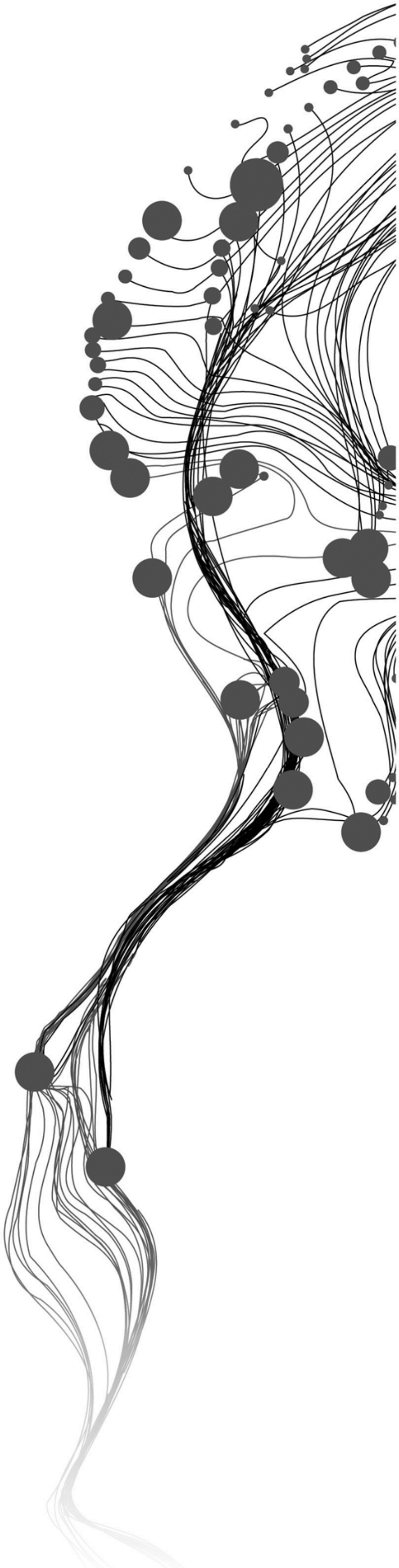
A SPATIAL APPLICATION OF AN OPPORTUNITY COSTING METHODOLOGY FOR THE ASSESSMENT OF THE CLIMATE VALUE OF CYCLING

CLASSIO JOÃO MENDIATE
February, 2011

SUPERVISORS:
Dr. Ir. M. H.P. Zuidgeest
Drs. E.J.M. Dolpheide



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Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
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SUPERVISORS:
Dr. Ir. M. H.P. Zuidgeest
Drs. E.J.M. Dolpheide

THESIS ASSESSMENT BOARD:
Dr. R.V. Sliuzas
MSc. R.A. Massink (External Examiner)

ABSTRACT

Sustainable transportation, especially cycling contributes to mitigation of CO_2 emissions as cycling possesses an intrinsic zero-emission value. Cycling mobility can be seen as a 'CO_2-sink' because each bicycle trip represents potential CO_2 emission when replaced with an alternative motorized transportation mode. Only few studies have been conducted to assess the climate value of cycling and those studies used the aspatial version of the opportunity costing methodology which gave statistical analysis of the city as a whole. This research aims to use the spatial version of the opportunity costing methodology which assigns a value to a bicycle kilometre travelled based on the stated substitution mode for that trip by the cyclists. The model includes the first and second order effect of bicycle substitution which makes it more complex and accurate. It allows to visualize the spatial distribution of the climate value of cycling per ward and to identify the major contributors to the total climate value for the study area. The climate value was calculated for the sample and population. This resulted in a climate value of cycling of 1,062.4 tonnes CO_2 per year which corresponds to monetary asset between US$ 7,075.9 - 20,994 if traded in carbon market. Due to concentration of activities in the Stone town it was found that the major contributors to the total climate value of cycling were located far from activities, overall most of them were potential risk to emit CO_2 if cycling is no longer an option. To conclude, the spatial application of this methodology provided disaggregated information which could be used by the transport planners and decision makers to delineate policies for sustainable transportation system. Further to bring more strength to this model recommendation was made to update the primary data collection approach.

Key words: Bicycle trips, Stated preferences of cyclists, Mode shift, Climate value.

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Classio Mendiate
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CO_2	Carbon dioxide
CV	Climate value
EF	Emission factor
GIS	Geographic information system
GHG	Greenhouse gas
SP	Stated preference
SEV	Socio-economic value
PKT	Passenger kilometre travelled
TLFD	Trip length frequency distribution

1. INTRODUCTION

1.1. Unsustainable transport

Transport systems represent a cities' economic backbone, as they provide the basic mobility and accessibility options that are crucial to the reasonable functioning of most activities. Many transport systems around the world are beginning to threaten the very habitability of the cities they serve, as vehicle numbers and travel begin to outstrip the capabilities of existing infrastructure systems. The resulting traffic congestion has a direct effect on economic growth, and the level of Greenhouse Gasses (GHG) released to the atmosphere. These problems are particularly acute in the developing world's largest cities, growing incomes and proliferation of cheaper motorized vehicles increases car ownership, requiring large amounts of additional land and energy to supply thus large emission of CO_2 (Folton, 2001).

Urban transportation in developing countries is being affected by fast growing rural to urban migration. This increase of urban population is not accompanied with the distribution of land uses, resulting in a large number of people living far from their daily activities. Those living far from their activities are forced to shift away from cheaper modes, often with zero CO_2 emission and that are suitable for short distances like cycling to motorized vehicles, with remarkable higher cost and higher emission of CO_2. Hence urban form and urban growth may proof to be important factors causing unsustainable transport. Cycling, urban form and the climate impact of cycling, particularly in Zanzibar, Tanzania, is the topic of this thesis.

1.1.1. Background of urban transport in Tanzania

Most of African cities have expanded faster than the capacity of their governments to cope with the growing needs for infrastructure, resulting in incomplete and unconnected road networks. In Dar es Salaam (the largest city in Tanzania), the condition of roads, both paved and unpaved contributes to congestion, reducing the speed, profitability and useful life of public transport vehicles. The coverage of the paved road network, in particular, limits access of bus services in many areas of the city, most can be only reached by two-wheeled vehicles. The total road network is about 1140 km, of which only 445 km is paved (Kumar & Barrett, 2008).

In Zanzibar the road network is composed of 1600 km roads, of which only 85% is paved or semi-paved ("Zanzibar," 2010). Based on census 2002 the total population of Zanzibar island was 984,625 inhabitants and the paved or semi-paved road density per thousand inhabitants was 1268.65m ("Zanzibar Statistics," 2010) which is high compared to Dar es Salaam. According to the UN Millennium Cities Database, such road density for Zanzibar is acceptable since the average of paved road density for developing countries should be close to 1,000 meters per thousand inhabitants (Kumar & Barrett, 2008).

Cycling at Zanzibar is modest with an average of 41% of the modal split. With its relatively small scale (particularly the urban area) its relatively high road density, there is an interest in how current level of cycling perform (as related to other modes) as an sink of CO_2 emission. Of particular interest is how this varies by socio economic group and spatial locations (as a function of urban form).

The climate value (CV) of cycling represents the total amount of avoided CO_2 emissions by cycling trips in an area. Based on a prediction of the most likely alternative (substitution) mode for each bicycle trip, and calculation of the additional CO_2 emissions for that trip by the alternative mode, the climate value of cycling is calculated. In this study a spatially disaggregated application of the climate value of cycling model is developed for Zanzibar.

1.2. Justification of Study

1.2.1. Scope of the research

This research intends to quantify and visualize a spatial explicitly application of cycling model in GIS.

1.2.2. Relevance of a spatial explicit application of the opportunity costing model for cycling

The climate value of cycling model is based on opportunity costing theory. In economic terms opportunity cost is the cost related to the next-best choice available to someone who has picked among several ("The Economist," 2011). Applying this to cycling research, the cost of using the alternative mode to bicycling is referred to as the value of CO_2 emissions emitted. This enables the estimation of the climate value of cycling for any defined study area.

The model uses the stated preferences (SP) of cyclists in terms of the alternative transport modes (if bicycle is no longer option), travel distances to activities and origin location of the cyclist. Alternatively, the model uses a probabilistic model to forecast the most likely alternative mode as described in Massink (2009). That model is currently applied for several cities around the world; however, this has not been done in a spatially explicit way, to enable intra-city analysis, or in a GIS model to enable spatial and visual analysis. Such intra-city analysis would allow for analyzing contributions of different areas to the climate value of cycling as well as seeking possible spatial factors such as location characteristics, i.e. urban density, distance to city centre, and social characteristics of the location, i.e. income etc. Hence appropriate infrastructure and transport policies can be derived to sustain or enhance current levels of cycling mobility based on these factors.

For the present research the focus is on a spatial application of this method and applies it to a case study area in Zanzibar to be able to define zones within the city that have the highest potential in decreasing CO_2 emissions through cycling.

1.3. Research problem

Assessment of avoided CO2 emissions through non-polluter modes like cycling at an intra-city scale has not been done in general and for Zanzibar in particular

Sustainable transport has become an important goal in transportation planning and research in recent decades. One major reason is that the current auto-dependency of urban transportation systems in many cities is considered to be unsustainable. In particular, the auto-dependent city has contributed to the degradation of natural environments such as water, air, vegetation, and soils and depletion of finite natural resources such as petroleum (Rybarczyk & Wu, 2010).

Buses and other forms of collective transport are now losing their share of trips and travel to individual modes. This evolution is spreading to even the poorer large cities of the developing world, with two- and three-wheelers becoming more numerous than buses (Folton, 2001). However, an increasing number of city governments in developed and developing cities have recently begun actively transforming their transportation system into sustainable one with less GHG emission (Hook, 2003). Transforming today's unsustainable urban transport system into a sustainable one that consumes less energy is a huge challenge. Transport is a fundamental element of a hugely complex urban social and economic fabric extended over large amounts of land (VREF, 2010). Sustainable transportation systems are those with low impact on the environment, and those that avoid CO_2 emission. Assessment of avoided CO2 emission through non-polluter modes like cycling for intra city trips has not been done.

The concept of opportunity costing is used to calculate avoided emissions since bicycles have an intrinsic zero-emission value; the shift from cycling to motorized transportation creates an absolute increase. By evaluation a virtual substituting of all bicycle trips with their most likely (motorized) alternative transportation modes, the additional CO_2 emissions can be estimated and the intrinsic climate value of cycling becomes clear (Massink, 2009).

Previous studies using this model were conducted at a city wide level. The results of these studies were aspatial (non–spatial), because the data used was not spatially specified and they only allowed for city comparison, rather than within city policy development.

For the present study we use the same methodology but spatially disaggregated (at the ward level) and link it to a GIS model in order to assess the avoided carbon emission through cycling for specific areas within a city. The spatial application of this model can help decision makers to understand the current distribution of climate value of cycling for intra-city trips, and the main spatial and non-spatial factors that cause this. This insight helps in the allocation of resources for promotion and preserving cycling.

1.4. Research aim, objective and questions

1.4.1. Aim and objectives

The aim of the study is to gain insight on the spatial distribution of climate value of cycling within a city, by applying a disaggregated and spatially explicit version of the opportunity costing cycling model.

1.4.2. Main objective

To develop a geo-spatial application of the opportunity costing model for analyzing cycling mobility at an intra-city scale in terms of avoided CO_2 emissions through cycling.

1.4.3. Sub - objectives

The main objective is supported by the following sub objectives;

1. To describe the current travel behaviour of cyclists in Zanzibar town.

2. To assess the most likely substitution mode from the bicycle to other modes based on current travel patterns for demarcated areas in the town.

3. To calculate the disaggregated climate values of cycling per distinct geographical area and visualize it spatially.

4. To quantify the monetary value of the avoided CO2 of cycling.

6. To recommend on allocation of resources for promotion or preserving of cycling.

1.4.4. Research questions

Based on the sub objectives the following research questions are derived which are as follow:

Research Objectives	Research questions
To describe the current travel behaviour of cyclists in Zanzibar town	• What is the current travel behaviour of the cyclists and how does it vary per different trip purposes and spatial location?
To assess the most likely substitution mode from the bicycle to other modes based on current travel patterns for demarcated areas in the town.	• What is the most likely alternative transportation mode in case of a forced substitution of a bicycle trip?
To calculate the disaggregated climate values of cycling per distinct geographical area and visualize it spatially.	• What is the climate value of cycling per distinct geographical areas based on the most likely substitution mode? • What are the different visualization techniques and spatial indicators that could be used to display spatially distribution of climate value of cycling? • What are the factors that most relates to CO_2-sink capabilities of cycling for intra-city travels?
To quantify the monetary value of the avoided CO_2 of cycling.	• What is the monetary value of CO_2-sink through cycling for city wide scale?
To recommend on allocation of resources for promotion or preserving of cycling.	• What are the suitable wards to allocate resources to promote cycling?

1.5. Research methodology

The research methodology below gives an outline of the research strategy adopted. The research model in the figure 1-1 provides a structured overview of all the research processes.
It is divided into three phases: the pre-analysis phase, analysis phase and post-analysis phase. The numbers shown in the research models corresponds to each research question presented in section 1.4.4. The strategy for each phase is discussed below.

The pre-analysis phase

In the pre-analysis phase, the main problems were identified and the goals and objectives formulated. After that data collection strategy was designed and executed for primary and secondary data. For primary data information regarding the socio-economic characteristic of the cyclist, yesterday's bicycles trips, and alternative mode of transportation and destination choice was collected. For secondary data, demographic and administrative boundaries were collected, which were used to define the spatial scale of the study.

The technical analysis phase

The technical phase involves assessment of the climate value of cycling by using the opportunity costing methodology. This is the academic base for this research. The opportunity costing model consists of set of sub models which deal with the problem in four stages:

- Trip generation: Access the number of bicycle trips produced per wards and trip purpose, this answers the first question.
- Trip distribution: Provides spatial distribution of bicycle trips. It is modelled in ArcGIS and demonstrates the influence of the urban form in the distribution of bicycle trips. This gives insight to the second and sixth question.
- Derive mode substitution, distribution and generation effect: The model deals with the first and second order effect of bicycle substitution.
- Climate value model: Is modelled for sample and all population. The input data is basically the vehicle emission factor and Passenger Kilometre Travelled (PKT) and the output is the climate value for each bicycle trip and can be used for spatial modelling.

The climate value modelling framework is discussed with more details in the chapter five.

The post - analysis phase

The outcomes of the technical phase are applied in the GIS modelling. This provides the spatial application of the opportunity costing model and is able to calculate the climate and monetary value of cycling, to visualize and compare contribution of different wards to the total climate value of the study area. This gives answer for the remainder of the questions.

The three phases are conceptually depicted in the following figure 1-1

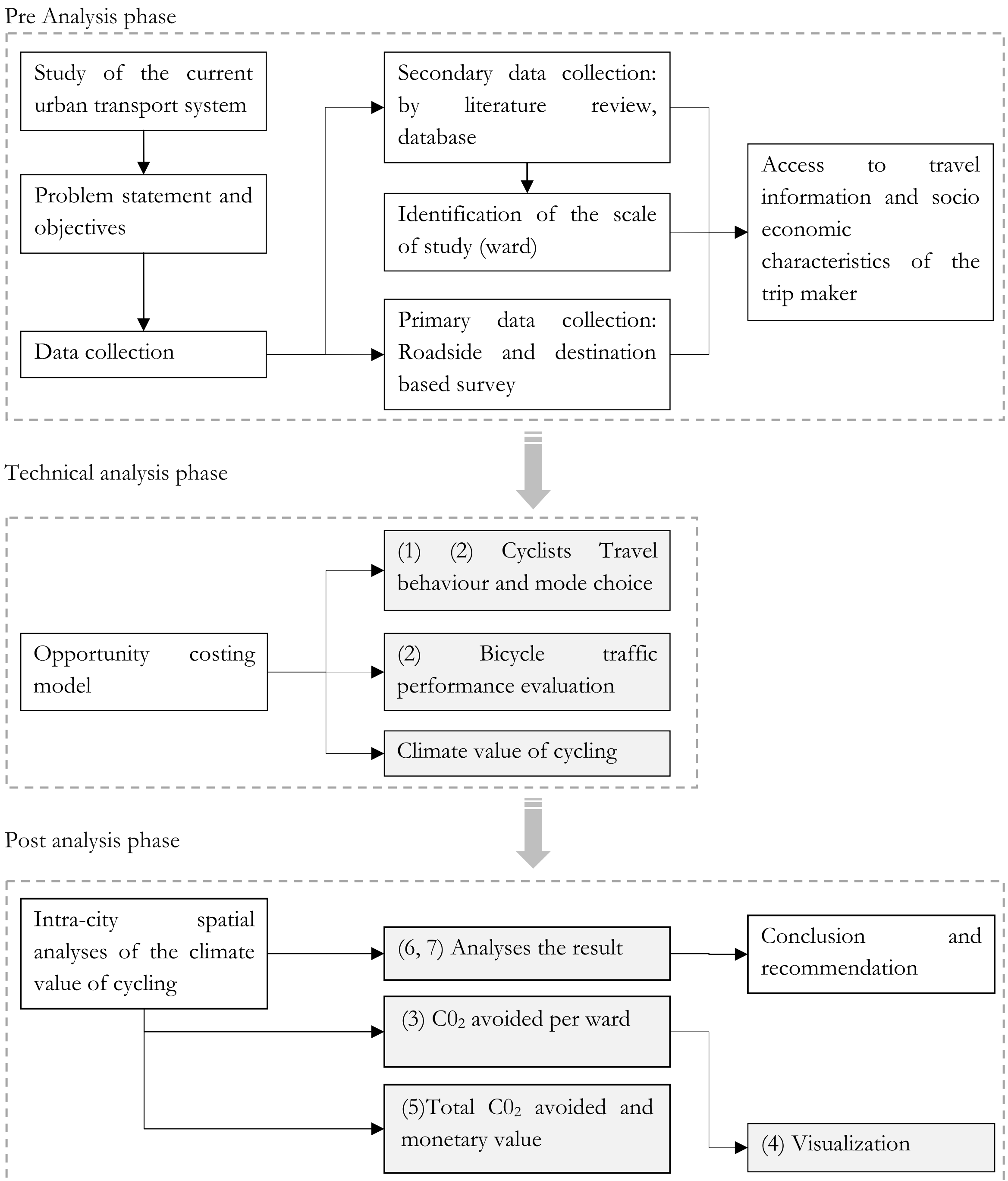

Figure 1-1: Research approach

Adapted from (Zuidgeest, 2007)

1.6. Research matrix

Research objective	Research question	Methodology	Data required	Source
To describe the current travel behaviour of cyclists in Zanzibar town	What is the current travel behaviour of the cyclists and how does it vary per different trip purposes and spatial location?	Field survey Modelling in SPSS Modelling in Excel GIS modelling	Socio economic characteristic of the trip maker, Trip distance. Origin destination data	Primary data
To assess the most likely substitution mode from the bicycle to other modes based on current travel patterns for demarcated areas in the city	What is the most likely alternative transportation mode in case of a forced substitution of a bicycle trip?		Mode shift data	
To calculate the disaggregated climate values of cycling per distinct geographical area	What is the climate value of cycling per distinct geographical areas based on the most likely substitution mode?	Opportunity costing model GIS modelling SPSS modelling	Socio economic characteristic of the trip maker, Emission factors Spatial data	Primary/secondary data
	What are the different visualization techniques and spatial indicators that could be used to display spatially distribution of climate value of cycling?			
	What are the factors that most correlates to CO_2-sink capabilities of cycling for intra-city travels?		Socio economic and Travel pattern data	

Research matrix (cont)

Research objective	Research question	Methodology	Data required	Source
To quantify the monetary value of the avoided CO_2 of cycling	What is the monetary value of CO_2-sink through cycling for city wide scale?	Modelling in SPSS	Carbon value on the market and the outputs of the third objective	Secondary data
To recommend on allocation of resources for promotion or preserving of cycling	What are the suitable wards to allocate resources to promote cycling?		Socio economic and Travel pattern data	Primary data

1.7. Thesis structure

The thesis comprises of 8 chapters as per following sequence

Chapter 1: Introduction:

This includes the general background of the research, defines the research problem, research objectives and questions and research methodology.

