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The Climate Value of Cycling

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Abstract

The reduction of CO_2 emissions constitutes one of the largest challenges of the current era. Sustainable transportation, and especially cycling, can contribute to the mitigation of CO_2 emissions since cycling possesses an intrinsic zero-emission value. Few studies have been conducted that appraise the CO_2 reduction potential of cycling. Opportunity costs enable the estimation of avoided CO_2 emissions resulting from bicycle trips. The methodology developed in this research allows the attribution of a climate value to cycling by substituting bicycle trips with their most likely alternative transportation modes and calculating the resulting additional CO_2 emissions. The methodology uses data on the current modal shares of cycling mobility, the competition of cycling with other transportation modes, and CO_2 emission factors to calculate the climate value of cycling. When it is assumed that the avoided CO_2 emissions of cycling mobility could be traded on financial carbon markets, the climate value of cycling represents a monetary value. Application of the methodology to the case of Bogotá, Colombia — a city with a current bicycle modal share of 3.3% on a total of 10 million daily trips — results in a climate value of cycling of 55,115 tons of CO_2 per year, corresponding to an economic value of between 1 and 7 million US dollars when traded on the carbon market.

Keywords: Cycling evaluation; climate change mitigation; opportunity costs; carbon markets; Bogotá; Colombia.

1. Introduction

Human induced emission of CO_2 is one of the most important challenges humanity has to deal with in the 21st century. The transportation sector is responsible for approximately 23% of global CO_2 emissions, a number that is growing, particularly in view of the increasing vehicle ownership and use in developing and emerging economies (IEA, 2008). While clean vehicle technology and cleaner fuels have been adopted as appropriate strategies to reduce greenhouse gas (GHG) emissions in the last few years, the discussion in the 2009 United Nations climate change Conference of the Parties (COP) 15 in Copenhagen concluded that a complete restructuring of the way urban mobility is organized is the only feasible climate mitigation strategy. Non-motorized transportation (NMT) development is therefore becoming a core strategy that has the potential to reduce CO_2 emissions. NMT also offers important benefits for society by promoting people's health, providing opportunities for economic development and contributing to social inclusion. Developing countries, particularly in Asia and Latin America, should play a major role in developing mitigation strategies, because much of the growth in transportation related CO_2 emissions is expected to be coming from these countries, if nothing is done (IEA, 2008). Sustainable transportation projects could induce reductions in CO_2 emissions of the road transportation sector by: (1) "Avoiding" the need for mobility; (2) "Shifting" mobility to sustainable modes of transportation, such as cycling; or (3) "Improving" sustainability of current mobility (Dalkmann and Brannigan, 2007).

Recent studies show that most current transportation policy efforts focus on "Improve" strategies, such as increasing vehicle and fuel economy efficiency, rather than "Avoid" and "Shift" strategies, where vehicle kilometres are reduced or shifted to non-CO_2-emitting or low-CO_2-emitting modes of transportation. Clearly, there exists a bias towards "Improve" strategies (Huizenga and Bakker,

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2009; Leather, 2009). Since extensive growth in road transportation in developing and emerging economies is expected, avoidance of motorized transportation by investments in sustainable, low-carbon modes of transportation should be preferred. Particularly in developing countries, economic resources often limit opportunities for implementing high-cost vehicle improvement technologies, indicating that investments in programmes avoiding CO_2 emissions, such as NMT projects, may be more suitable and feasible (Johansson, 2009). Besides directly reducing emissions through modal shift, these projects may also have substantial co-benefits such as public health (Woodcock *et al*., 2009) and traffic safety (Jacobsen, 2003) benefits. Non-motorized transportation, particularly cycling, has great potential because: (a) it is a cheap mode of transportation and can be obtained by even the poorest; (b) the investment costs for infrastructure 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 transportation mode (OECD, 2004; TRB, 2006).

Cycling projects and programmes are typically developed to accommodate and maintain current cycling levels and/or to expand cycling levels by providing good quality and safe facilities for cycling (i.e. bicycle lanes and protected crossings, traffic calming to enable shared road use, bike parking and rental facilities). In many countries current bicycle trips are decreasing due to economic growth and consequent increases in travel demand for motorized transportation. This coupling of growth and motorized mobility is problematic, particularly in view of the current climate debate, where present bicycle mobility avoids more CO_2 emissions being released, because each bicycle trip could potentially be motorized and emitting. In the context of the climate change debate, the "opportunity costs" of a bicycle trip are the additional CO_2 emissions that are generated when the traveller selects an alternative, motorized transportation mode for his or her bicycle trip. In terms of avoided CO_2 emissions, therefore, cycling provides significant "opportunity benefits".

When applied to carbon finance mechanisms, such opportunity benefits have an economic value. Investments in bicycle provisions could thus potentially generate carbon benefits. Once it is possible to appraise the carbon impact of cycling, UNFCCC mechanisms such as the Clean Development Mechanism (CDM), and financing facilities such as the Global Environment Facility (GEF), Climate Investment Fund (CIF) and the Clean Energy Financing Partnership Facility (CEPPF) could facilitate bicycle projects more easily. For the assessment of the opportunity benefits of cycling, a quantifiable evaluation framework is presented in this article.

The problem with assessing the carbon impact of cycling is that cycling has an intrinsic zero-emission value, making it difficult to attribute (direct) carbon benefits. There has been very little scientific research conducted into the estimation of the CO_2 reduction potential of cycling. General cost-benefit analysis of bicycle projects has been performed regularly (Cavill *et al*., 2009; Krizek, 2004; Litman, 2004; Lind, 2005; Lind *et al*., 2005; Saari *et al*., 2005; Sælensminde, 2004). However, the current state-of-the-art in bicycle evaluation generally ignores the avoidance of potential CO_2 emissions. Few studies included CO_2 emissions as a variable in their cost-benefit analysis (Browne, *et al*., 2005; Gotschi and Mills, 2008). These studies showed only marginal CO_2 reduction effects of bicycle projects, in most cases a result of the relatively small scale of the project such as the improvement of a single bicycle corridor. Browne suggests that CO_2 emissions reductions from city-wide cycling projects are more significant in both absolute and relative terms. Typical CO_2 evaluation instruments used in evaluating transport projects are also very data intensive and require large amounts of data on many variables to get the traffic estimates and perform the subsequent cost-benefit analysis (Schipper, 2009).

In developing countries that have no emission reduction targets, these data may not always be available, indicating the need for less data intensive methods to assess these projects. This article presents and demonstrates a method to calculate the CO_2 emissions benefits, or climate value, of cycling mobility using an opportunity costing approach. The climate value of cycling model is case tested for Bogotá, Colombia.

The next section discusses the policy relevance of the climate value of cycling. Section 3 presents the theoretical background of opportunity costs in transport evaluation and develops the climate value of cycling model. Section 4 gives the results for the case study of Bogotá, Colombia. Sections 5 and 6 provide a final discussion of the proposed methodology and present conclusions.

