This shows the vital importance of sustainable (environmental) development of the road transportation sector in the developing and emerging world.

Several opportunities for abatement of GHG emissions are available. Generally these are captured within (1) Avoid: avoid emissions by avoiding (motorized) mobility to reduce emissions; (2) Shift: shift motorized mobility to non-motorized mobility to reduce emissions; (3) Improve: improve efficiency of motorized transportation to reduce emissions. These strategies thus imply either a reduction of the total number of trips and VKT or a reduction of emissions per VKT. 'Avoidance' results from better traffic demand strategies. Land-use policies and location efficiency result in a better utilization of (urban) space and decrease the need for motorized mobility by e.g. creating compact cities. An efficient public transport system helps creating a sustainable urban transportation system by decreasing the emissions per personal VKT. 'Shift' is created by increased non-motorized transportation possibilities combined with both sustainable land-use policies and development of supporting urban public transportation. Especially in developing and emerging countries NMT and more specific bicycle transportation is a very promising mode of transportation because (a) it is a cheap mode of transportation and can be obtained by even the poorest; (b) the investment costs are much lower than for private motorized traffic infrastructure; (c) in dense and congested urban areas the bicycle is as time-effective as motorized traffic, particularly in travels less than 5 km; (d) it's a zero-emission mode of transportation [OECD, 2004, TRB, 2006]. 'Improvement' of vehicle and fuel technologies aim at reducing the emissions right from their tailpipe source. Increased efficiency of the combustion engine and cleaner fuel such as biodiesel or alcohol fuels are promising short-term solutions. For a long-term solution electronic vehicles prove to be the best development.

The development of bicycle projects in developing and emerging countries is generally hampered by a lack of political will and powerful stakeholders. The main reason for this is unawareness of transport technical, environmental and economical benefits of bicycling. This is caused by the absence of clear and presentable evaluation frameworks for the economic appraisal of bicycle projects. Every bicycle trip contains an economic value because it is an potential, emitting trip by a motorized vehicle. Carbon finance provides a potential economic benefit attached to these avoided C_2 emissions. Summed together this could mean a substantial amount of economic value in the CO_2-sink of bicycle traffic for an entire city. Consolidation and preferably an increase in the size of the sink could mean economic benefits. No ready to use methodologies exist for a quick assessment of the value of this sink. Current scientific literature gives a decent starting point but provides by no means sufficient background for an extensive economic evaluation of bicycling and / or bicycle projects. Furthermore, current development of carbon finance through the Clean Development Mechanism or the Voluntary Carbon Markets should be integrated in the assessment of bicycle projects since carbon finance is able to significantly increase the feasibility of bicycle projects.

The evaluation framework for the assessment of the Climate Value of Bicycling as developed in this research is based the shadow price methodology as proposed by Ploeger. It is based on the central question of what would be the CO_2 emissions of the traffic system when all bicycle trips are substituted by other transportation modes. The effects of this substitution are on three different levels. The first order effects are the direct effects of the substitution of bicycle trips on the *Transport Market* leading to a different demand of transport services. The second order effect are short-term effects impacting the *Travel and Traffic Markets*. The use of different transportation modes induces a different demand in activities and therefore different travel patterns. On the supply side the use of different transportation modes causes a change in the demand for traffic and problems on the traffic market because the traffic infrastructure supply cannot cope with the increased demand. Finally on the long-term the previously discussed effects will lead to a change in land use distribution on the demand side of travel and improvements to the traffic services on the supply side. The Shadow Traffic Model as developed in this research only accounts for the first order effects.

Chapter 4

Shadow Price Model

4.1 Model Principles

The basic principle of the Shadow Traffic Model is to assign a value to a bicycle-kilometer traveled based on the corresponding kilometer traveled by a different transport mode. For this research the value of a bicycle-kilometer traveled is based on the CO_2 value of the comparable bicycle-kilometer traveled by a motorized vehicle. This framework is necessary in order to comply with the specific demand for CO_2 evaluation in the research problem statement. Based on this information the following model principles are made:

1. Each passenger kilometer traveled (PKT) by bicycle is substituted by a corresponding PKT by a different transportation mode.

2. The measured social benefits (the demand curve) are the benefits that originate from making a trip irrespective of the used transportation mode. The possibilities that arise being at certain locations count as the most important benefit of traveling. It is therefore assumed that in both cases, the bicycle trip and the corresponding trip with a different transportation mode, the measured social benefits remain the same.

3. The measured social costs (the supply curve) are the costs that originate from making a trip. Since this model only calculates CO_2 emissions the measured social costs of a bicycle trip equals zero. The corresponding bicycle trip made by a motorized transportation mode leads to a marginal social cost equal to the emissions made during the trip and eventually multiplied by a monetary term (e.g. market price per ton CO2 emission).

The shadow price (or CO_2 value / climate value) of the CO_2-sink of bicycle traffic is calculated by substituting all bicycle-trips with the same trips executed by the most likely alternative transportation modes for that trip. The social benefits remain the same since the same trips are made in both scenarios. The social costs differ in terms of emitted CO_2. The resulting difference in marginal social cost the value of the bicycle-mobility.

4. The Climate Value of bicycle traffic is the difference between the social costs related to the actual bicycle trips and the social costs related to the substituted trips made by the most likely alternative transportation modes.

As discussed in section 3.4.1 the substitution of all bicycle trips has first, second and third order effects. Although the integration of all effects would lead to the optimal estimation of the Climate Value of Bicycling this research only accounts for the first order effects occurring directly on the Transport Market. The second and third order effects on the Travel and Traffic Market are excluded from this research to keep the model transparent and well-ordered.

5. **The Shadow Traffic Model as developed only takes first order effects into account. First order effects are defined as the *a* one-on-one substitution of all bicycle trips by *b* their most likely alternative transportation mode, based on modal share ratio analysis, while maintaining the same origin/destination.**

4.2 Model Assumptions

Initially, the first order effects are a 100 % substitution of bicycle trips with alternative transportation modes. In reality it could well be possible that not all bicycle trips are substituted with other transportation modes because the individual perceived travel costs exceed the benefit of traveling. In these cases a trip will not be substituted in reality. A validation module should investigate this hypothesis and eventually a factor of substitution can be added to the model to account for the fact that not all trips are substituted in the shadow traffic performance. However the validation data that is necessary for such a module is not available for the case study at the time of writing this thesis. It is therefore not possible to estimate the factor that accounts for the change in bicycle trip generation on the Transportation Market (see section 3.4.1 leading to the following assumption for the model development:

1. All trips bicycle trips are substituted into trips made with other transportation modes

The objective of applying the Shadow Traffic Model is to obtain the climate value of the CO_2-sink of bicycle traffic in a certain region. As defined the climate value can be calculated by identifying the additional CO_2 emissions caused by the substitution of all bicycle trips, in other words comparing the 'present traffic performance' with the 'shadow traffic performance'. A suitable measure for a traffic performance is a 'Trip Length Frequency Distribution' (TLFD). A TLFD is a frequency count of trips differentiated to trip length and transportation mode. Dividing the frequency count of transportation mode 'X' in trip length bin 'Q' by the total number of trips in trip length bin 'Q' results in the modal share of transportation mode 'X' in trip length bin 'Q'. Doing this for all transportation modes and all trip length bins leads to the construction of trip length dependent modal splits. A modal split can also be seen as a probability distribution, e.g. the chance that a randomly selected trip from bin 'Q' is a trip made by transportation mode 'X' is equal to the modal share of 'X' in 'Q'. This basic principle forms the backbone of the shadow traffic performance estimation. Since a TLFD provides frequencies for different trip lengths it can estimate modal splits dependent on trip length. Shorter distances will see more NMT modes while longer distances are more likely to be made with cars of public transportation. To estimate the most likely alternative transportation mode for one bicycle trip a logical thought is to look at the trip length and subsequent randomly select an alternative transportation mode based on the modal split in that bin (the trip length probability distribution). For one substituted trip this will give random results but when thousands of trips are substituted the results are the most likely alternatives for those trips. Another advantage of using TLFDs is that it is also easy to differentiate between different user groups. For the Shadow Traffic Model as developed in this research the socio-economic background and purpose of the trip is added to differentiate even more. This will increase the level of detail of the model information and therefore increases the estimation of the shadow traffic performance. For example people from lower classes are more likely to use more non-motorized or public transport modes while the higher classes are more likely to use private vehicles for their transportation. Another example is that people are more likely to choose a fast and reliable transportation mode for work purposes while for recreational purposes one would prefer enjoyable, healthy transportation modes. Information over the socio-economic background and purpose of the trip are descriptive for the type of mode choice people make. Therefore using different TLFDs will increase the accurateness of the shadow traffic estimation. In conclusion this leads to the following model assumptions:

2. Travelers within each combination of trip length, socio economic status and purpose behave similarly according to the corresponding probability distributions (modal splits). The most likely alternative transportation modes can then be selected from these distributions.

Application of model assumptions 1 and 2 leads to the shadow traffic performance.

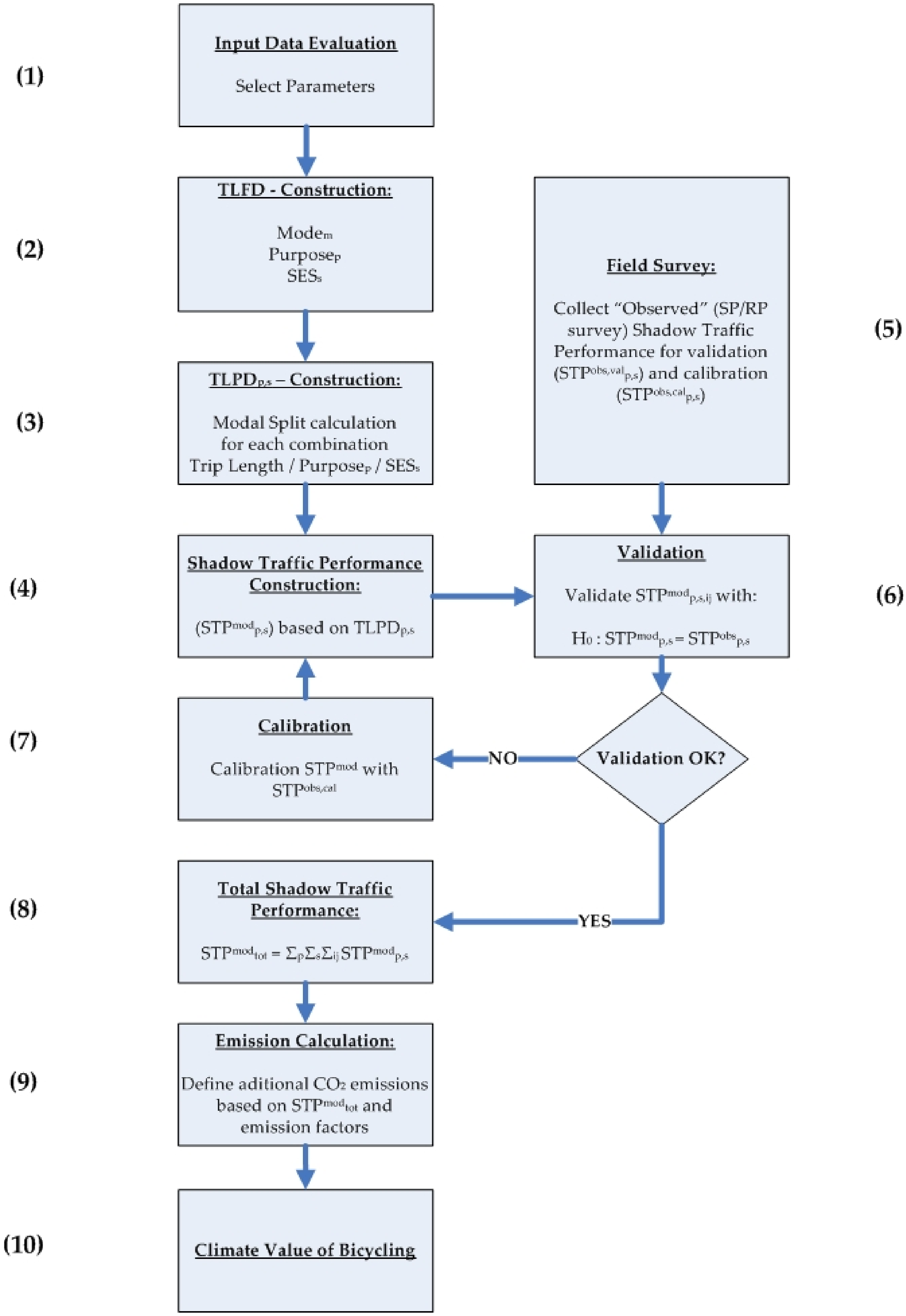


Figure 4.1: Shadow Traffic Model Development

4.3 Model Description

Figure 4.1 provides the Shadow Traffic Model for the climate evaluation of bicycling. It consists of 9 different steps which are discussed in the following paragraphs:

4.3.1 Input Data Evaluation

Before the Shadow Traffic Model can be developed the input data must be evaluated in order to define the parameters that are used in the model. The input data has to be evaluated in terms of trip amount and trip information such as trip length, socio-economic background, vehicle ownership, purpose of trip, origin-destination, etc. Based on this evaluation the choice for bin sizes and travel pattern combinations can be made. For the case study as presented in this research the selected bin sizes are 1km, 2.5km and 5km and the travel pattern combinations are disaggregated to trip length, socio-economic background and purpose of the trip because this information was readily available from the mobility survey which formed the input database for this research. Section 6.2 discusses the selection of parameters in more detail.

The selection of parameters are dependent on the case study to which the Shadow Traffic Model is applied. Depending on the information available on the case study the choice for travel pattern combinations and bin sizes can be made.

4.3.2 Trip Length Frequency Distribution Construction

The second step of the Shadow Traffic Model is the construction Trip Length Frequency Distribution(s) based on the input data. Depending on the source further processing of the input data might be necessary. A regional traffic model can give the total of trips made by different transportation modes as a standard output while a census or household data survey uses expansion factors to synthesize the trip database for the complete region of research. It is preferred to have several other explaining variables such as social-economic status, motive of trip and origin-destination statistics available. With this additional information the TLFD can be specified to different socio-economic status (SES or s) and purpose (p) travel combinations. With trip data specified to trip length, SES and purpose the Trip Length Frequency Distributions can be constructed.

4.3.3 Trip Length Probability Construction:

From the TLFDs a probability distribution of the most likely alternative transportation mode can be obtained. Trip Length Probability Distributions (TLPDs) are modal splits providing information on the share of each transportation modes. The TLPDs are specified to trip length box and to the different travel pattern combinations. The bicycle mode is excluded so the TLPD gives the probability distribution of all modes when bicycling is not available. In other words with the TLPDs the substituted transportation modes for bicycle trips can be estimated per trip length and travel patter combination.

$$TLPD_{m,b}^{s,p} = \frac{Trips_{m,b}^{s,p}}{\sum_{m=1}^{n_m} Trips_{m,b}^{s,p}} \qquad \forall\ s,\ p,\ b \tag{4.1}$$

Where:

$TLPD^{s,p}_{m,b}$	Trip Length Probability distribution for:
s	Socio-Economic background s
p	Purpose p
m	Mode m
b	Bin b
n_m	Total number of m

4.3.4 shadow traffic performance Construction:

For each TLFD$_{s,\ p}$ combination the shadow traffic performance is determined by substituting the bicycle trips with the most probable alternative travel mode based on the TLPD. The two assumptions as discussed above are the base of the shadow traffic performance. These assumptions are theoretical. In practical use it could well be possible that not all trips are substituted by other transportation modes because the travel costs (without being able to use the bike) are exceeding the travel benefits. Validation of these assumptions is of vital importance for the model development. Additionally the model can be calibrated using observed data from the field survey.

To calculate the shadow traffic performance bicycle trips are substituted based on the Trip Length Probability Distributions. Since it are probability distributions over an increasing trip length a stepwise approach should be used. Such an approach can easily be optimized with mathematical programming software by decreasing the step-size (however this is obviously dependent on the aggregation level and the amount available data). To calculate the total shadow traffic performance in terms of substituted kilometers in the transportation system, the shadow traffic performance is multiplied by the mean trip distance in each bin and further summed to the required level of detail.

4.3.5 Empirical Data Collection:

For the validation and calibration of the Shadow Traffic Model an independent data source is necessary. This empirical data is used to validate and calibrate the model assumptions made in previous sections. As remarked above, the most important assumption is that all bicycle trips are substituted. Empirical data based on stated preferences of bicyclists gives insight in the validness of this assumption. Furthermore, a stated preferences survey provides information on the 'real' substitution mode of the bicycle trips and can assesses the second assumption that travelers within each travel pattern combination behave similarly in choosing their substation transportation mode. The result of the empirical data collection should therefore be a shadow traffic performance in terms of stated preference trips made by actual bicyclists. The STP distributions should have the same travel pattern combinations as the modeled version. There are different approaches possible for the collection of required empirical data.

- **Stated Preference Survey:** a general traffic questionnaire where bicyclists are asked if they would substitute their trip with another transportation mode and what their alternative transportation mode would be, i.e. asking bicyclists what the shadow traffic performance of their trip would be. With such a stated preference traffic questionnaires it is possible to directly construct the different shadow traffic performance schemes in the form of hypothetical Trip Length Frequency Distributions (STP$_{obs}$), based on the information on alternative transportation modes given by the respondents. Furthermore the questionnaire could give information on the purpose, SES and OD. Appendix D provides an example survey executed for the study case Bogotá.

- **Mode Choice Modeling:** in some cases an already validated mode choice model is available for the subjected region of research. Such a mode choice model can be used to assess the alternative transportation of bicyclists and provides information on the synthetic construction of the hypothetical Trip Length Frequency Distributions (STP$_{obs}$).

The choice for one of these approaches is dependent on the available information at the subjected region of research and other contextual variables such as time and available funds. The stated preference survey obviously provides the most detailed and accurate information on the shadow traffic performance and should be preferred, ceteris paribus. Before the validation and calibration step can proceed the empirical data set has to be split. One set has to be used for calibration purposes while the other set account for the validation. This is due to the fact that dual-use of validation data for calibration purposes distorts a correct process of model validation. After the calibration the same validation data set has to be used to evaluate the effects of the validation and to validly approve the model based on equality assessment of observed and modeled data.

4.3.6 Validation:

The following section discusses the validation of the shadow traffic performance estimated by the Shadow Traffic Model. For the case study in this research this module is not been executed. This is due to the fact that the empirical data was not yet available at the time of writing.

When empirical data as discussed in the previous section is available, the shadow traffic performance can be validated with the observed STP for a selected $s,\ p$ combination with statistical testing:

$$H_0 :\ STP_{s,p}^{mod}\ =\ STP_{s,p}^{obs,val} \qquad \forall\ s,\ p \tag{4.2}$$

Where:

$STP_{s,p}^{mod}$	Modeled Shadow Traffic Performance
$STP_{s,p}^{obs,val}$	Observed Shadow Traffic Performance
s	Socio-Economic background s
p	Purpose p

If the null-hypothesis holds the model is correct the total STP can be calculated in step 8. However if the observed STP significantly differs from the modeled STP a calibration step has to be performed. The Kolmogorov-Smirnov Two Sample Test is a methodology for testing equality of distributions and can be used for this statistical test. When the null-hypothesis is accepted the calibration step can be skipped directly otherwise the model has to be calibrated based on the empirical data.