Chapter 2: Literature review:

Includes the theoretical background of the study, explains the basic concepts in the transport and climate change, the CO_2 avoidance strategies, carbon market and finally the spatial application of the opportunity costing methodology for bicycling research.

Chapter 3: Study area: The Zanzibar Town:

It discusses about the general introduction of the city and its transport system.

Chapter 4: Data Collection: Approach and methodology:

This chapter describes the data collection methodology during the fieldwork.

Chapter 5: Opportunity costing methodology:

This is the scientific description of all the steps followed to access the climate value for the sample as well for the scaled up population.

Chapter 6: Socio economic and travel characteristics of the sample:

This includes the descriptive statistic of the sample about their socio economic background, travel behaviour, bicycle trip distribution and analyze the first and second order effect of bicycle substitution

Chapter 7: The climate value of bicycling in Zanzibar town:

Here is accessed the disaggregated climate value of cycling for the sample as well for all population. The results are described and compared with previous studies using the same methodology and ongoing research on Social Economic Value (SEV) of cycling.

Chapter 8: Conclusion and recommendations:

It includes the summary of the findings and the methodologies used in the research, followed by recommendation and further research topics.

2. LITERATURE REVIEW

This chapter discusses literature on Greenhouse Gas (GHG) abatement in the road transportation sector by the implementation of different projects. The first section provides a background of the relationship between transport and climate change, which gives a detailed description of the possible abatement strategies and instruments focused for transportation sector.

The second section explains funding mechanisms for carbon reduction in transportation sector, emphasising the potential of certain mechanisms for using bicycling as carbon sink .The last section describes the spatial application of the opportunity costing methodology to access the climate value of cycling.

2.1. Transport and climate change

In the last years, world GHG emissions have grown at an annual rate of 3 to 4%. The primary GHG are Carbon Dioxide (CO_2), Methane, Nitrous oxide, and Sulphur hexafluoride, among which CO_2 is the main contributor (Vinot & Coussy, 2009). The problem of GHG emission was addressed within the Kyoto Protocol[1] , which had as the main objective "*Stabilization and reconstruction of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system*"("Kyoto Protocol," 2010). As a result of this protocol all member countries gave general commitments. Annex I countries[2] agreed to reduce their collective greenhouse gas emissions by average of 5.2% from 1991. These emission limits do not include emissions by international aviation and shipping.

For reduction of emissions from transportation sector in developing countries the main existing international instruments are (1) the Clean Development Mechanism (CDM), (2) the Global Environmental Facility (GEF) and (3) Clean Technology Fund (CTF). At the global level, the transport sector is the number two emitting of CO_2, it ranks second to energy, which encompasses electricity and heat production but emission from transportation sector still rising (see Figure 1)(IEA, 2010).

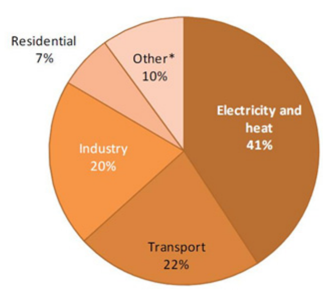

Figure 2-1: World CO2 emissions per sector in 2008

Source: (IEA, 2010)

[1] The **Kyoto Protocol** is a protocol to the United Nations Framework Convention on Climate Change (UNFCCC or FCCC), aimed at fighting global warming. The UNFCCC is an international environmental treaty with the goal of achieving "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system("Kyoto Protocol," 2010)

[2] There are 40 Annex I countries and the European Union is also a member. These countries are classified as industrialized countries and countries in transition("United Nations Framework Convention on Climate Change," 2010)

According to OECD (2007), transport sector emissions grew 31% worldwide between 1990 and 2003. For Leather (2009) this growth in emission is due to a growth of the number of motorized vehicles. The advantage of this growth is quick access to any geographical location and the disadvantages are increased level of noise; congestion and GHG emission which effects on the human health especially in densely populated urban areas.

2.2. Abatement strategies

Sustainable transport solutions are seen as the general contribution towards reducing CO_2 emission in many countries. The understandings of transport sustainability have different dimensions and approaches. For Dalkmann, et al.,(2007)the most acceptable approach was developed at the OECD Vancouver conference in 1996 by formulating nine principles of sustainable mobility:
(1) access to other people, place, goods and service; (2) social, interregional and inter-generational equity, (3) individual and community responsibility, (4) health and safety, (5) education and public participation, (6) integrated planning, (7) land and resource use, (8) pollution prevention and (9) economic well-being

Reduction of CO_2 emission is not explicitly named as a reduction of energy use, but the key concept should be pollution prevention which includes energy efficiency. Several strategies exist to reduce CO_2 emission by the transport sector. Huizenga & Bakker (2009) provide a comprehensive overview of strategies and instruments to reduce carbon emissions in the transport sector.

The framework presented below is divided into three groups; first is the layer of several strategies (Avoid, Shift, and Improve) and available instruments (Planning, Regulatory, Economic, Information and Technological), followed by impact on travel behaviour and finally carbon emission.

The focus of this research is to understand how the available instruments work in relation the shift from motorized vehicles to bicycles.

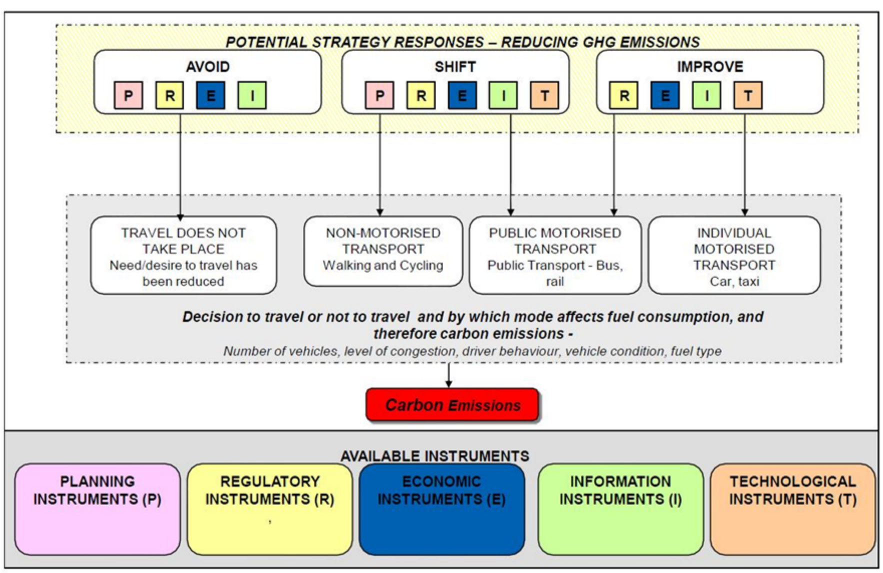

Figure 2-2: Strategies and instruments to reduce carbon from transport

Source: (Huizenga & Bakker, 2009)

2.2.1. Transport avoidance strategy

This strategy aims to reduce GHG emissions by reducing the need of motorized transportation or by redistributing traffic demand over mode, space and time (Leather, 2009). There are four instruments available (P-R-E-I) which can be used to avoid the need for travel, this research will be demonstrated only for planning instruments (P).

To reduce the need for travel, mixed land uses were found as strategic approach since different forms of land use (such as residential houses, offices, shops, public services, etc.) are not separated in different city quarters but mixed within close proximity of one another. This results in shorter travel distances for most of the activities, and reduces significantly the use of motorized vehicles for most of the trips and thus reduces energy consumption and CO_2 emissions.

Public transport will be more efficient in dense and mixed cities where major activity centres are concentrated locally, there will be a high demand for transport between these centres which can be served by efficient and frequent public transport services due to high demand. It has been estimated that benefits or savings from effective land use planning, combined with various traffic management schemes can create energy savings of 20 to 30% for bus operators, not forgetting additional savings for other road users (Martin *et al.,* 1995; in Karekezi *et al.,* 2003) sited by (Dalkmann & Brannigan, 2007).

A good example for integration between land use policies and transportation comes from Curitiba, Brazil; where they directed the growth out of the central city into arterial growth corridors. This displacement distributes the density in the city centre and the surrounding districts, avoids a sharp peak in the central city and reduces congestion. The land use density controls also encourage a shift of development activity from the central city to and around the structural axes. This locates high-density residential and commercial development in the same areas and matches density to the availability of public transport (Rabinovitch, 1996).

2.2.2. Avoid and Shift versus bicycling

This strategy is to identify possibilities of shifting travel to the most efficient modes, which in most cases will be either cycling or public transport (Bakker & Huizenga, 2010).

In many cities around the world buses and other forms of collective transport are losing share of trips and travel to individual modes. This evolution is spreading to even poorer large cities of the developing world, with cheaper two and three wheelers becoming more numerous than buses. Due to growing incomes more and more individuals choose motorized travel modes that contribute more towards CO_2 emission. Traditional non-motorised forms of transportation, such as walking and bicycling, give way to motorised transport - first buses, but as incomes grow increasingly motorcycles and finally cars. The end result is evident large urban transport systems built around the automobile, requiring large amounts of land and energy to support (Folton, 2001).

For urban trips bicycle is seen to be the most effective mode of transportation, increases the mobility and access to different opportunities within the city. Bicycle proves its value because (1) it is a cheaper mode of transportation and can be owned even by poor, (2) cycling infrastructures are less costly then for motorized traffic (3) is time effective in urban dense areas than motorized traffic (4) is zero emission mode (Massink, 2009).

According to Cervero & Duncan (2003) bicycling condition are affected by the quantity and quality of sidewalks, crosswalks and paths, path system connectivity, the security and attractiveness of cycling facilities, and support features such as bicycle racks and changing facilities. Developments of these conditions are the key strategy points to attract more cyclists and increase bicycle trips performance and reduce automobile dependency.

Due to the availability of motorized vehicles as mentioned above, it is understood that the *existing cycling performances have high climate value*, since each bicycle trip can be easily replaced by a motorized transportation mode and consequently increase CO_2 emission.

2.2.3. Transport efficiency and technology

This strategy aims to improve the existing forms of transport through technological improvement to make fuel and engines less polluters.

According to the framework, there are four instruments (R-E-I-T) which could be used. Vehicle and fuel technology improvement contributes for reduction of CO_2 for transport sector. For these strategies there are several aspects to take in consideration, but for this purpose will talk only about reduction of CO_2 emission by improving the performance of vehicle engines

For vehicle engine performance, vehicle maintenance system is relevant, because vehicle with poor maintenance tends to high emission and low fuel economy. To avoid that a regular maintenance could be strengthened quit cheaper. According to a research done in India, reported by Gwilliam (2003), during a series of inspection and maintenance of two-wheels vehicles, indicates that was a great improvement on fuel economy by an average of 17% and reduction of CO_2 emission by 44%. A well run, uncorrupted inspection and maintenance (I/M) programme should also reduce emissions significantly. However, designing effective I/M programmes has proved difficult due to a combination of technical and corruption problems especial in developing countries.

A successful policy mixes three primary means to reduce GHG emission (A-S-I) and it includes the provision for cycling and walking facilities, attractive and reliable alternatives to private cars it will make use of measures that restrict the use of car which will help to establish good land use planning practices and also promotes technological improvements such as cleaner fuels and it will set (monetary) incentives by applying appropriated economic instruments (Dalkmann & Brannigan, 2007).

The result of individual instruments is difficult to predict. Reductions are most likely to be achieved where a higher share of public transport or non-motorised modes is attained. In the table 5-1which shows the emission factor of different transport modes is found that some of the larger higher capacity vehicles produces higher emission per vehicle kilometre and tend to produce lower CO_2 emission per average passenger kilometre. Particular case is for public bases that has the lowest CO_2 emission per passenger. However, the average occupation rates (number of passage using the vehicle) is a crucial for emission per passenger (Ribeiro, et al., 2007).

As mentioned earlier, mixed policies can help to achieve a reduction or stabilization in the level of GHG emissions and other co-benefits. The table also shows that achieving a greater shift to public transport or non-motorized modes can bring greater benefits in terms of CO_2 and other GHG reductions.

Transportation Mode	CO_2 per PKT (kg/km/passenger)	Average Occupancy Vehicle
Walking	0	0
Bicycling	0	0
Motorcycles	0.023	1.20
Private Car	0.204	1.37
Taxi	0.332	0.81
Public Bus	0.040	20-33

Table 2-1: Emission factor of different transport modes

Source: (Massink, 2009)

2.3. Funding mechanisms for carbon reduction

This section provides an overview of the main international climate instruments addressed to the transport sector in developing countries, which are (1) the Clean Development Mechanisms (CDM), (2) the Global Environmental Facility (GEF) and (3) The Clean Technology Fund (CTF). The GHG emission reduction from developing countries is considered voluntary action as they do not have any commitment to reduce emission under the Kyoto protocol (Bakker & Huizenga, 2010).

2.3.1. The Clean Development Mechanism (CDM)

The CDM allows emission-reduction projects in developing countries to earn Certified Emission Reduction (CER) credits, each equivalent to one tonne of CO_2. These CERs can be traded and sold, and used by industrialized countries to meet a part of their emission reduction targets under the Kyoto Protocol ("Clean Development Mechanism," 2011).

The proposed projects have to use a methodology approved by the UNFCCC. This process of getting a methodology approved is time-consuming and the risk of rejection is considerable. However, if a specific project fits under an existing approved methodology, the whole process of setting up a project as a CDM project is much easier (Grütter, 2007).

Important aspect of an approved CDM project is that it has demonstrated that the planned reduction of CO_2 emissions would not occur without additional incentives provided by emission reductions credits. Among the projects financed under CDM, transport sector plays a very limited role as the numbers of transport projects are relatively few and the total amount of CO_2 avoided comparatively with other sectors is quite low. For instance for total projects submitted in 2010 contributed for only 0.4% of the total CO_2 expected. Comparing this at global share of CO_2 transport sector is under represented (Bakker & Huizenga, 2010).

2.3.2. The Global Environmental Facility (GEF)

GEF is an operational entity of the financial mechanisms of the UNFCCC, and provides grants for developing countries.

Initially, GEF supported transport projects focused on technological solutions; however GEF-4 (2006–10) emphasizes "nontechnology" options, such as planning, modal shift to low GHG intensive transport modes like cycling, and promotion of better managed public transit systems. This new strategic program prioritizes countries with rapidly growing small and medium-size cities. Although greater overall emissions reductions are liable to result from countries with larger total GHG emissions, smaller countries might also find reducing transport CO_2 emissions by prioritizing for the potential co-benefits of development and environment. Projects under the new program include a mixture of technical assistance and limited investment support (GEF, 2009).

The total projects presented during the period of 1999 to 2009 focused on actions to reduce GHG emission, a large part of projects come from Asia and Latin America. Estimating the impact of these projects to reduce CO_2 emission is difficult. The project document indicates an expected direct CO_2 reduction of 31.5 Megaton (Mt)CO_2 and an expected indirect CO_2 reduction of 34,5MtCO_2 (Bakker & Huizenga, 2010).

2.3.3. The Clean Technology Fund (CTF)

The Clean Technology Fund (CTF) is one of two Climate Investment Funds and provides scaled-up financing for demonstration, deployment, and transfer of low-emissions technologies that have significant potential for long-term GHG emissions savings, principally to emerging economies and to regional groups (Black & Mendiluce, 2010).

For transport sector, CTF support many projects including modal shifts to low carbon public transportation in major metropolitan areas, with substantial change in the number of passengers trips by public transportation, modal shift to low carbon freight transport with a substantial changes of the freight moved by road transport to rail, improvement of fuel economy and fuel switching. The investment has to be approved by the Trustfund and expert panel has to validate the emission reductions.

Important difference between CTF and GEF is that the methodological guideline to calculate the GHG reduction are outlined and not applied at the time of the initial approval of the investment program but at the time of detailed project design (Bakker & Huizenga, 2010).

Overall it was found that even CTF is operational from short time, it has more impact in reducing CO_2 emission for transport sector than CDM and GEF which have been in operation for longer time.

2.4. Opportunity costing of cycling

This section provides insight of the opportunity costing methodology, starts with a brief explanation of this concept followed by its application in transportation research.

In trade market there are goods or services which have no value or price constructed for them and they are not traded, cycling mobility is one of them. According to Heertje & Polak (2001) value of an object is determined by its production cost or labour sacrificed.

For this research the climate value of cycling is assessed by hypothetical substitution of bicycle trip with the most likely alternative mode, based on the stated preference of the cyclists. The avoided cost for using the alternative mode (CO_2 avoided) determines the value of that cycling. The climate value of cycling has a straight relation between the emission factor of the alternative mode and the Passenger Kilometre Travelled (PKT). The emission factor is the average rate of emission grams of Carbon dioxide (CO_2) released per mega joule of energy produced, it is expressed as number of kilograms of particulate per ton of the material or fuel (Schipper, et al., 2007).

Transport planning is undertaken at different strategic planning level and at different urban scales. Urban transport planning process is viewed at three phases namely the pre- analysis, technical analysis and post analysis phase (Zuidgeest, 2007).

The phases described are regarding the bicycle mode and analysis of their climate value.

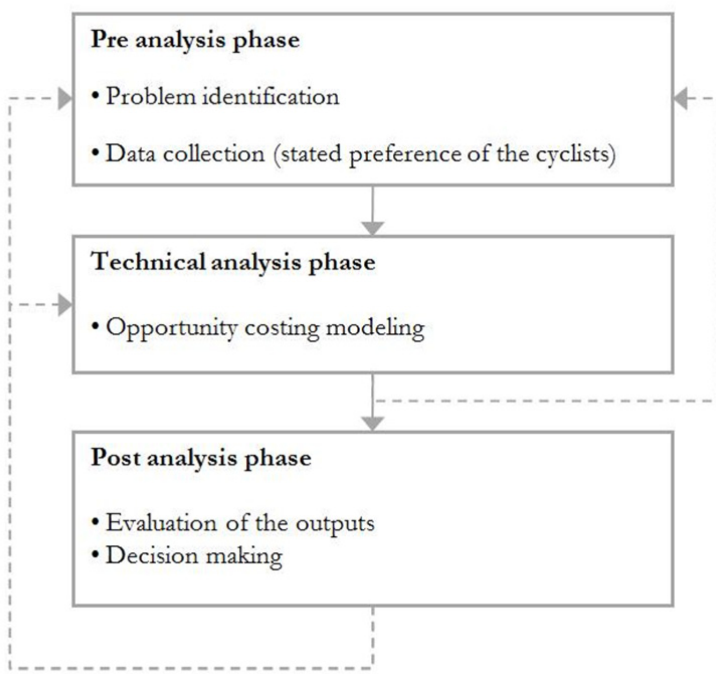

Figure 2-3: General representation of urban transport planning process

Adapted from: (Zuidgeest, 2007)

2.4.1. Pre analysis phase

This phase is regarding the problems and solutions. For this research the problem was to assess the disaggregated climate value of cycling and the solution was the introduction of the spatial application of the opportunity costing methodology.

Next the collection data are used in the analysis phase where the approach used to collect information regarding the choice for alternative modes is described.