2. Policy relevance of attributing climate value to cycling

There are several issues regarding the policy relevance of attributing a climate value to cycling. First, the importance of attributing a climate value to cycling is not self-evident to policymakers and their professional advisors. Second, the attribution of climate values to transportation in general is not very well established. Third, the assessment and validation of the climate value of non-emitting active transport modes like cycling and walking is more complex than for directly or indirectly emitting motorized transportation. The policy relevance of attributing climate value to cycling is linked to the absence of the transportation sector, non-emitting modes in particular, in Carbon Credit assessment and validation methodologies as applied in Kyoto Protocol mechanisms. The awareness of climate policymakers of the importance of the transportation sector has only recently been achieved in debates at the 15th UNFCCC COP in Copenhagen, in December 2009. The bicycle has always been positioned and used as the icon for sustainable climate policies but until very recently not as contributor to emission reduction targets (Huizenga, 2009b; Sakamoto *et al*., 2010).

It is foreseeable that under the post-Kyoto climate protocol the UNFCCC developing member countries will be able to benefit from carbon compensation in the Nationally Appropriate Mitigation Action (NAMA) projects (UNDP, 2008). The monetary aspect of carbon compensation is expected to increase the importance of NAMA projects in national policymaking including priorities in planning and budget allocation. NAMA has been identified as the most promising post-2012 instrument for the transportation sector. It is our belief that in this instrument, cycling — and thus the climate value of cycling — can play an important role.

3. Opportunity costing in transportation research

In economics, the concept of opportunity costs is commonly used to value goods or services which are difficult to valuate. According to the Oxford English Dictionary, the opportunity cost is the cost of an alternative that must be forgone in order to pursue a certain action; in other words, it is the loss of benefits that could have been received when taking an alternative action. In transport economics, opportunity costs are frequently used to evaluate the external effects of transportation (Heertje and Polak, 2001). The most common application is the evaluation of congestion using value of travel time (VOT) savings.

For the evaluation of the external effects of CO_2 emissions of transportation, opportunity costs are often referred to as avoidance costs (Bickel and Friedrich, 2001). The method of avoidance costs determines the monetary costs to avoid a certain level of greenhouse gas emissions and calculates the marginal avoidance costs for reducing one unit of greenhouse gas emissions. Because of uncertainties about the costs of the CO_2 emission reduction measures and the future developments of greenhouse gas emissions, the monetary values of avoidance costs are difficult to compare. Bickel *et al*. (2001) show, for example, that marginal avoidance costs range from \$18 to \$127 per ton of CO_2, depending on different reduction target scenarios and the future development of CO_2 emissions.

When evaluating the avoidance costs of transportation, motorized modes have positive avoidance costs and non-motorized modes avoidance costs of zero. Consider the climate effects of a person who can make his daily trip to the market by bicycle or car. Suppose the person chooses to go by bicycle. Based on the principle of opportunity costs, the avoidance costs of using the bicycle for this trip are: (1) the avoidance costs of the bicycle trip itself, minus (2) the avoidance costs in case of the alternative action, i.e. using his alternative mode, the car. The avoidance cost of the bicycle trip is zero but the avoidance cost of the car trip is the volume of CO_2 emitted during the trip, leading to a negative net environmental cost. The use of the bicycle for the trip thus has an "opportunity benefit".

The climate value of cycling represents the total amount of avoided CO_2 emissions by all bicycle trips, which is the summation of opportunity costs of each bicycle trip in the study area. The climate value of cycling is calculated based on a prediction of the most likely alternative (substitution) mode for each bicycle trip and the calculation of the additional CO_2 emissions for that trip by the alternative mode. The method for estimating these opportunity costs (or benefits) of cycling is discussed in more detail in the next section.

3.1. *Effects of bicycle trip substitution*

The opportunity costing method simulates a virtual substitution of bicycle trips with trips made with an alternative mode. This substitution affects the transportation system in the short and long term for both travel demand and infrastructure supply. The transportation system can be conceptualized as a model with different layers representing either activities, travellers, modes or infrastructure as described by van der Riet and Egeter (1998). The top layers, land use distribution and travel patterns, represent the transport demand side of the system, while the transport supply side is regulated by the bottom layers, transport services and traffic services. The interactions between each layer are controlled by market mechanisms for travel (demand), transport (services) and traffic (performance). The mechanics of these markets can be explained by microeconomic theories of utility maximization and the aggregation of individual choices made by travellers (Ben-Akiva and Lerman, 1985).

For the estimation of the most likely alternative mode, it is assumed that the utility of performing an activity at the destination is unaffected by the chosen mode. When substituting a bicycle trip with its most likely alternative mode, utility maximization theory provides two possible outcomes: (1) the disutility (or cost) of making the original bicycle trip with another mode doesn't exceed the utility of the trip, hence the bicycle trip will have an alternative mode; (2) the disutility of making the trip with another mode exceeds the utility of the trip, thus this particular trip will no longer take place. According to Lee *et al*. (1999), short run changes in traffic volume resulting from the substitution of bicycle trips with other modes are defined as "induced traffic" for an increase in traffic volume and "discouraged traffic" for a decrease in traffic volume. Both induced and discouraged traffic will again affect utility values for the modes, assuming that in the short run the capacity of the transportation system remains the same. This characteristic of the equilibrium framework of transport demand and infrastructure supply is not considered in this study.

In the long run, bicycle trip substitution may have a stronger impact. The substitution of bicycle trips with an alternative mode could change travel patterns as a result of the different opportunities the alternative mode provides and the individual objective of travellers for utility maximization. For example, the shift from a bicycle trip to a car trip can result in a new situation where the individual traveller goes shopping at a larger supermarket in the outer parts of the city instead of at the local grocery store. This shift in travel patterns induces a change in land use distributions. As a result, increased use of cars could lead to a more dispersed land use pattern while increased use of walking could lead to a more compact land use pattern (Schoemaker, 2002). On the supply side, changes in level of services of modes induces expansion or reduction of transportation infrastructure, e.g. bicycle facilities will be converted into car facilities in order to meet the increased car demand. These long-term changes are called "induced demand" effects (Lee *et al*., 1999).

Although the inclusion of both short and long run effects would lead to a most comprehensive estimation of the climate value of cycling, the model presented in this article only accounts for the induced traffic effects assuming a fixed transportation network. These induced traffic effects are considered to be the main effects, particularly given the high percentage of work and school purpose trips in the case study presented in this article, purposes for which an induced demand effect is less likely, particularly in the short run. A second consideration for excluding induced demand effects is the objective to develop a well-ordered and data extensive evaluation model and to provide the first solid starting point for evaluating bicycle mobility with opportunity costs.

3.2. Modelling framework

The main focus of the modelling methodology is to estimate the most likely alternative mode for each bicycle trip and to calculate the additional CO_2 emissions caused by this induced traffic. A behavioural model is designed to estimate the most likely alternative mode for each bicycle trip. In current mode choice modelling, methodologies like logit models, probit models, mixed logit models and nested logit models are available. The model described here builds on existing theories of the multinomial logit behavioural model and aims to provide a simple, transparent and data extensive methodology, which can be easily applied by transport planners, policymakers and politicians.