4.3.7 Calibration:

The following section discusses the calibration of the shadow traffic performance estimated by the Shadow Traffic Model. For the case study in this research this module is not been executed. This is due to the fact that the empirical data was not yet available at the time of writing.

With the STP^{obs,cal} obtained from the empirical data collection, STP^{mod} can be calibrated. The assumptions as mentioned in section 4.2 are subject to the calibration. The first calibration step handles on the amount of bicycle trips that are substituted. The observed data provides information on the percentage of substituted trips specified to the designated travel pattern combination (s, p). In the calibration step a factor of substitution can be obtained for each trip length (box) in the TLFDs. This factor accounts for the amount of trips that are substituted by other transportation modes, excluding all bicycle trips that are not being made anymore due to the changing condition of transportation mode. The second calibration step handles on the substitution mode. It is assumed that the bicycle trips are substituted based on the ratio of other transportation modes (as provided in the TLPDs). The observed data provides information on the actual substitution mode of bicycle trips. It is well possible that it is more likely that people who already use a bicycle prefer to use non-motorized modes of transportation such as walking for short distances more then the Trip Length Probability Distributions indicate. The observed data can provide adjustment factors for this effect.

4.3.8 Total shadow traffic performance:

The total shadow traffic performance can be calculated by summation over all different travel pattern combinations. The additional amount of traffic caused by the substitution of bicycling results from the subtraction of the present traffic performance from the shadow traffic performance. In terms of number of trips:

$$STP_{tot}^{mod} = \sum_s \sum_p STP_{s,p}^{mod} \tag{4.3}$$

Where:

STP_{tot}^{mod}	Total Shadow Traffic Performance
$STP_{s,p}^{mod}$	Shadow Traffic Performance per:
s	Socio-Economic background s
p	Purpose p

4.3.9 Emission Modeling and the Climate Value

The emission module uses emission factors per passenger kilometer traveled specified to the different transportation modes. Multiplication of the total amount of passenger kilometers traveled per transportation mode with the mode specific emission factor leads to the Climate Value of Bicycling.

Chapter 5

Study Case Description

The Shadow Traffic Model as adopted in the previous chapter is applied to a study case to assess its possibilities, and to calibrate and validate the model with empirical data. The city of Bogotá forms the test bed for this model. The choice for this city is based on three arguments:

- In order to comply with the requirements for carbon financing through the CDM the study case has to be located in a Non-Annex 1 country. The country of Colombia of which Bogotá is the capital is a Non-Annex 1 country and therefore falls within the geographical scope of this research.
- Bogotá is a city with one of the most extensive bicycle path networks of all Non-Annex 1 countries. This network or *ciclorutas* in Spanish were originally developed by former mayor Enrique Peñalosa and were part of an integral redevelopment of the city's infrastructure along with the construction of the Bus Rapid Transit system TransMilenio. Because of this bicycle path network the city shows a large percentage of bicycle traffic compared to other large cities in Non-Annex 1 countries. Therefore this city forms a suitable study case for the development of a Shadow Traffic Model.
- Because of the development of the first transport CDM, TransMilenio Bogotá, monitoring and evaluation data is broadly available in Bogotá. Multiple government agencies and non-governmental organizations have collected data on the transport system of Bogotá making it feasible to collect sufficient input data for the Shadow Traffic Model.

Based on these three reasons the city of Bogotá was adopted as the study case for this research. From August the 1^{st} to September the 20^{th} of 2009 the author of this report spent 7 weeks at the local partner of this research, the Universidad de Los Andes (Andes University), to collect the input data for the Shadow Traffic Model and to setup a field survey for the empirical data collection.

5.1 City Description

Santa Fe de Bogotá or more frequently used Bogotá is the capital of the Latin American country Colombia and has an estimated opulation of 7.881.156 inhabitants in 2005 [DANE, 2009]. Bogotá is located at an altitude of 2640 meters above sea level in the heart of Colombia. The eastern part of borders with a mountain range while the west of the city evolves in the Savannah of Bogotá, a high plateau in the Andes mountain range. Figure 5.1 shows a panoramic view of the city from the western mountain range.
The city of Bogotá is divided into 20 different districts, each consisting of several neighborhoods with a total of 5.811 neighborhoods. The urban layout of the city is based on the Spanish and American system

Figure 5.1: Panoramic view of Bogotá [Wikipedia, 2009]

where a central square (Plaza de Bolivar) forms the center of the city surrounded by a grid network of infrastructure which develops in a more modern network near the borders of the city. The city is a multi-nucleis city with different economic and social centers throughout the city.

Estratas of Bogotá	Percentage of Total Population
1. Lowest	9.3 %
2. Low	42.7 %
3. Medium-Low	30.2 %
4. Medium	9.1 %
5. Medium-High	3.7 %
6. High	1.7 %

Table 5.1: Distribution of Social Economic Classes [DANE, 2009]

The economic division of the city is based on *Estratas* ranging from 1 to 6. The distribution of social classes over the population is given in Table 5.1. The table shows that most of the population is living in low to medium-low economic conditions. This is already an improvement to 15 years earlier [DANE, 2009] but still most of the population can be indicated as low income groups. The economic Estratas are defined by geographical location. Each neighborhood has an Estrata value defined by the average income of its population. The lower social classes are dominantly located in the south and east of the city while the higher classes are located in the north and north-east of the city. Appendix C on page 95 shows a map of Bogotá with the different localities. The neighborhoods with predominantly low Estratas are Usme and Ciudad de Bolivar while higher Estratas are mostly found in Suba and Usaquén.

5.2 Transportation in Bogotá

The *Observatorio de Movilidad de Bogotá y la Región* (Mobility survey of Bogota and Region) of the Lá Cámara de Comercio de Bogotá (Chamber of Commerce of Bogotá), the Universidad de los Andes and the Secretaría Distrital de Movilidad (District Secretariat of Mobility) states that in 2005 a total of approximately 9.500.000 trips a day are made in the city of Bogotá [CCB, 2007]. Figure 5.2 shows the distribution of these trip to the various modes of transportation.

The majority of these trips are made by public transportation. 58 % of the trips are made by public buses or the TransMilenio. About 17 % of the trips are made with non-motorized transport of which 2 % by bicycle and 15 % by walking. About 19 % of the trips is made by cars (15 % private vehicles and 4 % taxi's). The distribution of trips to social classes is given in Figure 5.3.

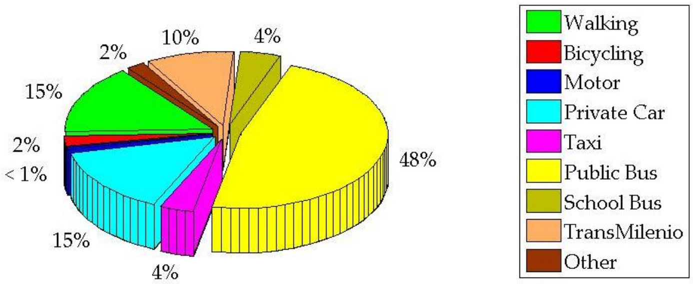


Figure 5.2: Distribution of Trips Bogotá [CCB, 2007]

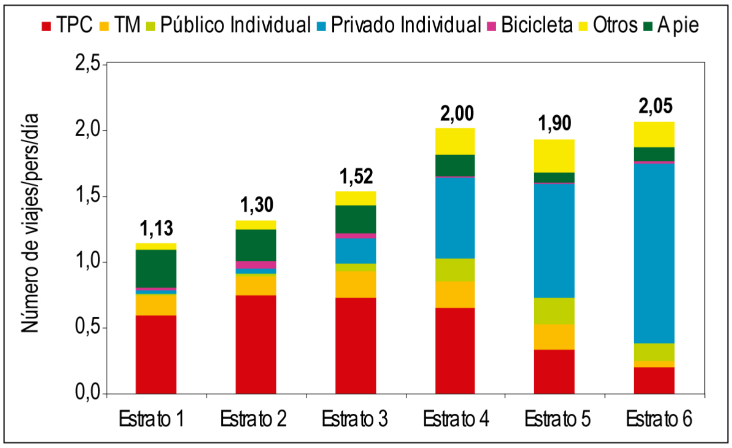
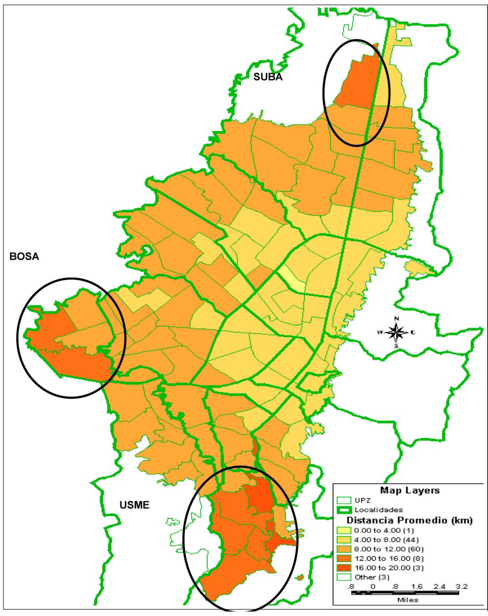


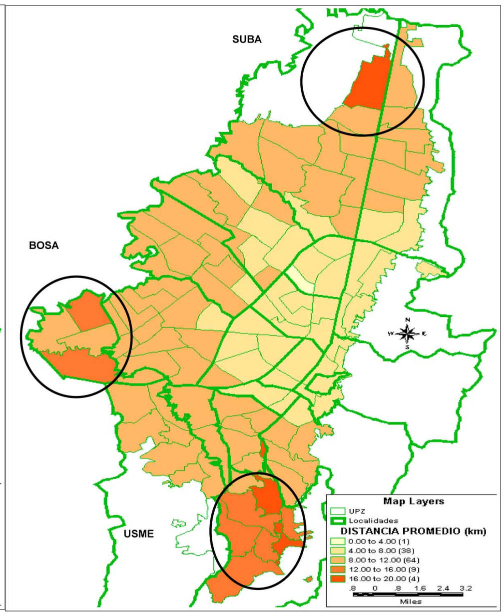
Figure 5.3: Distribution of Trips to Social Economic Estratas [CCB, 2007]

It shows that the number trips per day increases when going up in Estrata. Furthermore the share of public transportation and non-motorized transportation decreases while private transportation increases. This indicates that economic growth, resulting in people moving up in socio-economic Estrata, increases the share of private motorization in the streets of Bogotá. Figure 5.4a and 5.4b show the average trip length of travelers throughout the city of Bogotá for (a) all transportation modes and (b) public transportation. Travelers from the border of the city have the largest trip distances which is quite logical. The neighborhoods Usme and Bosa are among the poorest neighborhoods in the city which corresponds with high percentages of public transportation and non-motorized modes of transportation.

Over the last 15 years the're have been significant improvements to the transport network of the city. The TransMilenio BRT system now transports over 10 % of all travelers a day [CCB, 2007]. Furthermore non-motorized transportation gains in popularity mainly caused by the construction of the extensive bicycle network (ciclorutas). But also by the sunday event *Ciclovia* where major roads of the city are closed for motorized transportation and opened for recreational use of non-motorized transportation. Each sunday around 1 million recreants are using the Ciclovias resulting in increased awareness of the benefits of non-motorized transportation [Recreativa, 2009].



(a) For all Transportation Modes



(b) For Public Transportation

Figure 5.4: Trip Distance per neighborhood for (a) all transportation modes and (b) only the public transportation [CCB, 2007]

5.3 Data Collection

The development of a Shadow Traffic Model for the city of Bogotá requires input data in the form of a trip database of all trips made in the city and empirical data for the construction of the observed shadow traffic performance for validation and calibration purposes.

5.3.1 Input Data Collection

For the input data the database as used in the Observatorio de Movilidad ([CCB, 2007]) is obtained. The base of this report is the *Encuesta de Movilidad*. This mobility survey was performed by the Secretaría Distrital de Movilidad (District Secretariat of Mobility, SDM) and the Departemento Nacional de Estadística (National Department of Statistics, DANE) in 2005 [SDM, 2005b]. It was conducted in Bogotá and its 17 neighboring municipalities, together forming the urban region of Bogotá.

In total 20.686 respondents were asked to fill in trip diaries with transportation mode, purpose and origin/destination as well as extensive information on their socio-economic backgrounds. The respondents were selected throughout the complete region of research and with different economic backgrounds. The distribution of respondents over the different Estratas is made proportionally with the real distribution of inhabitants in the Estratas and is given in Figure 5.5.

This trip diary surveys resulted in a database of 90.637 trips which represents the average amount of trips made by the surveyed group per day. Expansion factors are used to expand the trips made by the respondents to the total population of the Bogotá Region. For the expansion of the trips in the Shadow Traffic Model as developed in this research two expansion factors are used. The first expansion factor comes directly from the Observatorio de Movilidad. This is a trip related expansion factor and directly expands each trip to obtain the corresponding city wide total. They are based on general information

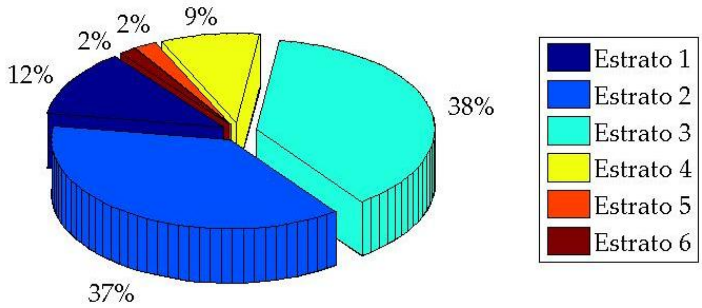


Figure 5.5: Distribution of respondents over Estratas [SDM, 2005a]

on the population, modal splits and distribution in time and are discussed in the final report of the District Secretariat of Mobility [SDM, 2005c]. A second expansion factor is a general factor applied to all trips and accounts for the lost trips caused by input errors in the Observatorio de Movilidad (from the 90.637 trips 12.100 trips have incomplete information, see section 6.1 on 55 for a more detailed explanation). This results in a total amount of trips made on an average day in Bogotá Region of 10.012.062.

The database resulting from this survey forms a perfect base for the input data as requested by the Shadow Traffic Model proposed in this document. Furthermore it provides detailed information on the socio-economic background of the travelers (and the total population of Bogotá) and the transportation modes, purposes and origin/destination making this suitable for this research.

5.3.2 Calibration and Validation Data Collection

Empirical data is collected to construct observed shadow traffic performance which are used to validate and calibrate the modeled shadow traffic performance. The empirical data collection should therefore collect similar information as to the modeled results: trip length, transportation mode, purpose of trip and socio-economic background (Estrata). Furthermore it must provide information suitable for the validation and calibration of the model assumptions regarding the percentage of trips that are substituted and that travelers from similar travel pattern combinations behave equally. The data that has to be collected is purely theoretical because it is not possible to observe the traffic performance without bicycles in real life. A stated preference survey of bicyclists is the best choice for this kind of field survey.

In cooperation with the School of Medicine of the Universidad de Los Andes a stated preference survey of bicyclists is developed in August and September of 2009. The shadow traffic performance stated preference survey is part of a much broader Cicloruta / Ciclovia survey of the School of Medicine consisting of several different MSc and PhD field researches. The final questionnaire of this survey is provided in Appendix D in Spanish. This survey is executed solely for bicyclists using the Ciclurutas. In short the following questions are of developed for this research:

- Question 5: What is your home address? **Information on socio-economic background of traveler**
- Question 12: What is your purpose for this trip? **Information on purpose for trip**
- Question 13: What transportation modes are available to you in terms of accessibility and costs?

Information on the equality of mode choices for travelers in similar travel pattern combination

- Question 14: If you could not use your bicycle for this trip, would you still make this trip? **Information on the ratio of substitution of bicycle trips**
- Question 15: Which transportation mode would you use for this trip if you can not use your bicycle? **shadow traffic performance**

Based on the answers to these questions the observed shadow traffic performance specified to Estrata and/or purpose of trip can be made. The observed shadow traffic performance is then used to validate and calibrate the Shadow Traffic Model and the model assumptions. The only problem with the field survey is that is being held in October and November of 2009 meaning that the results of this study are not available for processing in this MSc report. This report therefore only discusses the method of validation and calibration while the actual processing of the empirical data is done in a post-MSc program in cooperation with one of the partners in this research.

Chapter 6

Analysis of the Shadow Traffic Model of Bogotá

This chapter discusses the results of developing the shadow traffic model for the study case of the Bogotá urban region. Matlab v.2008b [Mathworks, 2008] was used as modeling environment for the shadow traffic model because it can handle large data packages such as the Observatorio de Movilidad database. Furthermore it provides a flexible environment in which adjustments to the model are easily made. The following sections discuss the results of the Shadow Traffic Model applied to the study case Bogotá.

6.1 Input Data Evaluation

The first two steps of the Shadow Traffic Model as discussed in section 4.3 evaluate the current traffic performance of the study case. The construction of the TLFDs and TLPDs for the study case are preceded by a data evaluation module that aims at evaluating the data (as provided from the Observatorio de Movilidad) and preparing it for model input by cleaning it from illegal entries. The database of the Observatorio de Movilidad as provided by the Secretaría Distrital de Movilidad consists of four different modules. Module A provides the socio-economic information of the respondent and; Module B provides information on the availability of different transport modes to the respondent; Module C provides the more detailed characteristics of the household members; and Module D provides the actual trip information of the respondent and the expansion factor for each trip [SDM, 2005b]. For the Shadow Traffic Model only the Trip Length, Transportation Mode, Socio-Economic Status (Estrata), Motive of Trip and Expansion Factor are of interest. This results in a Trip Database of 90.637 trips.

The originial database uses 17 different modes of transportation. The first step in the data cleaning process is to summarize these modes to 9 different modes of transportation corresponding to Figure 5.2. The second step is to review all the entries (Trips) in their consistency of data entry. In other words, to evaluate whether or not all variables for each entry have been entered correctly. If information is missing the entry is deleted because without the variable information it is not possible to attribute a trip to a specific travel pattern combination. These errors occurred when the data was not entered correctly or was forgotten by the respondent. It is assumed that these errors are random and not systematical. Data evaluation showed that only 78.537 trips remain from the 90.637. This is a percentage of 87 % of the total trips that can be included in the Shadow Traffic Model. Assuming that the deleted 13 % are from the same distribution, which is a logical assumption when looking at the large sample size, it is possible to adopt an adjustment factor to account for this loss in trips in the model development. This adjustment factor is applied when constructing the present traffic performance. The factor is calculated at $1/0.87 = 1.15$. Table 6.1 provides an overview of the variables in the Shadow Traffic Model and their values and the explanation of their values.