Data collection approach: Stated preference (SP) of the cyclists in the alternative mode choice

SP methods are widely used in travel behaviour researches and practice to identify behavioural response to choice situations which are not revealed in the market (Hensher, 1994). It consists of quasi- experiment based on hypothetical situation set up by the researcher. Individuals are asked in interview or questionnaires what they would choose to do in a hypothetical situation (Zuidgeest, 2007).

The major drawback of SP survey is whether an individual would choose the same option in reality as he stated. To overcome this problem, the set of hypothetical alternatives modes has to be carefully defined to fit the range of actual available modes in the study area.

2.4.2. The technical analysis phase

This phase describes each sub- model within the opportunity costing model.

Trip generation: Based on the collected data, the sample was modelled to assess the number of bicycle trips produced and attracted per ward. The output of this model was used as input to model for all population. At this stage, to make a good estimation of the trips produced and attracted, all the trips were classified by their purposes.

Trip distribution: The origin and destination of each bicycle trip are linked. It shows where most of cyclists go. The sample was used as input data.

Modal split analysis: This predicts the number of bicycle trips substituted by the alternative modes and also shows the most preferable alternative mode for cyclists. The modal split has a considerable implication on transportation policy, particularly at intra-city scale. For instance the decision to allocate resources to promote or preserve cycling should be informed by the prediction of this model.

The shift from bicycle to the alternative transportation modes has three order effects and influences all the transportation system from the travel demand as well as on infrastructure supply. Based on the model of different layers from Reit and Egeter (1998) presented by Massink (2009) this shift effects are:

For the *First order effect,* is the direct substitution of bicycle by the alternative mode. It has direct impact on the transportation market. If assumes that the utility of performing the activities at destination is the same, two possible scenarios can be depicted, based on utility maximization theory:

1- The disutility of making the trip with another mode of transportation exceeds the utility of the trip, the bicycle trip is not replaced by alternative mode or the trips do not occur.

2- The disutility of making a trip with another transportation mode does not exceed the utility of the trip; the bicycle trip is replaced by alternative mode.

The *Second order effect* have impact on travel patterns in transport demand side as well as transport services in transport supply side. For transport supply if for instance individual shifts from bicycle to public bus, this shift affect the transport services; reduces the number of passenger transported per unit of time and space due the increased number of users.

For demand side, there are changes on travel patterns; this are on trip distances, purposes, time or day. For instance the shift from bicycle to private car can result on change of trip distance, where individual in place of shopping in local grocery store goes to a larger supermarket outer part of the city in order to maximize its trip. This situation changes the trips distribution.

The effects from the *Third order* are for long term (they take time to be depicted), and can be seen on land use distribution for transport demand side and traffic service in supply side. Effects on land use distribution: For instance the shift from bicycle to car can influence the choice of location to fix a residence; can lead to leapfrog land use distribution rather than compact which is more suitable for bicycle mobility. For supply side, because of increase of number of cars, this will require more infrastructures thus more land which would lead to "swallow" the existing cycling infrastructure.

Climate value of cycling

This sub-model allows calculating the avoided emission through cycling and this corresponds to the cost (CO_2 emission) of using the alternative mode. It incorporates the first and second order effect of bicycle trip substitution. For fist order effect gives insight of the substituted bicycle trip by the alternative modes, discarded trip and the new travel time. For second order effects provides information for the new destinations and the new travel time to those destinations.

The climate value is assessed for the sample and for all population and it is attached to the origin of the trip.

2.4.3. Post analysis phase

By combining the results of the analysis phase to GIS modelling, it is possible to visualize the results spatially, understand the contribution of each ward to the total climate value and gives the indication of wards with high potential to emit CO_2 if bicycle is no longer an option.

Summary

Transport is one of the major contributors of the total CO_2 emission. There are several strategies used to reduce or mitigate it, one of them is the shift from motorized vehicles to non-motorized, where bicycle is seen as option since it has zero intrinsic emission.

Under the Kyoto protocol several climate mechanisms were defined in order to developed countries to reach their commitment in reduction of GHG emission, but especially those financing projects in developing countries have a very limited impact in terms of the CO_2 avoided.

To assess the CO_2 avoided through cycling, the spatial application of the opportunity costing methodology offered large advantage since it helps to visualize the contribution of each ward towards the total CO_2 avoided and the inclusion of the first and second order effect of bicycle substitution naturally increase its accuracy.

3. STUDY AREA: THE TOWN OF ZANZIBAR

This chapter gives a brief overview of the town regarding to urban form of the city, current urban transport systems and some features of the cycling mobility.

3.1. Introduction

Zanzibar, which is part of the United Republic of Tanzania, consists of two main islands of Unguja and Pemba and about 50 other small islets. The islands are located 40km off the Mainland coast of East Africa in the Indian Ocean between 5° 6´ South and 39.5° 40´ East. Unguja is the larger of the two main islands has an area of 1,666 km² while Pemba has an area of 988 km². The name Zanzibar refers to three different issues: the semi-autonomous state of Zanzibar, the island of Zanzibar and finally the Town of Zanzibar. This study uses the term Zanzibar referring to the Town of Zanzibar.

The town of Zanzibar is located in urban west district, Unguja Island. Historical, this city appeared when the islands became a base for traders voyaging between Arabia, India and Africa. The island offered a protected and defensible harbour, so the Arabs settled at what is called now stone town as it is a convenient point from where to trade with East African coast towns.

Figures 3-1 and 3-2 are presented below; they show the location of Zanzibar town and aerial view from the western side of the stone town respectively.

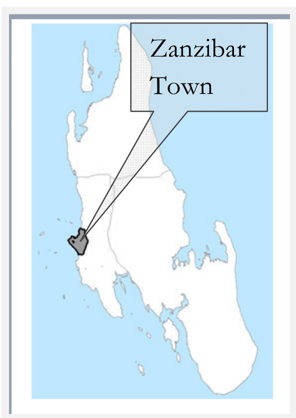

Figure 3-1: Location of the Zanzibar Town

Figure 3-2: Aerial view of stone town

Source: ("Stone Town of Zanzibar," 2011)

3.2. Population

According to the population census of 2002, Zanzibar town had a population of 231.241 people, the average population density was 194 people per square kilometre, distributed in 45 wards. Currently the estimated population for all islands is 1.193 million at population density of 400 people per square kilometre(*Zanzibar strategy for growth and reduction of poverty*, 2007). This has direct implication on the available resource, settlement development and demand for transportation.

3.3. Land use

The spatial arrangement of the activities determines the travel patterns of the city. The figure 3-3, shows the land use map for the year of 2005. In Zanzibar town, the activities are concentrated in the main core centre (Stone town), this influences the city transportation system and the travel patterns. During the morning peak hour heavy vehicle traffic is observed towards stone town and in the evening peak hours is from the main city towards the other parts.

The urban form contributes to CO_2 emission, because it increases trip generation and indirectly decreases the demand for non-motorized vehicles like walking or cycling, leading most of trips be executed by motorized vehicles. Is expected high climate value for the existing cycling mobility as result of unbalanced distribution of activities in the town.

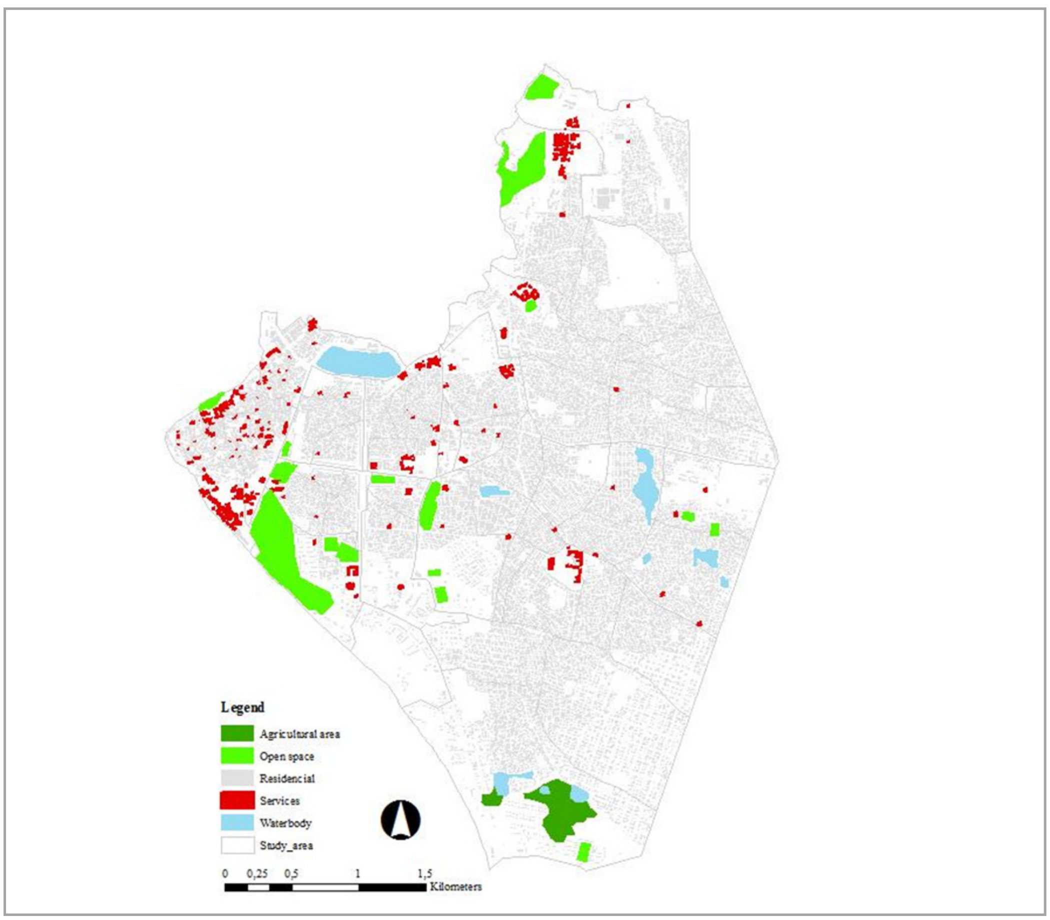

Figure 3-3: Land use map of Zanzibar city

Source: Department of Survey and urban planning (2005)

3.4. Current cycling in Zanzibar

The current traffic performance in Unguja island is composed largely of bicycling 41%, followed by private car 27%, motorcycle 17% and public bus with 13% (DROMAS, 2009), for more details see the figure 3-4. In 2006, based on Zanzibar master in the main town approximately 35300 vehicle trips per day was registered, where public buses carried the highest number of passengers which is around 150000 passengers per day (*Zanzibar Transport Master Plan Study*, 2007).

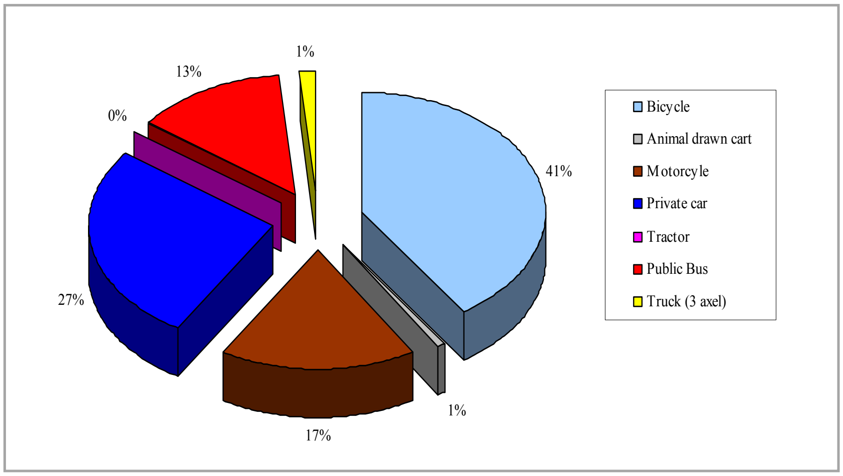

Figure 3-4: Modal share in Unguja island

Source: (DROMAS, 2009)

Actually there is no bicycling infrastructures in Zanzibar, which is the most basic (and important) factor to encourage more people to shift to cycling. In urban area cyclists share road with motorized vehicles, increasing risks for road accidents. In some part of stone town (the main touristic area) as well as in the informal settlements "Makuti", the roads are very narrow, which offer good condition for cycling.

This leads to expect most of bicycle trips have been executed for purposed with higher utility like working for instance, to justify the disutility due to road accident risks.

Summary

With growing population and increase number of vehicles, cycling will lose share in Zanzibar. Currently there no cycling facilities in the town, which means cyclists, are exposed to risk for road accidents. This situation discourages many others to use this mode, leading to increase of number of motorized vehicle thus CO_2 emission.

4. METHODOLOGY FOR DATA ACQUISITION

To construct the opportunity cost of cycling in Zanzibar town, primary data on travel behaviour (in terms of daily trips) and stated preferences of current cyclists is required in addition to secondary data.

This chapter describes the methods and the data required to construct the model, it is divided into three sections. First gives outline of secondary data collection and their sources, followed by the primary data collection and the procedures and processes used to acquire data. The last section is about the data processing and gives an overview of the collected data and the limitations of the data.

4.1. Secondary data acquisition

A major dataset used for the entire study is the outcome of the survey of cyclists. However, the data collected from the secondary sources are used to compliment the primary data to do the research. Notably among these datasets were the road network, land use and the socio-economic data of Zanzibar town. Some of the secondary datasets were given in digital and the rest and others in hardcopies. A table showing the list of all the datasets acquired is provided below;

Data	Description	Institution
Traffic count	General information about traffic count conducted in Zanzibar island, gives overview of modal split in entire Zanzibar. This information is from November 2008-hardcopy	Ministry of Communication and Transport
Attraction points (for cyclists)	Were identified 7 attraction points which were: Malindi market (fish market) Darajani market (bus station and principal market in Zanzibar), Michenzani market, Mikunguni market, Magomeni market, Mkunazini market and Mwanakerekwe market (this is out of our study area)	
Demographic information	The 2002 Population and Housing Census (hard copy, softcopy) Urban west District: Census Results in Brief (softcopy-year 2002) Urban west district: population distribution per sex, age, in each ward (excel sheet- year 2002)	Office of chief Government Statistician- Zanzibar
Socio economic information	Household Budget Survey Final report, September 2006 (hard, soft copy) Socio - Economic Survey- 2009 (hard, softcopy) urban district profile (hard, softcopy- year 2002)	
Administrative boundaries	Updated administrative boundaries of urban district-2010 (hard copy)	
Land use	Shape file	Department of Survey and urban planning

Table 4-1: Secondary data acquired

4.1.1. Travel speed of different transportation modes

A small survey was conducted to collect average travel speed of different transportation modes participating in the model.

For private car: For each trips executed the travel distance between origin and destination, travel time (departure and arrival time) was recorded. This information was used to calculate the average travel speed for each trip, thus the average speed for all trips executed during the field survey, which was around 50km/h

For Public bus: The average travel speed is calculated based on the trips executed in the route Darajani – Chukwani and Darajani – Miembene. Collected data regarding to bus travel time (min) and the spatial location of these two points was computed in ArcGIS to obtain the travel distance thus average bus travel speed. The average travel speed for all trips was around 35km/h.

4.2. Primary data collection (Selection of study area)

The initial idea was to take stone town as the study area, but after the first visit and also based on traffic count conducted by Ministry of communication and transport, most cyclists come from or live outside the stone town because there is no or less attraction points for cyclists. This could be because the land use is not that attractive for local residents, mainly this is touristic area.

So the study area was extended to cover the urban west district, which also includes the stone town. The wards included in our study area are the following: Amani, Chumbuni, Gulioni, Jangombe, Karakana, Kidongo, Chekundu, Kiembesamaki, Kikwajuni bondeni, Kikwajuni juu Kilimahewa bondeni, Kilimani_u, [3]**Kiponda**, Kisima, Majongoo, Kisiwandui Kwaalamsha, Kwaalinatoo, Kwahani, Kwamtipura, Magomeni, Makadara, **Malindi**, Matarumbeta, Mchangani, Meya, Miembeni, MigombanI, Mikunguni Mkele, **Mkunazini**, Mlandege, Mpendae, Muembe ladu, Muembe makumbi, Muungano, Mwembeshauri, Mwembetanga, Nyerere, Rahaleo, Sebleni, **Shangani**, Shaurimoyo, Sogea, Urusi, Vikokotoni. For details see the map in the appendix A

4.2.1. Questionnaire design

The questionnaire was designed to gather information about the current and alternative travel behaviour of the cyclists, climate value of cycling and socio-economic value. The variables in the questionnaire were selected during the preliminary fieldwork preparation phase. Discussion with some staff of National Bureaux of Statistic of Zanzibar was carried out in order to enrich the questionnaires especially on socio-economic data, and the sequence of the question to give a reasonable flow. It was agreed that the questionnaire to be translated to Swahili to help the field assistants to administer them with ease. For details see the questionnaire in appendix B.

The first nine questions relate to the socio-economic characteristics of the cyclist like age, household composition, income, vehicle ownership, attraction point where the cyclist was interested and origin point where the cyclist started the trip. The second part is regarding to previous trip (yesterday's trip), the aim is to understand the travel pattern and travel time. Last part is about the alternatives, such as for

[3] Bolded wards – belongs to Stone town

transportation mode, destination, purpose, travel cost. This gives insight of the climate as well as socio-economic value of cycling.

4.2.2. Sampling design

The design of sample was made in order to intersect as many cyclists as possible in the study area. The survey areas were those were most cyclists were expected to be concentrated (attraction points). The Ministry of Transport and Communication provided information that was relevant to selection the areas:

- A traffic count document which was conducted in the city was given.
- Identification of the main roads along which most cyclists are found within the study area.
- Stations or locations where these cyclists converge for their daily activities were selected along these major roads so they could be interviewed. These happened to be the market centres.

Figure 4-1 below shows the spatial location of each attraction point; they are numbered as the sequence of survey:

- 1. Malindi market
- 2. Darajani market
- 3. Mkunazini market
- 4. Michenzane market
- 5. Mikunguni market
- 6. Magomeni market
- 7. Mwanakwerekwe market (out of study area)

Figure 4-2 shows pictures of the most important markets in Zanzibar town.
The top left (1) is Malindi market, the most important fish market. As can be seen most of cyclist come to this point to buy fish and distribute/sell to the other markets.

The top right (2) is Darajani market: is located in the busiest area is the city as the bus stations and most of shops are located there.

The bottom left (6): Magomeni market: its importance is due its location within a very populated area.

The bottom right (7): Mwanakwerekwe market: is the largest market in the city and has enormous influences on the cycling traffic in the study area, the reason to conduct the survey in this point.