The behavioural part of the climate value of cycling model defines mode choice situations based on the length and purpose of a trip and the socio-economic background of the trip maker. The model requires an input database describing the present traffic characteristics at trip level, indicating trip length, socio-economic background and trip purpose. Trips that share the same values for trip length, socio-economic background and trip purpose are clustered together into one class. Because the background information of travellers within one cluster is the same, these clusters are defined as mode choice situations. Irrespective of mode, all trips are clustered into classes of trips sharing the same mode choice situation. For each class, bicycle trips are redistributed to the most likely alternative modes based on observed modal share ratios of the remaining modes in that class.

The approach makes the assumption that the probability ratios of choosing one mode over the other remain unchanged when the bicycle mode is excluded from the choice set. This assumption is one of the major properties of the multinomial logit choice model and is described by Luce and Suppes (1965) as the Independence of Irrelevant Alternatives (IIA) axiom, i.e. "Where any two alternatives have a non-zero probability of being chosen, the ratio of one probability over the other is unaffected by the presence or absence of any additional alternative in the choice set". This means that when cycling is excluded from a choice set, the ratios of probabilities between the other modes remain the same, because utility values for the various mode options can be assumed to be unaffected by the exclusion and substitution of bicycle trips. According to de Ortúzar and Willumsen (2001) this axiom is generally perceived to have disadvantages, making the model fail when the bicycle alternative is not independent or when there are taste variations among individuals as a result of different cost perceptions.

The assumption of independence of the bicycle mode from the other modes can be justified by the fact that all trips are clustered into small classes, sharing trip characteristics and thereby capturing the taste variations among individuals related to socio-economic stratum and purpose of trip. For example, it is plausible that people from the lowest socio-economic stratum with a home to work trip of approximately two kilometres have similar mode choice options and selections. In addition, the bicycle mode only has to be independent from the other modes. Unobserved associations between the other modes can still exist in the model and do not hamper the ability of the model. Statistically, IIA violation can and should be tested using the Hausman and/or the Small-Hsiao test (Hausman, 1978; Small and Hsiao, 1985).

3.3. Climate value of cycling model

The modelling framework provides the base of the climate value of cycling model which is case tested for Bogotá, Colombia, in section 4. The modelling procedure consists of three steps: (1) clustering of trips in mode choice situation classes; (2) calculation of induced and discouraged traffic; and (3) calculation of opportunity costs.

The first step of the model is the clustering of trips in specific mode choice situation classes. All trips are clustered in discrete trip length bins b with sizes depending on the sample. Within each trip length bin classes are created, differentiating all trips by socio-economic stratum s

and purpose of trip p. To estimate the alternative modes, discrete probability distributions are estimated for each class based on the observation within that class, as derived in equation (1).

$$f_{x_{b,s,p}}(x_{b,s,p}) = \Pr(X_{b,s,p} = x_{b,s,p}) = \Pr(\{m_{b,s,p} \in M_{b,s,p} : X_{b,m,p}(m) = x_{b,s,p}\}) \qquad \forall b, s, p \tag{1a}$$

$$= \Pr(\{m_{b,s,p} \in M_{b,s,p} : X_{b,m,p}(m) = x_{b,s,p}\}) \qquad \forall b, s, p \tag{1b}$$

$$= \Pr\left(\left\{m_{b,s,p} \in M_{b,s,p} : X_{b,m,p}(m) = \frac{N^m_{b,s,p}}{\sum_{m=1}^{m} N^m_{b,s,p}}\right\}\right) \qquad \forall b, s, p \tag{1c}$$

$$P(X_{b,s,p}(m) = x_{b,s,p}) = \left[\frac{N^m_{b,s,p}}{\sum_{m=1}^{m} N^m_{b,s,p}}\right] \qquad \forall m, b, s, p \tag{2}$$

where:

- b trip length bin b;
- s socio-economic strata;
- p trip purpose p;
- $m_{b,s,p}$ mode m in subclass: trip length bin b, socio-economic strata and trip purpose p;
- $M_{b,s,p}$ sample space M for subclass: trip length bin b, socio-economic strata and trip purpose p;
- $N^m_{b,s,p}$ number of trips of mode m in subclass: trip length bin b, socio-economic strata and trip purpose p.

Equation (1c) defines the probability that mode m is the alternative mode for a bicycle trip in mode choice class b, s, p based on the probability mass function for each subclass (Johnson *et al*., 1993). The sample space M consists of all modes in that subclass excluding the bicycle mode. Equation (2) gives the probability that mode m is the alternative mode for a bicycle trip in subclass b, s, p. To include the discouraged traffic effect resulting from individuals who do not make an alternative trip with another mode, the discouraged traffic factor is introduced. The discouraged traffic factor controls the number of trips that have an alternative mode and is estimated using survey results (see Section 4.1).

$$\Delta PKT_m = \sum_{p=1}^{p}\left[\sum_{s=1}^{s}\left[\sum_{b=1}^{b}\left(F^s_{DT} * N^{bicycle}_{b,s,p} * (P(X_{b,s,p}(m) = x_{b,s,p}) * (\mu^m_{b,s,p})\right)\right]\right] \qquad \forall m \tag{3a}$$

$$= \sum_{p=1}^{p}\left[\sum_{s=1}^{s}\left[\sum_{b=1}^{b}\left(F^s_{DT} * N^{bicycle}_{b,s,p} * \left[\frac{N^m_{b,s,p}}{\sum_{m=1}^{m} N^m_{b,s,p}}\right] * \mu^m_{b,s,p}\right)\right]\right] \qquad \forall m \tag{3b}$$

Where:

- ΔPKT_m induced traffic of mode m in subclass: trip length bin b, socio-economic strata and trip purpose p;
- F^s_{DT} discouraged traffic factor specified per socio-economic strata;
- $N^{bicycle}_{b,s,p}$ number of bicycle trips in subclass: trip length bin b, socio-economic strata and trip purpose p;
- $\mu^m_{b,s,p}$ average trip length in subclass: trip length bin b, socio-economic strata and trip purpose p.

Equation (3b) calculates the induced traffic effect for mode m in each subclass: trip length bin b, socio-economic stratum s and trip purpose p for each mode m. The discouraged traffic factor can be estimated using a stated preference survey of cyclists as has been done for the case study of Bogotá. The discouraged traffic factor is given per socio-economic stratum s. Finally, the total opportunity costs or climate value of cycling is calculated by multiplying the induced traffic per mode with a modal emission factor. The climate value of cycling is finally calculated by:

$$CV_{cycling} = \sum_{m=1}^{m} \Delta PKT_m * EF_m \tag{4}$$

where:

- $CV_{cycling}$ climate value of cycling (kg CO_2);
- EF_m emission factor for mode m in kg CO_2 / km.

4. Case study: Bogotá, Colombia

Santa Fe de Bogotá or Bogotá is the capital of Colombia and in 2005 had an estimated population of 6.7 million inhabitants (DANE, 2009). Bogotá is located at an altitude of 2,640 m above sea level in the heart of Colombia.