Trip ID	Trip Length	Transportation Mode	Estrata Respondent	Trip Motive	Expansion Factor
[1:78537]	[0.38:75.85] km.	1. Walking 2. Bicycling 3. Motor 4. Car 5. Taxi 6. Public Bus 7. Private Bus 8. TransMilenio 9. Other	1. Estrata 1 2. Estrata 2 3. Estrata 3 4. Estrata 4 5. Estrata 5 6. Estrata 6	1. Return Home 2. Work 3. Study 4. Business 5. Shopping 6. Personal 7. Transfer 8. Other	[3.7:2453]

Table 6.1: Overview of Variables

In addition to the adjustment factor for lost trips in the data cleaning process the Observatorio itself provides expansion factors for each trip to account for the complete traffic performance of Bogotá. Expansion of the trip 78.537 trips in the trip database with the trip specific expansion factors and the general expansion factor leads to a total collection of 10.012.062 trips that are being made daily in Bogotá Region. This is around 600.000 trips more then compared to the results from the Observatorio de Movilidad as published by the Camara de Comercio Bogotá as can be read in section 5.2. This is probably caused by a different model approach and data interpretation of the Cámara de Comercio de Bogotá. Figure 6.1 shows the distribution of trips over the different Estratas.

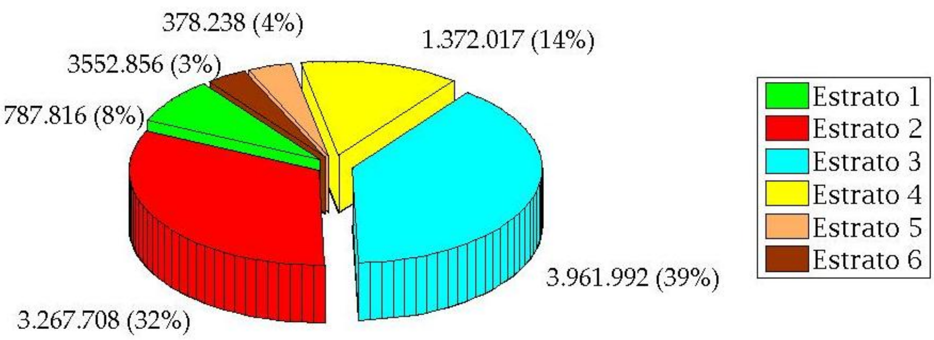


Figure 6.1: Total Trips per Estrata from Observatorio de Movilidad [SDM, 2005b]

6.2 Model Parameters

Before the Shadow Traffic Model can be developed the model parameters have to be set up. The choice for bin size and travel pattern combinations have influence on the model and should be investigated.

6.2.1 Bin Size

Since the Shadow Traffic Model is based on frequency distributions the size of the bins plays an important role. Small bins might provide more detailed information but requires larger databases to validly fill the

TLFDs. Larger bin sizes creates less detailed TLFDs but require less data. To analyze the robustness of the model results by using different bin size, the Shadow Traffic Model is developed for three bin sizes: 1 km, 2.5 km and 5 km. Smaller bin sizes are unfeasible regarding the amount of trips in the database.

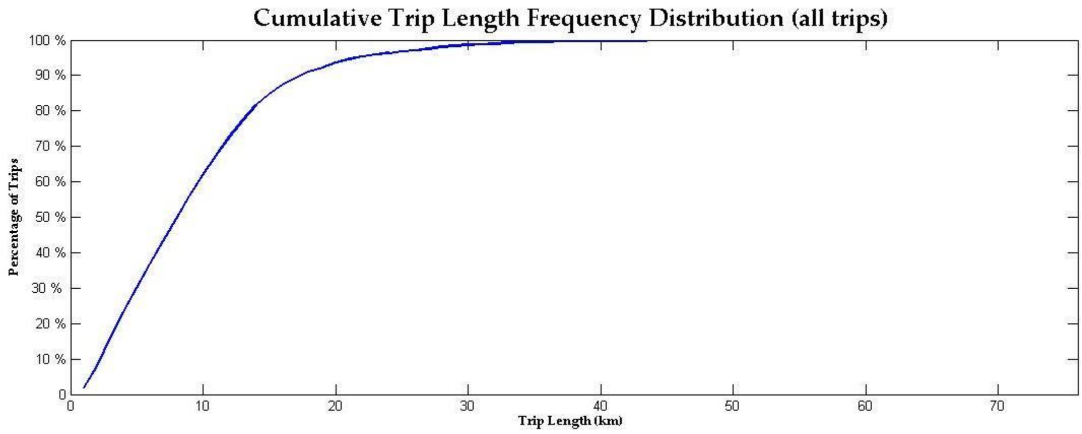


Figure 6.2: Trip Length Distribution for all trips in Bogotá Region

Figure 6.2 shows the cumulative trip length distribution of all trips in Bogotá Region using. It concludes that 98 % of all trips made are less then 30 km. Since only 2 % of the trips are larger then 30 km it makes no sense to make bins between 30 km and 76 km (the largest trip distance in the database). Therefore the bins are constructed up to 30 km and all the trips larger then that are placed in one final bin >30 km. This results in 31 bins for the 1 km bin size; 13 bins for the 2.5 km bin size; 7 bins for the 5 km bin size.

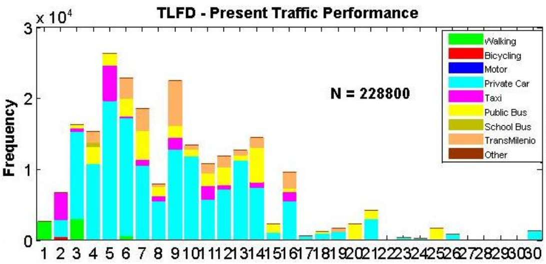
6.2.2 Travel Pattern Combinations

The Shadow Traffic Model assumes that travelers with similar travel pattern combination make similar mode choices. The selection of more detailed travel pattern combinations leads to more detailed choice information which result in more accurate model estimations. The quantity of input data and the bin size are factors here. For the construction of the trip length frequency distributions sufficient input data is required in order to create valid distributions. The choice for travel pattern combinations or explaining variables is therefore dependent on the quality and quantity of the input data. The Observatorio de Movilidad provides information for each trip in the database on gender, educational background, working or not, household information such as number of persons and vehicle ownerships, purpose of trip, etc. Although all these parameters could be useful in explaining choice behavior of the travelers in the Shadow Traffic Model of Bogotá only socio-economic background and purpose of trip are selected. The choice for socio-economic background is based on the fact that Bogotá has a very well classification of socio-economic statuses in the form of geo-referenced Estratas. It is therefore an easy applicable variable and has strong explaining behavior since mode choices are closely related to the socio-economic status of the traveler. Purpose is selected as second explaining variable because the purpose of trips provides significant information on the preferred modes. Generally people use specific modes for their work related trips which are different then for their shopping or transfer related trips. Therefore purpose of trip is also selected as explaining variable in the travel pattern combination. It is arguable whether or not other variables should be added as well. For example vehicle ownership provides detailed information in terms of availability of transportation modes. However it has less explaining power for the lower Estratas, in which most of the bicycle trips are located, since people in these Estratas generally don't own a vehicle.

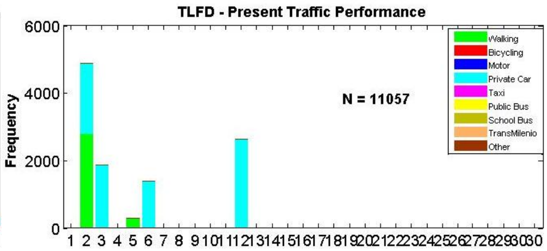
For the Shadow Traffic Model of Bogotá four aggregation levels are therefore selected:

1. All Trips
2. Trips Specified to High Socio-Economic Status (Estratas 4 - 6) and Low Socio-Economic Status (Estratas 1 - 3)
3. Trips specified to 6 Socio-Economic Statuses (Estratas 1 to 6)
4. Trips specified to 6 Socio-Economic Statuses (Estratas 1 to 6) and 8 Purposes (Purpose 1 to 8)

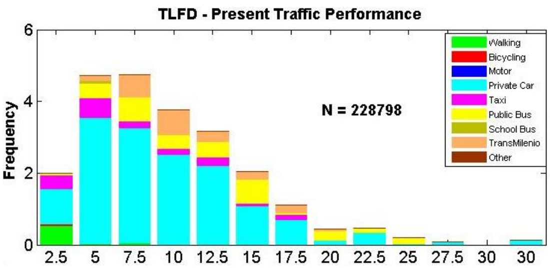
The first level is obviously feasible but provides no other explaining variables other then trip length to estimate shadow modes. The second level divides the dataset in two clusters of 66.554 trips (Low) and 11.983 (High) trips. It shows that most trips are located in the Low Estratas therefore disaggregation to the different Estratas will provide more detailed information on the choice behavior of travelers. The third level seems feasible because the average amount of trips in each Estrata is around 13.000 (and an expanded average of 1.972.000) which is assumed to be an sufficient amount counts for the construction of a frequency distribution.



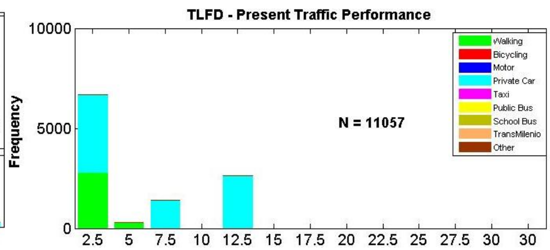
(a) Work 1 km bin



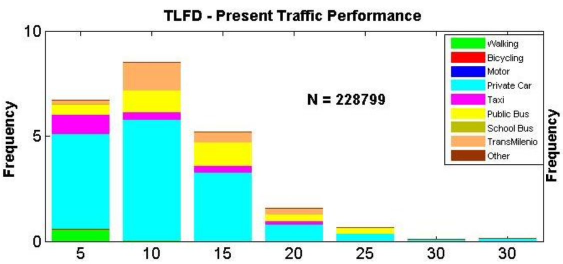
(b) Shopping 1 km bin



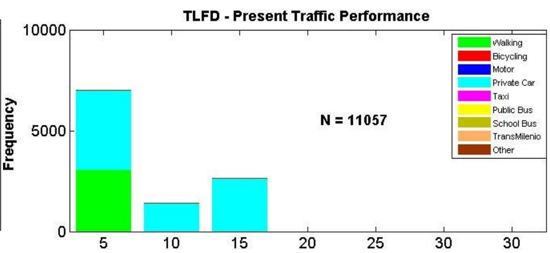
(c) Work 2.5 km bin



(d) Shopping 2.5 km bin



(e) Work 5 km bin



(f) Shopping 5 km bin

Figure 6.3: Trip Length Frequency Distributions for Estrata 5 (a),(c), (e) work and (b), (d), (f) shopping

Graphical analysis of the fourth aggregation level (aggregation to Estrata and Purpose) gives insight in the feasibility of this level of aggregation. Figure 6.3 shows the TLFD plots for Estrata 5 and the purposes

'Work' and 'Shopping'. It clearly shows the differences in form between a validly ('work') and invalidly ('shopping') filled TLFD. An 'Invalid TLFD' is identified when the slope shows strange peaks and valleys as can plotted in 6.3b. Another reason that a TLFD is selected as 'Invalid' is that an insufficient amount of different modes are present in the TLFD as shown in Figure 6.3f. Although it indicates that the Walking and Private Car are the most dominant modes of transportation for Estrata 5 and the Purpose of Shopping, it still deems illogical that only 2 modes of transportation are used of the purpose of shopping in Estrata 5 for the complete Bogotá Region. Figures 6.3a, 6.3c and 6.3e represent 'Valid TLFDs' for the three different bin sizes. A decrease in bin size improves the form of the TLFD nevertheless they are still invalidly filled as can be seen in Figures 6.3b, 6.3d and 6.3f were the TLFD Estrata 5, Purpose Shopping are plotted.

When looking at the amount of trips in these TLFD, Estrata 5 and the Purpose shopping accounts for 11.057 which represents only 0.1 % of the total amount of trips in the Shadow Traffic Model. A second importation notion is that the TLFDs for Estrata 5 - Shopping doesn't contain any bicycle trips. This means that this TLFD will already be skipped in the Shadow Traffic Model. Concluding, if the total amount trips and the total amount of bicycle trips in all 'Invalid TLFDs' are relatively small it can still be a good choice to use this third level of aggregation because the increase in detail for the other TLFDs provides extra information for the shadow mode choice model which is a big benefit.

Bin Size (km)	# Invalid TLFDs	% Trips	% Bicycle Trips
1	18 (1)	1.56	1.02
2.5	14 (3)	1.01	1.02
5	11 (3)	0.72	0.34

Table 6.2: Results from Graphic Analysis of TLFDs of Estrata-Purpose Aggregation Level

For the second aggregation level (only Estratas) all the TLFDs are accepted as provided in Figure 6.5. Table E.1 on page 104 shows the results of the graphic analysis of the third aggregation level (Estratas - Purposes). This table concludes that only ± 1 % of all bicycle trips are within a 'bad TLFD'. For the 1 and 2.5 km bin sizes these bicycle trips are only in 3 TLFDs while for the 5 km bin size only 1 TLFD contains bicycle trips, of a total of 48 TLFDs. Based on these neglibgible small amount of trips it can be concluded that the Shadow Traffic Model can validly be developed for both the second as third aggregation level.

6.2.3 Summary

The Shadow Traffic Model will therefore be executed for 6 different setups. The results of these different models will be compared an analyzed to assess the robustness of the model. The following setups are used:

1. All Trips Model: 1 km Bin Size / 2.5 km Bin Size / 5 km Bin Size

2. Low-High Model: 1 km Bin Size / 2.5 km Bin Size / 5 km Bin Size

3. Estrata Model: 1 km Bin Size / 2.5 km Bin Size / 5 km Bin Size

4. Estrata - Purpose Model: 1 km Bin Size / 2.5 km Bin Size / 5 km Bin Size

6.3 Present Traffic Performance of Bogotá

The present traffic performance is constructed based on the information provided by the Observatorio de Movilidad. This section gives an overview of the results of this model step:

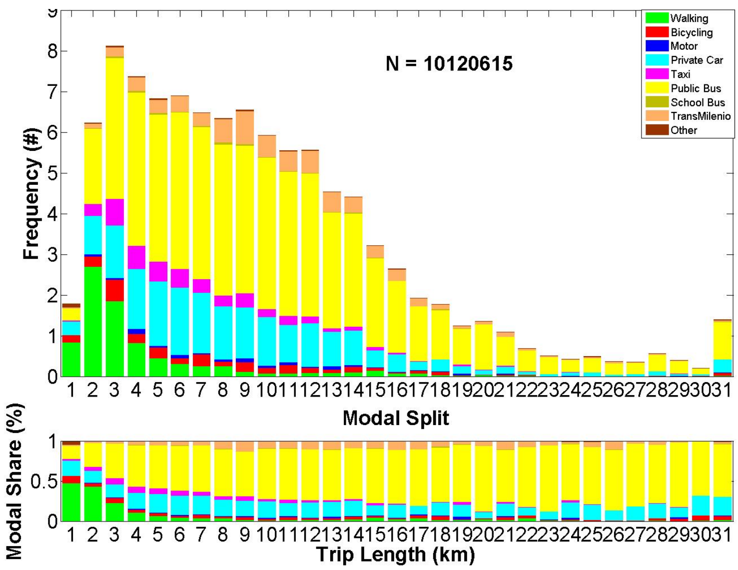
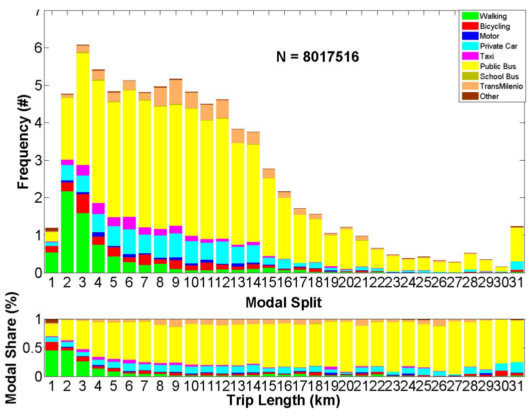
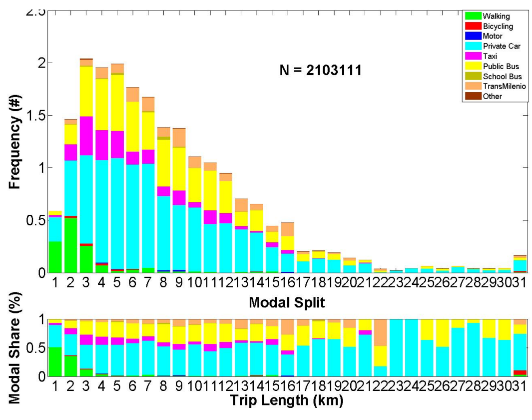


Figure 6.4: TLFD: Present Traffic Performance of the All Trips Model - 1km Bin Size

Figure 6.4 indicates that most trips in Bogotá are made by Public Transportation, yellow. The trips in red are made by Bicycle. The disaggregation of All Trips to the Low-High divisions leads to more insight in the present traffic performance of Bototá.



(a) TLFD: All Trips in Low (Estratas 1 - 3)



(b) TLFD: All Trips in High (Estratas 4 - 6)

Figure 6.5: TLFD: Present Traffic Performance of the Low-High Model - 1km Bin Size

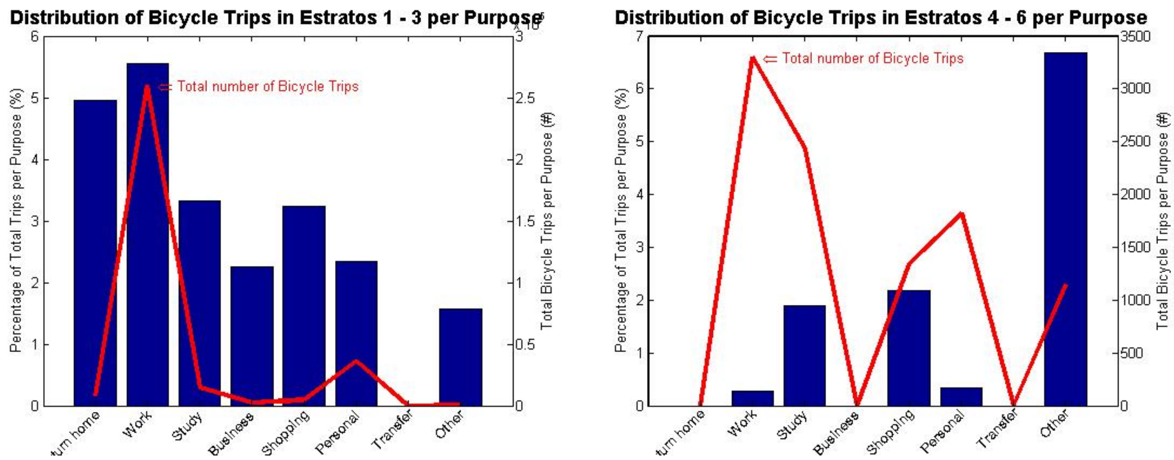
Figure 6.5 shows that the public transportation and non-motorized modes of transportation are dominant in the lowest three Estratas. In the lower three Estratas public transportation accounts for almost 80 % of all trips. As for bicycling, 97 % of all bicycle trips made in Bogotá Region are made by people from the lower Estratas. Private transportation is the dominant transportation mode in the highest three Estratas. This indicates that the division in Estratas definately has affect on the Shadow Traffic Modes because most of the bicycle trips will probably be substituted by public transportation trips while in the All Trips level Private Car will also take show up with large substition. Based on this information the disaggregation to different levels of detail will give more information on mode choices.