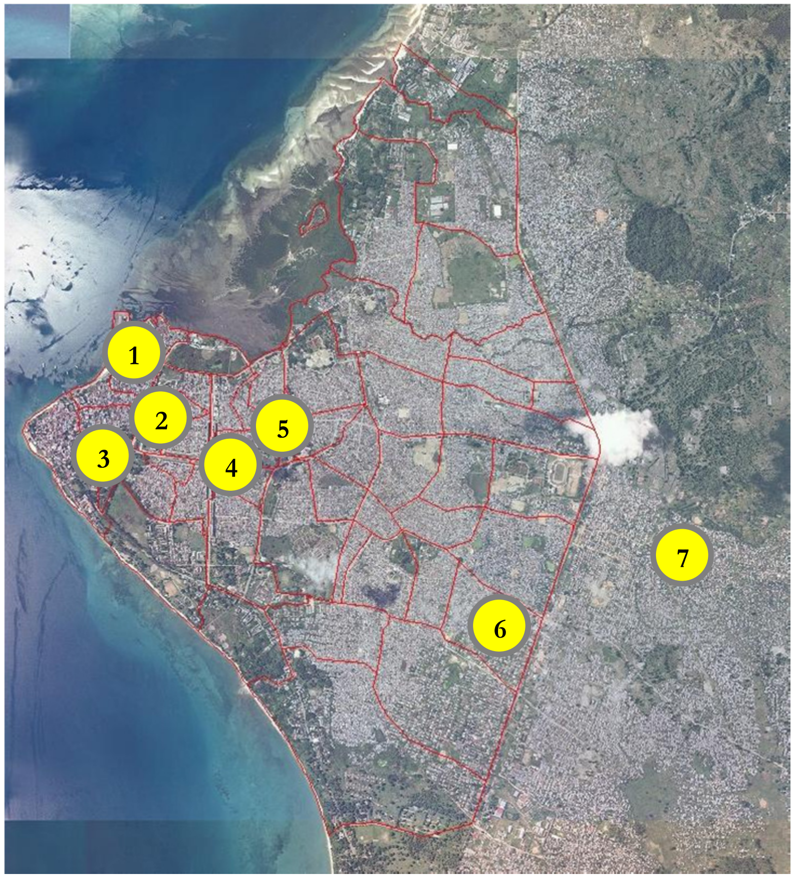

Figure 4-1: Location of the attraction points

Figure 4-2: Pictures of most important markets in Zanzibar town

The listed markets above were considered as the major attraction points in the study area according to the Ministry of Communication and Transport. So decision was made to visit these markets one after the other (following the numbering sequence) to interview cyclists. During the visits, available cyclists were selected one after the other and interviewed.

The cyclists were asked questions regarding their socio-economic, previous and alternative trip characteristics as mentioned in the questionnaire design above. The previous trip could be a trip made yesterday or a day before yesterday so far as the cyclist remembers all the trips he made that day. The survey was conducted from Tuesday to Saturday and as early as 7:00AM to 5:00PM. Sundays and Mondays were used to prepare for the survey, because it was predicted that the number of previous trips on these two off- days is minimum as they are not working days.

After visiting all the seven attraction points or centres, the Centrality Index (CI) calculation was used to identify the origins of the majority of the cyclists. The origin of these cyclists then became the next batch of attraction points. It was assumed that the probability of finding more cyclists in these areas is higher.

To identify the wards from where most cyclists were originating, the Fuzzy Cognitive Mapping (FCM) was used which gave a possibility to visualize the complex and dynamic interaction of bicycle trips and helped to represent the relationship between origin and destination wards. For this particular case, only the attraction wards have Indegree and Outdegree values, and the rest of the wards have only indegree values.
Outdegree (od): Sum of all bicycle trips with origin outside attraction ward intersected in a certain attraction points. Indegree (id): Sum of all bicycle trips with the same origin intersected in different attraction points.

After assigning all bicycle trips in OD matrix, all the values were standardized, using maximum standardization. The number of cyclists is considered as benefit, and the standardization was done by dividing the score by the maximum score, because FCM allows only values maximum to one. The figure 4-3 below is the diagram of centrality index of all the wards in the study area.

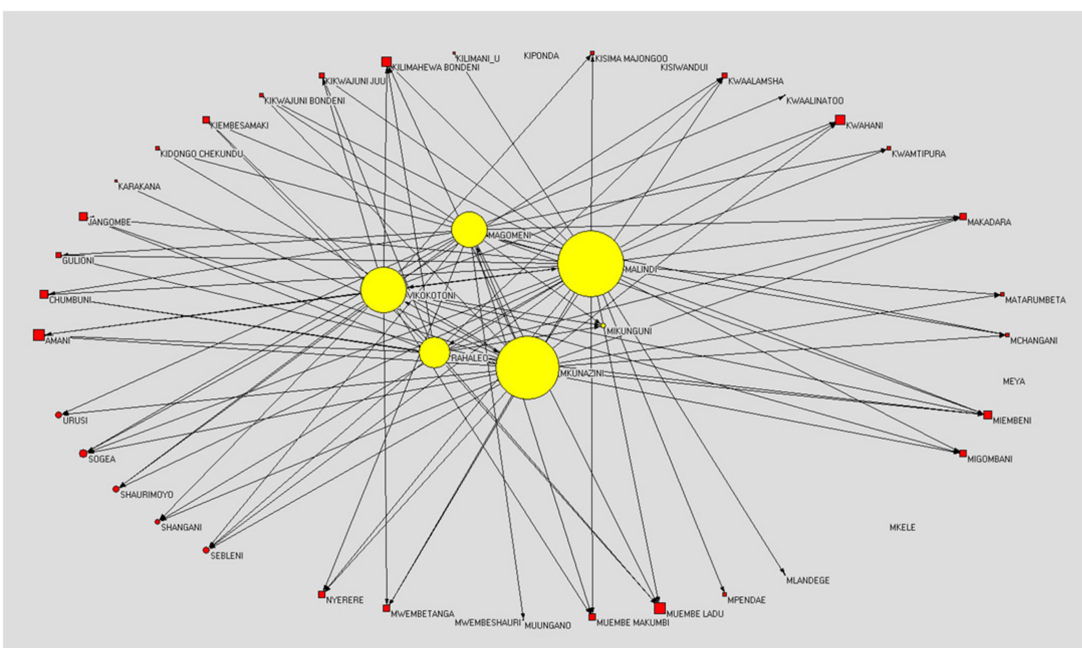

Figure 4-3: Centrality index for all the wards in study area

The centrality index (CI) is the sum of the Indegree and the Outdegree values, thus the centrality expresses how large a role of a given variable plays in the system. A high centrality shows a large importance and a low centrality reflects a lesser importance (Kirsten., et al., 2009).

- The yellow circles represent attraction points; the size represents centrality index, which shows the number of cyclists from different wards intersected in a particular attraction point and the number of cyclists with origin in this attraction point intersected in another attraction points.

- The red boxes represent the rest of wards: the size determines centrality index, shows how many cyclists with same origin were intersected in different attraction points.

- The arrows represent the direction of the bicycle trips

Similarly, these origins were also visited one after the other and the available cyclists were interviewed to answer the same questions mentioned in the questionnaire design above.

4.3. Data entering and overview of the collected data

Data collected was put into spread sheet software MS Excel and later transferred to SPSS for further statistical processing. The survey was conducted by four surveyors, two from National Bureaux of Statistics of Zanzibar and other two from University of Zanzibar. For data entering, was created 155 columns, to input all information from previous trip up to alternative trip.

Summary

The data collection was executed into two different stages at destination point (attraction points) and later at origin pints. To identify the main origin points the collected data at destination point was modelled into FCM, this points became the next destination points for survey.
The collected data provided information about the socio economic characteristics of the cyclists and offered an important source of information for transport planning application. The stated preference of the cyclists helped to understand their alternative modes to cycling and alternative destination.

5. OPPORTUNITY COSTING METHODOLOGY

5.1. Overview of the modelling process and its analyzes

Urban transportation modelling plays an important role in urban transportation planning by helping to predict and judge the performance of the current cycling traffic and the alternative modes to cycling. The sample contains disaggregated information about trip generated and attracted per ward, trip distribution and the shift to the alternative transportation mode.

For the purpose of this study once the collected data contains detailed information for each transportation modelling stage, this would be used to represent (not to predict) the behaviour of the cyclists. The outputs of the samples modelling would be used as input to model for all population and to access the climate value of cycling.

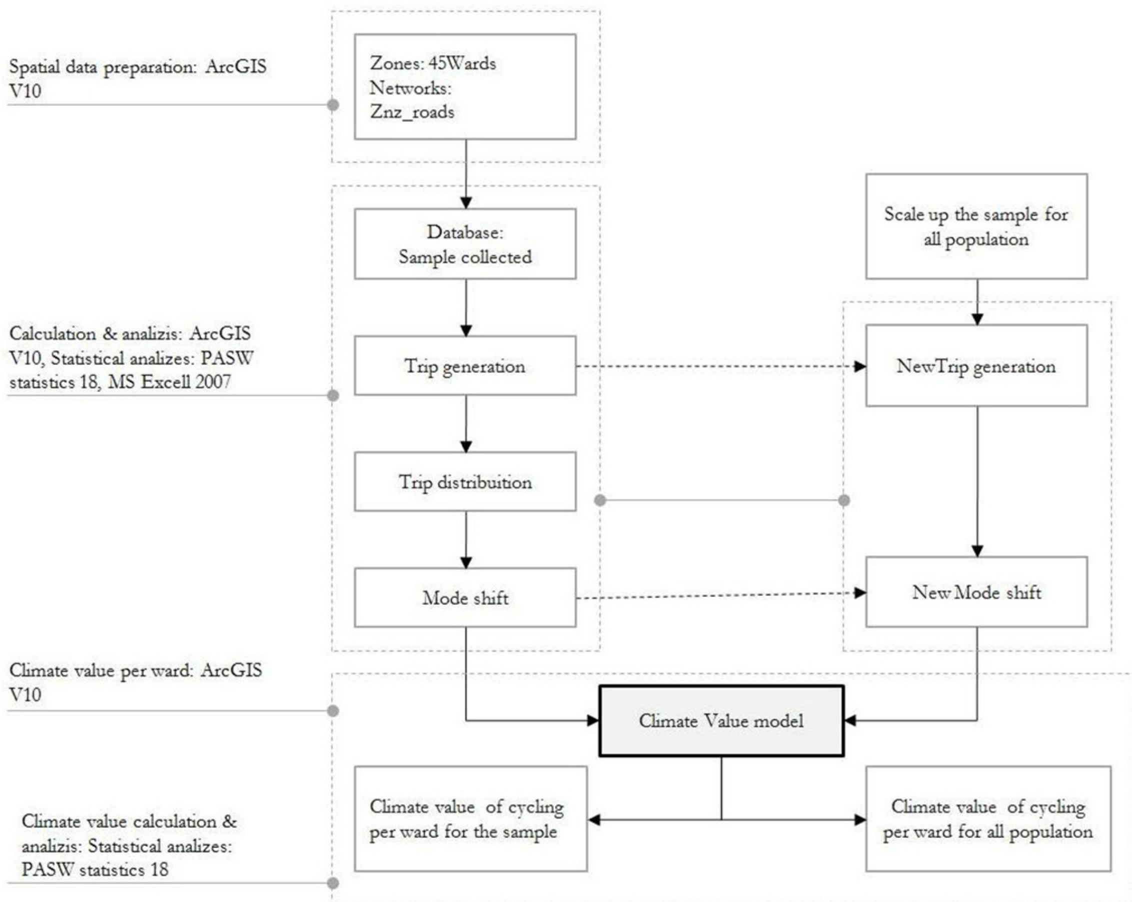

Figure 5-1: Overview of the modelling process for the samples and total population

5.2. Model principles

The main principle of this methodology is to assign a value (in this case climate value in terms of the CO_2 emissions) to a bicycle kilometre travelled based on the stated substitution mode for that trip by the cyclists. The value of bicycle kilometre travelled corresponds to the CO_2 emitted per kilometre by the alternative motorized vehicle. The higher the CO_2 emitted, the higher the climate value of that bicycle trip.

For that several assumptions were made and are presented as the follow:

1: Each Passenger kilometre Travelled (PKT) used in the model represented a substituted bicycle trip.

2: The model developed takes into consideration the first and the second order effects. The first order effect is to identify the alternative modes in case of bicycle substitution, and the second order effect looks into the new travel time and destinations based on the stated preferences of the cyclists.

3: For bicycle trips which do not change destination means the utility of the activities at destination exceeds the disutility of using the alternative mode.

The opportunity costing of cycling is assessed by the substitution of all bicycle trips with the most likely alternative mode based on the stated preference of the cyclist. So it can be stated that opportunity costing of cycling is the difference between the social cost regarding to the actual trip (emission of bicycle traffic = 0) and social costs of the trip made with the alternative transportation modes (emission of alternative traffic performance $\neq 0$).

5.3. Model assumptions

a) Transportation modes used in the model: Private car, Public bus, Taxi, Motorcycle, Walking and Cycling

b) Travel Speed by vehicle categories

Some assumption were made to execute this calculation,

1. The average speed for private car and public bus was taken as 50km/h and 35km/h respectively. This data was calculated based on the small survey carried on during the fieldwork.

2. For Taxis and Motorcycles assumption was made to have the same average travel speed.

Taxis: Most of the fleet is composed by vehicles with the same class (don't exceed five passengers including the driver) which was similar to the vehicle used for survey. Was assumed they have similar speeds which is 50km/h.

Motorcycle: Most of them are 50cc (Cubic Centimetres) engine size, their top speed doesn't exceed cars, but for intra-city trips they offer more flexibility to travel so their average travel speed was considered as for private car.

3: Walking: Based on Wikipedia ("Walking," 2010) the average speed was considered 4,8km/h

4: Bicycling: The average speed for cycling was considered 13,7km/h (Chen, et al., 2009)

c) Emission factor (EF)

The data used as emission factor was collected from the research conducted in Bogotá due to lack of this data for the study area.

5.4. Steps for modelling the climate value of cycling for the sample

5.4.1. Evaluation of the collected data

The first step to assess the climate value of cycling was to determine the first and second order effects of bicycle substitution. Only bicycle trips replaced by motorized vehicles, contributes to the climate value of cycling.

Among the surveyed bicycle trips only 2350 bicycle trips were replaced, and 249 were not replaced. Among the replaced trips 86 were replaced by motorcycles, 18 by private cars, 4 by taxis and 1493 by public buses and 749 by walking, which means only 57,8% of the total bicycle trips contributed for the climate value of cycling.

The database was designed basically by information about origin trip, socio economic characteristics of the trip maker, trip purpose, trip distance (min) and these were the basic input data to the model.

5.4.2. Construction of Trip Length Frequency Distribution (TLFD)

The second step was to construct the "Alternative traffic performance" constituted by all trips made by the alternative transportation modes and aggregated according to travel distance to activities. This will provide insight of the contribution of each transportation mode to the total CO_2 in the study area.

5.4.3. Calculation of Passenger Kilometre Travelled (PKT)

The third step is to calculate the Passenger Kilometre Travelled (PKT). Is aggregation of the distances of all individual trips in that wards by that mode. It is based on the average travel speed of the alternative mode (s_m) and the new travel time (t). The formula used is:

$$\mathrm{PKT}_{m,w,i} = S_m \times t_i \qquad \forall m \qquad (5.1)$$

Where:

m Transport modes (Walking, Public bus, Motorcycle, Private car and Taxi)

w Wards of origin trip

i Cyclist

Emission per vehicle kilometre travelled

The last steps is to assess the climate value of cycling (CO_2 emissions per passenger kilometre travelled) for each substituted trip (a), then aggregate per ward (b) and finally for the whole study area (c).

a) Assessment of the climate value per each substituted bicycle trip ($AE_{m,w}$)

It is a product of the total distance travelled by that mode within that ward ($PKT_{m,w}$) and the emission factor of that mode (EF_m). This represents the climate value of each bicycle trip. Below is the formula used to calculate the climate value each individual trip.

$$AE_{m,w} = EF_m \times PKT_{m,w} \qquad \forall m \qquad (5.2)$$

Where:
AE: Avoided Emission
EF: Emission Factor
PKT,: Passenger Kilometre Travelled

b) Assessment of the climate value of cycling per ward (AE_w)

Avoided emission per ward (AE_w) is based on aggregation of the total emission for the various modes in that wards ($AE_{m,w}$). These emissions are assigned per origin ward, because was objective to indentify wards to assign resources to promote cycling or preserve cycling.

To assess the disaggregated climate value per ward, below the formula used:

$$AE_w = \sum_m AE_{m,w} \qquad \forall\ m \in w \qquad (5.3)$$

c) Assessment of the total climate value of cycling in the study area (AE)
The avoided emission for the study area is based on an aggregation of the AE for the wards (AE_w). This gives a general picture of the total CO_2 sink through cycling and can be compared with other cities. The formula used is:

$$AE = \sum_w AE_w \qquad \forall w \in sa \qquad (5.4)$$

Where:
sa: Study area

5.5. Steps for modelling the climate value of cycling for all population

The sample was scaled up to all population in the study area, in order to get the actual contribution of each ward to the climate value of cycling. Several steps were done and are presented below.
The descriptive process to access the climate value for all population is similar for the sample.

Scale up the sample to all population

To obtain the total number of households within each ward, the disaggregated population per ward obtained from the Census 2002 was divided by the average household size which is 5.9 (*Household Budget Survey*, 2006).

Taking the ward Amani as example:

- Population per ward = 5532 inhabitants.
- Average Household size= 5,9
- Number of household = Population per ward ÷ Household size, which =*938*.

Secondly to derive the total number of households owning bicycle per ward, the total number of households was divided by average bicycle ownership.
For Amani it would be:

- Number of Households = 938
- Bicycle ownership = 48,6% of the total households (*Household Budget Survey*, 2006)
- Number of households owning bicycle = Number of households × Bicycle ownership which = 456.

This value did not tell much because it is assumed that though some households own a bicycle do not use it. The next step was to find those households owning and using as they are the potential targets.

Third, from the Average Annual Daily bicycle Traffic (AADT) count done by Zanzibar consultants Ltd, in one point within some wards in the study area like Amani, Magomeni, Miembeni, Kilimani, Malindi and Mkunazini the number of bicycle trips observed in these wards were collected. It was found around 3500 trips, 3000 trips, 4100 trips, 3150, 4650 trips and 3700 trips in the respect wards. During the field survey it was observed that in Amani the number of cyclists was 40 which were equal to the number of households, where 5% of them started their trips from that ward. To scale up this assumption was considered to represent the behaviour of all population. For Amani it would be:

- Number of daily bicycle trips observed (AADT): 3500
- Number of bicycle trips collected which start their trip in Amani: 5%
- Number households using bicycle daily= AADT × Number of bicycle trips starting in that ward, = 175.

This means from the total 456 households owning bicycle *in Amani, 175 (38,74%) used bicycle for their daily trips.*

This calculation was repeated for all wards which were executed both for traffic counts by the Zanzibar consultant as well as the field survey. But two possible outcomes can be predicted:

1- No trip starting from the ward was collected during the field survey.
2- The number of trips starting in that ward exceeds the total number of households owning bicycle in that ward, this can be due to different periods of the information collection.

For instance the traffic count was from the year 2006, field survey was from 2010, population was from 2002, and this can result in some inconsistency. For the wards reflecting the above conditions the calculations were based on the average households using bicycle done in other wards with complete information, for details please see the appendix C.

After getting the total number of cyclists who use bicycle daily, it was multiplied with the number of sample shifting to a certain mode in a particular ward, followed by its average PKT per ward then emission factor of that mode and the climate value per ward, see the appendixes D, E and F for details.