Table 1. Distribution of population, trips and cycling trips in Bogotá over strata in the present traffic performance

	Population Size (%)	Number of Trips	Percentage of Total Trips (%)	Number of Cycling Trips	Percentage of Total Cycling Trips (%)	Average Distance of Cycling Trip (km)
Stratum 1	10.8	787,816	7.8	30,530	9.1	13.6
Stratum 2	35.4	3,267,708	32.3	203,578	60.4	8.4
Stratum 3	39.2	3,961,992	39.1	92,963	27.6	5.3
Stratum 4	10.6	1,372,017	13.6	7,331	2.2	8.9
Stratum 5	2.2	378,238	3.7	1,718	0.5	3.1
Stratum 6	1.7	352,856	3.5	985	0.3	9.2
Strata 4-6 (if merged)	14.5	2,103,111	20.8	10,034	3.0	7.9
Total	100.0	10,120,627	100.00	337,105	100.0	8.0

Source: SDM (2005).

Compared to other cities in Latin America, Bogotá has a high modal share of cycling trips of 3.3% (CCB, 2007). Bogotá was the first substantial case of carbon crediting in the transportation sector, used for the financing of vehicle procurement for the TransMilenio Bus Rapid Transit (BRT) system. The certification of the carbon credits was based on the scrapping of old buses and replacement with more energy efficient vehicles and improved system operation. The implementation of the TransMilenio system in Bogotá was part of an extensive urban space upgrading programme, including a high quality bi-directional cycle way network which has a combined length of 291 km (Cervero *et al*., 2009). For these reasons, Bogotá was selected as a case study for this research.

4.1. Input data

The *Observatorio de Movilidad* (Mobility survey) was used as the input database for the climate value of cycling model. This household travel survey was performed by the District Secretariat of Mobility (SDM) and the National Department of Statistics (DANE) in 2005. The survey was conducted in Bogotá and its 17 neighbouring municipalities. Together, these areas form the urban region of Bogotá.

In total, 20,686 respondents were asked to fill in trip diaries providing information on transport mode, socio-economic stratum of the respondent, trip purpose and origin/destination information. These trip diaries resulted in a database of 90,637 trips, which forms a representative sample of the daily trips of the response group. The trip survey was stratified based on the socio-economic strata classification scheme commonly used in Bogotá. The socio-economic strata index in Bogotá was determined using the classification from the Bogotá Planning Department based on physical characteristics of the household and surrounding areas (i.e. conditions and accessibility of the roads, presence of sidewalks, and construction materials of the house). Seven trip purposes were listed in the survey, i.e. Business, Education, Personal, Return home, Shopping, Work and Other.

Table 2. Discouraged traffic factors per socio-economic stratum, based on field survey

Stratum	Respondents	Discouraged Traffic Factor
1	61	0.98
2	465	0.96
3	400	0.92
4	63	0.87

Source: Authors' elaboration.

More than 85% of the *Bogotanos* are from the three lowest socio-economic strata. This population group accounts for 79.2% of all trips but 97% of all cycling trips made in Bogotá (See Table 1). Bicycle trips of stratum 1 are also significantly longer in length than in the higher classes. Both indicate that, in Bogotá, cycling is class dependent. It should, however, be noted that Rosero (2004) concluded that significant proportions of households at the top of the income distribution are classified among those in the three lower classes, so the results of the modelling procedure should be interpreted with care. Using expansion factors, the sample database is expanded to account for the complete population of Bogotá. This expansion results in a total trip database of 10,120,615 daily trips made in Bogotá.

To obtain the discouraged traffic effect of bicycle trips without an alternative mode, a roadside stated preference survey of cyclists in Bogotá was performed in October 2009, in collaboration with *Universidad de los Andes* in Bogotá. An intercept survey among a thousand adult cyclists was conducted. For this, the bicycle network was divided according to the socio-economic stratum of the neighbourhoods, area and the density of cyclists in the area using a GIS. Based on this, ten interception points across the bicycle network were selected for conducting the interviews. The cyclists were asked if they would still make their present bicycle trip if their bicycle was no longer an option for that trip. With this information the discouraged traffic factor (F_{DT}) for each socio-economic stratum *s* could be estimated (Table 2). Because the survey only resulted in 5 responses in the 6th stratum, 17 in the 5th stratum and 40 in the 4th stratum, these strata are merged. The results show a trend of increasing discouraged traffic factors with higher socio-economic stratum. This can be explained by the fact that in the higher socio-economic strata, relatively more bicycle trips are made with a recreational trip purpose. A study in The Netherlands also found that the share of recreational bicycle trips increases with income (CBS, 2003). It seems therefore logical that most people who use the bicycle for recreational purposes do not have a substitution mode for that particular trip, resulting in higher discouraged traffic factors among recreational trips and thus higher discouraged traffic factors for the higher socio-economic strata.

In addition, the model uses emission factors collected by Behrentz and Giraldo (2006) and Behrentz and Rodríguez (2009) for Bogotá and the Project Design Documents for the CDM approval of TransMilenio (Grütter, 2006). These studies provide detailed information on the vehicle fleet, occupancy rates and the vehicle specific CO_2 emissions for Bogotá, which allowed the estimation of CO_2 emissions per Passenger Kilometer Traveled (PKT). Table 3 gives an overview of the emission factors. For the public bus, school bus and TransMilenio, bandwidths are given to cope with variability in occupancy rates.

The present traffic performance as observed from the household travel survey is presented in Table 4. Using the emission factors in Table 3, the total annual CO_2 emissions of the present traffic are given.

On an average day, 10 million trips and 91 million passenger kilometres are travelled within the network of Bogotá. Ninety-three percent of the trips are made with a

Table 3. CO_2 emission factors

Transportation Mode	CO_2 per VKT (kg/km/vehicle) [a]	Average Occupancy of Vehicles[b]	CO_2 per PKT (kg/km/passenger)
Walking	—	—	—
Cycling	—	—	—
Motorcycle[1]	0.028	1.2	0.023
Car	0.28	1.37	0.204
Taxi	0.269	0.81[2]	0.332
Bus[3]	0.8	27.5 ± 7.5[4]	0.032 ± 0.008
BRT (TransMilenio)	1.74	96 ± 10[5]	0.018 ± 0.002
Other[6]	1.179	1	1,179

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

Table 4. Present traffic performance of Bogotá, Colombia

	Total	Walking	Cycling	Motorcycle	Car	Taxi	Bus	BRT	Other
Present traffic (Trips/day)	9,826,150	8.4%	3.3%	1.0%	18.7%	4.4%	57.1%	6.8%	0.3%
Present traffic (PKT/day)	91,031,438	3.6%	2.9%	1.0%	18.0%	3.1%	63.6%	7.5%	0.2%
Present emissions (tCO_2/day)	6,523 ± 477	0	0	21	3,342	945	1,853 ± 463	123 ± 14	239

Source: Authors' elaboration.