A second conclusion that can be drawn from these figures is that travelers from the lower Estratas significantly travel more kilometer since the peaks in the TLFD are much broader, remaining up to 14/15 km while in the higher three Estratas the peaks are <10 and declining fast after that. The total distance traveled in Bogotá Region per day is ± 94 million kilometers. In total 83 % or ± 78 million kilometers are made by people from the lower Estratas. First of all this is caused by the fact that 67 % of the total population is from these Estratas. Second because people from lower Estratas live at the borders of the city which requires them to travel longer distances to reach their destinations.

Estrata	Total Trips (#)	Mean Distance (km)	Total Distance (km)	Total Bicycle Trips	Mean Distance Bicycle (km)	Total Distance Bicycle (km)
1	787’816	8.3	10’192’819	30’530 (3.9 %)	10.5	415’654 (4.1 %)
2	3’267’708	10.9	34’174’614	203’578 (6.3 %)	13.8	1’706’631 (5.0 %)
3	3’961’992	9.5	33’232’334	92’963 (2.4 %)	10.8	489’886 (1.5 %)
4	1’372’017	5.7	10’607’087	7’331 (0.5 %)	2.0	64’981 (0.6 %)
5	378’238	2.9	2’944’571	1’718 (0.5 %)	0.2	5’346 (0.2 %)
6	352’856	2.2	2’608’117	985 (0.3 %)	0.5	9’069 (0.4 %)
Total	10’120’627	6.6	93’759’542	337’105 (3.3 %)	6.28	2’691’567 (3.9 %)

Table 6.3: Present Traffic Performance of Bogotá Region. The percentage values in the columns Total Bicycle Trips and Total Distance Bicycle are the percentages value of each compared to their corresponding Estrata.

Table 6.3 shows the overview of the Present Traffic Performance of Bogotá Region for the Estrata Model. The table also shows that the bulk of bicycle trips are within the first three Estratas. Almost 97 % of all bicycle trips are located in the lowest three Estratas. This shows that bicyclingn currently is a mode of transporation almost solely used by the poor of Bogotá. The percentages between the brackets gives the modal share of bicycling in each Estrata indicating that the bicycle is the most important transportation mode in Estrata 2. Furthermore it gives the remarkable information that people from the higher Estratas mostly use the bicycle for really short trips.



(a) Estrata 1 **(b)** Estrata 2

Figure 6.6: Distribution of Bicycle Trips for Low (6.6a) and High (6.6b) Estratas. The bars represent the modal shares of Bicycle Trips in each purpose while the red line gives the total number of bicycle trips

Figure 6.6 gives the ratios of bicycle trips for each purpose compared between the lower and higher Estratas. It can be concluded that people from low Estratas mostly use the bicycle the purposes Return Home, Work and Shopping, i.e. utilitarian uses. Although the absolute number of bicycle trips is the highest for Work purposes in the higher Estratas, the bicycle is relatively most used for 'Other' purposes which can be interpreted as 'Recreational' purposes. The bicycle is thus a more important mode choice for people from lower Estratas.

6.3.1 Summary of the Present Traffic Performance

Based on the analysis of the present traffic performance of Bogotá it can be concluded that the division of All Trips to (1) Low-High Estratas and (2) All 6 Estratas provides more information on the mode choices made by people from Bogotá. Figure 6.5 gives the valuable information that the private car is mostly used in the higher Estratas and not the lower ones while public transportation is more dominant in the lower Estratas. Furthermore it shows that bicycling is only being done in the lower Estratas. The division into socio-economic classes therefore is useful. Second when looking at Table 6.3 it indicates that the division of the Low socio-economic class into the different Estratas also provides more information. It indicates that in Estrata 2 the bicycle is more frequently used (6.3 % modal share) as opposed to the other two Estratas (3.9 % for Estrata 1 and 2.5 % for Estrata 2).

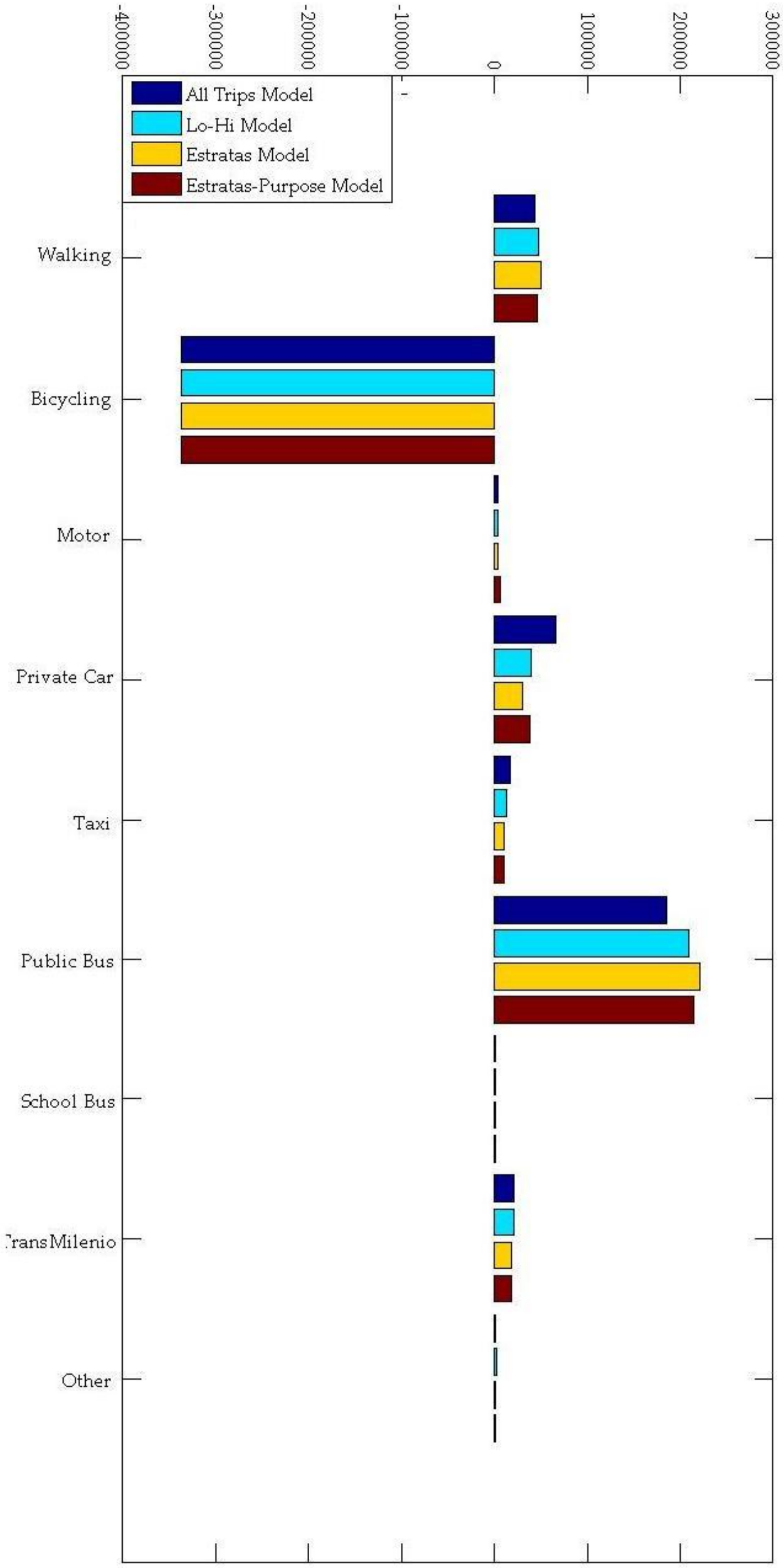
6.4 Shadow Traffic Performance of Bogotá

For the definition of the Shadow Traffic Performance first the Trip Length Probability Distribution (TLPD, see Section 4.3) are calculated. The TLPD gives the modal share in each trip length box of the transportation modes in the present traffic situation excluding the bicycle mode. Thus the TLPD defines the probabilities of substitution of the bicycle trips. The Shadow Traffic Performance is then calculated by assigning the substitution trips based on the TLPD ratios.

6.4.1 Shadow Traffic Performance

The model results of the shadow traffic performance estimation of the Shadow Traffic Model are given by the Δ number of trips caused by the substitution of all bicycle trips. The overall results for all different bin sizes and model setups are given by Δ trips or Δ passenger kilometers traveled in an i-by-s-by-b matrix where i corresponds to the transportation mode, s to the model aggregation level and b to the bin size. To give an example of the model results for the 1km Bin Size, Figure 6.7 plots the shadow traffic performances for the four different aggregation levels. Since the results are given in Δ trips all bicycle trips are negative because these trips are discarded from the traffic performance. In Figure 6.7 the results of the shadow traffic performance estimation for all four aggregation levels are aggregated to the highest level (All Trips). This means that depending on the aggregation level of the model setup the results need to be summed over the dimensions trip length (for all Models), socio-economic status (only for the Lo-Hi, Estrata and Estrata-Purpose Models) and purpose (only for the Estrata-Purpose Model).

The results indicate that for the 1 km bin size the substitutions are equal in order of magnitude but do show slight variations in results. Most trips, approximately 55-65 % of all bicycle trips, are substituted by the Public Bus system. Second is the alternative Walking accounting for aprroximately 13-15% of all substitutions. The third most important substitution mode is the Private Car accounting for 11-19 % of all bicycle substitutions. It can be concluded that these three modes of transportation have the



#PKT (km)	#Model
43,022	All Trips Model
47,231	Lo-Hi Model
49,590	Estrata Model
46,588	Estrata-Purpose Model
-337,104	All Trips Model
-337,105	Lo-Hi Model
-337,105	Estrata Model
-337,105	Estrata-Purpose Model
3,160	All Trips Model
3,760	Lo-Hi Model
4,345	Estrata Model
6,113	Estrata-Purpose Model
65,378	All Trips Model
39,797	Lo-Hi Model
39,294	Estrata Model
38,570	Estrata-Purpose Model
16,890	All Trips Model
12,493	Lo-Hi Model
10,427	Estrata Model
10,453	Estrata-Purpose Model
184,863	All Trips Model
209,686	Lo-Hi Model
221,773	Estrata Model
214,181	Estrata-Purpose Model
1,383	All Trips Model
1,271	Lo-Hi Model
1,186	Estrata Model
1,520	Estrata-Purpose Model
20,778	All Trips Model
20,719	Lo-Hi Model
18,616	Estrata Model
18,391	Estrata-Purpose Model
1,625	All Trips Model
2,238	Lo-Hi Model
962	Estrata Model
1,293	Estrata-Purpose Model

Figure 6.7: Shadow Traffic Performance for the Four Different Model Setups with 1km Bin Size

strongest relation with bicycling in terms of mode choices. With respect to the Transportation Market of Schoemaker [Schoemaker, 2002], the cross-elasticity between the Bicycle market and the Public Bus market is by far the strongest followed by Walking and Private Car. Any changes on these markets thus have a strong effect on the Bicycle Market as well.

6.4.2 Comparison of Model Setups

As mentioned, the analysis of Figure 6.7 also shows slight differences in the model results for the different model setups especially for the highlighted transportation modes Private Car and Public Bus. For the Private Car the difference between the All Trips Model and the Estrata-Purpose Model is almost a factor of 2. For the Public Bus the relative difference are smaller but their absolute values have a significant effect on the model results of the different setups. The occurrence of these difference indicates that the disaggregation to other explaining variables such as the socio-economic status and purpose of the trip have an impact on the model results.

But how can the differences between the different model setups be explained? And what conclusions regarding the effects of the inclusion of the explaining variables trip length (bin size), socio-economic status and purpose can be made from this. For the analysis of the difference in model output, the simple Standard Deviation (σ) can already provide information. The Standard Deviation (σ) is a measure for the reliability of a statistical estimate [Dodge, 2003]. Although σ is not a sufficient measure to test the hypothesis of equality in distributions it does give information on the existence of variance between distributions. The measure of variance gives information if the modeled results differ from each other and to what extent. In this case the standard deviation is calculated for the modeled shadow traffic performance for each transportation mode i and the mean results within the three different bin sizes b or the four different aggregation levels s. By the analysis of σ, the different effects related to either the change in bin size or the change in aggregation level can be identified. σ Bin concludes on the statistical differences in model output related to changing bin sizes. σ Model gives information on the statistical differences in model output caused by the use of different aggregation levels. To obtain the σ values, the model results first have to be averaged over either the dimension aggregation level/model setup (for the evaluation of the bin size effect) or the dimension bin size (for the evaluation of the aggregation level/model setup effect). σ Bin is calculated based on the averaged model results of the four different Model Setups within each bin size (1, 2.5 and 5km) with the following formulas:

$$x_{i,b} = \frac{\sum_{s=1}^{n_s} x_{i,s,b}}{n_s} \qquad \forall\, i,\ b \tag{6.1}$$

$$\mu\, bin_i = \frac{\sum_{b=1}^{n_b} x_{i,b}}{n_b} \qquad \forall\, i \tag{6.2}$$

$$\sigma\, bin_i = \sqrt{\frac{1}{n_b - 1}\sum_{b=1}^{n_b}(x_{i,b} - \mu\, bin_i)^2} \qquad \forall\, i \tag{6.3}$$

Where:

$x_{i,b}$	Number of Trips for bin size b and transportation mode i when averaged over all four model setups
$x_{i,s,b}$	Number of Trips for bin size b, transportation mode i and model setup s
n_s	Total number of model setups (aggregation levels): 4
$\mu\ bin_i$	Mean number of trips within Bin Size for transportation mode i
n_b	Total number of bins: 3
$\sigma\ bin_i$	Standard Deviation within Bin Size for transportation mode i

σ Model is calculated based on the averaged model results of the three different bin sizes within each Model Setup. It uses the following formula:

$$x_{i,s} = \frac{\sum_{b=1}^{n_b} x_{i,s,b}}{n_b} \qquad \forall\ i,\ s \tag{6.4}$$

$$\mu\ model_i = \frac{\sum_{s=1}^{n_s} x_{i,s}}{n_s} \qquad \forall\ i \tag{6.5}$$

$$\sigma\ model_i = \sqrt{\frac{1}{n_s - 1}\sum_{s=1}^{n_s}(x_{i,s} - \mu\ model_i)^2} \qquad \forall\ i \tag{6.6}$$

Where:

$x_{i,s}$	Number of Trips for model setup s and transportation mode i when averaged over all three bin sizes
$\mu\ model_i$	Mean number of trips within Model Setups for transportation mode i
$\sigma\ model_i$	Standard Deviation within Model Setups for transportation mode i

Table 6.4 provides the results of these calculations. The σ values presented in this table are absolute values and should be compared, in order of magnitude, with the μ values for each transportation mode. The σ values indicate that the use of different bin sizes show significantly less variance in the model results than the use of different aggregation levels. For example the Private Car: the σ Bin value of 325 and the σ Model value of 15,377 on a μ of 43,092 indicate clearly that (1) aggregation levels results in larger variances in model results than bin sizes and (2) there are significant differences in model results between the different aggregation levels. Based on this information it can be concluded that it does not matter which of the three bin sizes are used for the Shadow Traffic Model while it does matter which aggregation level is used. In other words, socio-economic status and/or purpose of trip are thus important variables when explaining shadow mode choice behavior while trip lengths only have to be specified to bin ranges of 5km.

When comparing the σ values with the μ values for each transportation mode, it can be concluded that the differences mainly occur for the transportation modes Private Car and Public Bus and to a lesser extent Walking and Taxi. It deems logical that the first three transportation modes show the highest σ values since these three transportation modes are the most important substitutions for bicycle trips,

Mode	σ Bin	σ Model	μ
Walking	2,686	2,547	44,923
Bicycling	0	0	-337,105
Motor	99	1,174	4,459
Private Car	325	15,377	43,092
Taxi	143	3,029	12,648
Public Bus	2,478	16,368	209,596
School Bus	85	89	12,54
TransMilenio	398	1,497	19,546
Other	81	342	1,588

Table 6.4: Standard Deviations of Bin Sizes (Column 2) and Aggregation Level (Column 3) and the Means for each transportation mode in the Shadow Traffic Performance Estimations

hence the large absolute μ values for these modes. By performing a more detailed analysis of the results given in Figure 6.7 more insight in the reasons for these variances in model results can be obtained. Since it was concluded that bin sizes don't have an (significant) impact on the model results it also does not matter which bin size results are used for this analysis.

	All Trips Model	Δ	**Lo-Hi Model**	Δ	**Estrata Model**	Δ	**Estrata-Purpose Model**
Walking	43,022	4,209	47,231	2,359	49,590	-3,002	46,588
Bicycling	-337,105	0	-337,105	0	-337,105	0	-337,105
Motor	3,160	600	3,760	585	4,345	1,768	6,113
Private Car	**65,378**	**-25,671**	**39,707**	**-9,503**	**30,204**	**8,366**	**38,570**
Taxi	16,890	-4,397	12,493	-2,066	10,427	26	10,453
Public Bus	**184,863**	**24,823**	**209,686**	**12,087**	**221,773**	**-7,592**	**214,181**
School Bus	1,383	-112	1,271	-85	1,186	334	1,520
TransMilenio	20,778	-59	20,719	-2,103	18,616	-225	18,391
Other	1,625	613	2,238	-1,276	962	331	1,293

Table 6.5: Analysis of the Differences in Shadow Traffic Performance Estimation

Table 6.5 shows the model output for the shadow traffic performance estimation of the four different model setups (while using bin size 1km). It is important to analyze this variance because the trade-off between the different transportation modes has a large impact on the final emission modeling as discussed in the next section.

The differences between the All Trips Model and the Lo-Hi model, especially for the modes Private Car and the Public Bus, are caused by the fact that the All Trips Model uses averaged probabilities over the total population of trips while the Lo-Hi model specifies between trips made in the lower Estratas and higher Estratas. This causes the All Trips Model to overestimate Private Car substitution and underestimate Public Bus substitution compared with the Lo-Hi Model. As discussed in section 6.3 it is concluded that 97 % of all bicycle trips are located in the lower Estratas. The averaging of all trips from both the lower and higher Estratas in the All Trips Model skews the modal splits resulting in the differences in results between the All Trips Model and the Lo-Hi Model.

Figure 6.8 shows the mentioned effect. The average modal split used for the shadow mode determination of the All Trips Model is showed on the left and the average modal split of the Lower Estratas from the Lo-Hi Model is showed on the right. Since 97 % of the bicycle trips are within the lower Estratas the comparison between both distributions is reasonable. The comparision shows that because of the inclusion of the modal splits from the higher Estratas the Private Car is overestimated and the Public Bus is underestimated.