Below the climate value model framework is presented

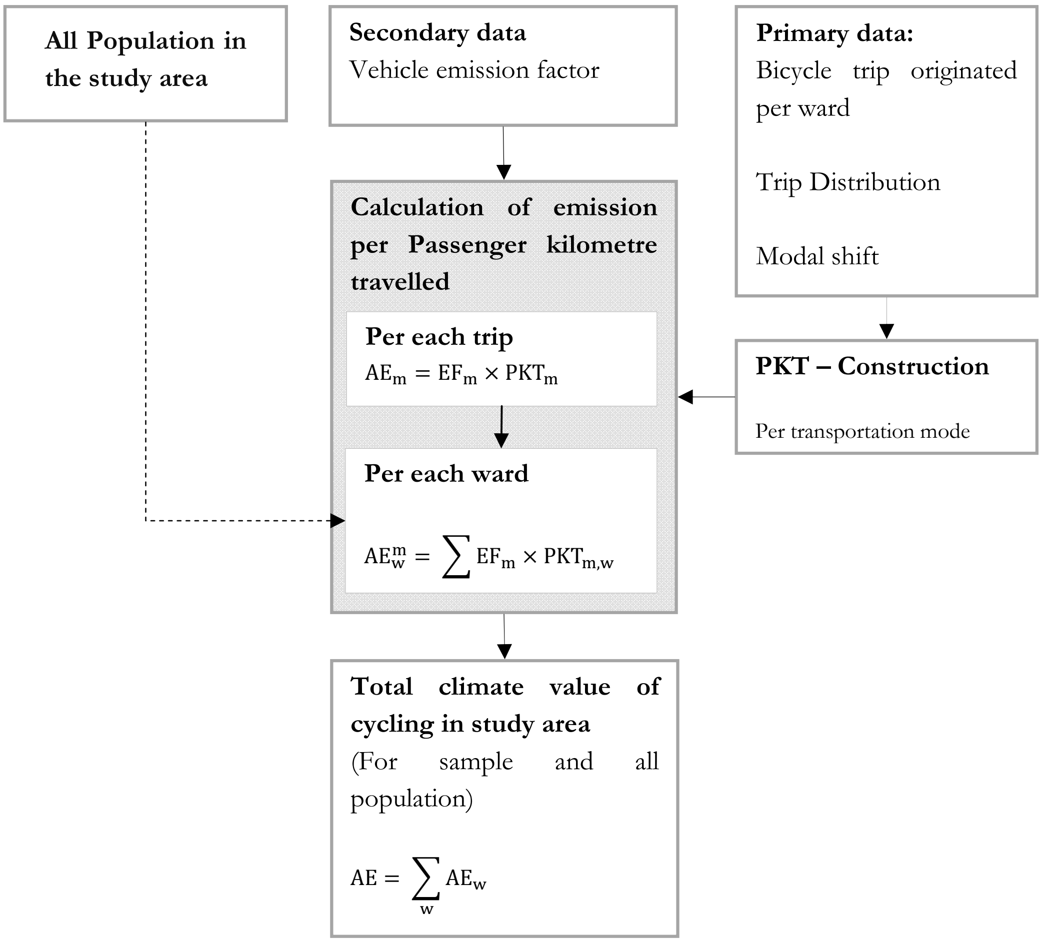

Figure 5-2: Modelling framework to access the climate value cycling

Summary

The opportunity costing model is constituted by several sub models including the climate value model and assesses the climate value of bicycle based on the stated preference of the cyclists in terms of alternative transportation modes and destination.

- There are several assumptions made to access the climate value of cycling, like average travel speed for different transportation mode, the calculation was based on the speed data collected during the field work.
- The vehicle emission factor used is adopted from Bogotá – Colombia. This choice was made due to lack of the specific data for the study area.
- The climate value of bicycling will be accessed for the sample as well as for the entire population.

6. SOCIO-ECONOMIC CHARACTERISTICS AND TRAVEL PATTERNS OF THE SAMPLE POPULATION

There are several factors that influence travel behaviour of cyclists such as weather, physical condition, income, car ownership, activity participation, supply of infrastructures for non motorized transport mode and attractiveness of competing mode (Rietveld & Daniel, 2004).

There is a close relationship between socio-economic characteristics and the level of mobility of a cyclist. The more mobile the cyclist, the higher is the range of socio-economic opportunities available to them. In fact both level of mobility and socio-economic characteristics influence the type, frequency of their participation in activities.

To describe the socio-economic characteristics, the 'household income', is used as an indicator of socio-economic status and 'vehicle ownership' as an indicator for level of mobility available. For travel pattern, the 'travel time' is used as an indicator and 'trip purpose' as an indicator of activity participation.

This chapter presents the socio-economic characteristics and the travel patterns of the sample population. According to the modelling process the evaluation of travel behaviour of the cyclists is based on the three transportation models stages, starts from trip generation up to mode shift.

6.1. Socio-economic characteristics of the household

Socio-economic characteristics of the household such as sex, age, occupation, household size, and vehicle ownership play an important role in explaining travel behaviour of the cyclists such as mode use, distance travelled, number of stops on home –to –home trip, type of destinations visited frequency travelled. For the total of 1020 cyclists interviewed 97% were male and only 3% were Female. Regarding to their occupation, 43% are self employed 30% employed, while 17% are students. The remainder 3% comprised of pensioners and 6% unemployed.

Items	Absolute value (N)	Relative value (%)
Socio-economic characteristics		
Number of individual observations	1020	
Sex		
Male	988	97%
Female	32	3%
Status		
Employed	309	30%
Self employed	435	43%
Student	176	17%
Pensioner	33	3%
Unemployed	62	6%
Level of education		
No education	41	4%
Primary	280	27%
Secondary	652	64%
University	34	3%
Other	13	1%
Age		
14 - 30	383	38%
31 - 50	562	55%
51 +	74	7%

Table 6-1: Socio economic characteristics of the sample

As for the level of education of most of the cyclists were up to secondary school (64%) and most belonged to the age range of 31 – 50 (55%) and 14 – 30 (38%) years.

Overall, most of the households had a monthly income in the range of100001 - 130000 TZS per month (US$: 67 – 87 [4]). The average household size of the sample is 5.7 members. Regarding to vehicle ownership, 79% of the households had only bicycle and the remaining had bicycle and a motorized mode.

[4] 1 TZS = US$ 0,00067 ("Exchange - Rates," 2011)

Items	Absolute value (N)	Relative value (%)
Household characteristics		
Average household size (St . Dev)	5, 77 (2,24)	
Minimum	1	
Maximum	15	
Average household income (TZS)		
> 70000	22	2%
70001 - 100000	148	15%
100001 - 130000	321	31%
130001 - 160000	271	27%
160001 - 190000	227	22%
< 190000	29	3%
Vehicle ownership		
Only bicycle	804	79%
Bicycle + motorized vehicles	213	21%
Only motorized vehicles	3	0%

Table 6-2: Household characteristics

A research done by Hanson & Hanson (1981) about the relationship between travel patterns and socio-economic characteristics found that larger the household size more the motorized trip generation and reduction in the percent of trips made by non motorized like walking or cycling, because they travel longer distances and also they do much higher trips for shopping purpose than others with much lower household size. Also household income and education level have been found to be related with certain aspects of travel. Those with higher incomes make more motorized trips per day, undertake more social trips, and travel greater distances to shop. Level of education has also been related to travel frequency, so it is also expected from the sample.

6.2. Travel pattern in combination with socio economic characteristics

To access the travel patterns first an analysis of departure time for all trips was done, which gave insight of the distribution of all the trips during the day and peak hours for bicycle trips were identified. Next the combinations of Trip Length Frequency Distribution (TLFD) with trip purposes were done to identify the purpose of most of bicycle trips.

6.2.1. Departure time distribution of bicycle trips

The study area the trips were found to start very early in the morning from 4AM till 10:00PM in the evening. In the morning the peak hour is around 7:00AM and in the evening peak hour is around 17:00PM, from the figure below it is clear that the afternoon peak is more spread than the morning peak due different departure times to return to home.

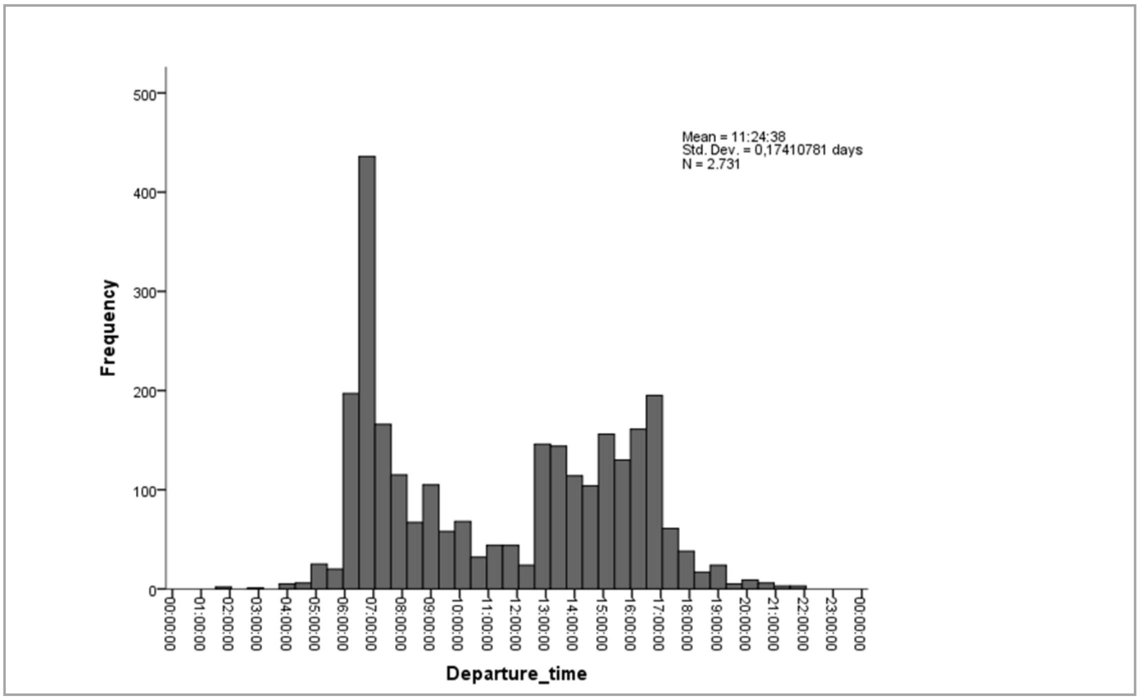

Figure 6-1: Departure time of bicycle trips (sample population)

6.2.2. Travel pattern and combination with trip purpose

The trip purposes are aggregation of Home based (HB) trips and non home based (NHB) trips. According to Zuidgeest (2010), Home-based (HB) trips are those where home is the origin or destination, and is classified as:

- Home based work(HBW)
- Home based school (HBS)
- Home based shopping(HBSH)
- Home based others (HBO), this includes trips for other activities like sell, pray, recreation, visit etc.

Non-Home-based (NHB) trips: Neither the origin nor the end of the trip is the home of the traveller. It is also classified in the same sequence as the HB trip.

The sample reveals that most of trips are made for HBWs (28%), followed by HBOs (19,3%). Comparing with cities in developed countries like Germany almost 2/3 of cycling trips are for shopping (29%) (Schley, 2001), but in case of Zanzibar it is found that most of the trips are for activities with higher utilities like HBWs .

In terms of travel frequency to activities, a figure 6-2 show that most of cyclists participate in activities within the range of 2 to 12km and the average number of trips was 2.6. Overall it was found that they travel more distances for HBWs and HBOs.

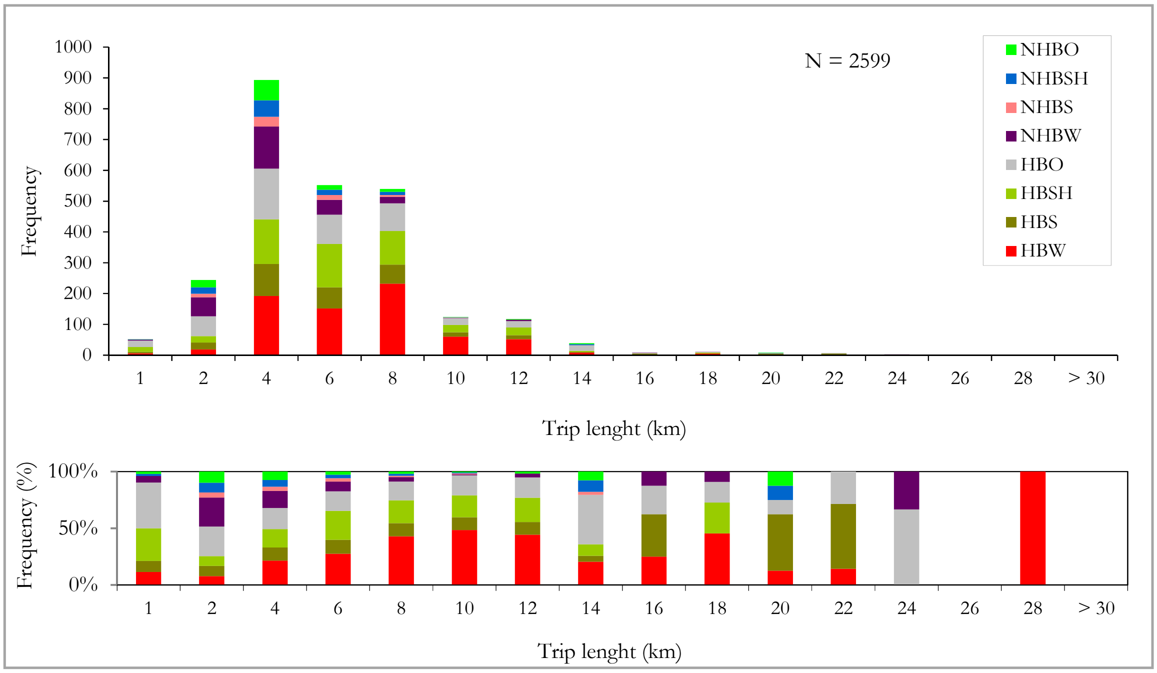

Figure 6-2: TLFD of all bicycle trips and combination with trip purpose

6.3. Distribution of bicycle trips

The trip distribution link the origins and destinations of all trips collected during the field survey. The result of this model can be viewed graphically in the form of desire line diagrams. In the figure 6-3 the trips are distributed by different travel distance class where the threshold is 2.2km, represents 10 min cycling time which is found as suitable travel time for activities. Due to the large number of O-D pairs, only the first class was visualized.

To establish a reference level, a threshold limit was derived which is 3.2km, this represents the average travel distance for all trips executed within the study area. Considering the threshold the large part of bicycle trips occurred within the study area. Analyzing each class independently, the fist class shows that 88% of the total number of trips starts within the stud area.

As the travel distance increases, the number of trips starting within the study area is reduced, which clearly shows that most of attraction points for cyclists (markets, jobs, recreation etc) are concentrated within the study area.

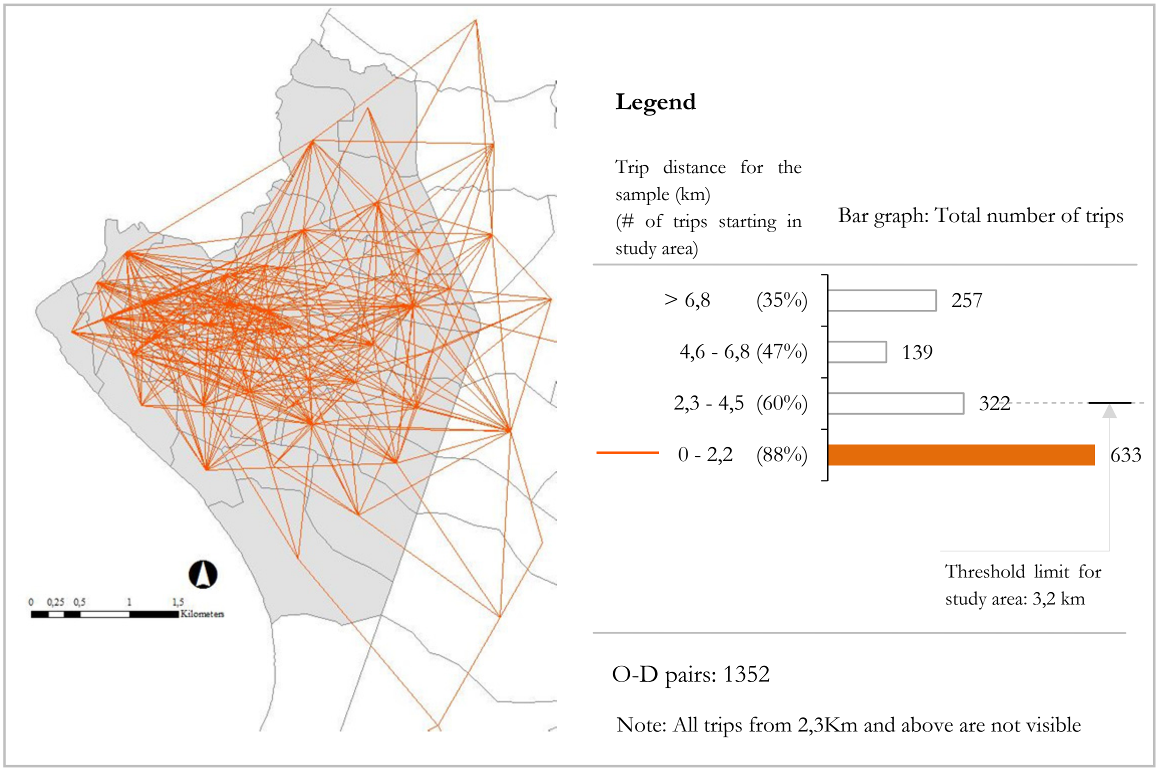

Figure 6-3: Desire lines diagram of all bicycle trips

6.4. Present traffic performance of the alternative modes

This section presents the traffic performance of the alternative modes by executing their TLFD, followed by its aggregation per income group. The idea was to understand how the choice for a certain alternative mode is influenced by trip distance and income.

The present traffic performance of the alternatives modes was developed based on the stated preference of the cyclist regarding to alternative mode choice. It is composed of all trips executed with the alternatives modes and the results are presented in the figure 6-4.

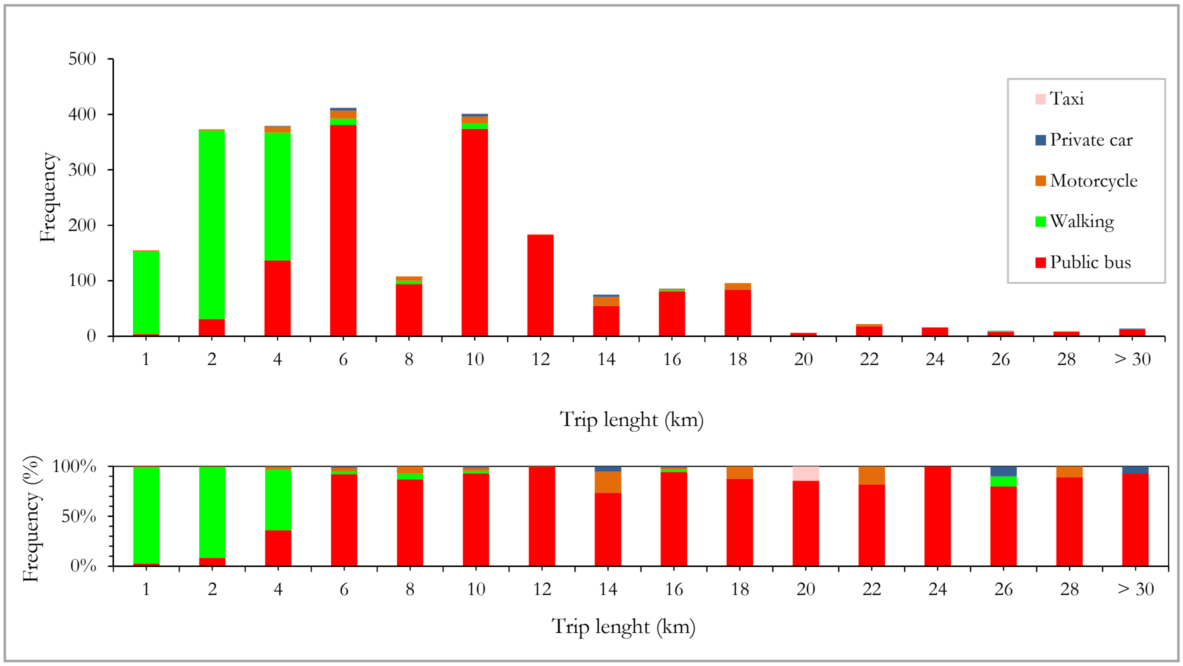

Figure 6-4: TLFD of all trips executed by the alternative modes

From the figure above it was found that a large part of the sample shifted to public bus (63.5%) followed by walking (31.8%). About 9.5 % (249) of bicycle trips are not executed. One important remark for the huge shift to public bus was due its fare attractiveness. In Zanzibar, unlike other countries or cities bus fare is fixed for a route not by kilometre travelled.