Table 5. Fitting statistics for the Multinomial Logit Models and IIA test statistics for the bicycle mode

	Fitting Statistics						IIA Test Statistics for the bicycle mode					
							Small-Hsiao			Hausman		
Bin (km)	Observations (All)	Observations (Cycling)	Nagelkerke R2 (%)	McFadden Adj R (%)	LR Test	Prob > LR	Chi_2	df	P > Chi_2	Chi_2	df	P > Chi_2
0-2	5,636	327	18.6	6.8	1,087	0.0	17.81	18	0.56	−130.50	17	—
2-4	11,040	503	24.9	9.3	2,959	0.0	18.05	18	0.50	−25.48	17	—
4-6	9,768	328	25.7	10.3	2,665	0.0	57.21	18	0.44	−30.05	15	—
6-8	9,800	317	24.9	10.5	2,526	0.0	17.80	18	0.51	−289.00	17	—
8-10	9,813	308	19.4	8.0	1,911	0.0	16.73	18	0.57	−2.66	16	—
10-12	8,795	249	18.1	8.0	1,540	0.0	14.94	18	0.65	−48.88	17	—
12-14	7,207	197	20.5	9.4	1,440	0.0	15.80	18	0.60	10.52	15	0.79
14-16	4,830	84	23.6	11.3	1,108	0.0	15.07	18	0.65	−2.31	16	—
16-18	3,199	121	25.0	12.4	767.4	0.0	13.60	18	0.58	−1.61	15	—
18-20	2,153	33	27.7	15.4	546.2	0.0	12.91	18	0.64	6.02	14	0.97
20-25	3,010	86	22.4	11.1	634.2	0.0	13.72	18	0.71	8.76	17	0.95
25-. . .	3,286	160	24.9	13.0	762.7	0.0	86.39	18	0.38	24.17	18	0.15

Source: Authors' elaboration.

motorized and emitting mode. This accounts for average CO_2 emissions of approximately 6,500 tons per day. Almost 50% of these emissions are caused by car traffic while only 18% of all passenger kilometres are attributable to car mobility. The dominant mode is the public bus, accounting for 60% of the traffic movements within the city.

4.2. Estimation of the model

To appropriately estimate the alternative modes, the IIA assumption for the bicycle mode should not be violated. Hausman (1978) and Small and Hsiao (1985) provide statistical procedures to test for IIA violation. These tests are performed on discrete choice models and test the hypothesis H_0 that IIA assumption is not violated. For this statistical test it is thus necessary to estimate multinomial logit models (MNL) for the data for Bogotá. Table 5 provides the fitting statistics for these models and gives the IIA test statistics. Because the climate value of cycling model uses trip length bins, separate MNLs are estimated for each trip length bin, controlling for the remaining trip characteristics, socio-economic stratum and trip purpose. In order to provide appropriate sample sizes, bins of 2 km are used. Above 20 km only two bins are constructed, of which the last one contains all trips longer than 25 km.

The available indicators show that the model is appropriate for each bin and has a good fit. The pseudo-R^2 values of Nagelkerke's R^2, ranging from 18.1% to 27.7%, and the adjusted pseudo-R^2 values of McFadden's R^2, ranging from 6.8% to 15.4%, indicate a good fit for each of the separate MNLs. To capture the variation in test results caused by the random division of the sample into two subsamples, the Small-Hsiao test statistics are estimated based on the average results of a hundred repeated tests. The resulting statistics are appropriate and indicate that IIA is not violated for the bicycle mode. Hausman does not reject the IIA assumption for any of the trip lengths bins. However, for eight of the bins, the test statistic is negative. This possibility is noted by Hausman and McFadden (1984) and they conclude that a negative result is evidence that IIA has not been violated. Overall, it can be concluded that the IIA assumption has not been violated and is therefore appropriate in this case.

4.3. The climate value of cycling for Bogotá

By using Equations (3b) and (4) the alternative mode for each bicycle trip is estimated and the resulting induced traffic and opportunity costs are calculated. The results for

Table 6. Modelling results: The climate value of cycling

	Total	Walking	Motorcycle	Car	Taxi	Bus	BRT	Other	Discouraged Traffic
Induced Traffic (Trips)	**310,314**	12.6%	1.8%	10.2%	2.7%	61.9%	5.3%	0.4%	–5.2%
Induced Traffic (PKT)	**2.490.825**	5.0%	1.7%	9.8%	1.9%	70.2%	6.2%	0.6%	–4.7%
Opportunity Costs (tCO_2)	**151 ± 14.3**	**0**	**1**	**52**	**17**	**73 ± 14**	**3 ± 0.3**	**19**	**0**

Source: Authors' elaboration.

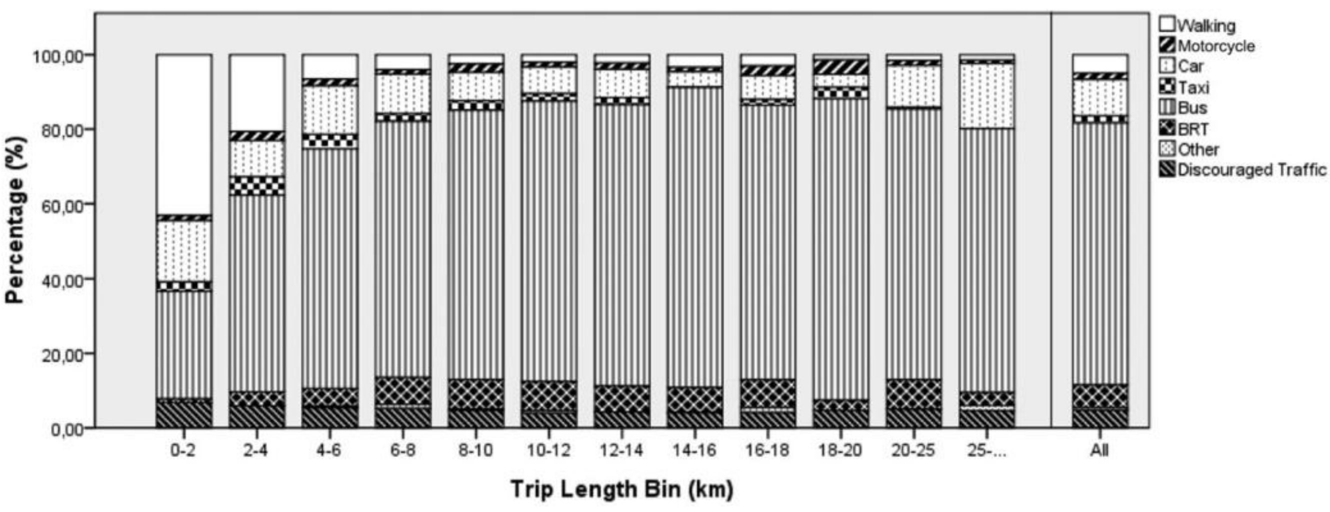

Figure 1. Distribution of alternative transportation modes for bicycle trips per trip length bin
Source: Authors' elaboration.

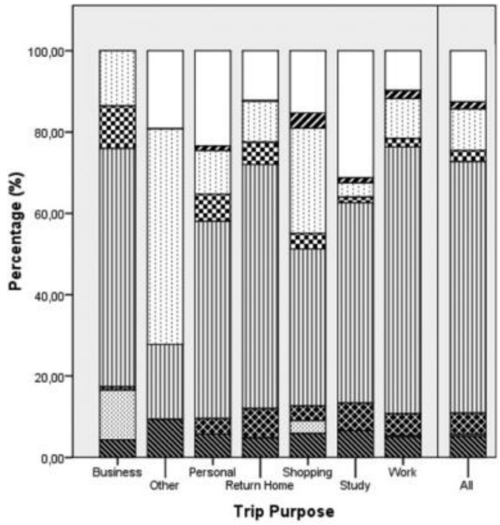

Figure 2. Distribution of alternative transportation modes for bicycle trips per trip purpose
Source: Authors' elaboration.