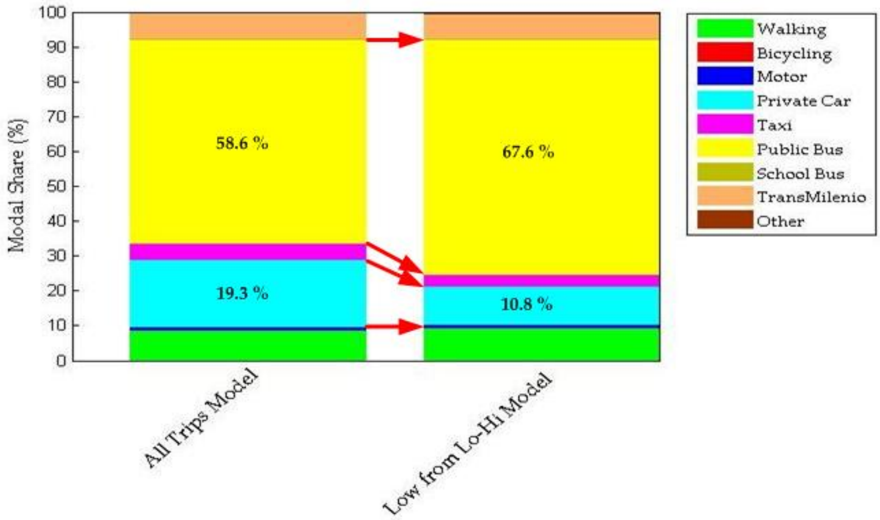


Figure 6.8: Modal Split Differences between All Trips Model and the Low section of Lo-Hi Model

The comparison between the Lo-Hi Model and the Estrata-Model shows a similar effect. Compared with the Estrata-Model, the Lo-Hi model overestimates Private Car substitution while underestimating Public Bus substitution. This is caused by the same effect that an increase in aggregation level creates a more precise estimations because the disaggregated modal splits are stronger related to the bicycle trips that substituted. Based on this information it can be concluded that the integration of socio-economic information has a significant impact on the model results and should therefore be included in the model.

The most detailed aggregation is given by the Estrata-Purpose Model. When comparing the values given in Table 6.5 it shows a different effect than the higher aggregation levels. Compared with the Estrata Model the Estrata-Purpose Model just gives a higher estimate for Private Car Substitution and a lower estimate for the Public Bus substitution. However the differences are still lower than for the other comparisons. The reason for this effect to occur is that when disaggregating to purposes it some trip purposes in the lower Estratas have both a larger Private Car as Bicycle share compared to other purposes. This results in the higher estimation of Private Car substitution in the Estrata-Purpose Model.

The differences resulting from the increase in aggregation level from Estrata to Estrata and Purpose are not significantly changing the order of magnitude of the results. Keeping in mind that purpose information might be difficult to include in datasets for future case studies it might be sufficient to use only the socio-economic data. Validation of the model results with field data could also provide insight in this.

Table 6.6 gives the passenger kilometer traveled (PKT) values for all transportation modes and all four aggregation models (1km bin size). The total values are zero indicating that all bicycle kilometers are substituted by other transportation modes.

	All Trips	Lo-Hi	Estrata	Estrata-Purpose
Walking	130,001	145,645	158,708	158,708
Bicycling	-2,691,569	-2,691,569	-2,691,569	-2,691,569
Motor	25,622	29,773	35,177	35,177
Private Car	514,171	345,981	235,539	235,539
Taxi	92,027	70,182	57,317	57,317
Public Bus	1,714,265	1,883,771	2,010,914	2,010,914
School Bus	11,259	10,470	8,063	8,063
TransMilenio	196,346	196,694	174,139	174,139
Other	7,878	9,053	11,712	11,712
Total	**0**	**0**	**0**	**0**

Table 6.6: PKT values for each Transportation Mode and for all four aggregation Models (1km bin size)

6.5 Calibration and Validation

The calibration and validation of the Shadow Traffic Model is a vital part of the model development. However because the empirical data collection is scheduled unfeasible for this MSc Research it is not possible to perform these steps as discussed in section 4.3.6 and 4.3.7. Future research should definitely process the validation data in order to make quantitative judgments on the best model setup. It also enables a judgment on which aggregation level would be sufficient in terms of the trade-off between the increased accuracy of the model results caused by more detailed information and the costs of collecting the more detailed data.

6.6 Emission Modeling

The final step of the Shadow Traffic Model is to calculate the total additional emission caused by the shadow traffic performance. This calculation is based on simple CO_2 emission factors per km^{-1} multiplied with the amount of traveled kilometers per transportation mode. One important remark here is that the Present Traffic Performance and the Shadow Traffic Performance are based on Passenger Kilometers Traveled. Emission factors are based on Vehicle Kilometers Traveled (VKT). PKTs have to be specified in VKT.

Transportation Mode	CO_2 per VKT (kg/km/vehicle)[1]	Average Occupancy Vehicles[2]	CO_2 per PKT bandwidth (kg/km/passenger)
Walking	-	-	-
Bicycling	-	-	-
Motors[3]	0.028	1.20	0.023
Private Car	0.280	1.37	0.204
Taxi	0.269	0.81[4]	0.332
Public Bus[5]	0.800	20-33[6]	0.040 - 0.024
School Bus	0.800	20-33[6]	0.040 - 0.024
TransMilenio	1.740	86-106[7]	0.020 - 0.016
Other[8]	1.179	1	1.179

Table 6.7: CO_2 Emission Factors. [1]Source: [Behrentz and Rodríguez, 2009]. [2]Source: [Grütter, 2006]. [3]Including mopeds and moto-tricycles. [4]Excluding taxi driver; some taxi's do not always carry passengers. [5]Including micro- and autobuses. [6]Based on 66 % occupancy (Source: [Grütter, 2006]) and 30-50 passenger capacity (own calculation based on [Behrentz and Rodríguez, 2009]). [7]Based on 66 % occupancy (Source: [Grütter, 2006]) and 130-160 passenger capacity (own calculation based on [Grütter, 2006]). [8]Including trucks, tractors and agrarian- and industrial vehicles.

Behrentz et al. from the Universidad de Los Andes in Bogotá performs frequent researches to the transport related emissions in Bogotá [Behrentz and Giraldo, 2006],[Behrentz and Rodríguez, 2009]. These researches provide detailed information on the vehicle fleet and the vehicle specific CO_2 emissions. The

Project Design Documents for the CDM approval of TransMilenio (see Appendix A) supplies data on the occupancy rate and capacity of vehicles [Grütter, 2006] which are necessary for the calculation of VKT from PKT. For some transportation modes literature provides exact estimations for other transportation modes a bandwidth is constructed based on estimations of capacities.

Table 6.7 gives the CO_2 factors per passenger kilometer traveled for each transportation mode in the Shadow Traffic Model. Walking and bicycling don't emit CO_2. Motors emit only small amounts because most motors and mopeds in Bogotá have small engine sizes. Only for the Public Bus, School Bus and TransMilenio a bandwidth is given since all other transportation modes have exact estimations based on the PDD of the TransMilenio. TransMilenio buses are articulated and therefore have more capacity then conventional public buses resulting in smaller PKT emission factors. Analysis of the emission factors shows that traveling by Public Bus or TransMilenio is far more efficient in terms of CO_2 emissions than the Private Car or Taxi. Each PKT by Private Car emits 5 to 8 times more CO_2 than a PKT by Public Bus. This is an interesting notion when calculating the total emissions of the shadow traffic performance.

	All Trips (tCO_2/year)	**Lo-Hi** (tCO_2/year)	**Estrata** (tCO_2/year)	**Estrata-Purpose** (tCO_2/year)
Walking	0	0	0	0
Bicycling	0	0	0	0
Motor	215	250	295	417
Private Car	38,285	25,762	17,538	21,743
Taxi	11,152	8,505	6,946	7,164
Public Bus	15,017 - 25,028	16,502 - 27,503	17,616 - 29,359	17,042 - 28,404
School Bus	99 - 164	92 - 153	71 - 118	102 169
TransMilenio	1,147 - 1,433	1,149 - 1,436	1,017 - 1,271	982 - 1,227
Other	3,390	3,896	5,040	8,235
Climate Value (bandwidth)	**69,305 - 79,667**	**56,156 - 67,505**	**48,523 - 60,567**	**55,685 - 67,359**
Climate Value (mean)	**74,486**	**61,831**	**54,545**	**61,522**

Table 6.8: Climate Value of Bicycling: Yearly CO_2 emissions avoided by bicycling in Bogotá for the four aggregation Models (1km bin size)

Table 6.8 gives the results of the emission modeling. The last two rows give the total added emissions caused by the shadow traffic performance and are the Climate Values for Bicycling for the different aggregation levels. The emission factors as estimated in Table 6.7 are applied to the PKT as given in Table 6.6. The use of a range of capacities for the bus services in the model leads to a bandwidth. More accurate field observation on the exact capacity can narrow this bandwidth.

Overall it shows that the yearly CO_2 emissions avoided by current bicycling in Bogotá accounts for 55,000 - 75,000 tCO_2/year. In more detail it indicates that in total the Private Car is emitting in the same order of magnitude as the Public Bus while the Private Car has far less substituted bicycle kilometers than the Public Bus (see Table 6.6, which is caused by the larger emission factors for Private Car. When comparing the different model setups it shows that for the All Trips Model the Private Car even emits more CO_2 per year than the Public Bus. For the other model setups the values are more or less the same. As discussed in the previous section the All Trips Model gives an overestimation of Private Car substitution and an underestimation of Public Bus substitution. Compared to the Estrata Model the All Trips model overestimates Private Car substitution even by a factor of 2.2. Based on this information it can be concluded that the results from the Lo-Hi, Estrata and Estrata-Purpose model are more plausible Climate Values of Bicycling for Bogotá.

The results in Table 6.8 represent the range of the Climate Value of Bicycling in Bogotá. The total **Climate Value of 3.3 % Bicycling in Bogotá represents a yearly amount of 55.000 - 62.000 tCO_2**. The results from the All Trips model are discarded since these are not found plausible. This means that for each percentage point (pp) of bicycling in the modal split the following Climate Values are applicable:

Model	Climate Value (ton/pp)
Lo-Hi	18,737
Estrata	16,529
Estrata-Purpose	18,643

Table 6.9: Climate Value per percentage-point of bicycle share in total modal split

6.7 Opportunities for Carbon Financing

6.7.1 The Value of Current Bicycling

When the avoided CO_2 by bicycle mobility could be traded as carbon credits on the carbon markets the true potential and context of the Climate Value of Bicycling becomes clear. As discussed in section 3.2 multiple carbon markets exist. For this analysis the CER (Certified Emission Reduction) and the VCI (Voluntary Carbon Index) market values are used to account for both the Clean Development Mechanism (CER) as the Voluntary Carbon Market (VCI). From August 2008 to April 2009 the average market value of a CER was $20.60 with a standard deviation of $4.80 [BlueNext, 2009]. For the same period the VCI average price was $9.80 with a standard deviation of $2.20 [Finance, 2009].

Model	Climate Value (tCO2/year)	VCI Price ($/ton)	CER Price ($/ton)	Climate Value (VCI) ($/year)	Climate Value (CER) ($/year)
Lo-Hi	61,831	$ 9.80 ± $ 2.20	$ 20.60 ± $ 4.80	$ 0.6m ± $ 0.15m	$ 1.3m ± $ 0.30m
Estrata	54,545	$ 9.80 ± $ 2.21	$ 20.60 ± $ 4.81	$ 0.5m ± $ 0.10m	$ 1.1m ± $ 0.25m
Estrata-Purpose	61,522	$ 9.80 ± $ 2.22	$ 20.60 ± $ 4.82	$ 0.6m ± $ 0.15m	$ 1.3m ± $ 0.30m

Table 6.10: Monetary Climate Value of current Bicycling in Bogotá

With the current market prices current bicycling in Bogotá represents a value of $0.5-0.6m per year on the Voluntary Carbon Markets and $1.1-1.3 in the Clean Development Mechanism which could be invested in better infrastructure or other bicycle beneficial projects. Because the VCI and CER market prices are dependent on market mechanisms these values can change in time which is not the case for the values given here. This calculation is merely done to give an indication of what the current bicycling would represent when it's benefits are monetized.

6.7.2 Carbon Financing Bicycle Projects

To assess the opportunities of carbon financing of bicycle projects let's suppose a scenario in which bicycle infrastructure investments lead to a larger share of bicycling in Bogotá. Suppose the simple project of a 20 year investment program in the bicycle network infrastructure of Bogotá (CicloRutas). The project aims at an 'Shift' of (motorized) transportation to non-emitting transportation modes by accommodating bicycling. Currently the CicluRuta network consists of 300km. The project has the following time line:

- Phase 1: 0-10 year → 250 km expansion of CicloRuta creating better connectivity for Estrata 1-3 neighborhoods

- Phase 2: 10-20 year → 250 km expansion of Cicloruta creating better connectivity for Estrata 4-6 neigborhoods

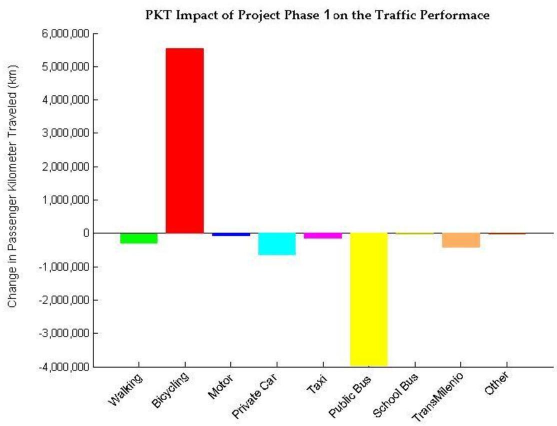
For the sake of the analysis it is assumed that the effects of the expansion of the network takes place immediately at the start of the phase. Since 97 % of all bicyclists are in the lower three Estratas it is assumed that effects in these areas are stronger than in the higher Estratas. For Phase 1 it is assumed that the total bicycle modal share increases from 3.3 % to 10 % all caused by bicycle trips that substitute other transportation modes, made by travelers from the lower three Estratas. For Phase 2 it is assumed that the bicycle modal share increases more from 10 % to 15 % all caused by bicycle trips that substitute other transportation modes, made by travelers from the higher three Estratas. This assumption seems reasonable since the network is already expanded and now accommodates the higher Estratas to their needs. For the calculation of the costs and benefits ceteris paribus is assumed. This means that only the first order effects are taken into account (see section 3.4.1).

Costs The costs of 1km of bicycle path are estimated at $ 130.000 [C40, 2009] and it's assumed that each km needs $ 5.000 maintenance cost per year. This results in the following costs of the project:

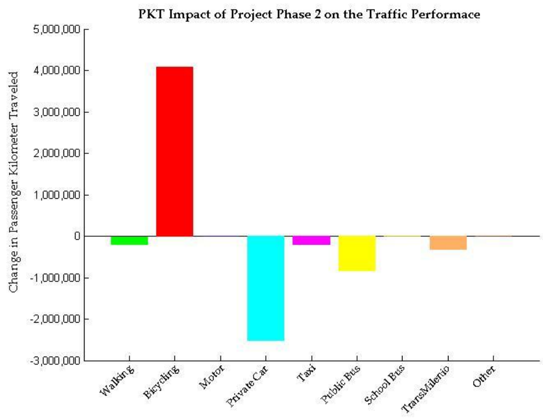
	Investment Costs	Maintenance Cost	Total
Phase 1	$ 32m	$ 25m	$ 57m
Phase 2	$ 32m	$ 25m	$ 57m
Total	$ 65m	$ 50m	**$ 115m**

Table 6.11: Costs related to the Expansion of the CicloRuta Network

Benefits The CO_2 benefits of the bicycle project are estimated using the Lo-Hi modeling approach because this approach consists of the division between the lower and higher Estratas clusters. Other benefits such as decreased congestion, decreased maintenance costs to the other traffic services, increased road safety due to less traffic and higher bicycle modal share, etc are not taken into account in this calculation. Figure 6.9 shows the impact of the increase in bicycle modal share from 3.3 % to 10 % for Estrata 1-3 (6.9a) and from 10 % to 15 % for Estrata 4-6 (6.9b).



(a) Shift in PKT caused by Phase 1 in Estrata 1-3



(b) Shift in PKT caused by Phase 2 in Estrata 4-6

Figure 6.9: Shift in PKT caused by Phase 1 (a) and Phase 2 (b) in (km/day)

The 'Shift' in PKT from other transportation modes to the bicycling leads to an increase in the CO_2-sink of bicycling. By using the Shadow Traffic Model the added value to the CO_2 is evaluated leading to the following CO_2 benefits of the project:

	Avoided CO2 (tCO2/year)	**Total Avoided CO2 (tCO2/20 years)**	**VCI Revenues (\$/ 20 years)**	**CER Revenues (\$ / 20 years)**
Phase 1	121,967	2,439,340	$ **24m $\pm$ $ 5m**	**$ 50m $\pm$ $ 12m**
Phase 2	224,098[1]	2,240,980[1]	**$ 22m $\pm$ $ 5m**	**$ 46m $\pm$ $ 10m**
Total	346,065[1]	4,680,320	**$ 46m $\pm$ $ 10m**	**$ 96m $\pm$ $ 22m**

Table 6.12: The Carbon Financing Benefits of Project Phase 1 and Phase 1. [1]Only in Phase 2: 10-20 years

The model results show that the benefits of the bicycle project over a 20 year period are approximately 4.7 $MtCO_2$ over the twenty year period. When these avoided emissions are traded on the carbon markets this represents a value of $ 46m when traded on a Voluntary Carbon Market and $ 96m when traded on the CDM Market which corresponds with yearly revenues of $ 2.5m per year in Phase 1 and $ 7.1m in Phase 2. One should, however, keep in mind that the actual economic benefit of the increased bicycling can be different in reality. The VCI/CER market prices are current values and not accurate estimates for the 20 year period. The total carbon finance benefits could therefore be very different when the tCO_2-equivalents are actually traded.

Altogether, this very simple analysis with the Shadow Traffic Model shows that the carbon finance benefits of a hypothetical 'Shift' bicycle project are significant. When traded on the VCM the carbon finance benefits account for 40 % of the costs and when traded in the CDM the carbon finance benefits even account for 80 % of all investment and maintenance costs. This indicates that carbon finance of 'Shift' programs to non-motorized modes of transportation can be very effective. The fact that the 7.7 % increase in bicycle PKT in Estrata 1-3 (Phase 1) has a lower yearly CO_2 benefit than the 5 % increase in bicycling in Estrata 4-6 is a result of the different traffic compositions in both clusters. It indicates that for the lower Estratas most trips new bicycle trips are substitutes for Public Bus or Walking trips while in the higher cluster bicycle trips mostly substitute Private Car trips. It is therefore much more effective to 'Shift' users from higher Estratas to bicycling than users from lower Estrata.