For walking mode, the sample reveals to be more attractive for shorter distances, it means when the travel distance increases the frequency decreases.

To understand the influence of income to the modal choice, figure 6-5 shows aggregation of the modal split by income class. Income classes were defined during the field survey. It was found that most of the shifts to motorized vehicles occur in the income range of 100001-130000TZS. The sample revealed that higher the income the lower the shifts to walking.

Based on Millennium development goal (MDG), was found that very few numbers of cyclists are below the poverty line, which means a large number of the existing cyclists are potential contributor to CO_2 emission since if they stop cycling would easily replace the bicycle trip with motorized vehicle.

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The average income for cyclists starting their trips within the study area was between 130000 -160000 TZS, using this as threshold to evaluate the shifts in the study area, this indicates that most of bicycle trips starting in the study area are replaced by motorized vehicles.

Overall 31% of the total bicycle trips replaced do not contribute to the CO_2 avoided as they are substituted by walking mode.

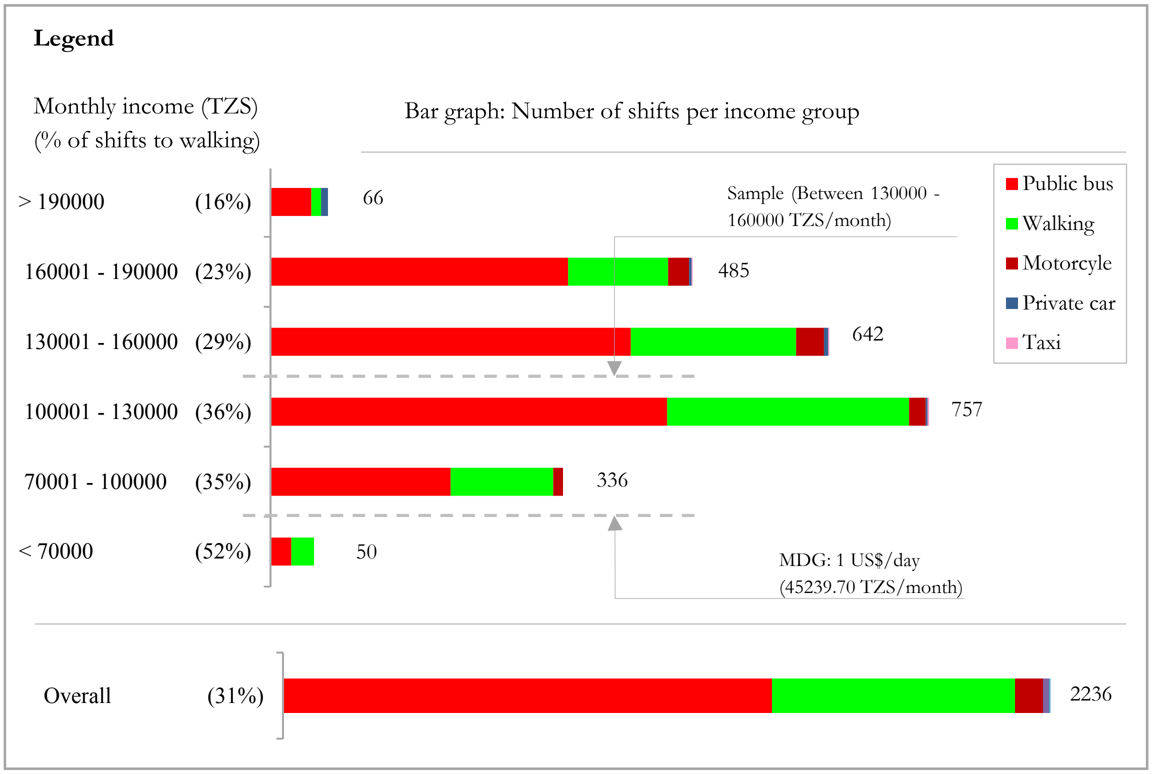

Figure 6-5: Aggregation of the modal shift per income class

Summary

The study has helped to establish the relationship between the socio-economic characteristics of the cyclists and their travel pattern and the choice for the alternative mode to cycling.

In summary, was found that large parts of the cyclists are within the income range of 100001-130000TZS/month. They travel more for home based work (HBW) purpose and most of their trips start early in the morning. Large number of bicycle trips occurs within the study area (urban west district) and they have a average travel distance of 3,2km by average of 2,6 trips per day.

Regarding to modal shift, large number of bicycle trips are replaced by public bus, and in combination with income was found that when increases the income reduces the number of cyclists shifting to walking.

7. CLIMATE VALUE OF CYLING IN ZANZIBAR TOWN

The next phase following the modelling process is to assess the climate value of cycling for the study area. It was assessed first for the sample followed by the population. To observe its spatial distribution over the city, the climate value depicted was visualised using appropriated techniques.

7.1. Climate value of the sample

7.1.1. Construction of Passage Kilometre Travelled of all modes (PKT)

The PKT is developed based on the sample collected and assumptions regarding to average speed for each transportation mode. To each mode the clustered trip purpose was added in order to depict the high contributors for the climate value of cycling. The figure 7-1 below is regarding to the sample and shows the reduced mode (bicycle) and the alternative modes to cycling.

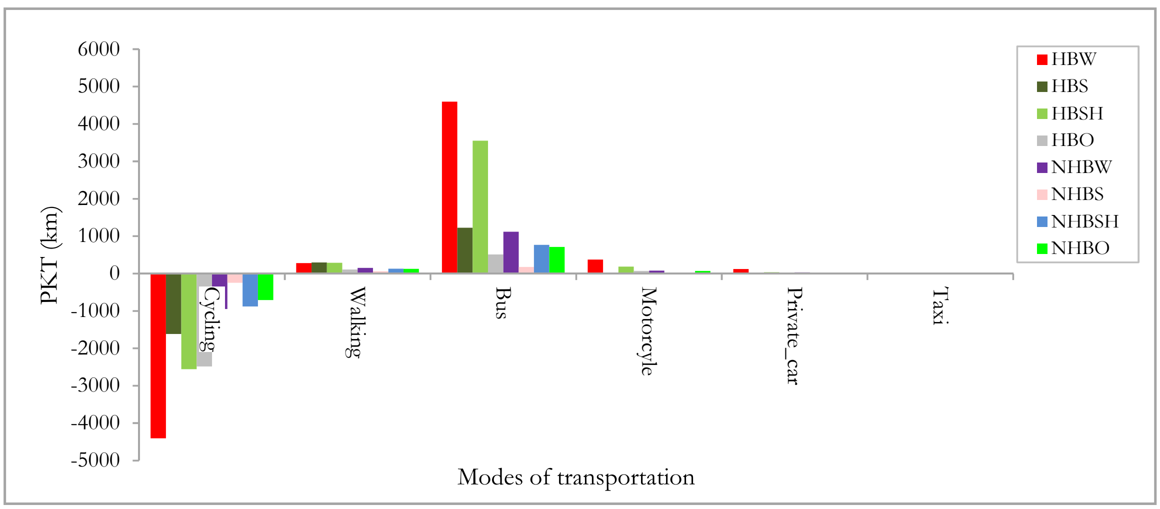

Figure 7-1: Aggregated PKT per trip purpose and mode of transportation

The trip purposes are presented by different colours and those executed by bicycles were negative values to represent that they do not participate in this model (opportunity costing model).

As result of *first order effect of bicycle substitution*; Public bus makes the largest share of modal shift (12656 km), followed by walking (1443 km). Combining with trip purpose HBW has the largest share with 4595 km, followed by HBSH with 3551 km. Large part of bicycle trips made for HBOs (72.2%) and some of HBSs (5.6%) were discarded or not replaced. Based on the utility Maximization theory it means that the disutility of making those trips with the alternative modes exceeded the utility of the trip.

Added trips are the result of the *second order effect of bicycle trip substitution*, where cyclists change their travel patterns, in order to maximize the utility of their trips as result of different opportunities of the new transportation mode; trip makers may change their destinations.

Based on the data this mostly occurs for HBSH trips with additional 1501.7km to the existing bicycle trips. See the table 7-1 for additional information.

Passenger Kilometer Traveled (Km)								
Trip Purpose	Cycling	Walking	Bus	Motorcyle	Private_car	Taxi	(-)Descarted trips/(+)Added	% Descarted trips/Added
HBW	-4407	280.9	4594.6	371.2	123.2	18.3	+981.2	22.2
HBS	-1614.9	298.3	1226.8	0	0	0	-89.8	5.,5
HBSH	-2555.8	287.3	3551	186	33.3	0	+1501.7	58.7
HBO	-2484.6	107.4	507.8	70	5.0	0	-1794.4	72.2
NHBW	-948.5	151.2	1116.8	77.4	30.9	0	+427.8	45.1
NHBS	-245.9	61	180	13.3	0	0	+8.3	3.3
NHBSH	-877.5	130.9	766.8	19.1	0	15.8	+55.1	6.2
NHBO	-711.6	125.7	712.2	71.6	0	0	+197.9	27.8
Overall	**-13846.1**	**1442.7**	**12656**	**808.6**	**192.4**	**34.1**		

Table 7-1: Aggregated PKT per trip purpose and mode of transportation

7.1.2. Spatial distribution of the climate value of cycling (Sample population)

The total C0$_2$ emission avoided through cycling for the sample in the study area is **131.4tonnes CO_2 [tCO_2] per year.**

The figure 7-2 below shows the spatial distribution of the climate value of cycling per ward. The highest contribution per day comes from trips starting in Mikunguni (32 KgCO_2/day), followed by Malindi (30 KgCO_2/day), Mkunazine (27 KgCO_2/day) and Amani (24 KgCO_2/day). For details of contribution of other wards see the appendix G.

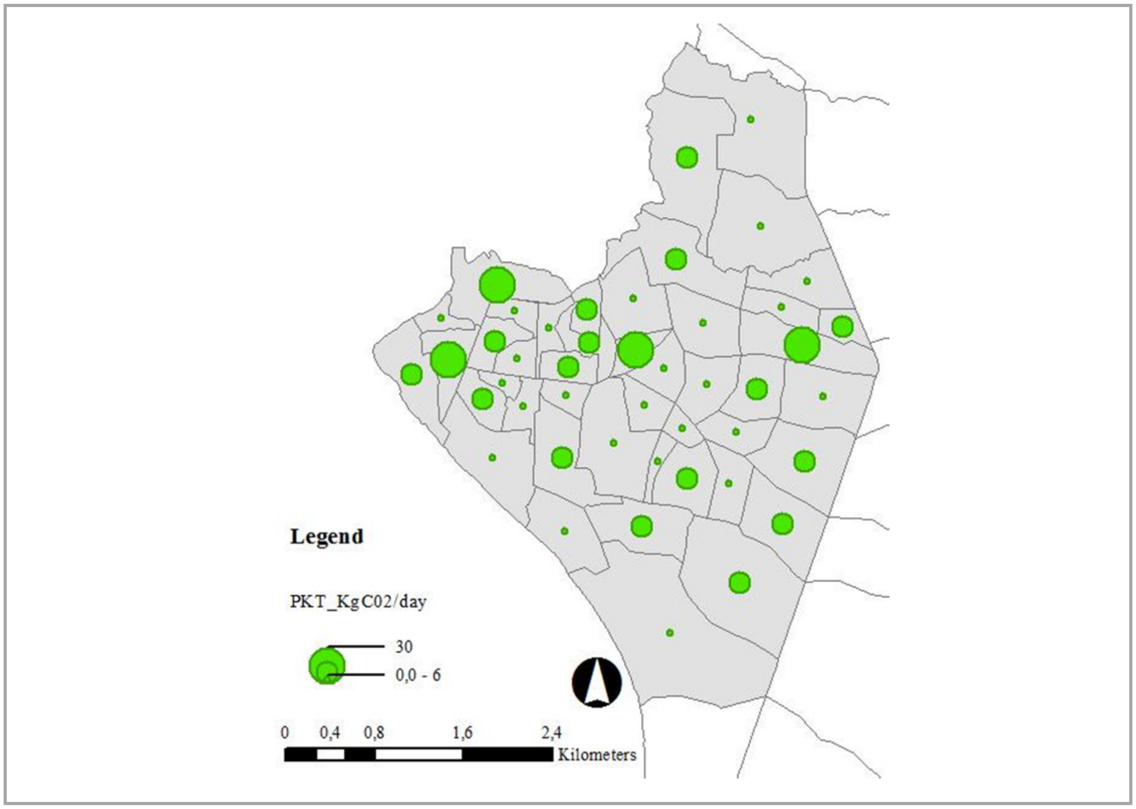

Figure 7-2: Spatial distribution of the climate value of Cycling (KgCO_2/day; for the sample)

7.1.3. CO_2 avoided per cyclist at ward level (Sample population)

To understand the contribution of each cyclist starting trip in a particular ward to the total climate value of cycling in the study area CO_2 avoided per cyclist at ward level was determined. This gives the average CO_2 avoided per cyclist started trip started in a particular ward. The travel behaviour of the cyclist is related to the choice of the alternative mode and the travel distance to the alternative destination.

The climate value per cyclist is obtained by dividing the total CO_2 avoided per ward by the total number of cyclists starting trips in that ward. For bicycle trips which were not substituted and those substituted by walking are not included as they do not participate in the total CO_2 avoided.

The variation of the CO_2 avoided per cyclist at ward level is presented in the figure 7-3 below. The side graph shows the percentage of bicycle trips belonging to that range and in brackets is the number of wards in that class.

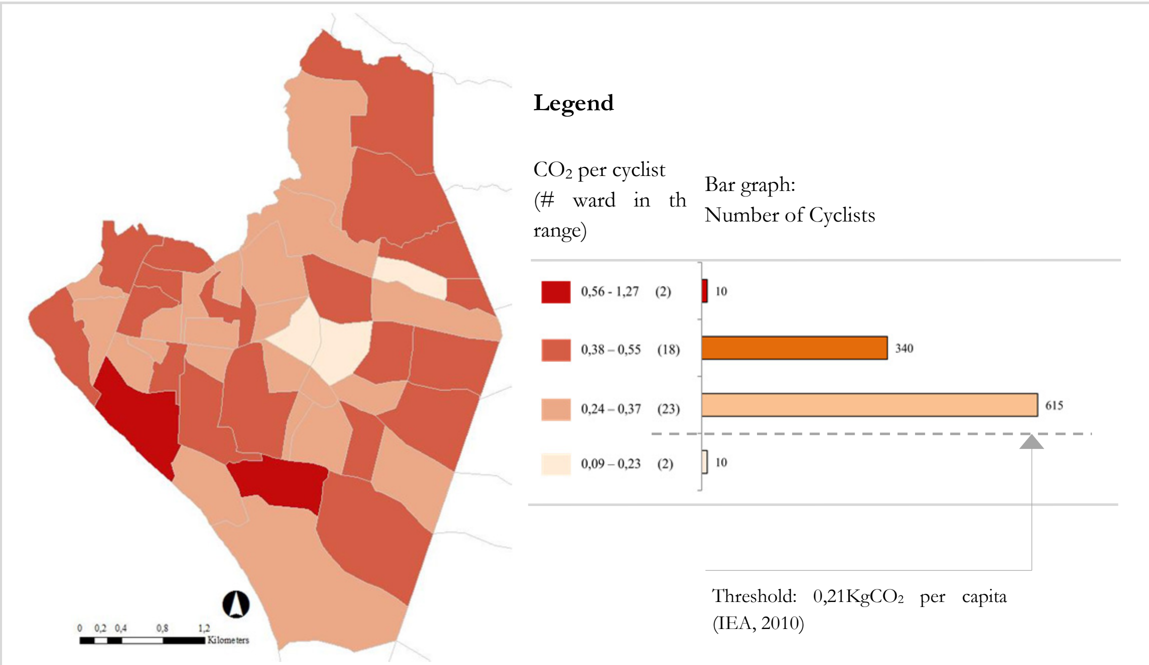

Figure 7-3: CO_2 avoided per cyclist at ward level (KgCO_2 per Cyclist)

Mostly, the wards in the central part of Zanzibar town were found to have low CO_2 avoided per cyclist as compared with northern and southern wards. According to IEA (2010), in 2008 the average CO_2 emission per capita for road transport sector in Tanzania was 0,21KgCO_2 per day. Combining this with the results from the sample it was found that 98.9% of the cyclists were above this average. This means if cycling is stopped it will contribute significantly to increase the CO_2 emission.

Comparing this result with results in the figure 7-2 it was found wards with total high climate value but lower per cyclist. This means the total climate value per ward is the result of substitution of many bicycle trips by many motorized vehicles with lower CO_2 emission per PKT.

For wards with total lower climate value and high per cyclist, meant that the climate value per ward resulted from the substitution of few bicycle trips with motorized modes with high CO_2 emission per PKT.

7.2. Climate value for all population

This section presents an estimate of the climate value for all cyclists within the study area. First presentation and discussion of the results obtained followed by its comparison with results of the research conducted in Bogotá which was applied the same methodology and at last compare with the results of the research about Social Economic Value (SEV) of cycling conducted in the same area.

The results from the calculations showed that the climate value of bicycling in Zanzibar is around **1,062.4 tonnes CO_2 [tCO_2] per year**. Table 7-2 presents the total climate value of cycling (the value of avoided CO_2 emission) disaggregated per alternative transportation mode.

Transport mode	Person trips daily	Modal shift (%)	Total distance travelled per day (km)	C02 Avoided ($tC0_2$/year)
Walking	2994	31.4	93.4	0
Public bus	5865	61.5	379.6	723.6
Motorcycle	451	4.7	309.1	40.9
Private car	222	2.3	125.8	295.6
Taxi	4	0.05	34.1	2.2
Overall	**9536**	**100**	**942.2**	**1,062.4**

Table 7-2: Avoided CO2 by different transport modes

Public buses and private cars provide the largest share of avoided CO_2 emissions. The share of public buses is logical due the number of shifts to this mode and the total travelled distance for this mode was 379.6km.

For private car the larger CO_2 share is explained by the fact that the emission factor (CO_2 per PKT) of this mode is relatively high, compared with the public bus it is almost five times higher.

To give an indication on how this climate value is distributed, figure 7-4 presents the spatial distribution of the climate value of cycling.

It can be seen that, the higher climate value is depicted in the wards located far from the main centre. This is what was to be expected as most of the trips are heading to the attraction locations which are mostly located in the centre, and because of the distance cycling is replaced by motorized transport.

In the table 7-3 all the wards were clustered according to the CO_2 avoided class. This shows that the climate value per ward is directly influenced by the number of bicyclists (1), number of the replacement for motorized vehicle (2) and the travel distance (3). Most of wards were within lower class (22 wards) and they contributed with almost 13 % of the total CO_2 avoided in the study area. Wards within high CO_2 avoided class had almost three times more cyclists compared with lower class, were composed of only 8 wards and contributed with 57% of the total CO_2 avoided in the study area. These are the most suitable wards to assign resources to promote or preserve cycling, because investing there can benefit many cyclists and avoid many others to shift to motorized vehicles.