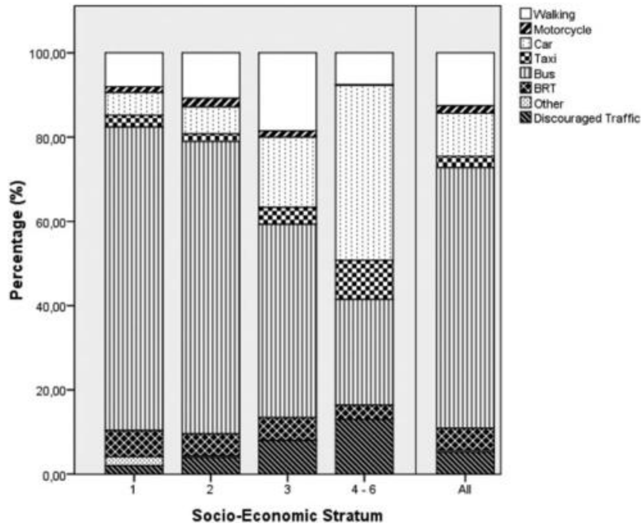

Figure 3. Distribution of alternative transportation modes for bicycle trips per socio-economic stratum
Source: Authors' elaboration.

the climate value of cycling for present mobility in Bogotá are presented in Table 6.

In total, 337,105 cycling trips are generated each day (see Table 1) corresponding with 2,613,247 PKT. Based on the discouraged traffic factor, only 310,314 trips and 2,490,825 PKT have an alternative mode. Bus accounts for the largest share, 61.9% of the trips and 70.2% of the PKT. Car, BRT and walking have significantly smaller shares, respectively 10.2%, 5.3% and 12.6% of the trips and 9.8%, 6.2% and 5.0% of the PKT. The total induced traffic from the alternative modes is equivalent to an opportunity cost of 151 tons of CO_2 per day or 55,115 tons of CO_2 per year, which can be seen as an "opportunity benefit" because it represents avoided CO_2 emissions. Compared to the total traffic performance of Bogotá, this corresponds with an avoidance of 2.4% of total CO_2 emissions.

The distribution of alternative modes per bin is presented in Figure 1. The dominant alternative mode for bicycle trips up to 2 km is walking (43.2%) followed by bus (28.9%) and car (16.3%). Throughout the remaining bins, bus is the main alternative mode for bicycle trips. The final bar "all" in Figure 1 presents the distribution of alternative modes for the complete set of trips (the graphical depiction of Table 6).

The distribution of alternative modes per trip purpose, as shown in Figure 2, differs significantly. Obviously, the bus remains the most dominant alternative mode for the purposes: Business (58.6%), Personal (48.5%), Return home (60.0%), Shopping (38.6%), Education (49.3%) and Work (65.5%). The second and third most important alternative modes are walking and car. For the Other trip purpose, the car is the most important alternative mode (53.0%) and for Shopping this is the second most important alternative mode (25.9%). Walking trips are the second most important mode in the cases of: Education (31.3%), Personal (23.4%), Return home (12.3%) and Other (19.2%). These differences are explained by the choices made by travellers from the same mode choice situation class. Travellers from the lowest socio-economic stratum and trip purpose Education are most likely to walk to their school or university because travellers from this mode choice class have limited mode choice options. Travellers from the highest socio-economic stratum with a shopping trip purpose are far more likely to have the car as alternative mode since comparable travellers in the same class select a car in most cases. This is also shown in figure 3, where the distribution of alternative modes is specified by stratum. In the lowest stratum, the bus is the most important alternative mode (72.0% bus and 5.4% car in stratum 1) while in the highest strata (25.1% bus and 41.6% car in strata 4-6) the car is the dominant alternative mode.

This observation results in smaller marginal climate values per bicycle kilometre travelled for people in the lower socio-economic strata (0.06 kg CO_2) as compared to those in the higher socio-economic strata (0.15 kg CO_2). The marginal climate values per average bicycle trip in the lower three strata show a comparable trend with 0.5 kg CO_2 per average bicycle trip as compared to 1.2 kg CO_2 per average bicycle trip made in the three higher socio-economic strata. The difference between the marginal climate values in the lower socio-economic strata and the higher socio-economic strata could even be larger when considering the observations made by Rosero (2004). As explained in section 4.1, a significant number of high income households are distributed in the lower strata resulting in the administration of trips from high income travellers in the lower strata. Because travellers with a higher income tend to make more car trips, this could mean that car trips administered in the lower socio-economic strata are actually car trips made in the higher socio-economic strata. Car substitution of bicycle trips in the lower socio-economic strata would therefore be lower leading to smaller (marginal) climate values, while for the higher socio-economic strata the opposite would be true.

Regarding the relevance of the climate value of cycling in climate change mitigation policies, it may be argued that an avoidance of 55,115 tons of CO_2 per year is small. However, this modest climate value of cycling can become significant for the development of sustainable transportation projects, when these avoided CO_2 emissions could be traded as carbon credits on the carbon market. Based on literature, Bickel and Friedrich (2001) estimated the marginal avoidance costs of 1 ton of CO_2 at $18-127. For Bogotá, this translates into monetary opportunity benefits of cycling ranging from $2,718-19,177 per day to $1 million-$7 million per year. With an average infrastructure investment cost of $130,000 per km of bicycle path (C40, 2009), an annual increase of the bicycle path network in Bogotá ranging from 8 km in the lowest price scenario and 54 km in the highest price scenario is possible.

5. Discussion

5.1. Induced traffic and demand

When cyclists use an alternative mode for their trips, additional traffic is induced in the short run and travel demand is induced in the long run. For example, a shift from cycling to walking trips forces travellers, in the long run, to select destinations closer to their origin while a shift to a motorized mode allows travellers to travel farther. These effects can be explained by the law of constant travel time and trip rates by Hupkes (1982). This law states that people have a fixed travel time budget which allows people to make longer trips when average travel speed increases and shorter trips when average travel speed decreases.

For example, compare two cities with the same population size, urban area and cycling modal share. One city is developed with a high rate of private motorization. The other city is in a developing state and its transportation system relies heavily on public transport and walking, with only a small percentage of private motorization. The climate value of cycling will be larger in the developed city because the car will be the most likely alternative mode for most cycling trips. On the other hand, in the developing city, walking or public transport would be the most important alternative mode. This difference exists because cycling in a developed city is usually considered to be less class-dependent, because the average cyclist has several mode choice options available, including a car. In a developing city most cyclists are captive to their bicycle, resulting in a very limited set of alternative mode choices, such as cheap public transportation or walking. The induced travel demand effects in the long run may be different, as well. In the developed city, the dominant alternative car option could induce longer trips and longer trip-chains, resulting in a shift in locations of activities and land use distribution. This shift in land use leads to a more dispersed urban form which again induces longer trips. On the other hand, an increased usage of public transport and walking in the developing city might eventually lead to more compact urban developments around residential areas and public transport corridors. This may result in shorter trip lengths and smaller climate values of cycling.