When interpreting these results one should, however, keep in mind that several assumptions have been made that might not hold their truth when applied in reality. First of all it is assumed that the effects of the expansion take place immediately after implementation which is obviously not the case in reality. Also the impact of 250 km in lower Estratas and 250 km in higher Estratas might not result in the desired increase in modal share from 3.3 % to 15 %. Furthermore only first order effects are taken into account while over a 20 year period second and third order effects also take place. People might change their travel patterns to smaller trips which in 20 years time will result in different land use distributions. This results in a smaller total traffic performance which should also be integrated in the analysis because a smaller traffic performance emits less emissions. On the other hand positive effects such as decreased congestion of the motorized network, increased traffic safety and increased public health are also not included in the analysis. Finally the estimated costs could be much higher due to the changing (geo)economics of Bogotá.

In conclusion, the analysis performed here is merely to indicate the order of magnitude of the results of an increase in bicycle share from the current 3.3 % to 15 %. The analysis shows that significant carbon finance benefits arise when implementing an extensive expansion of the bicycle network. A more detailed analysis should provide insight in the other costs and benefits related to this project.

Chapter 7

Discussion

This chapter discusses the decisions, principles and assumptions made for the development of the Shadow Traffic Model. It places them in context of traditional traffic modeling, cost-benefit analysis and carbon financing and argues its drawbacks.

The Shadow Traffic Model is a methodology for assessing the economic value of the CO_2-sink, created by bicycle trips that potentially could be emitting motorized trips. In the context of carbon financing this CO_2-sink possesses an economic value, the *Climate Value of Bicycling*, which can be estimated using the Shadow Traffic Model. It combines the economic concept of shadow pricing with traffic impact modeling and cost-benefit analysis. In traditional approaches bicycling can only have a CO_2 value when an increase in bicycling results in a decrease of motorized transportation. Other than that bicycling has no value in traditional traffic models. The advantage of the shadow traffic modeling compared to traditional approaches is its ability to attach value to something that has an intrinsic zero value, namely CO_2 emissions (avoided) by bicycling.

However there are some disputable aspects to the Shadow Traffic Model as presented in this report. First of all, since shadow pricing has not yet been grounded in academic research, through publications in authoritative transport related journals, a concrete scientific base for the development is absent. Shadow pricing is a widely used concept in economics but it still has to prove its applicability in transportation research. This report helps in defining this applicability but without the validation of the model with empirical data of actual bicyclists this model holds no scientific truth yet.

7.1 First, Second and Third Order Effects

Regarding the main principle of the Shadow Traffic Model that states to only take first order effects into account leaving second order effects out of the equation a drawback of the model is identified. First order effects are defined as the *a* one-on-one substitution of all bicycle trips by *b* their most likely alternative transportation mode. The first order effects take place immediately. The substitution of bicycle trips results has an immediate effect on the Transport Market but changes on the Travel and Traffic Market also take place on the short-, mid- and longterm. For example, people who change from bicycle to car for shop-related trips are likely to increase their benefits of the trip by choosing a different location for shopping. On the short- and midterm travelers will thus adopt different travel patterns. On the long-term this different travel pattern will have an effect on the Travel Market resulting in a different land use distribution (see Figure 3.6. On the other side the use of different transportation modes has a short- and midterm effect on the distribution of transportation modes leading to problems such as increased congestion or decreased traffic safety for non-motorized transportation. On the long-term these effects cause changes on the Traffic Market resulting in a different composition of traffic services with an emphasis on motorized transportation. These effects have not been taken into account in this version of the Shadow Traffic Model. The Climate Value as calculated by the Shadow Traffic Model therefore does not reflect the true value.

When applying the Shadow Traffic Model to other cities than Bogotá the second and third order effects are different due to different composition of the Transportation, Travel and Traffic Markets of the subjected study areas. For example, travelers in the Netherlands already have higher vehicle ownerships. For a city in the Netherlands the Private Car substitution will be dominant while in Bogotá the Public Bus substitution is. This will result in an even stronger effect on the change of land use distributions leading to more dispersed urban sprawl than in Bogotá. On the other hand, in Bogotá the effect of no bicycles on the roads will lead to higher speeds of motorized modes and decreased traffic safety. This effect is much smaller in the Netherlands because the transport infrastructure is more segregated.

So what would change in the results of the Shadow Traffic Model for Bogotá when second and third order effects are also included? Bicyclists who are forced to use a motorized transportation mode do not change the destination of a trip to a place closer to their origin, but choose a destination that further increases their benefit of making the trip, e.g. a better job, a cheaper supermarket. In most, if not all, cases this location will be further away than the original situation because the operating radius of travelers has been increased. They might combine different trips into one trip-chain but in total the amount of kilometers traveled will be higher than in the original situation. On the Travel Market this results in a shift in land use distribution causing a more dispersed urban layout due to the fact that most people don't mind to travel a longer distance. These effects catalyze each other leading to longer trip distances and more VKT in the transportation system. This results in larger estimates of the Climate Value of Bicycling. And on the other side of the model, if the Traffic Market aims at accommodating motorized transportation more due to the increased demand for motorized transportation people are stimulated to use motorized transportation modes even more.

Altogether the integration of second and third order effects will probably lead to a higher estimate of the Climate Value of Bicycling for Bogotá. To obtain a valid place for shadow traffic modeling in transport research these second and third order effects have to be investigated more carefully.

7.2 Shadow Mode Choice Modeling

The backbone of the Shadow Traffic Model, the shadow mode choice modeling, is also prone to discussion. To estimate the shadow traffic modes of bicycle trips this model uses a mode choice module based on the following assumptions:

- All trips bicycle trips are substituted into trips made with other transportation modes
- Travelers within each combination of trip length, socio economic status and purpose behave similarly according to the corresponding probability distributions (modal splits).

This mode choice model is of course, as in all models, a simplified virtual assessment of reality. But compared to mode choice models as present in current, traditional traffic models the assumptions might be to plain. Although the model assumes equality in choices, it could be possible that bicyclists in a specific travel pattern combination have different mode choices then their related car or public transportation users from the same travel pattern combination. For example, some bicyclists in the lowest socio-economic class could be captive bicyclists, i.e. they use the bicycle because they don't have the opportunity to use other transportation modes in terms of costs and accessibility, while other bicyclist in the same class have the opportunity to use more different transportation modes. Captive bicyclists will remain to use the bicycle until other modes become available to them, gradually expanding their choices based on increased wealth. This effect of increased choice opportunities has been accounted for in the model by using different travel pattern combinations. Nevertheless the division of people in six different socio-economic classes might not be sufficient in segregating groups of travelers with equality in mode choices. The lack of validation of this model with actual, mode choice data collected from the field is a major drawback of this research. With this information it becomes possible to give quantitative judgments whether or not the model assumptions remain valid when put to practice in the field.

In traditional traffic models more explaining variables are used for mode choice modeling. Variables such as vehicle ownership or social status of student, working can also be used in explaining mode choice behavior. For example, in static modeling origin and destination information is used in addition to socio-economic status and purpose of trip. The usage of origin and destination information in combination with land use information enables a the Shadow Traffic Model to give more accurate estimations on the shadow mode choices. Although information on origin and destination of trips was available in the input database of the Shadow Traffic Model it is not used in order to decrease the complexity of the model and to preserve the orderly and transparent approach. Furthermore disaggregation to origin and destination pairs expands the number of travel pattern combinations even more, decreasing the amount of trips per combination and with that the ability to validly construct probability distributions in the form of modal splits. However the omission of origin and destination information and/or other explaining variables can be seen as a drawback of the Shadow Traffic Model.

7.3 Limitations of the Data

The Shadow Traffic Model uses a trip database constructed from a household survey. This survey consisted of 20.686 respondent representing 0.3 % of the total population of the study area. These respondents make an average of 90.637 per day. This number of trips accounts for 0.9 % of the total trips made in Bogotá. It is disputable whether or not this sample size is large enough to create a valid depiction of the traffic performance in the study area. Compared with the respondent/population ratio of 0.4 % for the Mobility Survey Netherlands (MON) this seems like a reasonable amount of trips [CBS, 2006]. The only problem with the database is that 15 % of the trip entries are unusable due to absence of variable information resulting in an extra synthesize step to account for the loss of these trips. This makes the trip database on which the Shadow Traffic Model is based less reliable. For the model development it is assumed that these entry errors were random nevertheless it could be possible that these errors were systematic resulting in a systematic error of the Shadow Traffic Model. This has not been investigated.

Regarding the analysis of the data the measure of standard deviation does not give enough statistical depth. Especially when field data is obtained a more thorough statistical measure needs to be adopted to validate and calibrate the Shadow Traffic Model. Investigation into the available non-parametric statistical tests should give more insight in this matter.

Chapter 8

Conclusion and Recommendations

The objective of this research was to develop and apply a shadow price methodology for the calculation of the monetary value of avoided CO_2 emissions of bicycling in medium-sized to large cities in Non-Annex 1 countries. By providing the Shadow Traffic Model which can estimate the climate value of bicycling this objective has been reached successfully. This chapter answers the research questions as given in section 2.3, concludes on the findings of this research and gives recommendation for future application and research.

8.1 Conclusion

The economic concept of shadow pricing states that when a service or good is traded on an imperfect market the true value of the service or good can be estimated by shadow pricing it on a different market. The markets of transportation and the external effect of CO_2 emissions are an example of this. Shadow pricing applied to the estimation of the CO_2 value of bicycling leads to the substitution of bicycle trips by trips made with other transportation modes, i.e. other transportation markets. Summation of the additional CO_2 emissions caused by these substituted trips results in the estimate of the CO_2 sink of bicycle traffic or, as more often used in this report, the Climate Value of Bicycling. For the study case of Bogotá, with 10 million trips per day and an modal share of 3.3 % bicycling, the Climate Value of Bicycling is 55.000 - 62.000 tCO_2 per year corresponding with an economic value of \$ 1.1-1.3 million per year when traded on the CER carbon markets.

When exploring the opportunities of carbon finance of bicycle projects in Bogotá the Shadow Traffic Model estimates that an 7.7 % increase in bicycle modal share in Estrata 1-3 and 5 % increase in bicycle modal share in Estrata 4-6 leads to 0.35 $MtCO_2$ avoided CO_2 emissions per year. When traded on the carbon finance markets with current CER values this represents a yearly revenue of approximately \$ 7.1m which can be invested in bicycle infrastructure. Based on this information it can be concluded that there are significant opportunities for integration of carbon financing in the development of bicycle projects.
The advantage of the Shadow Traffic Model is its possibility to determine the value of something that originally has an intrinsic zero value, in this case the (avoided) CO_2 emissions of bicycling. Based on simple information on trip length, socio-economic background and purpose of the trips made in the study area the Climate Value can be estimated. In comparison to traditional traffic modeling, the mechanisms adopted in the Shadow Traffic Model are simple, intuitive and provide an orderly and transparent overview of the effects. The shadow modes are selected based on choice probabilities given by modal

splits specified to different trip lengths, socio-economic backgrounds and purposes assuming equality in choice making of the people within each combination. This leads to an easy to apply estimation model for the Climate Value of Bicycling. The Shadow Traffic Model does not require network information making it less data extensive as traditional traffic models.

Due to the simplicity of the modeling approach the Shadow Traffic Model also contains several drawbacks. First of all it does not account for second and third order effects of changing individual travel patterns caused by the forced use of a different transportation mode and resulting changes on the Travel and Traffic Market such as changes in the land use distribution and traffic infrastructures. Integration of these effects proved unfeasible due to the increase in model complexity and data requirements. This absence of second order effects resulted in a lower estimate assuming that people who change from bicycling to motorized transportation increase their travel distance and thereby increase the amount of CO_2 emissions.

A second drawback of the Shadow Traffic Model development is the absence of validation and calibration of the model. Empirical data giving the stated preference of bicyclists regarding their mode choice opportunities and shadow mode choice is being collected at the time of writing and is thus yet unavailable for this report. The modeling approach presumes that all bicycle trips are substituted based on the mode choice probabilities given by the modal splits specified to travel pattern combinations while assuming equality of choice decisions of people in these travel pattern combinations. Validation of these assumptions is vital for the quality assessment of the Shadow Traffic Model.

The validation also gives insight in which of the different model setups provides the best estimates for the Climate Value. Changing the bin sizes gives small difference in shadow traffic performance estimation resulting and therefore has negligible effects on the Climate Value. However changing the level of detail from all trips in one cluster (All Trips Model) to low and high socio-economic clusters (Lo-Hi Model) and further disaggregation to all six socio-economic classes (Estrata Model) leads to significant variances in the model results. Since 97 % of all current bicycle trips are located in the lower three Estratas it can be concluded that the results from the All Trips Model do not reflect the correct shadow traffic performance. It can be concluded that the similarity of mode choices increases when the level of detail of the explaining variables, travel pattern combinations, increases. Segregation of all trips from one socio-economic background into different purposes (Estrata-Purpose) results in purpose specific mode choice distributions. These distributions have a higher likelihood of providing equality in terms of mode choices then the aggregated distribution. For example the dominant modes for the purpose of 'going to work' might be different than for the purpose of 'shopping'. In the aggregated form these nuances are omitted and with that valuable information for the shadow mode choice selection is lost. Although segregation is thus preferred the amount of trips available from the traffic survey dictates the possibilities of disaggregation because with a small amount of (different) trips the Estrata-Purpose specific distributions can not be filled correctly resulting in skewed results of the shadow traffic estimation.

Altogether the Shadow Traffic Model provides an intuitively correct and straight forward modeling approach for estimating the Climate Value of bicycling. It is in fact a very simple traffic model based on macro data of the present traffic performance. It can be applied to various different situation since it does not require information about the infrastructure network. This is also one of the drawbacks of the model. The lack of second and third order effects and the unvalidated mode choice model might result in the incapability of the Shadow Traffic Model to estimate the *True Climate Value of Bicycling*. In order to increase the reliability of the estimations, the validation with empirical data is of vital importance. When this module is integrated the actual value of the Shadow Traffic Model can be assessed. Although the Shadow Traffic Model might not be an all-inclusive CO_2 estimation model it does provide an orderly and transparent modeling framework which can form the base of further research in the correct assessment of avoided CO_2 emissions caused by bicycling or other non-motorized modes of transportation.

8.2 Recommendations

For future research it is recommended that the Shadow Traffic Model is validated with the empirical field data collected in Bogotá. With this information the Shadow Traffic Model can be evaluated and eventually calibrated in order to give the best possible estimates. Calibration of the Shadow Traffic Model leads to the adoption of two factors. One to account for the fact that perhaps not all bicycle trips are substituted into new trips with a different transportation mode. A second one to account for the percentage of captivity in choices bicyclists could have. An example: for Estrata 1 80% of all trips are substituted and 40% of all bicyclists are captive to the modes Walking and Bicycling. With these kind of factors, which can be extracted from the observed shadow traffic performance resulting from the field survey, the accuracy and reliability of the Shadow Traffic Model can be improved.

It is also recommended to investigate the integration of second and third order effects into the Shadow Traffic Model. Although this increases the model complexity the accuracy of the Climate Value will benefit greatly. By defining a search algorithm based on simple rules such as: "10 % work trips are not prone to change or 60 % of shop trips are prone to change" trips that have a potention to change can be selected. Based on a trip generation model which iterates with modal choices the new origin and destination for the trips can be estimated resulting in a new Shadow Traffic Performance which takes second order effects into account. The subsequent integration of land use-transport interaction models can provide more insight in the iterative impact of changing transportation modes, travel patterns and activity locations.

This methodology can also be applied on other cites because it only requires macro data on the present traffic performance. It is recommended that the input data of a new case study is consistent with the following requirements:

- Trip survey contains at least 1 % of all trips made in study area
- Trip expansion factors for each trip to obtain total traffic performance
- Trip lengths classification of each trip into at least 5km bin sizes
- Socio-economic classification of each trip into at least 2 different classes
- Purpose of trip classification of each trip

For the application of the Shadow Traffic Model in terms of assessing carbon finance opportunities of bicycle projects the current version of the model is too static. A solution towards the embedding of forecasting is the adoption of the concept of 'mobility career'. A mobility career model gives estimations on what kind of transportation modes people are using spread out over their lives. Starting with the choice for walking and bicycling as a kid and leading to the choice of car and taxi when the person has a well paid job. Economic growth rates can also give estimations on the future distribution of inhabitants over different socio-economic classes. Rough estimations of land use changes in the city also give information on the increase or decrease in average trip length. All combined makes it possible to assess future scenarios and to estimate emission reduction potentials of bicycle projects.

It has to be clear that the economic funds that are estimated in the Climate Value are not solvent funds. The Climate Value remains a virtual asset until it is integrated in a Clean Development Mechanism or Voluntary Carbon Market project and produces emission credits. The carbon finance calculations given in this report are static numbers and do not account for future changes in CER/VCI prices. Referring to the scale of bicycle projects as mentioned by Browne et al., the city wide approach of the Shadow Traffic Model of Bogotá does produce enough emission credits for a feasible integration of the CDM in future bicycle project. This report does not provide a road plan towards the implementation of bicycle projects in the CDM or VCM but does give a clear indication of the opportunities of CO_2 reductions caused by bicycling and these are very real. The Shadow Traffic Model expanded with the afore mentioned recommendations can prove to be a powerful instrument in transportation research for assessing carbon finance opportunities.

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Appendix A

The CDM Project Cycle

The following CDM project cycle is based on information provided by Grutter [Grütter, 2007]:

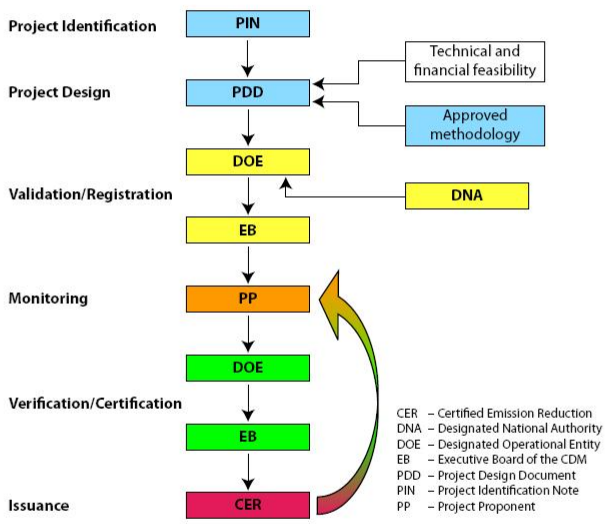

Figure A.1: The CDM Project Cycle [Grütter, 2007]

Project Identification: CDM projects are not designed as stand-alone projects. Normally projects that have a reduction potential are identified as a potential CDM project. CDM is a mere component of the project which can make conventional transport projects more feasible. The Project Identification Document (PIN) can be used as a selling document for attracting interest of potential buyers and investors in the CDM part of the project.

Project Design Phase: Project is to be formulated in the specific format given by the UNFCCC resulting in the Project Design Document (PDD). Projects may opt for a crediting period of 10 years non-renewable or 7 years renewable up to twice.

Validation / registration phase: The validation of a PDD is done by a UNFCCC approved Designated Operational Entity (DOE). The project owner selects, contracts and pays the DOE. During the validation phase the project hast to receive approval from the host countries respective Designated national Authority. After receiving DNA approval and positive DOE validation the DOE makes a request for registration of the CDM project. The registration will be considered valid after 8 weeks if no request for review was made by minimum 3 members of the Executive Board of the CDM. Projects can only create CERs after registration.