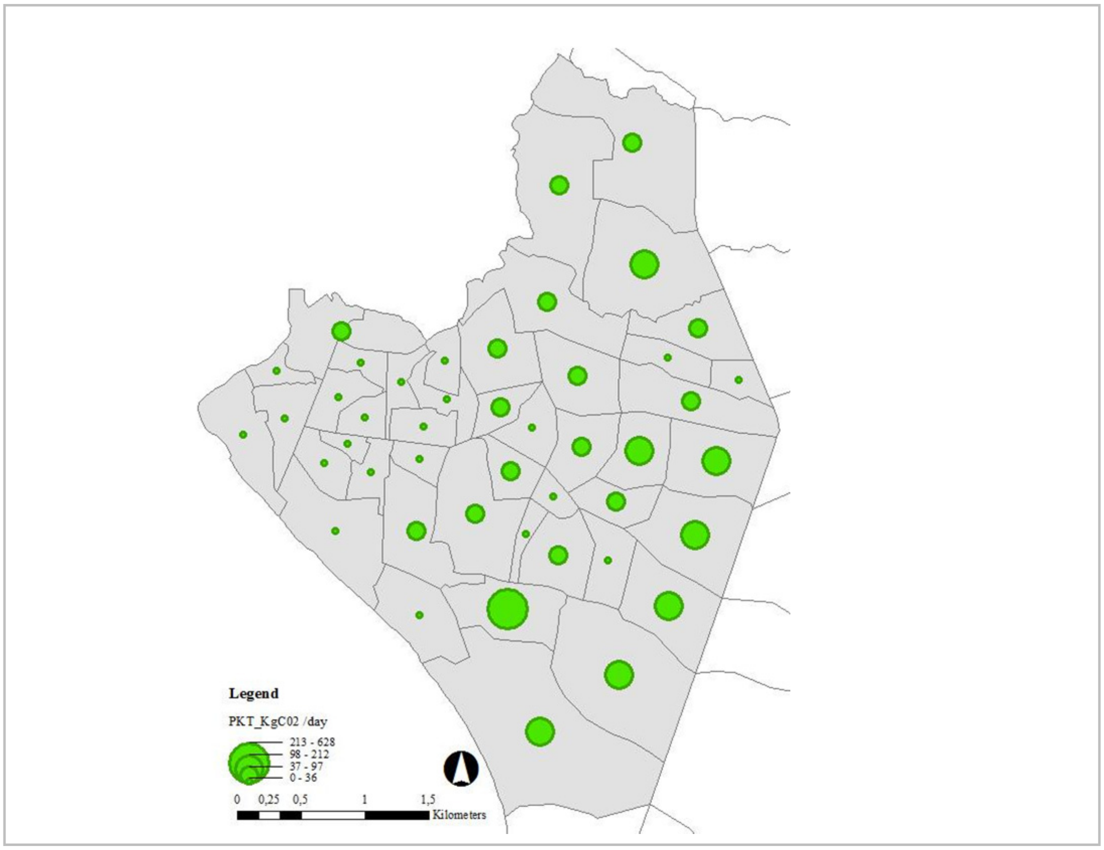

Figure 7-4: Spatial distribution of the climate value of cycling for the total cyclists (Population)

CO_2 class ($KgCO_2$/day)	# wards	# bicyclists	# shifts to motorized vehicle	% shift to motorized vehicle	Avarage travel distance	Total CO_2 avoided per day	% CO_2 avoided
0-36	22	2566	1270	19.4	7.5	397	13.6
37 - 97	15	3481	2447	37.4	8.6	864	29.7
> 97	8	3533	2825	43.2	8.8	1649	56.7
Total	**45**	**9580**	**6542**	**100**		**2910**	**100**

Table 7-3: Factors explaining the avoided CO_2 emission

7.3. Comparison of the opportunity costing outputs with research conducted in Bogota

When applying the results of this model to compare with Bogotá, the first order effects of bicycle substitution was found as the only indicator to measure the differences between these two cities. The no bicycling effects in Zanzibar would result in a large shift to public bus same as Bogotá. But due to the large population and large number of cyclists the shifts in Bogota would produce more bus trips and consequently more CO_2 emission.

The second order effect was not used to model the climate value for Bogotá. This is a drawback of "aspatial" application of this methodology since a large rate of additional trips to cycling were lost or excluded to the model. For instance additional trips in Zanzibar contributed with 21% of the total CO_2 avoided, for Bogotá it could have been even larger due to urban sprawl and composition of urban transport.

7.4. Classification of wards according to their risk to contribute to emite CO_2

Parallel to this research, another research was conducted to assess the socio-economic value (SEV) of cycling in the same study area. SEV of cycling is hypothetical additional cost for using the alternative modes as compared with the cost of using bicycles for the same trip. These costs include the difference in travel time and the additional costs for using the alternative mode.

Low SEV means that if an individual stops cycling, the person will not incur many additional net costs in using the alternative mode. It was understood that the threshold to shift to that alternative mode is very low.

Combining the SEV and climate value (CV) results it was possible to classify the wards according to their risk to contribute to CO_2 emission in case of bicycle is no longer an option. The threshold for CV was defined based on IEA(2010) which the average CO_2 emission per capita in Tanzania was 0.21kgCO_2 per day. For SEV the threshold was defined as US$ 0,47 per capita per day which corresponds to basic need poverty line defined for Zanzibar (*Household Budget Survey*, 2006).

Below is presented the table 7-4 which show the relationship between SEV and CV and the figure 7-5 which shows the spatial distribution of the risk to emit CO_2.

	Low SEV	High SEV
Low CV	These were considered middle risk, since they are likely to shift to their alternative modes, but these modes would emit less CO_2.	This is Low risk scenario, since the use of the alternative mode would incur high costs. So there are not likely to use the alternative mode, but if so, they will emit less CO_2.
High CV	This was considered high risk, since they are likely to shift to alternative modes, and the alternative modes would have high CO_2 emission	Was also considered as middle risk, since they are not likely to shift to the alternative mode, but if they shift they would emit CO_2.

Table 7-4: Relationship between SEV and CV

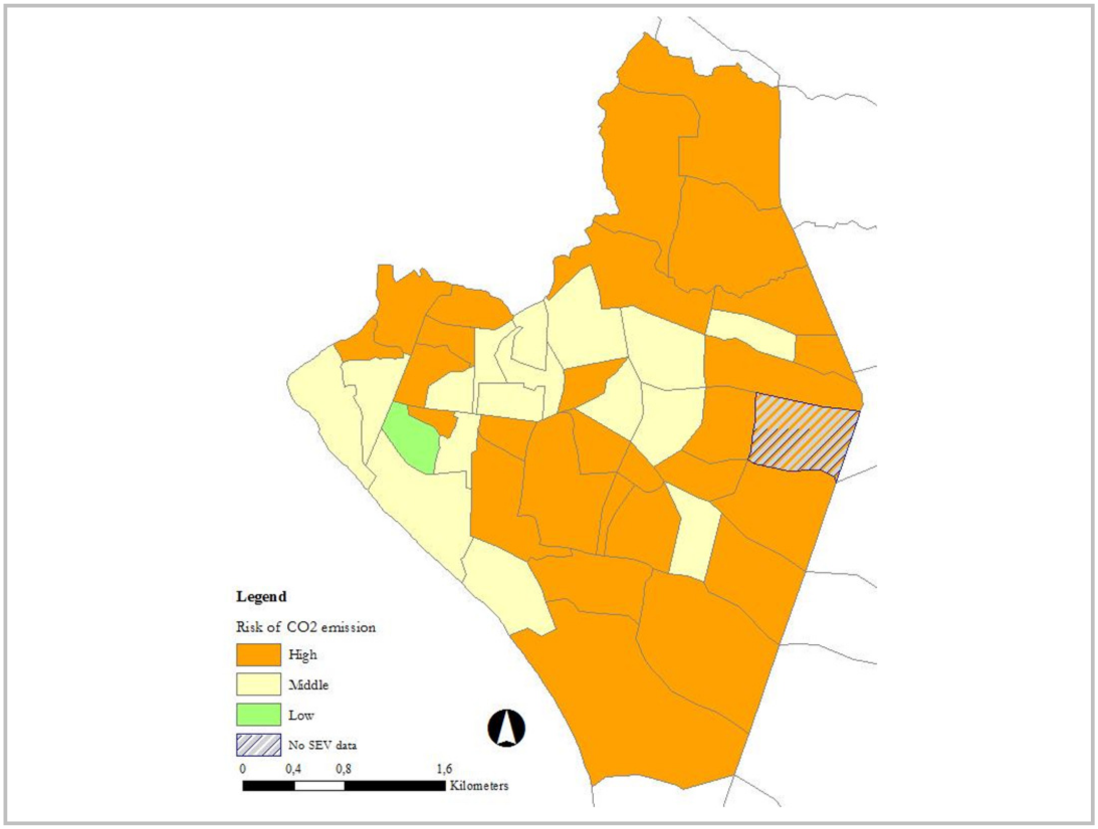

Figure 7-5: Classification of wards according to their risk to emit CO_2

It was found that only one ward is in low class, 16 in middle risk class (low SEV- low CV), 27 within high risk class and no wards in middle (high SEV- low CV) risk class. This means most of wards are within high risk class. This is justified as the average SEV per cyclist is US$0.17 per day which is far from the threshold defined. Most cyclists are likely to shift to their alternative mode since the costs for using it are low. The average CV per cyclist was found to be 0.25kgCO_2 per day, which is relatively high if compared with the threshold. This means that most of the alternative modes are motorized vehicles.

It can be stated that in the Zanzibar town most of cyclists are likely to shift to motorized vehicle thus the risk to emit CO_2 is high if they stop cycling.

7.5. Opportunity for carbon finances

The avoided C02 by bicycle mobility can be traded as carbon credit in the carbon market. Motivated by the Kyoto protocol this emission saved can be traded in different market programs like Clean Development Mechanism (CER) or Voluntary Offsets Markets (VCI).

For the purpose of this study, the carbon price from Clean Mechanism Development (CER) was considered from the average from August 2008 to April 2009. The average price was €14.95 equal to US$19.76 (BlueNext, 2010). The prices were converted to US$ to fit with the prices in VCI market. For that the values was converted using the rate of $1= €1.321 (Reuters, 2011). For the Voluntary market (VCI) the average prices for tCO_2 in equal period of time is US$6.66 with (Sjardin & Marcello, 2009). This calculation was done to indicate the potential monetary value of cycling in the study area.

Modal shift	Climate value tCO_2/year	Climate Value (VCI[5]) ($/year)	Climate Value (CER[6]) ($/year)
Public bus	723.7	4819.8	14300
Motorcyle	40.9	272.5	808.6
Private car	295.6	1968.8	5841.2
Taxi	2.2	14.8	44.1
Total	**1,062.4**	**7,075.9**	**20,994**

Table 7-5: Monetary value per different transportation mode

The annual amount of money expected from the carbon market is US$ 20,994 if sold in CER and US$ 7,075.9 if sold in VCI. This amount could be invested in bicycle infrastructures and thus induce more shifts to this mode and will increase the climate value of cycling and adds to sustainable urban transport.

Summary and conclusions

The analysis of the climate value of cycling serves as a good indicator to measure the environmental and economical sustainability of the current cycling mobility. The information provides the planners and decision makers an important instrument to outline actions and scenarios to promote or preserve cycling. The climate value of cycling in Zanzibar was assessed for both sample and all population, and the emissions were allocated at the origin to identify wards to assign resources to promote cycling.

The socio-economic, travel characteristics and spatial distribution of the activities in Zanzibar play an important role in determining the climate value of cycling. In general, public buses provided larger CO_2 share as compared with other transport modes and wards located far from activities have high climate values. However by combining the climate value with the out puts of the SEV it was able to identify wards with high risk to emit CO_2 in case of no cycling scenario. It was considered high risk to those wards with high climate value and lower SEV.

The assessed emission was converted into monetary asset based on CDM and VCI, to give insight to the possible monetary value from the current cycling in Zanzibar.

[5] VCI price (Sjardin & Marcello, 2009): US$: 6.66

[6] CER price (BlueNext, 2010) : US$:19.16

Limitation in climate value analysis

The analysis of the climate value of cycling had some drawbacks as well as advantages. Most of the limitations were depicted in the interpretation of the results. First it is affected by the accuracy of the analysis from the previous sub-models and also constrained by the data availability since it requires larger primary data.

To scale up the sample for all the population, several assumptions were made, since it needs large disaggregated data in terms of vehicle ownership. The vehicle emission factor used was based on the information for Bogota, which perhaps may change per the local driving conditions, state of vehicles maintenance, age of the vehicles and other factors.

Aside of these limitations, the climate value provides an important source of information in terms of the avoided emission per ward and helps decision makers to take appropriate actions to promote cycling.

8. CONCLUSION AND RECOMMENDATIONS

This chapter presents the outlines all the findings and achievements made per research objective. The recommendation presents the further relevant research issues that could be undertaken into consideration.

8.1. Conclusion

The main objective of this research was the spatial application of an opportunity costing method to assess the disaggregated climate value of bicycling for intra city trips. The data collected during the field survey provided information about the socio economic characteristics of the cyclists, their travel behaviour and their virtual modal shifts. These data were used as an input for each stage of the transportation model. Using an opportunity costing approach the outputs of the models was used to estimate the climate value of cycling for both the sample and the population.

As per the specific research objective, the following conclusions are drawn:

1. The travel behaviour of cyclists in Zanzibar town.

It was found that in Zanzibar Island cycling represents 41% of the modal share. In the study area large part of cycling was executed for home based work purpose (28%), followed by home based others (19,3%).

Large part of bicycle trips started early in the morning from 4AM till 10:00PM in the evening. In the morning the peak hour is around 7:00AM and in the evening peak hour is around 17:00PM. In terms of travel frequency to activities, most of cyclists participate in activities within the range of 2 to 12km and the average number of trips per day is 2.6.

2. Preferred alternative mode for cycling

Information about the modal shifts was collected during the field survey, based only on the stated preferences of the cyclists. This information allowed combination with TLFD and income to access the modal shift. Analyzing the data, 63.5 % of the total bicycle trips were replaced by public buses while 31.8% by walking. Most shifts from cycling to walking mode were found for shorter travel distances less than 4km, while for motorized vehicles for long distances mostly for more than 6km. When compared with income, it was found that when income increased the shift to walking decreased.

3. Climate value of cycling for the sample and the population

The climate values of cycling for the study area were analyzed for the collected sample and for the population to get the actual contribution per ward. The climate values were spatially represented in maps using appropriated visualization techniques.

The derived climate value per ward was directly influenced by choice of alternative transport mode, travel distance and number of cyclists per ward.

Urban form played important role in distribution of the climate value as most of the activities in Zanzibar town are concentrated in stone town. High climate values were observed for wards located far away from stone town. This indicates that in those wards if cycling is no longer an option, it would be replaced by motorized vehicle thus emit CO_2. In combination with the socio economic value of cycling, the wards were classified according to their potentiality (risk) to pollute, and where aggregated from low to high. Most of wards were found to be in high risk to emit CO_2.

The study showed that the climate value per cyclist per ward can be reduced if the cyclists from all income groups are encouraged to use more sustainable transport modes (public bus), assuming trip distance and travel demand to remain the same.

GIS technology offered good possibilities for communicating the results since it helped to analyze the spatial distribution of the climate value of cycling over the city and provided important information for land use and transport planning.

4. Monetary assets of the avoided CO_2 emission through cycling in Zanzibar.

The total CO_2 avoided per year was found to be 1,062.4 tCO_2 per year. If this is traded in the carbon market can be obtained a monetary asset between US$ 7,075.9 – 20,994. This capital can be used to invest in cycling infrastructures to accommodate the existing cycling traffic and attract more.

5. To recommend on allocation of resources for promotion or preserving of cycling.

The spatial application of the opportunity costing methodology resulted in spatial distribution of the climate value per each contributor (ward). This was found as strength of this model since it allowed identifying and visualizing the major contributors and combined with additional information like population, number of cyclist per ward to identify suitable wards to assign resources.

8.2. Conclusions in general

Opportunity costing methodology is an economic concept which allows value for goods which do not have intrinsic zero value, for this study the avoided CO2 emission is given value. The climate value of each bicycle trip is accessed based in the stated preference of the cyclists in terms of alternative modal choice and trip length.

Stated preference of the cyclists provided a means to study the choice for hypothetical (not yet existing) alternative transportation modes. Analyzing the choice made by the cyclists helped to estimate the potential share of trips for public buses and it provided important information for transport planners to know the potential market share of the existing public buses.

The inclusion of the second order effect of bicycle trip substitution was found as a powerful component of the spatial application of the opportunity costing model since it includes all trips made with the alternative modes resulting in very accurate outputs.

The disaggregated climate value of cycling per ward provided information about the spatial variations of the climate value over the city and areas with high climate value, which can be depicted. Climate value per cyclist explains how the travel patterns and choice of the alternative modes influences the total CO_2 per ward. When this avoided emission is traded in carbon market it results in monetary value which can be used to promote cycling.

For technical aspect, the combination of the stated preference of the cyclists, transport models and GIS (ArcGIS) provided a strong platform to understand the transport system in Zanzibar. The use of appropriated techniques and software helps planner and decision makers to have a future vision, and identify places to assign resources to promote or preserve cycling.

To conclude, it was found that the existing cycling in Zanzibar represented a sustainable transport mode as 68% contributed to avoid CO_2.

8.3. Recommendations

Two major recommendations for future research were proposed, which are to (i) upgrade primary data collection approach, (ii) validation of the stated preferences of the cyclists

Upgrade primary data collection approach

Large parts of data used in this model are derived from the field survey. This provides the climate value for the sample. To access the climate value for all population scale up was necessary to the sample.
For a better representation of the number of cyclists per ward, detailed workout in the design phase was required. The survey methodology could be further upgraded with the traffic count or all other appropriated technologies to collect more data, such as email, telephone, internet etc apart from road/destination based survey. This would provide a more accurate scale factor to access the total CO_2 avoided for all population.

Validation of the stated preferences of the cyclists

Hypothetical alternative modal choices of the cyclists provided the input data for this model. Validating this information with their socio-economic characteristics would provide exact modal choice per cyclists, their travel time with the alternative modes therefore giving more precise climate value of cycling.