Induced travel demand effects may therefore increase the climate value of cycling in developed cities, while it may decrease for developing cities, as compared to the baseline presented in this study. This does not mean that cycling is of lesser value in a developing city. When looking at sustainable transport development, environmental effects are not the only concern. Social and economic effects are as important. Even though the avoided emissions in the developing city are less significant, the other benefits of cycling — in terms of providing access to opportunities, e.g. attending school, going to work, or utilizing public health services — also have a social and economic value. Estimating the socio-economic value of cycling next to the climate value of cycling is part of on-going research.

The fact that the climate value of cycling is higher in places with large motorization rates indicates the importance of cycling mobility as a CO_2 emission mitigation strategy in developed cities. However, even though developing cities have smaller marginal climate values of cycling, it is expected that many of the developing cities of today will be the developed cities of tomorrow. For example, in Beijing the cycling modal share has decreased from 38.5% in 2000 to 23% in 2007, while the car modal split has increased from 26.5% to 32.6% in the same years (Hongyang *et al*., 2005). When citizens from lower socio-economic strata improve their economic status they will also change their mobility preferences. In the absence of decent bicycle facilities, it is more likely that private motorized transportation will be used. Guidance in the form of investment in bicycle facilities is therefore of vital importance in creating a sustainable transport future. The climate value of cycling model can assist in estimating the benefits of cycling and thus, appraise the carbon impacts of cycling.

5.2. Alternative mode choice modelling

The mode choice model estimates alternative modes based on observed modal shares within the mode choice situation classes. This methodology assumes that the IIA assumption holds. For the case of Bogotá, independence of the bicycle can correctly be assumed because the results of the statistical tests for IIA violation of Hausman and Small-

Hsiao are satisfactory. This also seems logical, since the average length of a cycling trip in Bogotá is 8 km. When compared with the 4 km for walking trips, this indicates that, in terms of active transportation, the bicycle is used for different trips than walking. This gives validation to the assumption that cycling is uncorrelated with walking. It is also established that cycling in Bogotá is class-related, since 97% of the cycling trips are made by people from the lowest three socio-economic strata. In Bogotá, only 10.3% of the cyclists own a car, and only 2.2% own a motorcycle (SDM, 2005). So, the majority of cyclists in Bogotá only have the opportunity of using a bicycle when selecting a private mode. However, for other cities this may not be the case, as correlations between cycling and other alternatives could well exist. For example, travellers could make their mode choices based on a nested choice. With this nested logic, cycling could correlate strongly with walking (the non-motorized transport nest), but not with motorbike and car. Such logic is not captured here.

6. Conclusion

In this article, the concept of the climate value of cycling is introduced. This concept allows one to calculate the opportunity benefits of cycling in terms of avoided CO_2 emissions. The methodology shows that bicycle mobility contributes to climate change mitigation. The climate value of cycling is dependent on the amount of cycling mobility in the case study area, the competitive relation of the bicycle with the other modes and mode specific CO_2 emission factors. The model provides an intuitive, straightforward approach, which allows urban planners, politicians and scientists to assess the value of current cycling mobility based on minimal input data and with minimal transport modelling knowledge. It assists in the redefinition of urban mobility planning by demonstrating the value of avoided CO_2 emissions that cycling and non-motorized transportation intrinsically provide, thus inducing a paradigm shift from "Improve" strategies of motorized transportation to "Avoid" and "Shift" strategies.

Although carbon financing instruments of transportation projects are still under discussion, the climate value of cycling model contributes to the inclusion of cycling as one means to achieve sustainable development. Application to Bogotá, Colombia, a city with a bicycle modal share of 3.3%, showed that the CO_2 opportunity benefits are approximately 151 tons of CO_2 per day and 55,000 tons of CO_2 per year. Capitalization of these carbon emissions on the carbon markets could correspond to an economic input of $1 million to $7 million per year, depending on the height of the marginal avoidance costs.

The climate value of cycling model for Bogotá is the first step in the development of simple, well-ordered and transparent CO_2 evaluation tools for cycling mobility. To prepare the climate value of cycling model for general application, the ability to cope with different case studies is vital. To identify potential violations of the IIA assumption, statistical tests need to be performed. If IIA is violated, it is recommended to investigate the opportunities of using different mode choice models, such as nested choice, probit or mixed logit modelling. This would, however, significantly increase the modelling complexity.

It is also recommended that the relations between the climate value of cycling and the socio-economic value of cycling are investigated. The discrepancy between these measures indicates difficulties when developing cycling as both a "pro-poor" and "pro-climate" transportation solution. To address these issues, further research should focus on a comparative analysis of the climate values of cycling from a set of cities differing in traffic, demographic and urban characteristics.

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References

Behrentz, E. and Giraldo, L., 2006. *Estimación del inventario de emisiones de fuentes móviles para la ciudad de Bogotá e identificación de variables pertinentes* (Estimated inventory of mobile source emissions for the city of Bogotá and identification of relevant variables). Working paper Series/Report No. ICYA 2006-38, Grupo de Estudios en Sostenibilidad Urbana y Regional (SUR), Universidad de Los Andes, Bogotá, Colombia.

Behrentz, E. and Rodrí guez, P., 2009. *Actualización del inventario de emisiones de fuentes móviles para la ciudad de bogotá a través de mediciones directas* (Update inventory of mobile source emissions for the city of Bogotá through direct measurements). Working paper Series/Report No. MIC 2009-I-27, Grupo de Estudios en Sostenibilidad Urbana y Regional (SUR), Universidad de Los Andes, Bogotá, Colombia.

Bickel, P. and Friedrich, R., 2001. *Environmental External Costs of Transport*. Springer-Verlag Telos. p. 139

Browne, J., Sanhueza, E., Silsbe, E., Winkelman, S. and Zegras, C., 2005. *Getting on Track: Finding a Path for Transportation in the CDM*. International Institute for Sustainable Development, Winnipeg, Manitoba.

C40, 2009. *C40 cities: Climate leadership group — best practices — transportation — Bogota: cycling system*. Available online at: www.c40cities.org. Accessed 20 November 2009.

Cavill, N., Kahlmeier, S., Rutter, H., Racioppi, F. and Oja, P., 2009. Economic analyses of transport infrastructure and policies including health effects related to cycling and walking: A systematic review. *Transport Policy*, 15(5): 291–304.

CBS, 2003. *Onderzoek dagrecreatie 2001/2002*, Statistics Netherlands, CBS: Voorburg, The Netherlands (in Dutch).

CCB, 2007. *Observatorio de movilidad de Bogotá y la región* (Mobility Observatory of Bogotá and its region). Technical report, Camara de Comercio de Bogotá.

Cervero, R., Sarmiento, O.L., Jacoby, E., Gomez, L.F. and Neiman, A., 2009. Influences of built environments on walking and cycling: Lessons from Bogotá. *International Journal of Sustainable Transportation*, 3(4): 203–226.

Dalkmann, H. and Brannigan, C., 2007. *Module 5e. Sustainable Transport: A Sourcebook for Policy-makers in Developing Cities*. GTZ, Frankfurt.