Monitoring: The emission reductions achieved during the monitoring period are summarized in a monitoring report and can then be verified, certified and sold. CERs can only be sold at the end of each monitoring period. So its up to the project owner to decide for a monitoring period. Large projects might opt for a short period to cover expenses while small projects might opt for large monitoring periods to minimize verification and certification procedures.

Verification and certification: The monitoring report is verified by a DOE.

Appendix B

Overview of Cycling Evaluation Studies

Category	Reference	Objective	Methods	CO_2 Emissions Included	Other Emissions Included	Other Benefits Included	Costs Included	Main Result
Literature Review	Cavill, N. K., S.; Rutter, H.; Racioppi, F.; Oja, P. (2009) **Economic analyses of transport infrastructure and policies including health effects related to cycling and walking: A systematic review.** Transport Policy.	To review studies that presented the findings of economic valuation of an aspect of transport infrastructure or policy, and included data on walking and/or cycling and health effects in the valuation	Comprehensive literature search was carried out to collect all relevant papers available. All studies were reviewed and from 16 studies data, with a focus on health effects related to physical activity, was extracted for further analysis towards the different approaches used	Not included	Not included	Quantitative: health effects are discussed	Investment, maintenance and operating costs	b/c ratios ranging between -1 to +30
	Krizek, K. J. (2004). **Estimating the Economic Benefits of Bicycling and Bicycle Facilities: An Interpretive Review and Proposed Methods.** TRB 2004 Annual Meeting, TRB.	To review and interpret the literature that evaluates economic benefits of bicycle facilities	Definition of 6 core benefits and how to apply these in policy	Not included	Qualitative: Social transportation benefits (congestion; energy); user transportation benefits; social benefits (livability; option value); user safety; user health; agency benefits	Qualitative: Social transportation benefits (congestion;	Not included	Recommendation of a framework in which different benefits could be estimated and subsequently compared against one another

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Category	Reference	Objective	Methods	CO_2 Emissions Included	Other Emissions Included	Other Benefits Included	Costs Included	Main Result
Benefit Analysis	Browne, J. S., E.; Silsbe, E.; Winkelman, S.; Zegras, C. (2005). **Getting on Track: Finding a Path for Transportation in the CDM.** Winnipeg, Manitoba, Canada, International Institute for Sustainable Development.	To examine possible scenarios for using the Clean Development Mechanism (CDM) as a tool to promote sustainable transport in Chile's transportation sector.	The report consists of two parts. First, a discussion on CDM and transportation in general. Second, analysis of five case studies in Santiago (Chile) of which two bicycle projects. Benefit analysis with respect to the CDM are used in case studies	Quantitative: By comparing the forecasted data (with implementation of bicycle projects) with baseline data, the amount of avoided CO2 becomes clear. Earnings are based on $10 per avoided ton CO_2	Not included	Not included	Not included	Annual revenues: Bikeway project: $735 Bicycle network: $273000 - $996000
	Gotschi, T. M., K. (2008). **Active Transportation for America: The Case for Increased Federal Investment in Walking and Cycling.** Rails-to-trails Conservancy.	To provide a quantitative assessment and an overall estimation of the monetary value of the benefits of current and future bicycling and walking in the United States	A benefit analysis for three future scenarios based on projected modal shifts and VMT avoided. Several first and second order effects are investigated. Costs are not covered in this research.	Quantitative: CO2 emissions monetized by evaluation of the criteria 'quantity of reduction' and 'cost per ton of CO2 avoided'. Projected earnings of 1 ton CO2 range between $10 - 80.	Other air pollutions are not included.	Quantitative: Congestion relief; fuel savings; health effects;	Investment costs included in example case studies.	Fuel savings are the most direct financial benefits from increased bicycling and walking. In total, annual benefits of $10 bln in modest scenario up to $ 65bln in more substantial scenarios

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Category	Reference	Objective	Methods	CO_2 Emissions Included	Other Emissions Included	Other Benefits Included	Costs Included	Main Result
	Litman, T. (2004). **Quantifying the Benefits of Nonmotorized Transportation For Achieving Mobility Management Objectives.** Victoria, Canada, Victoria Transport Policy Institute.	To investigate the ability of NMT to help achieve transportation planning objectives such as congestion reduction, cost savings, etc.	A benefit analysis based on generic estimates of costs and benefits. Per reduced VMT a monetary value is calculated	Only in general environmental term	Quantitative / qualitative: defines an air pollution cost of 1-12 c per VMT. Invariable additional environmental benefits such as water pollution, wildlife deaths, habitat fragmentation and increased impervious surface	Quantitative: Congestion; roadway, vehicle and park cost savings; noise; energy conservation; traffic safety; Qualitative: health, fitness; strategic land use objectives; economic development; user enjoyment; livability	Investment, maintenance and operating costs	Each NMT mile travelled reduces seven VMT. Benefit estimates per reduced VMT between 1 to 5+ $
Cost-Benefit Analysis	Bundesministerium für Verkehr, Bau und Stadtentwicklung (2008). **Kosten-Nutzen-Analyse: Bewertung der Effizienz von Radverkehrsmaßnahmen.** Abstract only, Berlin	To develop an assessment method for evaluation of cycling projects	CBA	Included	Pollutant emissions	Reduced accidents; operational cost abatement; traffic abatement cost; health; improvement of quality of life; social inclusion; abatement of land consumption	Maintenance cost	It has been proved that the developed approach is appropriate for the assessment of cycling measures.However further pilot applications with different types of measures and different cost levels are needed

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Category	Reference	Objective	Methods	CO_2 Emissions Included	Other Emissions Included	Other Benefits Included	Costs Included	Main Result
	Cycling Centre of Excelence (2004). **A Business Case and Evaluation of Impacts of Cycling in London.** Transport for London	To summarize all costs and benefits that might arise if adequate cycling facilities are provided throughout London.	CBA for three development scenarios based on data gathered through surveying.	CBA for three development scenarios based on data gathered through surveying.	Quantitative: Reduced external costs such as air and noise pollution can arise from a shift from car trips to cycling [...] resulting in a benefit of £2m to £10m per year.	Quantitative: Safety; travel time reductions; congestion relief; comfort improvement; health; reduced car parking costs	Investment, maintenance and operating costs	b/c ratios: basic scenario 1.6:1 to 2.2:1 proposed scenario 1.8:1 to 2.5:1 boosted scenario 2.5:1 to 3.6:1
	Foltýnová, H. B. K. M. **Cost-Benefit Analysis of Cycling Infrastructure: a Case Study of Pilsen.** Prague, Charles University Environment Centre.	To analyze impact of cycle network improvements in Czech city of Pilsen	CBA based on data gathered by a SP survey.	Only in general environmental term	Quantitative: evaluation of changes in atmospheric pollution modeled using ExternE (European Commission)	Quantitative:health; accidents; reduced insecurity; travel time	Investment, maintenance and operating costs	b/c ratio: for neutral -0.62; for conservative -0.33
	Macdonald, B. (2007). **Valuing the Benefits of Cycling: A report to Cycling England.** SQW Limited.	To review the evidence of the potential economic benefits of increased cycling and assess its contribution to some of the major challenges faced by society and Government	CBA based on information gathered in England	Not included	Quantitative: Annual economic benefit of increased health by reduced pollution of one person switching to cycling would be £69.14 - £12.98 depending on area.	Quantitative: health; car reduction; congestion; accidents; journey ambiance; social inclusion	Investment, maintenance and operating costs	Cumulative savings for 20/30/50 % increase in cycle trips is £523/£785/£1308 million

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Category	Reference	Objective	Methods	CO_2 Emissions Included	Other Emissions Included	Other Benefits Included	Costs Included	Main Result
	Sælensminde, K. (2004). **Cost-benefity analyses of walking and cycling track networks taking into account insecurity, health effects and external costs of motorized traffic.** Transportation Researcy Part A: Policy and Practice 38(3): 593-606.	To perform a CBA of cycling projects as part of program to prepare a National Cycling Strategy of which the main goal is to make it safer and more attractive to choose bicycle as a means of transportation	CBA of walking and cycling tracks in three Norwegian cities. Based on average annual number of trips undertaken data.	Only in environmental general term	Quantitative: C02 emissions, air, noise and congestion pollution estimated at NOK 1.36 to 9.03 based on data provided by Eriksen [Eriksen, 2000]	Quantitative: traffic accidents; travel time; insecurity; health; fitness; parking cost	Investment, maintenance and operating costs	Hokksund: b/c 4.09 (6 % emission reduction benefits) Hamar: b/c 14.34 (6 %) Trondheim: b/c 2.94 (4 % emission reduction benefits)

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Category	Reference	Objective	Methods	CO_2 Emissions Included	Other Emissions Included	Other Benefits Included	Costs Included	Main Result
	Wittink, R. B., J. (2000). **De Economische Betekenis van het Fietsen: een onderzoek om kosten en baten van fietsbeleid te illustreren.** Den Haag, Interface for Cycling Expertise; Stichting Habitat Platform.	To explain the economic significance of cycling	CBA for four different cities (Amsterdam, Bogota, Delhi and Morogoro) based on project data provided by stakeholders.	Quantitative: Only included in Amsterdam case where fl.15.60 accounted for 1000 VKT. For Bogota, Delhi CO2 was covered in environmental general term.	Quantitative: For Amsterdam economic values for other GHG based on avoided VKT were given. For Bogota the economic value of saved motorized journeys were given. For Delhi the emission savings per saved liter petrol were given. For Morogoro no economic term was given.	Quantitative / qualitative: Health; Safety; Time savings; Theft prevention; Less maintenance; Less parking space; Better accessibility and employment; Fuel savings	Investment, maintenance and operating costs	Amsterdam: profit fl.186mln b/c 1.5 Bogota: Profit $1124 mln b/c 7.3 Delhi: Profit Rs.2323mln b/c 20 Morogoro: No data
CBA of Cycling Conference, Copenhagen 2005	Lind, G. H., C.; Persson, U.; (2005). **Benefits and costs of bicycle infrastructure in Sweden.** CBA of Cycling, Copenhagen, Nordic Council of Ministers.	To perform a CBA for a hypothetical cycling program in Sweden in order to increase awareness.	CBA of cycling projects based on experienced change in demand caused by cycling programs/projects.	Only in general term	Quantitative: as decreased external effects for society (maintenance, emissions, noise, accidents, etc.) 0.45 SEK per VKT	Quantitative: travel time, delay time (SEK/h); comfort (WTP SEK per trip); operating costs; habitual increase of cycling; mode shift to cycling; health; safety	Yearly investment, maintenance and operating costs	Yearly benefit/cost ratio in hypothetical case study: 9.1

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Category	Reference	Objective	Methods	CO_2 Emissions Included	Other Emissions Included	Other Benefits Included	Costs Included	Main Result
	Saari, R. M., H.; Tervonen, J. (2005). **Finnish guidelines for the assessment of walking and cycling projects.** CBA of Cycling, Copenhagen, Nordic Council	To develop guidelines for the assessment of walking and cycling projects	Framework for assessing walking and cycling projects. Impact analysis consists of CBA, Effectiveness and Feasibility assessment. Based on projected modal shift	Not included	Quantitative: in example case study (Turku) benefit of E 0.9 mln - E 2.6 mln. But no argumentation for values	Quantitative: health; reduction of congestion; reduction of wear and tear	Investment, maintenance and operating costs	2.9 (cycling 37% => 40%)
	Lind, G. (2005). **CBA of Cycling: summary of conference proceedings.** CBA of Cycling, 2005, Nordic Council of Ministers.	To summarize all proceedings from the 'CBA of Cycling' conference held in Copenhagen (2005)	The report summarizes the knowledge of CBA of cycling in the Nordic countries and discusses the relevance of advanced methods for cycle planning.	Not included	As discussed in the various papers above. However in this summary no specific attention to emission reduction of cycling programs/projects	As discussed in the various papers above.	As discussed in the various papers above.	Quantitative overview of effects of cycle policy and their respective monetary values

Table B.2: Overview of Cycling Evaluation Literature

Appendix C

Map of Bogotá

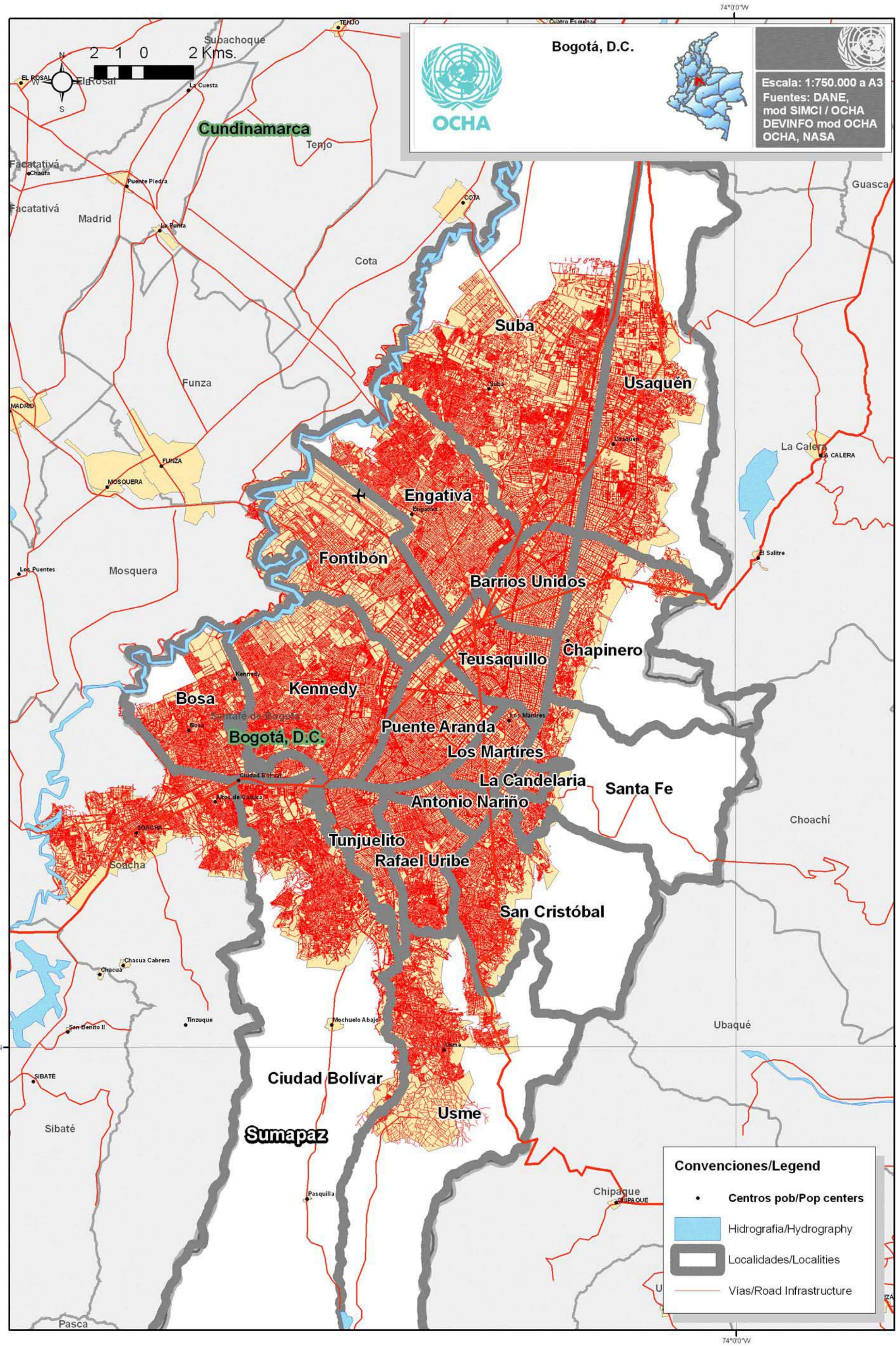

Figure C.1: Map of Bogotá [OCHA, 2009]

Appendix D

Field Survey: Universidad de los Andes

Cuestionario CicloRuta

Entrevistador: ___________________________________ Formulario #:___________________________

Dirección de la encuesta: ___________________________

Fecha: Mes___ ___ Día____ ___Año___ ___

Hora: ____:____ ☐ am ☐ pm

Clima:

Soleado ☐ Llovizna ☐

Nublado ☐ Despejado ☐

Aguacero ☐

Buenos días/tardes. Mi nombre es…. Y estoy realizando este estudio con la Universidad de los Andes Sus respuestas son muy importantes. La información que nos suministre es totalmente confidencial y sólo será utilizada con fines de investigación.

Parte 1 - Datos Sociodemográficos

Voy a comenzar haciéndole unas preguntas generales:

01. Sexo (que lo marque el encuestador)
☐ Masculino ☐ Femenino

02. ¿Cuál es su edad en años cumplidos?
☐☐ Años

03. ¿Cuál es su estado civil?
☐ Soltero/ Viudo ☐ Casado/unión libre
☐ Otro_________

04. Ubique el ingreso mensual en pesos de su hogar en alguno de los siguientes rangos.

Ingreso	
0-$200.000	☐
$200.001-$400.000	☐
$400.001-$700.000	☐
$700.001-$1.000.000	☐
$1.000.001-$1.500.000	☐
$1.500.001-$2.000.000	☐
$2.000.001-$3.000.000	☐
$3.000.001-$4.500.000	☐
Más de 4.500.000	☐
No responde/No sabe	☐

05. ¿Cuál es la dirección de su casa? (Intersección aproximada en caso de que el informante no quiera dar la dirección)

Pase a la pregunta 7 si respondió esta pregunta

06. Responder solo si no da la dirección ¿Cuál es el estrato que aparece en su recibo de servicios públicos?

☐ 0 (No le llega recibo)
☐1 ☐2 ☐3 ☐4 ☐5 ☐6

07¿Cuál es el nivel educativo mas alto alcanzado?

☐ Ninguno
☐ Preescolar
☐ Primaria (1-5)
☐ Secundaria (6-11)
☐ Educación superior
☐ Postgrado
☐ No Informa

08. ¿Cuál es su ocupación?
☐ Trabajador cuenta propia o independiente
☐ Trabajador familiar sin remuneración
☐ Patrón o empleador
☐ Pensionado o Jubilado
☐ Estudiante
☐ Desempleado
☐ Otra ¿Cuál?_________________________

09. ¿Cuánto gasta mensualmente? De una cifra aproximada.
$

Parte 2– Actividad física relacionada con transporte

Ahora piense en cómo se transportó usted de un lugar a otro en los últimos 7 días.