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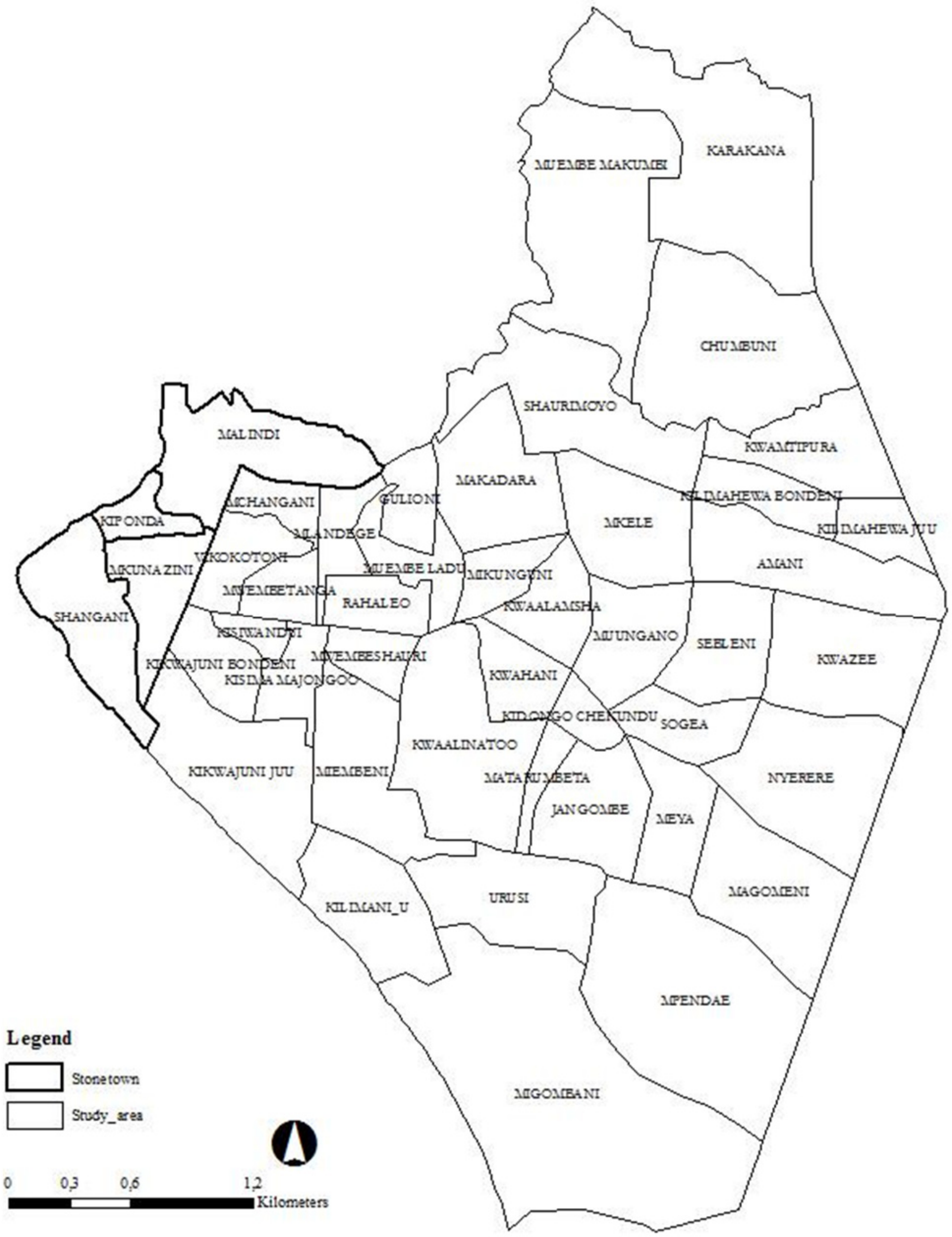
APPENDIXES

Appendix A: Distribution of wards in the study area



Appendix B: Questionnaire

Survey date and surveyor — 1

Day	Monthly	Year

Time	Hour	Min
Am		
Pm		

Interviewer	
Supervisor	
Location ID	

Address of household — 2

		Code
Region		
District		
Shehia		
Street		

Characteristics for the respondent — 3

Male ☐ Female ☐ Age ☐☐

Head of family

Yes ☐ no ☐

Education of level — 4

No education	☐	Secondary school	☐
Junior school	☐	University education	☐
Primary school	☐	Others	☐

Total number of persons who live together in your living quarter — 5

	Total		under 6 year old		6 years old and above: Working		Students		Others
Male		=		+		+		+	
Female		=		+		+		+	

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Employment status of the cyclists				6
Self employed	☐	Employed	☐	
Domestic workers	☐	Pensioners	☐	
Unemployed	☐	Students	☐	
Other	☐			

If Employed (employment type)				7
Governmental	☐	Private	☐	

Total income of the house hold (in tsh per month)				8
less than 70000	☐	130001 - 160000	☐	
70001 - 100000	☐	160001 - 190000	☐	
100001 - 130000	☐	More than 190001	☐	

Vehicle ownership/ availability				9
Motorcycle	☐	Bicycle	☐	
Passenger car	☐	Bajaj	☐	
Pick up -van	☐	Other	☐	
Truck	☐			

Origin place information

Place		Address of the place		10
1. Home	☐	Region		
2. Working place	☐	District		
3. School	☐	Shehia		
4. Worship place	☐	Street		
5. Other	☐			
Departure at	☐☐ ☐☐			

Trip information			
Mode of transport		Travel time (min)	

Destination place information

Arrival at ☐☐ ☐☐

11

Place		Address of the place	
1. Home	☐	Region	
2. Working place	☐	District	
3. School	☐	Shehia	
4. Other	☐	Street	

Departure at ☐☐ ☐☐

Trip information

Mode of transport ☐ Travel time (min) ☐

Travel cost (Tsh) ☐ (ask if by bus)

Arrival at ☐☐ ☐☐

12

Place		Address of the place	
1. Home	☐	Region	
2. Working place	☐	District	
3. School	☐	Shehia	
4. Other	☐	Street	

Departure at ☐☐ ☐☐

Trip information

Mode of transport ☐ Travel time (min) ☐

Travel cost (Tsh) ☐

Arrival at ☐☐ ☐☐

13

Place		Address of the place	
1. Home	☐	Region	
2. Working place	☐	District	
3. School	☐	Shehia	
4. Other	☐	Street	

Departure at ☐☐ ☐☐

Trip information

Mode of transport [ ] Travel time (min) [ ]
Travel cost (Tsh) [ ]

Alternative transportation mode

Which alternative mode of transportation would you have used if you had not used your bicycle? 14

Motorcycle	☐	Truck	☐
Passenger car	☐	Walking	☐
Pick up -van	☐	Other	☐
Bus	☐	____________	

If you would not used your bicycle yesterday would you have changed your destination? 15

Yes ☐ No ☐

Alternative destination place information

Arrival at ☐☐ ☐☐

15

Place		Address of the place	
1. Home	☐	Region	
2. Working place	☐	District	
3. School	☐	Shehia	
4. Other	☐	Street	

Departure at ☐☐ ☐☐

Trip information

Mode of transport [ ] Travel time (min) [ ]
Travel cost (Tsh) [ ]

Arrival at

16

Place
1. Home
2. Working place
3. School
4. Other

Address of the place
Region
District
Shehia
Street

Departure at

Trip information

Modeof transport
Travel time (min)
Travel cost (Tsh)

Arrival at

17

1. Home
2. Working place
3. School
4. Other

Address of the place
Region
District
Shehia
Street

Departure at

Trip information

Mode of transport
Travel time (min)
Travel cost (Tsh)

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Appendix C: Scale up sample for all population

WARD_NAME	Population 2002	#_ Households	HH_bicycle	%_using_biycle	#_HH_using bicyle
AMANI	5.532	937	455	38,40	175
CHUMBUNI	10.398	1762	856	50,3	431
GULIONI	2.414	409	198	50,3	100
JANGOMBE	5.885	997	484	50,3	244
KARAKANA	6.169	1045	508	50,3	256
KIDONGO CHEKUNDU	2.217	375	182	50,3	92
KIKWAJUNI BONDENI	2.435	412	200	50,3	101
KIKWAJUNI JUU	2.477	419	204	50,3	103
KILIMAHEWA BONDENI	4.645	787	382	50,3	192
KILIMAHEWA JUU	3.385	573	278	50,3	140
KILIMANI_U	2.931	496	241	50,3	121
KIPONDA	1.922	325	158	50,3	80
KISIMA MAJONGOO	4.162	705	342	50,3	172
KISIWANDUI	900	152	74	50,3	37
KWAALAMSHA	3.471	588	285	50,3	144
KWAALINATOO	5.147	872	423	50,3	213
KWAHANI	4.293	727	353	50,3	178
KWAMTIPURA	9.199	1559	757	50,3	381
KWAZEE	6.933	1175	571	50,3	287
MAGOMENI	10.971	1859	903	53,11	480
MAKADARA	5.398	914	444	50,3	224
MALINDI	3.491	591	287	50,3	145
MATARUMBETA	2.665	451	219	50,3	110
MCHANGANI	2.291	388	188	50,3	95
MEYA	3.457	585	284	50,3	143
MIEMBENI	5.273	893	434	48,14	209
MIGOMBANI	14.081	2386	1159	50,3	583
MIKUNGUNI	3.090	523	254	50,3	128
MKELE	6.120	1037	504	50,3	254
MKUNAZINI	3.527	597	290	63,67	185
MLANDEGE	2.200	372	181	50,3	91
MPENDAE	12.115	2053	997	50,3	502
MUEMBE LADU	3.314	561	272	50,3	137
MUEMBE MAKUMBI	8.187	1387	674	50,3	339
MUUNGANO	4.934	836	406	50,3	204
MWEMBESHAURI	2.091	354	172	50,3	87
MWEMBETANGA	2.766	468	227	50,3	115
NYERERE	13.059	2213	1075	50,3	541
RAHALEO	1.983	336	1637	50,3	82
SEBLENI	4.703	797	387	50,3	195
SHANGANI	3.989	676	328	50,3	165
SHAURIMOYO	8.248	1397	679,4115254	50,3	342
SOGEA	4.564	773	375	50,3	189
URUSI	12.416	2104	1022	50,3	514
VIKOKOTONI	1.793	303	147	50,3	74

Appendix D: Modal shift for all population

WARD_NAME	Shift_bus	Shift_Walking	Shift_ Motorcyle	Shift_ private car	Shift_ taxi
AMANI	154	10	5	0	0
CHUMBUNI	287	144	0	0	0
GULIONI	56	40	4	0	0
JANGOMBE	139	98	7	0	0
KARAKANA	85	128	43	0	0
KIDONGO CHEKUNDU	73	18	0	0	0
KIKWAJUNI BONDENI	31	61	4	0	4
KIKWAJUNI JUU	0	103	0	0	0
KILIMAHEWA BONDENI	38	154	0	0	0
KILIMAHEWA JUU	85	43	0	6	0
KILIMANI_U	44	66	11	0	0
KIPONDA	27	0	53	0	0
KISIMA MAJONGOO	52	121	0	0	0
KISIWANDUI	37	0	0	0	0
KWAALAMSHA	112	32	0	0	0
KWAALINATOO	213	0	0	0	0
KWAHANI	109	59	10	0	0
KWAMTIPURA	203	127	51	0	0
KWAZEE	192	0	0	96	0
MAGOMENI	320	124	36	0	0
MAKADARA	129	69	26	0	0
MALINDI	11	100	11	22	0
MATARUMBETA	88	22	0	0	0
MCHANGANI	47	32	16	0	0
MEYA	72	72	0	0	0
MIEMBENI	143	48	10	0	0
MIGOMBANI	547	36	0	0	0
MIKUNGUNI	113	10	5	0	0
MKELE	95	158	0	0	0
MKUNAZINI	41	123	0	0	0
MLANDEGE	14	70	7	0	0
MPENDAE	314	167	21	0	0
MUEMBE LADU	86	46	6	0	0
MUEMBE MAKUMBI	276	64	0	0	0
MUUNGANO	128	26	51	0	0
MWEMBESHAURI	67	10	10	0	0
MWEMBETANGA	57	57	0	0	0
NYERERE	386	129	26	0	0
RAHALEO	37	32	9	0	0
SEBLENI	142	35	0	18	0
SHANGANI	55	110	0	0	0
SHAURIMOYO	238	83	21	0	0
SOGEA	139	40	10	0	0
URUSI	367	73	0	73	0
VIKOKOTONI	14	54	0	7	0

Appendix E: Average PKT for each transportation mode per ward (all population)

	Avarage PKT per transportation mode (Km)				
WARD_NAME	**Bus**	**Walking**	**Motorcycle**	**Private car**	**Taxi**
AMANI	8,5	1,7	16,7	0,0	0,0
CHUMBUNI	10,3	3,3	0,0	0,0	0,0
GULIONI	8,4	2,3	9,4	0,0	0,0
JANGOMBE	8,9	2,8	12,5	0,0	0,0
KARAKANA	10,7	3,4	20,8	0,0	0,0
KIDONGO CHEKUNDU	7,2	1,7	8,3	0,0	0,0
KIKWAJUNI BONDENI	6,8	2,5	7,9	10,0	4,2
KIKWAJUNI JUU	12,8	2,3	0,0	0,0	0,0
KILIMAHEWA BONDENI	3,6	2,2	0,0	0,0	0,0
KILIMAHEWA JUU	9,1	2,4	5,8	4,2	0,0
KILIMANI_U	7,8	2,2	9,4	0,0	0,0
KIPONDA	7,1	1,6	9,6	0,0	0,0
KISIMA MAJONGOO	7,9	2,6	0,0	0,0	3,3
KISIWANDUI	7,5	1,4	0,0	0,0	0,0
KWAALAMSHA	4,7	3,2	0,0	0,0	0,0
KWAALINATOO	9,7	2,6	0,0	0,0	0,0
KWAHANI	8,5	2,1	10,0	0,0	0,0
KWAMTIPURA	9,9	2,8	14,6	0,0	0,0
KWAZEE	6,5	0,8	0,0	8,3	0,0
MAGOMENI	8,0	2,0	7,9	0,0	0,0
MAKADARA	7,6	2,1	11,7	0,0	0,0
MALINDI	11,0	2,1	8,2	9,2	0,0
MATARUMBETA	7,1	2,0	0,0	0,0	0,0
MCHANGANI	11,2	1,2	5,0	0,0	0,0
MEYA	10,3	3,4	0,0	0,0	0,0
MIEMBENI	8,5	2,2	9,8	14,2	0,0
MIGOMBANI	7,3	1,1	5,0	4,2	0,0
MIKUNGUNI	9,2	1,7	12,8	0,0	0,0
MKELE	10,7	2,3	0,0	0,0	0,0
MKUNAZINI	8,6	1,8	16,7	0,0	0,0
MLANDEGE	9,0	1,8	7,5	0,0	0,0
MPENDAE	9,5	2,3	4,2	4,2	0,0
MUEMBE LADU	7,4	1,9	10,0	0,0	18,3
MUEMBE MAKUMBI	8,2	1,6	8,3	5,0	0,0
MUUNGANO	5,8	1,9	10,4	0,0	0,0
MWEMBESHAURI	8,9	1,9	8,3	0,0	0,0
MWEMBETANGA	7,4	1,9	0,0	0,0	0,0
NYERERE	10,6	1,3	7,5	0,0	0,0
RAHALEO	7,7	2,2	8,9	0,0	0,0
SEBLENI	7,5	1,6	12,5	25,0	0,0
SHANGANI	8,9	1,8	3,3	0,0	8,3
SHAURIMOYO	7,1	1,9	11,1	0,0	0,0
SOGEA	8,2	1,5	6,7	0,0	0,0
URUSI	8,8	2,0	0,0	10,3	0,0
VIKOKOTONI	9,5	2,1	8,3	8,3	0,0

Appendix F: CO2 avoided per each transportation mode per ward (All population)

	Emission of per transportation mode (KgCO_2/day)				
WARD_NAME	**Bus**	**Motorcycle**	**Private car**	**Taxi**	**Total_KgC02_day**
AMANI	52,3	2,0	0,0	0,0	54,3
CHUMBUNI	118,6	0,0	0,0	0,0	118,6
GULIONI	18,8	0,9	0,0	0,0	19,6
JANGOMBE	49,6	2,0	0,0	0,0	51,6
KARAKANA	36,6	20,4	0,0	0,0	57,0
KIDONGO CHEKUNDU	21,2	0,0	0,0	0,0	21,2
KIKWAJUNI BONDENI	8,3	0,8	0,0	6,1	15,2
KIKWAJUNI JUU	0,0	0,0	0,0	0,0	0,0
KILIMAHEWA BONDENI	5,5	0,0	0,0	0,0	5,5
KILIMAHEWA JUU	31,2	0,0	5,2	0,0	36,4
KILIMANI_U	13,9	2,4	0,0	0,0	16,3
KIPONDA	7,6	11,7	0,0	0,0	19,3
KISIMA MAJONGOO	16,3	0,0	0,0	0,0	16,3
KISIWANDUI	11,2	0,0	0,0	0,0	11,2
KWAALAMSHA	20,9	0,0	0,0	0,0	20,9
KWAALINATOO	83,0	0,0	0,0	0,0	83,0
KWAHANI	36,9	2,3	0,0	0,0	39,2
KWAMTIPURA	80,1	17,1	0,0	0,0	97,2
KWAZEE	50,0	0,0	162,1	0,0	212,1
MAGOMENI	102,4	6,5	0,0	0,0	108,9
MAKADARA	39,2	6,9	0,0	0,0	46,1
MALINDI	4,9	2,1	41,5	0,0	48,6
MATARUMBETA	25,2	0,0	0,0	0,0	25,2
MCHANGANI	21,3	1,8	0,0	0,0	23,1
MEYA	29,4	0,0	0,0	0,0	29,4
MIEMBENI	48,7	2,1	0,0	0,0	50,8
MIGOMBANI	158,8	0,0	0,0	0,0	158,8
MIKUNGUNI	41,8	1,4	0,0	0,0	43,3
MKELE	40,6	0,0	0,0	0,0	40,6
MKUNAZINI	14,2	0,0	0,0	0,0	14,2
MLANDEGE	5,1	1,2	0,0	0,0	6,3
MPENDAE	118,7	2,0	0,0	0,0	120,7
MUEMBE LADU	25,3	1,3	0,0	0,0	26,6
MUEMBE MAKUMBI	90,6	0,0	0,0	0,0	90,6
MUUNGANO	29,7	12,2	0,0	0,0	42,0
MWEMBESHAURI	23,9	1,8	0,0	0,0	25,7
MWEMBETANGA	16,9	0,0	0,0	0,0	16,9
NYERERE	163,9	4,4	0,0	0,0	168,4
RAHALEO	11,2	1,9	0,0	0,0	13,1
SEBLENI	42,4	0,0	90,3	0,0	132,8
SHANGANI	19,6	0,0	0,0	0,0	19,6
SHAURIMOYO	67,2	5,3	0,0	0,0	72,5
SOGEA	45,8	1,5	0,0	0,0	47,3
URUSI	128,9	0,0	499,2	0,0	628,1
VIKOKOTONI	5,1	0,0	11,4	0,0	16,5
Total CO_2 per day	**1982,7**	**112,1**	**809,9**	**6,1**	**2910,9**

Appendix G: CO_2 avoided for the sample population ($KgCO_2$/day)

WARD_NAME	Total _KgC02/day _for the sample
AMANI	24,4
CHUMBUNI	6,2
GULIONI	9,0
JANGOMBE	15,2
KARAKANA	1,8
KIDONGO CHEKUNDU	3,7
KIKWAJUNI BONDENI	7,8
KIKWAJUNI JUU	2,4
KILIMAHEWA BONDENI	0,3
KILIMAHEWA JUU	7,6
KILIMANI_U	4,8
KIPONDA	3,9
KISIMA MAJONGOO	2,4
KISIWANDUI	0,6
KWAALAMSHA	1,3
KWAALINATOO	5,8
KWAHANI	4,5
KWAMTIPURA	4,2
KWAZEE	2,7
MAGOMENI	8,7
MAKADARA	5,4
MALINDI	30,5
MATARUMBETA	1,1
MCHANGANI	1,9
MEYA	0,8
MIEMBENI	10,4
MIGOMBANI	5,9
MIKUNGUNI	31,9
MKELE	2,1
MKUNAZINI	27,1
MLANDEGE	5,7
MPENDAE	11,5
MUEMBE LADU	14,8
MUEMBE MAKUMBI	8,8
MUUNGANO	1,9
MWEMBESHAURI	3,7
MWEMBETANGA	1,5
NYERERE	9,1
RAHALEO	9,8
SEBLENI	11,1
SHANGANI	8,5
SHAURIMOYO	10,6
SOGEA	5,4
URUSI	8,9
VIKOKOTONI	16,1
TOTAL	**361,9**