DANE, 2009. *Libro censo 2005* (Census book 2005). Bogotá, Colombia. Available online at: http://www.dane.gov.co/censo/files/libroCenso2005nacional.pdf. Accessed 20 November 2009.

Gotschi, T., Mills, K., 2008. *Active Transportation for America: The Case for Increased Federal Investment in Walking and Cycling*. Rails-to-trails Conservancy, Washington, DC.

Grütter J., 2006. *BRT Bogotá, Colombia: TransMilenio phase II-IV*. Technical report, Grütter Consulting on behalf of Corporación Andina de Fomento (CAF) and TransMilenio S.A.

Hausman, J.A., 1978, Specification tests in econometrics. *Econometrica*, 46(6): 1251–1271.

Hausman, J.A. and McFadden, D., 1984. Specification tests for the multinomial logit model, *Econometrica*, 52(5): 1219–1240.

Heertje, A. and Polak, J.B., 2001. *Analytical Transport Economics: An International Perspective (Transport Economics, Management and Policy Series)*. Edward Elgar: Cheltenham, United Kingdom.

Hongyang, W., Yulin, J., Peng, H. and Suoxiang, C., 2005. *Benchmarking efficiency of urban transport systems in China*. China Academy of Transportation Sciences (CATS). Beijing, P.R. China.

Huizenga, C. and Bakker, S., 2009. *Applicability of post 2012 climate instruments to the transport sector. Interim Synthesis Consultant Report*. Asian Development Bank, Inter-American Development Bank. Manila, Philippines.

Huizenga, C., 2009b. *Common Policy Framework on Transport and Climate Change*. Available at: http://www.slocat.net/bellagio-process/common-policy-framework-cpf-on-transport-and-climate-change-in-developing-countries. Accessed 25 October 2010.

Hupkes, G., 1982. The law of constant travel time and trip-rates. *Futures*, 14(1): 38–46.

International Energy Agency (IEA), 2008. *World Energy Outlook*. Paris, France.

Jacobsen, P.L., 2003. Safety in numbers: more walkers and bicyclists, safer walking and bicycling. *Injury Prevention*, 9(3):205–209.

Johansson, B.W., 2009. Restrictions on CO_2 emissions require reduction in transport demand? *Energy Policy*, 37(8): 3212–3220.

Johnson, N.L., Kotz, S., Kemp A., 1993. *Univariate Discrete Distributions (2nd Edition)*. Wiley.

Krizek, K., 2004. Estimating the economic benefits of bicycling and bicycle facilities: An interpretive review and proposed methods. In TRB (Transportation Research Board), *TRB 2004 Annual Meeting*. Washington D.C., January 11–15, 2004. TRB: Washington, DC.

Leather, J., 2009. *Rethinking Transport and Climate Change*. ADB Sustainable Development Working Paper Series. Asian Development Bank, Manila, Philippines.

Lee, D.B., Klein, L.A. and Camus, G., 1999. Induced traffic and induced demand in benefit–cost analysis. *Transportation Research Record*, 1694: 120–125.

Litman, T., 2004. *Quantifying the Benefits of Nonmotorized Transportation for Achieving Mobility Management Objective*s. Victoria Transport Policy Institute, Victoria, Canada.

Lind, G., 2005. CBA of cycling: summary of conference proceedings. In Nordic Council of Ministers, *CBA of Cycling: Nordic Council of Ministers' seminar*. Stockholm, Sweden, February 1–2, 2005. Nordic Council of Ministers: Copenhagen.

Lind, G., Hydé n, C. and Persson, U., 2005. Benefits and costs of bicycle infrastructure in Sweden. In Nordic Council of Ministers, *CBA of Cycling: Nordic Council of Ministers' seminar*. Stockholm, February 1–2, 2005. Nordic Council of Ministers: Copenhagen.

Luce, R.D. and Suppes, P., 1965. Preference, utility and subjective probability. In R.D. Luce, R.R. Bush and E. Galanter (ed.), *Handbook of Mathematical Psychology*. New York: John Wiley & Sons, pp. 249–410.

OECD, 2004. Implementing sustainable urban travel policies. Moving ahead: National policies to promote cycling. In OECD (Organization for Economic Co-Operation and Development), *European Commission of Ministers of Transport 2004*, OECD: Paris.

Ortú zar, J. de D. and Willumsen, L.G., 2001. *Modelling Transport*. Third ed., Chichester: John Wiley & Sons.

Riet, O.A.W.T van de, Egeter, B., (1998). *Systeemdiagram voor het beleidsveld vervoer en verkeer; beschrijving vervoer- en verkeerssysteem ten behoeve van het project Questa* (System diagram for the policy field of transportation and traffic; description of the transport- and traffic system for project Questa), Rand Europe, TNO Inro, Delft. (in Dutch)

Rosero, L.M., 2004. Estratificación socioeconómica como instrumento de focalización (Socioeconomic stratification as a tool for targeting). *Economía y Desarrollo*, 3(1): 53–67.

Saari, R., Metsäranta, H., and Tervonen, J., 2005. Finnish guidelines for the assessment of walking and cycling projects. In Nordic Council of Ministers, *CBA of Cycling: Nordic Council of Ministers' seminar*. Stockholm, February 1–2, 2005. Nordic Council of Ministers: Copenhagen.

Sakamoto, K., Dalkmann, H. and Palmer, D., 2010. *A Paradigm Shift Towards Sustainable Low-Carbon Transport — Financing the Vision ASAP*. Institute for Transportation & Development Policy. New York, United States.

Sæ lensminde, K., 2004. Cost-benefit analyses of walking and cycling track networks taking into account insecurity, health effects and external costs of motorized traffic. *Transportation Research Part A: Policy and Practice*, 38(3): 593–606.

Schipper, L., 2009, *Considering Climate Change in Latin American and Caribbean Urban Transportation*, University of California.

Schoemaker, T., 2002. *Samenhang in vervoer- en verkeerssystemen* (Consistencies in transport- and traffic systems). Bussum, The Netherlands: Uitgever Coutinho.

SDM, 2005. *Encuesta de Movilidad & Descripción de las bases de datos de la encuesta de movilidad* (Mobility survey & description of the database of the mobility survey). Technical report, Secretaría Distrital de Movilidad. Bogotá, Colombia.

Small. K.A. and Hsiao, C., 1985, Multinomial logit specification tests, *International Economic Review*, 26: 619.

TRB, 2006. *NCHRP Report 552 — Guidelines for Analysis of Investments in Bicycle Facilities*. TRB (Transportation Research Board), Washington, DC.

United Nations Development Program (UNDP), 2008. *The Bali action plan: key issues in the climate negotiations — Summary for policy makers*. Environment and Energy Group. New York, United States & Energy Group Publication.

Woodcock, J., Edwards, P., Tonne, C., Armstrong, B.G., Ashiru, O., Banister, D., Beevers, S., Chalabi, Z., Chowdhury, Z., Cohen, A., Franco, O.H., Haines, A., Hickman, R., Lindsay, G., Mittal, I., Mohan, D., Tiwari, G., Woodward, A. and Roberts, I., 2009. Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. *The Lancet*, 374 (9705): 1930–1943.