10. Durante los últimos 7 días, ¿Montó en bicicleta por lo menos 10 minutos seguidos para ir de un lugar a otro, con propósitos distintos a los de recreación y deporte? Incluya ir a lugares como su trabajo, supermercados, cines, bancos, sitios de estudio, entre otros.
☐Sí ☐No

Si respondió **no**, continué con la pregunta 12

11. ¿Cuáles días y cuanto tiempo montó en bicicleta por lo menos 10 minutos seguidos para ir de un lugar a otro, con propósitos distintos a los de recreación y deporte?
Encuestador: Llene esta tabla

Día	Sí	No	Horas	Minutos
Lunes	☐	☐		
Martes	☐	☐		
Miércoles	☐	☐		
Jueves	☐	☐		
Viernes	☐	☐		
Sábado	☐	☐		
Domingo	☐	☐		

12. ¿Cuáles son los principales motivo/s por el que usa la CicloRuta? Marque todas las que apliquen.
☐Transporte al/del Estudio
☐Transporte al/del Trabajo
☐Transporte del Negocio (mensajero).
☐Para hacer Compras
☐Para hacer diligencias personales
☐Llegar a TransMilenio
☐Llevar a sus hijos al colegio
☐Recreación
☐ Salud

☐ Otra. ¿Cuál?________

13. ¿A cuál o cuáles de los siguientes medios de transporte tiene acceso (entiéndase por acceso la cercanía al medio y la posibilidad de pagarlo) Marque todos los que apliquen.

Medio de transporte	
Caminar	☐
Moto	☐
Carro particular	☐
Taxi	☐
Bus/Buseta/Ejecutivo	☐
Bus Escolar	☐
TransMilenio	☐
Bicimoto	☐
Bicicleta eléctrica	☐
Otro ¿Cuál?___________	☐

14. ¿Si no pudiera hacer uso de la bicicleta para realizar el recorrido que está haciendo, lo haría de todas formas usando otro medio de trasporte?

☐ Sí ☐ No

15. ¿Cuál de los medios de transporte que marcó en la pregunta número 23 usaría para realizar el recorrido que está haciendo, si no lo quisiera hacer en bicicleta? Marque todas las que apliquen.

Medio de transporte	
Caminar	☐
Moto	☐
Carro particular	☐
Taxi	☐
Bus/Buseta/Ejecutivo	☐
Bus Escolar	☐
TransMilenio	☐
Bicimoto	☐
Bicicleta eléctrica	☐
Otro ¿Cuál?___________	☐

Ahora vamos a hablar de las caminatas que usted realizó durante los últimos 7 días.

16. Durante los últimos 7 días, ¿Caminó por lo menos 10 minutos seguidos para ir de un lugar a otro, para ir a hacer vueltas o diligencias, para ir al colegio o universidad o para ir y venir de su trabajo?

☐ Sí ☐ No

Si respondió **no** pase a la pregunta 18

17. Encuestadora: Marque en la tabla los días en los que caminó al menos 10 minutos seguidos para ir de un lugar a otro, para ir a hacer vueltas o diligencias, para ir al colegio o universidad o para ir y venir de su trabajo Escriba al lado por cuánto tiempo realizó la actividad.

Día	Sí	No	Horas	Minutos
Lunes	☐	☐		
Martes	☐	☐		
Miércoles	☐	☐		
Jueves	☐	☐		
Viernes	☐	☐		
Sábado	☐	☐		
Domingo	☐	☐		

18. ¿Tiene carro o Moto en su casa?

☐ Sí ☐ No

19. Durante los últimos 7 días ¿viajó en carro, moto, bus/buseta o TransMilenio?

☐ Sí ☐ No

Si responde **No,** pase a la pregunta 21.

20. Encuestadora: Marque en la siguiente tabla los días que viajó en carro, moto, bus/buseta o TransMilenio. Escriba al lado cuánto tiempo dedicó a estas actividades por día.

Día	Sí	No	Horas	Minutos
Lunes	☐	☐		
Martes	☐	☐		
Miércoles	☐	☐		
Jueves	☐	☐		
Viernes	☐	☐		
Sábado	☐	☐		
Domingo	☐	☐		

Parte 3 – Actividad física en tiempo libre

Vamos a hablar de las actividades que se hacen en el tiempo libre o de recreación. Le recuerdo que tiempo libre es el que tiene para usted mismo, el tiempo que usted decide como utilizar.

21. Durante los últimos 7 días, ¿Caminó por lo menos 10 minutos seguidos por recreación, deporte, o en su tiempo libre?

☐ Sí ☐ No

Si respondió **no** pase a la pregunta 23.

22. Encuestadora: Marque en la tabla los días en los que caminó al menos 10 minutos seguidos por recreación/deporte o en su tiempo libre. Escriba al lado por cuánto tiempo realizó la actividad.

Día	Sí	No	Horas	Minutos
Lunes	☐	☐		
Martes	☐	☐		
Miércoles	☐	☐		
Jueves	☐	☐		
Viernes	☐	☐		
Sábado	☐	☐		
Domingo	☐	☐		

23. Durante los últimos 7 días, ¿Realizó actividades físicas **moderadas** en su tiempo libre por lo menos 10 minutos seguidos? Estas actividades hacen que usted respire algo más fuerte de lo normal (Ej. montar bicicleta a paso regular, trotar a un ritmo suave, bailar, practicar yoga, etc).

☐ Sí ☐ No

Si respondió **no**, pase a la pregunta 25.

24. Encuestadora: Marque en la siguiente tabla los días en los cuales realizó actividades físicas moderadas en su tiempo libre por lo menos 10 minutos seguidos Escriba al lado cuánto tiempo dedicó a estas actividades por día.

Día	Sí	No	Horas	Minutos
Lunes	☐	☐		
Martes	☐	☐		
Miércoles	☐	☐		
Jueves	☐	☐		
Viernes	☐	☐		
Sábado	☐	☐		
Domingo	☐	☐		

Ahora piense en actividades vigorosas que requieren un gran esfuerzo físico.

25. Durante los últimos 7 días, ¿Realizó actividades físicas **vigorosas** en su tiempo libre por lo menos 10 minutos seguidos? Las actividades vigorosas hacen que respire mucho más fuerte de lo normal (Ej. aeróbicos, correr, pedalear rápido bicicleta, nadar rápido, jugar fútbol, jugar basketball, voleyball, escalar, deportes de combate, spinning, etc)

☐ Sí ☐ No

Si respondió **no,** pase a la pregunta 27.

26. Encuestadora: Marque en la siguiente tabla los días en los cuales realizó actividades físicas vigorosas en su tiempo libre por lo menos 10 minutos seguidos. Escriba al lado cuánto tiempo dedicó a estas actividades por día.

Día	Sí	No	Horas	Minutos
Lunes	☐	☐		
Martes	☐	☐		
Miércoles	☐	☐		
Jueves	☐	☐		
Viernes	☐	☐		
Sábado	☐	☐		
Domingo	☐	☐		

Parte 4 – Uso de CicloRutas

27. ¿Con qué frecuencia usa las CicloRutas?

☐ Por lo menos una vez al año ☐ 4 días/semana
☐ Algunas veces por mes ☐ 5 días/semana
☐ 1 día/semana ☐ 6 días/semana
☐ 2 días/semana ☐ 7 días/semana
☐ 3 días/semana

28. ¿En qué horario de Lunes a Viernes?

Horario de salida.
____:____ ☐ am ☐ pm
Horario de regreso.
____:____ ☐ am ☐ pm

29. ¿Cuál fue su lugar de origen en este viaje el día de hoy? (Dé una dirección/Intersección aproximada)

30. ¿Cuál es su lugar de destino en este viaje? (Dé una dirección/Intersección aproximada)

31. ¿Cuánto es la distancia total en cuadras, kilómetros y Minutos que recorre aproximadamente? Coloque las tres.

______________________________**Cuadras**
______________________________**Km**
______________________________**Minutos**

32. ¿Utilizaba la bicicleta antes de que hubiera CicloRutas?

☐ Sí ☐ No

33. ¿Si no hubiese CicloRutas, usaría la bicicleta como medio de transporte?

☐ Sí ☐ No

34. ¿Cuál es la principal razón por la que monta en bicicleta para transportarse? Marque todas las opciones que apliquen.

☐ Transporte al/del Estudio
☐ Transporte al/del Trabajo
☐ Transporte del Negocio (mensajero).
☐ Para hacer Compras
☐ Para hacer diligencias personales
☐ Llegar a TransMilenio
☐ Llevar a sus hijos al colegio
☐ Por que lo disfruto
☐ Salud
☐ No tengo carro
☐ Para hacer ejercicio
☐ Para ahorrar dinero
☐ para proteger el ambiente
☐ Por que la gasolina cuesta mucho
☐ Porque es seguro
☐ Porque la CicloRuta es atractiva
☐ Porque los lugares a los que quiero ir quedan cerca
☐ Porque parquear es difícil
☐ Otra. ¿Cuál?_________

Parte 5 – Uso de Ciclovías

La **Ciclovía** es un programa que consiste en el cierre temporal de algunas calles para el tránsito vehicular, permitiendo que los miembros de la comunidad realicen diferentes formas de Actividad Física y recreación. Se realiza todos los domingos y festivos de 7am a 2 pm en las principales vías de la ciudad.

35. ¿En los últimos 12 meses ha asistido a la Ciclovía?

☐ Sí ☐ No

Si responde **No**, pase a la pregunta 39

36. ¿Cuántas veces en los últimos 12 meses ha utilizado las Ciclovías?

☐ Por lo menos una vez al año ☐ 3 días/mes
☐ 1 día/mes ☐ 4 días/mes
☐ 2 días/mes ☐ Nunca
☐ Siempre

37. ¿Usa las CicloRuta para llegar a la Ciclovía?

☐ Sí ☐ No

38. ¿Qué haría usted si no existiera la Ciclovía?

☐ Ver Televisión
☐ Estar en la casa
☐ Otra actividad recreativa
☐ Uso de videojuegos o internet
☐ No sabe

39. Varios estudios han mostrado que las personas que usan regularmente la bicicleta tienen un menor riesgo de morir y más bienestar.
Por otro lado, el mantenimiento anual de la red de CicloRutas de Bogotá le cuesta a la ciudad $2'000.000.000 (dos mil millones de pesos) aproximadamente.

Teniendo en cuenta lo anterior,

Si el consejo de Bogotá estuviera planteando desmontar el programa de ciclorutas y no continuar su mantenimiento por falta de recursos, y sólo lo restaurarían mediante un cobro adicional a todos los ciudadanos, ¿cuánto sería lo máximo que estaría usted dispuesto a pagar mensualmente por preservar el tramo de ciclo ruta que usted utiliza? Asuma que este pago se realizaría mediante un cargo adicional en su factura mensual de servicios públicos.

Por favor piense cuidadosamente cuánto puede pagar de acuerdo a sus ingresos y de dónde provendría este dinero adicional. No responda una cantidad si: ve que realmente no alcanzaría a pagarla, si tiene gastos más importantes o si no está seguro de querer pagar. Trate de ser lo más realista posible.

Respuesta $________________

Parte 6 – Cicloparqueaderos

40. ¿Dónde ha visto ud cicloparqueaderos(marque todas las que apliquen)?

☐ En puntos de encuentro ☐ En portales TM
☐ En espacio público ☐ En centros comerciales
☐ En parqueaderos pagados (Cityparking, Parking, etc ☐ En entidades distritales
☐ En entidades nacionales ☐ Otro (cuál)
☐ En ninguna parte

Si respondió "**en ninguna parte**" por favor pase a la pregunta 47

41. ¿Cuáles de los cicloparqueaderos que conoce ha utilizado (marque todas las que apliquen)?

☐ En puntos de encuentro ☐ En portales TM
☐ En espacio público ☐ En centros comerciales
☐ En parqueaderos pagados (Cityparking, Parking, etc ☐ En entidades distritales
☐ En entidades nacionales ☐ Otro (cuál)
☐ En ninguna parte

42. ¿Cuáles de éstos cicloparqueaderos le parece que son de buena calidad (seguros, fáciles de usar) – marque solo los que cumplan con este requisito?

☐ En puntos de encuentro ☐ En portales TM
☐ En espacio público ☐ En centros comerciales
☐ En parqueaderos pagados (Cityparking, Parking, etc ☐ En entidades distritales
☐ En entidades nacionales ☐ Otro (cuál)
☐ En ninguna parte

43. Qué factores son los que más le interesan al usar un cicloparqueadero?

☐ Seguridad ☐ Comodidad de uso
☐ Protección contra intemperie ☐ Costo del servicio
☐ Trato del personal del parqueadero / estación ☐ Otro (cuál)___

44. ¿Con qué frecuencia usa alguno de estos cicloparqueaderos?

☐ Algunas veces por año ☐ 4 días/semana
☐ Algunas veces por mes ☐ 5 días/semana
☐ 1 día/semana ☐ 6 días/semana
☐ 2 días/semana ☐ 7 días/semana
☐ 3 días/semana ☐ Nunca

45. ¿Cuáles de los siguientes factores son los que le hacen pensar dos veces antes de ir en bicicleta a su trabajo / estudio?

☐ Clima ☐ Tener que usar el casco
☐ Viento ☐ Ciclorrutas hasta su destino
☐ Distancia hasta su destino ☐ Conflicto con automóviles particulares
☐ Conflicto con taxis ☐ Conflicto con motos
☐ Trato de policías de tránsito ☐ Inseguridad (robos)
☐ Odio las bicicletas ☐ La bicicleta es para pobres

46. ¿Cuáles de los siguientes factores son los que le motivan a ir en bicicleta a su trabajo / estudio?

☐ es rápida ☐ Me veo bien
☐ El viaje sale gratis ☐ Es divertido
☐ Se hace ejercicio ☐ Se protege el medio ambiente

Parte 7 – Capital Social

47. En términos generales, ¿cree usted que se puede confiar en la mayoría de las personas o que nunca se es demasiado precavido en el trato con los demás? Por favor responda en una escala de 1-10, donde 10 significa que se puede confiar en la mayoría de las personas y 1 que no se puede confiar en nadie.

☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

48. ¿Cree usted que la mayoría de las personas intentarían aprovecharse de usted si pudieran, o que intentarían ser justas con usted? Por favor responda en una escala de 1-10, donde 10 significa que intentarían ser justas con usted

☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

49. ¿Cree usted que las personas casi siempre intentan ayudar a los demás o que la mayoría de las veces están pensando principalmente en ellas mismas? Por favor responda en una escala de 1-10, donde 10 significa que intentan ayudar a los demás.

☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

Ahora, pensando en la CicloRuta, diga de 1 a 4 qué tan de acuerdo está con cada uno de los siguientes enunciados siendo 1: muy en desacuerdo, 2: en desacuerdo, 3: de acuerdo y 4: muy de acuerdo.

50. En la CicloRuta las personas están dispuestas a ayudarse unas a otras.

☐1 ☐2 ☐3 ☐4

51. En la CicloRuta la gente generalmente se lleva bien con los demás.

☐1 ☐2 ☐3 ☐4

52. La gente en la CicloRuta es confiable.

☐1 ☐2 ☐3 ☐4

53. La gente que asiste a la CicloRuta comparte los mismos valores.

☐1 ☐2 ☐3 ☐4

54. La gente que asiste a la CicloRuta se conoce entre sí.

☐1 ☐2 ☐3 ☐4

55. ¿Confiaría en alguien desconocido para que le cuide la bicicleta en la CicloRuta durante 40 minutos o más? Por favor responda en una escala de 1-4, donde 4 significa que SIEMPRE confiaría en alguien y 1 que NUNCA confiaría en nadie.

☐1 ☐2 ☐3 ☐4

56. ¿Cree que si se pinchara en la CicloRuta le ayudarían a des pincharse? Responda en una escala de 1-4, donde 4 significa que los demás le ayudarían y 1 que no le ayudarían.

☐1 ☐2 ☐3 ☐4

57. ¿Qué tan seguro se siente en la CicloRuta respecto al riesgo de accidentes? Responda en una escala de 1-5 donde 5 es la máxima seguridad y 1 es lo máximo de inseguridad.

☐1 ☐2 ☐3 ☐4 ☐5

58. ¿Qué tan seguro se siente en la CicloRuta respecto al robo? Responda en una escala de 1-5 donde 5 es la máxima seguridad y 1 la máxima inseguridad.

☐1 ☐2 ☐3 ☐4 ☐5

59. ¿Cuál de los siguientes factores es el que más contribuye a su percepción de seguridad/inseguridad en la CicloRuta?

☐ Criminalidad o robo

☐ Riesgo de accidentes por otros usuarios

☐ Riesgo de accidentes por tráfico vehicular

☐ Riesgo de accidentes por estado de las vías

☐ Otro ¿Cuál? ___________________________

60. ¿Pertenece a alguno de los siguientes grupos? Marque con una x los tipos de organización a los que pertenece y a continuación escriba a cuántos de cada tipo pertenece.

Grupo/Organización	Pertenece	¿Cuántos?
Grupo de cooperación sectores de producción (Ej. Sector agropecuario)	☐Sí ☐No	
Asociación de comerciantes o negociantes	☐Sí ☐No	
Asociación profesional	☐Sí ☐No	
Sindicato	☐Sí ☐No	
Comité de barrio o localidad	☐Sí ☐No	
Grupo religioso o espiritual	☐Sí ☐No	
Grupo o movimiento político	☐Sí ☐No	
Grupo o asociación cultural	☐Sí ☐No	
Grupo u organización deportiva	☐Sí ☐No	
Grupo asociado a identidad étnica	☐Sí ☐No	
Grupo u organización educativa	☐Sí ☐No	
Grupo de promoción de bicicletas	☐Sí ☐No	
Otros	☐Sí ☐No	

61. ¿Cuáles son su peso y talla aproximados?

Peso__________Kg

Talla___________mt

Muchas gracias por participar en esta encuesta.

Esperamos que tenga un buen día

Appendix E

Tables of Shadow Traffic Model Bogotá Region

Binsize	5KM			2.5KM			1km	
Invalid TLFD	Total	Bicycle	Invalid TLFD	Total	Bicycle	Invalid TLFD	Total	Bicycle
1-Business	3791	0	1-Business	3791	0	1-Business	3791	0
4-Other	10941	1143	4-Other	10941	1143	4-Other	10941	1143
5-Other	2366	0	5-Other	2366	0	5-Other	2366	0
5-Business	11313	0	5-Business	11313	0	5-Business	11313	0
5-Return Home	2448	0	5-Return Home	2448	0	5-Return Home	2448	0
5-Shopping	11057	0	5-Shopping	11057	0	5-Shopping	11057	0
6-Business	8621	0	6-Business	8621	0	6-Business	8621	0
6-Other	3777	0	6-Other	3777	0	6-Other	3777	0
6-Return Home	5428	0	6-Return Home	5428	0	6-Return Home	5428	0
6-Shopping	12362	0	6-Shopping	12362	0	6-Shopping	12362	0
6-Transfer	0	0	6-Transfer	0	0	6-Transfer	0	0
			1-Other	7487	0	1-Other	7487	0
			1-Shopping	8317	1894	1-Shopping	8317	1894
			6-Study	13437	407	6-Study	13437	407
						3-Other	13304	0
						4-Return Home	17584	0
						5-Study	16401	0
						5-Transfer	7093	0
Total	72104	1143		101345	3444		155727	3444
Total[1] (%)	0.72%	0.34%		1.01%	1.02%		1.56%	1.02%

Table E.1: Selection of 'Invalid' TLFDs.[1]Based on total number of trips of 10.012.062 and total number of bicycle trips of 337.104